INSTRUMENTED HORIZONTAL DRILLING
FOR
TUNNELLING SITE INVESTIGATION

by

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ABSTRACT

Traditional tunnelling site investigation drilling involving vertically-drilled boreholes spaced at wide intervals, provides inadequate information concerning the ground conditions along the proposed tunnel route. This study demonstrated that the quality of tunnelling site investigation data were improved by drilling long horizontal exploratory boreholes while monitoring the performance of a suitably instrumented Atlas Copco Diamec 250 rotary drilling rig.

Laboratory drilling trials were carried out in an assemblage of concrete blocks having various cement/water ratios and aggregate types. The blocks were arranged to simulate changes in lithology, variations in strength, fissures of various aperture and orientation with and without infilling material, gouge and rubble zones associated with faults. Horizontal boreholes were drilled into the block array to establish a catalogue of instrumentation responses for known features to aid interpretation of the data from later field drilling trials. In addition, a variety of geophysical and other borehole probes were evaluated as possible site investigation tools.

Underground field trials were conducted in a disused limestone mine near Corsham, Wiltshire. Four boreholes of some 20 metres length were drilled horizontally along a boundary wall of the mine while logging the drilling rig performance. Certain boreholes were logged using a closed circuit television camera, a borehole impression packer and a sonic velocity tool. Major structural features expressed on the walls and roof of the gallery were mapped and used to evaluate the accuracy of the predictions made from the drilling record against those obtained by more conventional techniques.

Both the laboratory and field experiments demonstrated that horizontal instrumented drilling for tunnelling site investigation was feasible and could make a significant contribution to the information required for modern tunnelling projects. In certain circumstances, the drilling trials showed that it was possible to estimate the strength of the rock being drilled, to determine frequency, location and aperture of open and infilled fractures, to decide upon the nature of the infill and to detect lithological variations. This information has direct relevance for many aspects of tunnel design, excavation technique, stability, construction and support.

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CHAPTER 1

SITE INVESTIGATION USING INSTRUMENTED HORIZONTAL DRILLING

1.1 Introduction

There is a generally held view that in no other area of civil engineering are the subsurface conditions of such critical importance in design and construction operations as they are in tunnelling[1]. The expected ground conditions exert a strong influence on all aspects of the provision of a satisfactory tunnel. They bear directly upon the choice of the tunnel route, the selection and the productivity of the method of excavation, the immediate and long-term stability of the opening, the type and the strength requirements of temporary and permanent tunnel support, the environmental impact of the tunnelling operation, in short, all principal aspects of tunnel design and construction. In view of the wide-ranging influence of the ground conditions upon the successful development and completion of a tunnel, great stress has been placed upon obtaining maximum, reliable information concerning the ground in which the tunnel is to be constructed[2,3].

Despite the emphasis placed upon the importance of tunnelling site investigations, there prevails within certain quarters of the tunnelling industry a belief that the quality of information derived from ground investigation is woefully inadequate. Indeed, it is said of tunnelling site investigations that the only reliable appraisal of the ground conditions along a proposed route derives from driving the tunnel itself. This cynical attitude doubtless reflects the frustration felt by tunnelling engineers when despite conducting a site investigation, unexpected ground conditions encountered during tunnelling impose financial penalties and occasional loss of life. Even when the quality of a conventional site investigation is beyond doubt, there invariably remain many uncertainties about ground conditions beyond the working face.

The linear nature of a tunnel, coupled with the fact that it is often associated with rugged terrain, places severe demands upon geotechnical engineers charged with obtaining information about expected ground conditions along the tunnel line. The traditional approach to tunnelling site investigation involves a number of widely-spaced boreholes sunk vertically below the proposed tunnel invert. Only in the immediate tunnel portal areas is there normally anything approaching adequate ground information and this derives largely from short inclined or horizontal boreholes drilled parallel to the proposed tunnel alignment. Beyond the portal areas, other than proving the lithology, only a minimum percentage of the exploratory borehole involves rock directly relevant to the tunnelling operation. It can be argued that adoption of the traditional tunnelling site investigation approach commits the tunnelling fraternity to an expensive investigation method which is predisposed to providing insufficient and inadequate data. The purpose of the present investigation was to address the need expressed by the tunnelling industry for reliable ground information at design and construction stages of a tunnelling operation by using instrumented horizontal drilling for tunnelling site investigations or for probing ahead of the working face.

1.1.1 Background

It was widely predicted in the 1970's that in the future, the world-wide demand for tunnelling was expected to grow at an increasing rate. For example, in 1970, an Advisory Conference on Tunnelling in Washington D.C.[4] noted that over the decade 1960-69, some 13000 km of civil engineering tunnels were constructed. However, of greater importance was the prediction that the next decade would witness a doubling in construction rate for tunnels.

Similar forecasts of increased tunnelling activity were made in the United Kingdom. The BRE/TRRL Committee on Tunnelling[5] predicted a substantial increase in UK tunnelling activity, particularly tunnel construction in rock associated primarily with sewerage and water supply schemes. While it is now known that the forecast increase in tunnelling construction was over-optimistic, the prospect of increased tunnelling activity at that time led the industry to review a number of aspects of tunnel construction in anticipation of the predicted boom. Most notable amongst those topics isolated for improvement were pre-tunnelling site investigation and probing ahead of the working face[6], largely as a consequence of the difficulties noted above. In addition, the increased use of roadheader and full-face tunnelling machines was placing greater demands upon the quality of site investigation data since their cost effectivness in comparison to conventional drill and blast techniques depended heavily upon reliable information about ground conditions along the tunnel route.

Recent improvements in tunnel boring machine (TBM) technology meant that, for tunnels in excess of some critical minimum length, TBM's provided an economic alternative to traditional excavation techniques in all but very strong and abrasive rocks. Unfortunately, the potential benefits which accrued from the use of TBM's were not being fully realised. The selection of a method of excavation and its economic implementation required that sufficient site investigation data of high quality were available to machine manufacturers and contractors at the tender stage. Brown and Phillips[7] have noted that although valuable experience was being accumulated continually, and useful guidelines to tunnelling machine performance had been published by Pirrie[8], Robbins[9] and others, deficiencies in the information on anticipated ground conditions normally rendered predictions on likely advance rates, power consumption and rates of cutter wear unreliable. The BRE/TRRL Working Party also expressed concern on this matter as follows:

> "The growing use of machine excavation has added to the risks involved in tunnel driving without adequate investigations ahead of the tunnel face. Tunnelling machines for a road or a railway tunnel are large and expensive to operate. Delays to tunnel driving necessitated by dealing with unforeseen instability of the ground can be very costly to the contractor. The consequences are much more serious if the machine is damaged or engulfed by a collapse of the tunnel roof which may require piecemeal dismantling of the machine or extensive excavations of chambers above and around the machine to allow it to be extricated and repaired".

Brown and Phillips stressed that, although the art of using site investigation data to choose an excavation method and to predict its performance required improvement, a greater need existed for obtaining more pertinent data from the site investigation process.

Brown and Barr[10] suggested that measurement of the forces and energy required to advance a probe into the ground could yield valuable information for predicting the performance of a TBM. They argued that the most suitable probe was that currently used in tunnelling site investigations for drilling boreholes for in situ and laboratory testing purposes. The advance of a drill bit through the rock which it encounters can be likened to a destructive test on the rock assuming efforts are taken to control and monitor the forces and energies involved in rock comminution. However, what limited instrumentation exists on site investigation drilling rigs to date is provided normally for the driller to monitor his interaction with the rig with little thought given to the information which was potentially available regarding the interaction of the drill bit and the rock.

The TRRL recognised the potential value of monitoring and recording drilling variables during site investigation drilling, particularly if the necessary instrumentation was suited to a machine capable of drilling horizontal boreholes. The BRE/TRRL Working Party had stressed that the most certain way of obtaining continuous detailed information about the ground or water conditions along the entire route of a tunnel was to bore in that direction, more or less horizontally[6]. They recommended that *this should become regular practice in all tunnel construction.* Although pre-tunnelling horizontal boring would solve many difficulties regarding ground conditions along the tunnel axis, the Working Party foresaw the need for probing ahead of the working face at regular intervals to seek out local abnormalities and solution channels or cavities in limestone. Ideally, the pre-tunnelling horizontal boring would provide indicators to systematically locate these features while the record of the drilling variables when probing ahead would provide immediate confirmation of their existence. Consequently, a research contract was awarded to Imperial College by the Transport and Road Research Laboratory to investigate the suitability of recording horizontal drilling performance and conducting other tests upon the core or in the borehole to enhance the quality and quantity of information derived from tunnelling site investigations. In short, the objective was to prove the practicability of employing instrumented rotary drilling rigs to bore horizontal boreholes to obtain maximum information for excavation design purposes at the pre-tunnelling and/or the in-tunnel probing ahead stage of construction.

1.1.2 The concept of recording exploratory drilling performance

In rock, core drilling will form part of the site investigation, but open-hole water-flush rotary drilling using a non-coring bit is generally used in probing ahead of the tunnel face. In the latter case, the only information directly available on the nature of the rock comes from cuttings carried back in the return water. The driller's observations on the behaviour of the drill can also provide useful indications of the nature of the ground ahead. A potentially valuable way of quantifying such information is to instrument the drill rig to monitor the major drilling variables as drilling proceeds. The background to the use of instrumented drilling in tunnelling site investigations and its potential advantages have been discussed by a number of researchers[7,10,11] and is treated extensively in Chapter 3 of this investigation.

In general, it may be possible to improve site investigation data acquisition and ultimately to predict tunnelling performance from information obtained by recording a number of the variables associated with exploratory drilling. In the usual case of rotary diamond drilling, these variables are rotary speed of the bit, thrust and torque applied to the bit, the rate of penetration of the bit into the rock, wear of the bit and the drilling fluid hydraulics. Much of the information required by engineers when deciding upon a method of tunnel excavation and estimating the associated rate of advance of the method, can be derived from a study of detailed geotechnical logs of boreholes using logging formats such as those described by the Geological Society Working Party[12]. However, ample evidence exists[13-22] to suggest that the development of instrumentation for drilling rigs and suitable techniques for interpreting the data gathered could provide useful additional information about the location and type of discontinuities, rock strength, energy requirements for cutting and abrasivity of the rocks. In addition, it may be possible to eliminate some expensive coring operations by using open hole bits while monitoring rig performance in order to assess ground conditions.

The difficulties inherent in this approach should not be understated. To begin with, the type of rock cutting mechanisms differs between the various types of cutters involved. Also, the applicability of data derived from high speed rotary diamond drilling to excavation by low rotary speed TBM's using pick, disc or button type cutters raises a number of questions. In addition, the relevance of traditional vertical or sub-vertical exploratory boreholes to a horizontally bored tunnel requires re-appraisal.

These problems aside, the major difficulty involved is one of scale. The dimensions of a tunnel can be many orders of magnitude greater than those of exploratory boreholes, the sampled volume of rock often being of the order of 10^6 less than the volume excavated by the TBM. Increasing the number of boreholes and obtaining totally relevant data from them for a given site would not avoid the issue of statistical validity. When is the geotechnical engineer justified in trusting the data at his disposal? This is the dilemma continually faced by site investigation engineers generally, but never more acutely than that confronting tunnelling engineers in particular[23]. It explains the BRE/TRRL Working Party's interest, and more recently that of CIRIA and others[24-26], on applications of geophysics to tunnelling site investigation in order to sample a more representative volume of rock.

1.2 Site Investigation for Tunnels

The construction of the Thames Tunnel (1825 to 1843) was a remarkable engineering feat for a number of reasons[27], including the following:

1) It represented the first tunnel crossing of a navigable river.
2) The project represented the first recorded use of a tunnelling shield, patented by Marc Isambard Brunel, to provide a safer working environment for the navigators.

3) Improved tunnelling shields and equipment were introduced as construction proceeded and experience of the ground conditions improved.

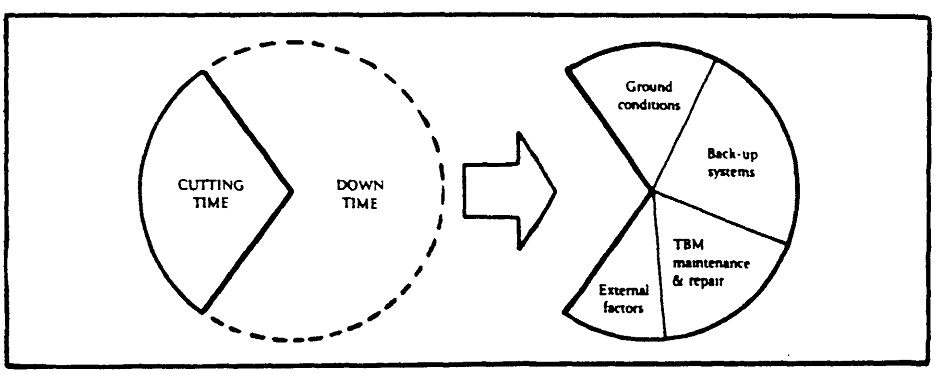
4) Tunnel advance was continually delayed by the installation of the(brick)lining.

5) The original site investigation failed to detect the presence of gravel lenses which caused repeated flooding of the tunnel and burial of the tunnelling shield.

6) Major delays caused by flooding of the tunnel resulted in financial difficulties which forced suspension of the project for 6 years. The tunnel was finally completed after 18 years effort and at a cost well in excess of the original subscribed capital of £160,000.

Brunel's difficulties remain familiar problems today according to a recent CIRIA report[28]. Figure 1.1 shows a generalised breakdown of time devoted to various activities associated with mechanized tunnelling based on a number

FIGURE 1.1: RATIO OF TBM CUTTING TIME TO DOWNTIME



of typical tunnelling projects. The ratio of cutting time to downtime, considered by many as a measure of overall efficiency, was regarded as low by CIRIA and open to improvement. They suggested that improvement would be best achieved by reduction of the downtime rather than attempting to further improve the cutting rate. The downtime activities suggest that the problem can be approached in several ways: by individual attention to each aspect - to site investigation to reduce uncertainty, to cutting maintenance by improved selection and use of equipment - and by overall management of the various activities in a co-ordinated manner, executing them simultaneously wherever possible. While vast improvements in equipment and techniques have been made in the 150 years which have elapsed since the Thames Tunnel shield ran into unexpected ground conditions, a thorough site investigation remains the essential first step to a successful tunnelling operation. This was the predominant view expressed at a recent British Tunnelling Society Meeting where a wide range of opinion was voiced on the value of site investigation for tunnels[29].

1.2.1 Site investigation requirements for tunnelling

The difficulties which attend the design and construction of underground works and the pre-tunnelling site investigation associated with them was the subject of recent editorial comment[30]. The same general theme was discussed by Cook[31] when he described the problems faced by engineers charged with structural design in rock.

According to Cook, the geotechnical engineer must accept natural construction materials of potentially variable quality and strength over which he has limited or no knowledge and frequently can exert limited control. To minimise this uncertainty, the engineer must determine the material property restraints imposed by the rock mass prior to design by carrying out a site investigation. Since site geology, rock and rock mass characteristics determine the quality and subsequent engineering behaviour of his construction medium, this site investigation must be logically executed.

Many schemes for conducting site investigations have been proposed[32-36], one of the most recent being that by Weltman and Head[37], and sources of site investigation data for the initial stages of investigation have been reviewed by Barr[24] and others[25]. A programme for tunnelling site investigation presented by Dumbleton and West is summarised in Table 1.1 which outlines the major stages of a site investigation and Table 1.2 which details the associated reporting stages. While small variations in emphasis can be noted between researchers, this site investigation format is characteristic of a well planned approach which calls to hand available information prior to formulating a pre-construction ground investigation. The pre-construction information is summarised and used to decide upon a tunnel design and method of excavation but, more important, it should be assessed continually against encountered conditions as the works progress, in order to confirm the design or highlight the necessity for further ground investigation during construction

TABLE 1.1 STAGES OF SITE INVESTIGATION
(After Dumbleton and West, 1976)

STAGE I: PRELIMINARY APPRECIATION OF SITE AND GROUND CONDITIONS

Examination of existing and more readily available information to assess feasibility at first sight, to select possible routes, to make preliminary estimates of cost, and to plan more detailed investigations.

a) Available information
   – including geological and other maps and reports

b) Geological and engineering enquiries

c) Air photographs and surface reconnaissance

d) Interpretation and recommendations for next stage of investigation

STAGE II: GROUND INVESTIGATION BEFORE CONSTRUCTION

a) Preliminary ground investigation
   – an amount of work, where required, sufficient to confirm the feasibility and to establish the approximate cost of the project, to narrow route options, and to aid in the planning of the main ground investigation; it may include selected boreholes or open excavations, perhaps a geophysical investigation, and selected tests

b) Main ground investigation
   – to obtain the information required for the final alignment, design and construction of the tunnel. It will usually include a programme of *in situ* and laboratory tests

c) Other investigations before construction
   – eg geophysical surveys, trial adits, trial shafts, grouting trials, dewatering trials, rock bolt trials, monitoring of experimental sections, recording the condition of buildings

d) Interpretation and recommendations for ground investigation during construction

STAGE III: GROUND INVESTIGATION DURING CONSTRUCTION

Observation, and investigation where necessary, continued during the construction phase to confirm and supplement the earlier investigations.

a) Observations on ground conditions during construction
   – these should always be made

b) Probing ahead in tunnels

c) Other investigations during construction
   – eg extra boreholes, observation of ground movement and settlement, grouting trials, rock bolt trials, monitoring of experimental sections

d) Review and amendment of plans and sections
   – this is a continuous process throughout the work

TABLE 1.2 SITE INVESTIGATION REPORTS
(After Dumbleton and West, 1976)

I: PRELIMINARY APPRECIATION REPORT

The report should:

a) summarise work done and list sources of information located

b) give preliminary appreciation of site and ground conditions in relation to the project

c) make recommendations for the next stage of the investigation.

Part of this work may be incorporated into a Feasibility Report or application for Parliamentary or statutory approval, which may also include results from the Preliminary Ground Investigations.

II: GROUND INVESTIGATION REPORTS (PRE-CONSTRUCTION)

Each phase may have its own report, but where timing permits the information should all be correlated in the report of the Main Ground Investigation. Recommendations should be included for observations and investigations to be made during construction.

DESIGN STATEMENT AND CONSTRUCTION BRIEF

A separate document stating the assumed ground conditions on which the Engineer has based the design, and indicating how ground conditions may affect construction procedures.

III: POST-CONSTRUCTION REPORTS AND RECORDS

a) Geotechnical Report

including – as-found records of geology and ground conditions
– investigations during construction, including probing ahead and monitoring of performance

b) Fuller information kept for general construction records

Further items complementing a) and b) but outside the scope of this report:

c) Record of construction experience, incidents and expedients

d) As-built records of the structure.

Finally, a post-construction report should document the ground conditions encountered during construction and compare these results against those predicted by the site investigation, listing any implications which departure from the anticipated ground conditions had upon the progress of the tunnel. Notwithstanding the importance of Stage 1 in this scheme, it is the "before construction" and "during construction" stages to which the present study relates in view of their traditional reliance upon exploratory boreholes to secure information.

Most geotechnical engineers would agree that Dumbleton and West's Stage II of the site investigation should establish the geological structure and succession and the nature of the strata present along the tunnel line to highlight potential problems. Specifically, the site investigation should answer questions relating to the extent, depth, properties and nature of the soil/rock interface, groundwater conditions, faults and/or areas of potential instability, discontinuity pattern, weathering, relic landforms (buried valleys, karst, etc.), hard or abrasive horizons or intrusions, natural or man-made cavities, or any feature which might pose a hazard to the safe construction of the tunnel. This information is essential for making technical and economic decisions on the following[25]:

1) the tunnel line and length
2) the shaft and portal positions
3) the method of excavation and construction
4) the prediction of stability and the selection of the means and timing of ground support
5) the prediction and control of adverse water conditions
6) the prediction of overbreak relative to the possible methods of excavation
7) the requirement for special expedients (ground freezing, compressed air, etc.)

The location and spacing of boreholes for tunnel site investigation purposes varies according to the size and the complexity of the project and the anticipated difficulties posed by the ground. Boreholes are normally sited at each shaft position and portal area, and at key locations for clarification of geological conditions (suspected faults, etc.). Other boreholes are spaced at regular intervals between those locations, generally 1 km apart unless geological complexity dictates otherwise. The TRRL[25] have made a number of recommendations regarding the depth to which boreholes should be taken and under what circumstances they should be drilled on the tunnel axis, as opposed to being located on either side of the proposed tunnel line. They also recommend use of inclined or horizontal boreholes in certain circumstances.

1.2.2 Tunnelling problems related to ground conditions

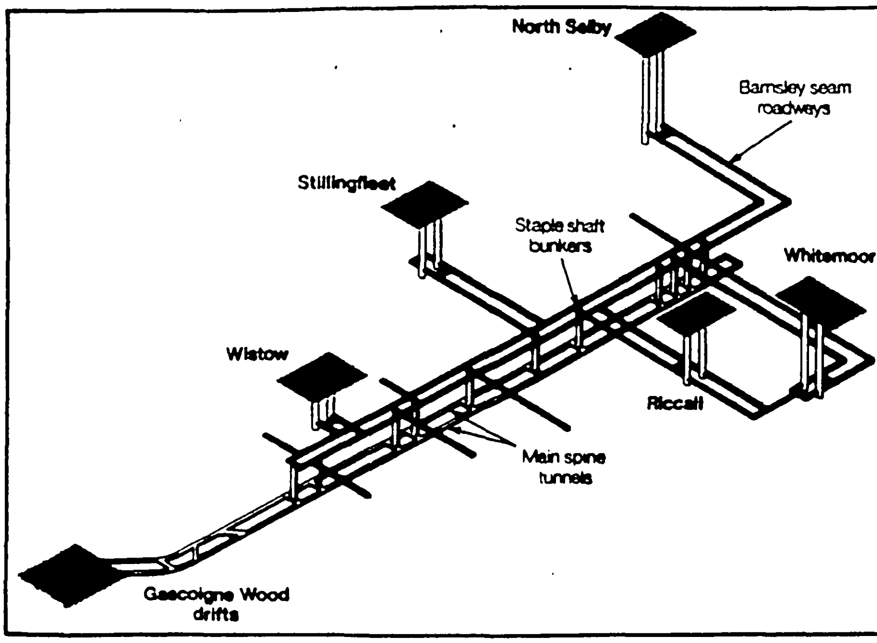
Case histories abound concerning tunnelling projects which have encountered serious difficulties caused by the presence of unexpected ground conditions. Frequently, these have forced major modifications in either excavation technique and/or design, normally with severe cost penalties. When confronted by such stories, the reader must keep them in perspective since many tunnelling projects are completed with minimum problems or delays. Equally, the case histories should impress upon the reader the potentially disastrous consequences of encountering wholly unexpected ground conditions.

Korbin[38] noted that the normal practice of spending only 2 $\sim$ 3% of total project cost on site investigation derived largely from experience with traditional methods of tunnel construction and fails to take account of the reduced versatility associated with TBM's. With traditional techniques, a difficult ground condition normally requires a temporary change in construction method with a delay commensurate with the time required to effect the change. With TBM's, and full-face TBM's in particular, the tunnelling engineer has committed himself to a method, partly as a consequence of the financial investment which the machine represents and the sheer difficulty of withdrawing the TBM once it has been installed. When a full face TBM encounters bad ground, restricted access to the machine face limits the remedial actions available to the engineer in order to advance the tunnel. If the ground conditions are particularly severe, then often more effort is expended in rescuing the machine than driving the tunnel. Some examples will serve to illustrate the consequences of driving TBM's into areas of bad ground.

<u>Selby Coalfield Complex</u>

Two 14½ km long spine roads are currently under construction in hard rock some 70m below the coal bearing strata with the intention of linking five separate mine sites at Wistow, Stillingfleet, Riccall, Whitemoor and North Selby. Coal will be transported on a conveyor system to two 1 in 4 drifts at Gascoigne Wood where the coal handling, storage and loading facilities are located[39]. Figure 1.2 shows the layout of the various mines in relation to the spine roads. The NCB in this instance intended to start transporting coal from each of the mines as soon as they were linked to the spine tunnels in an attempt to produce revenue even although the spine tunnels were still under constructuion. The north spine tunnel was being driven with

FIGURE 1.2: THE SPINE TUNNELS AT SELBY



a Titan 134 roadheader at an average rate of some 50m/week placing it some distance behind the 5.8m diameter Robbins TBM which was advancing about 100m/week in the south drive. When the TBM was approximately 1 km ahead of the roadheader, the Robbins machine drove into an area of badly faulted ground on the 19th February, 1983. Seven months later[40], the TBM is still sitting idle while extensive remedial works are being carried out to bridge the fault zone.

The fault zone was not unexpected as it had been encountered 78m above the spine tunnel when Wistow roadways were being developed. The fault zone in the spine road proved to be far more serious than expected since the NCB now estimate that five major faults have converged at this location. Remedial works have involved excavation by conventional methods ahead of the machine to install in situ reinforced concrete beams just above crown level. A further 6 to 8 weeks delay was anticipated before the TBM could continue excavation of the remaining 55% of the south spine tunnel. The parallel roadheader drive (70m away) encountered the same fault zone but the faults were wider spaced and hence easier to traverse.

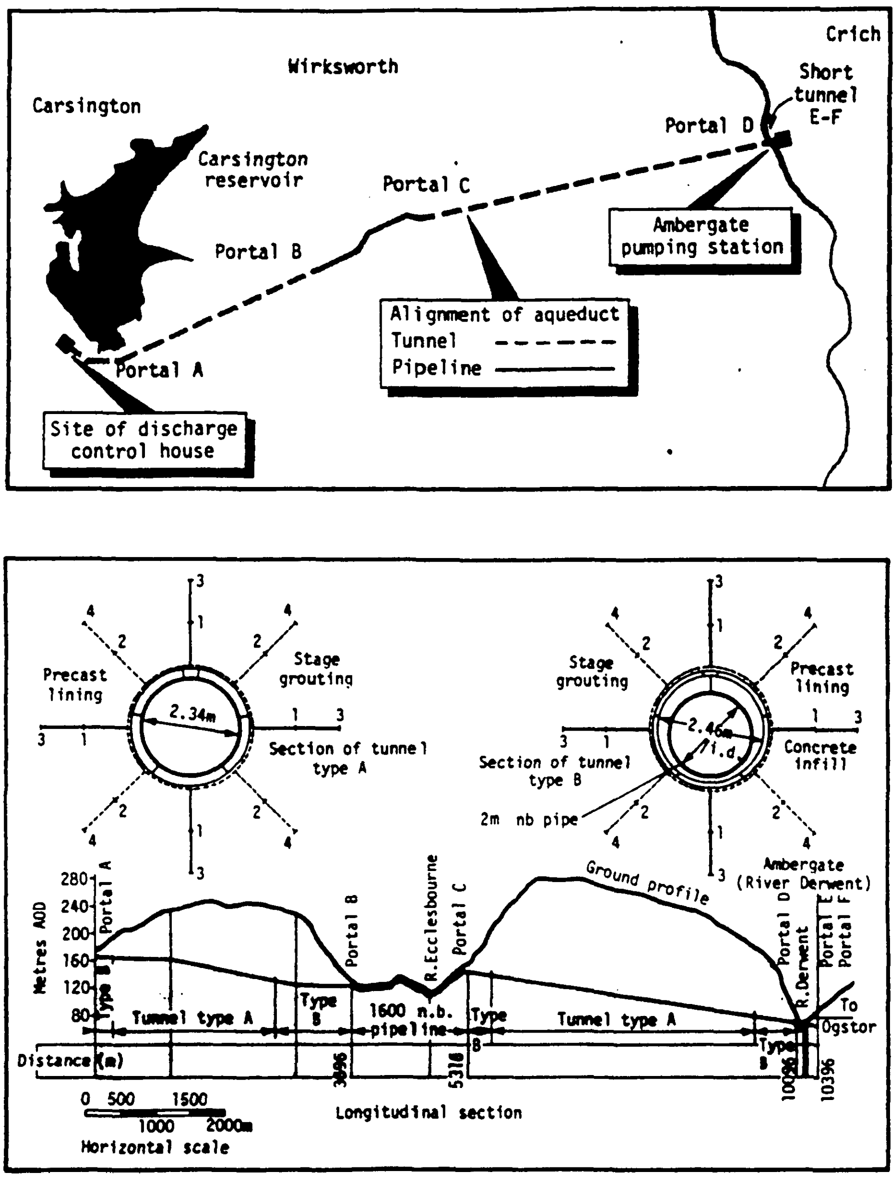
Carsington Aqueduct

The Carsington aqueduct is currently the largest tunnelling project, outside of the coal industry, in the U.K. However, it has run into severe geological problems which threaten to delay completion by as much as two years and double the contract price of £15.1 million to construct the 10.5 km long aqueduct[41]. The tunnelling contract called for two main tunnels, at a maximum depth of 160m, through hills separating the reservoir from the Ambergate pumping station (Figure 1.3). One tunnel is 3.6 km long, while the other is 4.8 km linked by a 1.6 km pipeline across an intervening valley. A conventional site investigation was carried out in 1979 when deep boreholes were sunk along the tunnel axis at 1 km intervals, with several extra shallow boreholes at the intended portals. Core was taken, stored and made available for examination at the tender stage. The exploratory boreholes indicated that the tunnels would be largely confined to the Ashover Grit series made up of interbedded strata, mudstones interbedded with siltstones and sandstones. A geophysical survey was conducted to confirm the borehole evidence. Supplementary borings at two of the portals at the design stage resulted in the relocation of one to avoid an area of surface instability.

Full face TBM's could not be used because large amounts of water were anticipated and easy access to the face was required for purposes of grouting. The use of drill and blast techniques were excluded from the bids, but for exceptional circumstances. With problems expected from known faults and methane from Coal Measures strata, shielded roadheaders flame-proofed to NCB standards were selected as the most appropriate method of excavation.

Four working faces were established using Anderson Strathclyde road-headers inside Markham and Grosvenor Steel shields. With only some 15% of the tunnel excavated, the ground conditions proved too difficult. The portal A drive was only 315m long after 14 weeks when the contractor with-drew the machine because of severe water problems and replaced it with hand-held clay spades. This technique requires a week of excavation to be followed by a week of ground treatment. Face advance as of March this year was averaging a meagre 7.5m/week. The portal B drive likewise suffered from water problems, up to 1000 l/min through 50 mm diameter boreholes, culminating in an inrush (August 1982) which washed away the face and submerged the equipment. The equipment was recovered and continued operation, but under compressed air at 1.75 atm pressure. Before the flood, progress in B drive was around 40 m/week but latest reports indicate that A and B drives now have the slowest rate of progress[42]. In the portal C drive, the roadheader was removed after 12 weeks and 210m of tunnelling because of excessive influx of water and harder than anticipated rock. The heading is now being advanced using drill and blast techniques. The redundant Markam shield is being pulled behind the advancing face. The roadheader in portal D was removed after driving 195m and was replaced by drill and blast.

FIGURE 1.3 PLAN OF CARSINGTON RESERVOIR AND AQUEDUCT SCHEME



(After Martin and Wallis, 1983)

Of the four roadheaders, the type of equipment recommended in the tender documents, none are now involved in tunnelling operations at Carsington. Probing ahead at weekends has been instituted on all working faces wherein three holes/face are bored to a depth of 25m and fanned out to 3m distance outside the tunnel route. Alternative methods of excavation are being reviewed, including soft ground TBM's, pending results from additional exploration boreholes.

Arc Isére Hydroelectric Scheme

A major tunnelling effort was undertaken as part of this hydroelectric scheme in southern France to link the Glandon and the Flumet valleys by an 18.9 km long tunnel[38]. Two headings were established, the 10 km drive from the Flumet valley used a 5.8m diameter Wirth 580H full face TBM suited to excavation in medium strength rocks (38 double disc cutters plus 4 pilot bits). Most of the rock was crystalline schist except for 1 km of sedimentary rock and about 0.7 km of granite-gneiss. The second heading, from the Glandon valley, employed traditional methods using a Montaber jumbo fitted with six hydraulic drills. The drill and blast technique was best suited for dealing with the high strength granite-gneiss along this section of the tunnel route. Several large shear zones were expected on both drives, some associated with water.

The sensitivity of TBM's to poor ground conditions was well demonstrated during this project. In good ground, the machine progressed an average of 16.3m/day, the best day being 35.4m/day. The average for the complete drive was only 10m/day however, largely as a result of difficulties in poor ground. It is significant that 300m or 3% of the tunnel length driven by TBM required 25% of the total construction effort to traverse 13 shear zones ranging in thickness from 10 to 50m.

Eight major delays resulted from collapse of the face which completely blocked the heading. Water inflows on these occasions were usually minor. Twice the machine was so seriously buried that conventional methods were employed to pass through the shear zones to free the machine. A pilot tunnel was used to traverse the shear zone into competent ground and then to a position on the tunnel axis. From here, a larger heading was driven backwards towards the trapped machine. Each of these rescues caused 5 and 3 months delay respectively. Korbin[38] noted that the rate of progress through the difficult ground was 0.85m/day.

Following the first major encounter with a shear zone (5 months delay), a hydraulic drill was mounted behind the cutter head in order to probe in advance of the tunnelling operation. It could only be used when the machine was stopped for routine servicing. This equipment was able to drill up to 50m ahead of the face in 2 hours, but continuous probing was not practiced since it interfered with advance. In fact, when the machine drove into a shear zone and got seriously trapped on a second occasion, tunnelling was actually advancing ahead of probing operations.

By comparison, drill and blast methods fared better overall than TBM operations at Arc Isére. In good rock the former technique averaged 8.5m/day, about half of the rate achieved by the TBM under similar conditions. However, in difficult ground,in the case of the drill and blast operation some 900m or 12% of the drive, daily progress averaged 2.7m. This was approximately three times better than the TBM in poor ground. In spite of these shear zones encountering high water influxes (often > 10 l/s), 12% of the drive required less than 25% of the total construction effort. Overall progress in the Glandon drive with conventional methods was 7m/day which, in view of the high proportion of bad ground, 12% versus 3%, was quite acceptable. Indeed, had the poor ground conditions been 7% or more in the TBM drive, drill and blast techniques would have been fastest overall.

1.2.3 Vertical versus horizontal exploratory boreholes

The three examples of tunnelling problems caused by bad ground conditions which went undetected using conventional site investigation techniques, were not presented by way of implied criticism. Retrospective wisdom is acquired easily in recounting situations such as those described above. Instead, these case histories argue strongly in favour of greater emphasis being placed on horizontal exploratory boreholes for pre-tunnelling site investigation and/or probing ahead, particularly when the presence of adverse ground conditions are known or strongly suspected. For example, the TBM difficulties in the Selby spine tunnel might have been averted had an exploratory probe investigated the recognised fault system.

Equally, specification of the wrong excavation method in the contract documents for the Carsington Reservoir project might have been avoided if site investigation boreholes had been drilled along the tunnel axes. The relatively short lengths of tunnel, 3.6 km and 4.8 km, coupled with the availability of four portals, potentially would permit horizontal or inclined boreholes to be drilled over considerable portions of the intended route. This approach might have detected the adverse water conditions and stronger than anticipated rock, particularly in view of the early onset of these problems.

The difficulties experienced with shear zones in the Arc Isére project present a strong case for probing in advance of the working face. In fact, following burial of the machine on the first occasion and the associated 5 month delay, probing ahead of the Wirth TBM was instituted. Nevertheless, the machine apparently drove headlong into another shear zone, incurring a further delay of 3 months, after probing had been suspended since tunnelling operations were being delayed. It is easy to understand the pressure which the contractor and others must have felt regarding making up lost time, but, as the name implies, probing ahead must not be allowed to fall behind tunnelling operations if it is to be effective.

1.3 Horizontal Drilling

Inclined and horizontal drilling technology has made substantial advances in the last twenty years. Much of this technology is derived from the petroleum industry; witness the ability to drill directional wells in the North Sea and British Gas' plans to employ slant-rig drilling techniques to reduce the number of offshore platforms required to produce the relatively shallow Morecambe Bay gas field. In the coal industry, horizontal boreholes have been used to drain methane from coal seams prior to mining, to harvest methane as a natural resource and to prove the continuity of seams for mine planning purposes. Similarly, in the oil industry, this ability to drill directional holes is being used to establish in situ retorts to exploit oil shale. Civil engineers have used this means to drive pipelines, power and communication cables beneath rivers without having to resort to traditional techniques which would interfere with navigation. Precision drilling of inclined and horizontal boreholes has been used to install instrumentation below nuclear waste storage facilities to monitor leakage. Horizontal boreholes coupled with geophysical logging was employed to select sites for thermonuclear weapon tests at the Nevada test site. Gradually, attention has begun to focus on the use of inclined and horizontal drilling for purposes of pre-tunnelling site investigation, particularly in the U.S.A. where pilot tunnels are becoming prohibitively expensive. The ability and equipment to drill long horizontal boreholes for ground exploration exists and this technology must eventually find general acceptance within the tunnelling industry.

1.3.1 History of horizontal drilling

A listing of representative pre-1975 horizontal boreholes is presented in Table 1.3, based on a study for the US Federal Highway Administration[2]. The longest horizontal hole drilled at that time, and to date, was a 1615m (5300 ft.), 172mm diameter hole which was drilled on the Seikan Tunnel Project in Japan. The hole was drilled in soft ground using a FS-400 Horizontal Boring Machine built by Koken Boring Machine Company Limited of Tokyo. A tri-cone bit was used to drill the hole while a Dyna-Drill down-hole motor and a Sperry-Sun magnetic multishot survey tool were used for directional control.

At that time, all other horizontal drilling beyond 610m (2000 ft.) depth employed diamond coring techniques. Table 1.3 shows that Longyear Company of Minneapolis and subsidiary companies in Canada and South Africa have drilled boreholes in excess of 1200m (4000 ft.) in medium and hard rocks using wireline coring techniques. Holes sizes range from 60 to 76mm, typical site investigation diameters. Also, horizontal holes up to 914m (3000 ft.) have been drilled by Boyles Brothers Drilling Company of Salt Lake City in medium and hard rock with similar equipment.

Carroll and Cunningham [43] provided details of 33 horizontal boreholes in excess of 300m in depth, the maximum depth being 1125m (3690 ft.), drilled in soft volcanic tuffs in Nevada for the Defence Nuclear Agency of the US Department of Defense. The holes were drilled using a Longyear 44 drilling rig powered by a 6-cylinder Ingersoll-Rand air motor. The holes were continuously cored with NQ bits and an NXC-3 Christensen core barrel on a Longyear NQ wire-line barrel, allowing core retrieval without pulling the drill string. An interesting feature of this ongoing project concerned the use of geophysical probes in these boreholes to detect adverse rock features within 125m of possible nuclear weapon test chambers, which might prevent adequate containment of the by-products of a nuclear detonation. These holes were surveyed by line-of-sight until the survey light was lost. Thereafter, single-shot magnetic surveys were run every 6.1m by pumping the tool down the hole and recovering it on wireline. Electrical resistivity logs were run to detect clay zones based upon empirical data relating resistivity measurement to clay content. Generally, rock with resistivities less than 20 ohm - m was considered potentially unstable and below 10 ohm-m indicated substantial amounts of clay. Water saturated rock zones were defined using sonic velocity measurements. Zones in the rock with velocities less than 2450 m/s were considered suspect. Detection of these features are used to define unstable ground conditions for tunnelling in the case of clay and shock wave attenuation zones in the case of the presence of partially saturated rock. Excessive

TABLE 1.3 REPRESENTATIVE HORIZONTAL DRILLING

Distance/Diameter Feet (Meters)/Inches (Millimeters)	Material	Method/Equipment	Guidance	Goals	Contractor/Client	Date	Location
(1) 5,300 (1615)/6.75 (171)	Soft	Rotary/Koken FS400	Sperry-Sun/ Dyna-Drill	Rotary 6600 (2000) Downhole 16,400 (5,000)	-	1971-72	Seikan Tunnel, Japan
(2) 4,000 (1,220)/2.36 (60)	Medium-Hard	Diamond Coring/ Longyear 44	Wedging	5,000 (1,520)	Boart Drilling Ltd. (Longyear Subsidiary)	To Present	South Africa
(3) 4,000 (1,220)/2.36 (60)	Medium-Hard	Diamond Coring/ Longyear	Wedging	-	Canadian Longyear Ltd. /Brayhorn Mines Ltd.	≈ 1964	Central British Columbia
(4) 3,690 (1,125)/3 (76)	Very Soft	Diamond Coring/ Longyear 44	Wedging	-	Reynolds Electrical & Engineering/AEC	Nov. 72 - Present	Mercury, Nevada
(5) 3,000 (914)/2.36 (60)	Medium-Hard	Diamond Coring/ Longyear	Eastman/ Wedging	-	Boyles Brothers Drilling Co.	-	-
(6) 2,630 (802)/ -	Soft	Diamond Coring (?)/ Tone TEL-2C	-	-	-	1972-74	Seikan Tunnel, Japan
(7) 2,540 (774)/2 (51)	Coal	Rotary/Fletcher	-	3,000 (914)	Kerr-McGee	To Present	-
(8) 1,980 (604)/3 (76)	Medium-Hard	Diamond Coring/ Sprague & Henwood	Tro Pari Compass	-	Sprague & Henwood/ Penn. Turnpike Authority	1954	Lehigh Tunnel, Penn. Tpk.
(9) *1,700 (518)/3 (76)	Soft-Coal	Downhole, Diamond Bit/Dyna-Drill, Joy 22 Surface Rig	Sperry-Sun/ Dyna-Drill	-	Calvert Western, Fenix & Scisson/ Bureau of Mines	1973-74	-
(10) **≈1,600 (488)	Soil	Dyna-Drill	-	-	Titan Drilling	To Present	-
(11) 1,468 (447)/3.4 (87)	Soft	Double Tube Reverse Circulation (Continuous Coring/ Tone Surface Rig	-	-	Taisei Corp.	-	Seikan Tunnel, Japan
(12) 1,340 (408)/7.625 (194)	Soft	Rotary/Koken FS400	Sperry-Sun/ Dyna-Drill	-	-	-	Seikan Tunnel, Japan
(13) 1,257 (383)/2.36 (60)	Medium-Hard	Diamond Coring/ Canadian Mine Services	-	2,000 (610)	Canadian Mine Services	To Present	-
(14) ≈1,200 (366)/3-4 (76-102)	Soils	Rotary Drag Bit/ Aardvark, Tigre Tierra, Inc.	-	5,000 (1,524) with Wireline Coring	Soil Sampling Services	To Present	-
(15) 1,102 (336)/3.5 (89)	Coal	Rotary/Specially Built Longyear	Sperry-Sun/ Drilling Parameters, Dyna-Drill	-	Fenix & Scisson/ Bureau of Mines	1972	Ohio
(16) 1,180 (359)/3 (76)	Medium-Hard	Diamond Coring/ Longyear	Modified Eastman Wedging	-	Charles S. Robinson & Assoc.,	1970	Wheeler Junction, Colorado
(17) 1,034 (315)/3.5 (89)	Soft-Coal	Rotary, Roller Bit/ Specially Built Longyear Rig	Cableless Telemetry System by Telcom, Inc./ Drilling Parameters, Dyna-Drill	-	Fenix & Scisson, Telcom/Bureau of Mines	1972	Ohio
(18) 864 (263)/4 (102)	Medium-Hard	Downhole Percussive/ Ingersoll-Rand	None	1,000 (305)	Jacobs Assoc./ ARPA	1972	-
(19) 800 (244)/3-6 (76-152)	Soft-Coal	Rotary, with & without Down Hole Thruster, Roller Bit	On Board Survey Package/ Down-Hole Hydraulic Steering Shoe	-	By and For Continental Oil Co.	-	-

*Started 18° from vertical, drilled 1300 ft. to coal seam (at a depth of 700 ft) and 400 ft more horizontally in coal seam.
**Curved holes.

NOTE: All units are expressed in English units accompanied by metric equivalent units in parenthesis.

(After Harding et al, 1975)

attenuation would result in incomplete closure of the tunnel following detonation leading to contamination of the underground area. In short, a combination of pre-tunnelling horizontal boreholes and down-hole geophysical logging were used to make technical and economic decisions regarding tunnelling.

In 1954, an NX size borehole was drilled by Sprague and Henwood Incorporated in the Lehigh Tunnel for the Pennsylvania Turnpike Commission to a depth of 604m (1980 ft.) in medium and hard rock using diamond coring techniques.

An Ingersoll-Rand pneumatic downhole percussion drill was used by Jacob Associates to drill 102mm diameter boreholes in medium to hard rock. The longest hole was 263m (864 ft.). Specially developed drill rod handling equipment allowed drill pipe to be tripped at rates up to 61 m/min.

1.3.2 State-of-the-art

Horizontal drilling

Additional studies of horizontal drilling techniques have occurred since the Federal Highway Administration survey in 1975. Brezovec[44] reported the use of horizontal boreholes drilled up to 300m into the Blue Creek seam in Alabama for methane drainage purposes. Productivity of continuous miners has improved as a result of reduced methane emissions.

A research project at General Blumenthal colliery in the Ruhr coalfield aims at developing a horizontal drilling method to allow core drilling in boreholes up to 1000m long[45]. Initial tests with a Wirth B5H hydraulic rock drill resulted in a 652m long borehole, despite encountering a number of large faults. Over that distance the drill had only deviated several metres in azimuth. However, layered strata deflected the drill string 22m below the target line. Later tests with specially stabilized drill strings have resulted in holes up to 807m depth with a maximum azimuthal deviation of 7m, although once again strata-induced deflection meant the hole was 69m below the target line.

A co-operative research project between the U.S. Department of Energy, Sandia National Laboratories and the University of Missouri-Rolla has developed a high pressure water jet for horizontal drilling in coal seams having assessed the seam from a vertical borehole. In use, the water jet was lowered down the borehole on an articulated drill string, rotated to the horizontal at the coal seam and advanced into the coal. Downhole instrumentation provided data on water nozzle pressure, rotary speed of the drilling head and orientation of the borehole. This information was fed to the driller on surface to allow him to adjust the drilling head orientation via a drilling head/drill string pitch control. Tests in open pit sites have resulted in 15 to 20 cm diameter holes drilled at a rate of 60 cm/min for a maximum distance of 31m in clean coal. The system will be used eventually for underground coal gasification well linking and methane drainage[46,47].

Mining Research Division of Conoco Incorporated, the parent organisation of Consolidation Coal Company, have been engaged in horizontal drilling research for nearly a decade. Again the objective of the work was to develop techniques and equipment for drilling long horizontal boreholes in advance of mining to drain gaseous coal seams. By 1975, they had developed techniques to drill upwards of 300m ahead of mining operations and advance degasification experiments began the following year. Encouraged by the results of these early tests, a horizontal drilling system was designed to include a drill rig, a drill bit guidance system and borehole surveying equipment. The drilling system is discussed in detail by Thakur and Poundstone[48] along with the procedure followed in 'kicking off' the borehole from a heading using a downhole motor and an eccentric deflection sub. Surveys are run every 10m and take approximately 20 minutes at 300m depth. Hole sizes range from 75 to 150mm using tri-cone or Stratapax bits. Working at full capacity, a driller and roughneck have drilled a 105m hole in an 8 hour shift. The system is widely used by Consolidation Coal Company mines, mainly for degasification, but it has been used also for exploration of coal seams, determining the extent of sand channels and production of oil and gas from shallow deposits.

Slant hole drilling

In recent years, considerable interest has been generated in 'slant hole drilling' techniques. The surface hole is spudded at an angle which is determined by inclining the drill frame or derrick in the case of larger drilling rigs. Angles up to 45° have been achieved with large scale drilling rigs. By starting in this manner and using standard directional drilling techniques, it is possible to obtain longer horizontal displacements than a conventional rig drilling to the same true vertical depth and final hole angle. As important, slant hole drilling allowed very substantial deviation from the vertical without potentially serious dog-legs (high radius of curvature in the well) being incurred. Since gravity alone cannot provide sufficient weight on the bit, slant hole rigs require a jacking arrangement for the drill string.

Skonberg and O'Donnell have described the range of equipment available for this drilling technique including: drilling rigs, downhole motors for directional drilling, survey instruments which provide single, multiple or near continuous indication of borehole trajectory and typical drilling programmes.

Ocelet Industries Limited recently developed the Bantry gas field in south eastern Alberta using slant hole drilling techniques to complete shallow gas wells (320 to 445m) below a man-made lake. The holes were spudded at 45° and either maintained at that angle to total depth or the angle was built to approximately 67° from vertical then held at that angle using a packed (rigid) drilling assembly. The high angles increased the length of the pay zone in the reservoirs by factors of 1.4 and 3 times for 45° and 70° boreholes respectively[50].

Texaco Canada Resources Limited[51,52] have completed recently an innovative drilling programme to develop three horizontal wells drilled from surface using drilling rigs with 45° slanted masts. Slant hole methods were required because the Athabasca oil sand targets were located at shallow depth ranging from 80 to 200m (260 to 660 ft.). Spudding at 45° allowed the three wells to build angle at 5°/30m and achieve a horizontal attitude at approximately 300m, due allowance being made for the depth of the conductor. The three wells have an average 334m (1095 ft.) horizontal section. Downhole motors, Dyna-Drills and Navidrills coupled to bent subs were used to build angle. A steering tool provided continuous data at surface on the trajectory of the hole. This record was checked by occasional multishot surveys. Directional control went extremely well and no severe doglegs were encountered. The successful application of slant hole techniques was considered by Texaco as an economic means of commercial production of bitumen by in situ methods.

Directional drilling

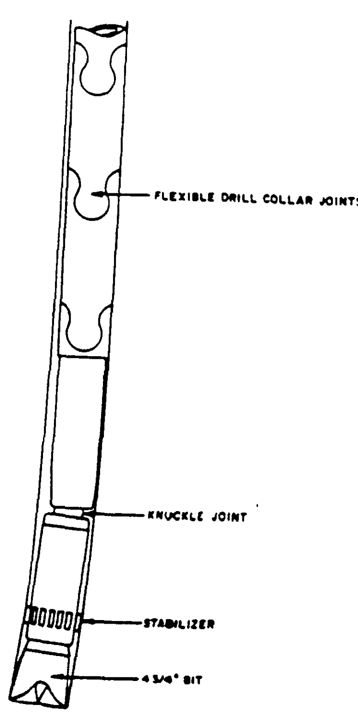
The inclined hole technique is a variation of the traditional method of directional drilling using a conventional drilling rig to spud a vertical hole. At some depth, known as the kick-off point, the well is turned from the vertical using a range of deflection tools including down hole motors with bent subs or bent motor housings and, less frequently nowadays, whipstocks. Deflection angles normally range up to 5° or 6°/30m, although angles of 8° to 10°/30m are known. This type of directional drilling probably has limited site investigation applications because of the depth requirement for the angle building section.

Interested readers are referred to the following literature for accounts of horizontal boreholes which were initially drilled vertically from surface. Oyler and Diamond[53] described a surface borehole which was spudded vertically then deflected to intercept a coal seam horizontally at a vertical depth of approximately 300m. The angle build rate was 6^{o}/30m. On entering the coal seam the well was completed, then three long horizontal boreholes were sidetracked into the coal seam from this common well. The longest horizontal segment in the coal was 978m (3207 ft.).

Elf Aquitaine have drilled vertical wells ending in horizontal completions at their Lacq field in southwestern France (2 wells) and offshore in the Italian Adriatic Sea on well Rospo Mare 6D. Well Lacq 90 extended 110m horizontally while Lacq 91 had a horizontal section of 370m at a total vertical depth of some 680m. The horizontal section of well Rospo Mare 6D was 470m. Numerous accounts are available in the literature[54-57].

ARCO have drilled four horizontal drainholes in their Empire Abo unit, Lea County, New Mexico from wells which were spudded vertically[58,59]. The most interesting aspect of these wells concerned the use of flexible drill collars known as 'wigglies' (Figure 1.4) to effect a 90^{o} turn in under 10m vertical drilling. The maximum length of horizontal section was 54m. Difficulties have yet to be resolved concerning directional control in the horizontal section.

FIGURE 1.4: SCHEMATIC OF THE ARCO DRILLING ASSEMBLY



Holbert[60] has discussed some of the theoretical aspects of this technique.

1.3.3 Horizontal drilling methods and tunnelling

Deviated drilling has made a substantial contribution to reducing the cost of developing oil fields in remote or hostile environments. Economical development of the North Sea would have been impossible without this technical capability. In exchange for increased cost and time for drilling, major savings are made by reducing the requirement for offshore production platforms or drilling islands in Arctic locations. As this technology became commonplace it was able to be applied in the less lucrative proving and winning of coal. Indeed, the ability to drill deviated or horizontal boreholes has potentially increased world coal reserves by making non-commercial deposits economically viable by means of in situ combustion. Combustion is sustained and derived gases are collected using directionally drilled boreholes to selectively locate bottom hole position within the coal seam.

Traditionally, tunnelling site investigation has relied on widely spaced, vertical or inclined holes which have the major shortcoming of providing limited information about conditions along the tunnel axis. In some cases this was overcome by excavating a pilot tunnel, but this technique was very costly, required long excavation time and placed personnel in a potentially hazardous situation. The author believes that directional drilling techniques makes the use of horizontal exploratory boreholes, combined with drilling rig instrumentation and downhole logging, a realistic choice for tunnelling site investigation. To date, the use of long horizontal boreholes in civil engineering has been limited by increased cost. It can be argued that costs were high because demand was low. In terms of cost effectiveness, a horizontal borehole provides substantially more information per metre drilled than the traditional tunnelling site investigation borehole. The economics of the various techniques needs review in light of recent developments in directional drilling equipment and capabilities. However, that topic lies beyond the scope of this investigation.

Where access permits, horizontal boreholes could be drilled on line with the proposed tunnel route. Elsewhere, slant hole drilling followed by deviation to the horizontal offers the added incentive of the benefits of traditional site investigation data gathering in addition to subsequent drilling along the tunnel line. Where depth to the proposed tunnel permits, a borehole could be spudded vertically and drilled to a desired depth. Then, the borehole could be plugged back and a deviated well drilled horizontally onto the tunnel line in each direction using existing sidetracking techniques.

1.4 Role of Drilling Rig Instrumentation

In 1975, the author was site engineer for a major geotechnical investigation for a proposed mine development in Eire. The geotechnical appraisal ran concurrently with the mineral evaluation, hence specific recommendations were made concerning the collection of data for geotechnical purposes utilising the diamond drill core acquired for assay. The information collected during the drilling operations was summarised on a detailed geotechical log by a geologist hired and trained specifically for this purpose. In addition, a specially formulated drilling report was issued to the foremen of the drill crews to record their observations during coring operations. The crews were instructed on the manner in which the reports were to be logged and were made to appreciate the importance attached to their maintaining an accurate record during drilling operations. The type of information requested from the drill crew involved comments upon the reason for ending a core run, condition of the hole, ease of emptying the core barrel, core recovery, percentage return of drilling fluid, drilling breaks, rough drilling, colour of returns and pockets of clay or sand. This information in association with the core logs provided extremely useful insight into geotechnical and hydrogeological conditions on the site[61,62].

Implicit in the use of the drill crew to record drilling events of possible geotechnical consequence was the acceptance of their ability to relate irregular drilling rig responses to downhole conditions. Numerous discussions with the drillers following submission of their reports indicated that they were adept at detecting variations. For example, to decide upon the presence of voids and sand or clay filled cavities, they employed a variety of diagnostic criteria, the most pertinent being :

1) A rapid advance of the rotary head down the drill frame.
2) An audible variation in motor pitch resulting from increased rotary speed caused by drastically reduced or non-existent resistance to drilling as the bit passed through infilled or void cavities respectively.
3) A sensible shock in the drill string and change in pitch of the rotary head motor(s) caused by the sudden contact with the rock at the base of the cavity and the associated reduction in rotary speed.
4) A change in the colour or the constituents of the flushings from the borehole indicating a void, clay or sand infill.
5) A 'core blockage' would normally result when penetrating clay infill causing little or no penetration when rock contact was re-established, and a loss of circulation since the clay would seal the annulus between the core lifter assembly and the outer barrel.

6) A partial or complete loss of circulation, particularly in void or sand-infilled cavities.

7) A measurable lack of core over the drilled interval.

Various combinations of these criteria allowed the driller to alert the geotechnical engineer and geologist to the possible presence of a cavity.

1.4.1 Advantages of instrumentation

The ability of the drill crews at Navan to decipher downhole features based on the response of their drilling rigs was proven repeatedly from corroborative evidence in the recovered core. It appeared to the author that a great deal of information was being disregarded by site investigation engineers by not considering the behaviour of the drill as it cut the core upon which such heavy reliance was placed for interpretation of the ground conditions. Core drilling is an expensive process and so it is important that the maximum return on site investigation investment be realised in terms of the quality and quantity of the information obtained. The effectiveness of core drilling as a site investigation tool depends upon complete recovery of all materials through which the drill passes. The most significant materials from a geotechnical point of view such as fault and gouge materials, joint fillings and soft, weathered or friable zones, are generally the most difficult to recover. The success of the coring operations depends on the drillers' ability to control the complete drilling process under difficult conditions. The more experienced the driller, the more likely these significant features will be recognised.

As a result of experience gained at Nevinstown Mine, the author believed that the less experienced driller could be assisted to exercise the necessary control by instrumentation which monitors drilling variables such as thrust, rotary speed, torque, penetration rate, and the flow rate and pressure of the flushing fluid during drilling. It is also suggested that data obtained from such instrumentation can be used to back-calculate mechanical properties of the materials through which the drill passes and so increase the quantity, as well as the quality, of the data obtained from site investigation drilling. In short, suitable instrumentation could be used to record the responses of the drilling rig to which an experienced driller reacts. On this basis it is possible that for sections of some holes the data obtained by monitoring drilling performance using a non-coring bit could meet all practical needs and so obviate the need for continuous coring with its attendant expense.

As demonstrated later in Chapter 3, ample evidence exists to indicate that drilling rig instrumentation can play a useful role in site investigation. Although detailed discussion of instrumented drilling literature is presented in that chapter, some general comments are warranted now.

The collected experience available indicates that drill rig instrumentation has considerable value from an operational point of view. The feedback provided by instrumentation output makes available to the driller information that he previously obtained by "feel". This information assists the driller to control the operation and improve drilling performance, particularly in terms of core recovery. In the case of an oil shale investigation carried out using the 90 h.p. machine described by Brown[63]. this improved control resulted in geological features not otherwise detected in the site investigation being observed in the core[64]. At the site of the Chinnor tunnelling trials, Boyd[65] obtained almost 100% core recovery in chalk using a small instrumented hydraulic rig. The improvement in core recovery over that obtained in the major site investigation carried out using standard techniques was attributed to the improved control that could be exerted over thrust and flushing fluid flow rate[66,67].

Recorder output also provides a detailed, permanent record of the drilling operations. The cause of each variation in drilling performance can be identified and noted on the charts. An analysis of this data can be most valuable in assessing the efficiency of drilling strategies and drill crews. Instrumentation can clearly be of value in training new operators. This has certainly been the experience of Scartaccini[18] who gives an example of how a consistent error being made by a trainee driller drilling alone for the first time was detected by an inspection of the recorder charts. Scartaccini also gives a number of examples of how mechanical faults and mis-use of his large blast hole drills was detected from the information available on the recorder charts. Not only were major mechanical failures prevented in these cases, but operator faults were also corrected.

Experience would suggest that the major operational advantages of drilling rig instrumentation are:

1) Provision of a permanent detailed record of the drilling operations prepared during and not after the event.

2) Aid in the determination of optimum operating conditions by rational rather than random methods. The efficiency of the operation is thereby improved.

3) Aid in training operators.

4) Provision of early warning of some types of mechanical faults.

5) Better control of the operation leading to higher core recovery and better quality core in many cases.

It is one of the purposes of this study to demonstrate the validity of these potential benefits.

1.4.2 Instrumented horizontal drilling for tunnelling site investigation

The combination of an instrumented drilling rig drilling a horizontal borehole, regardless of how that orientation is achieved, offers many benefits for pre-tunnelling or probing ahead exploration of the ground. The most immediate benefit of drilling along the proposed tunnel line, particularly in the pre-tunnelling stage, comes from improved knowledge of the ground conditions over a greater proportion of the tunnel route. This was one of the general conclusions reached by the BRE/TRRL Working Party:

> "Ground information obtained in the early stages contributes to the design of the scheme and there is greater assurance that the construction methods proposed are appropriate to the range of conditions likely to be encountered. There is everything to be said therefore for obtaining as much information on ground conditions as early as possible so that the correct decisions can be made right through the design, tendering, construction, planning and execution phases of the design".

A number of benefits stem directly from a better knowledge of the ground. All other factors being equal, a safer working environment must be expected when the risks of driving into unexpected ground conditions are lessened. Also, where bad ground conditions exist, the use of instrumented horizontal drilling methods increases the likelihood that they will be detected and special attention drawn to them at the tender stage. This knowledge might involve excluding particular methods of excavation, remedial treatment of the ground prior to excavation and/or specifying additional ground support before rather than during construction. With improved knowledge of the ground greater use of TBM's becomes practicable since their operation can be scheduled to avoid ground conditions for which they were not designed. Machine maintenance could possibly be deferred to coincide with suspension of TBM operation, while pre-planned conventional excavation methods cope with troublesome features. Whilst it must be recognised that neither pre-tunnelling horizontal drilling or probing ahead with a single borehole along the tunnel axis will always detect problematical ground for tunnelling operations, the probability of detecting such features is greatly enhanced using these techniques.

The BRE/TRRL Working Party recognised these and other benefits of horizontal drilling when they recommended trials to be carried out with a drilling rig suited to a tunnelling operation, equipped with a simple and robust data collection system, to correlate drill data with rock properties and tunnelling conditions. Their long term objective was the development and proving of probe drilling systems designed specifically for use in tunnel construction.

Boyd's efforts with an instrumented drilling rig at Chinnor established that monitoring of drilling rig performance was practicable. However, the records which resulted from these instrumented drilling trials were difficult to decipher because no characteristic responses or 'signatures' existed for specific ground conditions against which a comparison could be drawn. The research contract awarded to Imperial College by the TRRL was, in part, concerned with developing the interpretive capability of instrumented horizontal diamond drilling. A programme of laboratory drilling trials in 'constructed ground' was devised to clarify the response of the drilling rig instrumentation to known structural features prior to underground field trials under representative tunnelling conditions. At the same time, a number of borehole logging tools, such as those described in the following chapter, would be laboratory tested for eventual application in field logging trials. The ultimate aim of this aspect of the study was a reduction in expensive core drilling while maintaining the quality and quantity of geo-technical data by cheaper open hole drilling using an instrumented drilling rig supported by selective borehole probes.

CHAPTER 2

DOWN-HOLE INSTRUMENTATION FOR SITE INVESTIGATION PURPOSES

2.1 Introduction

Cook[31] has described the differing constraints imposed on engineers concerned with "conventional" engineering design and that undertaken by rock mechanics engineers. Conventional design engineers normally have at their disposal:

i) Materials having considerable tensile and compressive strengths;

ii) a selection of materials offering different properties;

iii) readily defined forces and motions which act upon conventional structures;

iv) materials of consistent and controllable quality.

The engineer involved with designing structures in rock, on the other hand, must utilize construction materials of potentially variable quality and strength over which he can exert limited control. Thus, while the conventional engineer can largely design a structure then select materials to comply with his design requirements, the rock mechanic must determine the material property restraints imposed by the rock mass prior to design. Having designed the structure, the engineer must then tailor his method and sequence of excavation to achieve his design at the least possible expense and minimum disturbance to the rock mass or else suffer the consequences associated with having altered his material properties, usually to the detriment of safe structural design.

The engineer concerned with the design and construction of subsurface excavations labours most under these severe restraints. Since site geology, rock and rock mass characteristics determine the quality and subsequent engineering behaviour of his construction medium, an extensive, logically planned site investigation is a pre-requisite to ascertaining the properties of the building materials. The site investigation should determine:

i) the type and location of flaws within the rock mass

ii) the strength properties of the rock

iii) the groundwater characteristics of the rock mass

iv) the assessment of abrasivity and/or hardness, particularly when mechanized excavation is anticipated.

Given this information, the implications of the various rock mass properties for design can be evaluated and, where necessary, remedial measures employed to improve the engineering performance of the rock.

Traditionally, and of necessity, a heavy reliance is placed on exploratory boreholes in obtaining parameters for structural design. Site investigation boreholes are used to provide information on:

i) the depth to rock head
ii) the lithological sequence
iii) the dip and azimuth of planar discontinuities
iv) the location of discontinuities
v) the strength of the rock
vi) the state of stress and deformability
vii) the depth and extent of weathering
viii) the presence of swelling ground
ix) the presence of noxious gas
x) the detection of excessive groundwater pressure and flow, and
xi) the rock abrasivity

As previously noted, knowledge of these features enables a stable design to be conceived and an excavation method and sequence to be selected. Hoek[68] has implied that without such knowledge a rational design procedure is impossible.

It is generally conceded that boreholes, particularly those associated with tunnelling site investigations, are an expensive and relatively inefficient means of sampling. However, they are frequently the only means of access available to the tunnelling engineer by which an assessment of rock mass geotechnical properties can be made. Table 2.1 lists the common geotechnical factors which affect the efficient utilization of tunnel boring machines (TBM's)[69]. The wide range of geotechnical factors presented by McFeat-Smith and Tarkoy highlight the important role of site investigation drilling in tunnelling site investigation. It is not surprising that site investigation programmes as they are presently conceived frequently fail to satisfy the requirements of machine manufacturers and contractors for detailed ground information upon which to base design and tendering decisions.

It follows that some means of optimising geotechnical data acquisition is desirable, pre-supposing the judicious placement of boreholes[24], if drilling costs are to be justified and data return maximized. As stated in Chapter 1, the development of an instrumented rotary diamond drill rig will hopefully achieve an improvement in the knowledge of the ground conditions along a tunnel alignment by supplementing existing site investigation techniques and/or reduce drilling costs by rendering a high proportion of core drilling unnecessary. This would be accomplished by virtue of the permanent drilling record made available to the geotechnical engineer being supplemented, as necessary, by additional data from the borehole probes which form the subject of this chapter.

Current practice places a habitual reliance on cored boreholes, in spite of the fact that the very nature of the sampling technique ensures a bias towards the strongest, most competent rock and excludes the zones of principal geotechnical interest (Table 2·1). In addition, considerable research and money has been devoted to the development of borehole instrumentation designed specifically to compensate for shortcomings in standard rock coring operations. This can result in either a coring operation forced to the additional expense of employing borehole probes to supplement gaps in the core record or, as a result of financial restraints, having to place reliance on an incomplete ground survey with all the attendant risks involved.

While it would be unwise to forego coring as a means of obtaining ground information, a strong argument can be made to support a site investigation programme which integrates cored boreholes principally for geological and rock testing purposes and less expensive open-holes surveyed by borehole probes. Both these techniques would be supported by continuous monitoring of drilling performance during coring. The benefits gained both in time and in money could be spent on a more comprehensive investigation or used to defray the costs of the borehole probes.

Hoek and Brown[68] outline the four principal areas of concern with respect to designing underground excavations in rock, namely:

i) instability due to adverse structural geology
ii) instability due to excessively high rock stress
iii) instability due to weathering and/or swelling rock, and
iv) instability due to excessive groundwater pressure

There is a marked similarity between these design requirements and the geotechnical factors which govern the performance of TBM's listed in Table 2.1. Most of these geotechnical features form the basis of the rock classification schemes of Bieniawski[70 71], Laubscher and Taylor[72] and Barton, Lien and Lunde[73 74]. Thus, any improvement in data acquisition techniques for one of these areas of concern has implications for the others.

A recent survey of borehole site investigation equipment by the author[24] indicated that a wide range of borehole probes exist, or may be adapted, to

TABLE 2.1: SUMMARY AND EFFECT OF GEOTECHNICAL FACTORS ON TUNNELLING MACHINE PERFORMANCE

			Nature of principal potential delays		
	Geological features	Condition	Machine	Tunnelling operation	Solution to minimise delay
Major features	Fault gouge	Moisture content, thickness and geometry important	Low machine utilisation due to tunnelling operations. Steering problems likely.	Support, mucking and bracing—all dependent upon geometry.	Machine design permitting early installation of roof and wall support. Good access to invert and face for hand mucking. Experienced driver to reduce steering problems. Minimise gap between cutting head and roofshield at crown.
	Seatearth				
	Intense jointing (shattering)	Spacing less than 0.15 metres.	Low utilisation. High cutter costs in very strong rock.	Support, mucking and possible bracing	
	Sub-parallel to parallel discontinuities	Critical angle about 10-15° for weaker rocks	Low utilisation. Steering.	As above. Overbreak highly dependent upon geometry. Bracing can be main problem.	As above. Machine design with one set of pads preferable.
	High to complete weathering.	Rock Type important	Strong rocks-low utilisation Weak rocks-low utilisation	Machine mucking system As with fault gouge	As with gouge. Mucking system with proven ability to handle material with high clay content.
	Major water inflows	Greater than 3000 m³ day in short zones	Low utilisation. General deterioration of pure argillaceous rocks. Electrical.	Support, pumping, mucking and silting of tunnel. Labour problems. Track laying.	Advance probing and possible grouting. Waterproofed electrical equipment, and large pumps available.
	Extremely strong rock	Greater than 200 MN m²	Low penetration. High cutter costs and maintenance.	Potentially good tunnelling media as joints can be tight	Selection of machine with proven ability to cut hard rock. Step up planned maintenance.
	Mixed face condition	Extreme variation Geometry important	High cutter costs. Estimate as full face of harder rock. Steering—dependent on geometry. Maintenance.	Bracing	As above—non-carbide cutters preferable. Experienced driver essential.
Minor conditions	High jointing	0.5-0.15 metres spacing	Higher cutter wear in very strong rocks.	Support and mucking	These factors create only potentially poor tunnelling ground and high delays will generally only be encountered where these factors work in combination with each other. As above the solution to minimise delays is the use of a machine design permitting clear access for tunnelling operations and maintenance.
	Open joints	No filling or non-cohesive filling, eg clay		Support	
	Inclined joints	Non-cohesive joints Critical angle about 20-50° to the vertical		Support	
	Slickensided joints	Joints smooth planar. Important when working in conjunction with above or sub-parallel joints		Support	
	Weathering	Rock type important.	Faint to slight weathering can have large effect in pure argillaceous rocks	Support and mucking	
	Anisotropy eg shaley bands in sandstones	Banding ±0.2m from soffit level		Support	
	Bedding planes argillaceous content.	Closely spaced planes forming prominent weakness planes.		Support and mucking both grading directly with argillaceous content.	
	Weak rocks	Less than 5 MN m² (Non-halite rocks)	Low utilisation. Steering problems	Support. Mucking and bracing.	
	Distributed water inflows	Rock type susceptible to water eg argillaceous rocks.		Support and mucking Potential labour problems. Track laying, pumping, silting	All electrical equipment must be shielded or preferably waterproofed.
	Mineralisation	Effective healing of joints and minor faults	High utilisation.	Good tunnelling conditions	Keep driving

(After McFeat-Smith and Tarkoy, 1980)

fulfill the data gathering requirements of the geotechnical engineer. The range of equipment is such that in many instances it could be employed in conjunction with an open-hole site investigation drilling programme or, in almost every foreseeable situation, as an adjunct to a combined open-hole/ cored hole drilling programme. While the author accepts that for any given engineering project the selection of suitable borehole probes is governed by the restraints imposed by the scale of the project (available funding for site investigations, desired degree of accuracy and the availability of trained personnel as required), nevertheless, the borehole equipment exists from which to obtain the information deemed essential elsewhere in this section.

Most of the techniques and equipment reviewed are restricted to borehole applications, except when a core-based technique warrants inclusion on the basis that the information it provides is fundamental for design and/or excavation and no viable borehole technique exists. The geotechnical features considered include: structural logging equipment for the description of discontinuities, borehole alignment equipment, groundwater investigation equipment and various methods of measuring rock strength. Geophysical methods are also considered since one of the objectives of this study is to assess the viability of limiting the necessity for diamond core drilling. Detailed consideration of geophysical instrumentation is not treated as the range of available equipment is vast. Also, the techniques require expertise which demands that measurement and interpretation be performed by highly trained specialists, usually on a logging service basis. Various measures of rock hardness and abrasivity are reviewed. While they are not borehole techniques in the strictest sense, they are included because of their obscure yet important relationship with respect to the machineability of rock. This is relevant to the ultimate decision which must be made concerning the use of conventional versus mechanised mining techniques.

2.2 Location and Measurement of Planar Discontinuities

"A drill core is considerably more valuable if the true attitudes of planar discontinuities can be logged. The orientation of a discontinuity is often its most immediately significant attribute; furthermore, the use of the sub-surface data for correlating structures from hole to hole is greatly enhanced when the core is absolutely oriented[75]."

2.2.1 Background

Determination of the attitude of planar structural features encountered during rotary diamond drilling can be accomplished in either of two ways, namely: (a) by measuring the attitude of discontinuities recorded in the core or (b) by determining azimuth and dips of structural features from their presence on the wall of the borehole. Both of these approaches have features to recommend them, as well as equipment peculiar to them.

If core, or impressions of the wall of a borehole, can be orientated with respect to a feature of known azimuth, whether a scribed line on the core, a geologic feature of fixed orientation or alignment of the recording device in a known attitude, it is possible to measure dip and azimuth of geological structures. Where vertical or horizontal boreholes are concerned this determination is straightforward; however, the measurement of azimuths and dips in angled drillholes or boreholes that have departed from their intended course need numerical or graphical solution[75,76].

Figure 2.1 shows a planar discontinuity intersecting a drill hole upon which is scribed a reference line. The maximum angle of the discontinuity trace with respect to the long axis of the core is denoted by β or its complimentary angle α, and is referred to as the dip. The reference azimuth ϕ of the planar trace is measured in a clockwise direction from the scribed reference line to the line of projection of the lowest point of the elliptical trace, as expressed on the circumference of the core (looking in the downhole direction). If the absolute orientation of the reference line is known it is possible to orient all geological structures on the core. Equally, if the absolute orientation of a particular feature is known, it can be used to determine the absolute orientation of the scribed reference line. Goodman[75] has demonstrated a stereographic technique for determining the orientation of a reference line scribed on core based on a knowledge of the borehole orientation, and the orientation of a planar discontinuity with respect to the scribed line. This type of analysis forms the theoretical basis for the scribing core barrels listed in Table 2.2.

Alternatively, the fracture trace as it is expressed on the surface of the borehole wall can be surveyed using a range of borehole survey probes which can be grouped into three broad classes, namely:

i) optical
ii) mechanical, and
iii) geophysical methods

A brief description of these borehole probes is presented in Table 2.2 and additional data on borehole cameras is detailed in Table 2.3. The reader

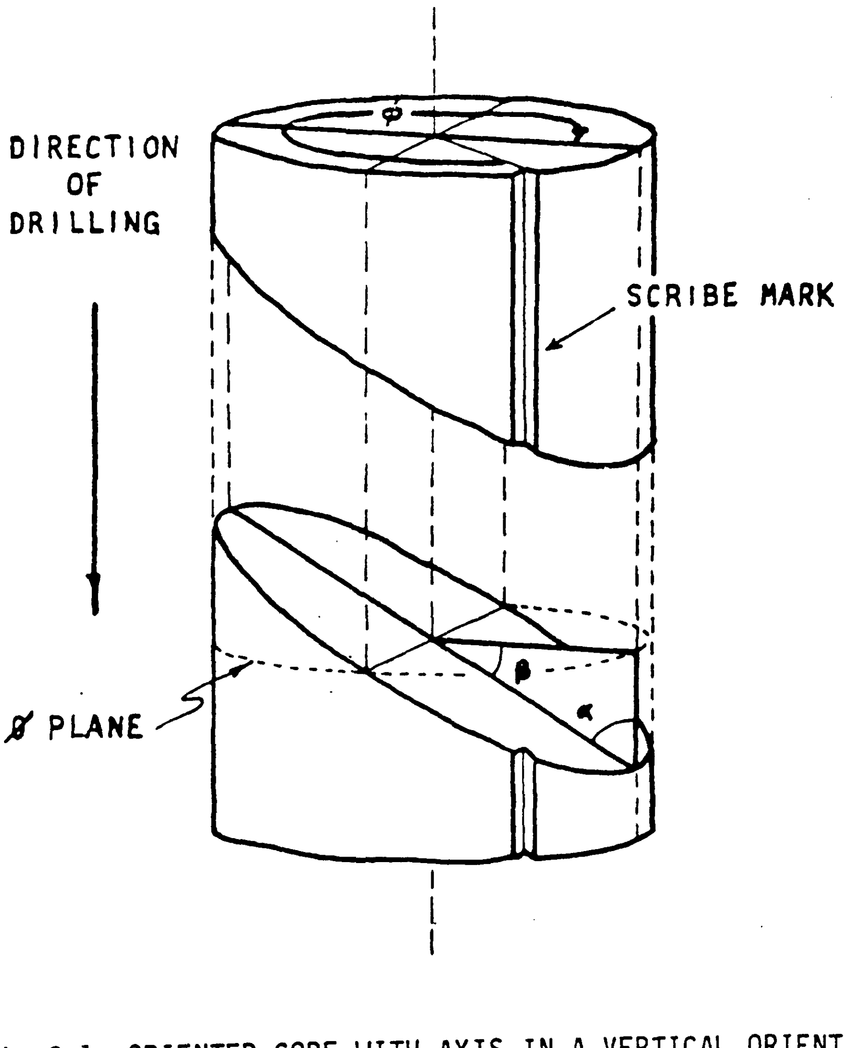
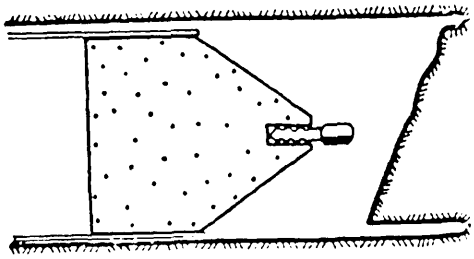
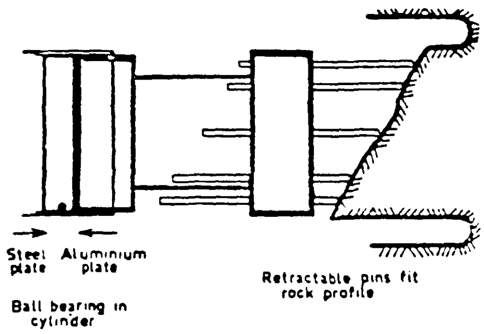


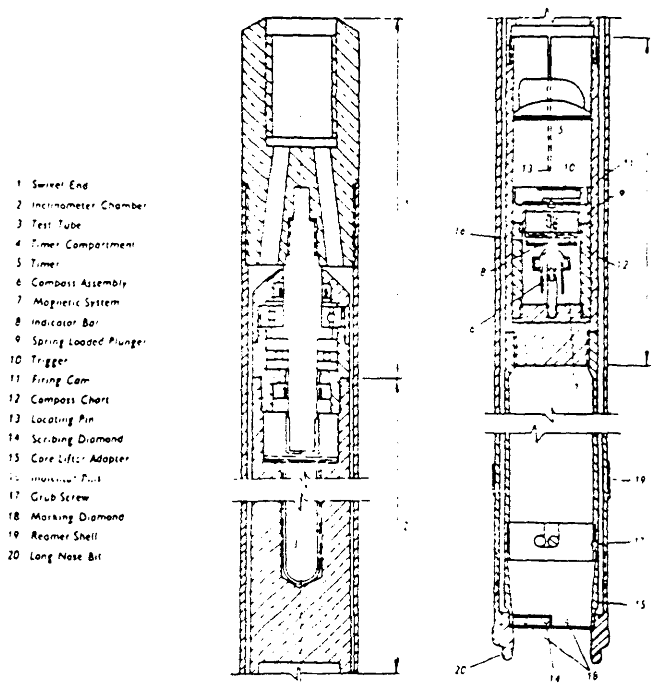
Fig 2.1 ORIENTED CORE WITH AXIS IN A VERTICAL ORIENTATION
(After Wahlstrom, 1973)



(a) Core stub markers



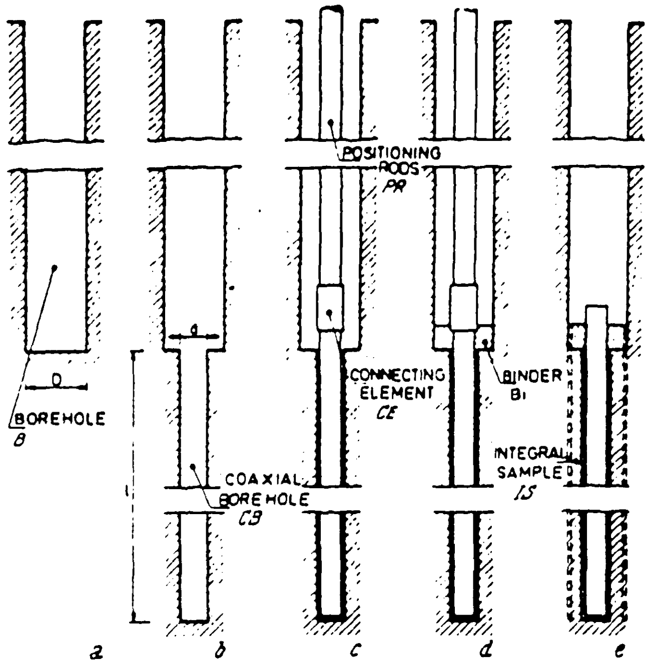
(b) Craelius core orientator

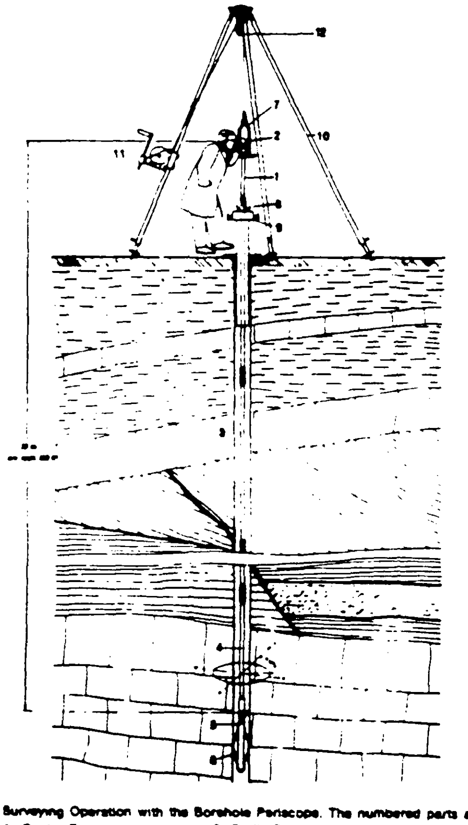


(c) BHP orientating core barrel

FIGURE 2.2 STRUCTURAL LOGGING TECHNIQUES
(After Rosengren, 1970; Moelle and Young, 1970)

(a)

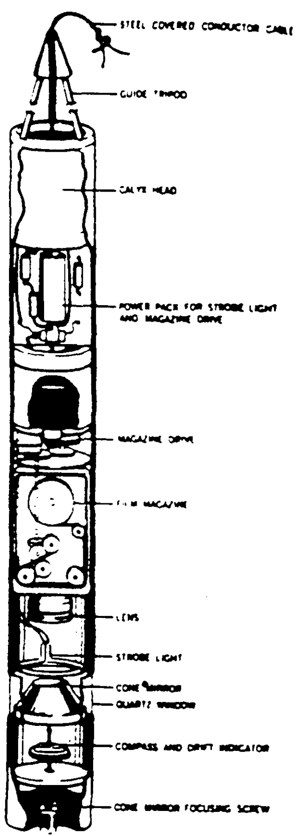




Surveying Operation with the Borehole Periscope. The numbered parts are.

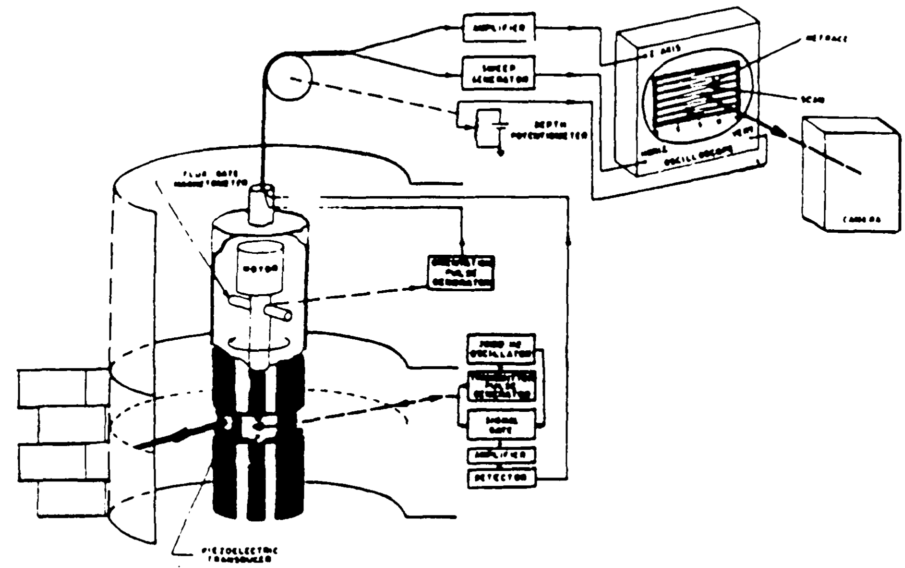
1 Ocular Tube
2. Eyepiece Attachment
3. Extension Tube
4. Objective Tube
5. Baffle Plate
6. Centering Springs
7. Ball
8. Baffle Plate
9. Suspension Collar
10. Tripod
11. Hand Winch
12. Sheave

(b)

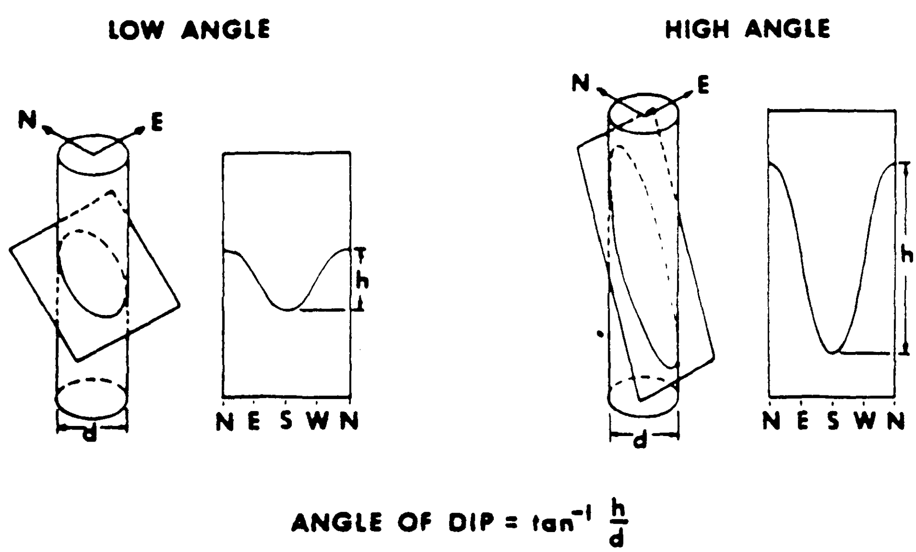


(c)

FIGURE 2.3 STRUCTURAL LOGGING TECHNIQUES:
(a) Integral Sampling (After Rocha, 1971)
(b) Borehole periscope (After Krebs, 1967)
(c) NX borehole camera (After Trantina and Cluff, 1971)

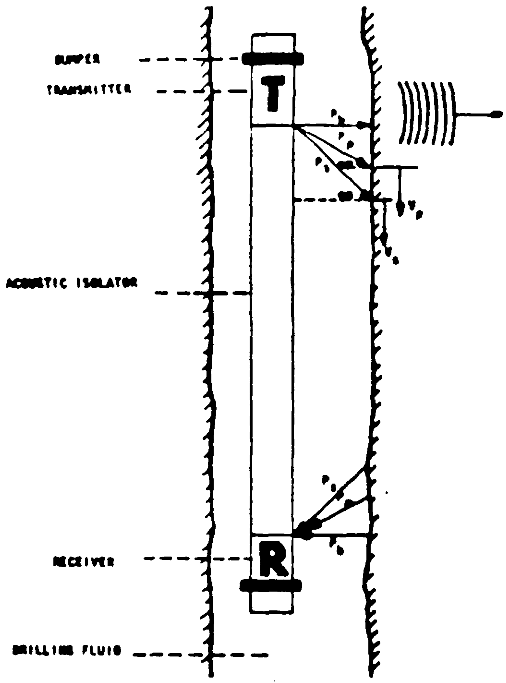


(a)

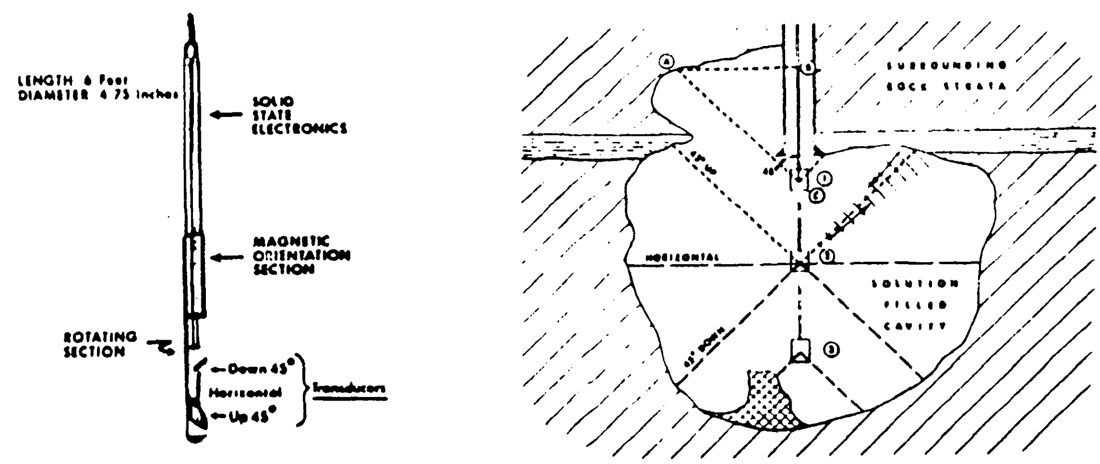


(b)

FIGURE 2.4 (a) Seisviewer logging system and
(b) Determination of dip and azimuth from the seisviewer record (After Caldwell and Strabala, 1969)



(a)



(b)

FIGURE 2.5 (a) Three-dimensional velocity log and
(b) the seiscaliper logging tool (After Caldwell and Strabala, 1969)

TABLE 2.2: BOREHOLE STRUCTURAL LOGGING TECHNIQUES (Adapted from Barr, 1977)

1. Methods Employing Core

Method	Technique	Limitations	Reference
Marker pen	A marker pen linked to a mercury orienting switch is mounted in a dummy barrel. The pen is located near the base of the borehole and the drill/string is rotated until the pen is in a known location as indicated by the mercury switch. The drill string is advanced to allow the pen to contact the core stub, thus leaving a reference mark.	Used at Mount Isa Mines in a near horizontal borehole of large diameter. Could experience difficulty in wet boreholes. Relies on good core recovery in order to fix the position of core fragments between marks.	Rosengren, 1970
Paint marker	A small vial of paint is broken against the core stub at the base of the borehole. The paint runs down the core stub to indicate the gravitational bottom of the bore (Figure 2.2).	Relies on good core recovery to be effective. Only useful in inclined boreholes.	Rosengren, 1970
Acid etching	The gravitational bottom of an inclined borehole is located by breaking a tube of hydroflouric acid against the core stub. Etching of the stub provides an indication of the gravitational bottom of the hole.	Relies on good core recovery to be effective. Only useful in inclined boreholes. The acid is subject to dilution in wet boreholes.	Boyd, 1975
Craelius core orientator	A simple mechanical device consisting of six self-locking pins which assume the profile of the core stub when pressure is transferred to a spring loaded plunger mounted behind the prongs. At the same time a freely moving ball bearing locates itself on the gravitational base of the device. The location of the bearing is imprinted on an aluminium disc. When drilling commences the device recedes into the core barrel (Figure 2.2)	Orientation of the core relies on being able to match the profile of the core stub and the pins. When the core stub approaches a normal or parallel alignment with respect to the long axis of the borehole, serious errors can result because of reduced sensitivity. If the borehole dips less than 10° from the vertical errors in the location of the gravitational bottom can result. Also, the device is expensive and relatively fragile. Finally, good core recovery is required for a continuous orientation.	Bridges and Best, 1971

BHP orientating core barrel	Prior to a core run, a mechanical timer is set to activate a down-hole recording system. After a pre-set time, a N-S reference is impressed on a paper disc which in turn is referenced to a scribing diamond inserted in the core lifter adaptor. As core passes into the barrel, a references line of known orientation is scribed on the core. Two additional diamonds help to align the core as well as assessing whether the inner tube remained stationary during drilling (Figure 2.2).	Strongly magnetic environments may restrict use of the barrel. Inclined boreholes can interfere with the compass unit. Trained personnel are required to operate the tool. The barrel will not pass through standard NX casing. Friable or muddy conditions render the barrel inoperative. Requires good core recovery for best utility. Requires a non-magnetic buffer between the drill rods and the barrel. Drilling time is limited by the pre-set timer. Requires a light bit pressure and a maximum penetration rate of 5 ft/hour to minimize core blockages.	Young, 1965 Moelle and Young, 1970.
Christensen-Hugel orientating core barrel	Operates in a manner similar to the BHP barrel but using three knives, mounted on a shoe which is fitted to the inner barrel, to scribe reference lines on the core. The barrel uses an Eastman Multishot directional survey instrument (described elsewhere in this chapter) to photographically record the compass bearing and the plunge of the borehole, as well as the orientation of a marker relative to one of the scribing lines.	Subject to most of the limitations of the BHP barrel. In addition, a delay is involved between recovery and development of the photographic record.	Rowley et al., 1971
Integral sampling technique	Developed primarily for sampling in difficult ground, the method requires: a) drilling to the depth where sampling is to begin, b) drilling a co-axial borehole to accept a reinforcing bar, c) location of the bar by positioning rods, d) bonding the bar in place, and e) overcoring the reinforced zone after the bonding agent has cured (Figure 2.3).	The method is slow and expensive. Orientation of the reinforcing bar is progressively less reliable as the hole gets deeper. The use of grout renders the core useless for testing purposes.	Rocha, 1971 and 1973

2. Borehole Wall Inspection Methods

Method	Technique	Limitations	Reference
Borehole periscope, borescope or strata-scope	The periscope objective lens has a light source located at the base of the probe. Incidental light from the borehole wall is refracted by an angular prism up the objective tube to the ocular tube where another prism passes the image through the eyepiece. Extension tubes can be introduced between the ocular and objective tubes. A tripod suspends the equipment and provides the means whereby the image can be referenced to magnetic north. (Fig. 2.3). A camera unit can be attached to the eyepiece. Can also be used in inclined boreholes.	Area of coverage is small. Affected by turbidity in wet boreholes. A practical limit of 100 feet of separation exists between the ocular and objective lenses as a result of light reflection and absorption.	Krebs, 1967 Maktab et al., 1973
Borehole cameras	A wide range of multishot 'still' and television cameras exist (see Table 2.3). The still cameras normally employ a conical mirror, whereas the t.v. cameras use conical mirrors and/or rotating angled mirrors to transfer the reflected image to the photo-sensing element of the device (Figure 2.3). Still cameras, in particular, usually include a photograph of a compass and a tilt indicator (through the hole in the conical mirror) to orientate the image. Independent orientation systems such as the Eastman Multishot are also employed.	Conical mirrors are subject to distortion towards their centre, although corrections can be made. The still cameras are subject to delay in analysis because of the time required to process the film. Distortion can also occur if centralizing devices are not employed. Also, inclined boreholes produce distorted images, particularly on conical mirrors. Both types of system are relatively expensive and can be rendered useless by turbid water. Both systems have a small area of coverage and are thus slow.	Burwell and Nesbitt, 1964. Trantina and Cluff, 1963. Anon, 1970. Reid, 1976. Halstead et al.,1968 Butler & Hugo, 1967 Lundgren et al.,1970 Farrell, 1963 Halstead et al.,1968 Rausch, 1965. Hoek and Pentz, 1968
Borehole Impression Packer	This is a pneumatically inflatable device which presses a deformable thermoplastic film onto the wall of the borehole. The film records any irregularities present on the borehole wall. The permanent record can then be analysed to provide information of fissure distribution, dip and aperture as well as lithology where textural variations exists.	Coverage per trip into the borehole is 70% wall coverage over a 1.75 metre run. Complete coverage of the borehole is accomplished by rotation of the tool and successive overlapping of the impressions. The survey is both rapid and relatively inexpensive. The thermo-plastic film can also be used as a photographic negative. Can be fitted with an alignment survey device.	Hinds, 1974 Barr, 1974 Barr & Hocking, 1976 Harper & Hinds, 1978

Seisviewer	Produces a high resolution acoustic picture of the borehole wall. An acoustic transducer combined with a fluxgate magnetometer emits an acoustic pulse, the position of which is referenced to magnetic north. The amplitude of the return signal is determined by the acoustical impedance of the rock and the physical properties of the borehole wall. Fracture zones are characterized by a weak to a non-reflected signal. The acoustic return signals and the magnetic-north-indicating pulse are amplified and transmitted to a surface processing panel. The margins of the generated image correspond to magnetic-north to permit orientation of structural features. Dips are determined from the amplitude of the sinusoidal waveform representation of the fractured trace (Figure 2.4).	The literature notes several successful applications. Appears useful as a logging device assuming that the borehole intercepts the cavity in the first instance.	Caldwell & Strabala, 1969 Baltosser & Lawrence 1970 Zemanek et al.,1969 Zemanek, 1970
Three-dimensional velocity logger	An acoustic pulse is transmitted to the rock mass by a magnetostrictive transducer. A piezo-electric receiver measures pressure variations resulting from the interaction of the compressive wave at the borehole wall/drilling fluid interface. Pressure variation is converted to an electric pulse and transmitted to a surface recorder. The system can be used as a cross-hole survey device. The position of fractures is indicated by attenuation of the compressive and/or shear waves. The device can also be used to measure elastic properties of the rock mass (Figure 2.5).	Vertically orientated fractures cannot be detected since neither the compressive nor the shear waves are attenuated. Presumably, as the fracture orientation tends towards the vertical, the sensitivity of the system decreases. Acoustic coupling requires immersion of the probe in drilling fluid.	Zemanek, 1970 Myung & Baltosser, 1972
Seiscaliper	The three-dimensional geometry of cavities is measured by monitoring the travel time for a reflected acoustic pulse. The distance to the reflecting surface is a function of time and the sound velocity of the fluid. Three individual signal transducers, one inclined 45^{o} downwards, another 45^{o} upwards and the third horizontally, can be independently assigned scanning priority from surface. The rotation rate of the transducer and pulse rate of the transmitter can be varied to suit the distance to the cavity wall. Returned signals are processed at surface and displayed on a polar co-ordinate oscilloscope, the image being referenced to magnetic north (Figure 2.5).	The accuracy of the system is directly proportional to the beam width. Since the transducer size is controlled by the diameter of the borehole, the only means of modifying the beam width is by varying the frequency. Beams are normally focused at widths of 2^{o} or less at a frequency of 500 kHz, this giving a maximum range of approximately 150m. Downhole calibration permits correction for ambient temperature, pressure and fluid density variations. A composite impression of the cavity geometry can be derived from the series of planar sections (2^{o} arc) provided by the system. The cavity must be intercepted by the borehole.	Caldwell & Strabala 1969

TABLE 2.3: BOREHOLE CAMERAS

Item	Manufacturer	Diameter(O.D.) (cm) (in)	Minimum Size Hole (cm)	(in)	Probe Length	Probe Weight	Power Supply	Depth Limit	Light Source	Film Type
Birdwell Down-hole Camera	Seiscor, Tulsa, Oklahoma	11.4cm (4½in)	15.2cm	(6)	1.22m (48in)	22.7kg (50lb)	115V, 60Hz	2438m (8000ft)	strobe light	16mm colour and b/w
Laval Down-hole Camera	AV Electronics, Inc., Fresno, California	12.1cm (4¾in)	15.2	(6)	-	15.9-22.7kg (35-50lb)	110V 60Hz	2438m (8000ft)	strobe cell	special 29mm colour or b/w
Republic NX Borehole Camera	Republic Research, St. Paul, Minnesota	7.0cm (2¾in)	7.6	(3)	0.76m (30in)	13.6kg (30lb)	110V 60Hz	2134m (7000ft)	strobe cell	16mm colour or b/w
Penndrill Horizontal Borehole Camera	Pennsylvania Drilling Co., Pittsburg, P.A.	14.3cm (5⅝in)	15.2	(6)	1.52m (60in)	13.6kg (30lb)	110V 60Hz	366m (1200ft) or g'water level	strobe	35mm colour or b/w
CSIR Cavity Camera	Council for Scientific & Industrial Research	3.8cm (1½in) probe unit	7.6	(3)	1.22m (48in)	-	12V for everything but photo-resistor (45V)	-	electronic flash	35mm colour or b/w
Laval TV Borehole Camera	AV Electronics Inc., Fresno, California	12.1 (4¾in)	15.2	(6)	1.27m (50m)	18.1kg (40lb)	110V 60Hz	91m (1500ft)	incandescent lamps	closed circuit t.v. - permanent video tape or photographic record
Eastman TV Camera F.B.400	Eastman International Co., GWBH, Hanover W. Germany.	6.4cm (2½in)	7.6	(3)	1.37m (54in)	27.2kg (60lb)	220V 60Hz	457m (1500ft)	incandescent lamps	closed circuit t.v. - permanent video tape or photographic record
Oceanographic TV Camera	Oceanographic Engineering, San Diego, California.	7.6cm (3in)	10.2	(4)	0.51m (20in)	9.1kg (20lb)	110V ac or dc	1219m (4000ft)	neon cell	closed circuit t.v. - permanent video tape of photographic record
Rees 81 TV Camera*	Rees Instruments Ltd. Old Woking, Surrey, England.	4.5cm with 01 0202 head 4.8cm with 03 head	5.1 with 03 head		0.48m (19in) with 01 head 0.61 (24in) with 02 head	1.72 (3.8lb) with 01 head	-	136m (450ft) underwater	gtz halogen lamps	closed circuit t.v. - permanent video tape or photographic record

*Manufacture a wide range of equipment

interested in a more comprehensive description of the equipment described in Table 2.2 should refer to C.I.R.I.A. Technical Note 90 (Barr, 1977), as well as references associated with each technique.

2.2.2 Summary of Structural Logging Techniques

The attitude of planar discontinuities is of fundamental concern to engineers concerned with the stability and the excavation of underground structures. This concern is reflected in the many numerical and graphical manipulations developed to utilize the dip and azimuth data acquired by an impressive number of borehole structural logging tools.

Acid etching or paint marking of core stubs is probably not accurate enough for detailed structural stability analysis, although it is useful in mining operations in areas where long term stability is unimportant or only a preliminary appraisal is required before verification by more accurate logging techniques. Similarly, core scribing techniques are of questionable value since they work best in competent rock (this is also true of the Craelius core orientator), rock which frequently is of least concern for the engineer. Since these techniques are very inefficient in fractured ground, this frequently leaves the engineer uncertain regarding zones of the rock mass about which he is most concerned. Broken ground can also cause damage to these logging tools, or else seriously hamper their operation by restricting the flow of core into the barrel.

Regarding broken ground and/or soft ground, Rocha's integral sampling technique is capable of providing a continuous core record, but the accuracy of the system decreases with increasing depth and the necessity for overcoring renders the method prohibitively expensive, except under the most select circumstances. Certainly, it could not be envisaged as a standard borehole logging procedure.

The benefits to be derived from using optical borehole inspection methods has been disputed frequently in the literature. In dry boreholes optical devices function on a par with any other logging method, the difficulty occurring when inspection of the borehole wall is required in water-filled holes as the optical elements in these probes cannot contend with the murky conditions which often prevail. Even the use of coagulents to clear the water often achieves only limited success. It is arguable whether the expense of many of these optical viewing systems is justified, given the paucity of data which can occur when viewing conditions are other than favourable.

The intimate contact between the borehole wall and the thermoplastic film of the borehole impression packer eliminates the difficulties experienced by optical techniques and it provides a permanent record which can be used as a photographic negative. The device works very well in rotary diamond drilled boreholes. However, it has yet to be proved in percussive drilled holes, although it should perform to an acceptable standard provided the borehole has been adequately flushed clean upon completion. Borehole logging by this means is relatively fast once expertise is gained in handling the thermoplastic film. The instrument shows promise of providing a relatively inexpensive logging technique.

The author must rely on the literature for an appraisal of the seisviewer, the three dimensional velocity log and the seiscaliper. Published reports appear favourably inclined towards these borehole tools noting various successful applications, although it must be borne in mind that this may in part be a reflection of editorial policy, etc. The seiscaliper certainly appears useful for logging suspected voids, provided these are intercepted by the borehole.

All of the structural survey methods require accurate information on the orientation of the borehole at the point of survey in order to determine the absolute orientations of the structural features expressed on the borehole wall or in the recovered core. Some of the structural logging tools (particularly borehole cameras and scribing core barrels) incorporated borehole alignment surveying equipment as integral components while other techniques require independent alignment surveys to be run.

2.3 Borehole Alignment Instruments

Directional surveying of boreholes whether for geological, mine development or geotechnical purposes is an essential adjunct to structural orientation measurements, whether structural orientations are measured from core or the borehole wall. Unless the attitude of the borehole is considered and appropriate corrections applied to the measured orientations of geologic structures, the structural data is of questionable value.

2.3.1 Background

In shallow boreholes, particularly rotary diamond drill holes, a simple correction for the inclination and direction of the drillhole is probably of sufficient accuracy for most purposes. In long boreholes or drillholes transecting steeply inclined strata, there is a tendency for boreholes to diverge from their intended course. Fortunately, a range of instruments exist to determine the true attitude of a selected zone of a borehole.

Such measurements can be used to correct structural orientation data related to that zone. The borehole alignment tools generally fall into one or both of the following classes, namely:

i) structural logging devices which incorporate alignment survey tools (discussed in Table 2·1) and

ii) independent survey systems which measure borehole deviation.

A survey of probe inclinometers is included in this section since many lend themselves to a possible dual role as borehole alignment devices, as well as ground displacement sensors. By observing the tilt of the probe for known orientations using keyways or a compass, it should be possible to calculate the degree and direction of deviation of a borehole. This information could thereafter be used to correct depths and attitudes of important geological features.

2.3.2 *Borehole surveying devices*

A wide range of purpose-designed borehole alignment survey tools are available for use in 'normal' size geotechnical boreholes. The equipment varies from the relatively unsophisticated drift indicator through to the highly complex and expensive gyroscopically based survey systems. Every device, with the exception of the drift indicator, provides borehole dip measurements which can be referenced to magnetic north. The more advanced equipment, and, in general, the more expensive, avoids the use of standard compass elements by resorting to the use of very accurate inertial systems, induced electromagnetic fields and positioning rods in order that they can operate in magnetically disturbed conditions. This equipment is briefly described in Table 2.4. A more comprehensive description of the items in Table 2.4 is available in the CIRIA Technical Note 90 .

As was suggested earlier, it may be possible to adapt borehole inclinometers to operate as a directional survey device. Borehole inclinometers are normally employed as a means of measuring tilt or inclination of a borehole resulting from ground movements associated with mining subsidence, embankments and dams, underground structures, etc. Apart from their obvious interest to this investigation as a means of monitoring rock movements about shafts, tunnels and underground structures in general, some inclinometers may be made to serve a dual role as a borehole directional survey tool.

In order to determine if borehole deflection has occurred, an inclinometer must be capable of determining its exact position in space relative to the walls of the borehole. Most probe inclinometers employ a cantilevered

TABLE 2.4: BOREHOLE DIRECTION AND INCLINATION SURVEYING DEVICES (Adapted from Barr, 1977)

Item	Manufacturer	Diameter	Minimum Hole Size	Probe Length	Accuracy	Depth Limit	Power	Recording unit	Limitations	Reference
Eastco drift indicator	Eastman International GWBH, Hanover, Germany	smallest barrel 32mm	-	170cm	Varies with angle unit	Determined by maximum timer setting (33 or 66 minutes)	Clockwork mechanism	Punched disc	1. no measure of the direction of deviation 2. designed for vertical boreholes 3. single measurement per trip	Eastman International
Tropari compass	Pajari Instruments Willowdale, Ontario, Canada	-	48mm	-	$\pm$ 0.5°	Determined by maximum timer setting for trip down borehole (90 or 150 mins)	Clockwork mechanism	Self-locking compass and plumb unit	Affected by magnetic environments	Pajari
Single-shot survey instrument	Eastman International GWBH Hanover, Germany	38mm with 20° angle unit	51mm	61cm	$\pm$ 5° dip $\pm$ 1° azimuth	6000m with special casing	12V dry cell	Strobe light and photographic disc	Single measurement per trip. Film disc processed on site.	Eastman International 1961 Krebs, 1964
Multi-shot instrument	"	41.4mm up to 34.5 MN/m² or 44.5mm up to 69 MN/m² pressure	48mm	-	$\pm$ 5° dip $\pm$ 1° azimuth	6000m with special casing	12V dry cell	Strobe light and 10mm film camera	Delay for processing film	Eastman International 1961
Dip and direction indicator	Atlas Copco ABEM Bromma, Sweden		36mm cased or uncased boreholes	-	most accurate 10° from horizontal to 10° from vertical 0.1° to 0.2° dip $\pm$ 2° azimuth	1000m	surface unit	Pendulum in electromagnetic field	Mounted on positioning rods but can be used in magnetic environments	Atlas Copco ABEM, 1968
Reflex-Fotobor	Atlas Copco ABEM Bromma, Sweden	45mm	46mm	12 metres	0.1m/100m	1800m in one run	110/220v (camera)	Simultaneous photograph of a ring-shaped bubble level and 3 positioning reflector rings.	Expensive but can be used in magnetic zones. Probe length may limited geotechnical application.	Atlas Copco, ABEM, 1974
Gyro clinometer KL3	Eastman International GWBH Hanover, Germany	72mm (50mm device available)	76mm	2.9m	-	designed for oil well applications	rechargeable battery	Multiple shot survey unit incorporating a gyroscope compass.	Expensive but extremely accurate and suited to magnetic environments	Eastman International
Gyro surveyor*	Humphrey Inc. 9212 Balboa Avenue, San Diego, California	45mm (GP07 probe)	-	various	about $\pm$ 0.1° dip	3000m	28V DC	DC signal to surface control box	"	Humphrey Inc. 1975

* Many combinations of gyroscopic systems and control units available.

pendulum as a tilt sensor in conjunction with a variety of devices used to monitor the amount of pendulum deflection. Interested readers are referred to Barr[24] and Butler[114] for a more detailed description of the design of the deflection sensing elements. Most of the inclinometers listed in Table 2.5 rely on borehole casing having either a square section or keyways, in order to orientate the inclinometer as it travels in the borehole (Figure 2.6).

2.3.3 *Summary of inclination surveying devices*

In most circumstances, structural data obtained from shallow boreholes need only be corrected for the inclination and direction of the drillhole. In long drillholes and/or those intersecting geological features which could conceivably deflect the drill string, it is advisable to survey the borehole and to correct borehole structural data accordingly.

There are innumerable ways of measuring dip as indicated in the foregoing discussion. However, while instruments like the Drift Indicator give a reliable indication of dip, they must be coupled to a direction sensing device if it is to be of any geotechnical value. In this regard, the Tropari compass incorporates both characteristics in an accurate, compact package suited to incorporation in "single-trip" borehole tools (i.e. borehole impression packer).

Alternatively, photographic survey tools are reliable but relatively expensive, particularly the more useful multiple shot instruments. Whilst these instruments can survey the borehole reasonably quickly, reading and transcribing the photographic record can be time consuming.

The use of inclinometers as directional surveying tools is practicable provided that the orientated keyways can be prevented from 'corkscrewing' in the borehole. Alternatively, where suitable (drill rod diameter just less than the borehole diameter), specially adapted drill rods may prove capable of guiding an inclinometer suspended on a wire line.

All systems employing compasses as direction sensing elements are rendered unreliable in magnetically disturbed ground. Such circumstances demand gyroscopic systems or devices like the Reflex-Fotobor, both of which are very expensive. Certainly the gyroscopic systems may be needlessly expensive as they provide correction values whose accuracy is far in excess of that required for structural stability analysis. Therefore, it may be advisable to develop a less accurate gyroscopic survey tool at a more competitive price to suit the geotechnical market. Alternatively, the establishment of a directional survey logging service may be a viable enterprise, particularly with increasing interest being shown in the use of long horizontal boreholes for tunnelling site investigations.

TABLE 2.5: PROBE INCLINOMETER SUITED FOR BOREHOLE ALIGNMENT SURVEYS (Adapted from Barr, 1977)

Item	Manufacturer	Casing Size	Casing Type	Range mm/m	Range degrees	Sensitivity mm/m	Sensitivity seconds	Mode of Operation	Reference
CRL inclinometer	Cementation Research Ltd.	45 x 45	square aluminium duct	±88 from vertical	±5	0.075	15	strain gauged pendulum	Franklin, 1975, Franklin & Denton, 1973
Inclinometer	Soil Instruments Ltd. London	50	aluminium tubing with keyways	360 from vertical	±20	0.2	41	strain gauged pendulum	Franklin, 1975 Franklin & Denton, 1973 **
C-350 slope meter	Soiltest Inc., Evanston, Illinois	45 x 45	square steel tube	±577 from vertical	±30	0.075	15	strain gauged pendulum	"
Borehole clinometer	Structural Behaviour Engineering Laboratory	76 x 76	square steel tube	±175 from vertical	±10	0.1	20	strain gauged pendulum	"
Slope reader	Eastman International GMBH, Hanover, Germany	51	plastic	±175 from vertical	±10	0.1	20	2 electrolytic levels at 90^o, servo motor & compass	"
Series 200-B slope indicator	Slope Indicator Co., Seattle, Washington	81	aluminium tube	±467 ±87	±25 ± 5	1.0	206	pendulum with rheostat	"
Horizontal inclinometer	Transport & Road Research Laboratory		aluminium tube			0.2	41	inductive acceleration transducer	Hudson and Morgan, 1974
68-062 inclinometer	ELE Geonor, Hemel Hempstead, Herts.	50	aluminium alloy	±792	±45	0.15	31	vibrating wire pendulum	Franklin, 1975 Franklin & Denton, 1973
MDS 83	(Maihak) Rocktest Ltd. Longuevil, Montreal, Canada	50 or larger	aluminium or plastic, optional keyways	±290	±15	0.05	10	2 directional vibrating wire pendulum, compass or keyway	"
Digitilt	Slope Indicator Co. Seattle, Washington	30/7/81	aluminium or plastic	±577 infinite	±30 ±90	0.1	21	Servo accelerometer	Franklin, 1975 Franklin & Denton, 1973
M.P.F. Clinometer	Telemac, Paris, France	65 probe diameter	plastic with keyways	±259	15^5	0.1	21	vibrating wire	**

** Manufacturer's Trade Literature

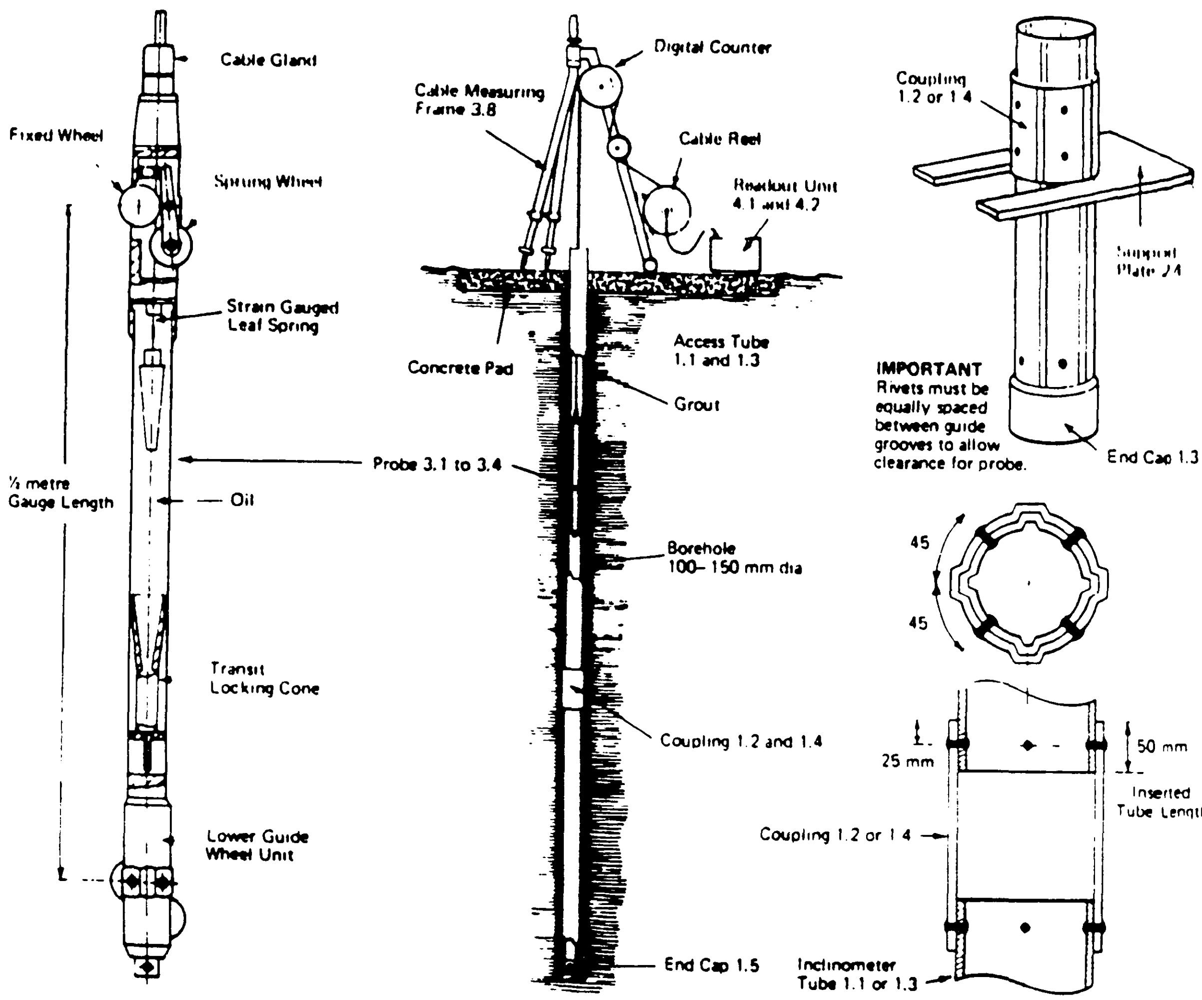


FIGURE 2.6 TYPICAL PROBE INCLINOMETER SURVEYING OPERATION
(After Soil Instruments)

2.4 Geophysical Techniques of Potential Application in Tunnelling Site Investigations

2.4.1 *Introduction*

Geophysical techniques have recently been the focus of considerable attention in the geotechnical field, particularly in the tunnelling industry where the need for a rapid and comprehensive rock mass investigation system to supplement tunnel boring machines is being expressed. Naturally, the potential benefit of geophysical techniques has not gone unobserved. Nevertheless, it would appear that they are incapable of fulfilling the requirements of the tunnelling industry at the present time (particularly when considered in isolation), being of limited benefit even when supported by comprehensive site investigation data.

2.4.2 *Geophysical techniques*

Tables 2.6 and 2.7 describe the various surface and borehole techniques which may offer potential benefit to the tunnelling engineer. The application and limitations of the various methods have been suggested based on a literature survey. Two recent articles have been published on the use of geophysical methods for site investigations for roads[117] and for probing ahead of tunnels[6]. In the main, both sources tend to be pessimistic about the immediate benefits that the geotechnical engineer will derive from the application of geophysics in any but the most selective of sites. West and Dumbleton suggest that the reasons for failure of geophysical investigations in the past are many and varied including, among others:

i) unsuitable sites and/or geology
ii) use of the incorrect geophysical technique, method or equipment
iii) improper interpretation of results
iv) poor initial specification for the survey

Considering potentially successful applications of surface-based geophysics, the BRE/TRRL Report[6] and West and Dumbleton[117] suggest that depth to bedrock measurements (normally seismic refraction) are usually the most successful, although they stress that the survey should always be proved by boreholes. If the location of features which could threaten a tunnelling operation are considered, some rather sobering facts emerge. With respect to faults; when complex geology, geophysically similar strata on either side of the fault or drift cover exist, geophysical methods are unlikely to locate the feature in question. In trials to locate an old shallow adit of known location at 6 metres depth, all methods including gravity, resistivity,

TABLE 2.6 GEOPHYSICAL AND SEISMIC METHODS (After Barr, 1977)

Method	Principle of Operation	Geological Environment	Applications	Limitations
Seismic refraction (6, 68, 118, 119, 120)	Measures first arrival travel times of shock induced elastic waves. Accuracy $\pm 2 \times 10^{-3}$ sec. = ±3 to 9 metres. Linear coverage at any desired spacing. Requires velocity increase with depth.	Sedimentary, igneous and metamorphic to an effective depth of 150 metres; greater depths require large horizontal extension of operation	Measures depth to bedrock along survey line. Used to determine P and S-wave velocities which if formation density is known can be used to derive elastic constants. P-wave velocity provides qualitative measure of fracturing and weathering. Reveals configuration and continuity of rock surfaces.	Depth determinations require vertical velocity calibration. Poor in deeply dipping strata. Uneconomic for small projects. Cross-hole techniques limited to 50-100 metre maximum spacing.
Seismic reflection (6, 68, 119, 120)	Measures travel times of shock induced elastic waves. Relies on sufficient thickness and velocity contrast between lithologies to cause reflection of of part of the seismic pulse. Accuracy $\pm 2 \times 10^{-3}$ sec. = 1.5 to 7.5 metres decreasing with depth. Coverage is linear at any desired horizontal spacing.	Mainly sedimentary rocks. Land based surveys limited by an effective depth of 100 metres or greater because the early reflections are masked by high energy shear & surface waves.	Locates discontinuities such as faults. Measures depth and continuity of rock layers.	Depth determinations require vertical velocity calibration. Cross-hole techniques limited to 50-100 metre maximum spacing. Can normally only be interpreted for depths which usually extend beyond requirements of civil engineering.
Micro reflection/ refraction (120)	Measures travel times of shock induced energy in 10^{-3} sec. with an accuracy of 5×10^{-6} secs. Effective instrumental accuracy is $\pm 2 \times 10^{-3}$ secs. Coverage is one point per measurement (up to 12 for refraction)	Soil or alluvium. Effective depth ranges from 0 to 25 metres, greater depths under certain conditions.	Measuring depth to bedrock, locating aquifers and gravels.	Less accurate. Limited arial extent, geologic environment and depth of effectiveness.
Magnetometer (6, 68, 120, 123)	Measure total magnetic intensities in gamma to ±1 gamma for total field, 2.5 to 10 gamma for vertical field and ±10 gamma for horizontal field. Coverage is at point.	Mainly igneous. Effective depth not selective but field strength decreases as square of distance from observer.	Locates metallic bodies including dolerite dykes and sills. Can detect faults by sensing displacement of marker horizons. Locating mine shafts.	No indication of rock mass geometry. Affected by power cables. electric railways, moving vehicles and population centres generally. Frequently difficult to interpret.
Gravitymeter (6, 68, 120, 123, 124)	Measure relative acceleration of gravity(which can be related to total density of rock) in 10^{-8} gals. Accuracy ±0.01 milligals. Coverage is spherical about a point.	Any rock type. Effective depth exceeds 900 metres but intensity of signal decreases as square of depth.	Density contrasts used to detect major faults, buried channels infilled with low density alluvium, and large cavities. Can be employed in boreholes. Useful for interpretation of seismic data.	No indication of rock mass geometry. A topographic survey correction is required for irregular terrain. Only gross features are detectable with any certainty. Too slow & expensive for speculative use in site investigation.
Electro-magnetic (6, 124)	Measures amplitude and phaseangle of electromagnetic field. Measurements in scale readings. Coverage of a point.	All rock types. Effective depth surficial	Aquifer detection	Restricted application and ambiguous results.
Electrical resistivity (68, 123—128)	Measures relative electrical conductivity of rocks (ranging from 3×10^{-3} to 10^{4} ohms) based on rock porosity, pore fluid salinity and clay content. Sensitivity about $\pm 2 \times 10^{-1}$ ohms. Coverage linear over short distances.	Any, but performs best in overburden. Effective depth about 900 metres but normally less than 30 metres.	If salinity constant, porosity variations can be detected. If uniform composition and porosity, salinity variations can be mapped. Because of sensitivity to clay content can be used to located faulted or weathered zones using constant separation technique. Used for ore prospecting, water exploration, depth to bedrock measurements and gravel deposits(expanding electrode method). Qualitative assessment of rock strength Has been used to detect infilled shafts and buried voids(must be above water table.	Can often produce ambiguous results. Requires water saturated formations for best performance.
Ground probing radar (6, 129, 130, 131)	A pulse of ratio energy is transferred to the rock mass a portion of which is reflected by an object of interest back to a receiver. The travel time determines the distance to the object $D = T/2n$ where D is in feet, T in nano-seconds and n is a slowing factor for the intervening rock $(1.4 \le n \le 4)$ Operating frequences range from 5 MHz to 5000 MHz	Any geological environment. Probing distances vary according to the "transparency" of the particular material to radar waves. Discouraging outlook for soft ground applications with ultimate probing limit of 15 to 20 metres in clays and muds. Present day limits are very much less.	Potential applications extend to locating bedrock surface, cavities clay bands, faults and shatter zones. Voids in particular appear to be easily detectable. Many targets have been detected under controlled conditions Can be located on surface or underground and borehole probes are being developed. The N.C.B. has used the method to probe for unmapped. abandoned workings.	Probing distances increase with wavelength but choice of wavelength restricted by considerations of resolving power and portability. Long wave lengths mean bulky equipment and inability to detect small targets. Interpretation of signals is at a very primitive stage. Potentially a most valuable technique but at present restricted to research applications

TABLE 2.7 BOREHOLE GEOPHYSICAL AND SEISMIC TECHNIQUES OF POTENTIAL VALUE IN TUNNELLING SITE INVESTIGATION (After Barr, 1977)

Technique	Principle	Geological Environment	Applications	Limitations
Spontaneous potential (132, 133, 143)	Records naturally occurring potential differences between a fixed surface electrode & a mobile borehole electrode.	Main applications in surficial deposits & sedimentary strata	Can detect impervious zones (clay & shale) and permeable strata (usually sands) but no value for permeability possible. Delineation of formation boundaries.	Requires conductive mud filled bore hole. Good resolving power in formations of low to moderate resistivity. In very resistive formations can detect shales but cannot accurately locate boundaries.
Induction logging (102, 132, 133)	Measures the conductivity (reciprocal of resistivity) of formations employing induced alternating currents. Capable of being focused to improve thin bed response.	Mainly surficial deposits and sedimentary strata	Used to define lithological boundaries of beds down to about 60 cm thickness. Other systems including laterolog and microlog operate in a similar fashion but operate on a reduced volume of rock, although with greater definition.	Requires conductive mud-filled borehole.
Gamma log (127, 132, 133)	Records naturally occurring gamma radiation usually employing sodium iodide crystal detector.	Sedimentary formations mainly	Distinguishes shales from other formations therefore used for bed definition, location of interfaces and correlation of strata. Performs in high salinity environments unlike SP log.	Used in empty or fluid filled boreholes. Can be difficult to interpret without supplementary logs for example, microlog. Affected by statistical variations.
Neutron logging (102, 127, 132, 133)	Records emission of gamma radiation from materials which absorbed neutrons emitted from a source in the downhole probe. The neutrons are particularly affected by hydrogen atoms since they are of similar mass. Linearly scaled to porosity.	Any, but primarily sedimentary rocks	Useful for delineating formations (particularly shales). A measure of hydrogen content is obtained that is moisture content above the water table and porosity below.	Can be run in cased, uncased & empty boreholes. Borehole diameter survey necessary. Affected by high salinity & statistical variations. Linear scaling with respect to porosity assumes water saturated pore spaces. A(n - γ)log can be run to cancel the effect of natural background gamma radiation.
Gamma-gamma log(density log, scattered gamma ray log or formation density log (102, 127, 132, 133)	Measures the absorption of gamma radiation by the surrounding rock between a source and detector. Linearly scaled with respect to porosity. Accurate to ±1 to 2 percent.	Any	Since absorption of gamma radiation is very sensitive to bulk density, a measure of the intensity of return rays can be used to determine formation bulk density. If the density is known from other sources, it can be used to determine porosity (water table depth must be known)	Does not operate in cased boreholes. Affected by statistical variations. Linear scaling with respect to porosity to determine density assumes water saturated pore spaces.
Continuous velocity log (102, 132)	Records the time required for a sound wave to travel a known path length. Times are recorded continuously in μ sec/ft. as the probe is pulled up the borehole.	Any formation but correlation easiest in sedimentary units	Relies on differing velocities to delineate lithologies for correlation purposes.	Can be difficult to interpret as recorded velocity depends the elastic properties of the rock, the porosity, fluid content and pressure. Requires an uncased fluid filled borehole. Borehole diameter survey necessary.
3-D Velocity log (102, 105)	Refinement of the continuous velocity log displaying the amplitude of elastic waves as a function of time and depth. Compressional, shear & boundary waves are recorded.	Any formation	Fractures are detected by recognizing the changes in compressional and shear wave arrivals which is in part a function of the angle at which the fracture plane intersects the borehole. The amplitude of the shear wave is used to detect fractures dipping at very low or very high angles. Compressional wave amplitudes are used for fractures between 33 and 78 degrees. Can determine dynamic elastic moduli. Has been used to assess grindability of the rock.	Vertical fractures can not be detected. Need to know the lithology, rock types, general geology of area and the condition of the borehole (caving etc.) to interpret the log.
Seisviewer (105, 132)	A pulsed, narrow acoustic beam scans the drillhole wall in a helical motion as the probe is raised.	Any	The amplitude of the reflected wave as projected on a cathode ray tube depects the borehole wall displaying fractures, vugs, etc. These can be oriented absolutely.	
Borehole dipmeter (132, 133)	Four independently sprung microelectrodes in contact with the borehole wall measure formation resistivity over a very small zone	Any formation	When a pad crosses a fissure a distinct resistivity fluctuation occurs. When correlated with the other pads the dip of a fracture can be determined. The orientation of the probe is monitored continuously thereby providing a dip azimuth value.	The device only operates underwater and the minimum borehole diameter is 11.5cm.

electromagnetic induction, magnetic and self-potential failed to detect the target. However, Barker and Worthington[134] successfully employed resistivity methods to locate a brick-lined mine shaft. The detection of solution cavities, on the other hand, is normally complicated by the masking effect of surficial deposits.

Stahl[135] assessed the ability of seismic refraction, magnetometry and electrical resistivity to detect faults in phosphate and uranium deposits. He concluded that horizontal resistivity profiling (with electrode spacings of 20 to 25 feet and 25 to 50 feet in the phosphate and uranium respectively) was the geophysical technique most diagnostic of faults[136].

Case histories involving the successful use of seismic exploration techniques to determine the depth of lithologies and locate faults for a Chicago tunnelling project, as well as locating an abandoned and flooded mine adjacent to an active mining operation, are discussed by Mossman and Heim[120]. Also, seismic refraction was successfully used from ground surface to delineate a zone of heavily fractured ground in the low pressure tunnel of the Foyers hydroelectric scheme[137].

An extensive research program aimed at predicting parameters of interest in tunnel construction by means of geophysical techniques was conducted by the USGS. The pilot bore of the Straight Creek Tunnel was used to estimate various aspects of the tunnelling operation required to take the tunnel to full diameter. Electrical resistivity, seimic velocity of rock at depth, rock thickness in the low velocity layer and relative amplitude of seismic energy were correlated against the height of the tension arch, stable vertical rock load, rock quality, construction rate and cost per foot, percentage of lagging and blocking, set spacing and type and amount of required steel support. The results are too extensive to consider in detail; however, it is worth noting that the correlation co-efficients ranged between 0.7 and nearly 1.0 suggesting, according to the USGS, the possible predictive capability of geophysical techniques employed ahead of the tunnel face[138].

The use of borehole geophysical techniques offers promise as a means of predicting certain ground conditions relevant to the performance of mechanized tunnelling machines in particular, and tunnel design and excavation in general. This stems in part from the fact that most borehole techniques have been tried and tested over many years in the hydrocarbon extraction industry. Also, considerable benefit accrues from the probe being in intimate contact with the borehole wall, thereby eliminating many of the problems which plague equivalent surface geophysical applications.

As suggested in Table 2.7, spontaneous potential and gamma ray logs may be useful for detection of shale beds and clay seams which can slow the advance of a tunnelling machine. The gamma-gamma log may prove useful in determining rock strength since this can often be correlated with density. Several borehole probes show promise as fracture logging tools, including the borehole dipmeter, the seisviewer, and the 3-D velocity log. Correlation of lithologies is also possible with many of the techniques.

Kennet[139] used the 3-D velocity logger to determine Poisson's ratio, Young's Modulus and the bulk and shear moduli with depth in a borehole, and compared the results with R.Q.D. values (Figure 2.7). The severe signal attenuation between 115 and 135 ft in the velocity log correlates with a drop in the elastic moduli and an increase in Poisson's ratio. This represents a weak zone in the rock mass as indicated by a reduced value for R.Q.D. Evison[140] also discussed the use of seismic techniques for the determination of the elastic modulus and Poisson's ratio.

Undoubtedly the petroleum extraction industry makes the most extensive

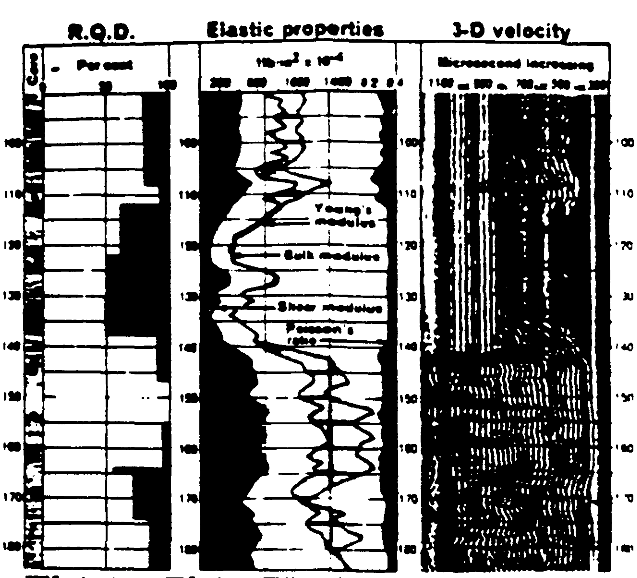


FIGURE 2.7 Elastic parameters derived from 3-D velocity logging compared to R.Q.D. (After Kennet, 1971)

use of borehole geophysics, placing virtual total reliance upon them for making decisions concerning the economics of a well. The state of the art is such that precise location of hydrocarbon producing zones in the borehole can be determined and accurate estimates of oil/gas ratios made.

These well logging tools have been designed to work at great depth and to operate at high speed which requires large, expensive multiple function probes. Certainly, in this format, the logging tools are quite unsuited to site investigation work, being too large in diameter and often in length. Also, the oil industry is searching for economic formations and frequently only require a resolution capability of one to two feet or more. Clearly, in many site investigation requirements the resolution of the instruments would have to be greater. Even so, the geotechnical engineer has at his disposal numerous instruments of well documented capability which may be potentially suited to modification for use in site investigations for underground excavations.

In 1976, the author attended a log interpretation workshop sponsored by Schlumberger Inland Services wherein a wide variety of logging tools, applications and interpretation techniques were discussed. Two techniques of direct relevance to this discussion are worth examining, namely: the mechanical properties log and formation evaluation[141].

i) Mechanical properties log

The mechanical properties log, as developed for the oil industry, provides a display of computed elastic parameters intended to yield an estimate of formation strength. This information is used to decide whether the hydrocarbon bearing formation will produce sand if it is exploited, or if the rate of production can be increased without damaging the well. The use of the sonic and density logs to compute dynamic elastic constants could have potentially wider application in geotechnical site investigation where these parameters are of fundamental interest in the application of stability analyses based on elastic theory to underground excavations.

The Schlumberger technique[142] derives values for the shear modulus (G) and bulk compressibility (c_b) by relating these dynamic elastic constants to the compressional-wave travel time (Δt_c), bulk density (ρ_b) and Poisson's ratio (μ). The following relationships are said to apply

$$G = 1.34\text{x}10^{10}\ \frac{A\rho b}{\Delta t_c{}^2}\quad \text{(psi)} \tag{2.1}$$

and $$\frac{1}{cb} = 1.34\text{x}10^{10}\ \frac{B\rho b}{\Delta t_c{}^2}\quad \text{(psi)} \tag{2.2}$$

when $$A = \frac{1-2}{2(1-\mu)} \text{ and } B = \frac{1+\mu}{3(1-\mu)} \tag{2.3}$$

The values for the compressional wave travel time (Δt_c) are derived from a sonic log while a density log measures values of ρ_b. An empirical relationship

$$\mu = 0.124q + 0.27 \qquad (2.4)$$

is used to determine values for Poisson's ratio where the "shaliness index" (q) is given as

$$q = \frac{\phi_z - \phi_e}{\phi_z} \qquad (2.5)$$

where ϕ_z is the total porosity and

ϕ_e is the porosity available to water and hydrocarbons

Figure 2.8 shows a typical log for a weak and strong sand ($G/c_b > 0.8 \times 10^{12}$psi).

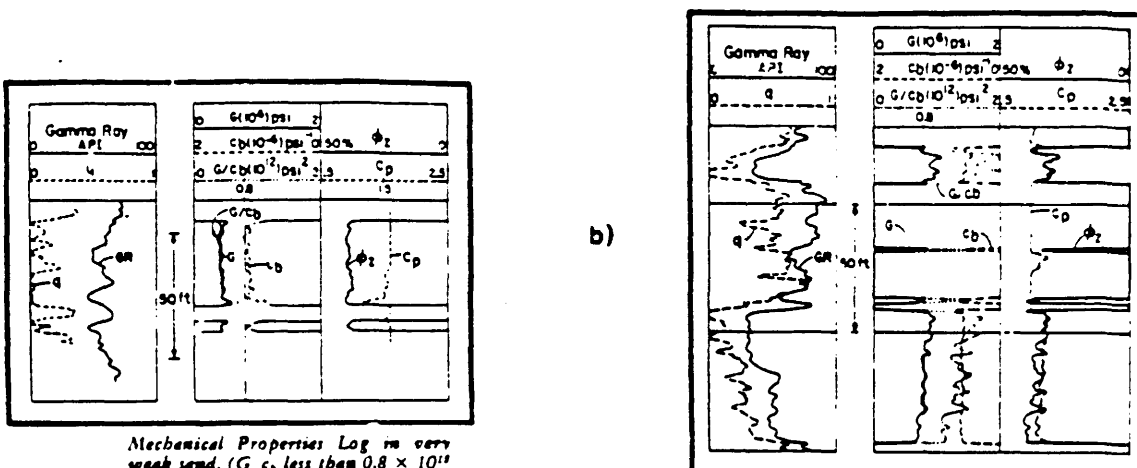
ii) Formation evaluation

Figure 2.9 displays the results of a sidewall neutron porosity (SNP) log. Looking left to right across the record, a dotted line indicates a nominal borehole diameter of 8.5 inches followed by a caliper log. The caliper log can be usefully employed to assess the general borehole condition. Where the caliper log indicates a borehole diameter greater than the nominal 8.5 inches, a soft lithology may be present (shale or clay). Where the borehole diameter is less than the nominal diameter, a build up of mud cake has occurred and this is normally indicative of porosity and permeability which may indicate a hydrocarbon formation. The next track in Figure 2.9 is the γ - ray log used to record the location of clean formations as the amplitude of the trace is a direct response to percent clay and/or shale in the rock. The last track records the porosity index in limestone units (based on a high purity block of limestone used for calibration of the logging tools).

A compensated formation density log (FDC) is presented in Figure 2.10 with nominal borehole diameter and caliper log values on the left and bulk density (gms/cc) on the right. If values for ϕ_N and ρ_b(as listed in Table 2.8) are cross-plotted some lithological features are apparent.

Figure 2.11 shows the data presented as a porosity versus density crossplot. The formation is a sandstone as indicated by points 1 through 9. The remaining points (17-19 and 22) suggest the presence of hydrocarbons.

The foregoing is a very simplified treatment of a difficult problem by way of showing the interplay of various logs in determining lithologies and presence of hydrocarbons. Many other crossplots exist which can assist in identifying many rocks and minerals including: borax, potash, gypsum, salt a)



Mechanical Properties Log in very weak sand. (G c_b less than 0.8 × 10^{12} psi^2.)

b)

Mechanical Properties Log in strong sand. (G c_b is greater than 0.8 × 10^{12} psi^2.)

FIGURE 2.8 Mechanical properties log in (a) very weak sand and (b) strong sand (After Schlumberger, 1974)

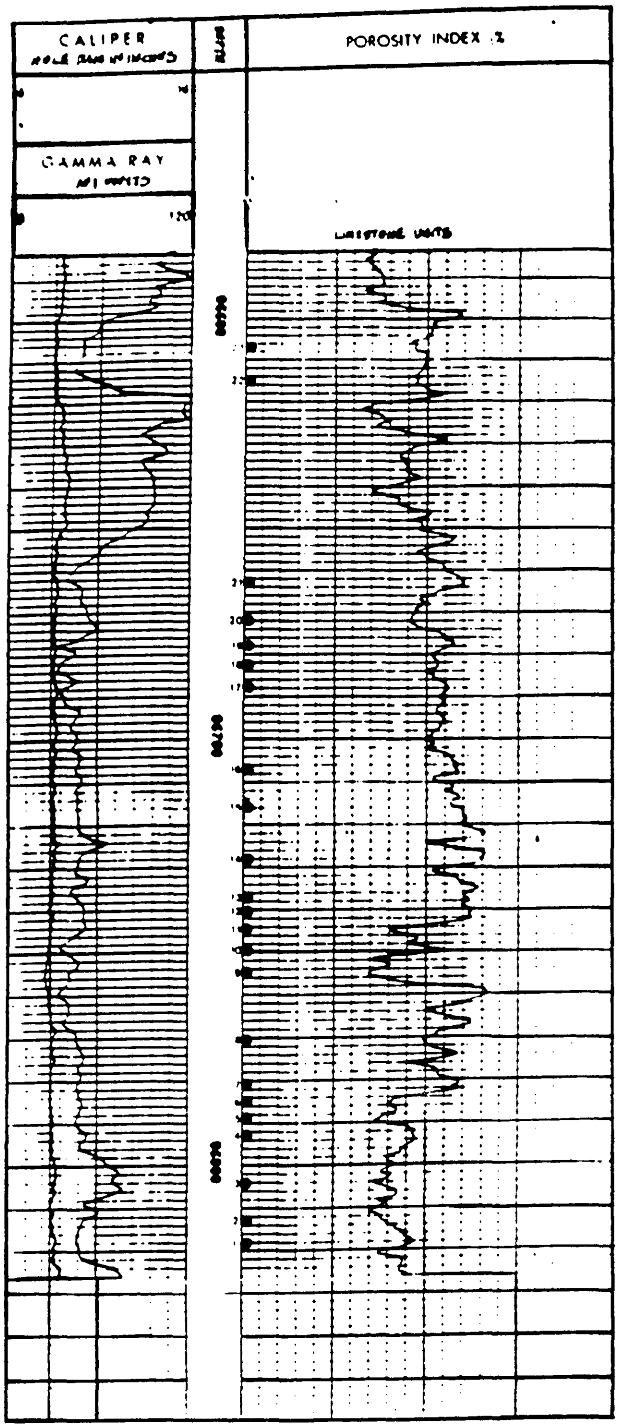


FIGURE 2.9 SIDEWALL NEUTRON POROSITY LOG
(After Schlumberger, 1976)

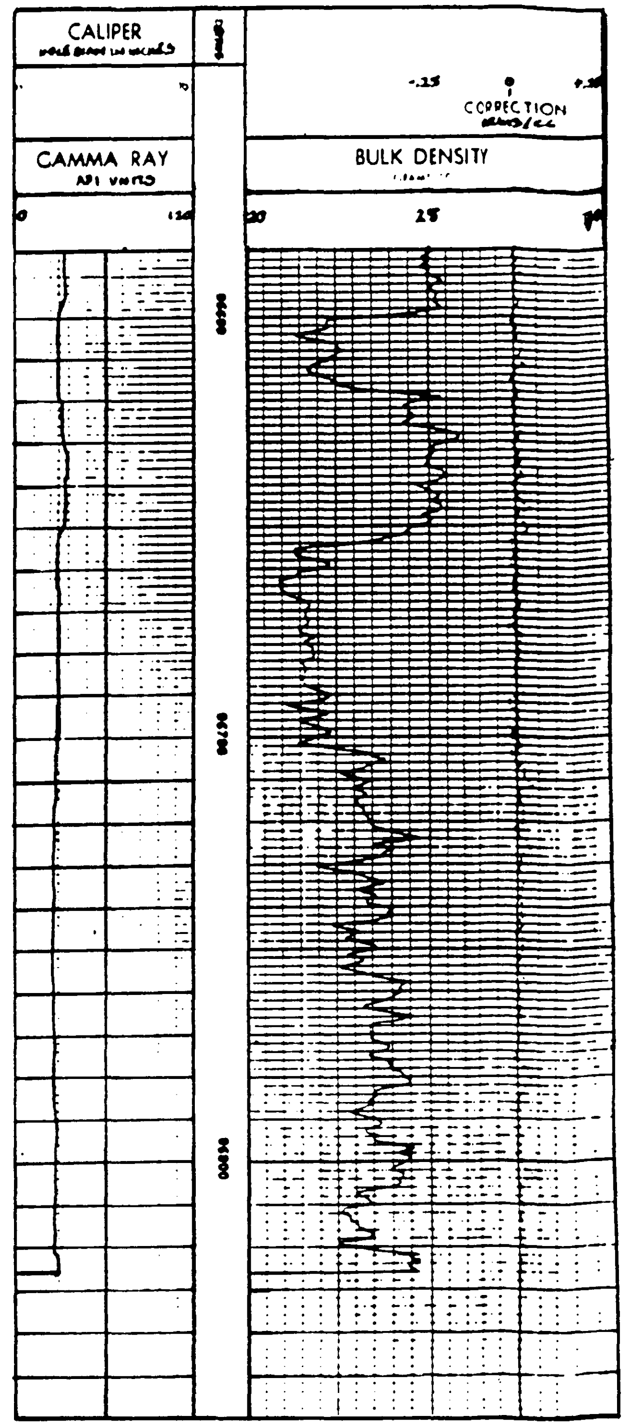


FIGURE 2.10 COMPENSATED FORMATION DENSITY LOG
(After Schlumberger, 1976

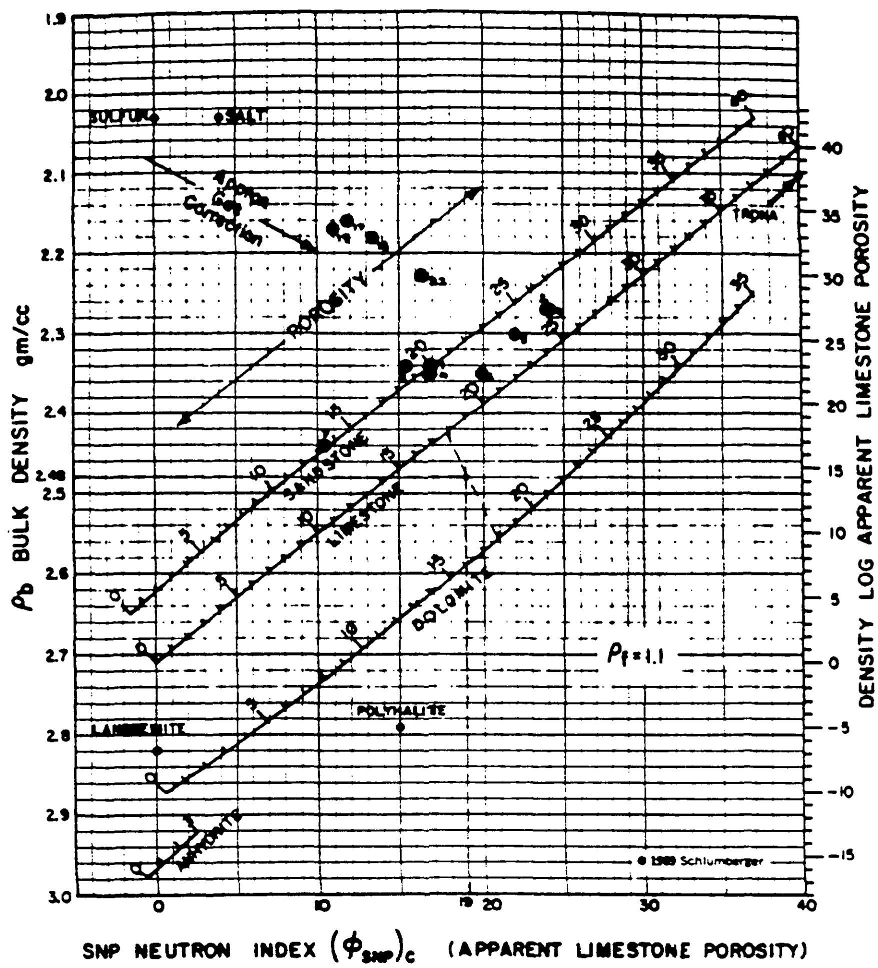


FIGURE 2.11 POROSITY VERSUS DENSITY CROSS PLOT (After Schlumberger, 1976)

TABLE 2.8: Porosity and density values for selected depths in Figures 2.9 and 2.10

Position	ϕ_N	ρ_b
1	17	2.34
2	24	2.27
4	17	2.35
5	22	2.30
6	20	2.35
7	10.5	2.44
8	15.5	2.34
9	24	2.27
17	12	2.16
18	13.5	2.18
19	11	2.17
22	16.5	2.23

anhydrite, sulphur, coal, shale, dolomite, limestone, sandstone, quartz and other less common rocks. For a very comprehensive treatment of logging probes and applications, the interested reader should consult Schlumberger literature[142,143,144].

2.4.3 *Summary of Geophysical Techniques*

Although only a limited survey of literature available on the subject was considered, the foregoing accounts of surface-based geophysical applications highlights the divergent views on the geotechnical benefits to be gained from this approach. In fairness, more often than not failure to perform successfully can be accounted for by the reasons listed in Section 2.4.2, often as a result of ignorance on the part of the engineer and/or unwarranted optimism on the geophysicist's behalf. It should, nevertheless, be remembered that targets of known location have been missed when circumstances favoured their detection. One must assume that such omissions will be resolved with improved analyses and equipment.

In making recommendations for increasing the success of surface geophysical surveys, West and Dumbleton suggest that (a) the survey method and the site must be suitable, (b) a particular technique works best in geologically simple sites, (c) last resort applications of geophysics are unlikely to succeed, (d) a suitable geophysical contrast must exist and (e) adequate borehole control must be provided.

If the oil extraction industry is taken as an example, borehole geophysical techniques should provide benefits for geotechnical site investigations. However, some major difficulties must be surmounted before widespread application of borehole geophysics is realised for most site investigation work. Some problems are of a theoretical nature while others are mainly economic, including that:

(i) It remains to be shown that the diagnostic techniques employed in the petroleum industry can be extended to treat non-sedimentary formations;

(ii) Logging tools must be scaled down to comply with the physical restraints of site investigation boreholes while maintaining, or in some cases improving, accuracy;

(iii) Logging tools must be capable of measurement in boreholes of any orientation;

(iv) Many of the assumptions inherent in existing analyses ("shaliness index" correlating with Poisson's ratio, for example) will require verification or direct measurement for engineering applications;

(v) Some techniques require expensive saline muds for best performance and this expense must be offset by corresponding benefits;

(vi) Well logging companies appear reluctant to exploit the site investigation market. This may reflect the large capital outlay necessary to redevelop logging tools for an uncertain market;

(vii) It may prove necessary for geotechnical engineering firms to develop their own equipment and analyses rather than relying upon the oil well logging services to expand their interests.

The use of geophysics should be considered in projects with sufficient funding in order to evaluate and improve their potential under 'controlled' experimental conditions in the field. Although Underwood[145] has said that geophysical measurements only provide qualitative information (and as yet do not provide quantitative information upon which to estimate tunnelling machine performance and costing, for example) it is only field trials which can improve this situation. The major well logging firms were forced to adopt this trial and error approach while they refined their technique and derived many empirical formulae upon which current logging practice is based. It may well prove to be the case that the geotechnical engineering companies will be required to do likewise if geophysical logging for geotechnical purposes is to be anything but a speculative art.

2.5 Assessment of Rock and Rock Mass Mechanical Properties

2.5.1 Introduction

The heterogeneous, discontinuous nature of rock masses requires that an in situ measure of design parameters be attempted where practicable. The nature of the sampling and preparation techniques required for laboratory based measurements (on necessarily competent rock specimens) makes it often unlikely that they will bear anything but passing resemblance to those derived from in situ tests[146,147,148].

In order to satisfy the requirements for rock and rock mass property measurements, a wide range of in situ test methods and equipment have been developed. Not surprisingly, borehole tools play a significant role in field measurement, being used for modulus, strength, stress and strain measurements. Although not borehole tools in the strictest sense, in situ tests on rock core recovered from boreholes can be used to measure uniaxial compressive strength, hardness and abrasivity, all of which relate to the ultimate method of excavation and as such have been included in this investigation since few, if any, borehole methods exist.

The vast array of modulus, stress and strain measuring devices are not treated in this discussion since such measurements tend to be made after tunnelling has occurred. As the main interest of this investigation is to improve the quality and quantity of site investigation data in advance of tunnelling operations, borehole modulus and stress measurement are peripheral to our main interest. However, this range of equipment, its theoretical basis for application and the various limitations associated with each device have been summarized by Barr[24].

2.5.2 Rock strength testing equipment

Several field techniques have been developed to determine the uniaxial compressive strength of rock to avoid the expense associated with standard laboratory procedures for measuring this parameter. Apart from yielding a rapid and simply obtained strength value for classification purposes[72,149-151] the uniaxial compressive strength has been shown to be an effective guide to predicting advance rates for drilling rigs and tunnel boring machines and the workability of rock in general[152].

Tsoutrelis[153] described a method for evaluating the uniaxial compressive strength of rock during rotary drilling based on the relationship:

$$R_o = k(P - P_o) \tag{2.6}$$

where

R_o is the penetration rate (penetration distance per revolution with a sharp bit)

P is the applied thrust

k is the slope of the P versus R_o graph

P_o is the P- axis intercept on the graph

Up to a limiting speed

$$k_o = k/N \text{ (constant for given rock and bit design)} \tag{2.7}$$

where

N is rotary speed

For a particular bit, k_o can be related to compressive strength by the following expression:

$$\sigma_c = \frac{A}{k_o + B} \tag{2.8}$$

A and B being constants the value of which can be determined from Figure 3.31[154].

By monitoring the variables related to the performance of the drill rig, it should be theoretically possible to produce a strength log for any borehole drilled by a suitably instrumented rig. Although untested under field conditions, the procedure has been shown to work in laboratory trials. This topic is considered in greater detail by Brown and Phillips in a recent CIRIA Technical Note[7] and in Chapter 3 of this study.

The point load test is one of the most widely used rock index tests in engineering rock mechanics. Research by Broch and Franklin[155] and Bieniawski[152] has established that the point load strength index provides a rapid and reliable field assessment of the uniaxial compressive strength of rock. The point load index is normally determined from axially or diametrically loaded core and as such is frequently correlated with other borehole derived parameters. Since uniaxial compressive strength plays a dominant role in many aspects of tunnelling site investigation, the point load index was considered too important to ignore in this review.

The loading system involves a test specimen held between conical platens which are used to apply a concentrated load which is raised by increments until the specimen fails. The point load strength index (I_s) is determined from

$$I_s = \frac{P}{D^2} \tag{2.9}$$

where

P is the load at failure

D is the initial distance between the platens

In keeping with the suggestion of the International Society for Rock Mechanics[156] the index should be reported as $I_s(50)$, obtained by correcting the measured I_s

value to a reference diameter of 50mm using a correction chart.

When point load index values are plotted against uniaxial compressive strength, the following relationship emerges

$$\sigma_c = 24 \, I_s \tag{2.10}$$

This relationship is based on data derived from NX (54mm), BX (42mm) and EX(21.5mm) core[152,155,157]. Carter and Sneddon[158] have suggested that the correction charts may not be accurate for specimens less than 50mm diameter and Bieniawski has recommended that samples less than 40mm diameter should not be tested. Possible inaccuracies in the correction charts have not prevented the wide adoption of this otherwise thoroughly reliable strength test by engineers concerned with the geotechnical characteristics of rock masses.

Testlab Corporation[159] have developed a borehole shear apparatus for in situ determination of cohesion and internal friction in soils. A foreseeable use of this device during tunnelling site investigations would possibly be in situ testing of fault goüge for stability analyses when samples are otherwise unobtainable. However, to the best of the author's knowledge, this device has not been favourably received by geotechnical engineers.

2.5.3 *Hardness and abrasivity*

It is generally conceded by researchers concerned with the performance of drill rigs and tunnel boring machines that rock hardness, abrasivity and quartz content are among the fundamental parameters requiring investigation if the mechanism of rock fragmentation which occurs during these operations is to be understood. Unfortunately, some confusion exists as to what is implied by the various terms, particularly with respect to hardness and to a lesser extent with abrasivity. Handewith[160] implied that much of this confusion stems directly from the numerous test methods which have been employed to assess these parameters noting that he is personally acquainted with fourteen different abrasion testing methods.

Hardness testing suffers from the same lack of standardisation of technique. Numerous hardness indices exist, yet for the most part no means exist whereby the results of one test method can be meaningfully related to those of another. Stimpson[161] noted that hardness tests have been used to measure such features as resistance to scratching, resistance to abrasives, cutting resistance, resistance to plastic deformation, ability to cut other materials, modulus of elasticity, strength, yield point, brittleness, lack of ductility and malleability, absence of stress wave damping, etc. Stimpson has shown that hardness correlates very well with unconfined compressive strength which makes this technique of potential value. This would permit a strength log to be quickly determined from core recovered during site investigation drilling and predictions to be made for ground conditions in advance of a tunnelling operation.

i) Hardness tests

Most hardness test instruments depend upon the availability of a homogeneous specimen for success. Clearly, such a situation rarely obtains in rock, hence a modified procedure must be adopted when testing. This adaptation of testing procedure attempts to obtain a representative hardness value by compensating for the scatter in values caused by the various minerals and particles composing the rock. This can be achieved mechanically by testing a comparatively large area or the same effect can be achieved statistically by making numerous measurements at random points and averaging the values. The various test procedures and instruments reflect the necessity for this type of integration which must be resorted to when testing rock hardness[162]. The most common hardness tests are listed in Table 2.9. The reader should realize that many other tests exist, including: the testing pistol described by Williams[174] the Gaede hammer[175], the Franck spring ball hammer, the Einbeck pendulum ball hammer, the Einbeck manual ball hammer and the Simbi hammer performator described by Voellmy[176], a dynamic hardness test described by Harley[177], the Honda rigidness and the penetration hardness tests cited by Kinoshita. The applicability of these and other tests listed in Table 2.9 to problems in geomechanics is the subject of considerable debate in the literature.

In 1927, Gyss and Davis[178] used Moh's scale of hardness to establish a rock material parameter for a study on factors influencing speed of drilling. The difficulty with the use of the Moh scale for hardness evaluation, particularly as suggested by Raymond, is that it is exceedingly slow and small errors in determining mineral composition can create large errors in the value derived for hardness.

Harley[177] described a dynamic hardness test whereby the amount of energy required to cut a unit volume of rock from a drillhole is measured.

If there are any hardness testing techniques which may be described as "standard" rock mechanics procedures they are the Schmidt Rebound Hammer in particular, and the Shore Scleroscope. Fowell and McFeat Smith[166] used the Schmidt hammer in a study concerned with factors controlling cutting performance of tunnelling machines. The test procedure they developed for obtaining representative values for hardness is worth noting. A competent part of each bed exposed in the tunnel was selected and ten rebound tests were made to measure the average hardness. That measurement completed, a series

TABLE 2.9: ROCK HARDNESS TESTS (After Barr, 1977)

Test	Description	Formula	Comments	References
Brinel indentation	A 10mm metal ball is forced onto and into the prepared surface of a test piece and the diameter of the indentation is measured. Recommended load for metal is 3000 kg.	$BHN = \frac{L}{\pi D/2(D-\sqrt{D^2-d^2})}$	Laborious test procedure requiring a heavy hydraulic press. Originally developed for metals	Hetenyi 1960
Vickers indentation	A four-sided diamond pyramid indenter having an apical angle of 136° is forced into the prepared surface of the test specimen. The ratio of the applied load divided by the pyramidal area of the indentation defines the Vickers hardness number (VHN).	$VHN = \frac{1.845\ L}{I_d}$	A number of tests must be run to obtain a statistically representative value for rock. The relationship between Vickers hardness and the response of rock to mechanical attack is obscure. Originally developed for metals.	Hetenyi, 1960 Roberts, 1977
Rockwell test	A 1/16 inch diameter steel ball (B test) or a conical diamond point (C test) is initially forced against the test surface under a load of 10 kg. Then, a major load of 100 kg (B test) or 150 kg (C test) is applied. The major load is removed while the minor load is maintained and the depth of penetration caused by the major load is determined from a specially calibrated dial gauge to obtain the Rockwell hardness.	Specially calibrated gauge provides the hardness number.	Originally developed for metals.	
Moh hardness scale	Minerals are graded according to their relative hardness by a scratch test. Minerals of a higher number on the scale are able to scratch minerals of a lower number. A rock hardness number can be determined by assessing the percentage of mineral constituents present and deriving a weighted value for each constituent.	$H = SM/100$	The scale is not an absolute measure because abrasive properties as well as hardness determine the position of a rock on the scale. Also, two rocks of similar strength but different mineral contents may not register similar values on the scale rendering the scale suspect for strength correlation. The procedure for Moh hardness determination for rock is very slow.	Roberts, 1977 Shepherd, 1950 & 1951
Schmidt rebound hammer	Impact energy (9.0J) is transmitted to the rock surface via elastic energy stored in a tensioned spring. A plunger is held vertically against the test surface and the device gradually depressed. A mass connected to the spring is released automatically upon reaching a predetermined pressure level on the housing. The mass travels down a guide bar, strikes the top of the plunger, then rebounds. An indicator is carried along a vertical scale by the rebounding mass. Rebound of the mass is expressed in 1/100 ths divisions of the total spring extension.	Schmidt rebound number read from the scale on the hammer casing.	The values derived from the Schmidt hammer correlate reasonably well with unconfined compressive strength. A number of readings must be taken at a test site in order to minimize the effects of scatter.	Roberts, 1977 Fowell & McFeat-Smith, 1976 Tarkoy, 1975
Shore scleroscope	The scleroscope hardness is determined by dropping a diamond tipped hammer vertically down a glass tube onto the test surface. The hammer rebounds, but short of its original height since some of the energy in the falling mass is dissipated through creating a small surface indentation. The rebound of the hammer is proportional to the surface hardness. A 140-point scale is established by calibrating the device against a metal standard.	The scleroscope hardness is determined from a graduated scale	A mean value from a large number of tests is need to determine a representative value for rock because of scatter associated with the small contact area between the diamond tip and the rock surface.	Roberts, 1977 Paone & Bruce, 1963 Kinoshita, 1956 Fish et al.
Schreiner hardness	A prepared rock surface is loaded by a flat-face cylindrical punch, the load upon which is increased until failure of the rock occurs. The volume of rock broken is determined by weighing the cuttings and applying the rock density which has been previous determined. Suitable measurements are made in order to plot a load/displacement curve.	$n = L_F/A$ (kg/mm²) and $S_D = V/W_F$ (mm³/kg mm)	Reasonably good correlation between hardness (n) and specific disintegration (s) Young's modulus and sonic velocity. Young's modulus value is dependent on the loading area of the punch. There is also a good correlation between hardness and drilling rate.	Gstalder & Raynal, 1966
Page's percussion hardness	A 25 x 25mm right cylindrical test piece is mounted on a platen and a metal sphere and plunger are located on the upper surface. Load is applied by dropping a 2kg mass onto the plunger. The fall distance of the mass is initially 1cm, increasing by 1cm increments until the specimen fractures. The maximum fall distance is adopted as the index of hardness.		Provides an estimate of the toughness of rocks. Kinoshita makes no mention of the correlation of Page's percussion hardness and drillability parameters; presumably the results were disappointing.	Kinoshita, 1956
CERCHAR test	A 90° dihedral-shaped tungsten carbide bit (8mm) is applied to an unprepared rock surface. The bit is rotated at 190 rpm with a bit weight of 20kg. Bit penetration is measured against time, penetration progressively decreasing as debris impairs the cutting action of the bit. The hardness index is defined as the initial penetration rate.	The index is determined as the gradient of the curve in the penetration versus time plot after a penetration of 1cm has occurred.	Used to predict the forces experienced by a pick under known working conditions. Best correlation exists for normal forces as opposed to tangential forces.	CERCHAR, 1973.

Definition of terms: L is the load (kg), D is the ball diameter (mm), d is the indentation diameter (mm),
I_d is the average length of the impression diagonals (mm), S is the percentage of a mineral constituent,
M is the Moh hardness of a particular mineral constituent,
L_F is the failure load (kg), n is the Schreiner hardness, A is the area of the punch (mm²)
S_D is the specific disintegration, V is the volume of broken rock (mm³) and
W_F is the work required to break the rock (kg mm).

of 20 tests were performed at a proven competent location. When hardness was plotted against test number the readings were seen to increase initially and then remain constant following 15 to 20 tests with only minor fluctuation about the level. Fowell and McFeat Smith defined this percentage increase as the deformation coefficient (D) as follows:-

$$D = \frac{H_z - H_i}{H_z} \quad 100\% \qquad (2.11)$$

where

H_i is the initial rebound value

H_z is the constant value after 20 tests

They showed that this index correlated with cutting performance.

Tarkoy[167] has also used the Schmidt hammer to assess parameters which influence rate of advance of tunnel boring machines. He combines the Schmidt hardness and abrasive hardness to define total hardness (H_T)

$$H_T = H_R \sqrt{H_A} \quad (\text{gms}^{-\frac{1}{2}}) \qquad (2.12)$$

where H_A is abrasive hardness

H_R is Schmidt hardness

He found reasonably good correlation between H_A and advance rate in friable sandstone whereas H_T tended to correlate well with all rock types. A sufficiently high correlation between H_R and advance rates was considered by him to render the Schmidt hammer a "relevent testing tool with respect to advance rates".

The Shore scleroscope is probably one of the most widely used rock hardness testing instruments. Originally developed in 1907 to serve as an industrial standard for hardness of metals, it has received increasing attention from geotechnical engineers. The Shore hardness is measured as a standard rock index property by the U.S. Bureau of Mines. Because of the small contact area between the diamond tip and the rock surface, test results can display considerable scatter. Therefore, the mean of a sufficiently large number of tests is required to determine a representative value for a rock specimen. Paone and Bruce[169] developed an elaborate procedure to reduce the scatter in Shore hardness values. The test surfaces were carefully lapped since, up to a point, hardness appeared to increase as lapping time increased. The lapping time required for a rock to reach maximum hardness varies from rock to rock; however, 20 minutes was established as a standard. Ten cylindrical specimens were cut to 2 inch lengths, lapped for 20 minutes on one end, air-dried for two weeks, then subjected to 10 scleroscope determinations on the lapped surface. Five drops were made on an arbitrarily determined x-axis and five on an orthogonal y-axis. Thus, 100 hardness values were determined for each rock, the statistical mean being used to represent the overall hardness.

Numerous researchers have employed the Shore scleroscope to measure hardness. Kinoshita[170], Alpan[179], Paone and Bruce[169] and Sasaki et al[180] suggest that the Shore hardness correlates reasonably well with penetration rate and can be used to represent drillability. Shepherd[165] and Singh[181] (employing a sklerograf which is similar to the scleroscope) maintain that scatter of hardness values made this type of test unreliable as a guide to drillability, as did Paone and Madson[182].

ii) Abrasion tests.

An important aspect in drilling or machine tunnelling concerns the prediction of the life expectancy and ultimately the cost of drill bits, or boring system elements such as discs or rollers.

In addition to rock hardness, a measure of the abrasive properties of rock is required in order that a meaningful estimate of cutting costs can be made. As noted earlier, numerous techniques exist to quantify this parameter, however, only a few of the more commonly applied tests are considered. The abrasion test techniques which are in relatively widespread use are detailed in Table 2.10, as are comments specific to each test.

Another commonly employed method of measuring abrasion involves measuring the wear on the cutting tool. During the course of rock drillability studies, Singh[118] assessed the abrasiveness of rocks by measuring the "width of wear flat" on a microbit using a Vickers vernier (accuracy 0.02mm) and a microscope at 200x magnification. Unfortunately, Singh found this measure of abrasiveness to be an unreliable guide to drillability. White measured abrasivensss of rocks by measuring the change in bit cutting edge profiles and was able to establish cost limits for particular cutting techniques for given rock types[188].

Weber[189] described how heading rates and tool costs were estimated by rolling a small steel disc under high pressure over the machined surface of a rock specimen for approximately 10 minutes. The depth of penetration, and wear on the bit, were used to estimate the performance of roller drilling devices. Clearly, a similar method could be used to determine the effectiveness of a particular type of tunnelling machine cutter on a given rock. Allowance could also be made for multiple cutter tests in order that the

TABLE 2.10: ROCK ABRASIVITY TESTS (After Barr, 1977)

Test	Description	Formula	Comments	Reference
Dorry abrasion test	A 25mm diameter cylindrical rock specimen is prepared and both ends are abraded on a rotating steel disc. The test piece is subjected to a 1.25 kg load and 1000 revolutions of the disc which has been charged with crushed quartz (between No. 30 and No.40 sieve size) as an abrasive. The weight loss of the specimen is measured to determine the abrasive hardness coefficient. Both ends of the test piece are tested independently then the values averaged to produce a mean value for the abrasive hardness.	$H_d = 20-(M/3)$	This test has been widely used and is well documented in the literature. Stimpson suggests that it is desirable to maintain a constant quartz feed rate, although this has been discounted by Obert et al. They also found that repeated tests on a single surface produced values within 5% of the mean. They note that specimen diameter influences the test, smaller diameters being more rapidly abraded.	Goldbeck & Jackson, 1912 Woolf, 1930 Obert et al., 1946 Stimpson, 1965.
Modified Tabor abrasion test	A 6mm thick, NX diameter disc of rock is mounted on a revolving turntable. A Tabor Calibrade H-22 abrasive wheel secured to an axle is placed on the specimen and a 250g load applied to the wheel. Rotation of the turntable establishes an abrasive action between the wheel and the test piece. Debris is continuously removed from the test platform. Abrasive hardness values are derived from the average of two tests. Abrasive hardness is defined as the reciprocal value for the average weight loss of the two discs expressed in grams.	$H_A = \frac{1}{W_L}$	Tarkoy has correlated abrasive hardness with tunnel advance rate	Tarkoy, 1975.
Paone & Madison abrasion test	This test involves a steel paddle turning at 627 rpm inside a steel drum which rotates at 74 rpm in the same direction. A 400g charge of rock between 0.95cm and 1.9cm in size is placed in the drum. Following a predetermined number of revolutions of the drum, the weight percent loss on the paddle is determined. The relative abrasiveness is calculated based on the weight loss of the paddle attributed by each rock as a ~~result of impact during rotation~~.		The relative abrasiveness was shown to correlate reasonably well with drill bit penetration rate, although rock matrix grain size effects weakens the correlation in particular situations. The fact that the test permits energy transfer through impact on the paddle suggests that the weight loss cannot be solely attributed to abrasion.	Paone & Madison 1966.
Los Angeles abrasion test	A 5 kg charge of rock aggregate is loaded, together with about 12 steel balls of 1¼ inch diameter, into a steel drum of 28" diameter which is fitted with an internal shelf. The drum is rotated at 30-33 rpm for 500 revolutions. The results of this test are expressed as the percentage weight of fines (passing No. 10 BS sieve) formed.		Developed as a roadstone aggregate test, its applicability as an abrasion test is doubtful. The specimens are prevented from sliding by the shelf until they are dropped to the bottom of the drum as it continues to revolve. This impact action as well as that involving the steel balls may not be representative of cutting conditions at a drill bit and/or a tunnelling machine/rock interface.	Road Research Laboratory, 1968
Newcastle abrasion test	A length of core is turned in a lathe and milled by a special tool over a fixed length of the specimen at a constant depth of cut. The diameter of the specimen is progressively reduced, and the wear of the tool assessed for a long equivalent linear travel to provide an abrasivity index for the rock.		A simple test procedure which closely represents the cutting action of drill bits and other point attack cutting elements. The test has been used for abrasivity tests for tunnelling machine manufacturers.	Potts, 1972 Brown and Phillips, 1977
CEPCHAR abrasivity test	The wear flat resulting from drawing a 90° cone-angled bit (200 kg/mm^2 steel) under 7 kg load through a distance of 1 cm on the surface of the test specimen is measured.		Used to predict pick consumption for shearing machines. A close correlation has been noted between the abrasivity value and the wear on picks under controlled working conditions.	CERCHAR, 1973
Scnimazek F coefficient	Pick wear is determined on a grinding wheel/abrasion test machine. A disc of rock is held in a chuck and rotated at 25 rpm. A 10mm conical steel pick (cone angle 90°), having a 0.3mm diameter tip, is gripped in a vertical slide and loaded with a mass of 4.5 kg. With each rotation of the rock disc, a spur-gear drive advances the pick 0.5mm radially outwards. After 100 revolutions, or about 16m pick travel, the test is stopped and the weight loss of the pick (72 kg/mm^2 steel) is noted. Ten picks and their average weight loss comprise a test. Results from these tests formed the basis of the Schimazek coefficient procedure. The relative percentage content of ~~abrasive minerals~~ is determined by performing a mineralogical grain count on geological thin sections (1000-1500 sample points). Percentage counts for each mineral present are then derived and grinding hardnesses are assigned to each mineral type relative to a quartz grinding hardness of 100%. An abrasive mineral content relative to its equivalent quartz value is then derived. Pick wear was shown to be related to variations in grain size, wear increasing with increasing grain size for equal quartz contents. Thus, the second component of the F index requires that mineral grain size be measured using standard petrographic techniques. The final component of the F index is the tensile strength of the rock since it was noted that abrasion increased approximately linearly to a threshold value of 50% then falls such that 30% and 70% contents have about the same wear effects. This is though to reflect the effects of grain adhesion which can be expressed quantitatively as tensile strength.	$F = Q_c \times Q_d \times S_t$ and $V_c = ke^{-F}$	An involved but apparently rewarding procedure. The results of the pick wear studies suggest that wear is a function of a) abrasive mineral content b) grain size of abrasive minerals c) tensile strength The index can also be extended to consider the cutting speed of the pick (V_c). The critical cutting speed is a function of the F index and temperature. These relationships can be used to match a heading machine to a given rock type to improve cutting efficiency. The ~~index is widely used by German~~ machine manufacturers in spite of the fact that the F index determination is time consuming.	Schimazck and Knatz, 1970 Brown & Phillips, 1979

Definition of Terms: H_d is the Dorry abrasive hardness coefficient, M_d is the weight of abraded rock (g)

H_A is the Tabor abrasive hardness, W_L is the average weight loss of the two tests (g)

F is the Schimazek coefficient (kg/cm), Q_c is the abrasive mineral content relative to quartz, Q_d is the average grain size of the abrasive minerals (cm), S_t is the tensile strength (kg/cm^2), V_c is the critical cutting speed, k is a constant related to pick geometry and temperature, e is the base of natural logarithms.

spacing of cutters could be varied to achieve maximum cutter interaction and thereby improve the rate of advance.

An abrasive test was developed by Fish et al, to investigate the effect of this rock property on the life of the cutting elements of rotary drill bits. A steel ball (Shore hardness 71) was loaded against the lightly sand-blasted surface of a core of rock which was mounted in a lathe. The ball was automatically traversed across the revolving surface of the rock cylinder at a predetermined number of revolutions, the rotary speed being matched to the core diameter to provide a 'bit' speed of 0.45 to 0.5 m/s. The load on the steel ball was in proportion to the compressive strength of the various rock samples, values ranging from 0.45 to 2.5 kg. Bit wear was shown to correlate poorly with the measured abrasive index since the abrasion test overlooked the frictional forces created by the thrust applied to the drill bits during laboratory trials. However, if the abrasive index is scaled with respect to the compressive strength of the rock under consideration, a linear correlation exists between the rate of bit wear and the scaled abrasive index[171].

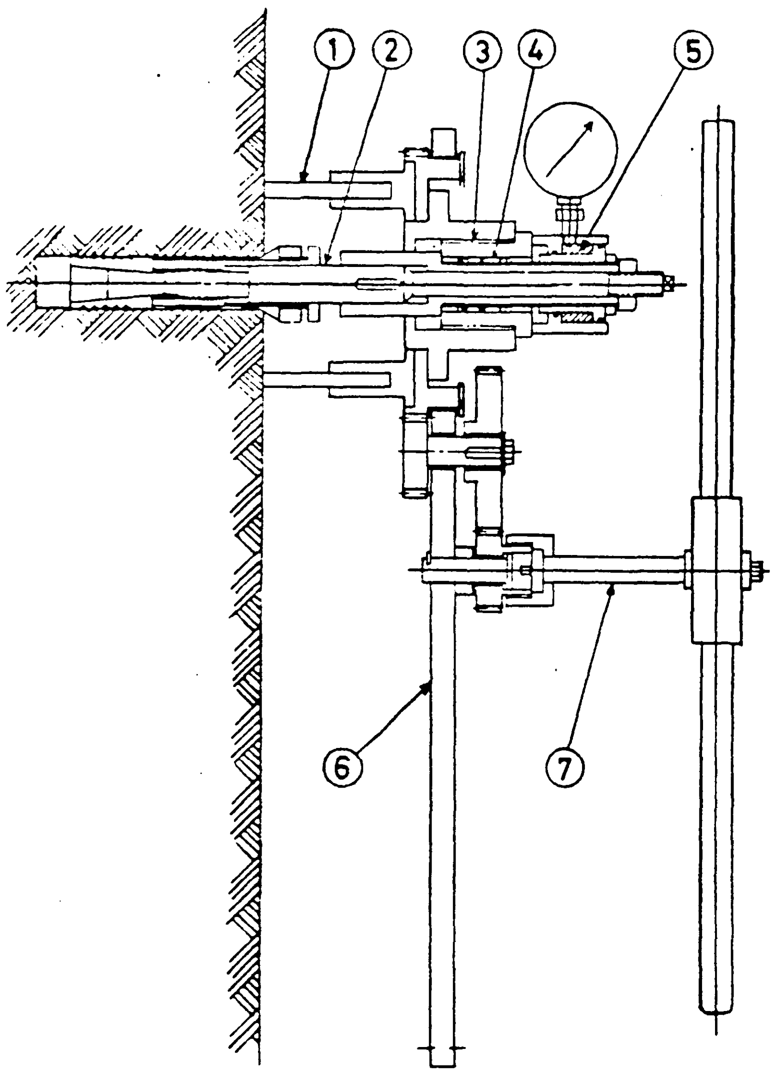
Since most abrasion tests are aimed at predicting the working lifetime of a drilling bit and/or the cutting elements of rock excavation equipment (in short, the machineability of rock). a promising test technique has been announced by Nishimatsu et al[190]. They have developed an in situ test aimed at assessing the machineability of rock with respect to the suitability of employing tunnelling machines for tunnel drivage. The machineability tester is shown in Figure 2.12 and consists of a rotating frame upon which three drag bits are mounted. The frame rotates about and advances along an expansion shell rock bolt which has been previously anchored at the test site. The rotation frame is driven manually by a rachet handle through a system of double reduction gears. The normal force on the drag picks can be calculated by monitoring hydraulic pressure with a Bourdon gauge. Laboratory calibration trials show a high correlation (0.98) between the cutting (calculated) and normal (measured) forces. Comparison between measured machineability indices and monitored productivity of tunnelling machines at 13 sites produce a correlation curve given by

$$P = 8.9R^{-1.3} \qquad (2.13)$$

where P is the specific productivity of the tunnelling machine (m^3/kwh)

R is the rock machineability index

Figure 2.12 THE ROCK MACHINEABILITY TEST
(After Nishimatsu et al., 1976)



1. Frame disc
2. Expansion shell type rock bolt
3. Female screw nut
4. Ball spline hollow shaft
5. Hydraulic pressure cell
6. Reaction lever
7. Ratchet handle

While the correlation is poor, for various reasons cited by the authors, the concept of an in situ test incorporating a more representative model of the mechanics of tunnelling machine-induced rock disintegration is attractive.

2.5.4 Summary of mechanical property measuring devices

Determination of uniaxial compressive strength using point load testing apparatus is unlikely to be superceded by alternative test techniques in the foreseeable future. This field test is reliable, accurate and rapid, factors which render it highly attractive as a standard index test for rock classification, assessment of machineability and as an aid to deciding potential support requirements for underground excavations. Tsoutrelis' drilling strength technique looks very attractive as a means of providing a continuous strength log from a suitably instrumented drilling rig. However, this procedure has yet to be proven in the field.

The borehole shear apparatus can only have limited application in rock mechanics, although use of this type of tool for testing otherwise unobtainable samples of fault gouge, clay and soft shale horizons is a possibility. The borehole shear apparatus appears deceptively simple from the manufacturers description (Section 2.5.2) and the author feels that comparison with proven techniques (standard shear box test) would be prudent before adoption by the geotechnical industry.

The choice of hardness test must be related to the particular form of mechanical attack to which the rock is to be subjected, whether drilling, blasting or rock cutting with a specified type of cutter. No clear understanding of the relationship between the various hardness tests and the potential effectiveness of the mechanical operations they are used to assess exists at present. This being the case, an empirical approach must be adopted to facilitate correlation between a particular hardness index and a specific rock property until such time as the theoretical relationships are clarified.

The Schmidt hammer and the Shore scleroscope are the most widely used hardness tests in rock mechanics, the Schmidt hammer being useful as an indicator of unconfined compressive strength, although grain hardness and density influences the result and the device is over-sensitive to low strength rocks and generally insensitive to rocks of high strength [7]. Both instruments have been used to predict boreability of tunnelling machines, the Schmidt hammer generally out-performing the Shore scleroscope. Regarding the other tests, insufficient experience in underground site investigations precludes judgement. Indeed, the use of hardness tests as a property index requires extensive study to clarify obscure relationships, particularly in view of the increase in mechanized tunnelling and the expressed desire for a simple, reliable field test(s) to assess machineability.

Measures of abrasivity suffer, in part, from the difficulties faced with hardness testing, insofar as the theoretical basis for correlation between abrasivity and machineability remains obscure. Fortunately, empirical relationships between "abrasivity" on the one hand and cutter consumption on the other, for example, can be more directly assessed and as a result may be more reliable indicators of machine performance than those related to hardness. However, as with hardnesss measurement, abrasivity alone does not determine the susceptibility of a rock mass to mechanical attack since the various measures cannot account for the influence of rock mass properties (discontinuity spacing, etc.). This is of particular importance to partial-face tunnelling machines, for example, where rock removal in fractured ground is often achieved by ripping as opposed to cutting, and advance rates are generally greater all else being equal. In this regard, the choice of abrasivity test must be decided upon the basis of that which most closely resembles the anticipated form of mechanical attack (scaled-down tests being particularly relevant), and due allowance made for rock mass properties. Since the various hardness and abrasion tests generally attempt to predict drilling costs and/or anticipated tunnel advance rates and cutter costs, in situ machineability index tests, such as that proposed by Nishimatsu et al, appear to be a much more logical approach to this difficult problem. Their test, albeit imperfect, better represents the cutting action about which they are hoping to make predictions, as well as approximating more closely the rock mass conditions within which excavation will take place.

2.6 Groundwater

2.6.1 General remarks concerning groundwater

Wahlstrom[76] suggests that no reliable method exists for precisely locating zones of high water flow or for estimating flow volumes to be encountered during tunnelling operations. This is a serious matter as adverse groundwater conditions can prove to be the most difficult problem encountered in underground operations. The BRE/TRRL Working Party Report on Probing Ahead for Tunnels [6] have placed great emphasis on the dangers inherent in advancing into uncertain ground and they too have underlined the dangers posed by groundwater. In addition, full-face tunnelling machines are particularly susceptible to unforeseen changes in ground conditions, and of these groundwater poses the most serious threat.

This factor coupled with the increasingly ambitious underground structures being built in this country and abroad serves to underline the importance which groundwater studies should assume during routine site investigation. Among the more serious problems posed by adverse groundwater conditions are the following:

i) a sudden inrush of water can inundate men and equipment

ii) control of groundwater by pumping, grouting and/or use of air pressure increases project costs

iii) large volumes of groundwater inflow or associated high pressures can result in structural instability, particularly at the tunnel face in non-indurated sediments or soft rocks

iv) the selection of the type of explosives for use in conventional drill and blast operations can be influenced by excessive groundwater

v) a limit exists beyond which water inflows to a full-face tunnelling machine operation can no longer be accepted as the combination of water and cuttings creates an extremely abrasive paste detrimental to the equipment

vi) uncertainty about groundwater conditions requires probing ahead of the working face which can slow the advance of the tunnel

vii) the contractor is in a less secure position to decide whether proceeding without probing involves an unacceptable risk.

Not surprisingly, a vast range of techniques and equipment has been developed to measure the two groundwater characteristics most relevant to engineering design and excavation, namely:pressure and flowrate.

Almost invariably, heavy inflows of water into underground operations in rock are associated with fissures. Although actual flowpaths are not predictable, heavily fractured zones should always be suspected of posing potential difficulties. Equally, fissures having large aperture widths are of greater concern than their smaller counterparts as they are capable of conducting larger volumes of water, since the permeability of a joint is proportional to the cube of its aperture. Therefore, an indication of water pressure via piezometer installations coupled with knowledge of the location of high permeability fissures using permeability tests and the impression packer or seisviewer, may suggest zones of potentially high water flow.

2.6.2 Water pressure monitoring

Piezometers range from simple standpipes installed in a drill hole to sophisticated electric transducer devices, depending on the response time of the probe and the permeability of the groundwater environment. Sharp[191] has extensively surveyed the types of piezometers currently available and has discussed their relative merits. Franklin and Denton[116] and Franklin[115] have also considered this topic. Understandably the author has relied on their studies to a considerable extent.

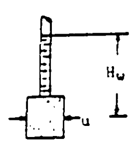
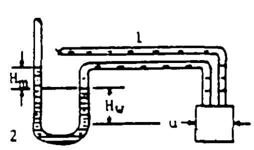
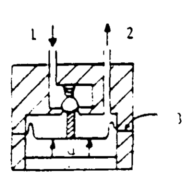
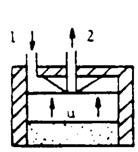
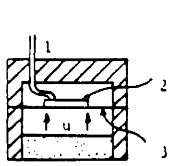
Two important considerations in the selection of a piezometer are the response time and read-out requirements associated with a particular device. Response time relates to the ability of the piezometer to detect and record a pressure fluctuation. Standpipe piezometers requiring an appreciable influx of water to indicate a pressure flux would be of limited value in a low permeability environment. This task would be better performed by an electrically-operated pressure transducer type piezometer. However, the faster response time is offset by the cost associated with a sophisticated probe requiring frequency monitors or Wheatstone bridge circuitry in the readout facility. The basic types of piezometers are discussed in Table 2.11, while 2.12 catalogues commercially available dip-meters used in conjunction with Class A piezometers. Finally, Table 2.13 lists the specifications of most piezometers in current use.

2.6.3 Rock mass permeability measurement

Increasingly, engineering projects require accurate values of hydraulic conductivity (permeability) for use as design parameters. This is particularly true for numerous underground structures which are becoming more commonplace as engineers gain greater expertise in rock mechanics. For example, Di Biagio and Myrvoll[192] discuss the role of permeability in the design of underground nuclear power stations and closed surge chambers. Morfeldt[193] has described the low permeability requirements necessary for unlined storage caverns as has Hauge and Hoffman[194]. Selmer-Olsen[195,196] has noted the considerable savings that accrue from leaving pressure tunnels and penstocks unlined when low permeability obtains in the rock mass. Numerous other examples could be noted but it should be evident that with major structures such as those cited above, reliable values of hydraulic conductivity are of paramount importance if needless expense is to be avoided and maximum project safety and serviceability ensured.

A wide range of groundwater monitoring and permeability testing techniques

TABLE 2.11 TYPES AND CHARACTERISTICS OF COMMERCIALLY AVAILABLE PEIZOMETERS

CLASSIFICATION	CLASS DESCRIPTION	READOUT EQUIPMENT	LIMITATIONS	ADVANTAGES
CLASS A: Open tube (standpipe) 	pressure(u) = $\gamma_w H_w$ Usually one or more open plastic tubes sealed in a borehole, variations in peizometric pressure are measured by recording water level fluxes in the standpipe. * R.V.D. - High	water level sensor (dipmeter) See Table 6.2 for commercially available probes	Not suited to detecting water pressures. Requires straight tube over entire length. Potential problems in small bore plastic tubes where water levels are significantly below 30 metres or less than 45° dip	Inexpensive. Suited to multiple installation. Easy to read.
CLASS B: Closed tube (hydraulic) 	u = $\gamma_m H_m + \gamma_w H_w$ where (1) flushing line (2) mercury manometer Water pressure sensed at peizometer tip equals the manometer pressure plus the water pressure variation between the manometer and tip. System requires charging with de-aired water. R V D - Medium to low	Normally a Bourdon gauge or mercury manometer	Not normally used where minimum head fluctuations exceed 8 metres below ground surface. Not suited to general borehole use.	Comparatively inexpensive. Can sense small negative pore water pressures.
CLASS C1: Mechanical diaphragm (pneumatic) 	u = P_2 Water pressure on diaphram opens ball valve. P_1 (air) raised until valve closed. Equivalent u measured at P_2. R V D - low to very low	Pressure transmitter	Not generally suited to negative pore pressure measurement. Subject to error in low permeability environments in certain circumstances (See Sharp(193) for details)	Long term stability excellent. Can be made very small.
CLASS C2: Mechanical diaphragm (hydraulic) 	u = P_1 Water pressure on diaphram closes outlet. P_1 (oil) raised until flow occurs at P_2. R V D - Negligible	Pressure transmitter.	Not suited to negative pore pressure measurement.	Long term stability excellent. Simple installation.
CLASS D: Electrical 	u = f(gauge output) where (1) electrical cable (2) electrical strain transducer (3) stiff membrane Normally vibrating wire gauges used to sense pressure induced deflection of a diaphram (bonded or unbonded strain gauges are less frequently used alternatives). R V D - Negligible	Specialised electronic processing	Most expensive, particularly in deep installations. Zero drift can occur	Best suited for measuring negative pressures. Easy to install. Suited to remote monitoring. Excellent in low permeability environments because of excellent response characteristics.

*R V D or relative volume demand refers to the influx of water into the device necessary to effect a response to a pressure fluctuation.

(After Sharp, 1973; Franklin, 1975 and Franklin and Denton, 1973)

TABLE 2.12: COMMERCIALLY AVAILABLE DIPMETERS.
(After Franklin and Denton, 1973).

Type of indicator	Operating principle	Maximum depth (m)	Calibration (m)	Manufacturer
Visual (ammeter)	Electric circuit closed by	100	0·5	ELE Stow
Visual (Ammeter) and	immersion of probe in water	100	1	ELE
Audible (Buzzer)		400	1	Soil Instruments
Visual	Water temperature actuates thermistor circuit	30	0·5	Wykeham Farrance
Visual	Diaphragm and vibrating wire	300	0·5	Maihak

TABLE 2.13: COMMERCIALLY AVAILABLE PIEZOMETERS

CLASS	MANUFACTURER	DIA.& LENGTH	PRESSURE RANGES	SENSIVITY AND/OR ACCURACY	VOLUME CHANGE	REMARKS
A	Many (local manufacturers usually available	Various	Limit depends on standpipe type and depth to water table	Sens.0.05 psi Acc.depends on stretch in measuring cable	Typically 2-4 cu.in. (30-60 cc) per psi	Must ensure adequate collector zone to obtain reasonable response
B	Many	Various	Any	Sens. 0.05 psi Acc.0.05 psi for manometer. Otherwise depends on gauge. (Also see Remarks)	Typically 0.15 cc per psi for manometers. Much lower for Bourdon Gauge	Note basic limitations of this class of piezometer (Section 6.2). System must be adequately de-aired for true readings. Not normally used in tunnelli[illegible] site investigations.
C1	Soil Instruments Limited		250 psi (17-1/2 bars)			
	Sinco	1.[illegible]" x 11.8"	250 psi (17-1/2 bars)	Sens.0.025 psi. Acc. depends on readout unit.	OVC[1]=0.5cc (0.03 cu.in.)	Readout accuracy available to 0.1 full range
	Terra-Tec	1.5" x 4.5" Also 0.75" dia.	a)250 psi (17-1/2 bars) b)500 psi (35 bars)	Acc.=0.1% of full range Acc.=0.5% of full range	OVC[1]=0.003cc (Negligible) OVC[1]=0.07cc	Flushable models available. However, where 3 or 4 tube models are used the volume change characteristics of the hydraulic tubing will adversely affect the response characteristics of the Type a) in a two-tube model should give response similar to Class C2 instruments.
C2	Gloetzl	1.6" x 8.2"	1500 psi (105 bars)	Acc.0.5 psi but read-out dependent	Negligible	Preferably operated using hydraulic (oil) monitoring system; static head in readout lines must be less than pressure to be detected. Otherwise, pneumatic operation is possible
	Terrametrics	1.75" x 9"	100 psi (70 bars)	Sens 0.15 psi Acc. depends on readout	Negligible	Hydraulic monitoring system, but diaphragm has initial prepressure equivalent to [illegible]00 ft. head of oil.
	Warlam	1.38 x 1.75"	500 psi (35 bars)	Sens. betters 0.1 psi. Acc. depends on readout	Negligible	Pneumatic monitoring system.
D	Geonor	1.26" x 11.0[illegible]	30/60/90/150 psi (2/4/6/10 bars)	Linearity < 2% FS Hysterisis < 2% FS	Negligible	"Rigid" diaphragm with vibrating wire strain sensor.
	MaihaK	1.8" x 8.25"	30/60/120/230/430 psi (2/4/8/16/30 bars)	"Measuring[2] errors" < 1% FS	Negligible	ditto
	Telemac	1.61" x 10.5"	30/75/150/300 600/900 psi 2/5/10/20/40/60 bars)	Sens.[2] < 0.2% FS	Negligible	ditto
	Carlson	2.75" x 6"	25/50/100/200 psi (1.8/3.5/7/14 bars)	Acc. = 5% FS Linearity = 2% FS	Negligible	"Rigid" diaphragm with resistance strain gauge

[1] OVC (Operating Volume Change) = (Instantaneous) volume change required for valve operation

[2] These manufacturers do not give specifications on accuracy (i.e. linearity and hysterisis)

can be applied to tunnelling operations including:

i) falling head tests
ii) injection tests
iii) well pumping tests
iv) tracing techniques
v) drill water flow monitoring

Each of these techniques have their own particular merits to recommend them and these are outlined in Table 2.14.

2.6.4 Equipment requirements for permeability testing

Table 2.15 lists the type of equipment usually required for falling head, injection and well pumping tests. Most of the equipment employed in conventional permeability testing is quite straightforward and requires no elaboration, however, certain points are worthy of note.

Many commercially available packers are far too short to effect a good seal between the expandable rubber sleeve and the borehole wall and leakage past the packer results. Before a test is performed, packers should be checked for leakage. In the author's experience, packers 1.0 to 1.5 metres long constructed of Ductube in a manner outlined by Harper and Ross-Brown[213] provide an adequate leakproof seal.

Dipmeters can also pose some difficulties in the field. Visual display sensors are adequate for checking the depth to standing water level in boreholes but are not well suited to detecting water levels in falling head tests, as the operator is frequently occupied with recording time intervals. In this regard, audible sensors are superior. Also, certain types of dipmeters are constructed such that it is possible to complete the detector circuit by contacting a wet wall of a borehole, thus yielding a spurious water level reading. Normally, with audible sensors this can be detected with the weak and erratic pulse which results, but it is best to ensure that the sensing element of the probe is prevented from contacting the wall.

Barr[24] provided specifications of many flowmeters suited for use in borehole permeability tests. The selection of a particular device will, of course, depend upon the anticipated groundwater conditions, scale of the project, test technique and required accuracy.

2.6.5 Comparison of permeability testing techniques

For determining aquifer characteristics of a rock mass, pumping tests

TABLE 2.14: BOREHOLE PERMEABILITY TESTING TECHNIQUES (After Barr, 1977)

Test	Description	Comments	Reference
Falling head test	This type of test requires that an excess head of water be imposed upon the water table and the subsequent decay of the imposed head be monitored with respect to time. The hydraulic conductivity of the zone under test is derived using the data pertaining to the rate of pressure equalization in the piezometer installation. The U.S. Navy developed a number of analyses to consider both cased and uncased boreholes having a variety of borehole end conditions. Hvorslev developed an equation based upon the inverse proportionability between the permeability of the medium and the time lag associated with the head decay. Harper developed a similar form of analysis for fissured rock conditions.	Most of the analyses require knowledge of the borehole geometry, usually diameter and length of the section under test. Harper's analysis requires an additional factor, namely: the radius of influence pf the test. In most field situations this factor is impossible to evaluate which means that the permeability values can only be compared relative to each other and can not be treated as absolute permeability values. Also, in uncased boreholes, the imposed head creates an artificially high groundwater table in the rock surrounding the borehole, the effect of which is uncertain. The extension of these porous media solutions to fissured rock implies that the rock can be treated as a continuum.	U.S. Navy,1961 Hvorslev, 1951 Hoek & Bray, 1974. Harper 1973 & 1974. Barr, 1974.
Constant head test	A constant excess head of water is imposed in a borehole while the rate of flow required to maintain the constant head is measured. Depending on the type of analysis used to determine the value for hydraulic conductivity, an observation well may or may not be required as an adjunct to the test borehole. Using this type of test between double packers permits permeability values to be derived for zones or even single discontinuities in the rock mass.	The numerical analyses associated with this form of testing requires knowledge of the flow rate to maintain the excess head, the geometry of the test bore and the amount of excess head. Normally, the flow rate is measured over a period of time until a constant value is obtained which signifies that the rock mass has adjusted to the disturbance created by the excess head. As with the falling head test, analyses exist for a variety of borehole conditions. Also, the extension of these tests to the treatment of fissured rock assumes that the rock behaves as a continuum.	U.S. Bureau of Reclamation, 1968. Hvorslev, 1951
Lugeon test	A section of borehole (usually 5 metres length) is subjected to a hydrostatic pressure and the rate of water flow is determined after five to ten minutes for several different pressures measured at the collar of the borehole once a constant flow rate is established. Permeability values are expressed in Lugeon units which is percolation of 1 litre/minute/metre under 10kg/cm^2 excess pressure. Flow rates are determined from $q = \frac{\pi}{6\eta \log_e (R/r)} p e^3$ where η is the viscosity of water, R is the radius of influence of the test, r is the radius of the borehole, p is the effective water pressure and e is the fissure width.	This test has been the subject of much criticism including: a) the flow is not proportional to the pressures measured at the collar b) the lack of repeatability of test results c) overestimation of permeability values caused by fissure dilation due to excessive test pressures. d) the difficulty of estimating the radius of influence of the test Various modifications to the test and the associated numerical analysis have been proposed.	Sabarly, 1968. Londe & Sobarly, 1966. Lugeon, 1933. Di Biagio & Myrvoll, 1972. Lancaster-Jone 1975. Serafim, 1968.
Well pumping test	A pump is installed down a borehole and, in most instances, pumping maintained at a constant flow rate, the discharge being directed away from the test site. Drawdown of the water table is monitored in the pumped well and in observation wells at various distances and directions from the pumped well. A record is maintained of the discharge rate from the pumped well and a detailed survey of water level readings in the well and observation boreholes is kept. Ideally, the water levels should be monitored for a period of time before, during and after the pumping phase of the test.	This is the most expensibe form of permeability test; however, it is generally the most informative. Numerous types of analyses are available normally based on the following assumptions: a) Darcy's law applies b) The Laplace equation applies c) steady or unsteady flow obtains in d) confined, unconfined or leaky aquifers. Most of the analyses were originally developed for porous media but they have been extended to treat fissured rock based on the assumption that the rock mass behaves as a continuum.	Kruseman & de Ridder, 1970.
Tracing methods	Apart from establishing flow lines, groundwater tracers can be used to determine rates of flow of groundwater. The tracer is injected into the particular formation under investigation while detectors are located in observation wells. Permeability (k) is determined from $k = V_s N_e / i$ where V_s is the seepage velocity, N_e is the effective porosity and i is the hydraulic gradient.	The seepage velocity tends to be underestimated because a linear flow path is assumed between the injection point and the observation well. The effective porosity is difficult to evaluate for rock. Certain tracers require Local Authority permission before use. Not suited to general application.	Todd, 1967. Cedergren, 1967. Brown et al, 1972. Drew & Smith, 1969.
Drill water monitoring	It is standard practice to record water circulation in the borehole during rotary drilling. Often, such records indicate a loss or a gain of water at specific depths, events which are considered to imply certain permeability characteristics. Boyd attempted to quantify this procedure by measuring water input with a turbine flow meter and output with a 15° V-notch weir with limited success.	The drilling record can be used to design subsequent borehole permeability test programmes but until the influence of the dynamics of a rotating drill string upon the flow of flushing water are resolved, no reliable permeability measurement is possible with this technique.	Boyd, 1975.

TABLE 2.15: EQUIPMENT REQUIREMENTS FOR PERMEABILITY TESTING

Equipment	Falling head test	Injection test	Well pumping test
Packer	Yes, depending on the form of the test	Yes, depending on the form of the test	When a particular lithology is to be tested
Dipmeter	Yes	Can be used to detect head fluctuation in gravity head situations	Yes
Timer	Yes	Not absolutely necessary	Yes
Pressure gauge	No	Necessary where a pressure head in addition to a gravity head is used	Depends on test procedure
Flowmeter	No	Yes	Yes
Pump	In some situations	Yes (surge free operation desirable)	Yes (surge free operation desirable)
Generator	No	Depends on prime mover of the pump	Usually
Observations wells	Desirable but not usually close enough to test borehole	Yes, depending on test procedure	Some form of well or piezometric installation is required depending on response time of the rock mass.

are unsurpassed. The nature of the test is such that an extensive volume of rock is influenced by the test, thereby generating averaged data which can be very useful for determining water flows into excavations, particularly in karstic sites where random solution channels may be overlooked by constant or falling head tests. Equally advantageous are the many tried and tested mathematical analyses that exist for the interpretation of pumping test data. These analyses include assumptions about aquifer geometry which allow pumping tests to be used in evaluating complex geological situations.

However, in comparison with other permeability testing techniques, pumping tests are very expensive and are normally only used when dictated by geological constraints or project requirements. Pumping tests also require numerous observation holes which further adds to their costliness. Additionally, these tests can only be performed below the water table and in many geotechnical situations this may not be encountered in shallow boreholes. A further limitation of pumping tests concerns the difficulties, and often legal restrictions arising from the disposal of the large quantities of water pumped from the test well. This is particularly true when chemical and biological constituents in the water might prove environmentally hazardous.

Falling and constant head tests are both cheap and relatively rapid to perform, although some disadvantages do exist with these methods. Both tests have a very small radius of influence in that they only affect a very small volume of the rock mass immediately adjacent to the borehole. As such, the permeability values derived from these tests may not be statistically representative of the rock mass. Quite apart from limitations imposed by statistical sampling (boreholes on 25 metre centres, for example, represent a very small percentage of a rock mass), the actual drilling of the hole disturbs the groundwater regime by connecting fissures which may have otherwise been independent flow paths. Localised disturbance of the rock mass as a result of drilling, fracturing because of excess drill fluid pressure, fracturing because of drill motion on the borehole wall, and clogging of fissures by drill cuttings can all have an effect on the derived permeability value.

Infiltration tests require that some degree of excess head be imposed on the prevailing groundwater conditions. Under some test conditions this imposed head results in unrealistic pressures and gradients being transmitted to fractures which may react with a corresponding increase in the aperture of the fissure. As noted previously, such an increase greatly affects the hydraulic conductivity of the fissure. These pressures are normally produced when testing is performed near the surface and there is insufficient overburden to resist the induced pressure.

Where packers are used, leakage between the packer and the borehole wall has resulted. As the falling head test normally employs lower pressures than the constant head test, leakage past the packer is less likely to occur using the former technique.

The monitoring of drill fluid flow characteristics presupposes that it will be possible to analyse the data on the basis of an injection test. However, it remains to be seen if variations in flow can be correlated with fissure distribution in the borehole, assuming compensation can be made for the dynamic flow situation created by the rotating drill bit. Equally, the continual flow of cuttings into fissures as the borehole is advanced may make their hydraulic characteristics time dependent.

The use of tracers is not recommended for routine permeability testing since reliance can only be placed on the technique when the source and monitoring boreholes are within several metres of each other. As most site investigation works do not drill boreholes on such a closely spaced grid, a special borehole would be required, and this can hardly be justified when alternative test procedures are available.

2.6.6 Summary of permeability testing techniques

Numerous permeability testing techniques are available for studying the groundwater characteristics around a proposed underground excavation. Also, most of the instrumentation required to effect the tests is readily available and generally of a non-sophisticated nature, thereby eliminating the necessity for specialist personnel to supervise its operation.

There should be no difficulty in obtaining rock mass aquifer characteristics using pumping tests or obtaining selective permeability values for localised zones of interest in the borehole using falling or constant head tests. These latter tests should prove advantageous in attempting to decipher the flowcharts from the drill water balance tests. In short, permeability values will be readily obtained, however, difficulties can occur when the data is put to use. For example: simply because a particular zone of a rock mass (fault, fissure, etc.) suggests a high permeability on the basis of its ability to conduct water during an infiltration test, it does not necessarily follow that the same feature will cause high water flows to a tunnel which penetrates it. Equally, because of the variability of geological structures, high water flows recorded at one location on a fault, for example, need not necessarily indicate similar flow conditions if that same fault is penetrated elsewhere.

In this regard it may not prove possible, or even advisable, to project drillhole permeability data to a hole of tunnel proportions and expect to accurately predict flow to the excavation on the basis of a few permeability values and some idealized assumptions. The entire field of predicting groundwater influx into underground excavations has been largely unexplored when compared with other rock mechanics problems and must therefore be approached with considerable reservation.

2.7 Summary of Downhole Instrumentation for Site Investigation Purposes

This chapter has summarized the extensive range of borehole equipment and techniques at the disposal of geotechnical engineers concerned with tunnelling site investigations. Given sufficient accuracy and reliability, this equipment could ideally reduce the necessity for expensive coring and subsequent laboratory testing which is currently required to describe many engineering characteristics of a rock mass. In situ testing has the additional advantage of exposing a greater proportion of the rock mass to the scrutiny of the geotechnical engineer, thereby providing more representative values for design parameters. Also, the savings which accure from reduced coring could be allocated towards financing a more comprehensive site investigation by permitting a greater number of boreholes to be drilled and/or more borehole measurements to be made. Unfortunately, the state-of-the-art regarding borehole instrumentation is such that elimination of coring during site investigation will not materialise for some time. Indeed, engineers may be reluctant to forego coring under any circumstances, relying upon the core as insurance should a borehole probe malfunction or produce questionable results.

This chapter has investigated the equipment and techniques employed to evaluate the basic parameters associated with the design, excavation and serviceability of underground structures. Among the parameters of interest cited by Brown and Phillips are the location and attitude of structural features, the determination of lithological boundaries, the characterisation of rock strength, the evaluation of hardness and abrasivity, and the measurement of groundwater pressure and rock mass permeability. Each of these areas of interest has an associated range of equipment which is used in the borehole or on core derived from it. The performance characteristics of these borehole tools and associated test techniques have been compared in detail elsewhere in this chapter; however, some concluding remarks are in order.

The most fundamental requirement of a tunnelling site investigation is the characterisation of the structural geometry of the rock mass. Fortunately, a wide selection of generally reliable equipment exists which will accurately record structural features intercepted by the borehole. Certain items (borehole cameras in particular) can be temperamental and opinion expressed in the literature reflects the diverse experiences of various authors. Unless the borehole tool can be mounted on a drill string, the orientation of the borehole can prove an obstacle to cable-suspended probes like borehole cameras and many seismic and geophysical tools. Generally, the simpler the structural logging device, and the more intimate the contact with the borehole wall, the more assured one is of obtaining reliable results. In view of the cost of many structural logging tools, failure to operate in a normal borehole environment must seriously question their utility.

A major limitation with most of the structural logging tools reviewed is the necessary requirement that structural features be intercepted by the exploratory borehole if their presence is to be recorded. As a borehole samples a very small volume of rock mass, the chance of a major structural feature existing undetected remains a possibility. This is particularly true in tunnel site investigations because the linearity of the structure often precludes close spacing of exploratory boreholes, hence the necessity of a well designed drilling program incorporating horizontal drilling where practicable.

Geophysical borehole probes sample larger volumes of rock but they too depend on the borehole intercepting the geological structure in most instances. Ground-probing radar is a highly attractive prospect for sensing structural features beyond a tunnel face. Unfortunately, limited penetration and uncertain interpretation of results limits this technique to purely research applications for the foreseeable future.

All things considered, structural logging equipment is well developed for most site investigation requirements provided equipment is not extended beyond design capabilities. A definite need does exist for an inexpensive orientation device to be incorporated in these probes, preferably one which could double as a borehole alignment survey device. An inexpensive gyroscopic instrument is most desirable, provided the necessary sacrifice in accuracy is within reasonable limits.

No borehole rock strength testing device exists, therefore laboratory determination of rock samples or field testing of core must remain the primary means of obtaining strength data. Field evaluation of uniaxial compressive strength can be measured several ways, point load testing being the most reliable, followed by Schmidt hammer tests. Both tests provide rapid and accurate determinations of a parameter which has wide application in tunnel design, excavation and support considerations. The drilling strength technique developed by Tsoutrelis is attractive, provided it can be proven under field conditions. If so, suitably instrumented drill rigs could provide a continuous strength log as a routine site investigation procedure. This possibility is explored elsewhere in this investigation.

Numerous tests exist with which to measure hardness and abrasivity, the results of which are normally used by tunnelling machine manufacturers to predict advance rates and wear on the cutting elements of the machines. As yet, no standardized index test has been designated from among these tests, although the Schmidt hammer is probably favoured among the various hardness tests. The chief difficulty with abrasivity and hardness tests is deciding what it is that requires measurement. Is it hardness at select points over limited areas, or is it the resistance offered by rock to indentation of a cutting element, Can a concept of abrasivity be extended to all rock types regardless of fabric, or must it be modified to take due account of type of cement, grain size, grain mineralogy, etc.? Another aspect of abrasivity is the questionable logic behind obtaining a measure of abrasivity by whichever technique outlined in Section 2.5.3 and using it to predict cutter consumption. Surely the lathe test developed at Newcastle-upon-Tyne, for example, could employ a scaled-down pick or disc cutter to effect mechanical attack on the rock and thereby provide a more direct assessment of wear and probable attrition rates for cutting elements. As the situation exists at present, the relationships between hardness and abrasivity on the one hand and rock machineability on the other are obscure and considerable research is required before the interaction of each with the other is clarified and a representative test(s) established. Indeed, it may prove advantageous to develop a test procedure which measures machineability directly as attempted by Nishimatsu et al.

Groundwater flow is acknowledged as one of the least understood aspects of engineering rock mechanics. While it is relatively easy to monitor groundwater pressures or determine permeability values for isolated points within a rock mass, using the results of such tests to predict potential groundwater flows into a tunnelling operation is at best a highly speculative art. The uncertainty of predicting groundwater flows into underground excavations is directly attributable to insufficient knowledge of a) the spatial distribution and interaction of conductive discontinuities, b) the degree and influence of surface roughness of the discontinuities on the groundwater flow characteristics, c) the recharge capability and boundary conditions of the groundwater system, d) the continuity of flow paths, e) aperture variation of discontinuities and many other factors. Engineers must direct their attention to developing numerical procedures to estimate groundwater flow to underground structures, particularly in view of the increased attention being given to underground storage of nuclear waste.

Immediately well pumping tests suggest a means of obtaining more representative results than smaller scale tests, but they too depend on many assumptions, the validity of which is difficult to evaluate in fractured rock. Also, these tests are financially prohibitive, except on very large projects where their limited use may be justifiable. The existing pressure monitoring and permeability testing equipment is adequate for tunnelling site investigations. What is required is a clearer appreciation of the groundwater flow relationships that exist in fractured rock and the analytical means of circumventing the obstacle posed by unobtainable data.

CHAPTER 3

FUNDAMENTAL RELATIONSHIPS BETWEEN TUNNELLING MACHINE AND ROTARY DRILLING RIG PERFORMANCE AND ASSOCIATED OPERATIONAL VARIABLES

It is expected that there will be a steady increase in the amount of tunnelling carried out in the United Kingdom and abroad, and that a higher proportion of this excavation will be in rock using tunnel boring machines[5,214,215].

The continual improvement in boring machine technology permits full face tunnel boring machines (FFTBM's) to excavate rock of 207 MPa (30,000 psi) strength or more, while partial face tunnel boring machines (PFTBM's) capably excavate rocks with maximum strengths in the region of 138 MPa (20000 psi) in favourable ground conditions[216]. However, it is doubtful that tunnel boring machines (TBM's) are being used to their full potential because the quantity and quality of site investigation data made available to machine manufacturers and contractors at the tender stage of tunnelling contracts is frequently inadequate[7,218]. This is particularly true of shorter tunnels where the economic advantage of machine versus conventional excavation may be marginal, the ultimate choice of method being largely governed by the anticipated ground conditions.

Even when a relatively thorough site investigation has been completed, the traditional approach of some vertical or subvertical borings from surface to the projected tunnel line, and possibly some short horizontal borings in the portal areas, often yields geotechnical data which can only be indirectly applied in the decision making process as regards the method of excavation[69,218]. Indeed, the unique site investigation requirements for tunnels suggest that techniques must be developed to satisfy the demands of the machine manufacturer and contractor.

Boyd[212] notes that a great deal of potentially valuable information is lost in standard site investigation drilling through ignoring the behaviour of the drill as it effectively performs a destructive test on the rock within which boring takes place. Several researchers[7,10,219] have suggested that the monitoring of the forces and energies associated with advancing a drill bit into rock could yield valuable information for predicting the performance of TBM's in the same formation. Certainly, many of the fundamental relationships involved in each of the excavation methods bear broad similarities one to another.

3.1 Mechanized Tunnelling and Operational Variables

Several authors[7,38,220] have noted that the performance of a tunnel boring machine is controlled by two distinct but inter-related groups of factors, namely:

i) the operational variables (the application of the available machine power to the excavation process) and

ii) the ground conditions (the stability of the excavation is determined by the ground conditions which in turn influence overall machine utilization and power consumption).

As the design of the cutting head and the rock loading systems of TBM's improve, ground conditions increasingly determine whether TBM's can be successfully employed on a given contract. Nevertheless, if site investigation drilling is to predict successfully the ground conditions for TBM's, the operational variables which apply to each system must be isolated and compared.

3.1.1 Tunnelling machine operational variables

Three principal variables are involved in the transmission of power to effect rock disintegration at the tunnel face; they are:

i) Rotary speed (N) The speed at which the cutting head rotates (RPM).

ii) Machine torque (T). The torque developed at the machine cutting head results from the summation of the moments required to move the tools across the rock face in their direction of cutting.

iii) Machine thrust (F). This is the axial force applied to the cutting elements of the rotary head to cause them to penetrate the rock at the tunnel face. As such, it is equivalent to the sum of the normal forces acting on the individual tools.

These three variables are inter-related as will be shown elsewhere in this chapter.

3.1.2 Machine performance parameters

Boring rate (R) is normally used to measure TBM performance. The boring rate is defined as the distance advanced per unit of time and is obtained from the product of the penetration per revolution of the cutting elements (p) and the rotary speed (N). The machine boring rate should not be confused with the machine utilization, the latter being the percentage of total time that the TBM is actively tunnelling as opposed to time lost to machine servicing, installing tunnel support, machine bracing and re-setting, debris removal, utility supply and installation, etc.[38].

The efficiency of the rock disintegration process effected by a TBM is expressed by the specific energy (e) of the system. The specific energy is defined as the work done in excavating a unit mass or volume of rock.

Several researchers[7,221-223] have considered the work done by a TBM in effecting rock disintegration. The total work done during machine excavation consists of two terms, namely:

i.) the energy due to torque (the rotation of the cutting head = $2\pi NT$);

ii) the energy due to thrust applied to the cutting elements in order to penetrate the rock (the thrust x the boring rate = FR).

In a tunnel of cross-sectional area A, by the time FR and $2\pi NT$ units of energy have been consumed, AR volumetric units of rock will have been excavated. The specific energy relationship can be expressed as

$$e = \frac{F}{A} + \frac{2\pi NT}{AR} \qquad (3.1)$$

where F is machine thrust

N is rotary speed of the cutting head

T is machine torque

R is boring rate

A is cross-sectional area of the tunnel

Roxburgh and Rispin[224] have shown the axial power term of equation (3.1) to be negligible in comparison with the rotational power term and it has been suggested[7] that the specific energy for TBM excavation can be defined as

$$e = \frac{2\pi NT}{AR} \qquad (3.2)$$

Gaye[221], while noting that the specific energy due to thrust is negligible, argued that equation (3.1) must be considered as a whole if the physical implications of the various factors involved in mechanized rock excavation are to be understood.

Innaurato et al[220] also considered the energy consumed by a tunnel boring machine. They noted that the total energy used for excavation was in excess of that theoretically required to remove the rock and could be considered to be the sum of the following two energy terms:

i) the energy required by the cutting tools to penetrate the rock (E) and

ii) the energy consumed by friction in power transmission to the cutting head, in the cutter bearings and at the cutter/rock interface (E').

Considering a single revolution of a rotary head equipped with disc cutters, the following energy relationship exists

$$e = E + E' \qquad (3.3)$$

or

$$e = KF + 0.55\ DF\ (A/R)^{\frac{1}{2}}$$

where K is coefficient
F is the net thrust
D is the tunnel diameter
A is the advance/revolution
R is the disc radius

3.1.3 In situ machine boreability studies

The evaluation of the field performance of tunnel boring machines is normally undertaken by one of several techniques. The most satisfactory method involves direct measurement of TBM variables and in addition measuring the forces on individual cutting elements using strain gauges. Brown and Phillips[7] note that this method was employed by Gobetz[225] for a 5.5 metre diameter Robbins TBM which was excavating mine development roadways in shale (U.C.S = 150 MN/m^2). The same approach was adopted successfully by the Transport and Road Research Laboratory (TRRL), with a 5 metre diameter McAlpine machine in chalk at Chinnor, Oxfordshire[226], and unsuccessfully with a Thyssen FLP35 boring machine in Coal Measures at Dawdon Colliery. It should be noted that the principal reason for the failure at Dawdon Colliery was the inability of the machine to cope with difficult ground, which eventually led to its withdrawal from the tunnel before any data was obtained[227].

An alternative method obtains machine specifications from manufacturers' catalogues and machine performance from contractors' shift reports. In this instance, specific energy is calculated by substituting values into equation (3.1). It should be borne in mind, however, that shift reports list the advance rate per shift and not the boring rate. The boring rate can only be estimated by assuming a utilization factor for the machine. Given the many constraints which can operate to modify the machine utilization time, this approach is substituted for the standard contractors shift report. This detailed form of reporting was employed by the TRRL[38,228] in their TBM performance monitoring programme at the Kielder Aqueduct involving two Demag TVM 34-38H and one Robbins 123-133 machines (3.5 metres diameter)[229].

Gaye[221] noted that during field trials of a 5.5 metre diameter National Coal Board tunnelling machine at Breedon and Dragonby, they adopted an intermediate approach between shift reporting and full instrumentation. The NCB's French counterpart, Le Centre d'Etudes et Recherches des Charbonnages de France (CERCHAR)[230, 231], carried out tests on one Robbins and two Wirth FFTBM's. A brief review of these and other in situ tests on TBM's provides a good survey of the relationships which operate between machine variables, machine design and utilization, and ground conditions.

One of the earliest fully instrumented field trials of an operating tunnelling machine was undertaken by the TRRL[232,233] in the Lower Chalk at Chinnor, Oxfordshire. The McAlpine shield machine was designed for weak rock (U.C.S. of 1 to 3 MN/m^2) using either drag picks or discs. Table 3.1 lists the test programme which was designed to investigate the optimum cutting conditions with respect to the cutting head cone angle, pick spacing, pick design and disc spacing.

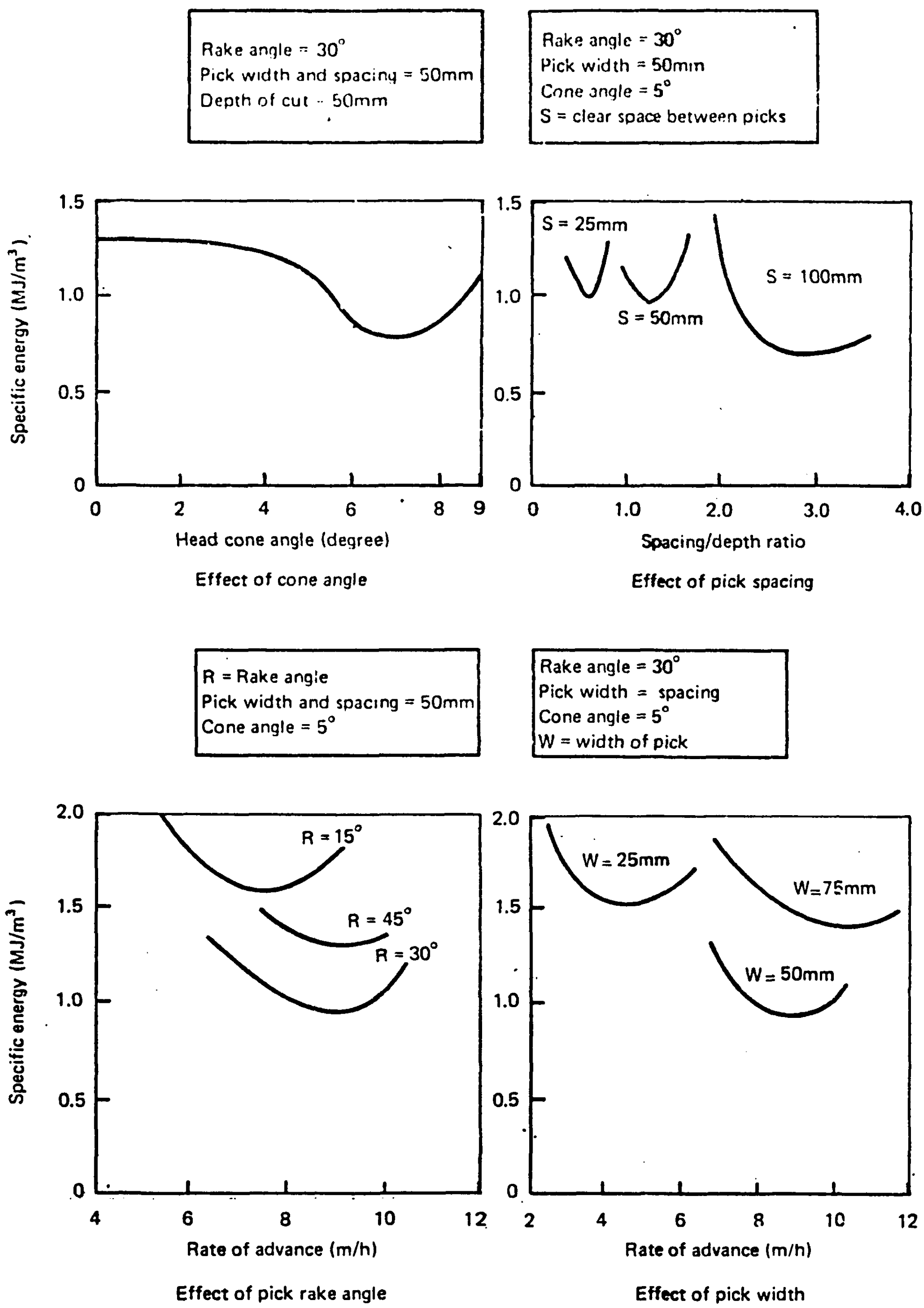
TABLE 3.1 PROGRAMME OF CUTTING TRIALS WITH VARIABLE CONE HEAD AT CHINNOR

Test series	Array				Variable	Test
	Pick width, mm	Rake angle, degrees	Depth of cut, mm	Cone angle, degrees		
1	50	30	50	–	0° cone angle	Power balance
2					0° cone angle	
3					3° cone angle	
4	50	30	50	–	5° cone angle	Effect of cone angle
5					7° cone angle	
6					9° cone angle	
7				3	25-mm spacing	
8	50	30	10–50	5	50-mm spacing	Effect of pick spacing
9				7	100-mm spacing	
10					15° rake angle	
11	50	–	20–50	5	30° rake angle	Effect of pick rake angle
12					45° rake angle	
13	25				25-mm pick width	
14	50	30	20–50	5	50-mm pick width	Effect of pick width
15	75				75-mm pick width	
16	280-mm diameter		10–25	3	75-mm pitch	Effect of disc spacing
17	90° edge angle discs		15–30	3	100-mm pitch	

(After O'Reilly et al, 1976)

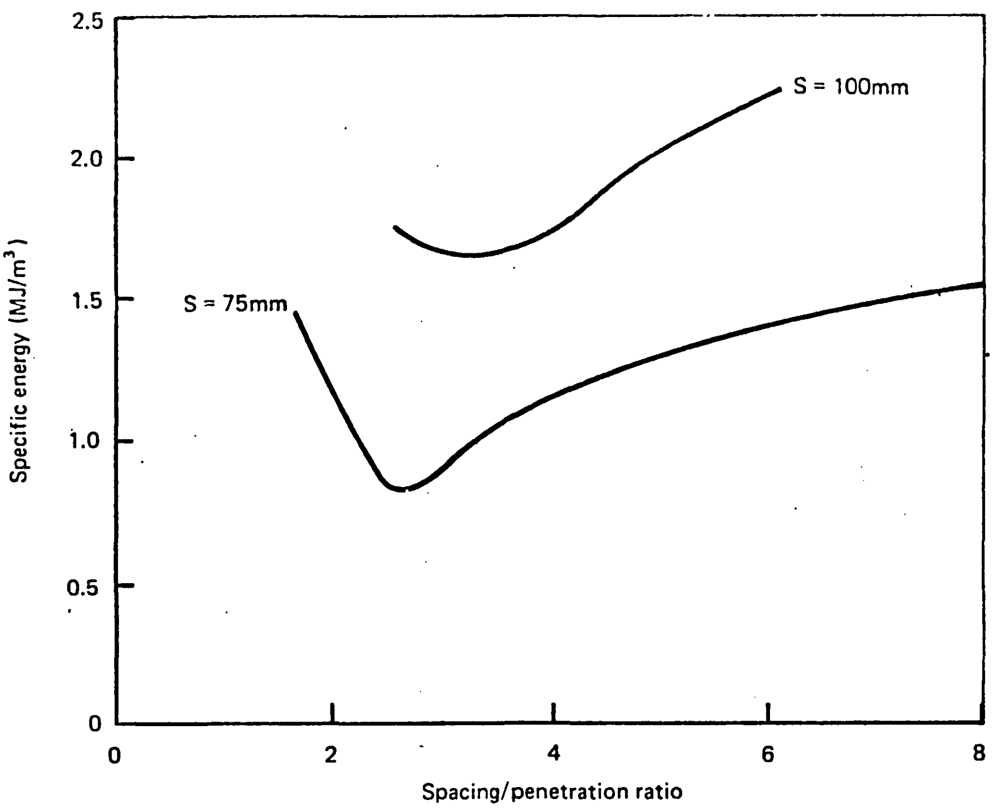
The results of the experimental trials provided a great deal of useful information. Figure 3.1(a) shows the specific energy consumed for given head cone angles, 7° being the optimum for the tool arrangement in this series of tests. The effect of pick spacing for a given depth of cut is demonstrated in Figure 3.1(b). The results show that minimum specific energy is consumed for 40mm depths of cut for each of the three pick spacings. When discs are employed (Figure 3.2), the optimum spacing to penetration ratio is approximately three for a 30mm penetration. The disc results are for a very limited number of trials; a better arrangement may exist for the 3.5 r.p.m. head speed. As shown, the 75mm disc spacing is the most efficient. Figure 3.1(c) indicates that a 30° pick rake angle has the lowest specific energy consumption followed by the 45° and 15° picks respectively. The effect of pick width is demonstrated in Figure 3.1(d) which shows that for relatively high advance rates, the 50mm wide pick performed better than the other two, although the 25mm wide pick may be a more favourable choice if lower advance

FIGURE 3.1 PICK CUTTING RESULTS OBTAINED AT FULL SCALE



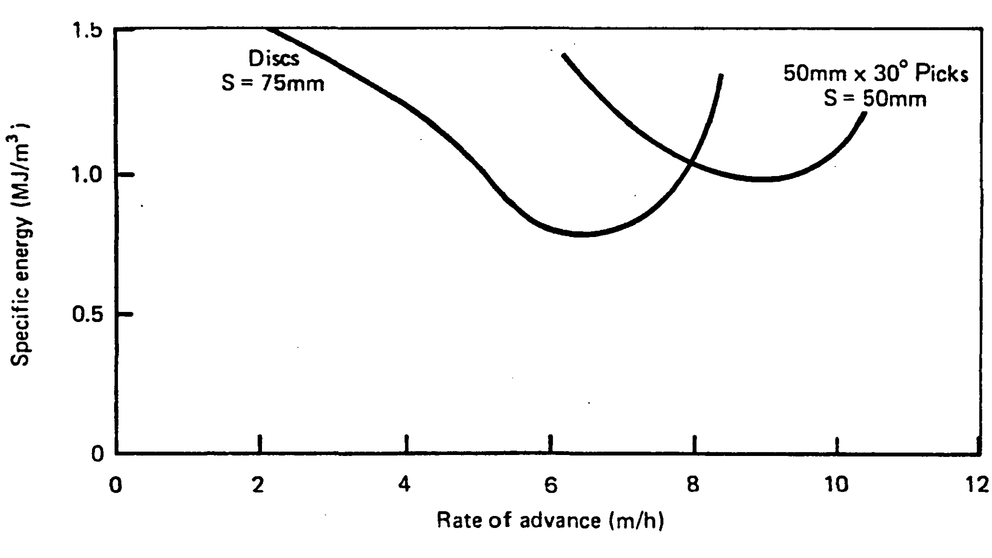
(After O'Reilly et al, 1976 and Hignett et al, 1977)

FIGURE 3.2 DISC CUTTING AND COMPARISON WITH PICKS AT FULL SCALE



Effect of disc spacing

S = clear space between picks



Comparison of picks and discs

(After O'Reilly et al, 1976 and Hignett et al, 1977) rates are required. Another important finding, as a result of measuring forces on the picks, concerned the considerably higher forces exerted on the peripheral (gauge) picks. This supports the need to increase the number of cutters at gauge positions.

The CERCHAR investigations carried out by Nizamoglu demonstrated that much useful information can be obtained without having to resort to the expense of fully instrumenting a TBM. As Korbin[38] has indicated, it is possible to gain a measure of the relative performance of a TBM for a given set of operating parameters by various manipulations of the machine controls coupled with careful monitoring of the simple instrumentation that exists on most machines. Using this basic procedure, Nizamoglu varied the thrust and rotational speed at the cutting head of a Wirth TBV-580H machine while the torque and the time required to excavate a given volume of rock was measured. Some interesting results arise from this research. Figure 3.3 shows that for a fixed rpm, a linear relationship exists between torque and penetration while Figure 3.4 demonstrates that penetration is directly proportional to thrust, although the relationship is not linear. Considering these two results leads to the conclusion that the machine torque is proportional to the applied thrust, as is shown in Figure 3.5.

Fortunately, Nizamoglu held the rotary speed of the cutting head constant during these early trials, which makes it a simple matter to determine the boring rate knowing the penetration.

$$R = 60\,pN \qquad (3.4)$$

where R is boring rate (mm/h)
p is penetration (mm)
N is rotary speed(rpm)

As expected, boring rate versus torque is a linear relationship (Figure 3.6), while boring rate versus thrust is slightly non-linear (Figure 3.7) for a constant rotary speed. Finally, Figure 3.8 plots boring rate against rotary speed for a thrust of 320 tonnes. Phillips[7] stresses the importance of this relationship for effecting rock excavation noting that high rotary speeds are desirable since boring rates are increased; however, he points out that tool penetration requires increased thrust. The two are incompatible since higher thrust and higher rotary speed demand larger cutting head motors in a limited available space, as well as higher bearing temperatures, causing increasing mechanical failure.

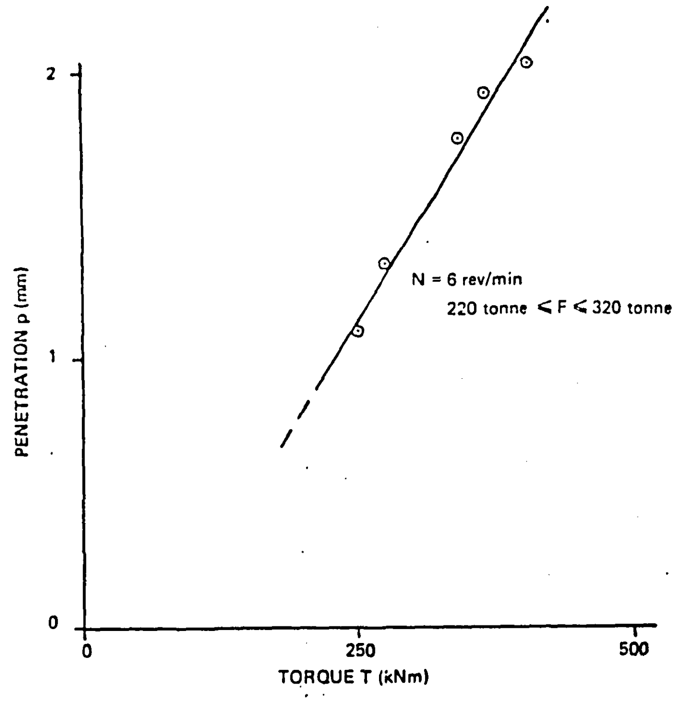


FIGURE 3.3 PENETRATION VERSUS TORQUE AT APPROXIMATELY CONSTANT THRUST FORCE (After Nizamoglu, 1975)

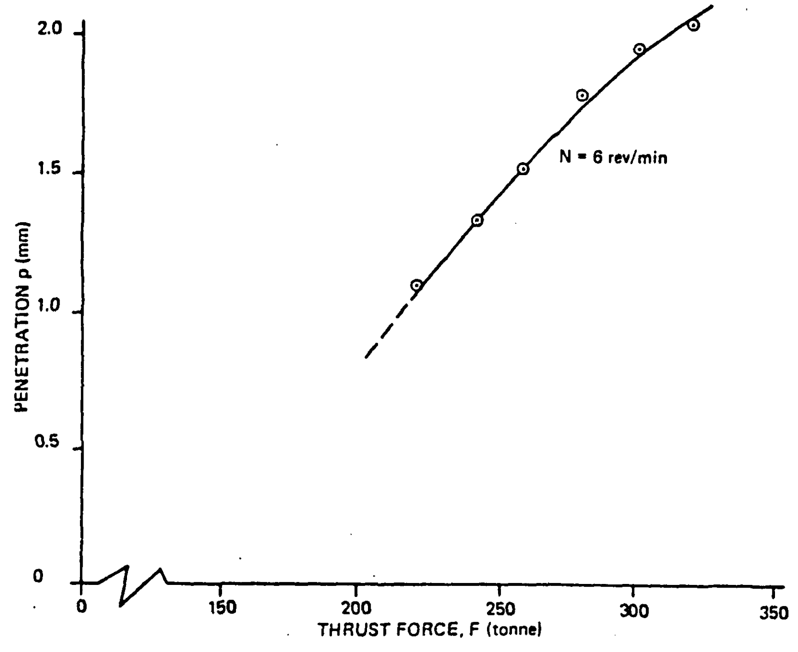


FIGURE 3.4 PENETRATION VERSUS THRUST FORCE AT CONSTANT TORQUE (After Nizamoglu, 1975)

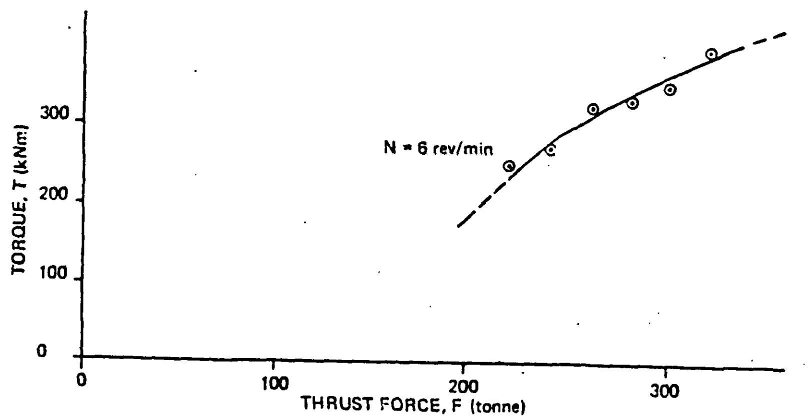


FIGURE 3.5 TORQUE VERSUS THRUST FORCE (After Nizamoglu, 1975)

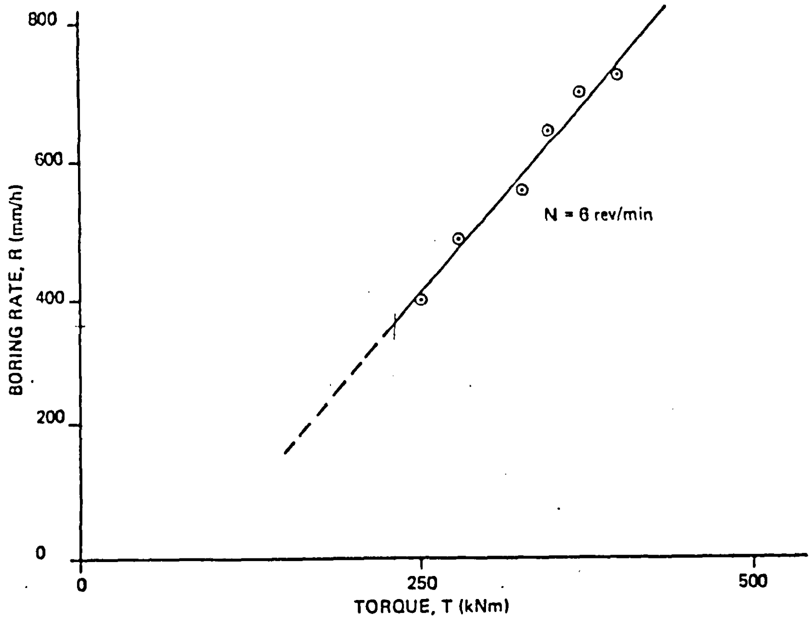


FIGURE 3.6 BORING RATE VERSUS TORQUE (After Nizamoglu, 1975)

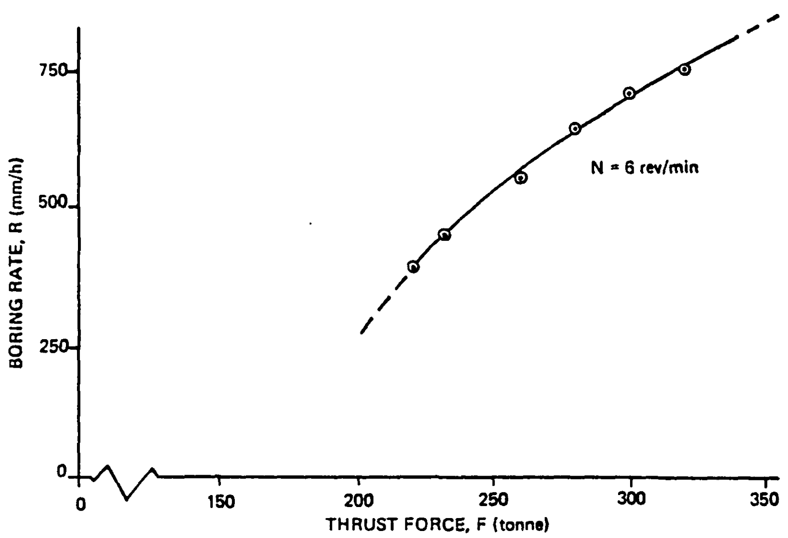


FIGURE 3.7 BORING RATE VERSUS THRUST FORCE (After Nizamoglu, 1975)

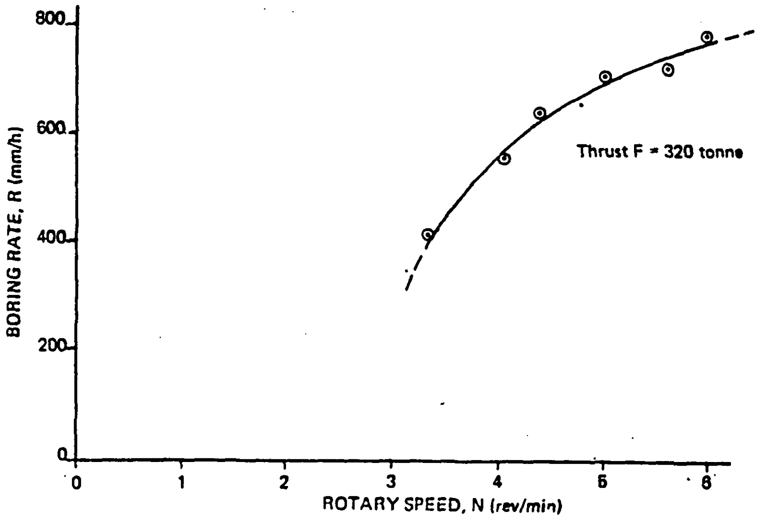


FIGURE 3.8 BORING RATE VERSUS ROTARY SPEED (After Nizamoglu, 1975)

Innaurato et al[220] present additional information, derived from a 6.4 metre diameter TBM operating in granite (UCS of 150 MN/m^2), which supports Nizamoglu's findings on thrust versus boring rate. Based on equation (3.3) and a disc cutter radius of 0.195 metres, Table 3.2 summarizes the performance of the boring machine in the granite. The results are explained in terms of a

TABLE 3.2: Thrust versus advance/revolution

	Net Thrust (tonne)	Advance/revolution (cm)	Friction Loss (%)	K (m)
a)	344	0.27	75 (280kw)	0.9
b)	425	1.5	25 (310kw)	0.3
c)	500	1.6	40 (400kw)	0.4

critical thrust. Only in excess of 350 tonnes thrust, does the advance per revolution achieve reasonable proportions. Below this value, the volume of rock between the discs is not fully shattered. The cutter continues to run in the groove with only slight attrition on the sidewalls of the groove taking place, and the cutter encounters high friction. Case (b) represents a minimum specific energy condition wherein the thrust level is such that excavation between grooves occurs because of the high lateral pressures transmitted by the discs to the rock. With increased thrust (Case c), a small improvement in advance/revolution occurs but, due to over-grinding of the rock, the energy consumption is not as favourable as Case (b). This optimum condition is specific to a given machine for given operating conditions and it is denoted by the inflection point on the thrust versus penetration rate plot in Figure 3.9, which is derived from the values given by Innaurato et al.

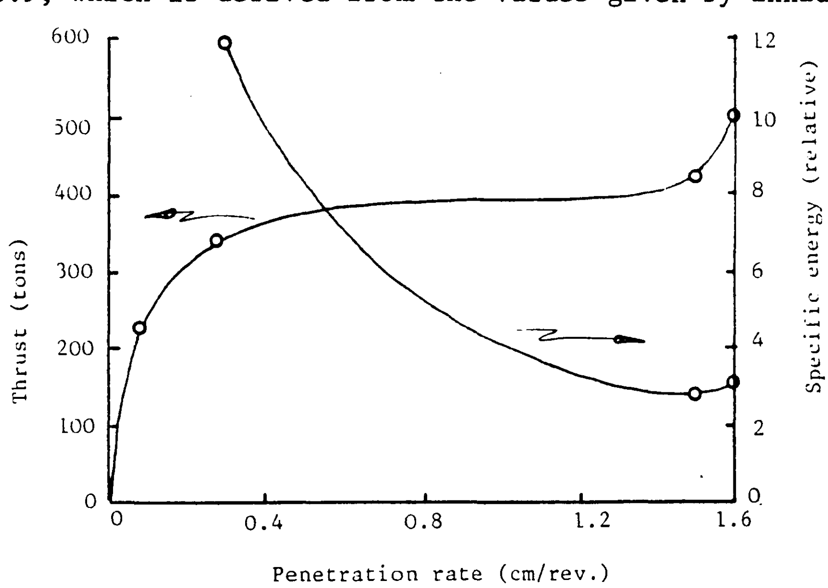


FIGURE 3.9: TBM PERFORMANCE USING DISC CUTTERS IN MEDIUM STRENGTH GRANITE. (After Innaurato et al., 1976).

Korbin, citing Erkelenz[234], gives details of a 2.1 metre diameter Wirth TBM excavating strong and abrasive rock (U.C.S. of 280 MN/m^2 and 72% quartz content), using 14 strawberry button cutters with tungsten carbide inserts. Figure 3.10 shows the thrust versus penetration relation which obtained in the granite. Although the details vary from those presented in Figure 3.9, the general features are the same, the optimum advance rate being 0.6m/h with

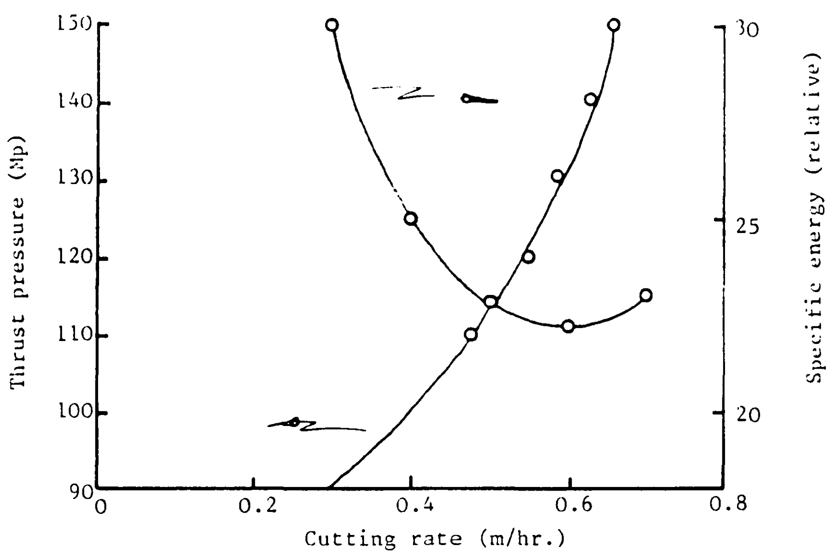


FIGURE 3.10: TBM PERFORMANCE USING STRAWBERRY BUTTON CUTTERS IN STRONG GRANITE. (After Erkelenz, 1968).

the button cutters, as opposed to 0.9 m/h with the discs. These variations reflect different machine characteristics and operational conditions[38]. The optimum specific energy coincided with a thrust of 130 Mp contact pressure, which fortunately proved to be the operating condition at which minimum wear occurred to bearing and cutter assemblies (minimum energy operation reduces the proportion of energy available for heat and friction, the agents of tool wear).

The optimum specific energy for excavation may not be the optimum economic condition for the operation of the TBM. In many instances, a lower rate of tunnel advance may have to be accepted, by maintaining thrust at a level equal to or lower than the optimum thrust, in order to reduce tool wear and machine damage. This restriction presupposes that tool design limitations (bearing load), available machine power, or mucking efficiency, prevents optimum excavation conditions being achieved.

Gaye's account of the NCB tunnelling machine's operation in Dragonby iron ore (U.C.S. of 33 MN/m^2) illustrated this point. As a result of the considerable amounts of debris produced at high thrust, secondary crushing (regrinding) caused a reduction in advance. Korbin rightly suggests that, with a more efficient mucking system, the optimum specific energy would have been associated with an advance rate greater than the recorded 3.9m/h.

Recent investigations by McFeat-Smith and Tarkoy[235], and by Korbin have demonstrated that overall machine performance may be far more important than being able to operate the TBM at optimum specific energy. The Kielder Water Scheme in County Durham, England, involved boring 28km of 3.5 metre diameter water diversion tunnels, employing one Robbins 123/133 and two Demag TVM 34-38H tunnel boring machines. While operating at different locations along the tunnel line, each type of machine was excavating in gently dipping Coal Measures. Table 3.3 indicates the different design features of the two types of boring machines.

Table 3.3: Specification of TBM's employed at Kielder water tunnels. (After Korbin, 1979).

Specification	Units	Tunnel boring machine	
		Demag TVM 34-38H	Robbins 123-133
Weight	tons	130	88
Diameter	m	3.5	3.55
Cutter head rotation	rpm	9.65	6.5
Forward stroke	m	0.8	1.05
Drive motor power	kW HP	360 430	440 600
Forward thrust	tons	320	312
Cutters	no.	(a) 13-17 triple disc plus pilot (2 tri-cone) (b) 12 double, 5 single plus pilot.	26 single disc plus pilot (1 double, 1 triple)
Cutter spacing	mm	(a) 80-40 (b) 102	80
Maximum thrust per disc	tons	(a) 7.8-6.0 (b) 10.3	10.1
Cutter layout		sequential single spiral	sequential single spiral
Nearest support point from face	m	12	2.5-3 and 15
Date built		1975	1970

The Robbins machine was fitted with 26 single discs, spaced at 80mm in a sequential single spiral, on a gently domed rotary head (average maximum thrust of 10 tonnes/cutter). The original cutter arrangement for the Demag machine was 17 triple discs plus a pilot giving a spacing of 40mm and a maximum cutter load of 6 tons. However, low advance rates relative to the Robbins machine led to the number of triple discs being reduced to 13 (80mm spacing) and single discs (102mm spacing). In spite of these modifications, the Robbins TBM consistently outperformed the Demag machine. Table 3.4 provides an account of the time devoted to various aspects of machine tunnelling for each type of TBM, while Table 3.5 considers the different TBM cutting rates experienced at Kielder.

Another feature of Table 3.4 concerns the relative consumption of cutters with respect to the two machines, the single discs of the Robbins machine consistently outperforming the various discs used on the Demag TBM. Single disc cutters also needed fewer costly bearing replacements compared with the triple disc cutters.

Utilization varies predictably and consistently for both machines according to rock type, best progress (utilization times penetration rate) being made in soft, competent formations. The Robbins machine averages about 34% for the Demag, although a new Robbins machine would be expected to give 45% utilization under similar conditions. One of the features of Table 3.4, which clearly limits the utilization of the Robbins machine, is the inadequacy of the early mucking train. Debris production was such that the train could not cope with the volume of spoils produced causing repeated delays at the tunnel face (approximately 15% of shift-time). When a higher capacity tram was installed these delays were reduced to about 7.5%. In general, the muck-handling capabilities of the machines, as opposed to the spoils train, showed that the Robbins TBM was markedly more efficient than the Demag machine.

Korbin makes some additional remarks about TBM performance noting, in particular, that even when the disc type and arrangement of the discs on the Demag machine were changed, only a 20% improvement in performance was noted. Figure 3.11 is a graphical presentation of Table 3.5 and shows that the Robbins machine was approximately twice as fast in lower strength rocks and about one half as fast again in higher strength rocks. Plotting penetration per revolution of the rotary head against rock strength (Figure 3.12) shows an even greater contrast between the two machines, given the slower rotary speed of the Robbins TBM. (Considering the variation in penetration between the two machines, Korbin cites the following as probable causes:

i) the Demag has 20-30% less thrust per disc edge compared with the Robbins machine,

ii) the use of single versus multiple discs on the Robbins

TABLE 3.4 BREAKDOWN ANALYSIS - PERCENTAGE SHIFT TIME

Demag TVM 34-38 triple disc button									
		Rock Type	Sandstone	Sandstone	Mixed beds	Mudstone	Limestone	Dolerite (Buttons)	Mudstone
		Condition	Siliceous	Siliceous	Hardened	Silty	Massive	Competent	Pure
		Distance from portal (km)	0-0.5 Learning period	0.5	1	2	2	3	5
		Test length (m)	500	200	450	150	850	200	100
		Penetration (m/hr)	1.2	1.2	1.6	2.0	1.4	0.6	2.7
ESSENTIAL DELAYS	1	Machine maintenance	2.7	4.1	7.8	11.5	11.8	10.7	11.6
	2	Cutter replacement	10.0	10.2	2.7	1.0	4.2	11.2	1.9
	3	Track/invert units	6.7		1.8	2.4	2.3		2.4
	4	Support	1.7		6.4	12.2	1.0	0.1	22.1
	5	Laser/survey	0.2					0.9	
	6	Services	1.8	0.2	3.4	3.5	4.9	1.1	8.4
	7	Changeover trains	2.3	3.4	6.2	3.7	6.0	2.5	7.8
NON-ESSENTIAL DELAYS	8	Chutes	4.1	4.6	1.6	5.7	2.1	1.0	10.9
	9	Conveyor	16.7	8.8	5.3	5.9	0.1	5.5	2.7
	10	Machine conveyor	3.0	4.5		4.1			2.6
	11	Machine electrical	1.0	1.9	2.0	2.0	1.8	1.4	0.9
	12	Machine mechanical	4.3	7.7	9.9	3.5	1.1	0.7	1.1
	13	Previous supports						0.4	
	14	Train derailments	2.3	0.6	0.4	0.5	0.1	1.0	2.0
	15	Water (non-conveyor)	2.8	0.2	0.2				
	16	Tunnel maintenance				3.1	2.8	5.4	4.8
	17	External	2.6	1.3			0.7	0.3	
	18	Miscellaneous	6.0	4.2	2.0	2.7	5.0	9.9	3.5
		Machine utilisation	31.8	48.3	50.3	38.2	56.1	47.9	17.0
		Progress m/120 hr wk	45.8	69.6	96.6	91.7	94.2	34.5	55.1

Robbins 123/133								
		Rock Type	Sandstone	Limestone roof	Sandstone	Sandstone	Mudstone	Mudstone
		Condition	Massive, gritty	Mixed beds in tunnel	Siliceous	Gritty Shaley	Silty	Pure
		Distance from portal (km)	0.5	3	4.5	5.5	7	7.5
		Test length (m)	200	560	100	750	210	170
		Penetration (m/hr)	3.5	3.0	2.3	3.7	2.9	3.0
ESSENTIAL DELAYS (length dependent)	1	Machine maintenance	4.0	13.2	3.8	8.8	4.4	6.3
	2	Cutter replacement	6.5	9.1	11.0	5.4	2.1	2.7
	3	Track/invert units	0.3	1.8	2.0	2.4	0.7	6.8
	4	Support	0.9	2.1		6.9	17.7	28.8
	5	Laser/survey			0.9			
	6	Services	4.9	5.4	3.0	3.4	5.5	2.4
	7	Changeover trains	14.6	15.0	13.5	16.0	8.7*	6.1*
NON-ESSENTIAL DELAYS	8	Chutes (Mucking)						
	9	Conveyor (Mucking)	0.6	0.3		1.5	0.9	1.1
	10	Machine conveyor (Mucking)						
	11	Machine electrical	3.8			0.3	1.4	1.6
	12	Machine mechanical	0.9	2.0	4.2	2.3	1.7	2.5
	13	Previous supports		1.2	2.0	1.1	3.7	
	14	Train derailments		0.7	4.0	2.6	1.5	3.2
	15	Water (non-conveyor)	26.2			0.5	1.3	
	16	Tunnel maintenance						
	17	External						
	18	Miscellaneous	9.2	10.1	12.6	13.8	14.4	15.6
		Machine utilisation	28.1	39.1	43.0	35.0	36.0	22.9
		Progress m/120 hr wk	118.0	140.8	118.7	155.4	125.3	82.4

*Train with larger mucking capacity introduced.

(After McFeat-Smith and Tarkoy, 1979)

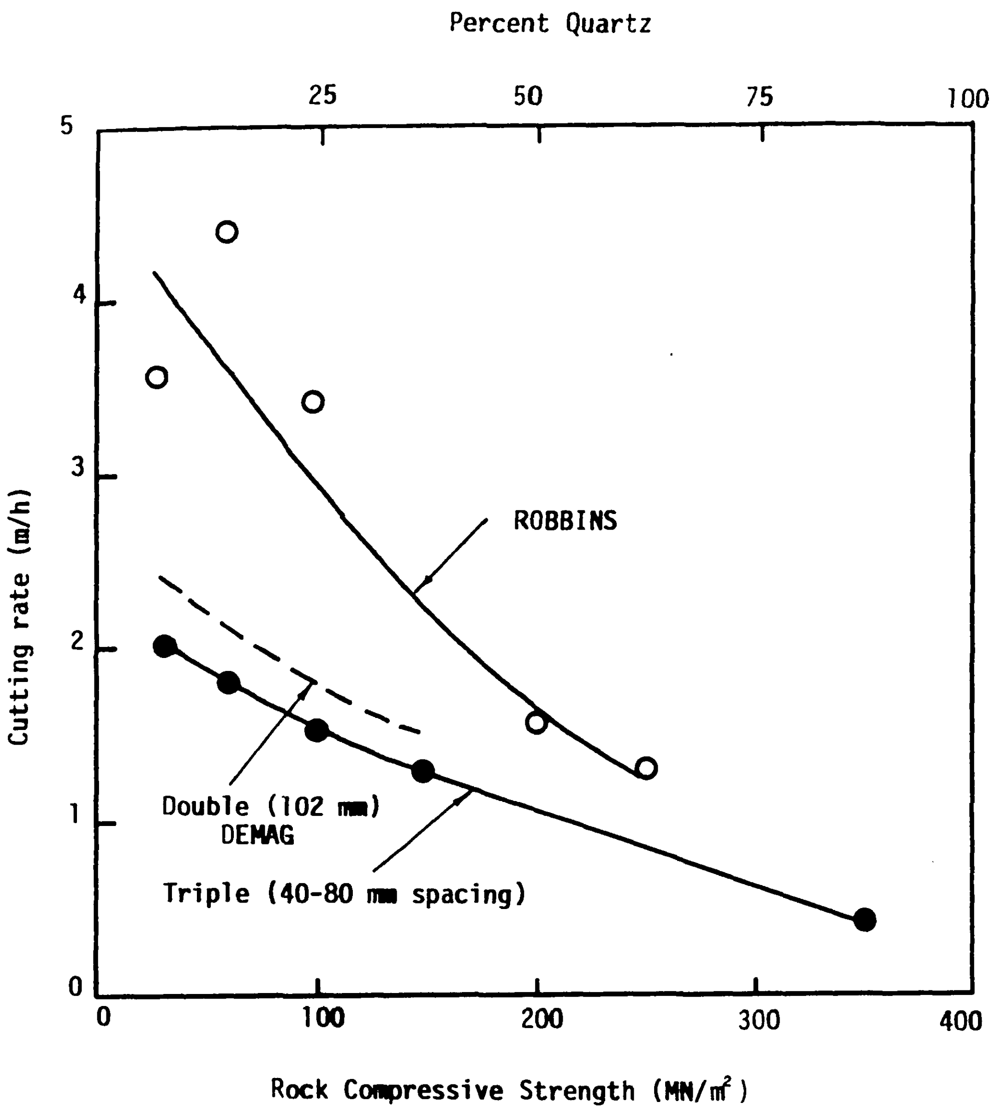


FIGURE 3.11 TBM CUTTING RATES VERSUS ROCK UNCONFINED COMPRESSIVE STRENGTH, KIELDER (After Korbin, 1979)

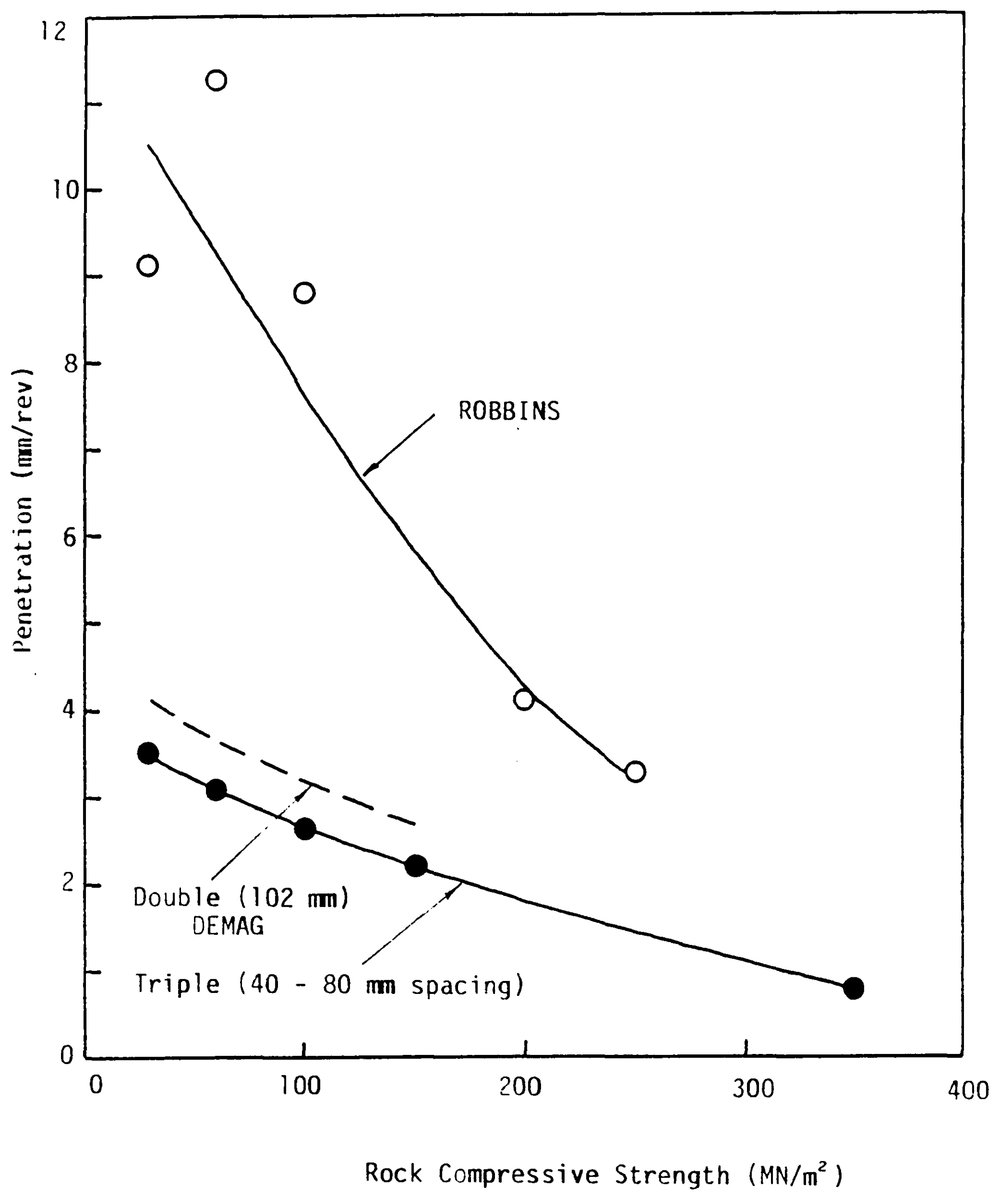


FIGURE 3.12 TBM PENETRATION RATES VERSUS ROCK UNCONFINED COMPRESSIVE STRENGTH, KIELDER (After Korbin, 1979)

Table 3.5: TBM cutting rates for different rock types encountered at Kielder. (After Korbin, 1979).

Rock type	Mean cutting rate (m/hr)				Compressive*** strength (MN/m)	Quartz*** content (%)
	*Demag 2		Robbins			
	Rate	Station (m)	Rate	Station (m)		
Mudstone	2.0	1270-1400	3.1 4.0	859-941 2600-2700	10-50	0-18
Mixed beds (mudstone and sandstone)	1.8	120-310	4.4 4.4	400-500 5100-5300	20-100	19-60
Sandstone	1.5	310-600	3.6 2.9 3.8	1500-2200 4100-4300 4900-5100	50-150	60-95
Limestone	1.3	900-1130	1.3 1.9	1052-1065 1325-1346	100-200	0-5
Dolerite	0.4**	360m SW	1.3	2716-2743	200-500	0-2

* 40-80 mm tool spacing

** Demag 1 (S Wear)

*** From Brown and Milow, 1979.

and the Demag machines respectively was not a problem; however, the spacing and penetration of each cutter relative to its neighbour on the Demag was not given adequate thought,

iii) the cutting tools on the Demag rotary head were subject to marked differential wear and poor penetration because of discontinuous variation (stepped) in the shape of the machine head.

The Kielder excavations also highlighted the effect of joint spacing on machine penetration rate. Korbin quoted a cutting rate of 1.3 m/h for an average joint spacing in excess of 1 metre, as opposed to a cutting rate of 3.9 m/h at a 1-10cm joint spacing for the Robbins machine. Associated with this increased drivage is a four times reduction in the specific energy required for excavation. In this instance, the increased penetration rate was achieved because no stability problems attended the reduced joint spacing, thereby demanding immediate support and thus offsetting the advantage of increased penetration. Fowell and McFeat-Smith[237] cited similar results for a Dosco road header tunnelling machine operating in Coal Measures. The instability which may accompany tunnelling in highly fractured ground has been discussed elsewhere by McFeat-Smith[69] who noted that in tunnelling environments where only 10% of the ground is badly broken, up to 30% of tunnelling time may be devoted to excavation in this ground. Not surprisingly, the detection of this type of ground was stressed as a site investigation priority.

3.1.4 Summary of tunnelling machine relationships

The main conclusions concerning the relationships which have been established for tunnelling machines are grouped into two broad categories, those associated with machine design and those controlled by prevailing ground conditions. The following general comments can be stated:

i) the evaluation of machine performance can be made by monitoring energy consumption during tunnelling;

ii) the cone angle of the rotary head of a TBM has an optimum value;

iii) all else being equal, for a given depth of cut, an optimum cutting tool spacing exists;

iv) an optimum rake angle and cutting tool width exists for picks in a given rock type;

v) for a given thrust, cutting elements in the gauge position experience greater forces;

vi) for constant torque (T), thrust (F) is proportional to boring rate (R); for constant r.p.m. (N), torque is proportional to boring rate and torque is proportional to applied thrust;

vii) tunnelling at optimum specific energy as regards boring rate may not be economic because of excessive stressing of equipment and/or the inability of mucking operations, support and service requirements to keep pace with tunnelling;

viii) ground conditions can exert a strong influence on TBM performance.

3.2 Correlation of Machine Performance with Rock Properties

Many attempts have been made to establish relationships between rock properties assumed to be important in tunnelling and the performance of tunnel boring machines. Machine manufacturers use these correlations in designing TBM's, while contractors employ them to estimate boring rates and cutter consumption for tender purposes. Some of the more widely used rock tests and boreability prediction methods are discussed below.

3.2.1 Material property tests and boreability

The various material properties of importance in deciding tunnel boring machine performance relate principally to rock strength and hardness. The tests employed to measure these properties have been treated in the previous chapter, where they were shown to be mainly dependent upon rock structure and mineralogy, and where in some instances, inter-relationships between indices were demonstrated.

The unconfined compressive strength of rock is one of the most widely used property tests in the tunnelling industry, mainly as a result of its ease of evaluation. While it would be unreasonable to assume that the strength properties of rock could be characterized by a single numerical value, nevertheless, interesting correlations between compressive strength and several machine variables have been made. The strength of the rock material has an important bearing on the power requirements of, and on the type, number and location of cutters on FFTBM's, as well as on the type of cutting head for PFTBM's.

Hibbard and Pietrzak[238], as quoted in an Ontario Ministry of Transportation and Communications report[1], demonstrate a relationship between the compressive strength of the rock and the specific energy developed by various TBM's in effecting rock disintegration. While a good deal of scatter exists in Figure 3.13, probably as a result of comparing dissimilar machines in different rock types, the machine designer supposedly can obtain an approximate idea of the energy requirements for a TBM in rock of a given strength. They also show that a correlation exists between unconfined compressive strength versus cutter consumption, and advance rate. Similar relationships are cited by Brown and Phillips[7] (Figure 3.14) for Anderson Mavor equipment, while McFeat-Smith and Tarkoy[235] compare Demag and Robbins TBM's with respect to these relationships (Figure 3.15). A similar comparison was made in Section 3.1 (Figure 3.11) when the effect of design on machine performance was considered. In every instance, as the rock strength increased there is a corresponding decrease in the advance rate and an increase in the consumption of cutters.

Handewith[160] has considered the constraints imposed by rock compressive strength on the operation of tunnelling machines. He argued that in soft rock TBM's are torque limited, whereas in hard rock they are thrust limited. This means that the machine must operate at optimum loading conditions while the penetration rate varies with the rock strength, as shown in Figure 3.16.

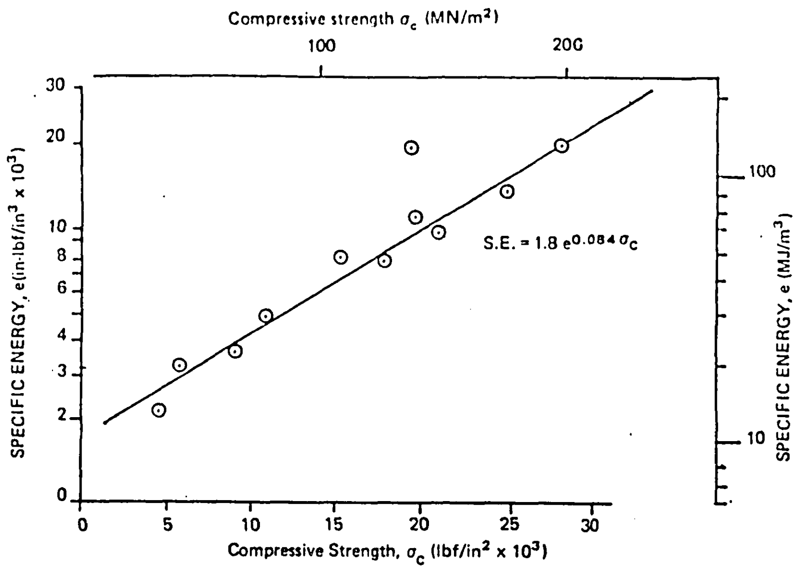
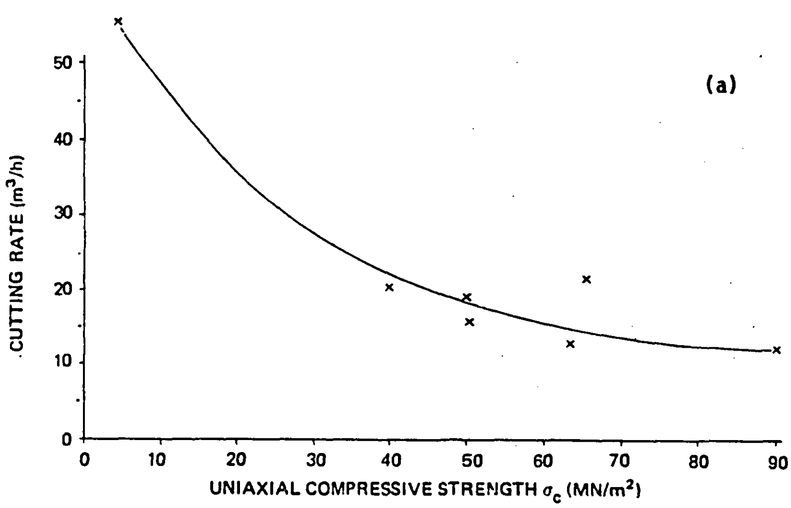


FIGURE 3.13 SPECIFIC ENERGY VERSUS COMPRESSIVE STRENGTH (After Hibbard and Pietrzak, 1972)



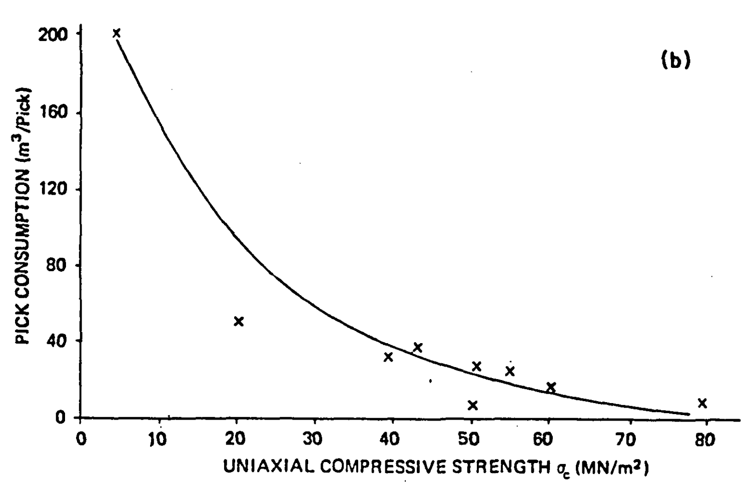


FIGURE 3.14 MACHINE PERFORMANCE (a) Cutting rate versus compressive strength for Anderson Mavor roadleaders and (b) Pick consumption versus compressive strength (After Brown and Phillips, 1977)

Calder[239] developed an empirical rotary drilling equation

$$R = \frac{(61 - 28 \log \sigma_c)\ F\ N}{250\ D} \tag{3.5}$$

where

R is penetration rate (ft/hr)

σ_c is uniaxial compressive strength (psi)

F is pull-down weight of the machine (lb)

N is rotary speed of the bit (rpm)

D is borehole diameter (inches)

which he used to predict the advance rate for a 12 foot diameter Lawrence Alkirk tunnelling machine on the assumption that the design of this TBM, having a pilot rotary bit, bore similarities to a rotary drill bit. Equation (3.5) is interesting in that the unconfined compressive strength is the only material parameter considered. Figure 3.17 shows the measured TBM penetration rates in rocks of varying strength as well as the TBM rates predicted on the basis of equation (3.5). Calder explained a 50% higher predicted value to the measured value as reflecting the better insert distribution in rotary bits as opposed to TBM rotary heads, and the higher relative thrust and bit rotation speed of rotary drills.

Rock hardness is probably the next most frequently measured rock property after strength. However, numerous hardness indices exist (Table 2.9, Chapter 2) to measure a wide range of material properties[161] and few means exist whereby the results of one test can be reasonably correlated with those of another. For the most part, the hardness tests employed in the tunnelling industry correlate reasonably well with compressive strength. Carter and Sneddon[158] demonstrated this correlation for Schmidt rebound hardness, point load strength and compressive strength, while Innaurato et al[220] related the Vickers and Moh hardness scales in attempting to assess the mineralogical contribution to cutter wear.

When applied to rock, the Schmidt rebound hammer and the Shore scleroscope (including similar devices) provide an indirect measure of rock strength. In this respect, they adopt a role similar to the point load test. In order to overcome errors induced by variations in the rock (mineralogy, grain size, etc.), statistical techniques are applied to the sampling procedure. One approach being to produce a reproduceable rebound number by performing multiple tests at a given spot[237] It has been suggested, however, that this technique will produce spurious values because of work-induced 'damage' to the rock. In spite of this and other shortcomings (Table 2.9), the Schmidt hammer test results can produce useful correlations with machine performance parameters.

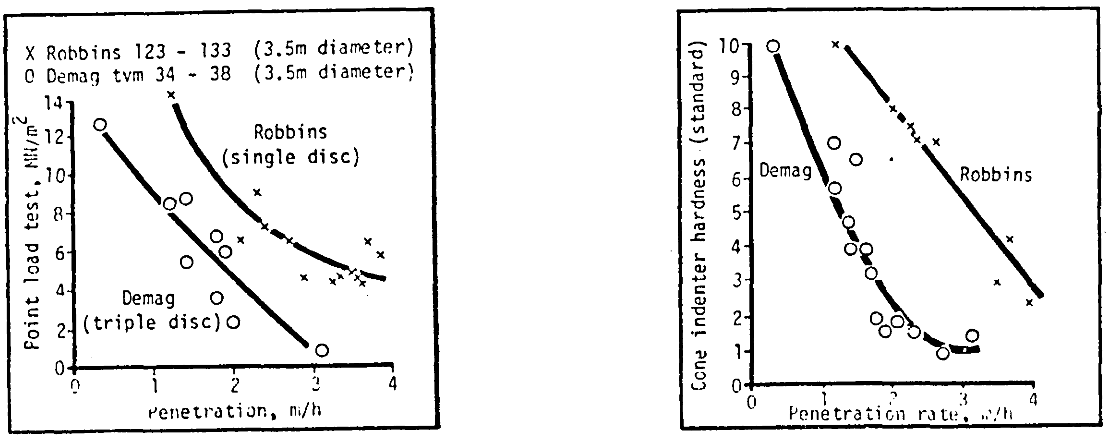


FIGURE 3.15 COMPARATIVE PERFORMANCE OF THE ROBBINS (SINGLE DISC) AND THE DEMAG (TRIPLE DISC) MACHINES (After McFeat-Smith and Tarkoy, 1979)

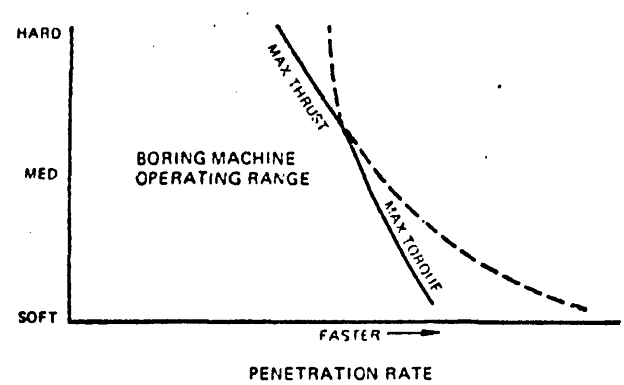


FIGURE 3.16 FORCE CONSTRAINTS ON A MODERN FULL FACE TUNNELLING MACHINE (After Handwith, 1972)

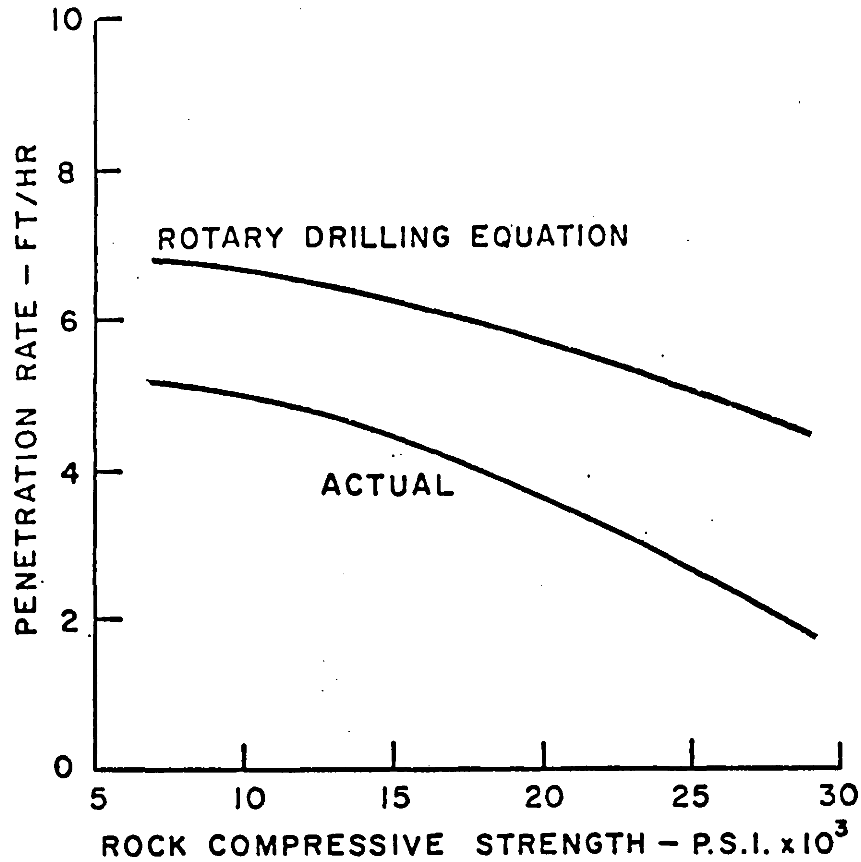
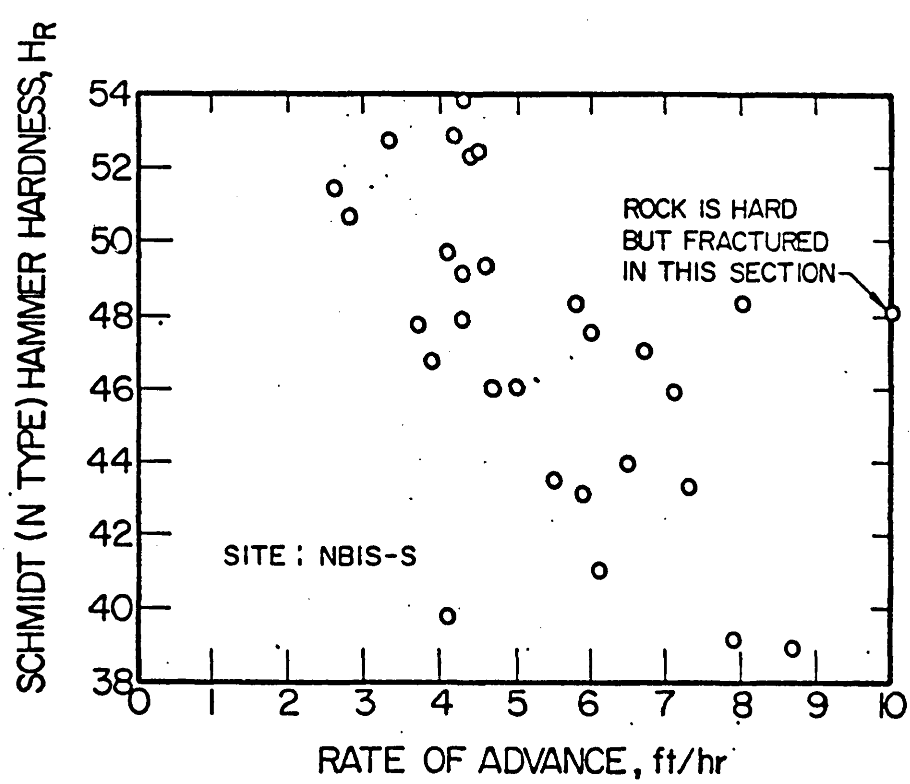


FIGURE 3.17 PENETRATION RATE VERSUS ROCK STRENGTH - PREDICTED AND ACTUAL (After Calder, 1972)

FIGURE 3.18 RELATIONSHIP OF SCHMIDT HAMMER VALUES TO TBM RATE OF ADVANCE (After Tarkoy, 1975)



Tarkoy[167] measured hardness values along a tunnel wall (mica schist) and found a trend between decreasing hardness and increasing rate of advance for a TBM. This relationship is shown in Figure 3.18. Related studies using the Shore scleroscope established a poor correlation between the Shore hardness and the rate of advance. Tarkoy recommended a Schmidt hammer be used to assess advance rates since the total hardness concept described in Chapter 2 was shown to be less well correlated with rate of advance. Despite this earlier condemnation of the total hardness concept, McFeat-Smith and Tarkoy apply this approach to the estimation of cutter costs, albeit with better correlation than earlier applications (Figure 3.19).

Mayo et al[240] note that, while most machine manufactures employ rock hardness measuring techniques to decide on cutter type and probable wear, the precise details of these tests are kept confidential for obvious reasons. Nevertheless, the Moh scale of mineral hardness can be applied to rock (Table 2.9) to obtain a rock hardness value. Mayo and his associates note that, to date (1968), no TBM's have been economically deployed in rocks with hardness greater than 7 in the Moh scale. Although more sophisticated hardness measuring techniques are available, the Moh hardness method is useful as a first approximation guide to the machineability of rock.

The total hardness concept mentioned earlier employs a measure of abrasivity of the rock in the determination of the hardness index. The abrasive characteristics of the rock are an important aspect of machine tunnelling since the abrasive percentage content of minerals help determine the life expectancy and ultimately the cost of TBM cutting elements. Tarkoy employed a modified Tabor test described in Chapter 2 to determine rock abrasivity. As noted previously, total hardness (the product of Schmidt and Shore hardness and the square root of the abrasive hardness) correlates well with cutter costs (Figure 3.19). Korbin argued that since the modified Tabor test is essentially a specific type of hardness test, it was unlikely that the combination of hardness and abrasion indices will yield an index of greater predictive capability.

The performance of a 5.8 meter diameter Wirth TBM was monitored by Combes[241] during the excavation of a 4712 metre headrace tunnel for a power plant at Echaillon in the French Alps. Of the total length, 4362 metres were machine driven in crystalline (gneiss) and sedimentary (limestone, dolomite, anhydrite, conglomerate, shale and sandstone) rocks using a rotary head combining 34 double discs and 4 picks. Table 3.6 summarizes the machine performance in the various rock groups.

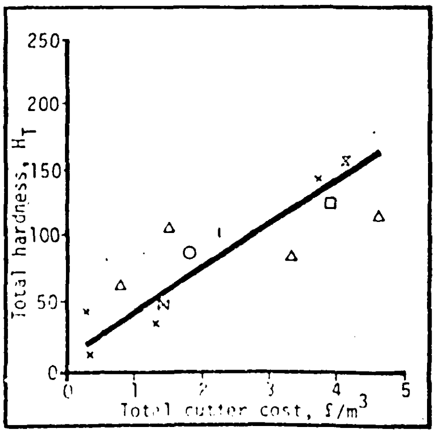


FIGURE 3.19 PREDICTION OF CUTTER COSTS FOR A RANGE OF TBM'S AND ROCK TYPES (After McFeat-Smith and Tarkoy 1979)

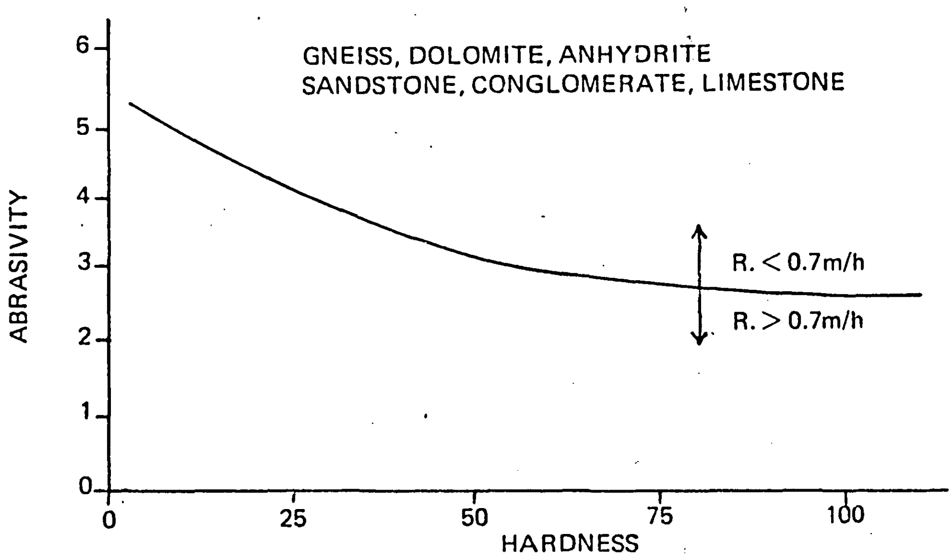


FIGURE 3.20 PERFORMANCE OF A WIRTH TBM (After Comes, 1974)

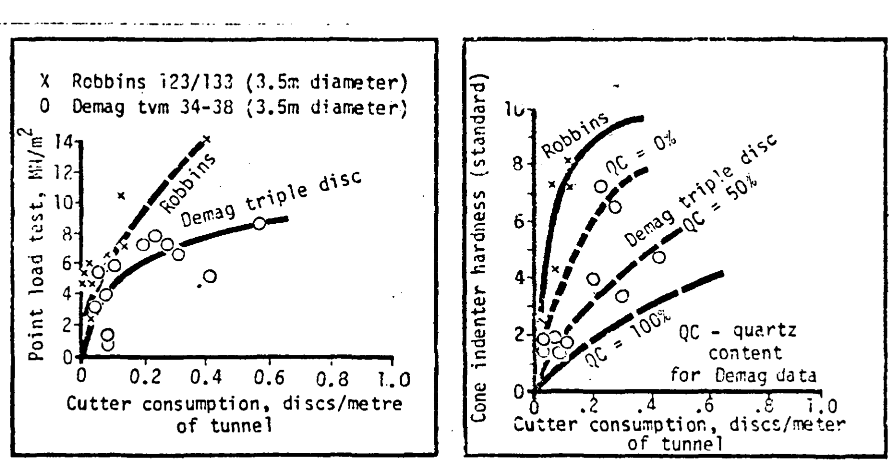


FIGURE 3.21 CUTTER CONSUMPTION RATES FOR THE ROBBINS AND DEMAG TUNNELLING MACHINES (After McFeat-Smith and Tarkoy, 1979)

Table 3.6: Wirth TBM Performance at Echaillon, France. (After Combes, 1974).

Rock	Rate of Advance (m/day)			Energy	Cutter Life
	Max.	Min.	Avg.	kWh/m^3	m^3
Gneiss	16.6	1.1	6.4	35	81
Trias	22.6	1.1	8.2	20	150
Lias	31.5	1.0	19.0	15	298
Flysch	34.3	1.1	12.9	16	206

Employing the CERCHAR 'durete' and 'abrasivite' tests led to the classification of the gneiss as being hard and abrasive/very abrasive while the sedimentary rocks were primarily medium hard and generally slightly abrasive. The one exception was the sandstone which ranked with the gneiss with respect to abrasivity, presumably reflecting high quartz contents for each rock. When the CERCHAR indices were combined with measured rates of advance, Combes defined a threshold hardness/abrasivity curve below which the Wirth machine gave rates of advance less than 0.7 m/h (Figure 3.20). Combes also considered the effect of rock strength and density on the rate of advance. In general, the rate of advance varied inversely with strength and directly with density.

The influence of quartz in effecting wear on cutters has been recognized by the tunnelling industry for a considerable time. Indeed, most abrasivity tests can be considered as a means of quantifying the abrasive influence of quartz in the rock to be excavated. The F coefficient of Schimazek and Knatz[187] is the complex product of the abrasive mineral content relative to quartz, the average grain size of quartz and the rock tensile strength. The index has been successfully applied to the installation of a Krupp tunnelling machine in a German coalmine and to the use of a Habegger heading machine at Lake Constance. The authors cite a case which demonstrates the influence of each component of the index by comparing different sandstones. One sandstone comprised 98% quartz of 0.55mm grain size and tensile strength of 23 MPa, while the other rock comprised 58% quartz of 0.18mm mean grain size and a tensile strength of 5.8 MPa. The critical cutting speeds were 0.18 m/s and 1.93 m/s respectively. In comparison, coarse grained sandstones were shown to induce up to fifty times more wear on the cutters.

Korbin notes, quite correctly, that the F index's reliance on quartz content as its principal component becomes less effective when applied to predicting tool-wearing strong rocks, which are low in abrasive mineral content. To support this statement, he cited the higher gauge cutter consumption on the Robbins TBM at Keilder when excavating in limestone (less than 5% quartz) as opposed to sandstone (greater than 75% quartz).

Handewith[160] described an empirical relationship which was used to explain the field observations on six Lawrence tunnelling machines. The dimensionless abrasion factor (Af) is given by

$$Af = \delta i \sqrt{\delta S} \tag{3.6}$$

where

δi is crushing rate index (kg/cm)
δ is penetration (cm)
S is volume content of silica

The value of δi can be determined either in the laboratory or in the field given information about the TBM, and the silica content is determined by atomic absorption techniques. The application of this formula will be considered later in this chapter.

Indentation tests constitute the last major type of individual measure which has been used to assess machine performance, particularly the NCB cone indenter test. McFeat-Smith[7] has correlated the cone indenter hardness with cutting rate in Coal Measure mudstones and siltstones and with pick consumption in various sandstones. The NCB test was used as a standard index test by Fowell and McFeat-Smith during Dosco roadheader trials at Blackhall Colliery[237]. More recently, the indentation hardness has been correlated with penetration rate and cutter consumption in a comparative study of the performance of Robbins and Demag TBM's at Keilder[235] (Figure 3.21).

Attempts have been made in the past[242] to predict boreability using reduced-scale drilling equipment based on matching the penetration rate and weight loss (wear) of the 'microbit' to monitored performance of a TBM. Tarkoy[167] has suggested that this procedure offers no discernible advantage over more easily performed index tests.

Another technique that attempted to correlate drillability with boreability relied on defining a drill rate index (DRI) by combining the results of brittleness, drilling and abrasion tests[243,244]. The Swedish brittleness value is measured on aggregate ranging in size from 11.2 to 16mm effective diameter. A 500g sample is placed in the crusher and crushed 20 times by dropping a 14.5 kg mass through a distance of 25cm onto the aggregate. The weight percent of crushed aggregate less than 11.2mm is defined as the brittleness value. This index correlated well with drilling rate, particularly when the value was adjusted using the Sievers J-value. This value is a measure of the penetration (in 1/10mm) of a wolfram carbide chisel-face drill bit after 200 revolutions under a 20kg load for a given rock type. Selmer-Olsen and Blindheim have produced a nomogram which permits the drilling rate index (DRI) to be determined readily from the brittleness and Sievers J values[243].

A series of drilling trials were performed with a Gardner Denver PR 123J rotary percussive drill rig employing Sandvik Coromant four-chisel cross bits, in a wide range of rock types. The drill rig was instrumented to record air pressure, stroke frequency, thrust and rotational speed while net penetration and bit wear were monitored during drilling. These investigations showed that the net drilling rate at optimum thrust correlated with the drill rate index. Also, a correlation between drilling rate and the frequency of discontinuities was noted. On the strength of these relationships, it was possible to correlate measured versus predicted drilling rates.

Bit wear, being the measured loss of bit height and diameter, was related to the length of drilling before bit regrinding was necessary. These results were extended to a correlation between predicted versus measured drilled length at the grinding limit.

Field trials also established goodcorrelation between the drilling rate and the point load strength of the rock. Since a similar relationship existed for TBM's, the finding was used to justify an extension of the technique to predicting the rate of advance of tunnelling machines. Data collected on the percentage increase in penetration for TBM's with respect to discontinuity frequency is presented in Figure 3.22. This plot shows correlation between penetration per revolution of the TBM and the DRI for eight rock types excavated using single disc cutters.

Handewith was of the opinion that TBM boring rates can be accurately determined in the laboratory provided that machine design torque and thrust loads are known. A crushing rate index (δi), the total force required to permanently deform a given rock to a given depth, is determined from the confined punch penetration test described elsewhere in the literature[245]. The index is related to various tunnelling machine parameters by the following formulae:

$$\delta i\ k = \frac{\Sigma(f/D)}{n} \tag{3.7}$$

and

$$\delta r = \frac{60\ \delta(N)\ (F)}{\delta ik} \tag{3.8}$$

where

δ is penetration/revolution (cm)

δr is penetration rate(m/h)

δi is crushing rate index (kg/cm)

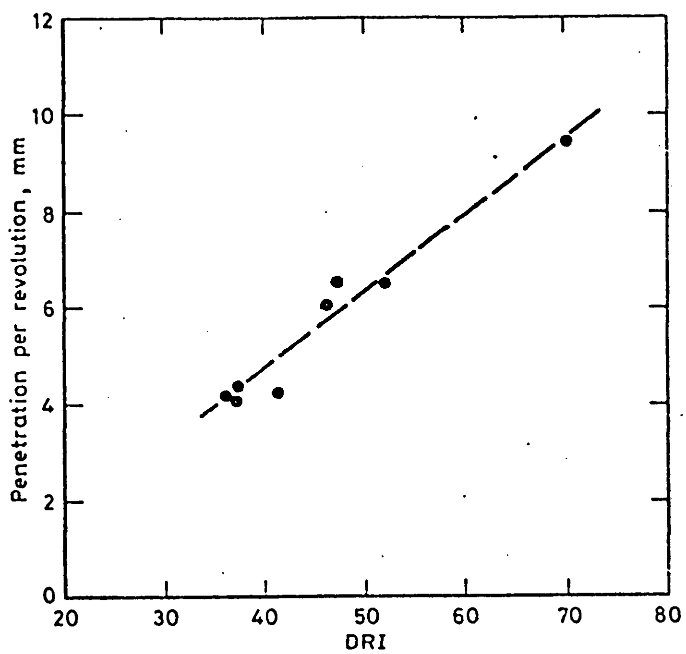


FIGURE 3.22 PRELIMINARY CORRELATION BETWEEN PENETRATION AND DRI FOR TUNNEL BORING WITH SINGLE-DISC CUTTERS IN MASSIVE OR NEAR-MASSIVE ROCKS (After Blindheim, 1979)

f is punch force (kg)
D is deformation of the rock specimen (cm)
k is a rock formation constant
F is applied force/cutter (kg)
N is rotary speed of the cutterhead (rpm)
n is number of data points.

The constant k is the difference between laboratory derived δi and actual δi calculated from machine performance and as such takes account of rock mass properties (and presumably differences in machine cutterhead design). The crushing rate index is reportedly a better indicator of TBM performance than unconfined compressive strength, although the two are related at high compressive strength. Field investigations using equations (3.6) to (3.8) inclusive produced the results listed in Table 3.7.

Table 3.7: Calculated versus observed rock and machine parameters. (Adapted from Handewith, 1972).

Lithology and Schmidt hardness (kg/cm^2)	Abrasion Factor x 10^3	Af Ranking	Machine Performance				Constant (k)
			Estimated		Actual		
			Rock Index (kg/cm^2 x 10^3)	Penetration Rate (m/h)	Rock Index (kg/cm^2 x 10^3)	Penetration Rate (m/h)	
1. Shale (633)	98	1	230	3.35	185	4.19	1.24
2. Sandstone mudstone & shale (1322)	250	4	451	2.35	386	2.74	1.17
3. Dolomitic limestone (1990)	193	2	1109 to 698	1,52 to 2.44	879	1.92	1.26 to 0.89
4. Argillite (2140)	389	5	741 to 495	1.83 to 2.74	947	1.43	0.78 to 0.52
5. Quartz-limestone & Conglomerate (2300)	219	3	668	2.74	1019	1.80	0.66
6. Sandstone, mudstone & shale (2600)	551	6	1263 to 631	1.52 to 3.05	1148	1.68	1.10 to 0.55

The estimated figures are based on geological data provided at the tender stage of the contract, as opposed to the actual figures which were derived during tunnel drivage. In the case of lithology (4) the frequency of discontinuities was overestimated from the core samples, while lithology (5) estimated values were based on surface outcrops which were not representative of the rock at depth. Handewith stressed the necessity of sound geological data at the tender stage if this type of boreability analysis is to be meaningful. Unfortunately, as evidenced in Chapter 2 and earlier in this chapter, sound geological data is frequently lacking in tunnelling contracts.

Finally, Graham[246] discussed, albeit in general terms, the means by which the Robbins Company estimate machine penetration and cutter costs. The rate of penetration per minute of boring time is given by

$$R = f_3 \left(\frac{F \times N}{D \times S \times C}\right) + f_4\left(\frac{J}{\sigma}\right) \tag{3.9}$$

where

F is machine thrust
N is rotary speed of the cutterhead
D is diameter of the cutterhead
S is cutter spacing
C is cutter edge angle
J is discontinuity frequency
σ is uniaxial compressive strength of the rock
f_3 and f_4 are functions which depend upon machine design and method of cutting

The estimation of cutter costs is based on an assessment of abrasivity of the rock, Graham favouring petrographic techniques to estimate abrasive mineral content, and is summarized in the following formula:

$$\text{Cutter cost} = f_1 \left(\frac{D^2}{F_c}\right) + f_2\left(\frac{\sigma A}{J}\right) \tag{3.10}$$

where

F_c is thrust per cutter
A is abrasiveness
f_1 and f_2 are functions dependent upon machine design and cutting techniques.

The consideration of the frequency of discontinuities in both of these numerical expressions highlights an important rock mass parameter which is not accounted for in most of the individual rock index tests, which attempt to predict machine performance or operating costs. Fowell and McFeat-Smith have demonstrated the important influence of the fractured state of the rock on the cutting rate for point-attack machines (road headers)[237].

3.2.2 *Summary of index test relationships*

There are a wide variety of index tests which can be used to assess rock properties with a view to predicting various aspects of TBM pefformance. Most of the tests relate directly or indirectly to a measure of strength or hardness (including abrasiveness). Given that these properties are strongly influenced by rock structure and mineralogy, it is not surprising that many of the index tests are inter-related (Schmidt rebound number and point load test, etc.). An impression that evolves from this partial survey of test methods is that there is a surfeit of index tests, often based on a vague relationship to some aspect of tunnelling. The tunnelling industry probably has sufficient experience with TBM's over the past 20 years or so to be in a position to rationalize

i) the number and types of test suited to boreability prediction, and

ii) the procedure by which the test results are used in a predictive or comparative capacity.

If the fact that many of the test procedures correlate strongly with unconfined compressive strength is conceded, surely unconfined compressive strength should be measured, where practicable, rather than some more 'esoteric', and frequently more time-consuming, index which is then related to compressive strength by a procedure which compounds errors. In this respect, the statistical comparison of various tests (including Schmidt rebound number, unconfined compressive strength, discontinuity frequency, rock quality index and the rock mass quality index) such as that carried out by Poole and Farmer[247] should prove suitable for deciding which tests are most beneficial. It may be worthwhile noting that Poole and Farmer found that the degree of correlation between single geotechnical factors and machine progress was limited.

Even where apparently well correlated data is presented for an index property and a machine performance parameter, care must be exercised if misleading conclusions are to be avoided. Korbin cited an example where unconfined strength was said to correlate poorly with cutting rate. The comparison involved excavations in granite and limestone rocks of similar strength (130 MN/m^2). Average penetration rates were 0.9 m/h for the Nast tunnel (granite) and 1.8 m/h for the Lawrence Avenue tunnel (limestone). The conclusion appears obvious until it is appreciated that two different TBM's equipped with different types of cutters excavated the tunnels. Even the well-structured comparison of the Demag and Robbins machines at Keilder relies on the assumption that the two machines working in the same lithographical units in relatively close proximity encountered comparable ground conditions.

Indeed, Korbin argued that the only valid application of indices for boreability prediction is "as calibrated by and applied to a specific machine operating under specific conditions".

The biggest limitation of most index tests is their failure to take account of rock mass properties. Clearly, the prediction of a high rate of advance in a rock of a given strength can be rendered meaningless by a dense fracture frequency which creates stability problems. A more fruitful approach must lie in the wider ranging boreability prediction techniques, namely:

i) the application of drillability data to the prediction of TBM performance (Calder, 1972; Blindheim, 1979),

ii) the blending of index tests and machine design characteristics (Handewith, 1972), or

iii) the blending of index tests, machine design characteristics and rock mass properties (Graham, 1976).

If the general level of success enjoyed by the Robbins Company in the tunnelling industry is a meaningful measure, then boreability formulations of this type are desirable. Even so, the Robbins formulation places a strong reliance on geotechnical data at the tender stage, thus highlighting the inescapable necessity for good quality site investigation drilling.

3.3 Rotary Diamond Drilling and Operational Variables

The earlier sections of this chapter reviewed the relationships which exist between TBM performance and the machine variables thrust, torque and rotary speed. In addition, the correlation between machine performance and rock properties were reviewed with a view to predicting machineability. This review included some of the more comprehensive boreability prediction techniques which have been formulated in recent years. This section concerns a similar comparison for rotary diamond drilling rigs in an attempt to make comparisons with tunnelling machines in particular, and for site investigation purposes generally through the analysis of recorded drilling performance.

The past few years have witnessed several reviews, concerned with rotary drilling performance and the theoretical and experimental relationships between operational variables, including Rowlands[248], Brown and Phillips[7], Brown and Barr[10], Brown[219], and Clark[249]. These investigations show that the operational variables fall into two classes - independent variables that are directly controlled by the operator, and dependent variables representing the response of the drilling system.

3.3.1 Independent variables

i) Thrust (F). A threshold axial thrust exists below which the indentors (diamonds or the inserts of metal bits) of a drill bit fail to overcome the yield strength of the rock being drilled, and so penetrate the rock. As drilling progresses and bit wear occurs, or stronger formations are encountered, an increase in thrust is necessary if the desired rate of advance is to be sustained.

ii) Rotary speed (N). If the penetration of the bit remains constant, then the rate of advance or the penetration rate should vary directly with increased rotary speed.

iii) Drilling fluid flow. The various fluids circulated in a borehole during drilling operations perform four principal functions - removal of cuttings from the bit face and ultimately the borehole, cooling the drill bit, lubricating the annulus between the drill rods and the borehole wall, and stabilizing the borehole. For high quality core recovery, flow rates should be commensurate with efficient drilling since excessive flows severely reduce core return in zones of geotechnical interest - soft and/or shattered ground.

3.3.2 Dependent variables

i) Penetration rate (R). The rate of advance of the bit through the rock (distance/unit time) is influenced by each of the independent variables. For constant bit indentor penetration, the penetration rate should increase directly with rotary speed. Increased thrust will also increase the penetration rate until a threshold value is reached signifying maximum indentor penetration. The penetration rate should also increase with increasing fluid flow up to a limiting value corresponding to the point at which all cuttings are removed from the bit/rock interface as soon as they are produced (perfect cleaning), or mechanical failure of a system component occurs.

(ii) Torque (T) In shallow boreholes, the torque acting on the drill bit is generated by the forces opposing the cutting action at the bit/rock interface from rotating the bit. Additional torque is necessary to overcome friction between the drill rods and the rock, and the shearing forces between the drill rods and the flushing fluid in deep deviated boreholes. For shallow holes, torque should increase with increased thrust and lessen with increased fluid flow rate.

iii) Drilling fluid pressure. For normal fluid circulation, a pressure difference exists between the fluid descending within the drilling rods and that ascending the annulus between the rods and the borehole wall. This pressure is required to counteract the difference in fluid densities due to suspended rock cuttings and to overcome frictional resistance to flow. Drilling fluid pressures can be expected to vary with thrust, penetration rate, flow rate, groundwater conditions and the nature of the discontinuities present in the rock mass being drilled. If the bit clogs while drilling through fault gouge, for example, inlet pressure will increase. Conversely, pressure losses may occur when open discontinuities or porous zones are intersected by the drill bit.

iv) Bit design. There are two basic types of diamond drill bit, those for coring and those for open hole drilling. The former is the most widely used since diamond coring bits are ideally suited for site investigation drilling. Variations in the size and the distribution of diamonds on the face (surface set) and through the matrix (impregnated) of the drill bit are widely variable, as are the drilling characteristics of the bits which result. These characteristics are matched to particular rock types and ground conditions largely based on the experience of the drill operator. The properties of the sintered metal matrix (usually copper-based) used to carry the diamonds in impregnable bits determine the rate of wear and the subsequent exposure of new sharp indentors.

v) Drilling resistance of rock. The independent variable in limiting penetration rate is the resistance of the rock to penetration. This collective term is used since, to date, no acceptable correlation has been made between drilling rate and an individual physical parameter of rock.

Variables (iv) and (v) may also be considered as independent since they help determine the response of the drilling system, rather than being responses themselves, although the operator clearly exercises no control over the latter variable (ignoring the use of surfactant solutions which appear to lessen the drilling resistance of rock[250]).

3.4 Theoretical Relationships Between Drilling Variables

3.4.1 The concept of specific energy

Teale[251], Rowlands[248] and others have investigated the theoretical relationships between drilling variables by calculating the specific energy (3) or the work done in excavating unit volume of the rock.

The work done during drilling (in terms of the variables defined in

Section 3.3) has two components, vertical and rotational, determined by the thrust (F) on the bit and the torque (T) respectively. If, as a result of removing unit volume of rock, the drill bit advances by an amount δ the work done by the axial force is $F\delta$. The work done by the tangential force per revolution is $2\pi T$. Since N/R revolutions occur during the time the bit advances by the distance Δ, the total work done by the torque is $2\pi T \cdot N\Delta/R$. If these two components of work are combined, while ignoring energy absorbers in the system it may be stated that:

$$\text{Total work done} = F\Delta + 2\pi T \frac{N\Delta}{R} \qquad (3.11)$$

Defining (A) as the cross-sectional area of the bit, the total volume of rock excavated over the drilled depth (Δ) is given by $A\Delta$. Dividing work by volume, the specific energy can be expressed as

$$e = \frac{F}{A} + \frac{2\pi NT}{AR} \qquad (3.12)$$

Teale notes that the thrust component of the specific energy equation is always small and frequently negligible in comparison with the torque component. Rowlands[252] found in laboratory experiments that the torque component was 500 times larger than that for thrust. As a result, it has been suggested that the specific energy can be defined by

$$e = \frac{2\pi NT}{AR} \qquad (3.13)$$

However, Fowler[253] made the point that the bit load had a major influence on the drilling operation. He also stated that this relationship can not be expanded to a full theory of rock drilling since it fails to incorporate any rock characteristics.

Rowlands' work indicates that for optimum drilling conditions, including uniform rock properties, no bit wear, perfect cleaning of the bit, no vibrational or frictional losses at the drill rod/rock interface, the specific energy (e) is constant for a given thrust, and torque is proportional to thrust. The torque/thrust relationship implied a constant coefficient of 'friction' at the bit/rock interface defined by

$$T/r = \mu F \qquad (3.14)$$

where (r) is the radius at which the tangential force may be considered to apply. Bearing in mind these underlying assumptions, it follows that

$$\begin{aligned} &T \propto F \quad \text{if } \mu \text{ is constant} \\ &R \propto T \quad \text{if } N \text{ is constant} \\ &R \propto F \quad \text{if } N, \mu \text{ are constant} \\ &R \propto N \quad \text{if } F \text{ is constant} \end{aligned} \qquad (3.15)$$

The laboratory assessment of the validity of these relationships has been investigated by numerous investigators including: Fish[254], Sasaki et al[255], Paone and Bruce[169], Paone and Madson[182], Tsoutrelis[154], Rowlands[248,250] and Everall et al[256] using a variety of diamond and rotary drag bits. These and other studies will be reviewed elsewhere in this chapter.

3.4.2 Relationships between rock properties and drilling variables

Paone and Bruce's classic laboratory study of rock drillability included the drilling strength of the rock in their analysis of the mechanics of diamond drilling. They proceed from the observation that the forces on a diamond core drill bit cause

1) surface failure or crushing due to the thrust on the bit, and
2) rock removal by the ploughing action of the diamonds

As in the previous section, rock resistance to drilling comprises two components - the reaction against thrust and the frictional resistance opposing the torque of the drill. Frictional resistance is again cited as the dominant factor. However, the abrasion of a rock surface results in a variable resistance because of intermittent shearing of asperities and variable properties due to the granular structure of rock[249].

Bowden and Tabor[257] define the coefficient of friction (μ) as follows:

$$\mu = \frac{\text{shear strength } (\tau)}{\text{yield strength } (\sigma_c)} \tag{3.16}$$

The shear strength approximates the bulk shear strength of the rock, while the yield strength under the diamond points may be considered as

$$\sigma_c = dP/dA \tag{3.17}$$

where dP is the average applied force for each diamond and dA is the mean cross-section area for each diamond-induced pit in the rock.

The total thrust F is obviously

$$F = n.\ dP \tag{3.18}$$

where (n) represents the number of diamonds contacting the rock. Using equations (3.17) and (3.18), the coefficient of friction can be expressed as

$$\mu = \frac{n\,\tau \cdot dA}{F} \tag{3.19}$$

The coefficient of friction is shown to be a function of the shear strength of the rock, the number of diamonds contacting the rock surface, the mean area of the indented pit and the applied thrust. Because the number of contacting diamonds and the value of dA cannot be evaluated, the value of the coefficient of friction cannot be obtained directly. In any event, the true value is dependent on other factors such as rock properties, lubrication, etc. Paone and Bruce assume a value of 0.4 for μ since it agreed best with experimentally derived penetration rates at optimum drilling conditions (μ = 0.4 need not necessarily apply in similar investigations where different drill bits are used, and different rock types and drilling conditions prevail).

The resistance to bit rotation can be written as μF. If a tangential force (F_t) is also applied to the bit, the force needed to abrade the rock, that is, to overcome the drilling strength (S), is the difference of these two forces. In other words, the work done per revolution of the bit (W_1) is

$$W_1 = 2\pi\, r(F_t - \mu F) \qquad (3.20)$$

where

r is the mean radius of the bit
= $D_1 + D_2/4$; D_1 and D_2 being the respective inside and outside diameters of the bit.

Since the applied torque (T) is given by $F_t r$, the equation (3.20) becomes

$$W_1 = 2\pi\,(T - \mu F\, r) \qquad (3.21)$$

The work done by the thrust per revolution of the bit is

$$W_2 = F.\delta \qquad (3.22)$$

where δ is the advance per revolution. Considering the drilling strength (S) or resistance to drilling of the rock, the work per revolution required to overcome this resistance is

$$W_R = S\,A\,\delta \qquad (3.23)$$

where

A is the cross-sectional area of the bit
$= \pi/4\,(D_2^2 - D_1^2)$

The work done in the rock and the work done by the applied forces must, at a first approximation[169], balance

$$W_R = W_1 + W_2 \qquad (3.24)$$

Therefore,

$$S\,A\delta = 2\pi(T - \mu F\, r) + F\delta \qquad (3.25)$$

or

$$\delta = \frac{2\pi(T - \mu F r)}{SA - F} \qquad (3.26)$$

However, the advance per revolution (δ) equals the penetration rate divided by the rotary speed, thus

$$R = \frac{2\pi N(T - \mu F r)}{SA - F} \qquad (3.27)$$

Equation (3.27) predicts the penetration rate of diamond drills, but the equation contains two unknowns: the coefficient of friction and the drilling strength of rock. As noted earlier, the coefficient of friction can be considered equal to 0.4, while Paone and Bruce state that substitution of the unconfined compressive strength for the drilling strength agrees favourably with experimental results (Figure 3.23).

An interesting comparison between equation (3.27) and the specific energy equation (3.13) has been made by Brown and Phillips. If the thrust term in equation (3.27) is considered to be negligibly small in comparison with the other terms and, in fact, is considered equal to zero:

$$R \simeq \frac{2\pi NT}{SA}$$

or

$$S \simeq \frac{2\pi NT}{AR}$$

An equality between equation (3.13) and (3.28) is established by substituting S = e. Such a substitution may be justified. Teale[251] found a strong correlation between the minimum specific energy and crushing strength for experimental data derived by Fish and Barker[258], the ratio of the two values being in the range 0.8 to 1.6 overall.

In subsequent investigations Bruce[259] tried to eliminate the friction coefficient from consideration by presenting the drilling strength (S) as a function of the unconfined compressive strength (σ_c). From the statistical analysis of drilling tests, the penetration per revolution is given by

$$\delta = \frac{2\pi T}{a\ \sigma_c A - F}$$

or

$$R = \frac{2\pi NT}{a\ \sigma_c A - F} \qquad (3.29)$$

where (a) is a constant. In plotting the data, 'a' was set equal to 10 to produce the best fit, but the determination of 'a' for various rocks and drilling systems appears to be as subjective as that for deciding the value of μ.

Somerton[260] performed a series of laboratory drilling tests in various rocks and concrete blocks of controlled but varied properties. The tests were conducted with a 32mm bi-cone microbit. The results of the investigations were analysed using two non-dimensional π terms derived from real drilling parameters, namely:

$$\pi_1 = \frac{F}{\sigma_c D^2}$$

$$\pi_2 = \frac{R}{ND} \qquad (3.30)$$

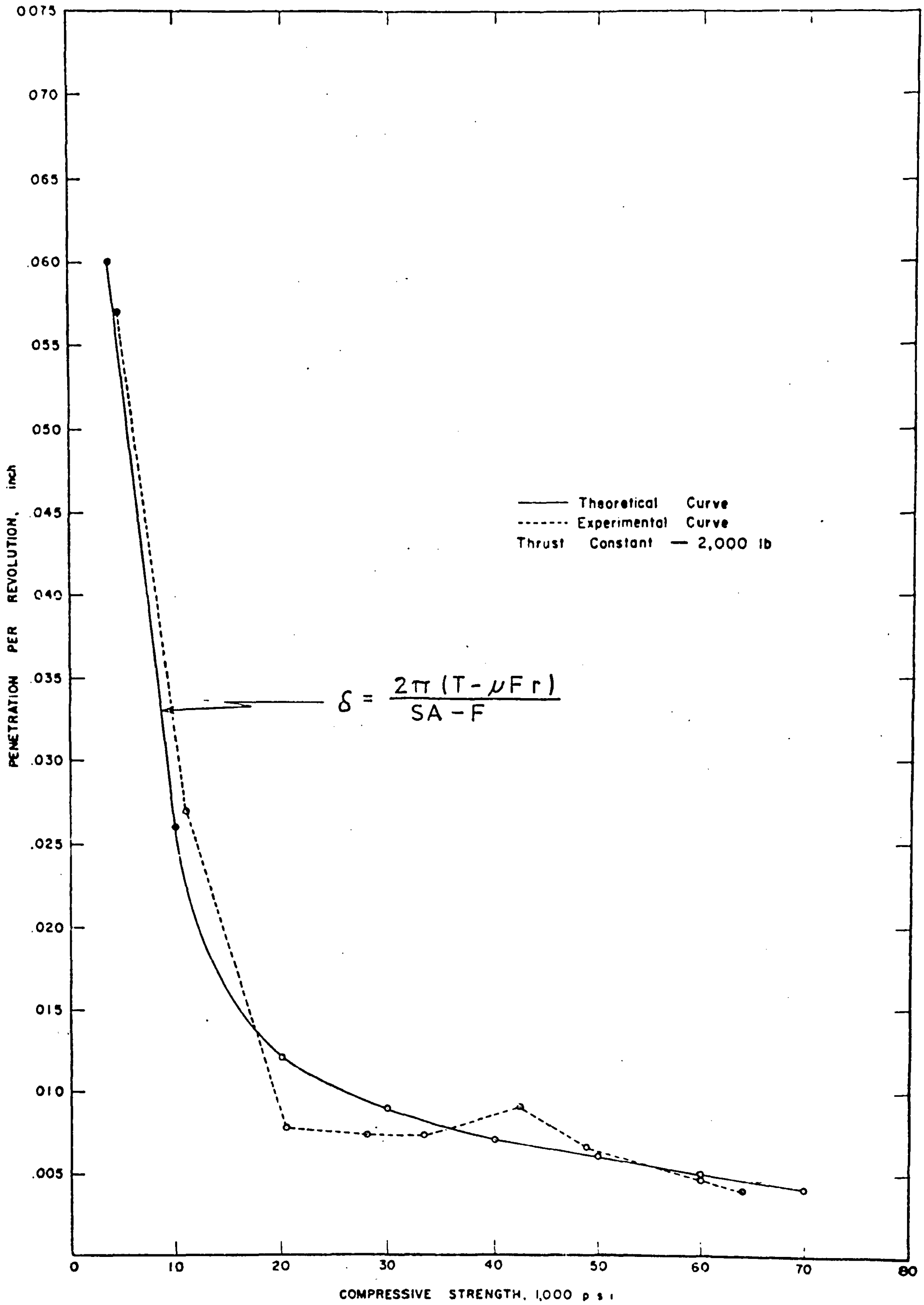


FIGURE 3.23 THEORETICAL AND EXPERIMENTAL RELATIONSHIPS BETWEEN PENETRATION PER REVOLUTION AND ROCK COMPRESSIVE STRENGTH (After Paone and Bruce, 1963)

for roller cone bits which produce an open hole, or redefined[253] as

$$\pi_1 = \frac{F}{A\sigma_c}$$
$$\pi_2 = \frac{R^2}{AN^2} \qquad (3.31)$$

for other types of bit, taking into consideration the actual area cut by the bit.

When log π_1 was plotted against log π_2, they were found to be highly correlated for individual lithologies, but little correlation existed between rock types. Following this, the compressive strength values were adjusted in order to reduce scatter in the plot. The scaled strength values were defined as the drilling strength (S). The best fit straight line for this data was determined as

$$R = 1.5 \; ND\left(\frac{F}{S\,D^2}\right)^2 \qquad (3.32)$$

Somerton stressed that this equation is not suited for general application but limited to the conditions of his tests. It does suggest, however, that a constant strength value may be assigned to a given rock to derive good correlations with the other drilling variables in the equation. These results and those of other experimental investigations form the subject matter of the next section of this chapter.

3.5 Laboratory and Field Studies of Drilling Performance

The foregoing discussion, which examined the theoretical predictions produced from equation (3.13), and summarized in equation (3.15), must be examined with respect to the experimental studies undertaken to see if the various relationships are evident in practice, if they bear any resemblance to those for tunnelling machines and if they offer any predictive capability as far as ground conditions are concerned.

3.5.1 Laboratory investigations

Numerous laboratory investigations of various aspects of rotary drilling have been undertaken during the past 30 years. A selection of the more familiar studies are listed in Table 3.8. The relationships between drilling variables which were established in these tests are discussed in turn.

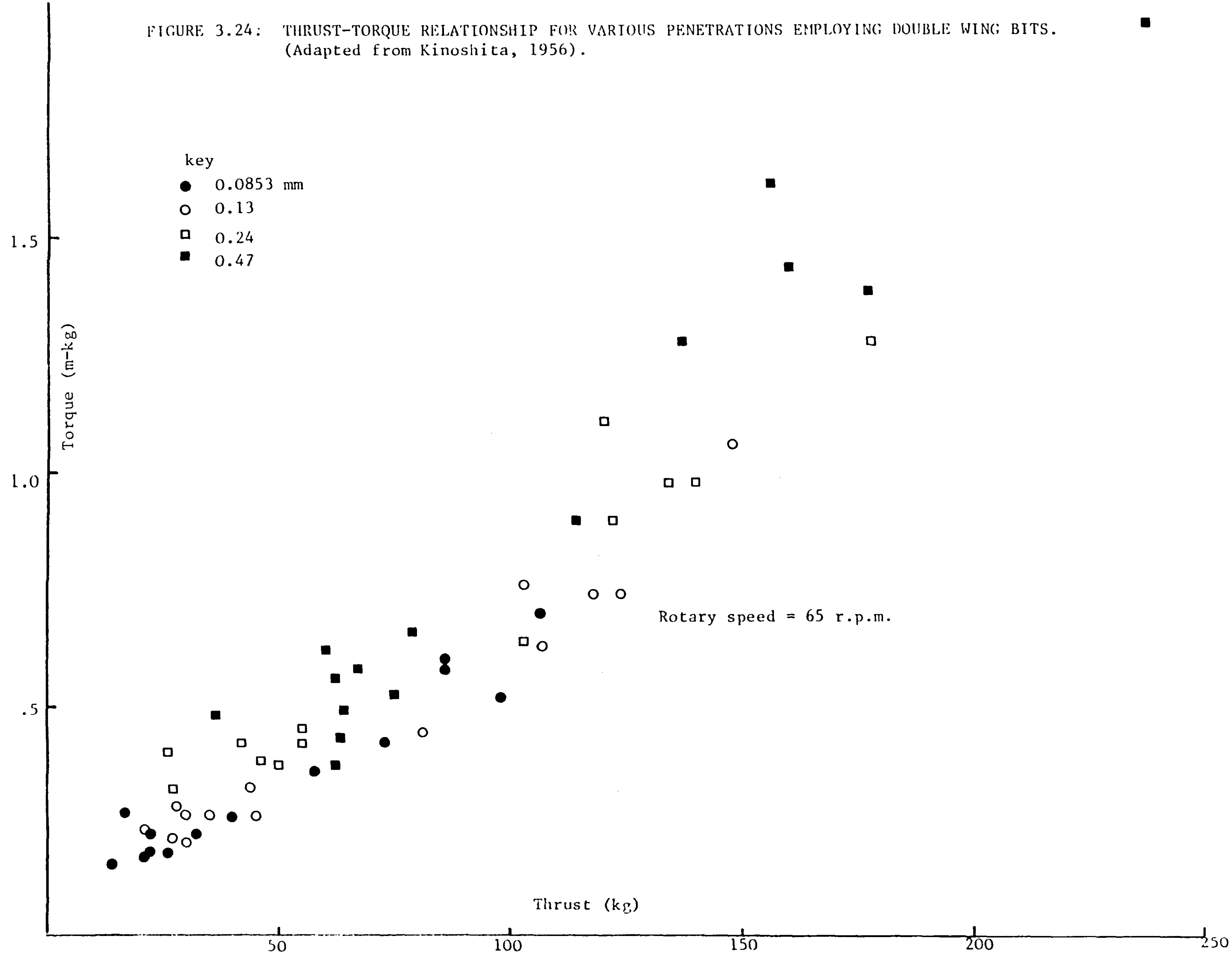
i) Torque (T) - thrust (F)

Kinoshita[170] presented the results of drilling trials with fifteen

Table 3.8: Laboratory Studies of Rotary Drilling Using Instrumented Rigs (Adapted from Brown and Phillips, 1977)

Researcher	ORGANISATION	DRILL TYPE	BIT TYPE	INSTRUMENTATION						NATURE OF INVESTIGATION
				Penetration Rate	Thrust	Torque	Rotary Speed	Flushing Fluid		
								Pressure	Flow Rate	
Fish and Barker	National Coal Board, UK	Purpose built horizontally mounted rotary drill with 7½ hp electric motor	Scroll-type dry drilling coal bits	(a) Photograph stop watch at equal increments of depth (b) Pen on recorder paper mounted on rig	Strain gauges on beam between hydraulic ram piston and drill carriage	Strain gauges on torque tube fixed between gears and drill carriage casing	Tachometer	-	-	Study of rotary drilling tool design
Sasaki et al	-	Exploration drill	46mm surface set diamond coring bit	Advance of the spindle closed a contact every 2mm	Strain gauge load cell.	Strain gauges on torque tube		Pressure gauge	-	Study of relationships between diamond drilling parameters
Paone et al	US Bureau of Mines	Electro-hydraulic diamond drill with	AX surface set diamond bit on a 0.46 core barrel AX impregnated with medium hard matrix	Penetration in 1-min intervals measured with a steel tape	Thrust gauge	Torque gauge	Tachometer	-	-	The investigation of the relationship between rock properties and drilling rates
Tsoutrelis	National Technical Univ.of Athens, Greece	Tone TS-6 diamond drill	Tungsten Carbide/ Cobalt bit 36mm O.D.	Penetration measured by a tape on a feed piston rod and a fixed pointer on the spindle. Each advance timed.	Pressure gauge measuring pressure in hydraulic loading system.	Rotary force on working table measured	Constant	Constant	Constant	Determination of the compressive strength of rock using drilling performance
Strebig et al	US Bureau of Mines	Cincinnati Brickford radial arm drill	Impregnated industrial diamond bits 32mm O.D.	Penetration measured by a linear wire-wound potentiometer. Signal differentiated to give rate.	Strain gauge load cell mounted between the air cylinder and bit.	BLH type B torque pickup mounted between spindle and bit.		Constant	Constant	Investigation of the effect of organic additives in the diamond drilling of quartzite
Rowlands	Univ. of Queensland, Australia	2 hp floor mounted	Surface set EX coring bit.	Penetration measured by DCDT attached to feed shaft	Strain gauge load cell mounted under the rotary table.	Strain gauges mounted on a cantilever arm measure reactional torque	Tacho-generator	Pressure transducer placed before water swivel	Flow measured by the capacitance effect of a mercury manometer	Fundamental investigation of the diamond drilling process
Everall	Dept. of Energy, Mines & Resources, Canada	Modified 1 hp multi-speed drill press.	Masonry type surface set diamond bits	Multi-turn potentiometer activated through pulley and friction wire. Signal differentiated to give rate.	Pressure transducer measuring pressure in hydraulic loading system.	Current passing through one phase of the drive motor measured.	Magnetic pick-up tachometer	-	Gravity-type flowmeter	Testing a strategy for automatic control of diamond drilling
Marx	Christensen Diamond Products, West Germany	Longyear L24 drilling head with 15 kW electric motor	46T surface set and EX impregnated bits	Electronically measured and recorded	Bit load indicator	Torque Transducer mounted above core barrel	Tachometer	-	-	Fundamental investigation of the diamond drilling process
Pfleider and Blake	US Bureau of Mines & Univ. of Minnesota	Standard drill press with 0.94 hp electric motor	16 and 25mm Truco F-1 surface set diamond coring bits	-	System of weights suspended from drill press lever arm.	-	Constant at each of 80,170 and 305 rpm	-	-	Study of the cutting action of diamonds
Kinoshita	Hokkaido Univ., Japan	Lathe adapted to hold bit and rotate specimen	Single and double wing auger bits	Regulated by the lathe controls	Strain-gauged bar	Torque pick-up (Kyowa Musen Comp.)	Constant 65 rpm	-	-	Investigation of the relationship between rock properties abd drilling rates
Somerton	Univ. of California, Berkeley.	Inverted drill press driven by a magnetic clutch electric motor	32mm bi-cone roller bits	Not specified	System of weights suspended from drill press lever arm	Power measured by watt hour meter at the drill motor	Constant	-	-	Relationship between drilling variables and drilling rates
Maurer	Jersey Productions Comp., New Jersey, USA	-	120mm W7R roller core bits	Not specified	Varied up to 18000 kg depending on test	Not specified	Constant rpm during test	-	Not specified	Fundamental investigation of rotary drilling
Cataldar & Raynal	S.N.P.A. Pau, France	Specially designed to simulate oil well conditions	108mm tri-cone bits	Method not specified	Hydraulic servo-jack produced constant bit load(2 and 4 tonnes)	-	Constant 155 rpm	Gypsum Mud (constant) at 102 kg/cm²	335 l/min	Relationship between rock properties and drilling rates
Singh	Univ. of Melbourne, Australia	a)Specially built table size inverted drill press b)Modified lathe	90° chisel-face microbits 43mm two-winged coal drag bits	- -	Constant 18 kg Hydraulic ram at 272 kg	-	Constant 136 rpm Constant 46 rpm	- -	- 4.6 l/min	Relationship between rock properties and rock drillability
Busch & Hill	De Beers Diamond Research Lab., Jo'burg, S.A.	Rigid three column machine powered by a 40hp electric motor	107mm impregnated diamond coring bits	Measured but not specified	Constant	Measured but not specified	Measured but not specified	Constant	Constant	Investigation of the relationships between drilling variables
Fowler	Nova Scotia Technical College, Halifax, Canada.	Specially built hydraulic drilling system	Ex diamond coring bits	Potentiometer coupled to hydraulic ram piston	Hydraulic ram pressure gauge	Measured pressure drop across the motor	Tachogenerator (500-1500 rpm)	Pressure gauge	Flowmeter-constant 14 l/m	Investigation of the relationships between drilling variables

FIGURE 3.24: THRUST-TORQUE RELATIONSHIP FOR VARIOUS PENETRATIONS EMPLOYING DOUBLE WING BITS. (Adapted from Kinoshita, 1956).



different rock types using wing bits for varying depths of cut. The results are shown in Figure 3.24. The torque is proportional to thrust for each particular rock/bit/depth of cut combination. Similar results were presented by Rowlands[248] for boreholes in micro-syenite using surface set EX bits at various speeds and thrusts under constant flushing rate. Sasaki et al[255] found the same results for a variety of rocks, but indicated the existence of a threshold thrust beyond which torque rapidly increased, while rotary speed decreased with the onset of stalling conditions.

ii) Penetration rate (R) - torque (T)

Figure 3.25(a) shows torque-penetration rate data presented by Fish[254] for Darley Dale sandstone drilled at 200 r.p.m. with scroll-type drilling bits. The results are generally linear except for threshold values below which effective penetration ceased and above which any increase in torque has a minimal effect on penetration rate. Similar results, Figure 3.25(b) were obtained by Paone and Madson[182] when drilling with AX impregnated diamond bits (rotary speed = 100 r.p.m.) in limestone, quartzite and taconite. The investigations of Everall et al[256] in quartzite using masonry-type surface-set bits produced comparable results. Kinoshita[170] noted that torque is roughly proportional to the square root of the feed speed.

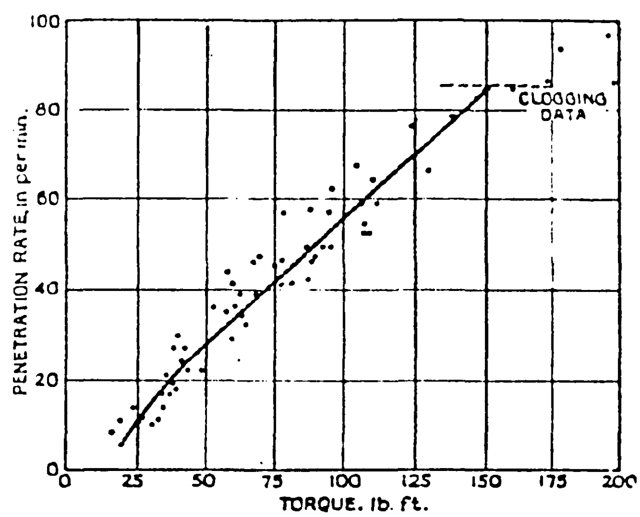
iii) Penetration rate (R) - thrust (F)

Numerous investigators have considered this relationship. Pfleider and Blake[263] found bit advance to be roughly proportional to bit force, provided cuttings were flushed away to prevent caking on the bit. Fish[254] presented data for drilling in Darley Dale sandstone, Figure 3.26(a), showing that, in general, variation of thrust is a linear fuction of penetration rate. They noted a departure from linearity in the upper range of the curve as a result of clogging of the bit, as well as a limiting thrust below which the indentors on the bit were not able to penetrate the rock. Similar results are presented by Tsoutrelis, Figure 3.26(b), for a variety of rock types drilled at 260 r.p.m., with thrust ranging from 170 to 570 kg using tungsten carbide/cobalt bits. Paone and Madson[182] present an extensive range of results in Figure 3.27 for different rotary speeds. Gstalder and Raynal[172] also report a direct proportionally between penetration rate and bit weight. Kinoshita described the relationship between feed speed and thrust by the following equation:

$$F = A\ (b + ut) \tag{3.33}$$

where

F is thrust on the cutting edge of wing bit (kg)



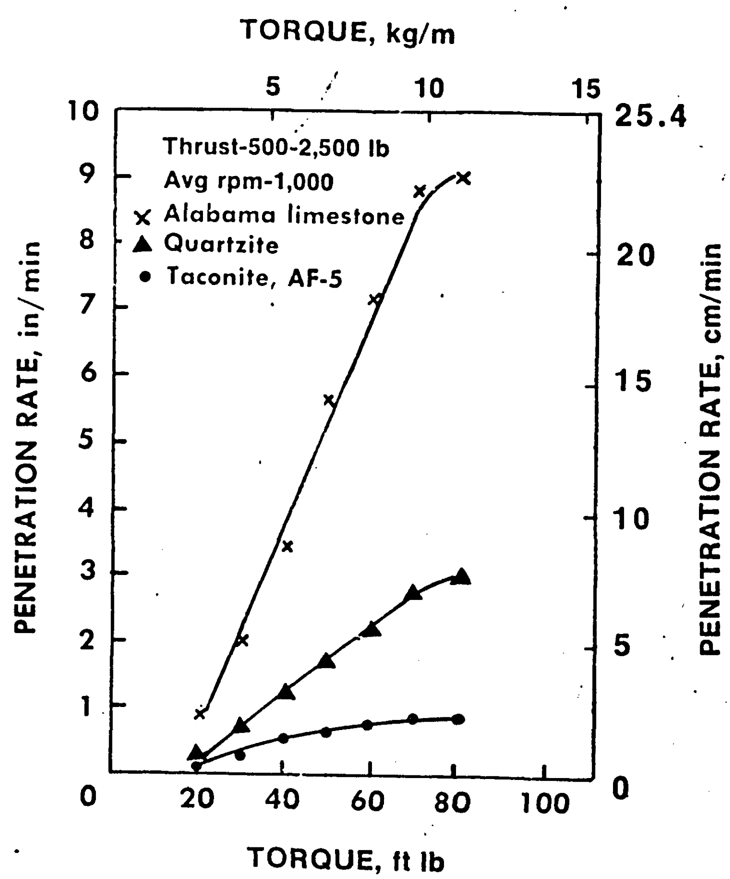
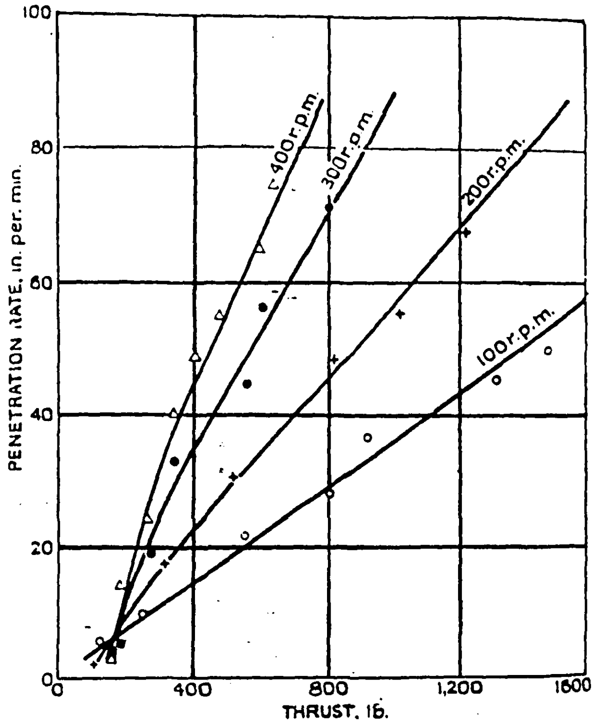
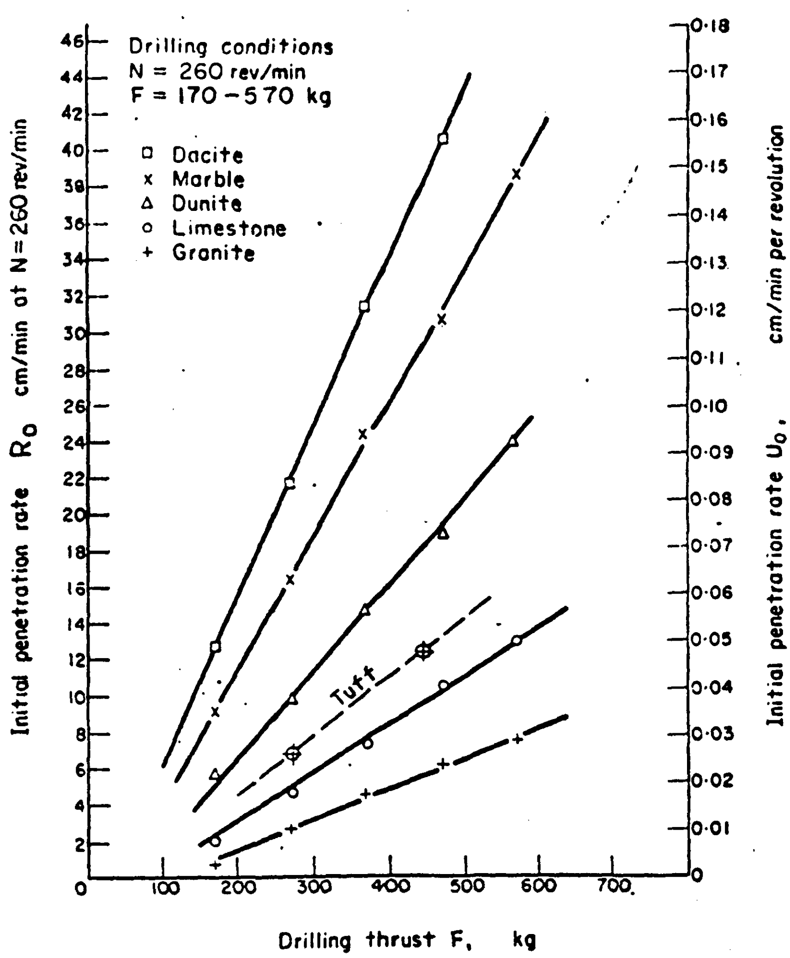


FIGURE 3.25 TORQUE-PENETRATION RATE DATA FOR DRILLING IN (a) Darley Dale sandstone at 200 rpm (After Fish, 1961) and (b) Limestone, quartzite and taconite (After Paone and Madson, 1966)



(a)



(b)

FIGURE 3.26 THRUST - PENETRATION RATE DATA FOR DRILLING IN (a) Darley Dale sandstone (After Fish, 1961) and (b) a variety of rock types (After Tsoutrelis, 1969)

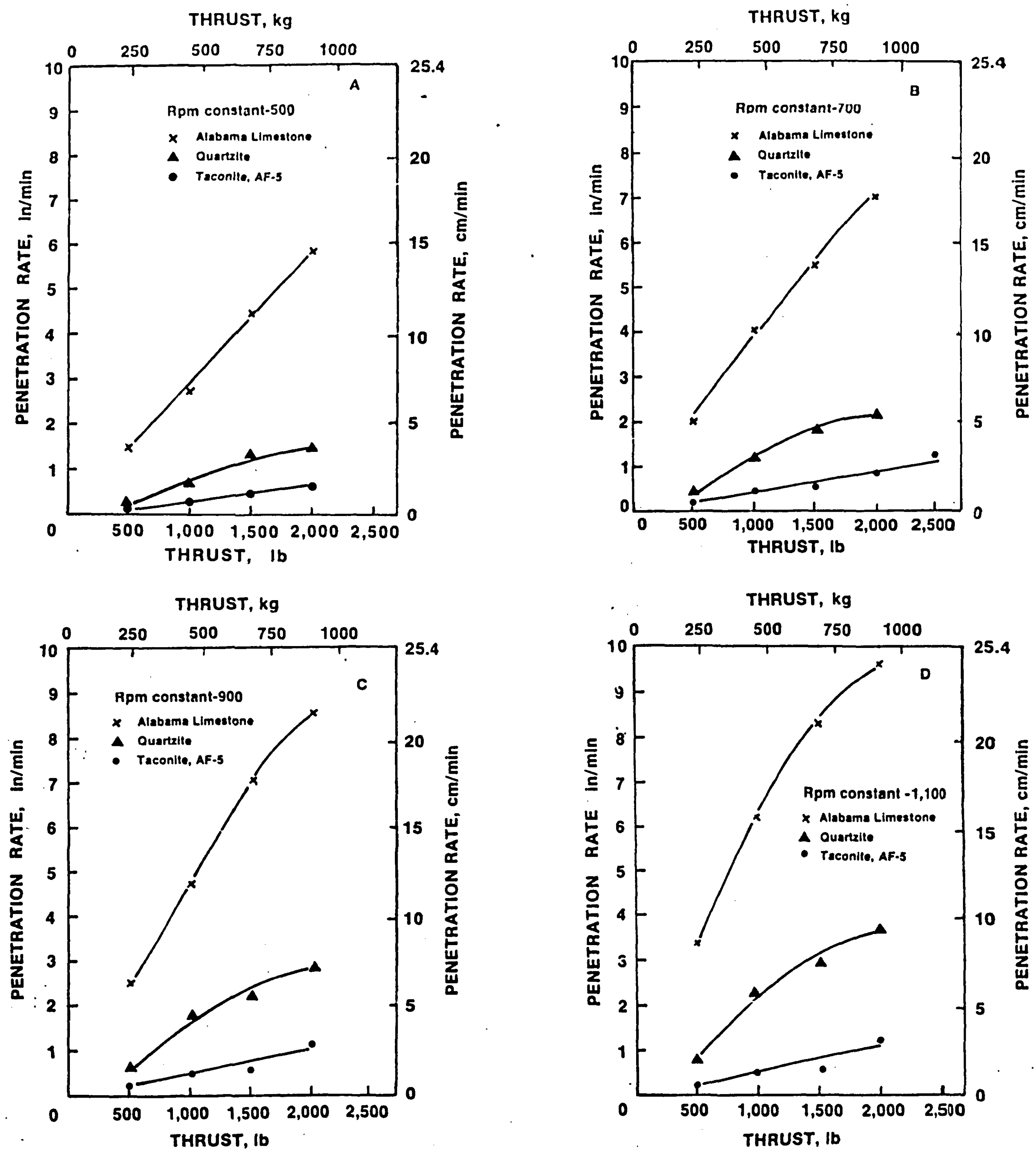


FIGURE 3.27 THRUST - PENETRATION RATE DATA FOR A RANGE OF ROTARY SPEEDS (After Paone and Madson, 1966)

t is feed speed of the lathe (mm)

A is a coefficient dependent on the rock properties, the rotary speed and the shape of the cutting edge

u is a coefficient dependent on similar factors to A

b is width of the cutting edge penetration on the rock surface

Generally speaking, the tendency for the curves to flatten off as thrust increased at higher speeds has been explained as either bit clogging, bit wear or the approach of stall conditions. Any or all explanations are possible depending on the rock characteristics, drilling rig and bit design.

iv) Penetration rate (R) - rotary speed (N)

A wide range of experience is documented in the literature regarding the relationship of rotary speed to penetration rate. For example, Pfleider and Blake[263] note that penetration rate is roughly proportional to rotary speed (thrust ranging from 0-450 kg) provided that the bit is kept clean of cuttings. Maurer[264] demonstrated a similar relationship for roller cone bits during drilling trials which simulated borehole conditions in the oil industry (thrust ranging from 3400 to 13600 kg). Fish has demonstrated a linear relationship between R and N at a thrust of approximately 270 kg in Darley Dale sandstone, Figure 3.28(a). Paone and Madson present additional data, Figure 3.28(b), showing a strong linear correlation between penetration rate and rotary speed for constant thrust values of approximately 450 and 900 kg for several rock types. Similarly, Everall et al. have provided results, Figure 3.28(c), for an EX bit at several constant thrust levels in St. Marc limestone, as has Rowlands, Figure 3.28(d), for various thrust levels in micro-syenite. More recently, Busch and Hill[22] have presented results for drilling with impregnated diamond drilling bits, having either hard or soft matrices, in plain concrete. They note that, in general, the higher the rotary speed and the thrust, the greater the penetration rate. Of N and F, thrust (F) was the most effective in increasing the penetration rate.

v) Specific energy (e) - penetration rate (R)

Little information is available for specific energy relationships in rotary drilling. However, Gstalder and Raynal[172] have produced data for specific disintegration (volume of rock excavated divided by the work done) as determined from a Schreinder hardness test performed on the rock being drilled. Reportedly, the test is indicative of the distinctive work done by the tooth of a rock bit. It is interesting to note that the reciprocal of specific disintegration is equivalent dimensionally to the specific energy term defined by Rowlands[248].

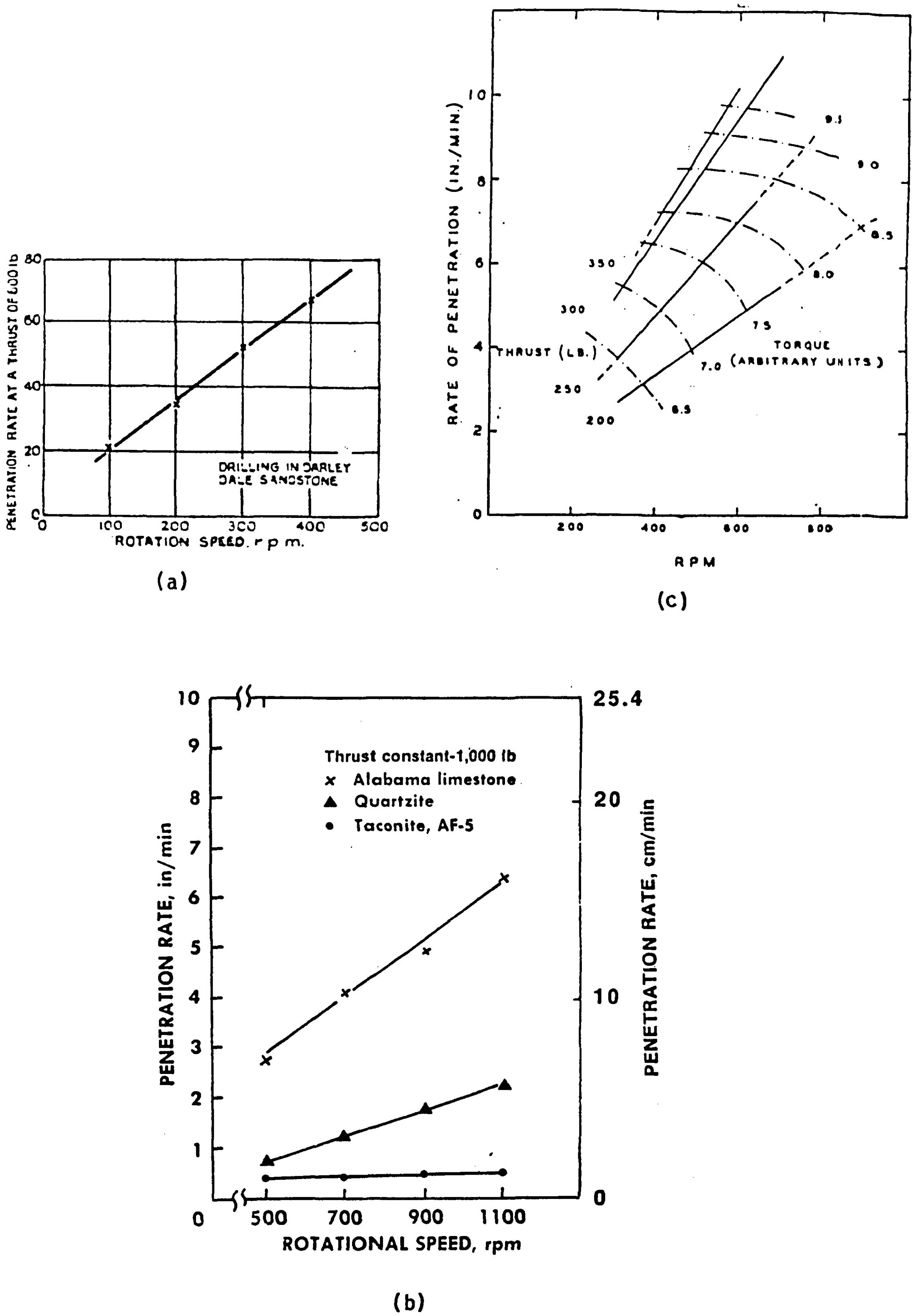


FIGURE 3.28 EFFECT OF ROTATIONAL SPEED ON PENETRATION RATE AT A GIVEN THRUST FOR (a) Darley Dale sandstone (After Fish, 1961) (b) Limestone, quartzite and taconite (After Paone and Madson, 1966) (c) St Marc Limestone (After Everall et al, 1973)

Figure 3.29 shows specific disintegration plotted against the penetration rates achieved in laboratory trials using tri-cone bits, suited to either hard or soft rocks, at thrust levels of 2 and 4 tonnes. The penetration rate decreased with increased rock hardness and increased with specific disintegration or decreased with increasing specific energy, if the conversion from one to another is valid. This is particularly true of the soft rock bit data.

vi) Specific energy (e) - thrust (F)

Rowlands provided information on the e - F relationship for drilling at constant rotary speed in microsyenite with EX surface set bits (Figure 3.30). In the first instance, it should be noted that above approximately 100kg thrust, the specific energy did not vary with rotary speed but depended on thrust alone for a constant circulation fluid flow rate. The plot suggests that with increasing thrust, the diamonds in the bit are forced into the rock, thus producing larger cuttings with a consequent reduction in the energy used to create new surface area under the bit face.

vii) Specific energy (e) - rotary speed (N)

The scant evidence available suggests that, in general, specific energy is independent of rotary speed above a threshold thrust. Figure 3.31 depicts the results obtained by Rowlands for this relationship. The specific energy has been plotted against rotary speed at various thrust values. At high thrust levels, the specific energy is independent of the rotary speed. With reduced thrust, scatter increases, particularly below 120kg (265 lbs). This probably signifies insufficient thrust to load the diamonds on the rock, causing wear (polishing) of the diamonds and resulting in inefficient excavation.

3.5.2 Field investigation

Very few field studies have been undertaken to investigate the relationships between drilling variables, most data being an almost incidental feature of a broader investigation. Nevertheless, some information is available and is of interest to this study. Humble Oil and Refining Company developed a computerised drilling system to try and reduce drilling costs. A detailed explanation of the theoretical basis of the optimization programme, the instrumentation and the control logic is provided by Young[265]. Part of the system testing involved field operations using 311mm (12.25 inch) roller bits in deep sand and shale formations of South Louisiana. Figure 3.32 shows the relationships established for various

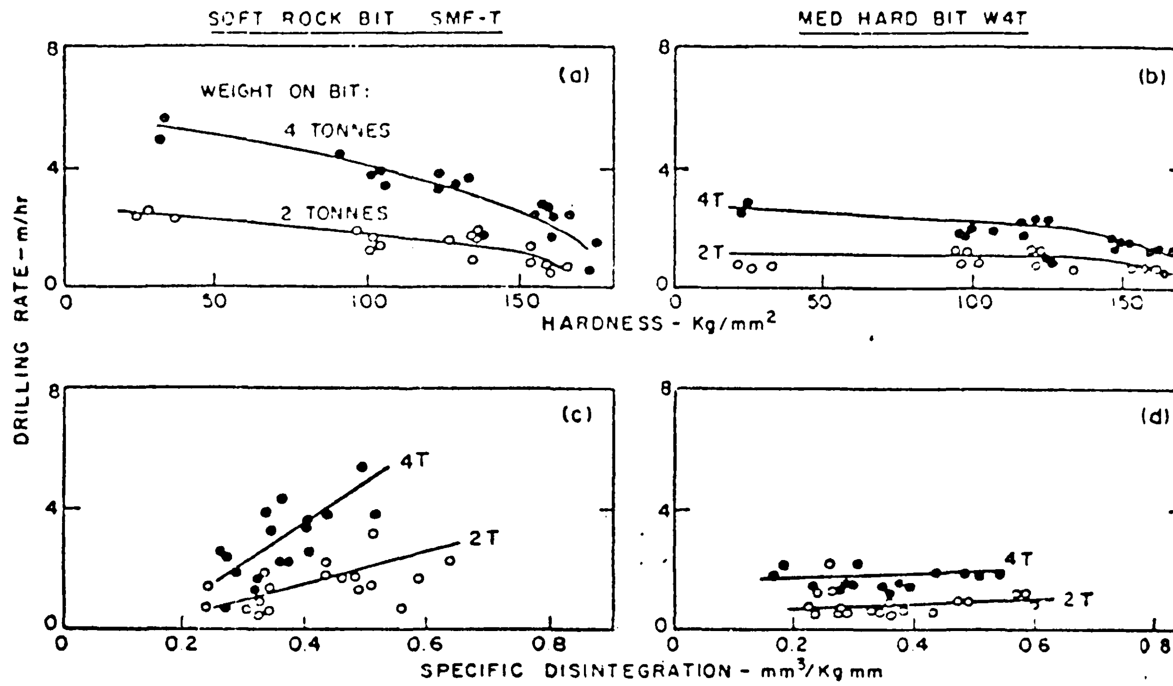
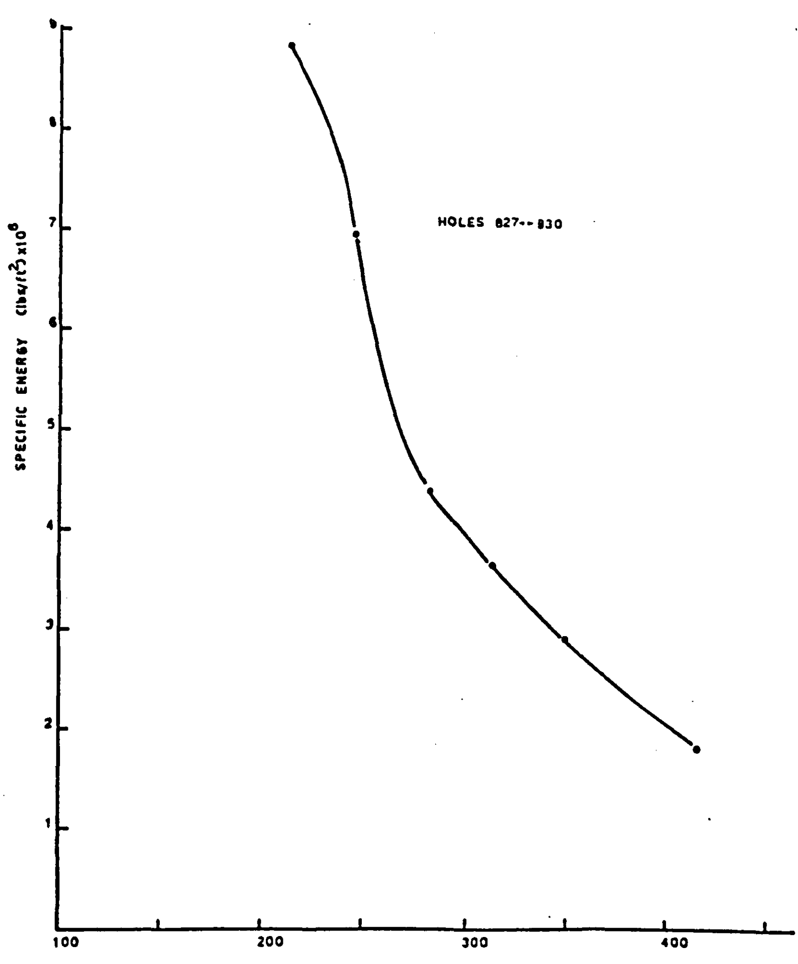


FIGURE 3.29 DRILLING RATE VERSUS HARDNESS AND SPECIFIC DISINTEGRATION AT VARIOUS THRUST LEVELS USING SOFT AND MEDIUM HARD ROCK BITS (After Gstalder and Raynall, 1966)

FIGURE 3.30 SPECIFIC ENERGY VARIATION WITH BIT THRUST (After Rowlands, 1971)



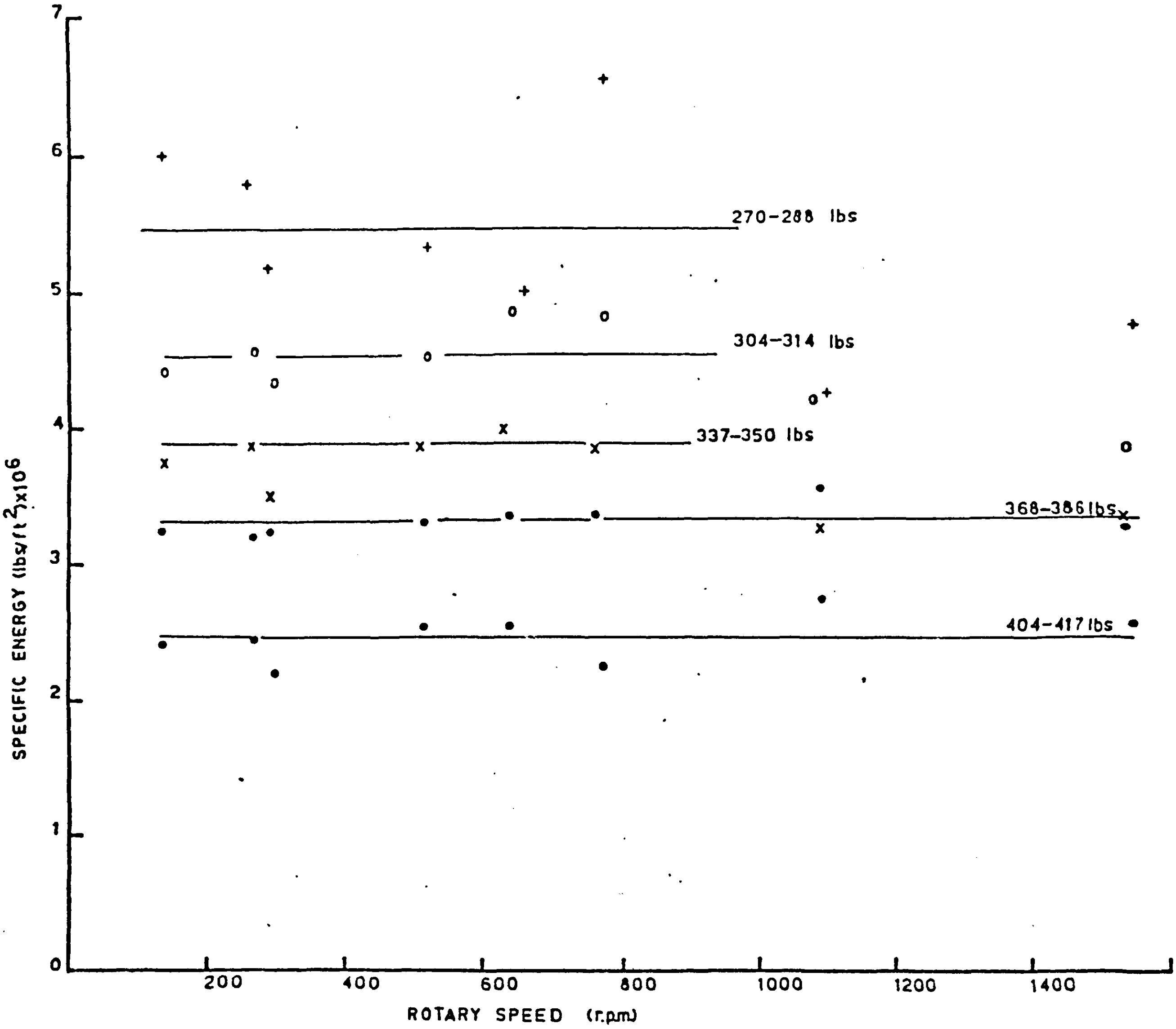


FIGURE 3.31 RELATIONSHIP BETWEEN SPECIFIC ENERGY AND ROTARY SPEED AT SELECTED THRUST LEVELS (After Rowlands, 1971)

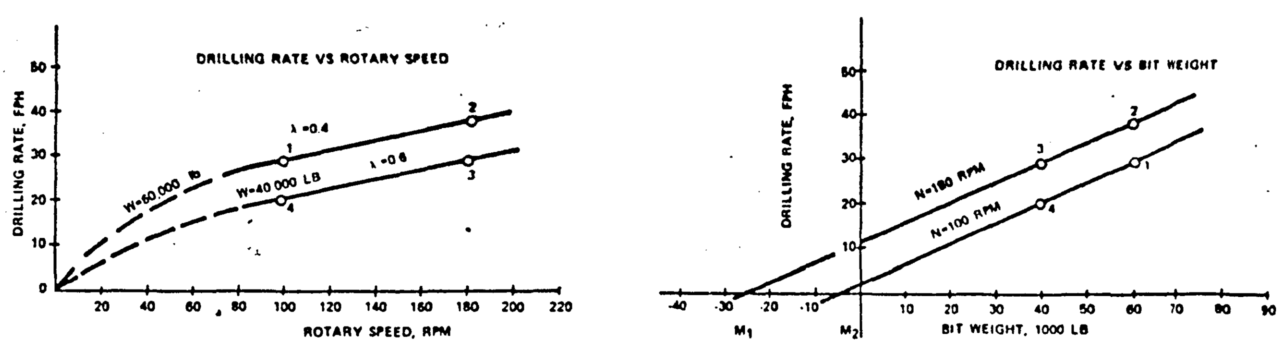


FIGURE 3.32 DRILLING RATE TEST RESULTS, SOUTH LOUISIANA WELL (After Young, 1969)

drilling variables. The drilling rate (R) response to bit weight (F) and rotary speed (W) are clearly linear over the test portion of the plots. These relationships are based on the following equation:

$$R = \frac{K\ (F-M)\ N\lambda}{1 + C\ H} \qquad (3.34)$$

where

K is the formation drillability

F is the bit weight

M is the bit weight extrapolated to zero drilling rate

N is the rotary speed

λ is an exponent expressing the effect of rotary speed on drilling rate

C is a constant

H is the normalized tooth height; sharp tooth equals zero, fully worn tooth equals 1

In 1975, the U.S. Bureau of Mines[250] undertook a series of horizontal drilling trials to investigate the effect of surfactants used during drilling on the measured penetration rate. AX surface set coring bits (48mm) were used to drill horizontal boreholes in PreCambrian amygdaloidal basalts using four different circulation fluids; water, nonionic, anionic and cationic surfactants. Diamond bit grade, thrust and rotation speed were also varied.

While the figures in Table 3.9 do not allow direct comparisons to be drawn between drilling variables, it is possible to see that the use of surfactants relative to the use of water results in an increase (28 to 35%) in the penetration rates presumably caused by a reduced drilling resistance at the rock/bit interface. It was noted that the use of surfactants made removal of core from the drill barrel easier and the implications this has for site investigation drilling hardly need be stressed, since it has long been recognized that core damage can be considerable during this operation.

A major study[266], which was being pursued at the same time as the present investigation, was carried out under the supervision of the Construction Industry Research and Information Association (CIRIA). A Boyles BBS-37 diamond coring drill equipped with a 64 hp diesel motor was instrumented to record thrust, penetration rate, torque, rotary speed, circulation fluid flow rate and pressure during drilling[220]. Drilling was undertaken in Carboniferous strata (mudstone, sandstone and limestone) at Rogerley Quarry, Weardale, Co. Durham using N size diamond bits for coring and 98mm roller bits for open hole operations. Figure 3.33 shows the relationship established for penetration rate against thrust for each of the major lithologies at the site, while Table 3.10

Table 3.9: Relationship of penetration rate to drilling conditions. (After Engelmann et al, 1975).

Surfactant Solution	Bit Condition and Grade	Distance Drilled, Ft	Rotational Speed, Rpm	Thrust Lb	Torque In.-Lb	Penetration Rate, Ipm	Specific Energy psi x 10^3
Nonionic	New - 1	15.0	310	1990	2440	3.25	530
	Used - 1	15.1	550	1280	2180	2.55	1070
	Used - 3	14.0	310	1990	2230	2.80	562
	New - 3	14.9	550	1290	2040	2.32	1101
Anionic	Used - 1	15.7	310	2100	2200	2.64	583
	New - 1	10.1	550	1130	2040	2.37	1077
	New - 3	15.0	310	2740	2440	3.15	546
	Used - 3	9.7	550	1930	2130	1.30	2051
Cationic	New - 1	15.0	310	1980	2160	3.05	500
	Used - 1	9.5	550	1050	2530	1.67	1896
	Used - 3	14.8	310	2280	2140	2.68	563
	New - 3	10.0	550	1100	2040	2.50	1021
Water	Used - 1	14.9	310	2330	2100	2.03	730
	New - 1	11.1	550	1290	2350	2.13	1381
	New - 3	15.2	310	2120	1640	2.46	470
	Used - 3	15.0	550	2700	2690	2.14	1573

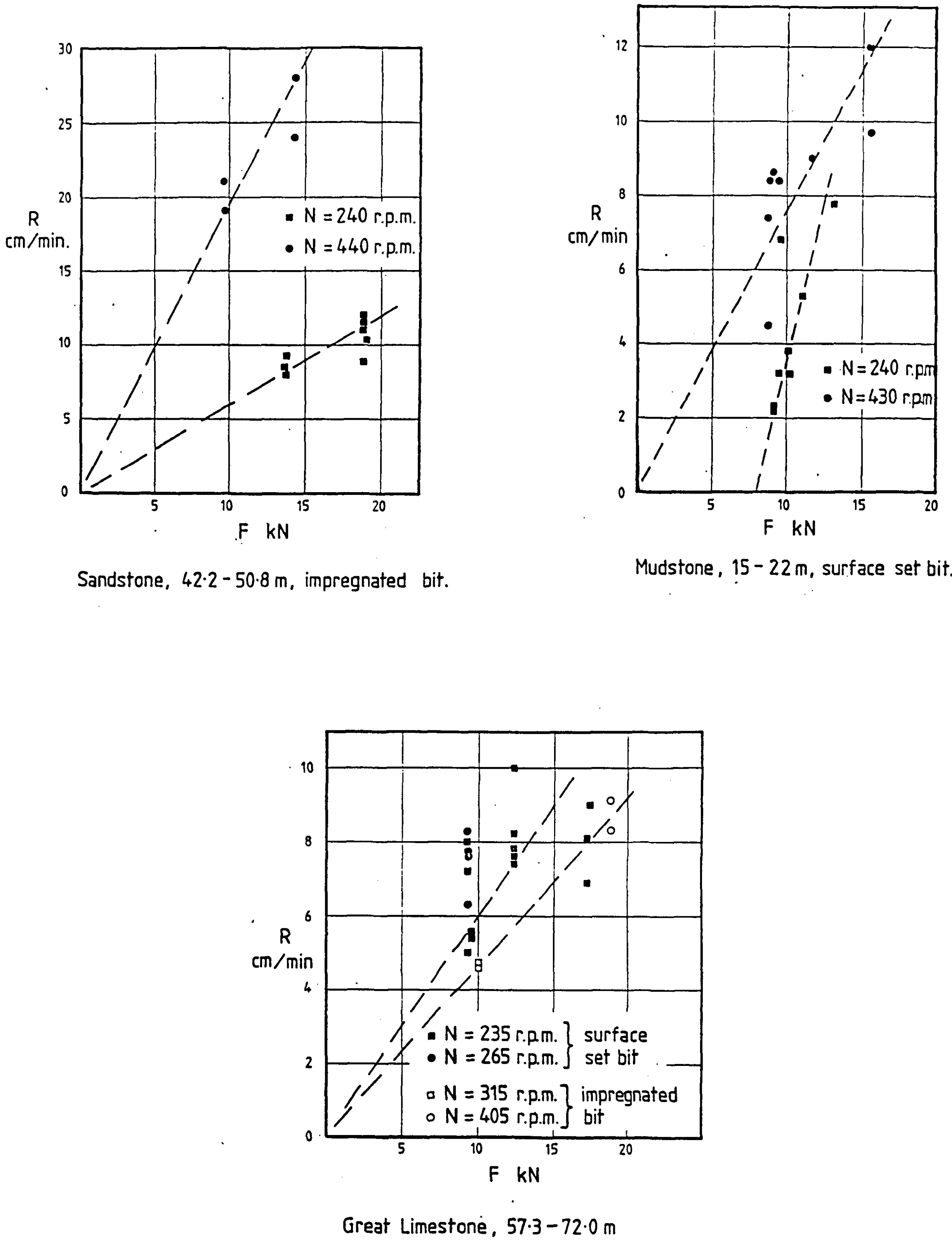


FIGURE 3.33 THRUST - PENETRATION RATE DATA FOR CARBONIFEROUS STRATA AT ROGERLEY QUARRY, COUNTY DURHAM (After Brown, 1979)

TABLE 3.10: R-F Relationship for instrumented drilling trials at Rogerley Quarry. (After Brown, 1979).

Lithology	Relationship	Rotary Speed (rpm)
Mudstone	R = 1.8 (F - 8.0)	240
	R = 0.76 F	430
Sandstone	R = 0.6 F	240
	R = 1.95 F	440
Great Limestone	R = 0.6 F	235 and 265
	R = 0.47 F	315 and 405

lists the best fit equations (approximately by eye) associated with each segment of data. Brown[266] noted that there is considerable scatter in the data which in turn is limited in range. Of the six plots, five pass through the origin thereby ignoring, although Brown recognized, the existence of a threshold thrust below which effective penetration rates are not achieved.

3.5.3 Summary of laboratory and field investigations

In general, the relationships between the drilling variables outlined in Section 3.3, predicted on the basis of specific energy consumption, are validated in laboratory trials. Most of the relationships between variables are linear. Where exceptions occur in this observation, either bit wear or limiting operating conditions have intervened to distort the general pattern.

Equally important, the relationships which were established between the variables which describe the performance of tunnel boring machines appear to have equivalent counterparts when a similar consideration is made with respect to rotary drilling operations. This has important implications for developing instrumented drilling systems for both general site investigation tools and, more specifically, predicting ground conditions in advance of tunnelling. It must be borne in mind, however, if only because of differences in scale, that direct comparison of performance between the two systems may not be feasible. Nevertheless, the similarities in performance appear to hold promising rewards for research directed in this area.

3.6 Correlation of Drilling Performance with Rock Properties

Just as tunnel boring machine performance has been correlated with various rock properties in order to predict boring rates, a similar procedure has been applied by various researchers to establish a drillability index for rock.

3.6.1 Significant rock properties

A considerable number of researchers have tried to relate a variety of rock properties to various drilling parameters, usually penetration rate, with a view to assessing the drillability of a particular rock. Some of the earlier investigations have been reviewed elsewhere in the literature[169] and therefore are not considered in detail for the purposes of this study. Active research of this topic gained renewed momentum after 1950; one of the workers in this area was Kinoshita[170] who found that specific gravity, porosity and Page's hardness did not correlate with drillability. He did find that an increase in the percentage of quartz present in the rock reduced the drillability. Shore hardness was shown to be a poor indicator of drillability, while compressive and tensile strengths were dismissed because of the difficulty in obtaining sufficient values. In general, none of the many physico-mechanical properties he considered provide an adequate measure of drillability for rotary operations.

Sasaki et al[255] suggest that penetration rate and thrust could be correlated with measurements of Shore hardness, indentation depth and rock compressive strength for the drilling system detailed in Table 3.8. Fish also notes a reasonable correlation between drillability and compressive strength.

The most comprehensive investigations of this topic have been undertaken by Paone and various co-workers at the U.S. Bureau of Mines. Paone and Bruce carried out extensive laboratory drillability tests with surface-set diamond bits, while Paone and Madson undertook a similar series of tests for impregnated diamond bits, followed by an applied multiple regression analysis of the accumulated results by Paone, Bruce and Virciglio[267]. Compressive strength, tensile strength, Shore hardness, relative abrasiveness, shear modulus, static Young's modulus and volumetric percent quartz content were evaluated for nine rocks drilled in the laboratory and twenty rocks drilled in the field, and a stepwise multiple linear regressions analysis was performed to determine correlation coefficients. Penetration rates using surface-set bits were most strongly correlated with thrust (F), rotary speed (N) of the drill, Shore hardness, compressive strength and quartz content of the rock. For impregnated bits, the parameters of most significance were thrust, shear modulus (G), Young's modulus (E), abrasiveness, quartz content and compressive strength of the rock.

Figure 3.34 depicts some of the principal findings of Paone and Bruce and Paone and Madson. Figure 3.34(a) illustrates the relationship between

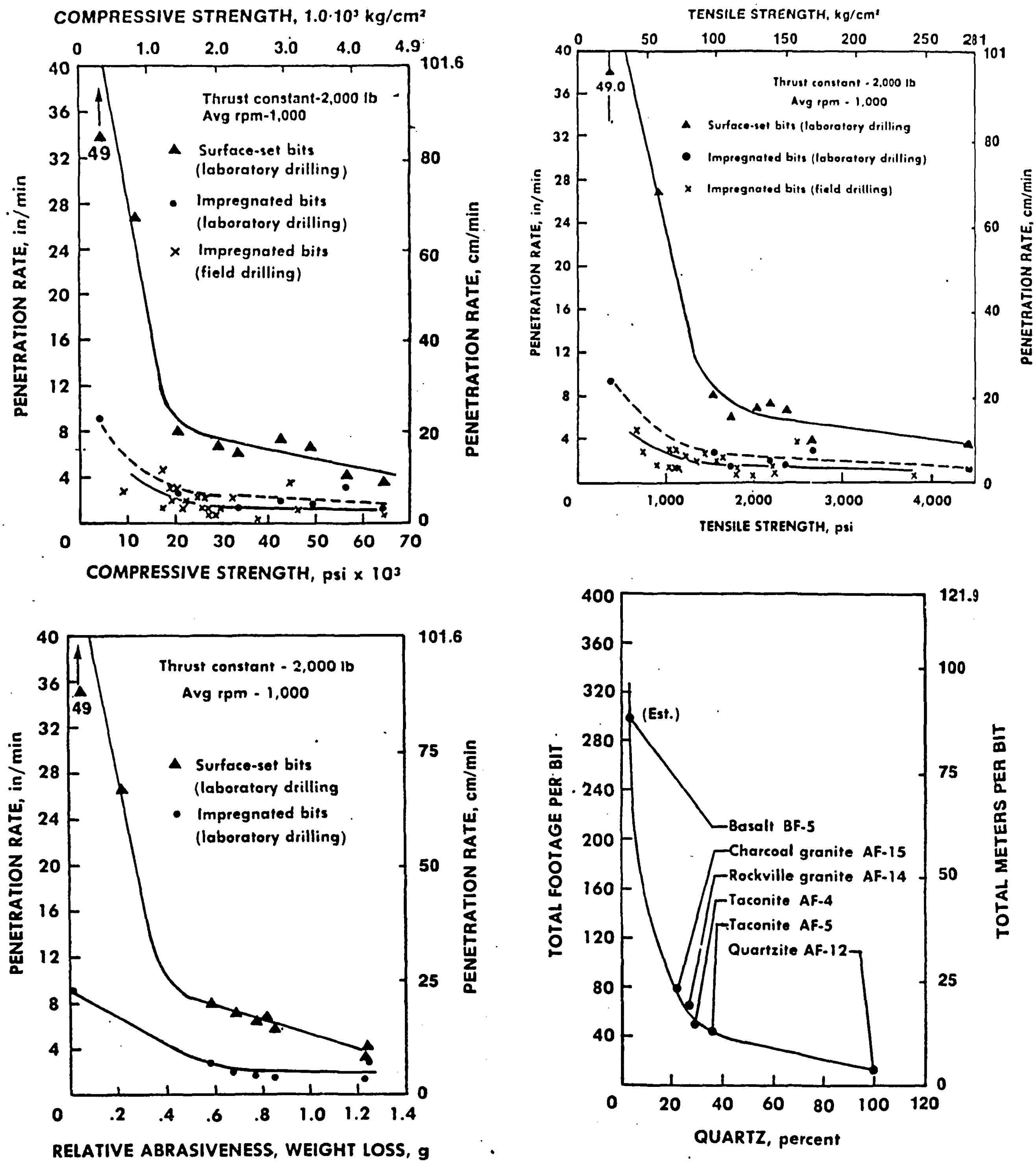


FIGURE 3.34 PENETRATION RATE VERSUS SELECTED ROCK PROPERTIES FOR A VARIETY OF BIT AND ROCK TYPES (After Paone and Bruce, 1963 and Paone and Madson, 1966)

penetration rate and compressive strength for constant thrust and rotary speed. With impregnated bits, no marked change is noted in penetration rate when 170 MN/m^2 (25,000 lbf/in^2) compressive strength is exceeded. A similar condition holds for the tensile strength, Figure 3.34(b), which is not unusual given its relationship to compressive strength. Figure 3.34(c), plots penetration rate against relative abrasiveness for laboratory trials under constant thrust and rotary speed. Clearly, impregnated bits are less subject to fluctuations in performance with changing abrasiveness, Finally, Figure 3.34(d) illustrates the dependence of bit life on the free quartz content of the rock.

An equally important aspect of these investigations was that the physical properties used in the studies were strongly correlated with each other. For example, tensile strength, Young's and shear modulus correlated very well with compressive strength. Similar findings have been reported by D'Andrea et al[157], which leads Brown and Phillips[7] to suggest that these properties might be best expressed in terms of compressive strength. Additional rock properties of note are quartz content and some measure of abrasivity. Reference to Sections 3.1.3. and 3.2.1 will show that these rock properties had significant influence on tunnel boring machine performance.

Gstalder and Raynal[172] demonstrated that some of these relationships applied to the penetration rates achieved with 108mm tri-cone bits in very porous, granular to hard, dense limestones. Figure 3.29 showed the relationship between penetration rate and Schreiner hardness, the penetration rate decreasing with increasing hardness, particularly in the softer formations. Similar forms of relationship between penetration rate, Young's modulus and sonic velocity are shown in Figure 3.35.

Singh[181] investigated the relationship between rock properties and the performance of microbits and two-winged coal bits. He found that hardness (measured using a sklerograf) was not a reliable guide to drillability, although a general trend towards increased drillability (D) was associated with a reduction in hardness (H) in the following manner:

$$D = 789 - 457 \log H \qquad (3.35)$$

Microbit testing established a relationship between drillability and compressive strength whereby:

$$D = \frac{150}{\Sigma N} \times 254 \, \Sigma d \qquad (3.36)$$

where

ΣN is the total number of revolutions for all holes drilled (150 revolutions/hole)

Σd is the total depth of corresponding holes

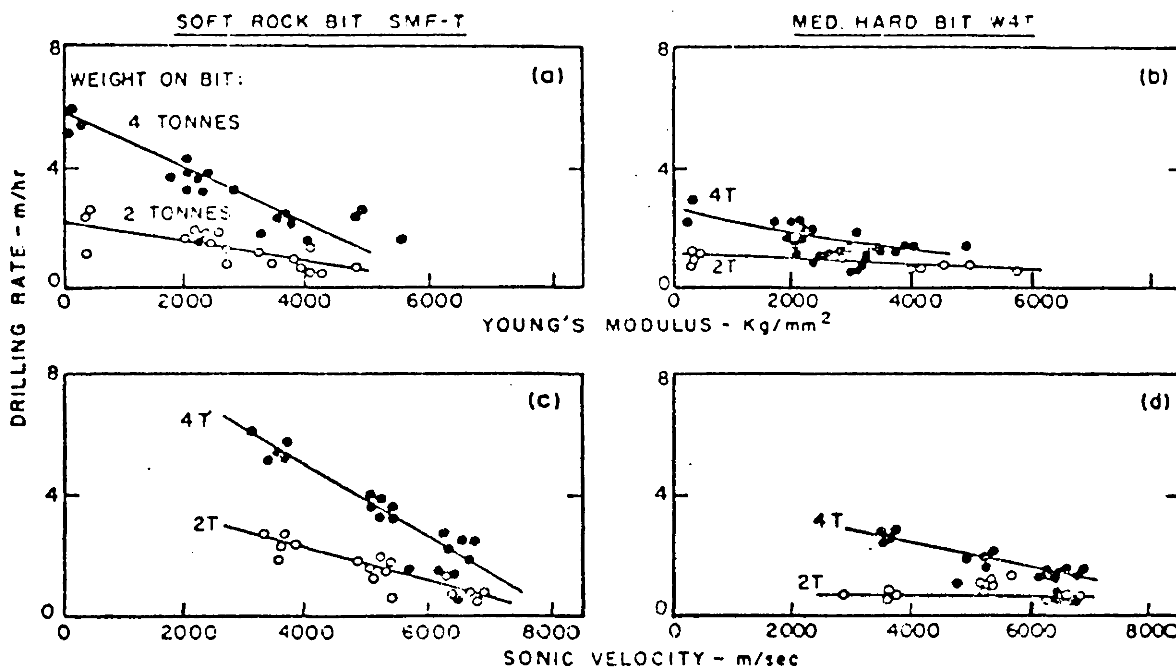


FIGURE 3.35 CORRELATION OF PENETRATION RATE WITH YOUNG'S MODULUS AND SONIC VELOCITY FOR 108 MM TRICONE BITS IN VARIOUS LIMESTONES (After Gstalder and Raynal, 1966)

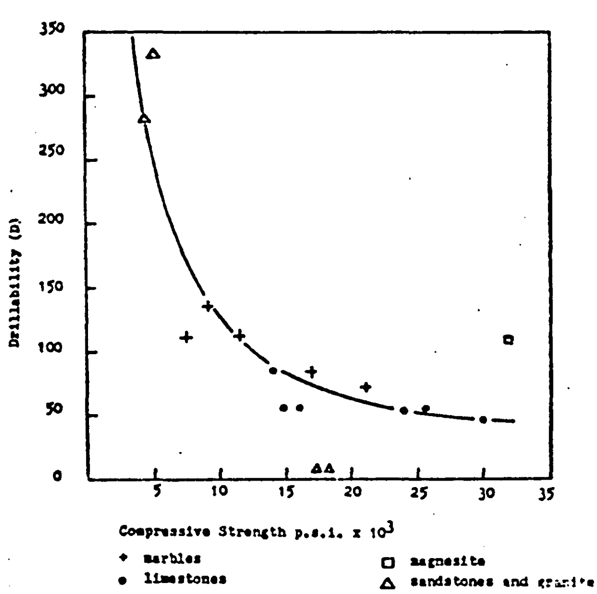


FIGURE 3.36 DRILLABILITY VERSUS COMPRESSIVE STRENGTH (After Singh, 1969)

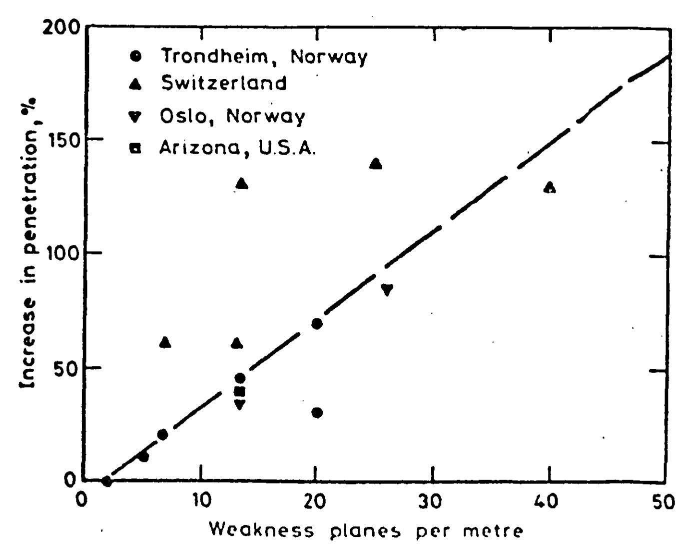


FIGURE 3.37 ESTIMATED RELATIVE INCREASE IN PENETRATION RATE VERSUS WEAKNESS PLANES PER METRE DRILL-HOLE (After Blindheim, 1979)

Figure 3.36 shows that compressive strength bears an indirect proportionality to drillability, although it is by no means linear. Singh noted that a similar relationship exists for tensile strength although, in both cases, the bit wear effects must be considered. In general, both measures of strength are reliable guides for drillability estimation in uniform non-abrasive rocks. As for abrasivity, it was found to be a poor guide to drillability, but a good indicator of bit life. Somerton[260] found a poor relationship between strength and drillability. A final aspect of Singh's investigations was that for an approximate 20 times difference in scale, microbit drillability studies provided a reliable indicator of full scale performance.

Finally, Blindhiem[244] noted that drilling rates are increased as the fracture frequency increases (Figure 3.37) a relationship which was also established for TBM's. However, as with tunnelling machines, this relationship must prove detrimental when fracture frequency and orientation are such that borehole advance during coring operations is reduced through core blockages.

3.6.2 Estimation of compressive strength from drilling performance

Aside from its general importance in geomechanics, compressive strength has been shown to influence the rate of advance of tunnelling machines and the penetration rate of rotary drills. The relative importance of this rock property is apparent from Chapter 2 where a number of indirect measures of compressive strength were considered, first and foremost being the point load test. Direct measurement for site investigation purposes requires expensive coring operations, time consuming laboratory preparations and testing to derive a parameter which must reflect the condition of the soundest rock encountered during drilling, given that the weaker samples will not survive the mechanical attack to which they are subjected. While point load testing of core eliminates one area of rock machining, it still requires core drilling and results are subject to wide scatter in the weaker range of rocks. Brown and Phillips have suggested that it may be possible to correlate compressive strength with in situ density measurements using one of the geophysical techniques described in Section 2.4, possibly coupled with Schmidt or Shore hardness to improve the correlation.

Alternatively, it should be possible to adapt any of the drillability formulae which relate rate of penetration to compressive strength and determine rock strength based on measured drilling performance. Table 3.11 lists a number of experimentally derived drillability formulae which incorporate compressive strength as one of the variables in the equation. The equations have been recast in terms of strength predicted from measured drilling variables.

TABLE 3.11: Formulae for predicting strength from drilling performance.

Investigator	Type of Drilling	Formulae	Comments
Somerton	Inverted drill press using 32mm bi-cone roller bits in shale, sandstone and concrete	$S = 1.22\frac{F}{D}(\frac{ND}{R})^{\frac{1}{2}}$	'S' is a rock strength parameter which would require a scaling factor to equal a given rock compressive strength.
Maurer	Drilling in dolomite with 120mm W7R roller cone bits	$S = k\,\frac{F}{D}\,(\frac{N}{R})^{\frac{1}{2}}$ (up to 300 rpm)	'S' is defined as drillability strength and may need a scaling factor to equal compressive strengtl 'k' is a constant.
Paone and Bruce	Drilling a variety of rock types with AX surface-set and impregnated diamond bits.	$S \approx \frac{2\pi NT}{A\ R}$	Ignored the contribution made by thrust during drilling. 'S' can be taken as unconfined compressive strength.
Tsoutrelis	Tone TS6 diamond drill using insert bits to drill a variety of rock types.	$R_o = k(F-F_o)$ and $\sigma_c = \frac{A}{k_o + B}$	'k' is the slope of the F-R graph and F_o the intercept. A and B are bit constants and k_o = k/N.
Fowler	EX surface-set bits used to drill granite, quartzite and limestone.	$S_c = \frac{0.028\ F^3}{T^2(\cos\phi)^3}$	Slope of the Mohr failure envelope = ϕ. Requires triaxial tests to obtain the ϕ values for each rock type. S_c is the ultimate compressive strength

A is the cutting area of the bit

D is the bit diameter.

The most comprehensive study of this subject is that conducted by Tsoutrelis A series of laboratory drilling tests on five rock types (limestone, marble, dacite, dunite and granite) employing a hard metal rotary bit with tungsten carbide/cobalt inserts. All tests were performed at a constant bit speed of 260 rpm, various thrust levels ranging from 170 to 570 kg and a circulation fluid flow rate of 4.5 l/min at 0.7 kg/cm^2 pressure. The penetration rate (R) prior to bit wear effects was found to vary linearly with thrust (F) such that

$$R = k\ (F - F_o) \qquad (3.37)$$

where k is the slope of the R - F graph

F_o is the thrust axis intercept

This relationship is depicted in Figure 3.38 for each rock type studied.

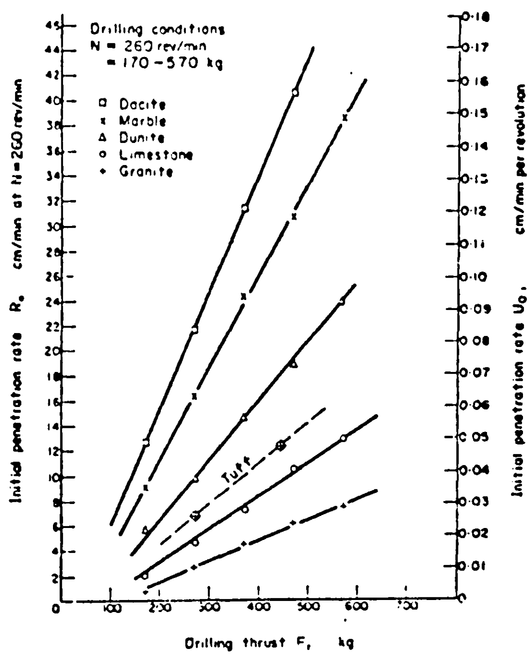


FIGURE 3.38 THRUST - INITIAL PENETRATION RATE RELATIONSHIPS FOR A VARIETY OF ROCK TYPES (After Tsoutrelis, 1969)

As the rotary speed of a drill bit is proportional to penetration rate for speeds up to 700 rpm[154], equation (3.37) can be re-written as

$$R_o = k_o (F - F_o) \qquad (3.38)$$

where

R_o is the initial penetration rate = R/N (cm/min/rev)

k_o is equal to k/N (N < 700 rpm)

TABLE 3.12: Drilling constants k and k_o and corresponding rock compressive strength. (After Tsoutrelis, 1969)

Rock Type	Drilling Constants k	Drilling Constants k_o	Compressive Strength (kp/cm^2)*
Dactite	0.0940	0.3615×10^{-3}	530
Marble	0.0742	0.2854×10^{-3}	640
Dunite	0.0476	0.1831×10^{-3}	840
Limestone	0.0280	0.1077×10^{-3}	1070
Granite	0.0190	0.0731×10^{-3}	1280

* 1 kp/cm^2 = 0.098 MN/m^2

When the derived k_o values are plotted against measured compressive strength, the relationship in Figure 3.39 results. Defining the term $z = 1/\sigma_c x 10^4$ allows the data to be linearised to produce a unique relationship between k_o and compressive strength (σ_c) such that

$$k_o = Az - B$$

or

$$\sigma_c = \frac{A \times 10^4}{k_o + B} \qquad (3.29)$$

where A is the slope of the line

B is the y-axis intercept

The values A and B are constants associated with the particular type of drill bit used during the drilling trials; in the case of Figure 3.39

$$A = 0.0253 \times 10^{-3}$$
$$B = -0.1230 \times 10^{-3}$$

Thus, knowing the values of k_o, A and B from a series of in situ or laborator-based drilling tests, the compressive strength of a rock can be determined.

The implications of Tsoutrelis' results with respect to drilling site investigation are clear. By carrying out a series of controlled tests to establish the relationship between k_o and σ_c for the particular bit in use, the in situ compressive strength of the rock can be derived by determining k_o values from the values of R, F and N recorded in the field. One difficulty which might be posed is that wear of the bit in abrasive rocks could make the determination of initial penetration rates difficult. The effect of bit wear on drilling performance is considered in Section 3.6.3 below. It is worth noting, however, that Tsoutrelis has presented a technique which allows initial penetration rates to be determined in excessive wear situations. Equally, the use of impregnated diamond bits as opposed to surface-set or metal rotary bits, should reduce the effect of wear.

Apart from obtaining an in situ strength log for any rotary drilled borehole, the Tsoutrelis technique could allow the use of drilling bits with a cutting action similar to some types of TBM's. This would require special strength test runs to be performed in the field and compressive strengths determined in order to make boreability predictions and cutter selection more rigorous.

To date, Tsoutrelis' method has only been successfully used in the laboratory Attempts by Brown[266] to predict rock strength at Rogerley Quarry proved discouraging. Bit wear was thought to be a likely cause of the unsuitable data. A test of this possible cause would be a drilling programme carried out in uniform non-abrasive rocks.

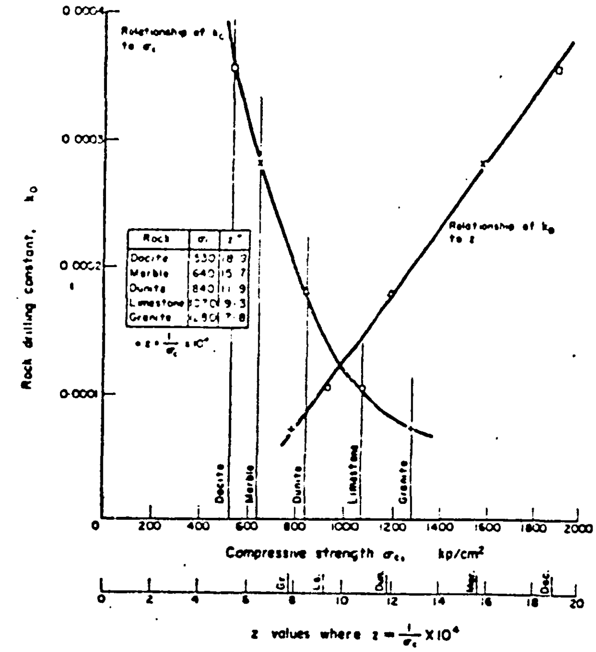


FIGURE 3.39 RELATIONSHIP BETWEEN UNIAXIAL COMPRESSIVE STRENGTH AND ROCK DRILLING CONSTANT K_o (After Tsoutrelis, 1969)

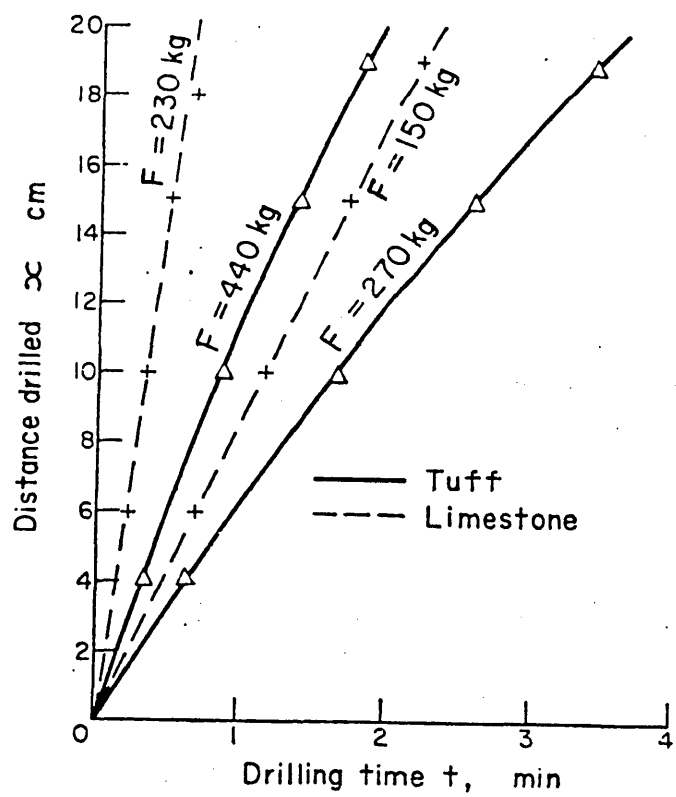


FIGURE 3.40 DRILLING TIME - DISTANCE DRILLED RELATIONSHIP (After Tsoutrelis, 1969)

3.6.3 Bit wear and abrasivity

The influence of bit wear is very difficult to assess, yet it exerts a marked effect on rotary drilling performance. The components of wear vary with the type of drill bit being used. However, the effect of wear need not be detrimental to the efficiency of drilling in certain circumstances. The principal components of wear with surface-set diamond bits are two-fold - wear of the matrix caused by abrasion or chipping and wear or loss of the diamonds held in the matrix. With surface-set bits, both of these effects can be considered to be detrimental. However, the efficient use of impregnated diamond bits requires a gradual wearing away of the matrix to expose new, sharp cutting points, ideally as the previous ones lose their cutting edge. This is the 'self-sharpening' condition discussed in the next chapter. Finally, with roller tooth bits or roller cone bits (and drag bits) having metal inserts, wear is not desirable under any circumstances, although it is unavoidable. As with surface-set diamond bits subjected to wear, the thrust on rotary bits is increased as wear progresses until penetration rates are no longer economic or the bearing loads or bit temperatures are excessive[265]. Fish[254] points out that the hardness of the inserts can be increased in order to extend the life of the bit, although such an increase is limited (Vickers hardness ≃ 1450) because of increased brittleness and the likely fracturing which would result under rotational impact forces.

Several theoretical and/or experimental studies of bit wear have been done, among the researchers are Fish, Guppy and Ruben[171], Tsoutrelis, Strebig, Selim and Schultz[261], and Rowlands[248]. The main findings of these studies have been detailed by Brown and Phillips and are only summarised here. Section 3.4.1 showed that under ideal conditions, the specific energy of rock removal by rotary drilling can be expressed as

$$R = \frac{2\pi}{A} \cdot \frac{NT}{e} \qquad (3.30)$$

For new bit conditions, Rowlands[252] found e constant for constant thrust. Also, from Paone and Bruce's definition of the coefficient of friction (μ) at the bit/rock interface, $\mu = T/r\,F$, it follows that $T \propto \mu$ for constant thrust (F). By substitution, equation (3.30) becomes

$$R = C\,N\,\mu \qquad (3.31)$$

where C is a constant

For a fixed rotary speed and thrust, $R \propto \mu$. If μ decreases with drilling (due to loss of diamonds or polishing in diamond drilling, or wear of cutting elements in other types of rotary bit), the rate of penetration decreases with distance drilled. Figure 3.40 depicts the influence of bit wear on the rate of penetration at constant speed and thrust in the form of a cumulative distance drilled (x) versus time (t) plot. Tsoutrelis represented such curves by the following equation:

$$x = \frac{R_o}{b} (1 - e_n^{-bt}) \qquad (3.32)$$

where
b is a wear factor (rock abrasivity index)
e_n is a constant = 2.718

The wear factor (b), using information from Fish, Guppy and Ruben, was found by Tsoutrelis to be related to the abrasion index (A_x) in the following way:

$$b = \lambda_1 \, e_n^{\lambda_2 \sigma_c A_x} \qquad (3.33)$$

where
λ_1 and λ_2 are constants depending on drilling and abrasion test conditions.

Differentiating equation (3.32) with respect to time (t) gives the instantaneous penetration rate at t as

$$R = R_o \, e_n^{-bt} \qquad (3.34)$$

If equation (3.32) is re-arranged, then

$$e_n^{-bt} = 1 - bx/R_o \qquad (3.35)$$

Substitution in equation (3.34) gives

$$R = R_o - bx \qquad (3.36)$$

for constant rotary speed and thrust. The linear decrease in penetration rate with cumulative distance drilled predicted by equation (3.36) is not always realised in practice.

Rowlands found an exponential decrease in the penetration rate with distance drilled according to the relationship

$$R = R_o \, e_n^{-b_1 x} \qquad (3.37)$$

where
b_1 is dependent upon the abrasivity of the rock.

Strebig et al present a more complex function for the relationship between distance drilled (x) and the instantaneous penetration rate (R), namely:

$$R = R_o \exp\{-b_1 (x - \gamma)^{\beta}\}$$

where
γ is a location parameter
β is a shape factor.

The shape factor $\beta = 1$ if wear is constant with time, but $\beta < 1$ if otherwise.

Equations (3.32) to (3.37) predict that for conditions of constant rotary speed and thrust, the instantaneous penetration rate varies with rock compressive strength and abrasivity. This has been verified by Singh[268] for wing-type rotary drag bits. Tsoutrelis stated that it is possible to derive values for σ_c and b from a distance drilled-time plot such as Figure 3.40 and presents the numerical procedure required for such a determination. The method demands that the relationship between σ_c and k_o for a particular bit type be established from controlled laboratory drilling trials on several rock types. The application of the Tsoutrelis technique to both laboratory and field drilling conditions is one of the intended aims of this investigation.

3.7 Instrumentation of Rotary Drilling Rigs

3.7.1 Acquired experience

Instrumenting drilling rigs to measure the drilling variables discussed in Section 3.3 of this chapter and recording the returned signal from the various sensors is a simple procedure, due allowance being made for the vagaries of different drilling systems. Indeed, in reviewing drilling studies by various researchers, it is evident that instrumentation technology has been applied to a number of drilling rigs in the past.

To date, the field-based instrumental systems have tended to be research tools developed by individuals or research groups. Table 3.13 provides details of some of these investigations. One of the most comprehensive field investigations was conducted by Boyd who instrumented an Atlas-Copco Diamec 250 drill and monitored drilling performance in a limestone-chert formation and agglomerates at Meldon Quarry, Devon and Lower Chalk at Chinnor, Oxfordshire. Only limited details of these investigations have been published[13].

The literature also cites examples of drill rig instrumentation for exploration purposes which are not listed in Table 3.13. Lang[14,15] recorded rotary speed, torque, thrust, sampling depth and sample recovery in drilling and sampling clays with a drive sampler. Bergman[21] instrumented an Atlas Copco ROC 601 crawler drill, equipped with a separately rotated BBE 57-01 percussive rock drill to automatically record rate of penetration, rotary speed and air pressure on the chain-feed motor during exploratory drilling. The holes were drilled using 64mm cemented carbide tipped drill bits using a water flush. Busch and Hill[22] instrumented a petrol-driven 8 hp screw-fed drilling machine to study drilling performance during routine drilling in plain

TABLE 3.13 SOME FIELD APPLICATIONS OF DRILLING RIG INSTRUMENTATION

AUTHOR(S) REFERENCE NO	ORGANISATION	DRILL TYPE	BIT TYPE	INSTRUMENTATION						NATURE OF INVESTIGATION
				Penetration Rate	Thrust	Torque	Rotary Speed	Flushing Fluid		
								Pressure	Flow Rate	
182	US Bureau of Mines	Longyear 24 trailer-mounted diamond drill powered by 15 hp gasoline engine	AX impregnated bits	Head movements recorded by a pen writing on recorder paper attached to rig	Hydraulic pressure gauge	-	Engine rev/min measured by electronic counter	Pressure gauge		Fundamental study of the relationships between rock properties and drilling variables
250	US Bureau of Mines	35H Sprague and Henwood skid-mounted diamond drill powered by 15.5 hp engine	AXL surface-set diamond bits	Drilling times recorded for a given penetration	Pressure transducer in hydraulic line to thrust cylinder	Strain gauges mounted on drive shaft	Tachometer connected by flexible cable to drive shaft	-		Investigation of the effectiveness of using surfactant solutions
13	Imperial College, London	Atlas-Copco Diamec 250	Special impregnated bit giving a 46mm dia.	Head movements measured by a LVDT. Chart driven at constant speed	Pressure transducer in hydraulic thrust system	Calculated from inlet oil pressure and swash plate angle in hydraulic motor		Pressure transducer	Flow meter in the feed pipeline	Investigation of the usefulness of drilling rig instrumentation

(After Brown and Phillips, 1977)

and re-inforced concrete. Lutz et al[16] have recorded longitudinal and torque vibrations of long drill strings as a matter of routine, while Lutz[17] describes a logging system for recording penetration rate, thrust and water injection pressure on a time or depth based scan for cored or non-cored boreholes. A range of logging equipment for percussive drilling systems is also described. Scartaccini[18] has recorded all the major drilling variables on a 60-12 Bucyrus-Eire percussive drill used to drill 229mm diameter blast holes at the Mission open-pit copper mine in Arizona. Gardes[19] describes the use to which recording the rate of penetration, thrust, torque and drilling mud pressure was put during grouting operations for the Vienna metro. The drill was used to detect sand lenses in Quaternary alluvial deposits which were then subjected to injection by bentonitic cement or silica gel grouts. In addition, karst limestone was detected by the system. Mouxaux[20] has described the general principles of this system.

With the exception of the Scartaccini (Totco recorder) and the Soletanche[19] equipment, the instrumentation referred to above is generally in the research/development state, and not commercially available. However, there are numerous commercial sources (Section 3.7.3) of recording systems available and organizations such as the N.C.B. make extensive use of them for recording the results of exploratory drilling in coal.

Probably the most committed user of drill rig instrumentation is the oil industry who make measurements of the type described above standard well drilling practice. Even a cursory glance through one of the industry's standard manuals[269] will serve to illustrate the diagnostic role that drill rig instrumentation plays in solving well bore problems. While the instrumentation is on a scale that is generally unsuited to most geotechnical applications, a great deal can be learned from the oil industry's experience in developing this technology.

3.7.2 Commercially available instrumented drilling rigs

In 1977, Brown and Phillips surveyed all known U.K. and several overseas manufacturers of drilling equipment in order to locate sources of instrumented drilling rigs. The availability of the type of equipment being sought proved to be limited in supply.

The details of fully or partially (at least two drilling variables recorded) instrumented rigs which were available at that time are listed in Table 3.14. It should be noted that larger rigs which are unsuited for site investigation drilling as it is generally conceived, have not been included in the table. Only the Wesdrill 60 is fitted with measuring and

TABLE 3.14 SOME DETAILS OF COMMERCIALLY AVAILABLE INSTRUMENTED DRILLING RIGS

MANUFACTURER (Country)	MODEL	B.H.P.	ROTATIONAL SPEED RANGE (rev/min)	MAXIMUM THRUST (kg)	MAXIMUM DEPTH/BIT SIZE	PENETRATION RATE	THRUST	TORQUE	ROTARY SPEED
Wesdrill (Canada)	60	90	15-1600	9000	600m HQ 900m NQ 1500m AQ	Measure return oil flow from thrust pistons	Strain gauge transducer between top and bottom thrust	Measure separation force on bevel gears in final drive unit with strain gauge transducer	Tachometer on one of final drive gears
Mindrill (Australia)	350	60	52-1430		1070m NQ	-	Hydraulic bit pressure gauge	-	Tachometer
	550	200	304-2200		915m HQ 1370m NQ	-	Hydraulic bit pressure gauge	-	Tachometer
Alfred Wirth (West Germany)	B-0	49	30-870	3000	200m NQ 320m AQ	-	Bit pressure gauge	Gauge	Tachometer as optional extra
	BIA	84	32-815	6000	520m HQ 830m NQ 1300m AQ				
Duke and Ockenden (UK)	Dando 250	60	0-800	4500	500m H/P 800m NQ	-	Hydraulic supply pressure gauge	Proportional to hydraulic supply pressure	Tachometer not standard but can be supplied
English Drilling Equipment Co (UK)	Mini-Hydrack -FR	15	54,87,165	4300	200m NQ	-	Bit pressure gauge	Gauge	-
Longyear (USA)	HC-150	65	0-1785	4808	250m HCQ 325m NCQ 460m AQ	-	Bit pressure gauge	Gauge	Tachometer

(After Brown and Phillips, 1977)

recording equipment for rate of penetration. While it is probably relatively easy to install this type of monitoring equipment, it suggests lack of foresight on the part of the manufacturer or the purchaser that this most fundamental drilling variable is not monitored at the control panel as standard practice. The Wesdrill 60 is the most fully instrumented commercially available rig suited to most site investigation applications. The rig has been described by Brown[63] who notes that penetration rate, thrust, torque and rotary speed are monitored by dials on the rig control panel or recorded by plugging suitable logging equipment into sockets provided on the control panel.

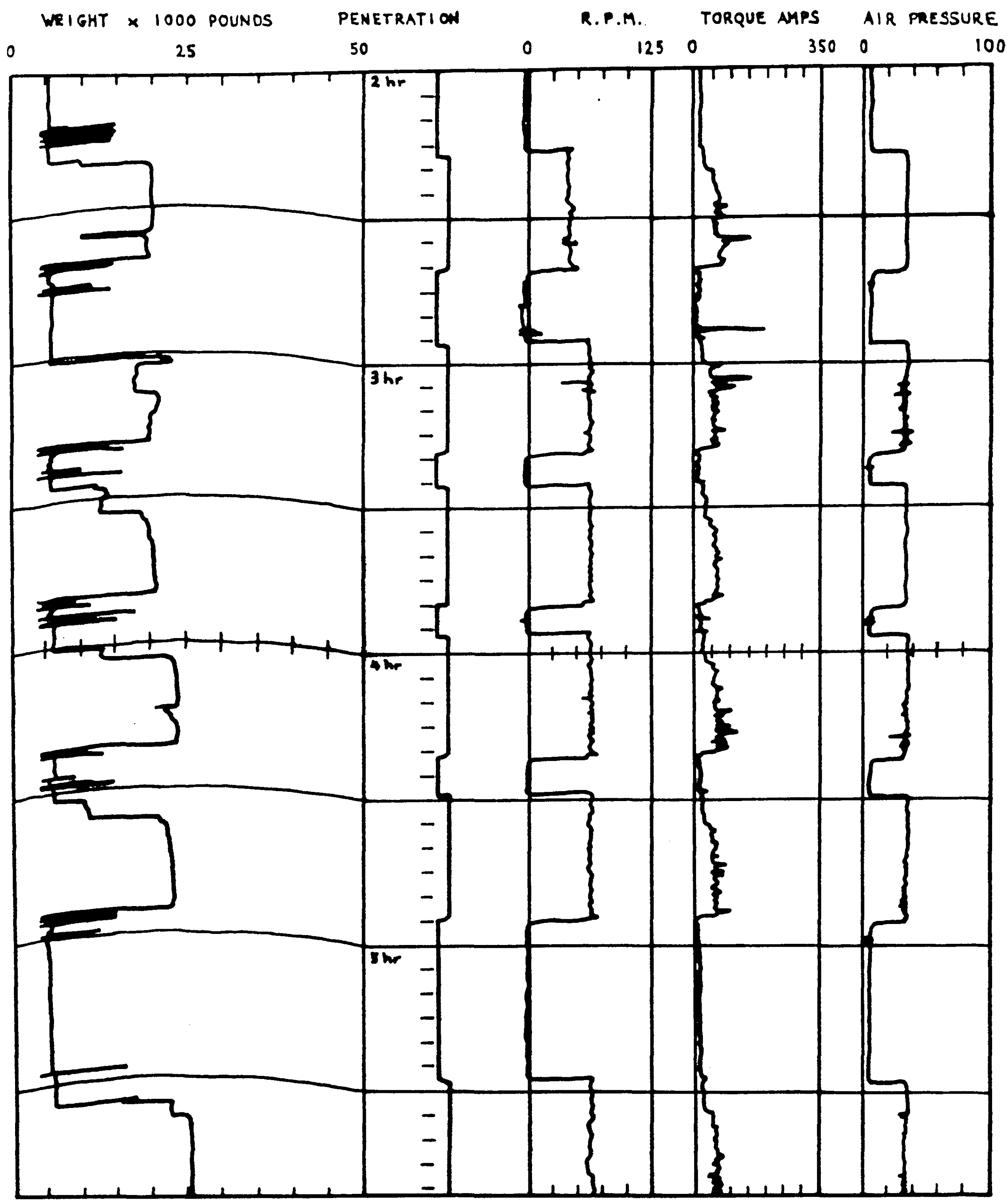
3.7.3 Examples of recorded performance

Several examples of recorded output from instrumented drilling rigs operating under field conditions are shown in Figures 3.41 to 3.47. Scartaccini has demonstrated how recorded performance can be usefully employed to correct errors in drilling technique. Figure 3.41 shows the record from a drilling run carried out by a drilling trainee during an off-shift when the drilling supervisor was not able to maintain a constant check on the trainee's progress. The record clearly demonstrates that the novice driller was not correlating down-pressure with rpm, as evidenced in the torque readings. When the supervisor saw the record, the faulty technique was explained and corrected.

Figure 3.42 is an example of the strip chart recorder output for the drilling trials in Lower Chalk conducted by Boyd and briefly discussed by Pearson[13]. Waterpressure, thrust, torque, head displacement and rotary speed are plotted against time. The rate of penetration at any point is given by the slope of the head displacement versus time curve. Reference to Figure 3.42 shows a marked increase in the rate of penetration after torque and rotary speed have not varied. No obvious geological reason was evident by way of an explanation of this behaviour, other than the fact that the level at which the change occurred coincided with ground water level. Anotherfeature to note on the record are the large 'spikes' which occasionally interupt the torque and rotary speed traces. These spikes signify an intermittent electrical fault in the instrumentation and are precursors of component failure.

A drilling record presented by Busch and Hill[22] in Figure 3.43 is a fine example of the effect which changing material properties can exert upon drilling performance. When the diamond impregnated bit strikes the 16mm diameter reinforcing steel bar, the torque increases while the rotary speed drops by about 10% and the penetration rate decreases. In the plain concrete

FIGURE 3.41 BLAST HOLE DRILL RECORD SHOWING FAULTY DRILLING TECHNIQUE (After Scartaccini, 1970)



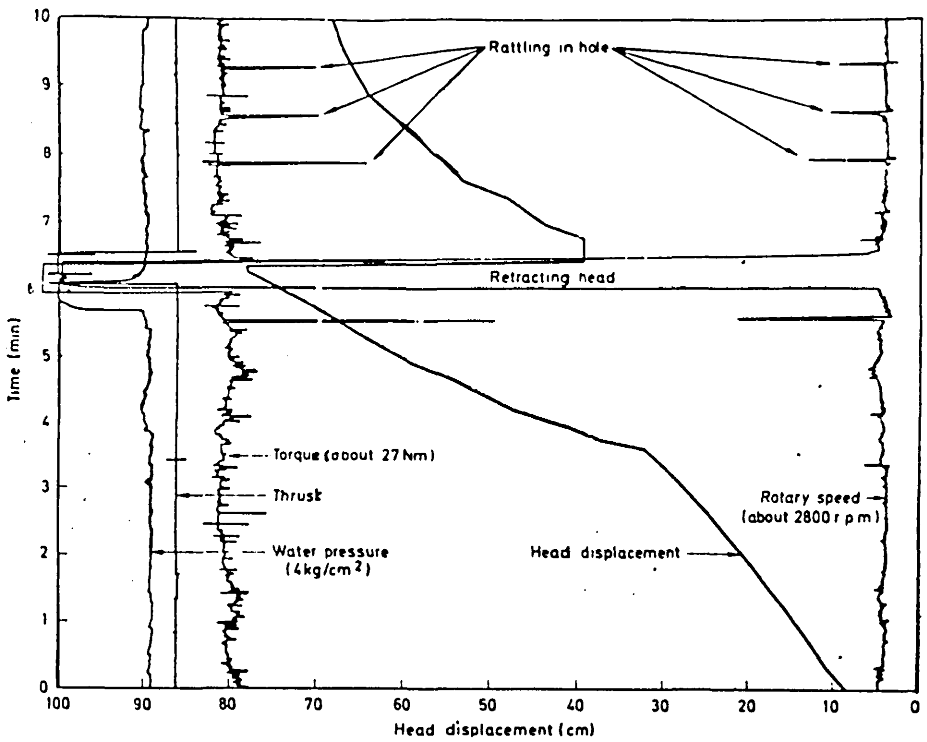


FIGURE 3.42 INSTRUMENTED DIAMOND DRILLING IN CHALK
(After Pearson, 1975)

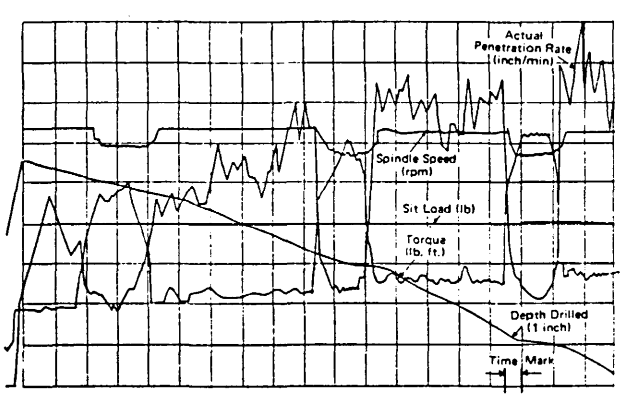


FIGURE 3.43 INSTRUMENTED DIAMOND DRILLING IN REINFORCED CONCRETE
(After Busch and Hill, 1975)

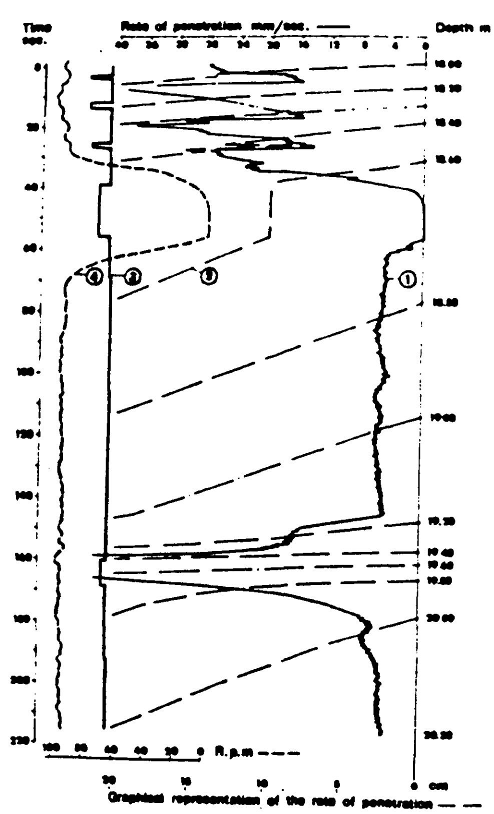
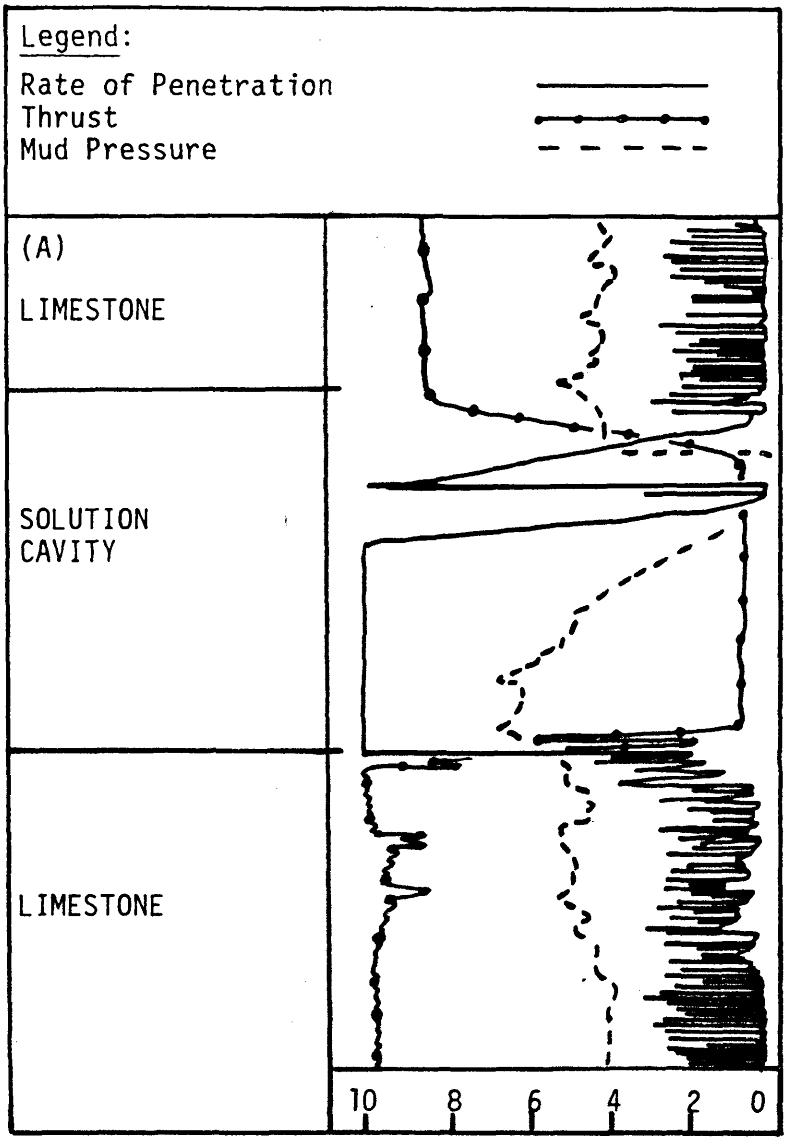
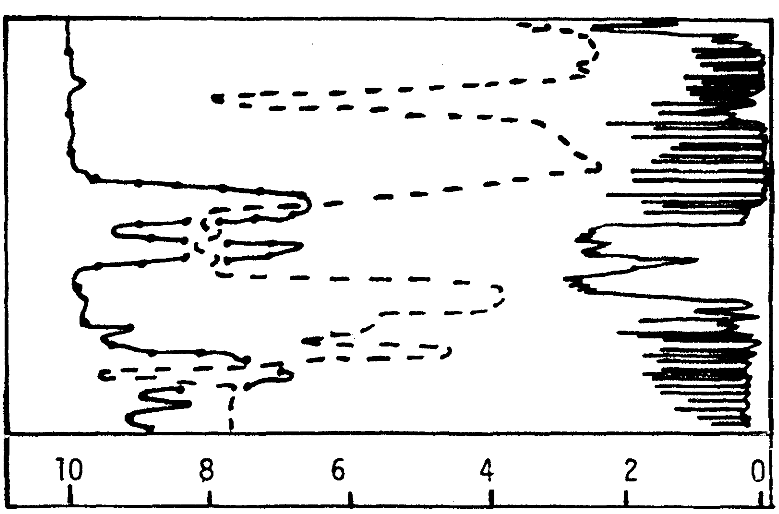


Figure 3.44 INSTRUMENTED PNEUMATIC DRILLING IN GLACIAL TILL
(After Bergman and Norlen)

FIGURE 3.45: DRILLING RECORDS IN LIMESTONE
a) with open solution cavities
and b) with clay infilled cavities. (After
Gardes, 1977).



(B)



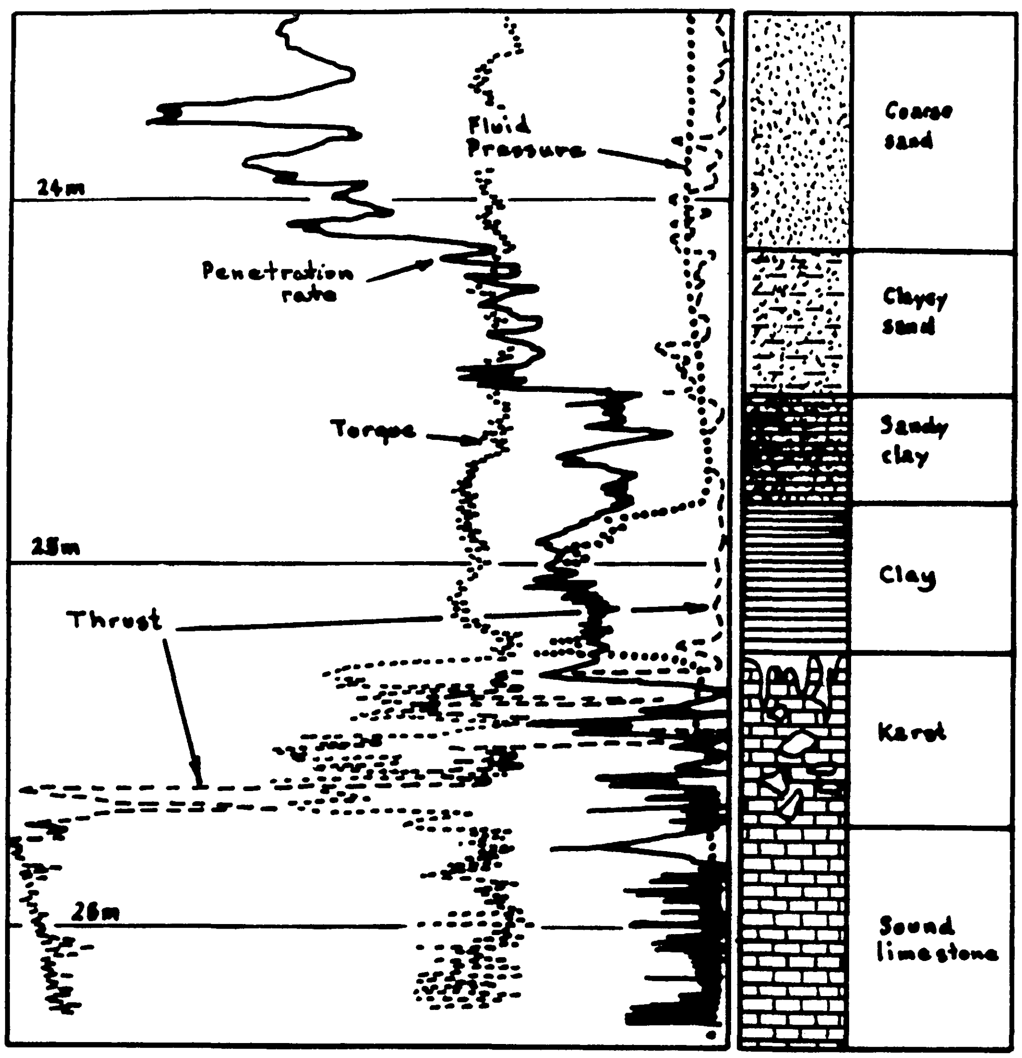


FIGURE 3.46 RECORDED OUTPUT FROM AN INSTRUMENTED DRILLING RIG (After Mouxaux, 1978)

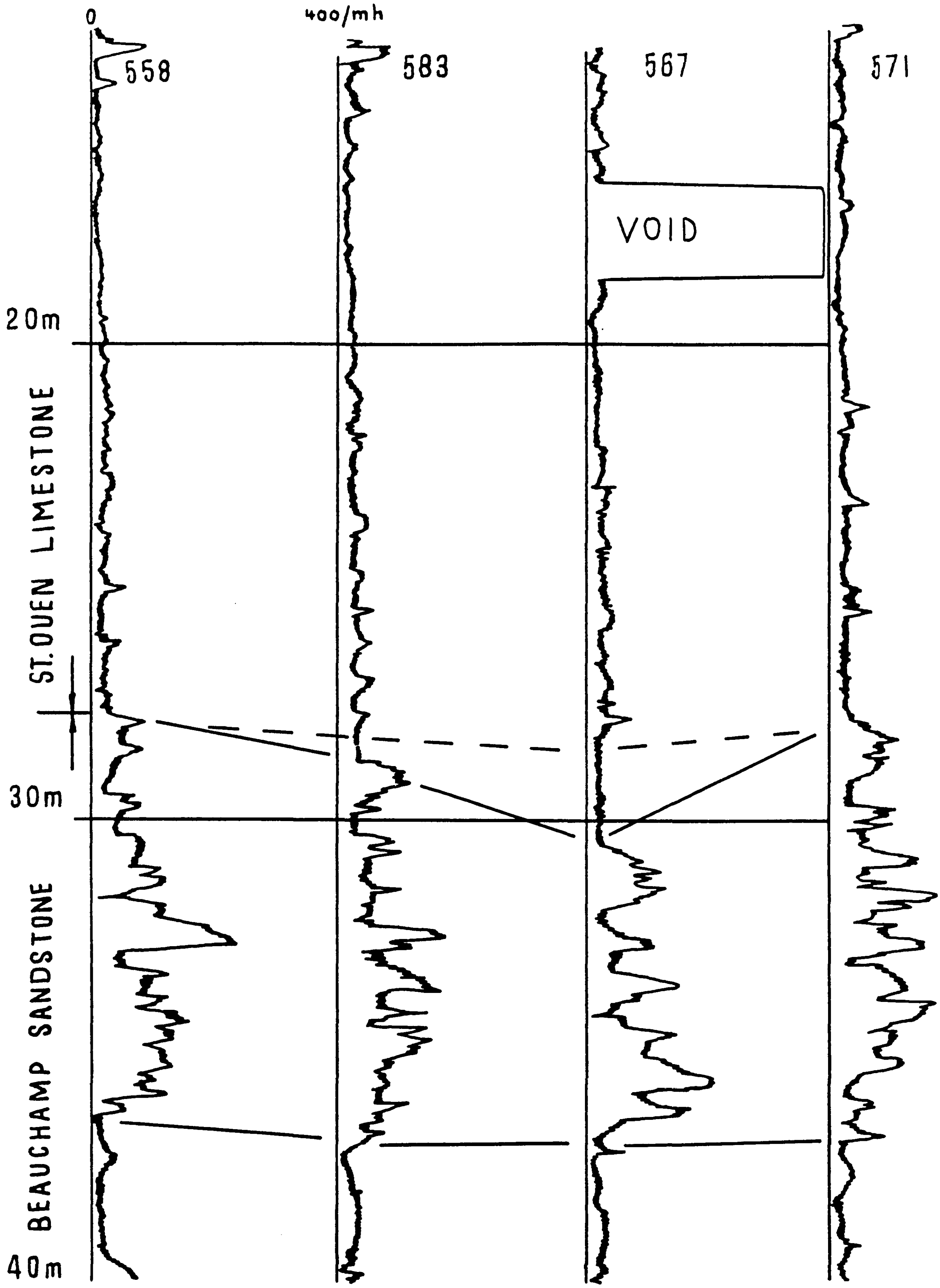


FIGURE 3.47 STRATIGRAPHIC CORRELATION BASED ON RECORDED PENETRATION RATES (After Lutz)

section, the penetration rate is subject to instantaneous fluctuation due to the inhomogeneity of the concrete.

Hagconsult AB (Stockholm) have developed instrumentation for a percussive drilling rig with a view to site investigation application in mixed soil and rock situations[21]. Figure 3.44 shows an example of recorded output obtained during routine drilling. The following drilling variables are plotted with respect to time:

1) instantaneous rate of penetration (mm/sec);
2) depth drilled in 20cm sweeps across the chart. The steeper these lines, the greater the rate of penetration;
3) position of the feed lever providing an indication of the level of applied thrust;
4) rotary speed.

The early portion of the recording suggests a variable stony material was being drilled. After a halt in drilling at 18.70m for 15 seconds, the penetration rates from 18.70m to 19.18m suggests that rock was being drilled, presumably a boulder. At a depth of 19.18m the rate of penetration suddenly increased to a level characteristic of earlier cohesive soils and assumed this level until encountering bedrock at 19.95m. This example demonstrates how drilling instrumentation provides useful site investigation data even in the absence of coring.

Gardes[19] presents some very interesting data obtained by a Soletanche instrumented drilling rig. Figure 3.45 shows two drilling records: one for a borehole in limestone intersecting an open solution cavity and another for a clay filled cavity. Gardes provides the following description of the records.

> "The presence of cavities corresponds with: a rapid increase in the rate of penetration, a drop in circulation fluid pressure and a decrease in thrust.
> It is interesting to note that, by careful examination of the results we can detect whether the solution cavities are infilled or otherwise and perceive the type of infill: sand or clay.
> (Figure 3.45b) gives a good example of a drilling record showing the intersection of a solution cavity filled with clay. We observe the same characteristics that obtained in (Figure 3.45a)with, however, an increase in the drilling mud pressure which corresponds to a blocking of the bit by the clay in the cavity"
> (Translation)

Mouxaux[20] presents a record which details the performance of the Soletanche drilling rig with respect to the lithologies found in a cored borehole. Figure 3.46 shows a progressive decrease in the rate of penetration as the drill bit passes through coarse sand, clayey sand, sandy clay and clay. In clay the thrust is reduced, the torque higher and there is a marked increase in the drilling fluid pressure. When the bit passes into fresh limestone the thrust increases and the rate of penetration decreases markedly.

Brown[220] shows a portion of the record derived from the CIRIA drilling trials at Rogerley Quarry for an open hole drilling situation in mudstone. Figure 3.47 shows the penetration of a very weak stratum at a depth of 39.8 metres. The penetration rate indicator went off the scale at 25cm/minute and the torque dropped to almost zero. This suggests that the material being penetrated (thought to be inferior coal) was so weak that the bit developed very little torque in passing through the stratum. The important point is that this information is still obtained in spite of the fact that this is a non-coring operation.

Finally, Lutz[17] has shown that it is possible to correlate stratigraphy using rate of penetration recordings (Figure 3.47). The recordings made in four boreholes, drilled with hydraulic equipment using a 108mm tricone bit, show the suspected contact between the St. Ouen limestone and the Beauchamp sandstone. In addition, a 2m thick void occurs in borehole 567 at a depth of 17 metres, thought to be associated with subsidence in the limestone.

3.9 Summary

Earlier sections of this chapter have established that simple theoretical relationships exist between the operational variables in tunnel boring and rotary drilling systems and that the specific energies of rock removal by each system are related in an identical manner. The inter-relationships between thrust, torque and rotary speed and the influence they exert on penetration or boring rate are qualitatively similar in each excavation process. Also, the rock and rock mass properties which exert an influence on boring or penetration rate are essentially the same in both systems. Thus, while there are differences in detail of the mechanics of rock removal by each process, the existing relationships and correlations suggest that the use of rotary drilling as an analogue of tunnel boring might be feasible. Indeed, if would appear that an instrumented rotary drill could be considered in the much broader context of a general site investiations 'tool'.

A promising feature of instrumenting a drilling rig concerns the prediction of compressive strength. Tsoutrelis has demonstrated that compressive strength can be accurately predicted from drilling performance as measured in the laboratory. Ideally, an operational procedure must exist whereby similar estimates can be made for field drilling conditions. One potential difficulty concerns the fact that Tsoutrelis' work is based on new bit conditions and requires laboratory calibration of each bit type. It should be borne in mind, however, that Tsoutrelis employed metal rotary bits in his investigations and that the use of impregnated diamond bits may reduce the effects of wear.

Tsoutrelis provided a means of correcting the measured values of drill performance to compensate for bit wear. Brown and Phillips note that, although this method works well in the laboratory, field applications may prove more difficult because of more varied rock conditions. They go on to suggest that it may be possible to derive a bit wear factor from monitoring drilling performance which could be correlated with abrasivity. Clearly, the intention would be to apply such an index to the estimation of TBM cutter consumption.

Boyd's work at Meldon Quarry showed that it may be possible to determine the water table level from a change in penetration rate, although the criteria whereby this decision can be made is by no means certain. Monitoring the drilling fluid balance in the borehole might prove useful in determining zones of anomalous flow conditions, but quantitative application of the results of such investigations would be limited. Groundwater conditions will, in spite of drilling rig instrumentation, remain one of the major uncertainties following site investigation drilling.

Some structural features in the rock surrounding a borehole may be discernible from the records obtained during drilling. Changes in lithology, assuming a penetration rate or another drilling variable contrast exists, are discernible and given some cored boreholes as a control, stratigraphic correlation appears possible. It must be expected that fault zones, infilled voids and open fractures should be sensible from the likely influence they will exert on the drilling rig's behaviour. Considering the array of borehole probes which can be used to supplement the information obtained from monitoring drilling performance, this must be seen as an area of potential development.

An instrumented drilling operation, whether it is based on one of the few commercially available systems or not, offers additional attractions to those cited above, including the following:

i) Provides a permanent detailed record of the drilling operations, prepared as drilling proceeds and not after the event.

ii) Aids in the determination of optimum operating conditions by rational adjustment of independent variables, rather than experienced guesswork, resulting in improved drilling efficiency.

iii) Aids in training drill operators.

iv) Provides advanced warning of some impending mechanical faults.

v) Allows better control of the drilling operation leading to improved core recovery and better quality core in many instances.

Whether or not some or all of the potential benefits cited are realized depends on the results of field-based experiments such as those conducted by CIRIA and the author.

CHAPTER 4

DIAMEC 250: OPERATION AND INSTRUMENTATION

4.1 Introduction

The preceding chapter discussed the variables and theoretical relationships which various researchers have deemed important in rotary drilling. In this chapter, a description of the Atlas Copco/Craelius Diamec 250 is followed by an outline of the rationale which governed the design of the instrumentation package. A detailed description of the instrumentation and the formulation of torque calibration curves completes the discussion.

4.2 Drill Rig Description

The Diamec 250 was introduced to the U.K. market in 1969 and at that time was an advanced machine compared with contemporary equipment. Machines now exist in a form similar to that of the Diamec 250, yet it still has numerous features which render it a worthwhile selection for these instrumented drilling trials, including the following characteristics:

i) a compact drilling assembly
ii) simple to set up and transport because of modular construction
iii) suited to one man operation
iv) automated drill rod handling
v) suited to drilling at any orientation
vi) improved drilling performance aided by a pressure compensated hydraulic system
vii) controls are grouped on a moveable console.
viii) primarily designed for underground operations

Since a Diamec 250 was already owned by the Royal School of Mines (R.S.M.), and this was an important consideration in its selection for the horizontal drilling trials, nevertheless the factors listed above were important in its initial selection and deserve to be recounted.

Figure 4.1 shows the five main units of the drill:

i) Rotation unit
ii) Rod holder
iii) Feed frame
iv) Power unit
v) Control console

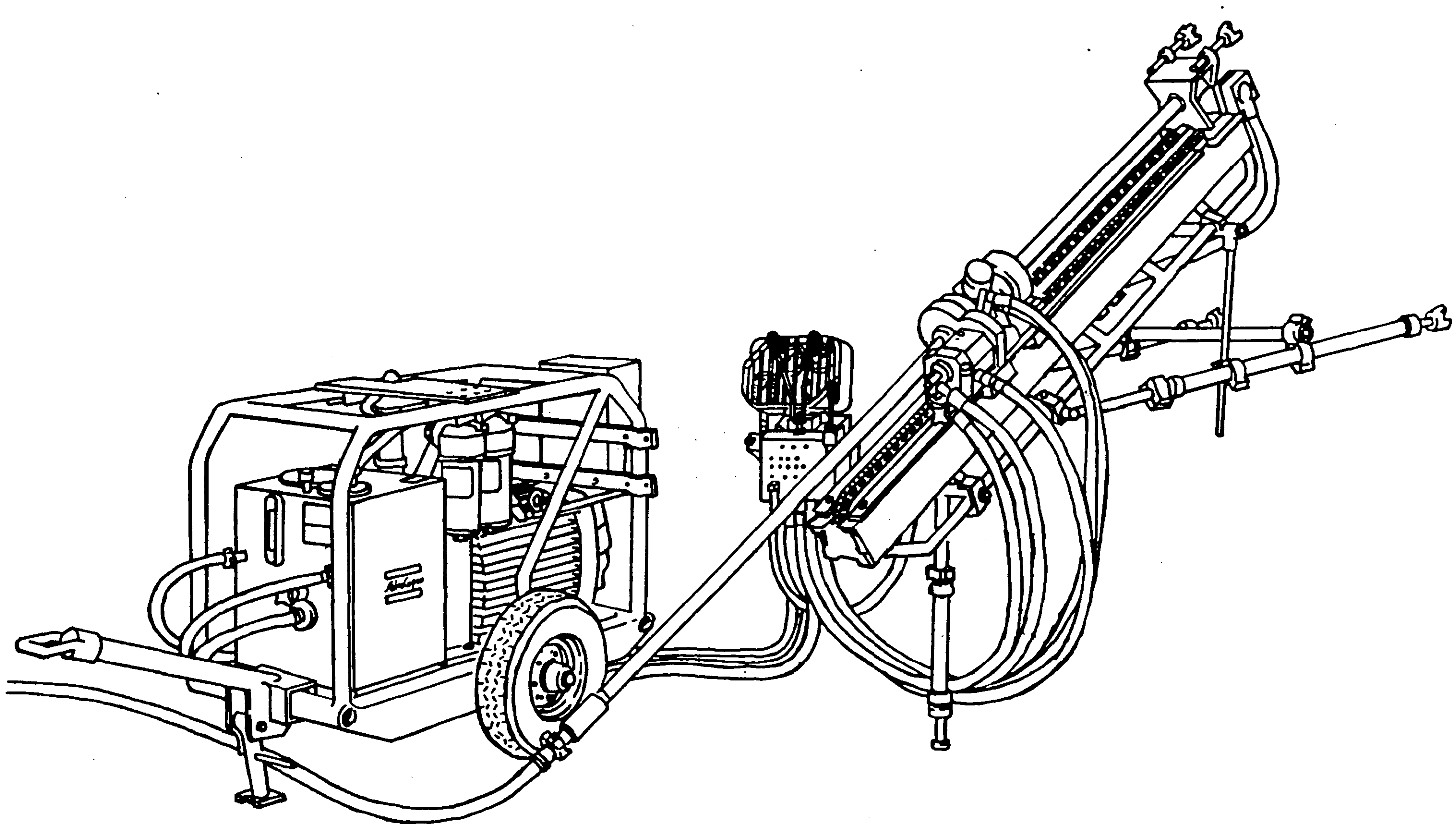


FIGURE 4.1 THE ATLAS COPCO DIAMEC 250 ROTARY DIAMOND DRILL

A brief consideration of each sub-system is necessary to fully appreciate subsequent instrumentation and the calibration procedure[270]. Figure 4.2 depicts the hydraulic system of the drill and shows how the various components are interlinked.

4.2.1 Rotation Unit

The rotation unit comprises a variable displacement axial piston hydraulic motor(6)* which powers the drill rods via a gear box and a hydraulic-mechanical chuck(9). The inner diameter of the rotation unit spindle is 58mm and is suited to handling flush rods and casings over a 33 to 50mm diameter range.

The maximum motor speed can be varied between 1600 and 3200 r.p.m. A choice of gears are available, the standard gears with ratio 1.5:1 providing a maximum spindle speed of 2100 r.p.m., while a 2.5:1 gear ratio reduces the maximum speed to 1250 r.p.m. The chuck functions automatically, the jaws gripping the drill rod upon the application of pressure or, alternatively, being forced to retract by mechanical springs when counter-pressure ceases. The rotary speed of the spindle can be varied to provide vibration-free operation. By exercising various controls on the rotation unit and the power pack (15-18), it is possible to reduce the rotation speed to a minimum of 200 r.p.m. The rotation unit and its relationship with the power pack is afforded comprehensive treatment in section 4.4.2.

4.2.2 Rod Holder

The rod holder (10) is located at the bottom of the feed frame. The spring-loaded jaws of the rod holder grip the drill rod until they are forced open by hydraulic pressure. This hydraulic-mechanical system ensures that the drill rod string cannot be dropped down the borehole in the event of a sudden drop in system pressure. The jaws have a maximum internal diameter of 58mm which, allowing for sufficient clearance between the jaws and the drill bit, effectively restricts maximum borehole diameters to 56mm.

The interaction of the hydraulic chuck on the rotation unit and the hydraulically operated rod holder on the feed frame permits fully mechanised rod handling. Rod coupling is accomplished by gripping the drill rod string in the rod holder, feeding an additional rod through the chuck and rotating the rod to mate the male and female threads on the rods. Uncoupling is

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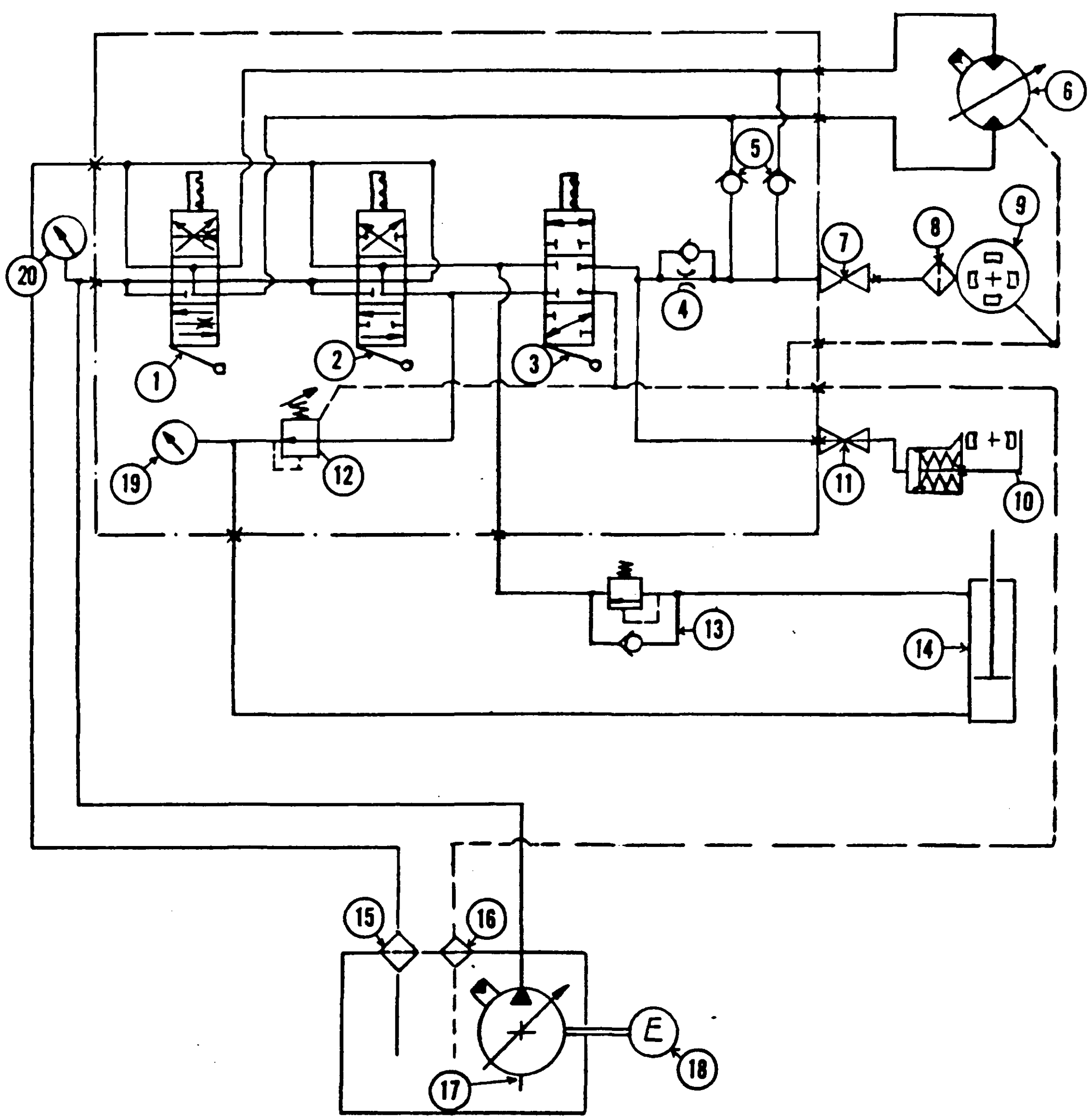
* Numbers in brackets refer to Figure 4.2

FIGURE 4.2 HYDRAULIC SYSTEM OF THE DIAMEC 250



1. Rotation lever
2. Feed lever
3. Rod driving lever
4. Maximum flow valve
5. Non-return valve
6. Hydraulic motor
7. Shut-off valve for chuck
8. High-pressure filter
9. Chuck
10. Rod holder
11. Shut-off valve for rod holder
12. Pressure reducing valve
13. Back-pressure valve
14. Feed cylinder
15. Main return filter
16. Drainage oil filter
17. Hydraulic oil pump
18. Power unit
19. Pressure gauge, thrust
20. Pressure gauge, system pressure

accomplished by reversing this procedure.

Feed and retraction of the drill rods is also achieved with the aid of the rod holder and chuck. During feeding, the rod holder releases the drill rod while it is gripped by the jaws of the chuck. As the rotation unit moves down the feed frame, it advances the drill rod string into the borehole.

Drilling and rod handling operations are co-ordinated hydraulically at the control panel using a permutation of rotation (1), feeding (2) and rod-running levers (3). Rod running speeds in the region of 20 metres (65 ft)/ minute are possible[271].

4.2.3 Feed Frame

The feed frame of the Diamec 250 is a rectangular steel section within which is housed a hydraulic feed cylinder (14). The cylinder effects movement of the rotation unit via a chain drive attached to a cradle which tracks on guide rails on the feed frame (feed length:850mm). The feed force can be adjusted up to a maximum of 3200 kg thrust. A double action piston in the feed cylinder permits pulling as well as feeding of drill rods up to a maximum of 2400 kg rod weight.

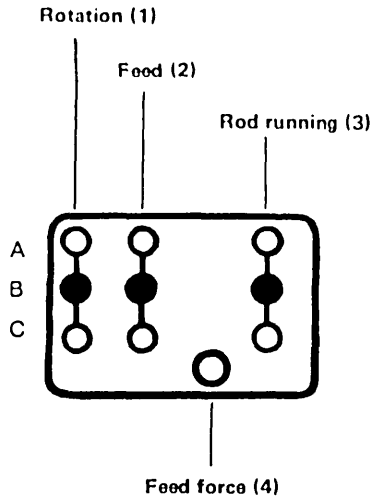
4.2.4 Power Unit

The power pack (15-18) for the Diamec 250 is mounted on a wheeled trolley, the frame of which can be used as a mount for the drill during relocation. The power unit comprises a prime mover (18) and an oil tank within which is incorporated an axial piston pump (17). Oil is pumped from the reservoir at a pre-set flow rate to the working components of the drill through the control panel before being returned to the reservoir.

The power pack is normally driven by an electric, compressed air or diesel motor, although it is possible to use a petrol driven prime mover (as was the case with the Royal School of Mines drill rig prior to modification by the author). This and other modifications will be treated elsewhere in this chapter.

4.2.5 Control Panel

This unit is essentially a valve block on which are located rotation, feed and rod-running levers as well as a pressure regulating valve (4) with which to control the thrust applied to the drill rod string. Figure 4.3 details the actions which attend particular settings of the levers. As implied by the figure, various setting combinations of levers 1, 2 and 3 control the sequencing of actions involved in drilling and rod handling.



Position	Rotation	Feed	Rod running
A	Drill rod rotates to the right	Chuck moves **toward** the drill hole	Lever position for feeding the rods forward
B	Neutral position	Neutral position	Drilling position
C	Drill rod rotates to the left	Chuck moves **away from** the drill hole	Lever position for pulling the rods
Handwheel for feed force:		increase	
		decrease	

FIGURE 4.3 DRILLING OPERATIONS AND ASSOCIATED CONTROL LEVER POSITIONS (After Atlas Copco)

Two shut-off valves are also located below the control panel in order to stem the oil flow to the chuck and the rod holder. A detailed account of the operating instructions for the Diamec 250 is provided by Atlas Copco[273], and need not be repeated here. Table 4.1 lists some manufacturers specifications for the drilling system. The power unit on the drill rig used for the horizontal drilling trials was a Type 25E.

4.2.6 Water Pump

The energy delivered at the drill bit in the rotary diamond drilling process is mainly absorbed in two ways, namely: in rock comminution and heat generated as a result of frictional resistance at the drill bit/rock interface. Thus an adequate fluid flush (air or water) in the borehole is required to cool the drill bit and transport cuttings out of the bore if damage to the equipment and loss of cutting efficiency are to be prevented[274].

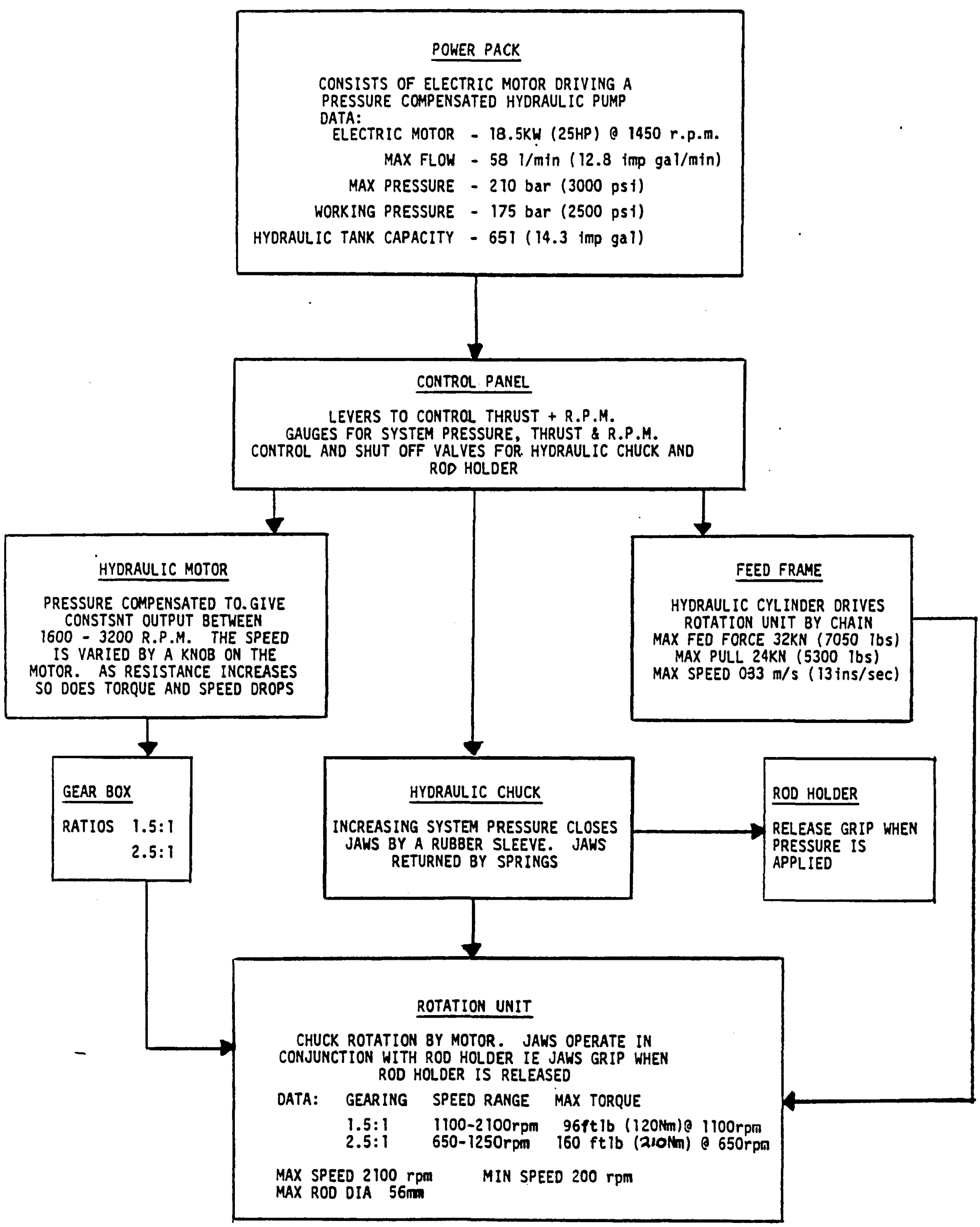
Water requirements for flushing during these trials were met with a Boyles BB7-12RD double-acting single cylinder pump. The pump was driven by a 5.5 hp. TEFC Newman electric motor (built to N.C.B. safety specifications). A selection of pulley ratios allowed for maximum flows and pressures of 91 l/min (20 gal/min) at 25 kg/cm^2 (350 p.s.i.) or 68 l/min at 32 kg/cm^2. In practice, water flows and pressures during the drilling trials are substantially lower than these values.

4.2.7 Modifications to the Drill Rig

The drill rig available to the author had been considerably modified by J. Boyd during vertical drilling trials at Chinnor[66] and Meldon quarry[67]. Also, it had suffered considerable abuse during site investigation drilling in the Shetland Islands. To evaluate the state of the drilling system under

TABLE 4.1

CRAELIUS "DIAMEC 250" DESCRIPTION AND SPECIFICATION



field conditions as well as gaining expertise in the operation of the Diamec 250, two sites were chosen for "shakedown" trials of the rig.

The first drilling site was kindly provided by the Amey Roadstone Corporation at Elm Farm Quarry, Stratton Audley, Oxon during December, 1975. The Diamec was trailer-mounted in a vertical attitude in a non-working area of the quarry. Water was pumped from a nearby flooded excavation by a Villiers petrol powered centrifugal pump to a nominal 50 gallon stilling tank. From there a Boyles BBS 7-12 skid mounted flush pump powered by a Lister SR-1 diesel engine supplied water to the drill rod string. The trailer was raised on jacks, a reaction bolt was grouted into the rock and secured to the appropriate recess on the base of the drill feed frame.

While the main interest in the site trials at Stratton Audley was to gain familiarity in the operation of the rotary diamond drill, a general appraisal of the condition of the Diamec and its operational features was of equal concern. In short, numerous minor faults were found and rectified on site (drive chain tension, new jaws for chuck, etc.). More serious faults, such as a fractured support plate for the oil tank on the power pack were corrected on return to Imperial College.

One feature which caused concern was the inefficiency of a twin-cylinder rod holder which had been commissioned by J. Boyd. This device was designed to grip standard drill rods while allowing core barrel assemblies of 102mm to pass through the jaws. The standard rod holder supplied by Atlas Copco has one jaw fixed in place while the other travels back and forth in response to oil pressure supplied to the hydraulic-mechanical chuck incorporated in the device (Figure 4.2). The double-action cylinder, however, had two opposing jaws, each of which moved to grip the rod. Whether this design was an attempt to speed the action of the rod holder or achieve a firmer grip is not known. In practice it did neither. In truth, it impaired the rod handling efficiency of the drill rig since the inner jaw diameter was increased from 58mm to in excess of 102mm, and with 50mm drill rods involved considerable travel to grip the drill string. This reduction in the speed of rod handling could be justified if the drill rig was capable of drilling beyond its design limits. This possibility was one of the features considered during subsequent site tests in Wales.

In April of 1976 the drilling equipment was transported to Dinorwic Slate Quarry near Llanberis. The purpose of this field trial was to use the drill in a horizontal attitude while drilling a 76mm diameter borehole.

The drill was set up in an area of the quarry in a trailor-mounted horizontal position. Access to the face was severely restricted by slate debris making it necessary to secure the rig to a reaction bolt which protruded about 0.5 metres from the face. Timber shoring was used to provide a reaction between the set screws on the rod holder and the rock face. Drilling with thin wall TT76 coring equipment highlighted the inadequate degree of stiffness in the set-up and in spite of repeated attempts to improve the rigidity of the system the combination of drilling a borehole of 76mm diameter and inadequate stability of the drilling platform forced abandonment of the site.

The rig was moved to a site elsewhere in the quarry and mounted vertically in a manner similar to that at Stratton Audley. A 76mm borehole was started and it very soon became evident that the drill rig was being subjected to unjustifiable abuse. While able to drill a borehole of this diameter with no apparent difficulty, the machine was unable to generate sufficient pull to fail the core at the core spring and thus allow tripping out of the borehole. The jammed drill string was finally freed by attaching a hoist plug above the rotary head, placing two hydraulic jacks between the chuck and the rod holder and jacking to produce sufficient pull to snap the core stub and free the barrel.

The major lessons learned from these two field trials were:

i) The Diamec 250 readily lends itself to use by inexperienced personnel and was thus admirably suited for the author's use.

ii) To ease potential setting-up difficulties, particularly at the TRRL, a rigid steel frame was built suited for use on a concrete drilling pad.

iii) Any attempt to drill boreholes of a diameter beyond the design limits of the drilling equipment was considered too ambitious if not detrimental to the drill rig. Therefore, if possible, any down-the-hole site investigation tools would be required to perform in a 56mm diameter borehole.

iv) In spite of setting-up difficulties at Dinorwic, horizontal drilling with the Diamec 250 was no more difficult than drilling vertically.

A thorough servicing of the drilling equipment and some structural alterations were evidently required before further drilling could be contemplated.
At the same time, design developments from Atlas Copco could be incorporated during the re-fit which would make the drill rig suitable for underground operation.

The drill rig was completely overhauled and worn parts replaced prior to making modifications of any kind. The power pack was extensively modified both to improve oil filtration and comply with National Coal Board equipment specifications for underground use.

The power pack in use prior to the horizontal drilling trials employed a Volkswagen 1600cc petrol engine as a prime mover. The 39 horsepower developed at 3000 rpm by the VW engine (converted to 1500 rpm by a 2:1 reduction gear box) adequately powered the hydraulic pump in the power unit. However, quite apart from the noise factor, the engine was unsuited to underground use on grounds of safety. As a 3 phase electrical supply was available at the TRRL (site for laboratory trials), and the Kielder experimental tunnel (site for field trials), conversion to electrical drive was appropriate. Therefore a Newman 25 hp TEFC electric motor operating from a 415 volt/3 phase/50 Hz supply was purchased for fitting to a Type 25E power unit skid frame (with removable wheels) supplied by Atlas Copco. The oil reservoir and pump from the VW-driven power unit were salvaged and connected to the electric motor on the new power pack.

In order to improve the power unit to the standard of that marketed by Atlas Copco, their recommended modification to the oil filtration system [275] was effected. The new filter system consists mainly of drainage and return filters which have a cleaning capability of 3μ (0.003mm) and offer prolonged life for the hydraulic pump and motor. The filtration unit includes a hand pump which has greatly eased the task of maintaining hydraulic oil reservoir levels. Routine servicing of the filter system has been aided by a warning device which indicates the need to replace a clogged filter.

The field trials clearly demonstrated that, for most hard rock conditions, the drill rig could not drill borehole diameters in excess of 56mm without serious risk of jamming the drill string in the borehole and/or damaging the rotary drill. Thus, the only justification for employing the double-acting 102mm rod holder was shown to be inappropriate. This rod holder was scrapped and replaced by that normally supplied for the drill. This meant that the Diamec 250 was essentially up to date as regards standard developments and modifications introduced by Atlas Copco.

Another modification to the rig arose from evaluation of the utility of certain borehole probes, either in a support role as regards site investigation using the instrumented drill rig, or if necessary to overcome the reliance on recovered core given satisfactory results from the borehole instruments. To avoid the time consuming procedure of dismantling the drill rig to provide access to the borehole for down-hole probes, both the rotation unit and the rod holder assembly were mounted on hinges. It was then possible to simply roll either or both clear of the borehole axis while keeping the feed frame in place. Having inserted the probe in the borehole, the chuck could be rolled back in place and used to advance the tool in the hole.

4.2.8 Coring Equipment

Rock coring equipment can be considered as comprising drill rods, core barrel and drill bit.

The first of these, the drill rods, assumed the three-fold role[274] of

i) conveying feed pressure from the drill unit to the bit

ii) transmitting rotation from the drill unit to the bit

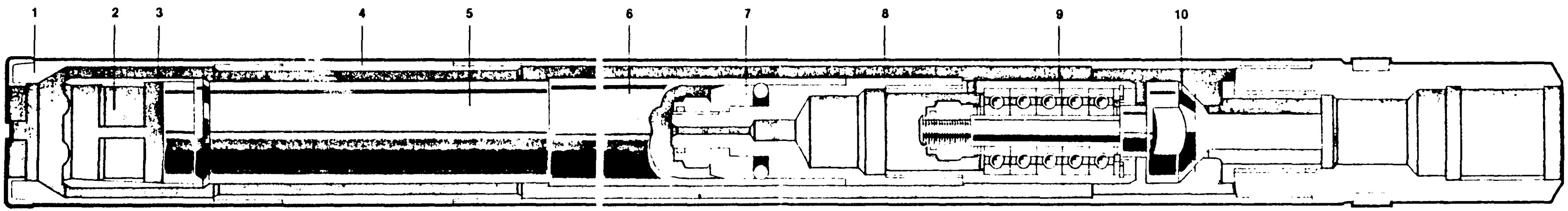
iii) conveying drilling fluid to the bottom of the drill string to flush cuttings clear of the bit/rock interface and to cool the bit.

In performing this task, the drill rod is subjected to a variety of stresses which restrict the rod size and dictates the use of steel or aluminium drill rods if efficient drilling is to be achieved. Atlas Copco[276] recommend that either 50mm steel or 53mm aluminium rods with steel couplings be used with TT 56 equipment.

Fortunately, the R.S.M. drill rig was equipped with 30 metres of 53mm aluminium drill rods as they offer considerable weight and stiffness advantages over their steel counterparts. The reduced weight meant less power was consumed in overcoming the inertia of the drill string and as a result vibration was reduced [276]. Vibration was also minimized because the aluminium rods (53mm) matched the borehole diameter (56mm) better than did the steel rods (50mm). The reduction in weight was the main consideration, however, as the drill was to be run horizontally. The lighter aluminium rods would offer comparatively less resistance to drilling in this attitude and ease the operators task during rod handling operations.

TT 56 super thin-walled drilling equipment was used throughout the drilling trials because of the many advantages it offers over its T2 rival. Most of the benefits accrue from the differences in the opposing bits associated with each type of equipment, but some advantages are incorporated in the TT 56 double barrel (Figure 4.4). The barrel performs best with

FIGURE 4.4 STRUCTURE OF THE TT CORE BARREL (After Atlas Copco)



1 Diamond bit 2 Core lifter 3 Core lifter case 4 Reaming shell 5 Extension tube 6 Inner tube 7 Snap on coupling 8 Outer tube 9 Bearing unit 10 Core barrel head

aluminium rods and is particularly suited to drilling in the medium to hard formations encountered during the drilling trials[277]. The TT 56 barrel is a double tube device which offers good protection for the core since the inner barrel remains stationary while the outer barrel and bit are rotated. Flushing water is passed down the annulus between the inner and outer barrel, through waterways on the bit (face discharge) and up the borehole.

The primary benefit gained from the use of TT equipment concerns the thin-walled bits which complement the TT 56 barrel. The kerf of the TT 56 bit is 5.2mm wide, as opposed to 7mm for that on the T2 barrel and offers the following benefits as a result:

i) reduced diamond content which lowers bit cost
ii) increased penetration rates
iii) reduced pressure and torque permits higher rotation speeds, reduced rod wear and increased service life of the equipment.

Throughout this investigation TT 56 HH and HM Diaborit diamond impregnated bits were used. These contain 30/40 U.S. mesh SDA synthetic diamonds set in a recently developed copper-based matrix which is reputed to give extended bit life[278].

The bits are designed to operate over a peripheral speed range of 2 to 5 metres/second and a feed force range of 500 to 2500 N/cm^2 (700-3500 psi) for maximum meterage. A balance between feed force and r.p.m. is sought to achieve a "self-sharpening" condition for the bit. This condition is unique for a given rock type, rotary speed and feed force. If the feed force is insufficient, the diamonds do not penetrate into the rock and are rendered useless, as they become increasingly polished. Alternatively, too high a feed force fails to markedly improve the penetration rate and simply accelerates the rate of wear of the bit. The advantages offered by the new Diaborit range centres on the fact that a wide range of hard rock types can be successfully drilled with only three bit qualities. The rock types suited to particular bit-matrix qualities are summarized in Table 4.2.

Impregnated diamond bits offer a great benefit in that when properly used the matrix wears at a rate commensurate with the wear of the diamond thereby continually exposing fresh diamond cutting points with which to abrade the rock. Thus a 'constant' penetration rate prevails until the bit

TABLE 4.2 DIABORIT BIT SELECTION CHART
(After Atlas Copco)

Hardness group	ROCK DESCRIPTION	Approximate hardness of rock	DIABORIT Diamond impregnated bits – Matrix HH	HM	HS
4	Sandstone Siltstone Alluvial deposits Calcite Medium hard limestone Hard shale	Medium hard abrasive rocks	■		
5	Hard sandy limestone Veined limestone Dolomite Hard limestone Limestone with dolomite Schist Serpentine	Hard slightly abrasive rocks	■	■	
6	Hard schist Mica schist Hard siliceous limestone Dolomite Marble Syenite Serpentine, peridotite Andesite Diabase Pegmatite Hematite, magnetite	Hard non-abrasive rocks		■	■
7	Metamorphic schist Gneiss Amphibolite Granite Leptite Basalt Diorite Gabbro Porphyry Rhyolite Trachyte	Very hard rock			■
8	Conglomerate Hard sandstone Quartzite Silexite Rocks with pyrite Emery stone	Very abrasive rocks	■		

HS fairly soft matrix suitable for hard polishing rock and drills with limited torque and feed force

HM medium hard matrix suitable for medium hard to hard and fine grained rock formations

HH relatively hard matrix suitable for hard abrasive rock or drills with "high torque, high feed".

is completely worn out[276]. Immediately behind the drilling bit is a reaming shell with inset diamonds designed to provide clearance for the core barrel and/or maintain the borehole diameter. This is followed by the core barrel which throughout these drilling trials was of the double tube type. Capping this was the core barrel head (having tungsten carbide inserts to maintain clearance in the bore), which allows coupling to the drill rods. Table 4.3 summarizes the main features of the coring equipment used in this investigation and compares it with recognized sizes in international use.

4.3 Instrumentation of the Diamec 250

4.3.1 Introductory remarks

An earlier chapter discussed the variables which are important in gaining an appreciation of the performance of a rotary diamond drill rig. The variables (which include: penetration rate, rotary speed, thrust, torque, drilling fluid flowrates and pressures), were monitored along with the drill motor inlet oil pressure, its swash plate position and the voltage supplied to the transducers and rotary potentiometers. The last four items were not strictly drilling variables, but it was necessary to record them since:

i) The position of the swash plate determines the power characteristics of the motor.

ii) Determination of a torque value relies on a numerical procedure based on dynamometer calibration curves relating torque to rotary speed or, if necessary, inlet oil pressure.

iii) All transducers and potentiometers are calibrated for 10 volts energizing voltage. Thus, the energizing voltage is monitored to permit corrections for slight fluctuations in the supply to be applied to the output values as recorded by the data logger.

Figure 4.5 locates the instrumentation on the drill rig while Table 4.4 provides a condensed description of the instrumentation and the information it provides.

The data recording system is outlined in Figure 4.6. Power to excite the sensor, whether a transducer or a rotary potentiometer, is provided by a Weir Twinpack 413/413D power supply. The excitation voltage is regulated by a Signetics (NE550A) precision voltage regulator to reduce excitation voltage fluctuations before the signal is passed to the sensor.

TABLE 4.3 STANDARD HOLE SIZES FOR METRIC AND DCDMA STANDARDS (After Atlas Copco)

Metric standard				For DCDMA hole dimensions			
Drill rod	Core barrel type	Casing tubes OD/ID mm in.	Hole diameter mm in.	Hole diameter mm in.	Casing tubes OD/ID mm in.	Core barrel type	Drill rod
NW 140 mm	K 3 SK 6 L[1])	**143/134** 5.63/5.28	**146** 5.75				
NW	K 3	**128/119** 5.04/4.69	**131** 5.16				
NW	K 3	**113/104** 4.45/4.09	**116** 4.57	**116.7** 4.59	HX **114.3/100.0** 4.50/3.94		HW
NW	T 2 K 3	**98/89** 3.86/3.50	**101** 3.98	**99.2** 3.91	NX **88.9/76.2** 3.50/3.00		NW HSK[3])
50 mm 50 mm 82 mm	T 2 K 3 K 3 S SK 6[1])	**84/77** 3.31/3.03	**86** 3.39				
50 mm 50 mm 72 mm	T 2 K 3 K 3 S SK 6[1])	**74/67** 2.91/2.64	**76** 2.99	**75.8** 2.98	BX **73.0/60.3** 2.88/2.56	TNW NSK[1])	NW NSK[3])
50 mm 50 mm 63 mm	T 2 K 3 K 3 S SK 6[1])	**64/57** 2.52/2.24	**66** 2.60				
50 mm } 53 mm[2])} 53 mm	{TT {T 2 ST 6[1])	**54/47** 2.13/1.85	**56** 220	**60** 2.36	AX **57.1/48.4** 2.25/1.91	TBW BST[1])	BW BST[3])
42 mm } 43 mm[2])} 43 mm	{TT {T 2 ST 6[1])	**44/37** 1.73/1.46	**46** 1.81	**48** 1.89	EX **46.0/38.1** 1.81/1.50	TAW AST[1])	AW AST[3])

[1]) Wire line core barrel [2]) Alurod
[3]) Interchangeable with corresponding WL drill rods in the Q-series

Note. DCDMA casing ID = inner diameter of coupling

TABLE 4.4 INSTRUMENTATION OF THE DIAMEC 250 ROTARY DIAMOND DRILL (After Brown and Barr, 1978)

PARAMETER	METHOD OF MEASUREMENT	INFORMATION OBTAINED
Rotary speed 1	The output frequency from a tachometer coupled to the drive shaft of the motor is processed by a frequency to voltage converter and transmitted to the data logger as a D.C. voltage proportional to rotary speed.	Important drilling parameter for correlation with rock mass properties. Also used in determination of torque developed at the chuck.
Head displacement 2	A rotary potentiometer monitors the movement of the pulley over which the rotary head drive chain passes. Output voltage is directly proportional to the position of the rotary head.	Used to determine instantaneous penetration rates for correlation with rock mass properties.
Thrust 3	A 0-35 MN/m^2 pressure transducer used in conjunction with an instrumentation amplifier measures the oil pressure applied to the thrust piston.	Useful parameter for controlling drilling performance.
Inlet oil pressure 4	A 0-70 MN/m^2 pressure transducer used in conjunction with an instrumentation amplifier monitors the oil pressure at the control panel.	Used in the estimation of torque (see below).
Swash plate position 5	A rotary potentiometer coupled to the swash plate shaft gives an output voltage proportional to swash plate angle.	Swash plate position and rotary speed are used to determine the torque delivered to the drill chuck from calibration curves obtained using a Heenan-Froude dynamometer.
Torque	An electronic multiplier connected in division mode is used to derive an approximate torque value from inlet oil pressure and rotary speed.	Provides an approximate torque reading to assist the driller during drilling operations.
Water flow rates Inlet 6 Outlet 7	The pressure drop across a venturi nozzle is measured by a differential pressure transducer and the signal processed by a square root extractor to produce a value of flow rate.	The net water balance in the borehole provides information on the groundwater conditions in the rock mass.
Inlet water pressure 8	A 0-1.7 MN/m^2 pressure transducer monitors the water supply to the drill string.	Useful in detecting discontinuities and as a correction to determine the effective thrust applied at the bit.
Outlet water pressure 9	A 0-0.7 MN/m^2 pressure transducer monitors the return water pressure as it passes through a stuffing box mounted on the rock face.	Useful in detecting discontinuities and sensing abnormal groundwater pressures.
Transducer and potentiometer supply voltages	Two precision voltage regulators ensure a stable supply. Any small fluctuations associated with the devices are recorded.	Recorded values of drilling parameters can be corrected for supply voltage fluctuations.

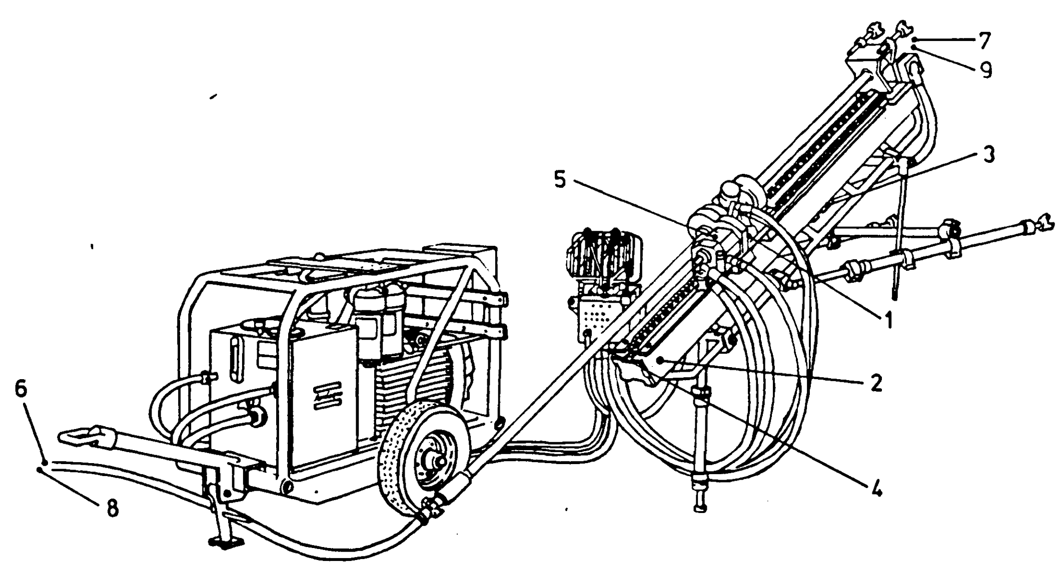


FIGURE 4.5 LOCATION OF INSTRUMENTATION ON THE DIAMEC 250 DRILLING RIG (Numbers refer to Table 4.4)

The excitation voltage is also transmitted to the data logger to provide a calibration check for subsequent data processing. When the sensor is disturbed, the resultant output voltage is transmitted to a signal conditioning unit where it is amplified and in some cases modified prior to transmission to the Mycalex data logger. Six signals are also passed to a Rikadenki strip chart recorder where they are continuously logged during drilling operations. These are:

i) head displacement
ii) torque
iii) thrust
iv) rotary speed
v) inlet water flow
vi) outlet water flow

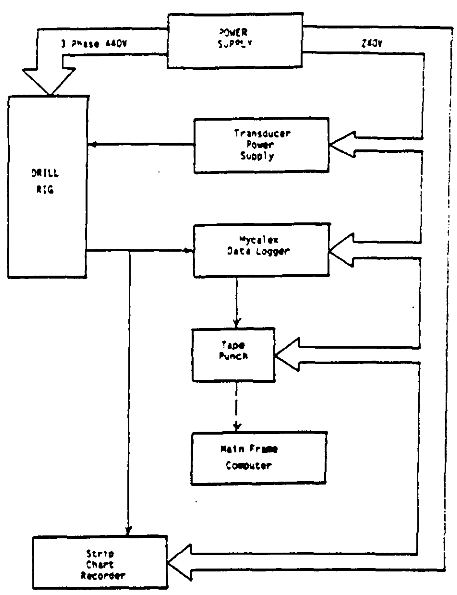


Figure 4.6: Block diagram of the electromechanical measuring system.

This provides the drill operator with more immediate information on the drill rig's performance and assists him in making adjustments to the equipment to improve cutting efficiency.

The mycalex data logger had been modified to monitor automatically up to 20 channels on four fixed voltage ranges from 0-10mV up to 0-10V each having a 15% over-range capacity. The scanning interval can be set between continuous scan to scan-on-demand. The scanning speed for any one scan can be adjusted between 50 channels/second down to 1/16 of that capability. Every scan recording is prefixed by a date/time statement followed by the value stored in each channel. A typical record might be

27160710 01 + 841 0

which means the record was made on the 27th of the month at 7 minutes 10 seconds past 4 o'clock, and channel 1 had a stored value of +8.41 volts (the 0 code at the end signifying a 0-10 volt range). This information is relayed to the Data Dynamics paper punch unit to provide a record suited to computer processing.

Each of the parameters in Table 4.4 is discussed in turn. While it is desirable to discuss the electronic circuity used to measure each parameter, it is recognised that such a discussion is not essential to a broad appreciation of the instrumentation. Therefore, it is possible for the reader to proceed to Section 4.3.9 and still obtain sufficient information to appreciate the rationale of the instrumentation package.

4.3.2 Rotary Speed

Monitoring rotary speed was a simple procedure since it was easy to fit a tachometer to the drive shaft of the Vickers motor which powers the chuck. There exists a 4:1 relationship between the tachometer output frequency and the rotary head speed with the 1.5:1 reduction gear train. The maximum speed for the Diamec 250 chuck is approximately 2200 rpm at zero load with the swash plate angle at 9^{o} and a hydraulic fluid flow rate of 60 litres/minute. Thus, with the 1.5:1 gear train the maximum motor speed is

$$2200 \times 1.5/60 = 55 \text{ cycles/second}$$

Therefore, the maximum frequency produced by the tachometer is 220 Hertz.

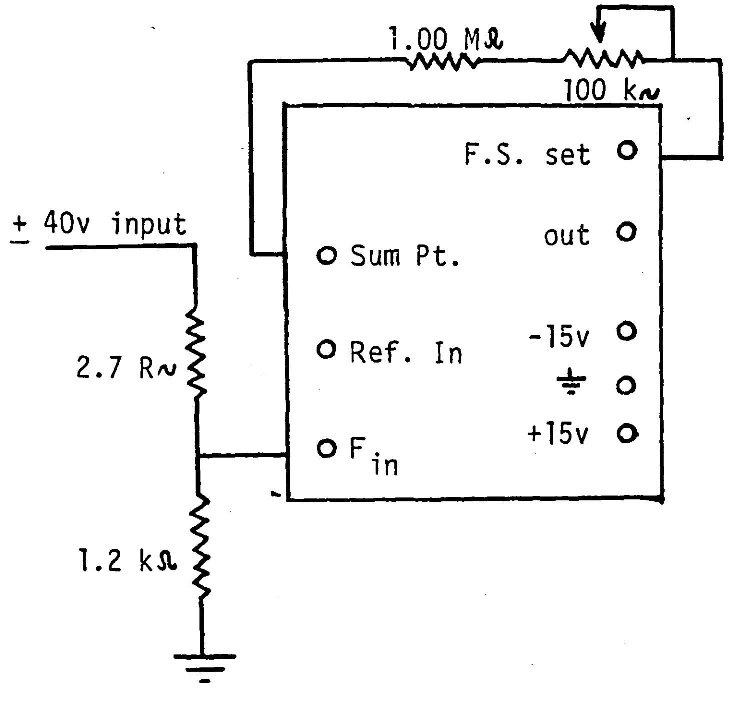
A Teledyne Philbrick (4722) frequency to voltage converter is used to provide a d.c. output directly proportional to rotary speed which is suited for transmission to the data logger. The frequency-to-voltage converter was set to provide a full scale reading (10.0 volts d.c.) at 300 Hz. Therefore, the maximum rotary head speed (2200 rpm) corresponds to 7.33 volts.

The device is connected as shown in Figure 4.7. The configuration permits the full scale factor of the device to be adjusted to provide 10 volts output for any input frequency between 100 Hz to 20 kHz by connecting a resistor (Rf) between the summing pin point and the output voltage pin. The full scale frequency is set according to the formula:

$$\underset{\text{(Ohm)}}{R_f} = R_1 + R_2 = \frac{2.7 \times 10^8}{\underset{\text{(Hz)}}{\text{desired full scale input frequency}}} \quad (\pm 20\%) \qquad \ldots(4.1)$$

the desired full scale input frequency being used to determine the size of the resistors R_1 and R_2. As noted previously, the frequency-to-voltage coverter was set to provide a full scale reading (10 volts) at an input

FIGURE 4.7 FREQUENCY TO VOLTAGE CONVERTOR WIRING DIAGRAM.



* Maximum input frequency of 300 Hz produced 10v output corresponding to a rotary speed of 3000 rpm.

frequency of 300 Hertz.

A calibration test was performed on September 27, 1977 to check the performance of the rotary speed instrumentation. A Strobosun 1203B stroboscope (Dawe Instruments Ltd.) was used to determine the velocity of the rotating chucks. (The stroboscope had guaranteed accuracy of 1% throughout its measuring range). Varying the flash of the scope, until an indicator on the rotating chucks was frozen in position, provided a measure of the rotary head speed. For successive measurements, the speed of the rotary head was adjusted via the manual over-ride for the swash plate position. The results of the calibration are listed in Table 4.5.

TABLE 4.5: Rotary speed versus tachometer output

rotary speed (r.p.m.)	tachometer output (volts)
1950	6.59
1800	6.16
1670	5.67
1560	5.30
1400	4.78
1320	4.47
1250	4.20
1150	3.86

Figure 4.8 shows a plot of these values and the best-fit line for the data as determined by the method of least squares. The equation of the regression line is

$$y = -0.08 + 0.0034\,x \qquad \text{....(4.2)}$$

where y is the tachometer output (volts)

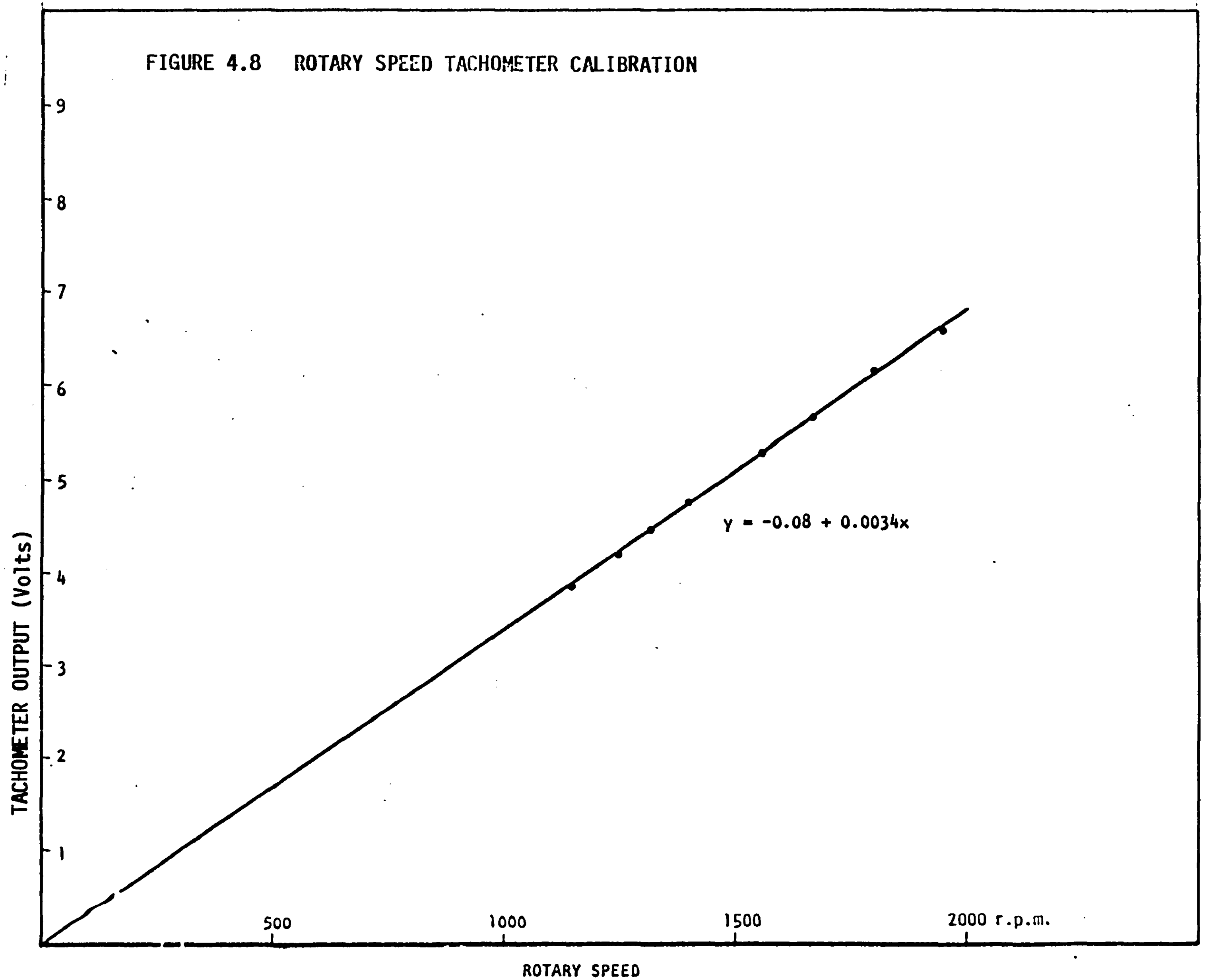
x is the rotary speed (rpm)

and the correlation coefficient is 1.00.

4.4.3 Rotary Head Displacement

The rate of penetration of the drill bit (head displacement/time) is probably the single most important parameter in drilling since it is the net effect of all the independent variables discussed in Chapter 3. Also, penetration rate is very sensitive to certain rock and rock mass properties, everything else being constant, which makes this parameter a potentially powerful diagnostic aid for assessing rock conditions in ground probing applications.

FIGURE 4.8 ROTARY SPEED TACHOMETER CALIBRATION



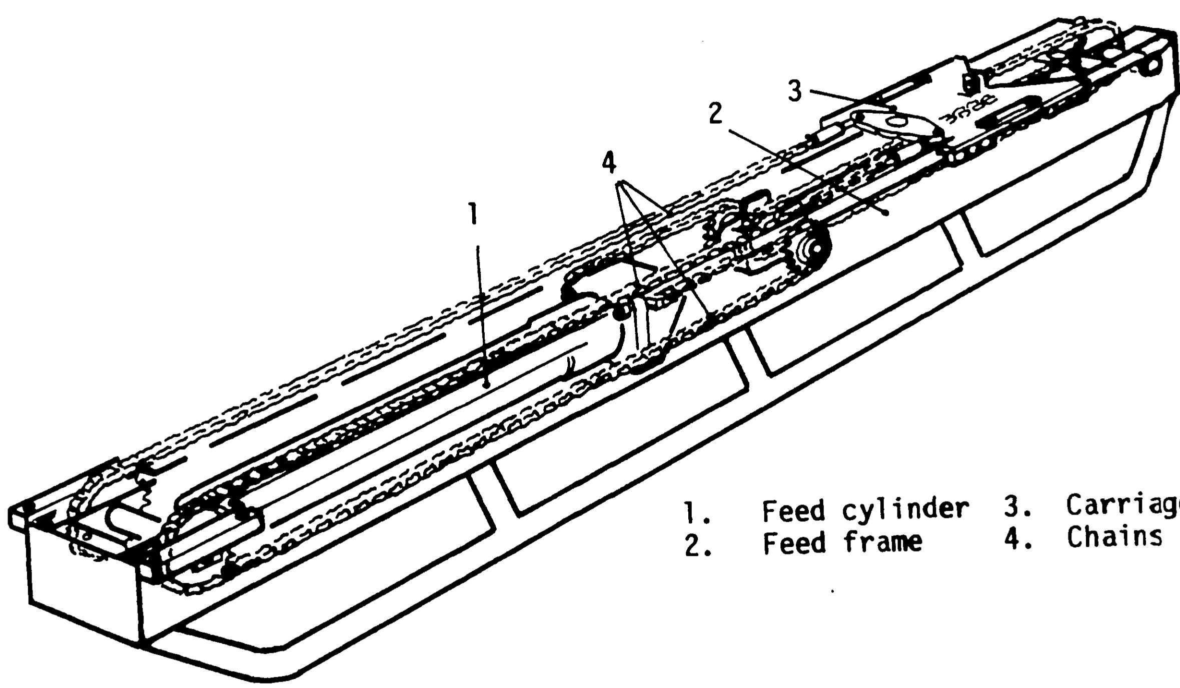
In the Diamec 250, thrust is imparted to the drill string in a hydraulic - mechanical fashion (3). Incorporated in the feed circuit is a hydraulic cylinder, located in the feed frame, which relays feed movements to the rotary head via feed chains attached to the cradle upon which the rotary head is mounted. From Figure 4.9 it can be seen that as the piston is driven out of its cylinder as a result of hydraulic pressure regulated by the pressure reduction valve on the control panel (Figure 4.2), a pull is exerted on the twin chains thereby advancing the carriage down the feed frame. Alternatively, when the action is reversed, the piston is driven back into the cylinder thus exerting a pull on the single chain which returns the carriage to the top of the feed frame. In each respective case, advancing and retracting, the single or the double chains assume a passive role.

Any forward or backward movement of the drill carriage causes rotation of the sprockets and their respective shafts, which carry the chains. Head displacement was monitored by coupling a Computer Instruments Corporation rotary potentiometer to the shaft of the single chain sprocket where it daylights at the top of the feed frame (Figure 4.5). The slider of the potentiometer results in linear variation of the voltage with the advance of the cradle (chuck). At recorded time intervals the data logger will note the voltage output from the potentiometer. Since a particular voltage corresponds to a unique location of the cradle on the feed frame, comparison of successive readings permits calculation of the head displacement over a particular time interval, the dividend being the averaged penetration rate over that interval. Using 10 volts excitation on the potentiometer, the circuit was calibrated such that the 85 cm travel of the rotary head down the feed frame corresponded to a voltage range of 7.59 volts or 0.01 volts was equivalent to 1.1199mm. The depth drilled is computed simply by keeping a record of all head advances during rock cutting. This permits association of events on the drilling record with the position of the bit in the rock mass.

4.3.4 Thrust

As noted in the preceding section, thrust is transmitted to the drill string via a hydraulic-mechanical linkage between the feed cylinder piston, and the chains attached to the cradle which carries the rotary head along the sliding surfaces of the feed frame. The feed pressure is regulated by an adjustable pressure reduction valve on the control panel and has a maximum limit less than or equal to the system pressure as a whole.

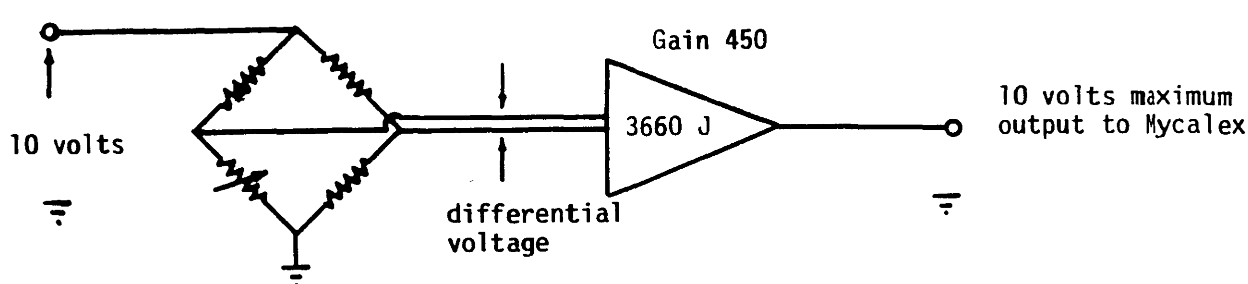
FIGURE 4.9 LOCATION OF THE THRUST CYLINDER AND ITS LINKAGE TO THE DRILL CRADLE (After Atlas Copco, 1969)



Incorporated in the circuit is a back pressure valve which permits free flow in one direction, whilst in the opposite direction opens at about 10 kg/cm^2. This arrangement prevents the rotary head assembly from dropping under its own weight when drilling vertically[272]. To advance the rotary head this back pressure must be offset by the substantially greater pressure which is brought to bear on the opposing side of the piston through manipulation of the pressure reduction valve. The double action of the feed cylinder also provides the facility for controlling rod manipulations.

The measurement of the thrust transmitted to the drill string was achieved by fitting a Bell and Howell pressure transducer (Type 4-326-L100) in conjunction with a Burr- Brown (3660J) instrumentation amplifier into the hydraulic circuit on the high pressure side of the feed cylinder. A Signetics (NE 550 A) precision voltage regulator provided 10 volts excitement for the transducer, while the differential voltage caused by the application of pressure to the transducer is amplified by the Burr-Brown amplifier (gain factor 450). This arrangement is shown schematically in Figure 4.10.

FIGURE 4.10 THRUST MEASURING CIRCUITRY



The thrust-monitoring circuitry was calibrated by recording the output voltage associated with a known pressure. This calibration was effected by mounting the transducer on a Budenberg dead-weight pressure tester and varying the load on the piston of the tester and recording corresponding voltages provided by the pressure transducer. Since the dead-weight tester is designed such that a known load on the piston corresponds to a given pressure at the transducer mount, voltage output could be scaled directly to pressure. During operation of the Diamec 250 the pressure in the thrust cylinder could easily be converted to thrust by taking into account the diameter of the thrust piston, due allowance being made for the opposing back pressure discussed earlier.

The thrust circuitry was designed for a full scale range of 10 volts at 5000 psi. Results of the Budenberg calibration tests are presented in Figure 4.11. A least-square fit for the data gives

$$y = 0.35 + 0.0018x \qquad \ldots.(4.3)$$

where

y is the pressure transducer output (volts)

x is the pressure (psi)

As might be expected given the design of the transducer, the correlation co-efficient was 1.00.

4.3.5 Inlet Oil Pressure

This parameter was measured for two reasons; as a potential means of developing a scheme for the indirect determination of torque, and as a diagnostic parameter for gauging the condition of the drill rig. The inlet oil pressure to the rotary head is monitored at a tapping on the pipework where the relevant hydraulic hose connects to the control panel.

The instrumentation used to monitor the inlet oil pressure is analogous to that used to record the thrust pressure. An Intersonde pressure transducer (Type PR15-350) is used as the pressure sensing element. The signal is again amplified with a Burr-Brown 3660J instrumentation amplifier prior to being transmitted to the Mycalex data logger (Figure 4.12). The transducer is excited by the same Signetics precision voltage source which was used to excite the Bell and Howell transducer. The full-scale range of the transducer is 15.84 millivolts according to the manufacturer's specification at nominal 10.00 volts excitation and at 10,000 psi input pressure. Thus, a gain factor of 630 allows a full-scale output of 10.0 volts corresponding to the full rated pressure. The transfer function of the amplifier is

$$V_{out} = \frac{100k}{R}(e_2 - e_1) \qquad \ldots.(4.4)$$

where

V_{out} is the output voltage

e_1, e_2 input signals

R is the value of the external gain setting resistor.

which, for a gain factor of 630 requires $R = 160\ \Omega$, the location of which

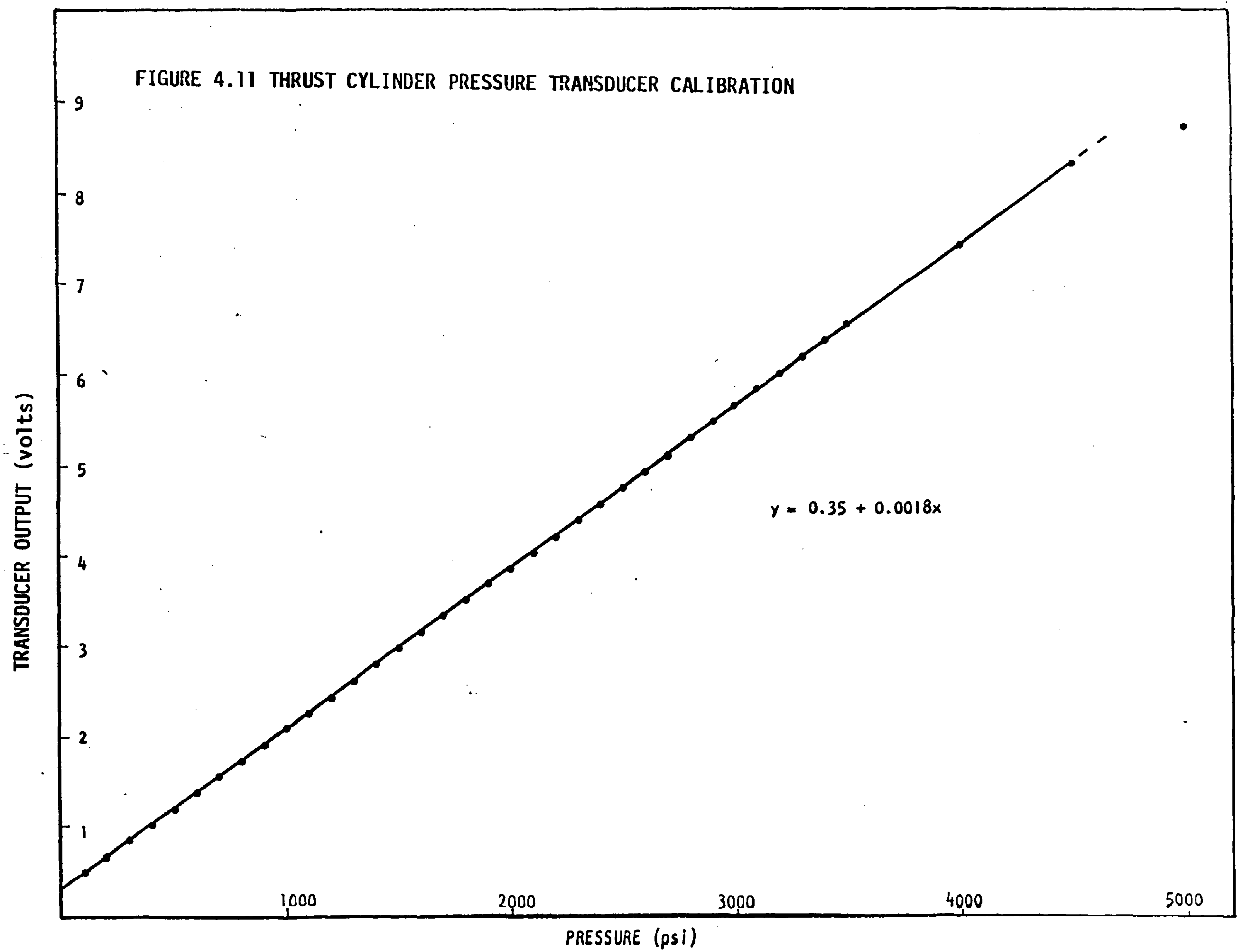


FIGURE 4.11 THRUST CYLINDER PRESSURE TRANSDUCER CALIBRATION

is shown in Figure 4.12.

Figure 4.13 shows the calibration curve for the output voltage from the transducer against pressure, as derived on the Budenberg dead-weight tester. The equation of the best fit straight line is

$$y = 0.21 + 0.0011\ x \qquad \ldots.(4.5)$$

where y is the output voltage from the inlet oil pressure transducer.

x is the pressure (psi)

with a correlation coefficent of 1.0.

4.3.6 Swash Plate Position

The Vickers motor which powers the rotation unit of the Diamec 250 is essentially an in-line axial piston pump. The pistons ride on a variable-angle swash plate, the angle of which determines the swept volume of the cylinders and ultimately the volume of oil consumed in effecting a revolution of the chuck. A manual over-ride is fitted to the motor which allows the swash plate angle to be set at any desired position between 9 and 17.5^{o}. However, since the volume of oil delivered to the motor by the power pack is fixed at 60 litres/minute, any adjustment of the swash plate position exerts an influence on the power characteristics of the drill motor. Thus, an infinite family of power curves theoretically exists over the angular range of the swash plate. In order to decide which power curve applied to a particular drilling situation, it was necessary to record the setting of the swash plate.

Fortunately, the shaft upon which the swash plate pivots daylights on the outside of the motor casing (Figure 4.5). This shaft was drilled and tapped to accept a brass coupling which in turn had a tongue fitted in the opposite end to allow it to marry with the slotted spindle of a Bournes 3535 S rotary potentiometer. The potentiometer was held fixed in place by an aluminium housing which also served to shield the electrical connections of the potentiometer from the incursion of water. This set-up ensured that any movement of the swash plate would be registered by the potentiometer and relayed as a voltage to the Mycalex data logger. This information could then be used to calculate the torque curve which operated at that particular swash plate setting. The method of deciding which torque curve applies at a given swash plate angle is treated in greater detail in Section 4.4.

FIGURE 4.12 INLET OIL PRESSURE WIRING DIAGRAM

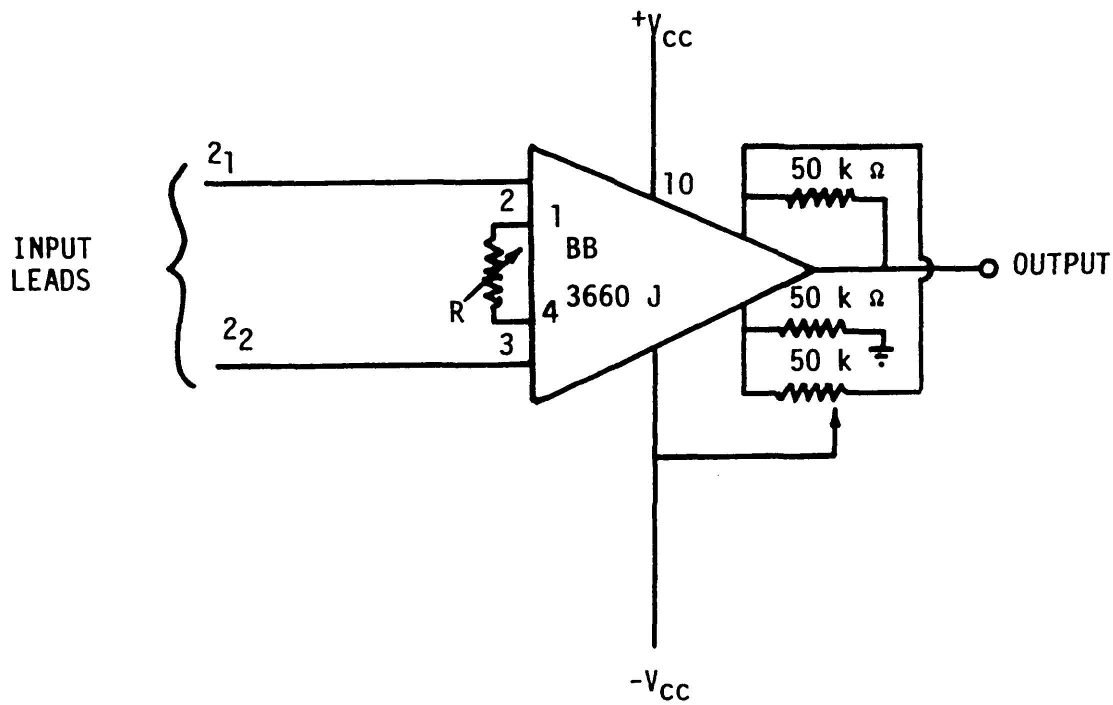
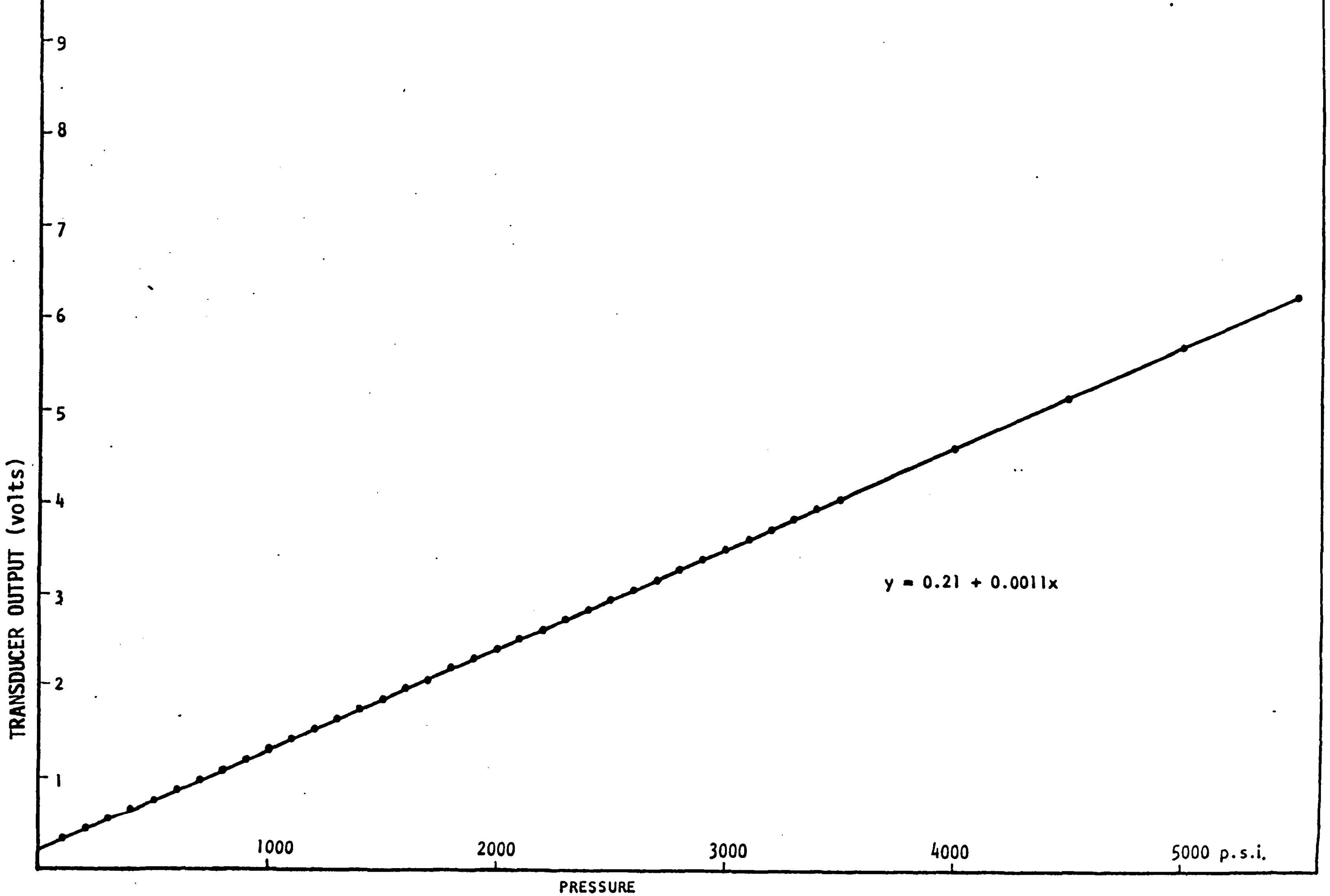


FIGURE 4.13 INLET OIL PRESSURE TRANSDUCER CALIBRATION



4.3.7 Torque

Two methods of monitoring the torque developed at the rotary head of the drill were employed throughout the drilling trials. The most exact technique was based on the results of dynamometer calibration tests wherein the rotary head was coupled to a Heenan-Froude dynamometer and developed torque was measured with respect to inlet oil pressure, rotary speed and swash plate position. These calibration trials are the subject of a detailed discussion in Section 4.4 and hence will not be treated here.

The other method of monitoring torque is based on the result of a particular dynamometer trial where the swash plate was in the minimum displacement position (highest idling speed). During this calibration run the rotary speed and the inlet oil pressures were recorded to provide Figure 4.14. While this relationship is not linear, the range over which the drill normally operates at this swash plate setting is a reasonable linear approximation. Since the torque value provided by this technique was to serve only as a guide for the operator during drilling operations the error inherent in the linear assumption was of little consequence. Similar plots for other swash plate settings are given in Appendix 1 . Also, the adoption of a linear approximation simplified the electronic circuitry required to model the dynamometer result.

A Burr-Brown 4206J multiplier connected in division mode in alliance with a LM 709 inverter was used to process the values of inlet oil pressure and rotary speed (Figure 4.15). From the dynamometer test, torque (T) could be characterised in the following manner:

$$T = K \frac{p}{\omega} \qquad \text{....(4.6)}$$

where

K is a constant

p is inlet oil pressure

ω is rotary speed

In division mode

$$E_{out} = 10 \; (E_Z/E_X) \qquad \text{....(4.7)}$$

where

$-10V \leq E_X \leq -0.1V$

$-10V \leq E_Z \leq +10V$

and

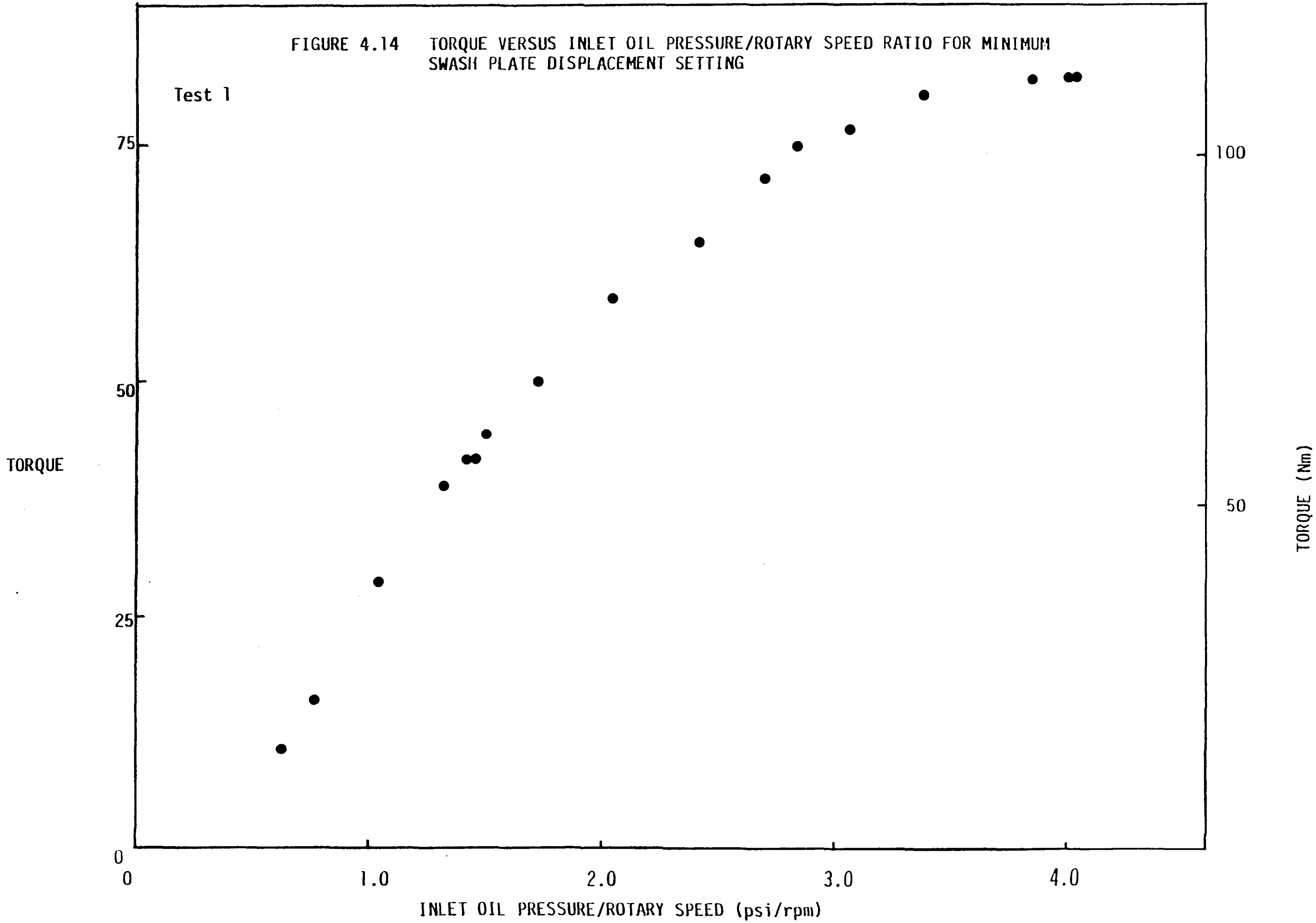
E_X is the inverted rotary speed signal(ω')

$\omega' = -\omega$

E_Z is the inlet oil pressure ($E_Z = -P$)

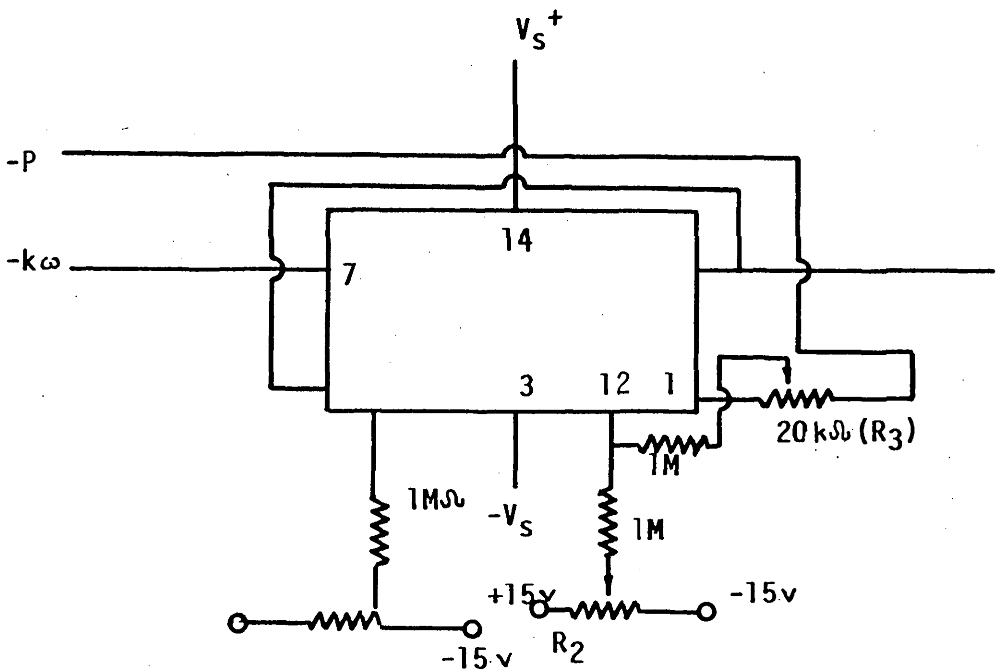
Thus over the working range of 660 to 2200 rpm, ω' lies between -2.0 volts

FIGURE 4.14 TORQUE VERSUS INLET OIL PRESSURE/ROTARY SPEED RATIO FOR MINIMUM SWASH PLATE DISPLACEMENT SETTING



TORQUE

(Multiplier 4206J - Burr Brown)



(Associated with LM 709 Invertor)

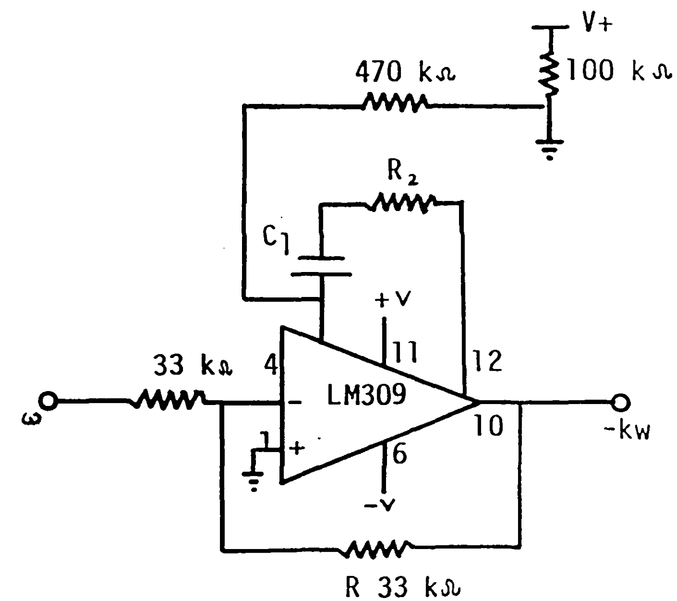


FIGURE 4.15 CIRCUITRY FOR APPROXIMATE TORQUE DETERMINATION

(-2.20v) and -7.5 volts (-7.33v), the figures in brackets being the values associated with the respective rotary speeds.

The full scale reading on the inlet oil pressure system is 1000 psi although in practice the maximum pressure value is equivalent to 3.0 volts. However, at the highest operating pressure (-3.0 volts) and lowest idling rotary speed (-2.0 volts) the output voltage (Equation 4.7) would exceed the device's limit of 10.0 volts and result in an overflow on the Mycalex. Therefore, if $\omega' = -k\,\omega$ then

$$E_{out} = \frac{10(-p)}{-k\,\omega} \qquad \ldots\ldots (4.8)$$

and at the lowest idling speed

$$E_{out} = \frac{10(-3.0)}{-k\,(2.0)} \qquad \ldots\ldots (4.9)$$

Hence, $k \geqslant 1.5$ for the output to stay in range. There is a second restraint which states that

$$k \text{ (maximum velocity of the rotary speed signal)} < 10 \text{ volts}$$

or

$$k\,(7.3) < 10 \text{ volts}$$

which restricts the value of k to < 1.36. Clearly both these conditions cannot be satisfied. In practice, however, if k = 1.0 the torque relationship between the inlet oil pressure and rotary speed will remain valid for speeds down to approximately 1000 rpm. This is satisfactory since this technique of torque measurement is only used to provide control data for the operator, who under normal drilling conditions wishes to maintain rotary speeds well in excess of 1000 rpm with the swash plate in the minimum displacement setting.

4.3.8 Net Water Flow Rate and Pressures

The flow of drill fluid in the borehole can provide considerable information on the nature of the rock mass through which the drill bit is penetrating. For example, a loss or decline in circulation probably indicates a zone of relatively higher conductivity and vice versa. At the same time inlet and outlet water pressures should offer potentially valuable information for identifying formations (shale, clay, fractured ground, etc.) and zones of high pressure groundwater (aquifer formations) of interest to tunnelling site investigations.

Figures 4.16 and 4.17 show schematic representations of the inlet

FIGURE 4.16 INLET WATER FLOW AND PRESSURE MONITORING SYSTEM

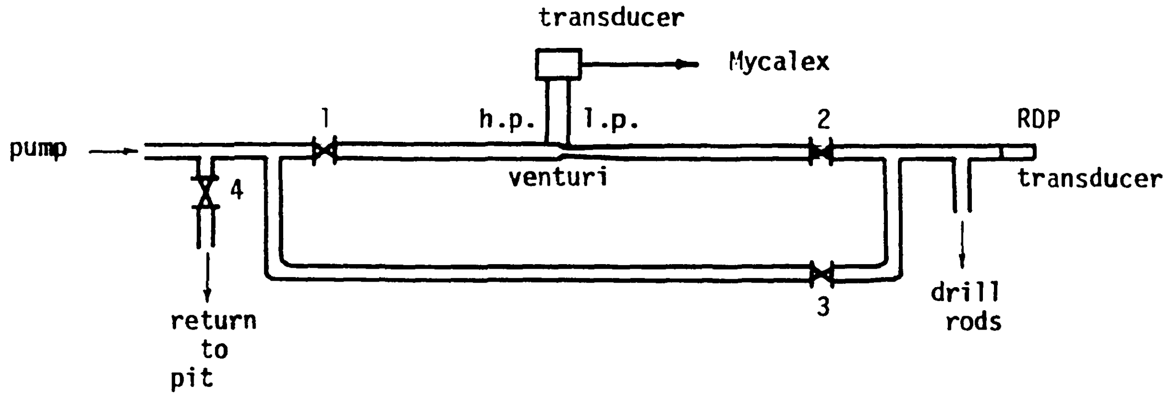
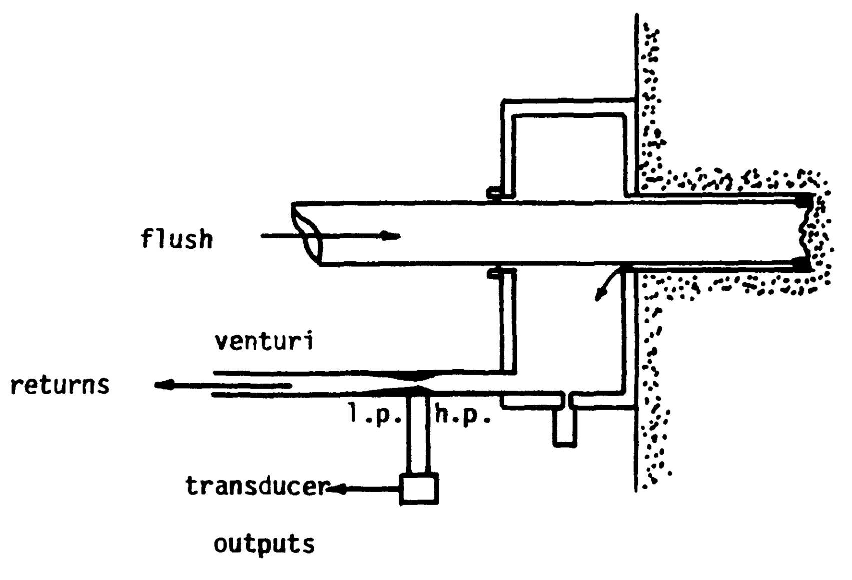


FIGURE 4.17 OUTLET WATER FLOW AND PRESSURE MONITORING SYSTEM



and outlet water flow and pressure monitoring systems respectively. Water flows were measured by a Tekflo venturi metering system which comprised

i) a venturi nozzle (Type VN20)

ii) a type TF2 differential pressure transducer with 0-40 metres water gauge differential pressure range and

iii) a type TR2 transmitter with a 0-10 volt range.

The venturi nozzle had an upstream portion which reduced sharply in area to a throat of approximately 1/3 of the upstream diameter. Beyond the throat the downstream section gradually assumed the original pipe diameter. Flow through the nozzle required an increased velocity accompanied by a reduction in pressure through the throat of the device. In the downstream end of the venturi the velocity is converted back to the original pressure except for a very slight friction loss which is approximately 0.1% of the velocity head at the throat[282,283]. The venturis were installed in compliance with the recommendations of British Standard 1042 [284].

The discharge from the venturi nozzle is determined from

$$Q = \frac{C\ A}{\left[1-(d/D)^4\right]^{\frac{1}{2}}} \sqrt{2g\Delta h} \qquad (4.10)$$

where

C is a velocity coefficient dependent on the Reynolds Number and diameter ratio (d/D)

A is the cross-sectional area of the throat

D is the diameter of the upstream section

d is the throat diameter

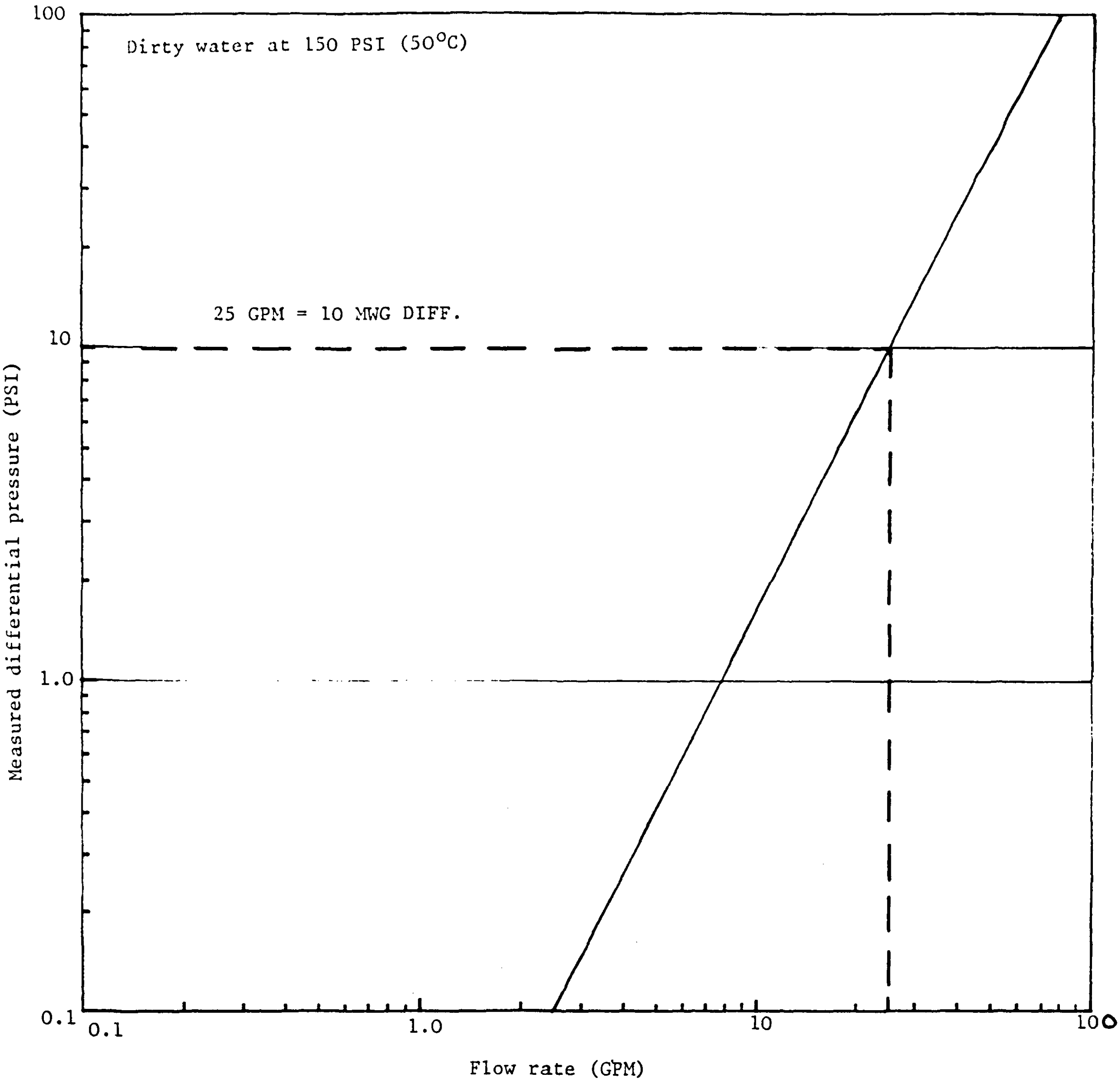
g is gravitational acceleration

Δh is the difference in piezometric head between the upstream section and the throat

Pressure tappings on the upstream and downstream side of the throat of the venturi are connected to the high and low pressure sides respectively of the differential pressure transducer, to provide a value for Δh. The differential pressure is converted to an analogue output and fed to the transmitter, which not only energized the transducer but also processed the input signal from the transducer and displays it as an analogue signal proportional to the flow rate.

The calibration curve for the venturi nozzles is shown in Figure 4.18. Flow rates ranging from 0 to 25 Imperial gallons/minute (0 to 114 l/min) are displayed as a single-ended voltage in the range 0 to 10.0 volts. The net flow rate in the borehole is determined by subtracting the outlet water flow values from the inlet water flow values.

FIGURE 4.18: CALIBRATION CURVE FOR THE VENTURI METERS



Figures 4.16 and 4.17 locate the position of the RDP pressure transducers used to monitor the inlet and outlet water pressures. The transducer in the by-pass circuit of the water supply had a range of 0-1.7 MN/m^2 (0-250 psi) while that on the stuffing box was limited to a range of 0-0.7 MN/m^2 (0-100 psi). The excitation voltage was provided by the Weir Twinpack power supply and the voltage was stabilized by the Signetics NE 550A voltage regulator.

Figures 4.19 and 4.20 show the calibration curves for the inlet and outlet water pressure transducers respectively. As before, the Budenberg dead-weight pressure tester was used to load the transducers during the calibration tests. The equations of the best fit lines for the data are

$$Y = 0.71 + 0.04\,X \qquad \ldots\ldots(4.11)$$

and

$$Y = 1.52 + 0.09\,X' \qquad \ldots(4.12)$$

where

Y is the output voltage
X is the inlet water pressure
X' is the outlet water pressure

In both cases, the correlation coefficient is 1.00.

4.3.9 Summary of Diamec 250 Instrumentation

Table 4.6 gives a detailed listing of the measured parameters during the drilling trials. All of these parameters are logged by the Mycalex and stored on paper tape. In addition, head displacement, torque, thrust, rotary speed and inlet and outlet water pressure are continuously recorded by a Rikadenki strip chart recorder. The chart recorder provided a useful guide for the operator during drilling operations, being particularly useful in highlighting core blockages, etc. The output from the chart recorder can also be used as a diary, particularly to mark events on the drill record which can be scrutinized at a later date.

4.4 Torque Calibration and Dynamometer Trials

4.4.1 Introduction

The most difficult problem to solve with respect to instrumenting the Diamec 250 concerned torque. Given the hydraulic drive which powers the rotary head of the drill several alternative methods of measuring torque were possible, including:

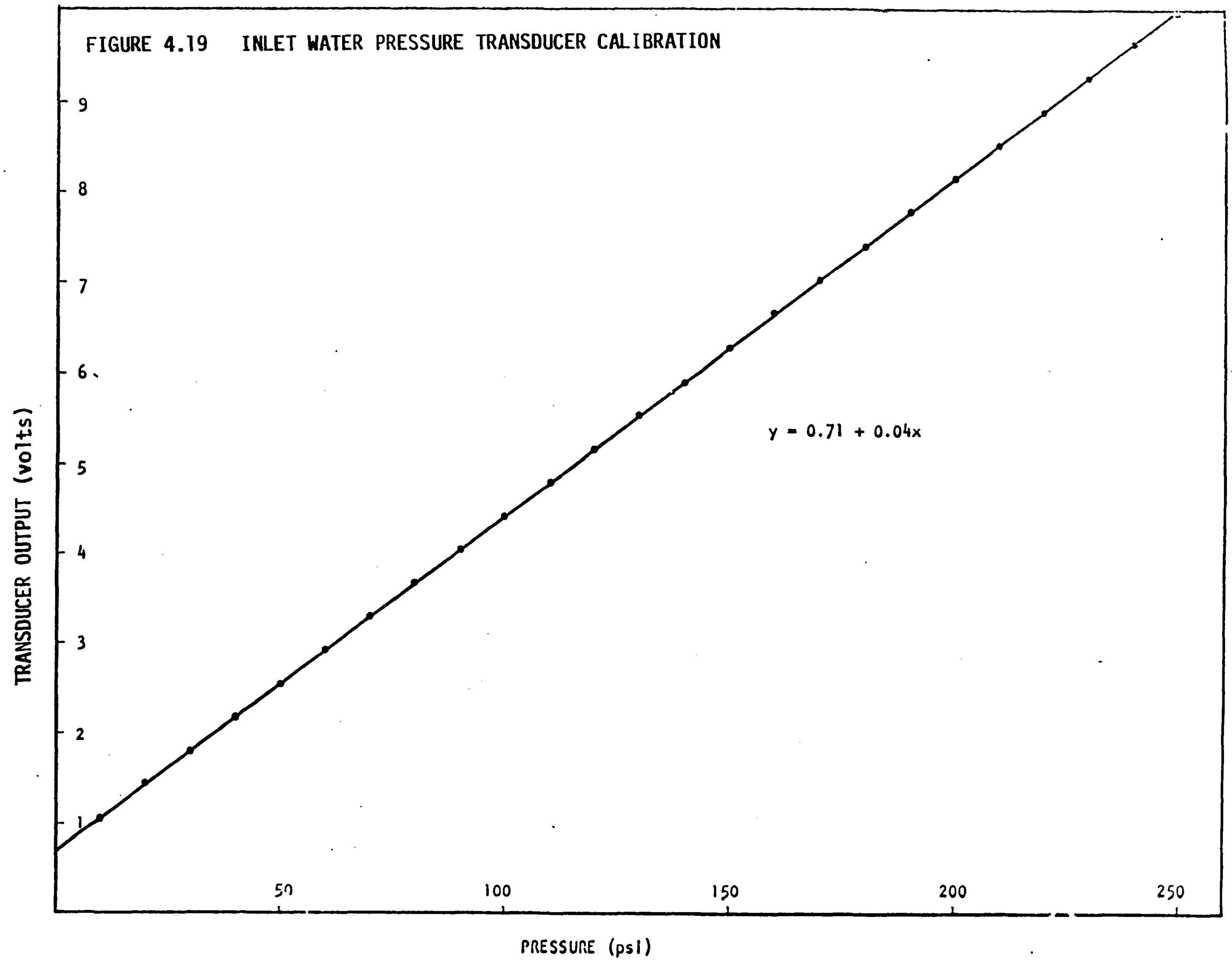


FIGURE 4.19 INLET WATER PRESSURE TRANSDUCER CALIBRATION
TRANSDUCER OUTPUT (volts)
1
2
3
4
5
6
7
8
9
y = 0.71 + 0.04x
50
100
150
200
250
PRESSURE (psi)

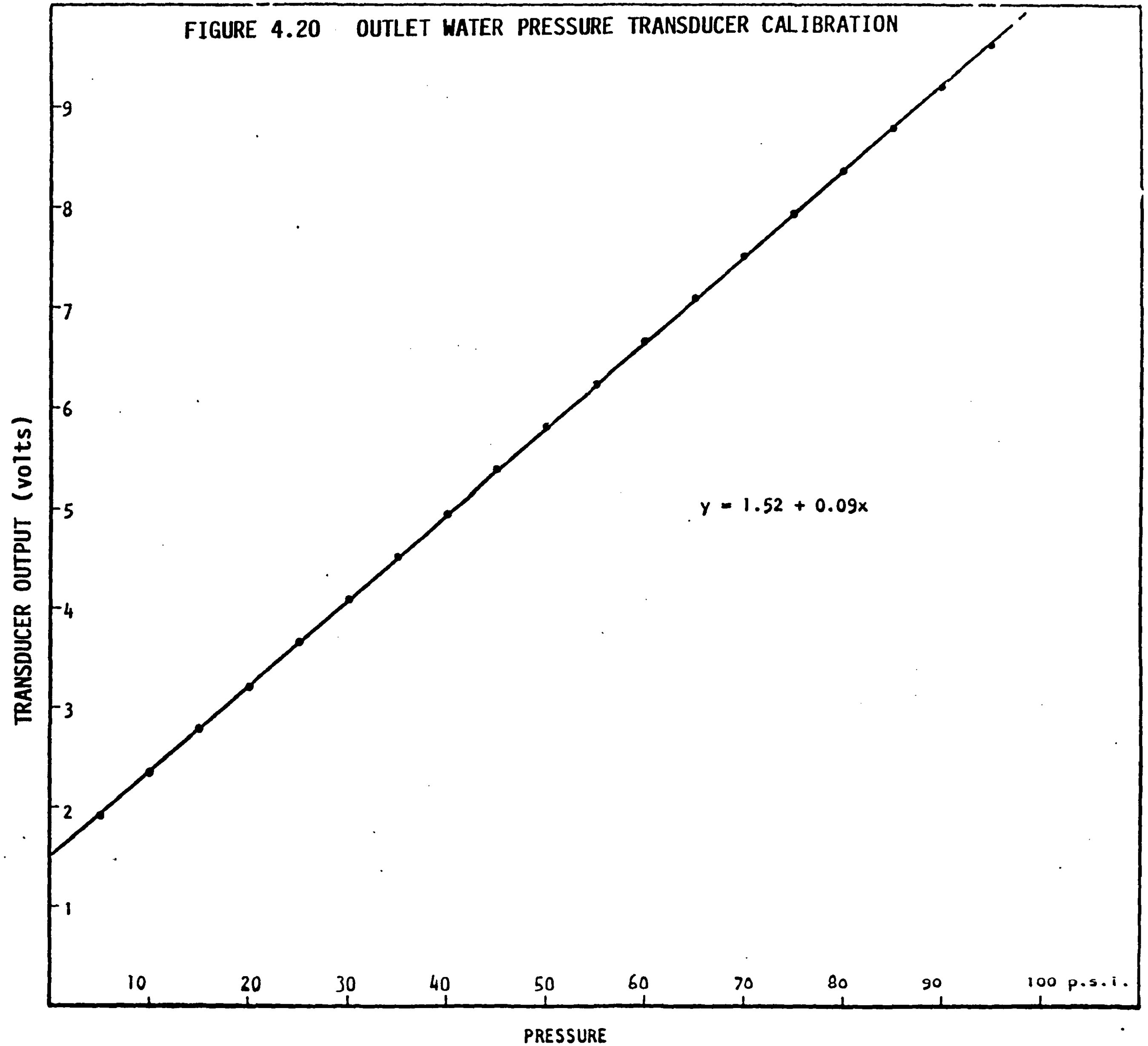


FIGURE 4.20 OUTLET WATER PRESSURE TRANSDUCER CALIBRATION

TABLE 4.6

INSTRUMENTATION OF THE DIAMEC 250 ROTARY DIAMOND DRILL

Parameter	Method	Range	Excitation voltage	Linearity	Sensitivity	Information
Rotary speed	The output frequency from a tachometer coupled to the drive shaft of the motor is processed by a Teledyne-Philbrick (4722) frequency-to-voltage converter and transmitted to the data logger as a DC voltage directly proportional to rotary speed	0 - 10 volts for 0 - 3000 rpm	Alternating voltage whose magnitude and frequency is proportional to the speed	± 1% of full-scale reading	± 3% of full-scale reading	Important drilling parameter used for correlation with rock mass properties. Also used to determine torque developed at the chuck
Inlet oil pressure	An Intersonde type PR15-350 pressure transducer in conjunction with a Burr-Brown 3660J instrumentation amplifier monitors the oil pressure at the control panel	0 - 10 volts for 0 - 70 MN/m^2	10 volts	± 0.3% of full-scale reading	0.3%	Used as a check on torque
Head displacement	A Computer Instruments Corp. rotary potentiometer monitors the movement of the pulley over which the rotary head drive chain passes. Output voltage is proportional to the position of the rotary head	0 - 850 mm	10 volts	± 0.5% of full-scale reading	1%	Used to derive instantaneous penetration rate for corrolation with rock properties
Thrust	A Bell and Howell type 4-326-L100 pressure transducer in conjunction with a Burr-Brown (3660J) instrumentation amplifier measures the pressure exerted on the Diamec 250 thrust piston	0 - 10 volts for 0 - 35 MN/m^2	10 volts	10.5% of full-scale reading	1%	Useful drilling parameter for evaluating drill performance
Swash plate position	A Bournes 3535S potentiometer is coupled to the shaft on which the swash plate pivots, the output voltage being proportional to the swash plate angle	0 - 230 millivolts for 0 - 8.5°	10 volts	± 0.5%	0.4% of full-scale reading	The swash plate position and the rotary speed are used to determine the torque delivered to the drill chuck from experimentally derived relationships using a Heenan-Froude dynamometer
Torque	A Burr-Brown 4206J multiplier, connected in division mode is used to derive an approximate torque value based on inlet oil pressure and rotary speed	N.A.	N.A.	0.05%	N.A.	Provides approximate torque reading to assist driller during cutting operations by employing an approximately linear relationship among torque, r.p.m. inlet oil pressure and swash plate position
Inlet/outlet water flow	The pressure drop across a Takflo venturi nozzle is measured by a differential pressure (83 MN/m^2 maximum) transducer and the signal processed by a square root extractor to produce a value for the flow rate	0 - 10 volts for 0 - 114 l/min	5 volts r.m.s. at 1400 Hz	± 0.5% of full-scale reading	0.114 l/min	Net water balance in the borehole provides information on the groundwater characteristics of the rock
Inlet water pressure	A RDP Electronics type P5/250 pressure transducer monitors the water supply pressure to the drill string	0 - 10 volts for 0 - 1.7 MN/m^2	5 volts r.m.s. at 5 kHz	± 0.5% of full-scale reading	0.002 MN/m^2	Useful in detecting discontinuities and as a correction to determine the net thrust applied to the bit
Outlet water pressure	A RDP Electronics type P5/100 pressure transducer monitors the return water pressure as it passes through a stuffing box on the rock face	0 - 10 volts for 0 - 0.7 MN/m^2	5 volts r.m.s. at 5kHz	± 0.5% of full-scale reading	0.001 MN/m^2	Useful in detecting discontinuities and sensing abnormal groundwater pressures
Transducer and potentiometer supply voltages	Two Signetics NE550A precision voltage regulators ensure a stable voltage supply. Small voltage fluctuations associated with the devices are recorded by a Mycalex data logger	0 - 10 volts	N.A.	75 dB ripple rejection over frequency of 50 Hz to 10 kHz	N.A.	Recorded values for transducer and potentiometer dependent parameters can be corrected for slight voltage fluctuations

i) Coupling a torque measuring device between the drill rods and the core barrel and passing a signal to a surface recording unit.

ii) Strain gauging the drive shaft of the drill motor.

iii) Fitting a torque transducer to the motor spindle which couples the motor to the gear box.

iv) Deriving torque values by measuring related parameters.

Methods (a) and (b) were dismissed as possibilities since obtaining a reliable signal from either location was extremely doubtful. Measuring the torque immediately behind the bit is the ideal solution to this problem as it provides a more reliable estimate of the forces which ultimately are directed towards the destruction of the rock by the drill bit. However, a torque monitoring device in this location required the measured signal to be passed to the surface along a cable terminating at a slip ring, along conducting elements built into specially constructed drill rods (a very costly procedure) or by a down-hole telemetry device. Whichever system is chosen it must be capable of surviving in a wet and possibly high pressure environment while being subjected to continuous vibration. Alternatively, strain gauging the drive shaft of the drill motor requires a slip ring to function in a high temperature oil bath (normal running temperature 70^{o}C).

Boyd[212] installed a torque transducer between the motor and the gearbox of a Diamec 250 during instrumented drilling trials at Meldon Quarry, Devon. The system performed well until the transducer failed owing to repeated flooding with hydraulic oil because of leaking oil seals. Since reliability was as important as accuracy during the envisaged instrumented drilling trials this method was rejected as being costly and of doubtful serviceability. Thus, an indirect measurement of torque was adopted for the drilling trials in this study. However, before the dynamometer calibration of the torque developed by the drill can be discussed it is necessary to consider the hydraulics of the rotation unit at some length.

4.4.2 *Hydraulic Mechanical Description of the Rotation Circuit*

The driving mechanism for the rotary head of the Diamec 1000 has been described by Lidstrand[285]. As the Diamec 250 and 1000 are operated by the same principle, Lidstrand's comments have been adapted by the author to conform to the design of the Diamec 250. In Figure 4.21 an in-line axial piston motor, on the right, is powered by oil supplied by an in-line axial piston pump, on the left. This pump is housed in the hydraulic oil reservoir of the electric power pack. Both the pump and motor are pressure-compensated.

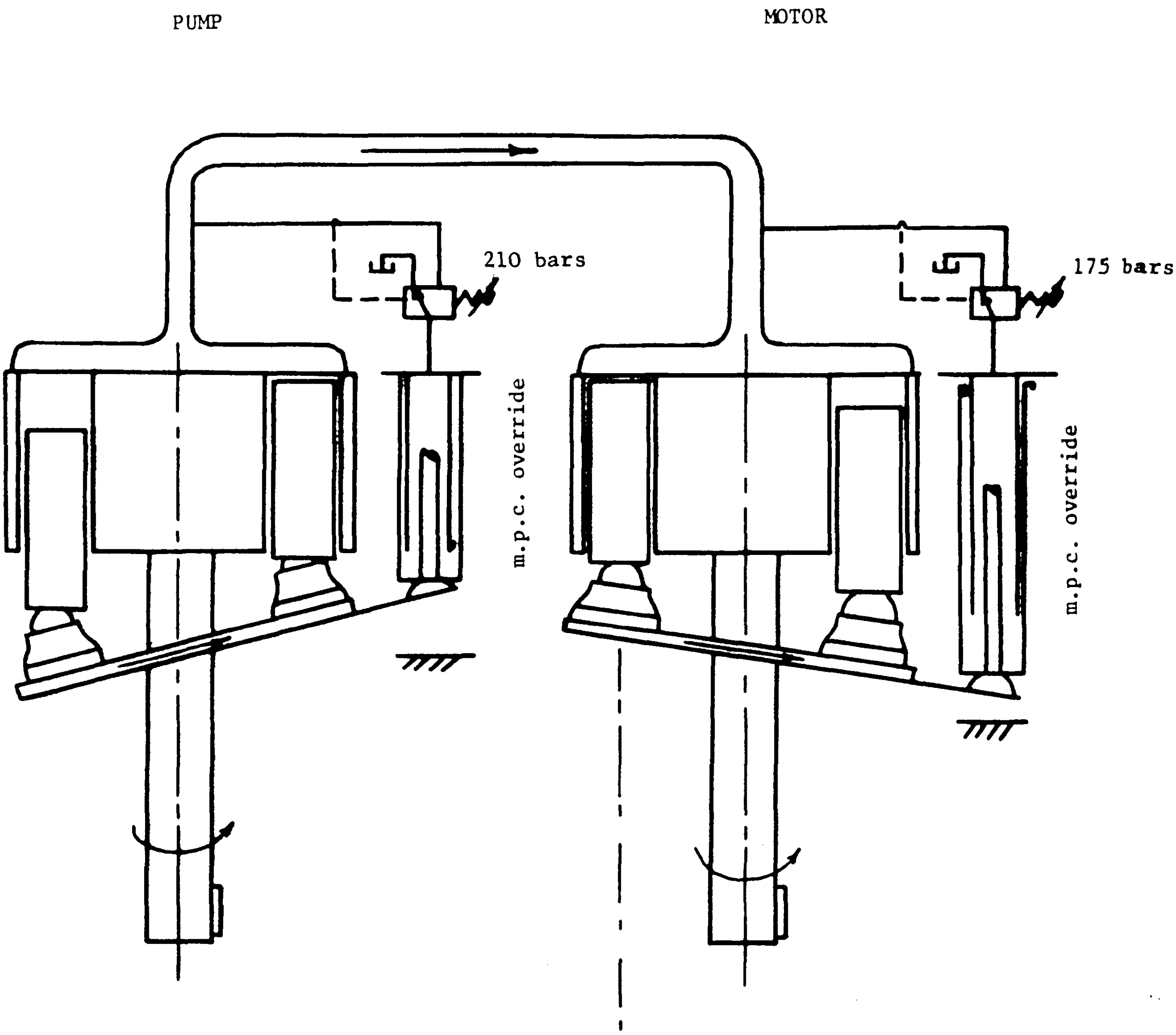


Figure 4.21 The pressure compensated, in-line axial piston pump and motor powering the Diamec 250 (after Lidstrand, 1976).

Considering Figure 4.21, when the prime mover (the 25 h.p. electric motor) rotates the shaft of the pump, the cylinder block and pistons rotate against an obliquely mounted swash plate. When contacting the lower part of the swash plate, the pistons will have vacated their cylinders, thereby sucking in oil. Continued rotation brings the pistons to the high side of the swash plate, thus driving the pistons back into their cylinders and forcing the oil out of the cylinders at pressure. The pressurized oil initiates the following sequence of events upon the motor. On the inlet side of the motor, the pistons will be driven out of their cylinders by the incoming oil and, as the pistons act upon an angled swash-plate, rotation is induced (Figure 4.22).

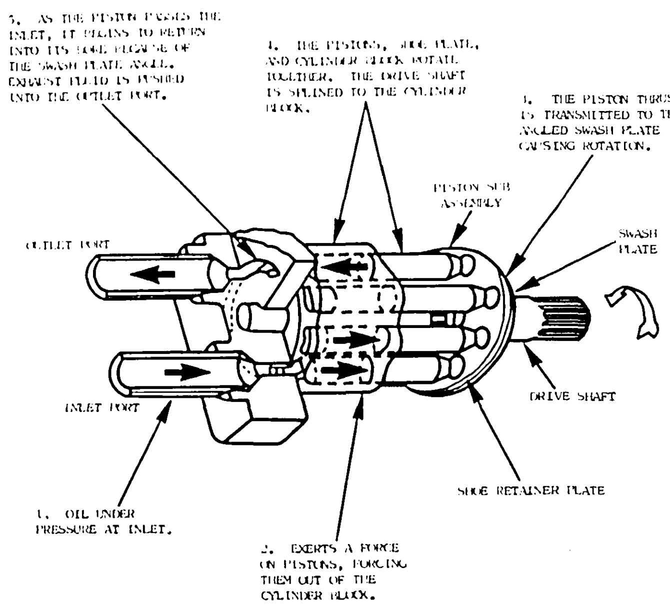
The displacement of the pistons is established by the angled swash-plate of the motor: the greater the angle, the longer the stroke and hence the greater the displacement volume per revolution[286]. The angle of the swash plate is variable, the motor normally operating between 9^{o} and 17.5^{o} below the horizontal while the pump ranges between 0^{o} and 17.5^{o} above the horizontal.

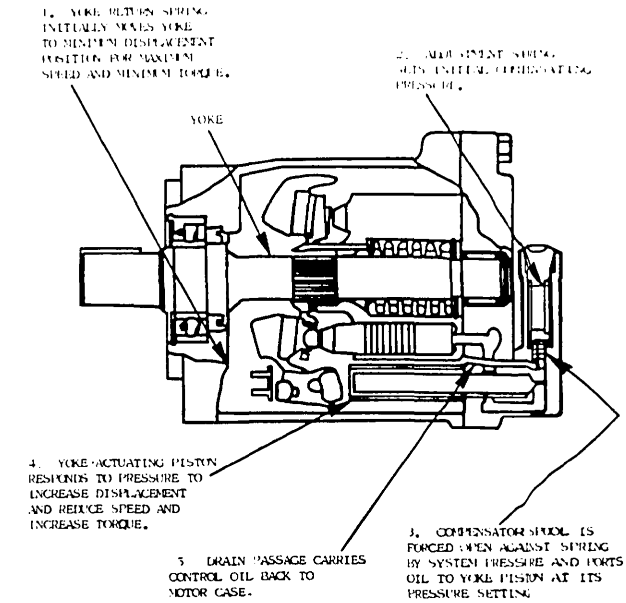
Atlas Copco Craelius designed the drill system to run within a desired rpm range in order to achieve the optimum peripheral speed for their drilling bits. In attempting to maintain this condition, Atlas Copco Craelius incorporated a pressure compensation device which automatically regulates the rotational speed, displacement and torque of the in-line axial piston pumps and motors to suit variations in rock conditions. The pressure compensators automatically adjust the swash plate angles of the motor and, if necessary, the pump to vary the displacement and torque to cope with varying drilling conditions. A mechanical override permits manual adjustment of the swash-plate angles to perform particular drilling operations (drilling overburden, setting casing).

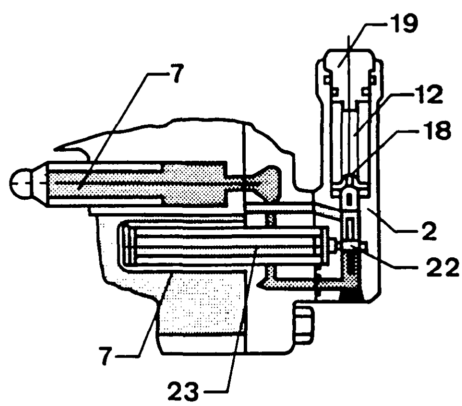
Any resistance to rotation encountered during drilling (e.g. interception of a quartz vein in slate) will induce the system pressure to rise. At a threshold oil pressure of 175 bars, the compensator operates on the rotation motor to automatically increase its displacement and consequently the torque, the torque of a motor being defined by

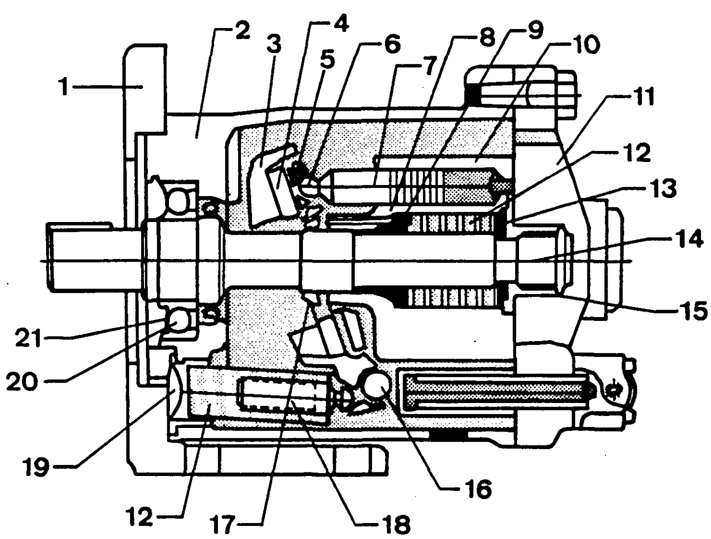
$$\text{Torque (ft/lbs)} = \frac{\text{hydraulic pressure (inlet) x displacement}}{24\pi} \qquad ...(4.13)$$

The pressure compensation system comprises a yoke actuating piston (Figure 4.23) which increases the angle of the swash-plate when the system pressure increases thereby increasing the displacement and consequently the torque of the motor. When the system pressure reaches 175 bars (the initial









HYDRAULIC PUMP WITH PRESSURE COMPENSATOR

Suction pressure

System pressure

1 Support
2 Casing
3 Obliquely mounted yoke
4 Obliquely positioned swash plate
5 Obliquely positioned gliding plate
6 Piston shoe
7 Piston
8 Pin
9 Shim
10 Valve block
11 Steering plate
12 Spring
13 Snap ring
14 Shaft
15 Needle bearing
16 Ball
17 Thrust washer
18 Seat
19 Plug
20 Ball bearing
21 Seal ring
22 Compensator spool
23 Piston rod actuating piston rod

FIGURE 4.22

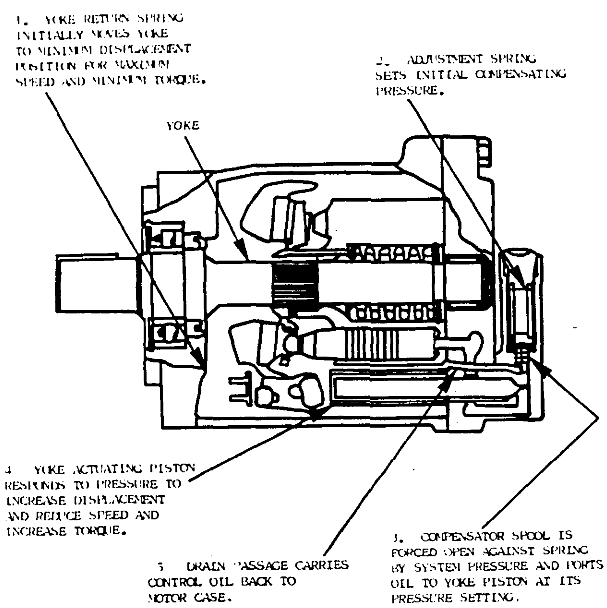


FIGURE 4.23

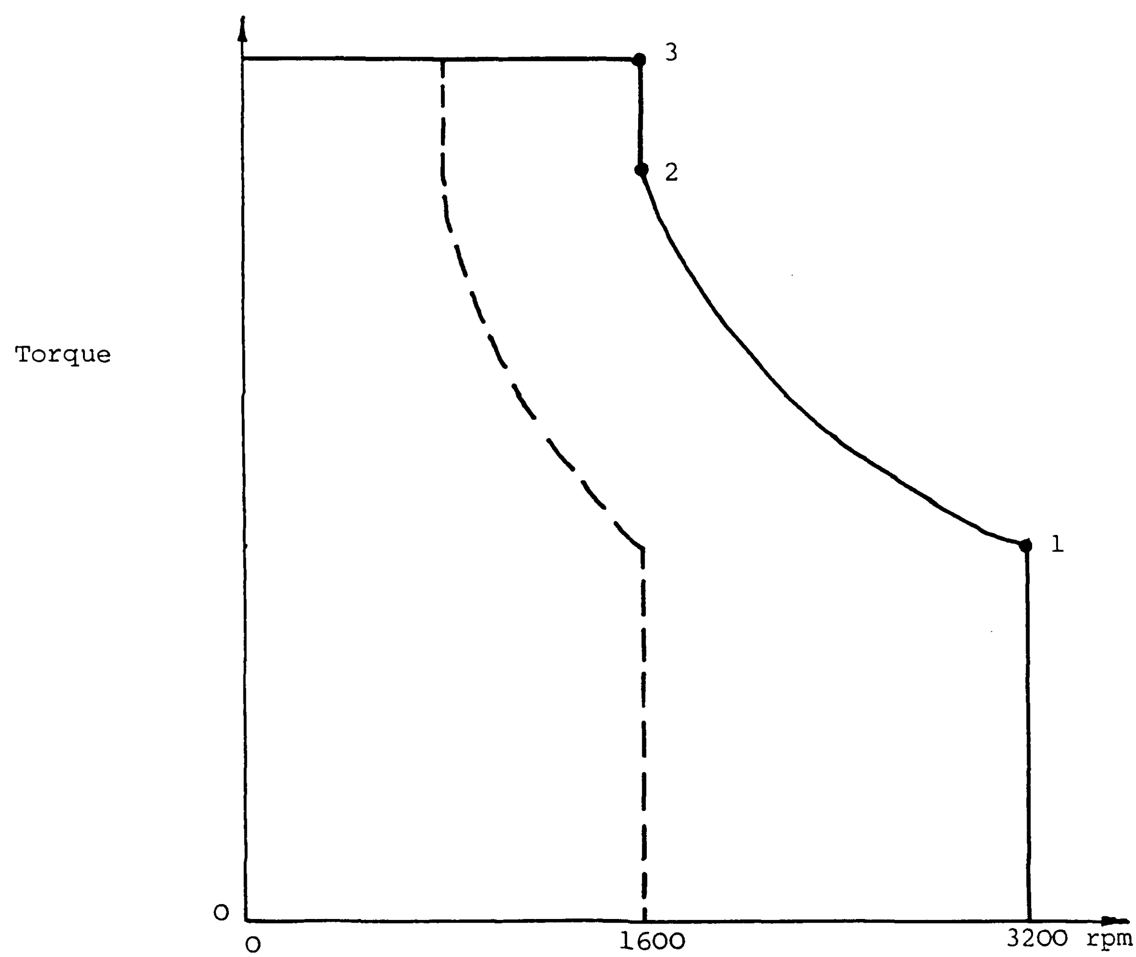
COMPENSATOR CONTROL ADJUSTS SPEED TO LOAD (After Atlas Copco) compensating pressure), the compensator spool is forced open against the adjustment spring, porting oil to the top of the yoke actuating piston. Forcing the piston downwards exerts pressure upon one arm of the yoke thereby driving it downwards. As the swash-plate is mounted on the yoke, this increases the swash-plate angle which in turn lengthens the piston stroke, thereby increasing the swept volume of the cylinders (increased displacement).

The swash-plate angle of the motor has a minimum setting of approximately 9^{o} increasing to a maximum of about 17.5^{o}. Moving the swash plate through this range doubles the displacement of the motor. Increasing the displacement reduces the speed since more oil is consumed per revolution. An increase in torque is desired and, in fact, it is doubled. A rotation pressure of 175 bars gives the desired balance between rotation speed and torque during normal drilling. However, the pressure compensator will be activated frequently to adjust for variations in drilling resistance[285].

Should the drilling resistance be such that even the doubled torque is incapable of effecting rotation, then the system pressure will exceed 175 bars up to a maximum of 210 bars (maximum delivery pressure of the pump). At 210 bars, the setting spring of the pump pressure compensator will allow hydraulic oil to port to the yoke piston, thus rapidly depressing the pump swash-plate to its 0^{o} setting. No displacement is possible in this circumstance and the drill will "stall" because of excessive feeding by the operator.

Figure 4.24 depicts the foregoing discussion graphically. The graph shows the motor speed as approximately 3200 rpm when the system hydraulic pressure is below 175 bars. Since the displacement of the pump is constant (fixed swash-plate unless altered by the mechanical over-ride), both torque and pressure are proportional to each other. With increased drilling resistance, torque increases up to position 1 (175 bars). Beyond 175 bars the pressure compensators engage to increase the displacement of the motor resulting in a higher torque. (It should be borne in mind that the pump has a constant displacement, and with increasing displacement of the motor the rotary speed must decrease as more oil is consumed in effecting a revolution). Curve 1-2 on the graph results from the action of the pressure compensators. Position 2 signifies maximum displacement of the motor - the displacement has doubled, the rotary speed has halved resulting in a doubling of the torque. During normal drilling the Diamec 250 continually adjusts itself between positions 1-2, according to the drilling resistance of the rock.

Figure 4.24: Torque versus rotary speed for the Diamec 250 motor.



(after Lidstrand, 1976)

If the drilling resistance of the rock is sufficient to further increase the pressure and torque to position 3 on the graph, a valve opens (210 bars) and ports oil to the pressure compensator of the pump. Pressure on the yoke forces the pump swash-plate to the "zero" position and rotation of the chucks ceases as no oil is being delivered to the motor. (Between positions 2 and 3, the motor runs at a constant speed as the maximum swash plate setting was achieved at position 2).

Upon stalling, the system hydraulic pressure falls below 210 bars allowing the pressure compensator valve to switch back, thus decanting oil from the pressure compensator into the pump housing. The pump swash-plate can then assume its working angle and pumping is again possible. The return spring (1) in Figure 4.23 forces the yoke of the motor to the initial setting for maximum speed and minimum torque, (swash-plate angle of 9^{o} under normal conditions).

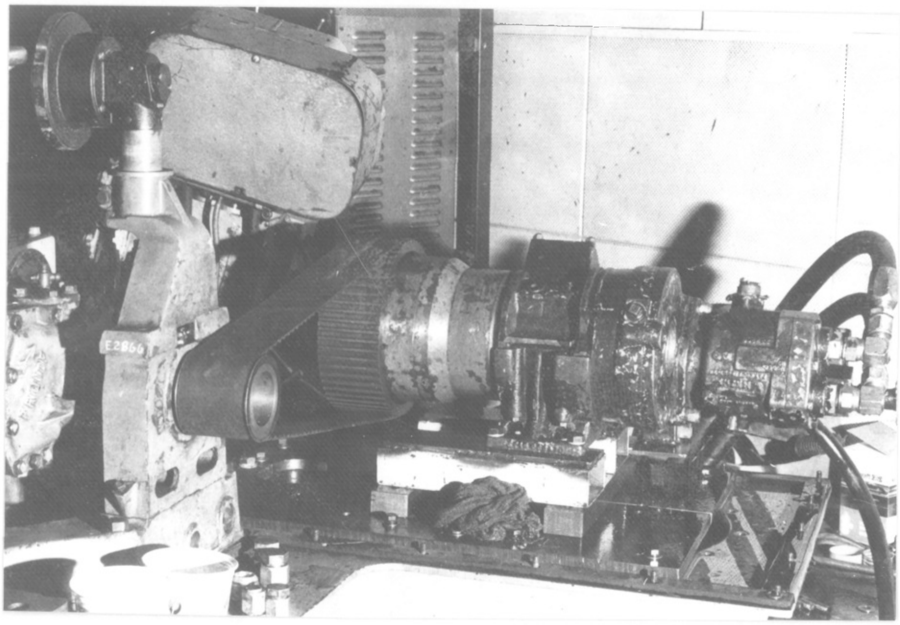
Certain drilling operations demand lower rotary speeds than is normally provided by the initial swash-plate position of the motor. (e.g. drilling through over-burden). Therefore, mechanical over-rides are fitted to both the pump and the rotation motor. Screwing the mechanical over-ride of the pump inwards reduces the displacement and shifts position 2 in Figure 4.24 to the left (dashed line). Simultaneously, the displacement of the motor can be manually increased and both actions combined to produce a very low rotational speed at high torque.

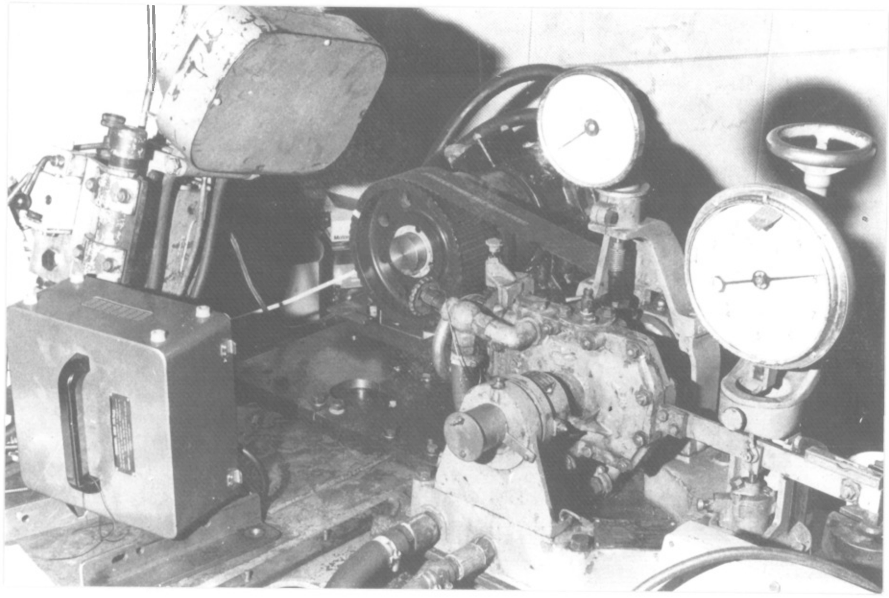
4.4.3 Dynamometer Description

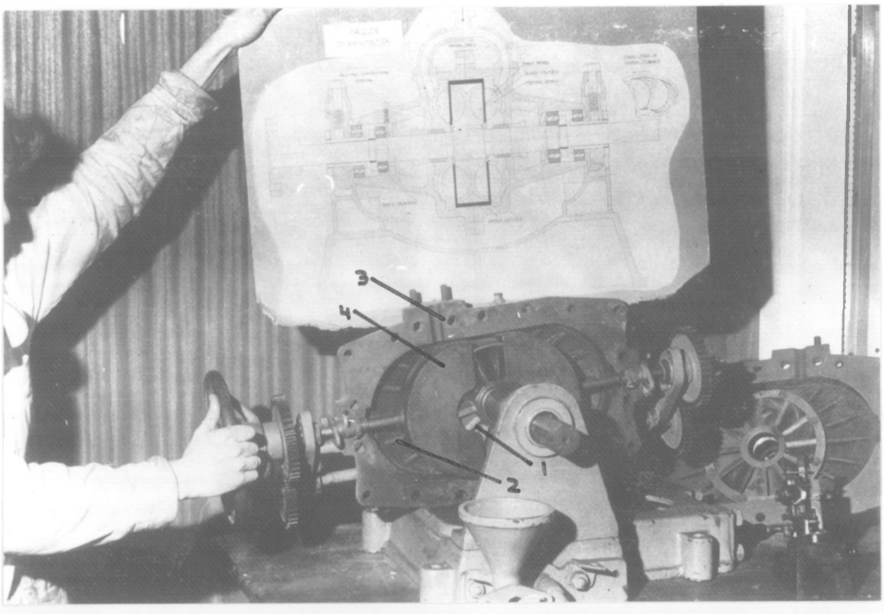
The Diamec 250 is capable of automatically adjusting the swept volume of the cylinders, thereby varying its displacement and hence the torque to accommodate variations in rock conditions. Thus, to evaluate torque it was necessary to monitor inlet oil pressure, rpm, and swash plate angle while the drill system was under load. This calibration was performed on a Froude DPXO dynamometer which was kindly made available by the Mechanical Engineering Department at Imperial College.

An absorption dynamometer of the Froude DPXO type consumes available power by doing work, normally against friction. The dynamometer is shown in Figure 4.25. A rotor (1) is coupled to the main shaft to which the measured power is supplied. Encompassing the rotor is a stator (2) which is fixed on the outer casing. The main shaft runs on ball bearings and is also carried on the outer casing. Finally, the outer casing is mounted on ball bearings carried by supporting brackets fixed to the bed-plate. In this manner all forces resisting the rotation of the dynamometer are made to react upon the weighing arm[288,289].

FIGURE 4.25 THE HEENAN-FROUDE DPXO DYNAMOMETER







Water is supplied to the brake via an inlet on the top of the casing (3). Semi-oval cups are cast in both faces of the rotor and in the adjacent faces of the stator. These cups are clearly visible in Figure 4.25. The engine on test is coupled to the main dynamometer shaft, thus transmitting power to the rotor revolving within the casing, through which water is circulated to effect a hydraulic resistance and to dissipate heat generated from the destruction of power.

Rotation of the rotor causes a high velocity discharge of water from the periphery of its cups into the pockets of the stator, by which it is then returned at reduced speed to the rotor pockets at a position near the shaft. Froude dynamometers are designed to resist rotation such that the absorbed horsepower varies approximately as $(\text{rev/min})^3$. The resistance offered by the water to the rotor motion reacts upon the casing tending to turn it on its ball bearing mounts. The tendency to rotate is resisted by a lever arm attached to the casing and terminating in a weighing device which measures the torque.

Load control is achieved by introducing adustable sluice gates (4) between the rotor and stator, thus severing communication between the rotor and a number of cups on the casing and thereby diminishing the resistance offered by the dynamometer. As the sluice gates can be adjusted while the dynamometer is in motion, a power curve can be obtained over a wide range of speeds in a relatively short period of time. A further reduction in load can be achieved by regulation of the water flow. When running at light loads with the sluice gates fully closed, the load may be further reduced by opening the water outlet valve and gradually closing the supply valve.

Prior to testing an engine, the static balance of the dynamometer must be established. This is effectively a zeroing procedure for the load recording apparatus of the dynamometer. This procedure is explained in detail in the manufacturers instructions and as such does not merit further consideration in this study.

When under load the balance arm tends to rotate. This tendency is off-set by placing weights on a balance pan suspended from the arm and returning the arm to a horizontal position by means of a hand wheel which is linked to a load indicating gauge. The length of the balance arm is designed so that a convenient formula can be used to calculate the brake horsepower (B.H.P.).

$$\text{B.H.P.} = \frac{W \times N}{K} \qquad \ldots(4.14)$$

where W is the net weight resisting dynamometer rotation

N is the speed (revs/min)

K is a constant

The value of K depends entirely on the design of the weighing apparatus and is normally chosen to give a convenient whole number. In this case the value of K was 4000.

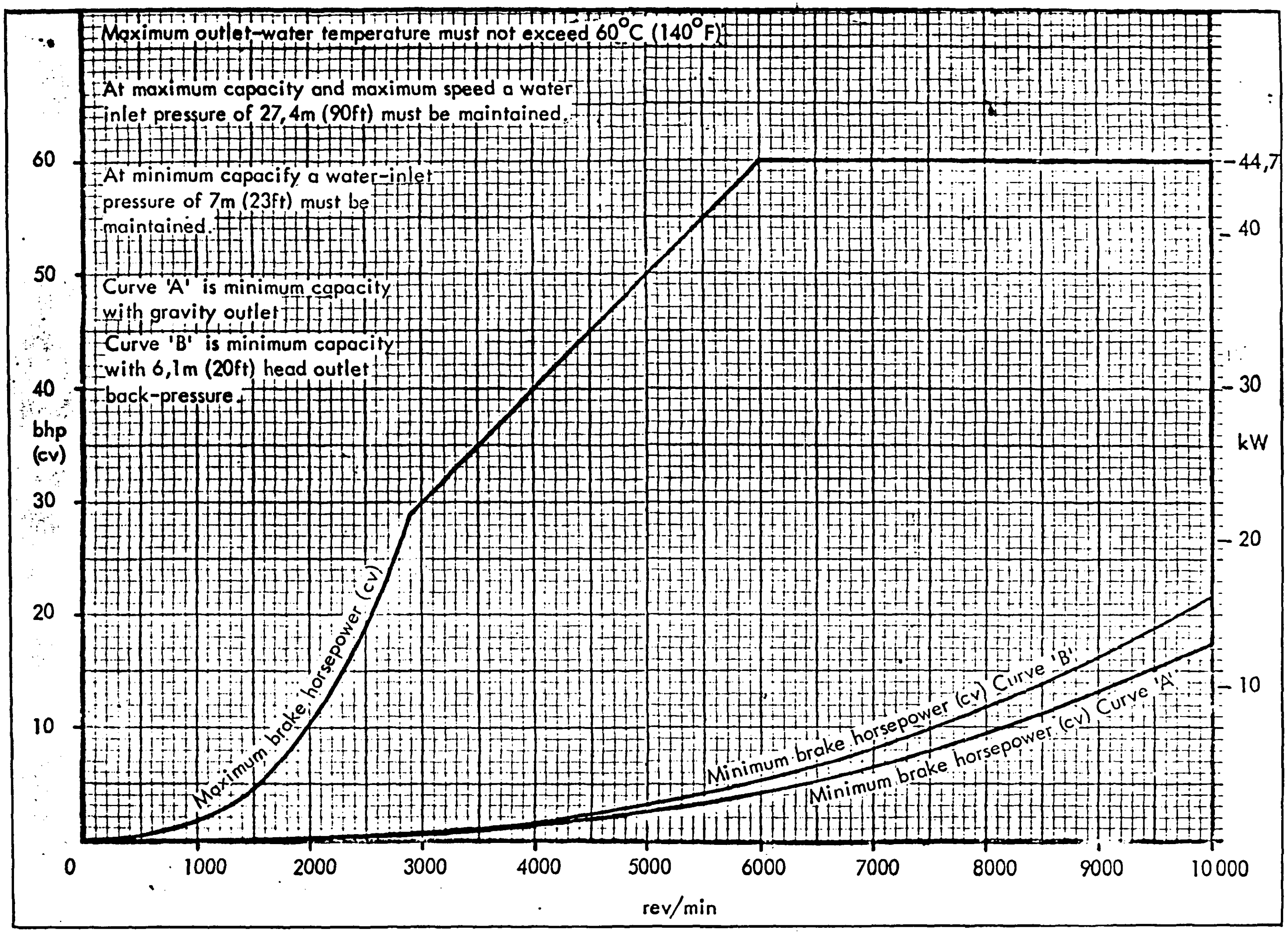
The setting up of the dynamometer test on the Diamec 250 required that the rotation unit be detached from the feed frame and an adaptor plate made in order that it could be mounted on the bed plate of the water brake. Power was supplied from a Type 25E electrically driven 25 hp power pack using the standard control panel supplied by the manufacturer. As the design of the dynamometer bed-plate rendered direct coupling to the dynamometer impracticable, a timing belt pulley system was used to link the chuck to the main shaft of the brake. The pulleys were selected to increase the r.p.m. transferred to the dynamometer, partly through a failure to appreciate in the initial stages of the test that the dynamometer capacity diagram (Figure 4.26) merely detailed the maximum and minimum measurable horsepowers at a selected r.p.m., rather than implying experimental design criteria. Stated another way, it was erroneously believed that if the maximum horsepower was exceeded for a particular r.p.m. setting then the dynamometer would be damaged. In point of fact, the capacity diagram implies that it is not possible to exceed the indicated levels since it is the resistance imposed by the dynamometer which determines the measured power, rather than the power being available and the dynamometer merely used to monitor it as was first thought. In either event, a 2.727:1 chuck pulley to dynamometer shaft pulley ratio was employed which produced a maximum dynamometer speed of approximately 5700 r.p.m. at a maximum chuck speed of 2100 r.p.m.

4.4.4. Test Procedure

In order to monitor torque indirectly, it was necessary to obtain calibration curves wherein torque was correlated with more readily measured parameters, namely: inlet oil pressure and r.p.m. for selected swash plate positions. As r.p.m. produced at the chuck is dependent on the oil flow to the axial piston pump (motor) from the pump in the power pack, an oil flowmeter was borrowed from Atlas Copco Craelius (Daventry) in order that the oil supply could be set at the recommended 60 l/min at 1500 r.p.m. by adjusting the regulator on the power pack.

As the calibration tests were prepared, it became obvious that the r.p.m. indicated on the control panel tachometer of the drill did not agree with that on the dynamometer, due allowance being made for the pulley ratio. Since in such a situation reliance cannot be placed on either indicator, an independent measurement of chuck speed was necessary. The Strobosun 1203B stroboscope

FIGURE 4.26 DYNAMOMETER CAPACITY DIAGRAM (After Redman Heenan Froude)



(Section 4.3.2) was employed to determine the velocity of the rotating chuck during the tests.

Inlet oil pressure was determined in two different ways. During all tests, pressure readings were recorded from the control panel meter, as well as from an Intersonde pressure transducer (the calibration of which is described elsewhere in this chapter). Values determined by the pressure transducer were used for horsepower calculations. The values from the control panel pressuremeter were only recorded to check the accuracy of the information available to the driller.

A test involved selecting a swash plate setting by adjusting the mechanical override on the drill motor prior to a calibration run. The power pack was started and the hydraulic oil was allowed to assume its normal operating temperature (about 70°C). The chuck was allowed to rotate throughout the duration of a calibration run. All runs were started under light load conditions (sluice gates closed) and as the test progressed increasing load was induced by adjusting the position of the sluice gates. At a desired setting, the balance arm was returned to the horizontal position by adjusting the hand wheel on the balance apparatus. When the arm was horizontal, values for the r.p.m., inlet oil pressure and load on the balance arm were recorded. Thereafter, the position of the sluice gates was varied and the procedure repeated.

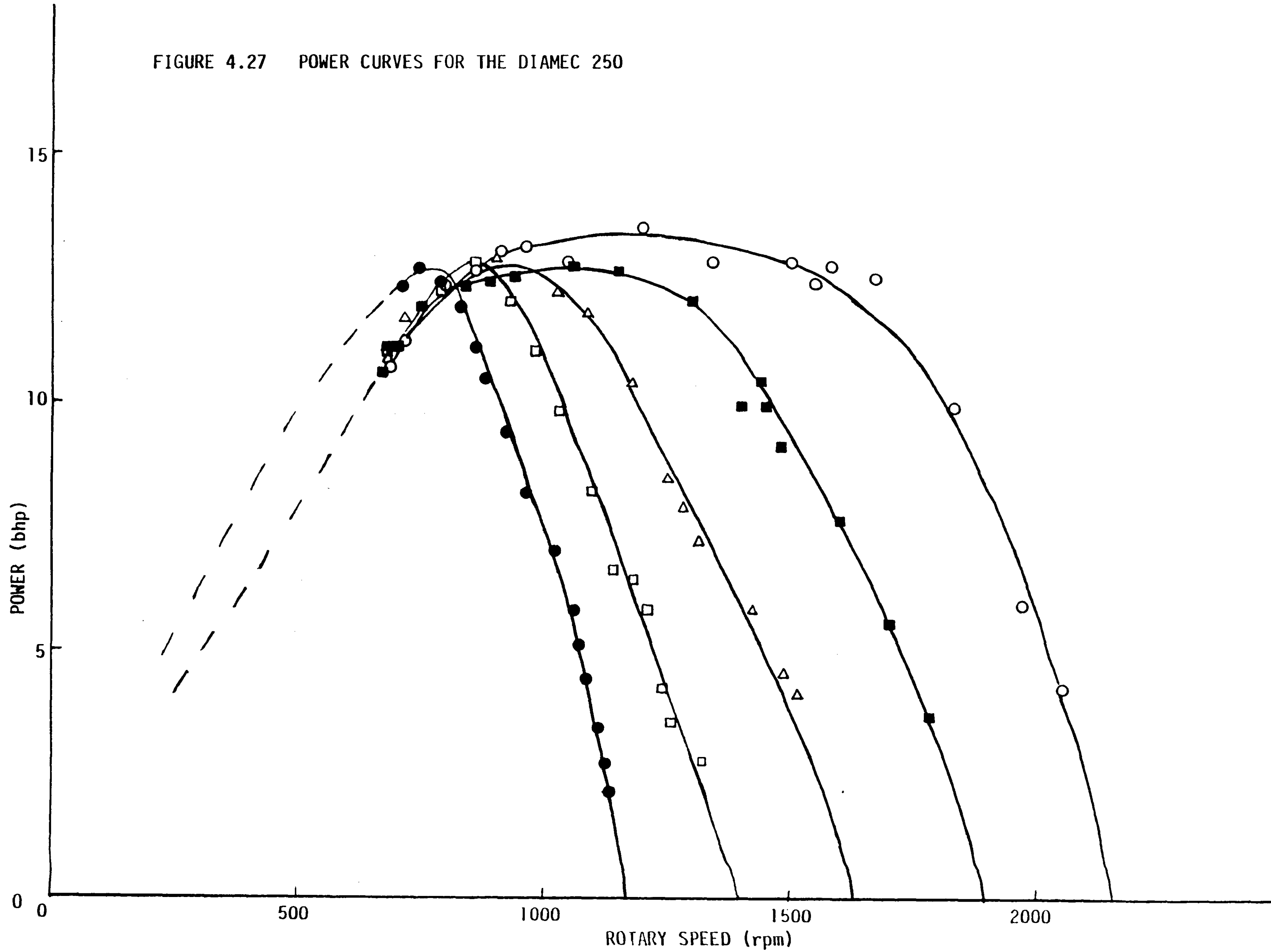
4.4.5 Test Results

The data recorded during the dynamometer tests are presented in Figure 4.27. In all, five tests were run spanning the full range of the mechanical override which controls the swash plate position of the drill motor. Figure 4.27 shows the power curves at each swash plate setting for a 1.5:1 gear ratio and 60 litres per minute oil flow. Several features of the power curves are noteworthy, namely:

- i) Increasing the swash plate angle and hence the swept volume of the axial pistons reduces the idling speed (zero load condition) of the drill.
- ii) The maximum power delivered to the drill string averages 12.5 to 13.0 brake horsepower.
- iii) The power curves vary in shape from a near parabolic curve for the 9° swash plate setting (maximum idling speed) to asymmetric curves for the remaining settings.
- iv) Maximum power is available at successively reduced r.p.m. as the swash plate angle is increased.

Figure 4.28 shows the torque transmitted to the drill string for the

FIGURE 4.27   POWER CURVES FOR THE DIAMEC 250



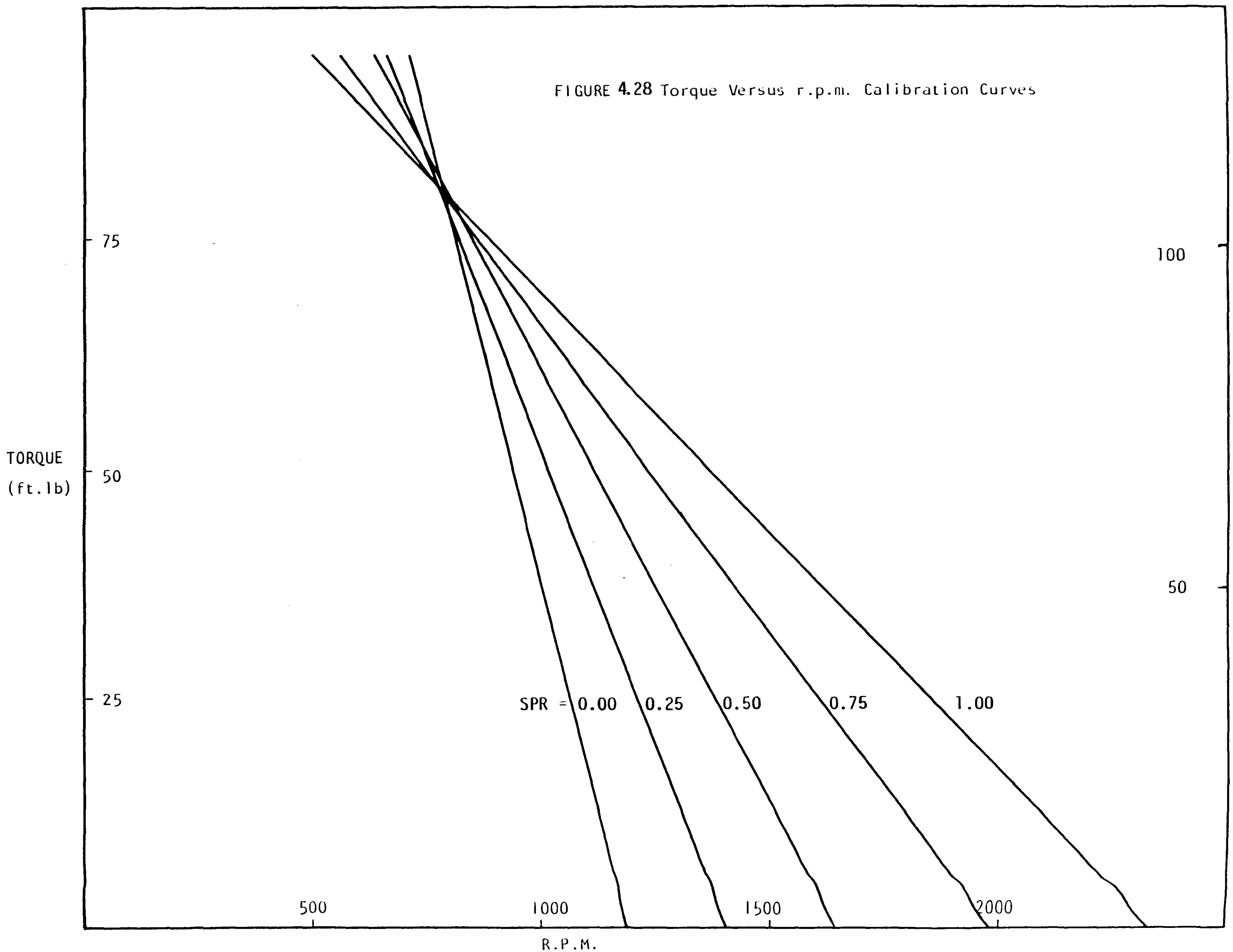


FIGURE 4.28 Torque Versus r.p.m. Calibration Curves

test conditions described above. The torque versus rotary speed plots display a number of characteristics of the motor including the following:

i) For a given swash plate setting the torque versus r.p.m. relationship is linear.

ii) Increasing the swash plate angle reduces the idling speed of the motor with the effect that less variation of rotary speed occurs with changing load.

iii) The family of lines describing the torque/r.p.m. relationship have a common focal point.

It is now possible to use this measured data to describe the torque/r.p.m. curve for any setting of the swash plate, provided that setting is known.

Table 4.7 lists values for swash plate setting, corresponding displacement, swash plate potentiometer output and swash plate ratio.

Table 4.7: Derivation of the swash plate ratio

Swash plate position (turns)	Displacement (in^3/rev)	Potentiometer Reading (volts)	Swash plate ratio (S.P.R.)
0.0	1.030	4.58	1.00
0.5		4.55	0.875
1.0	1.275	4.52	0.75
1.5		4.50	0.675
2.0	1.520	4.46	0.50
2.5		4.43	0.375
3.0	1.765	4.40	0.25
3.5		4.37	0.125
4.0	2.010	4.34	0.00

The swash plate ratio is derived from the expressions:

$$\text{S.P.R.} = \frac{\text{corrected voltage - minimum voltage}}{\text{maximum voltage - minimum voltage}} \quad \ldots (4.15)$$

for an excitation of 10.0 volts. Also, the relationship between the swash plate position and displacement is assumed to be linear. This assumption has been said by Sperry Vickers[290] to be effectively correct.

If the linear regression equation for a least squares fit to the data of Figure 4.23 is defined as

$$y = a_1 x + a_o \quad \ldots (4.16)$$

where a_o is the y-axis intercept
a_1 is the slope of the line

thenthe values in Table 4.8 define the torque/rpm regression lines relating to a particular swash plate setting.

Table 4.8: Regression data for torque calibration curves of Figure 4.28

Swash plate ratio	y-axis intercept	Slope (a_o)	Correlation coefficient (r)	Sample size
1.00	121.5737	-0.05203	0.99	15
0.75	132.8274	-0.06702	0.99	16
0.50	156.2922	-0.09482	0.98	16
0.25	180 9540	-0.12870	0.97	16
0.00	241.0608	-0.20320	0.99	17

These five regression equations were grouped to obtain their ten intersection combinations and solved simultaneously using Cramer's Rule to provide co-ordinates for each intersection. A mean value for the intersection co-ordinates was found to be (786, 80.7). This point was assumed to represent the focal point for the family of torque/r.p.m. curves generated by adjusting the swash plate angle.

A second set of co-ordinates now needs to be generated in order to derive an equation to describe the torque/r.p.m. relationship for any swash plate setting. To achieve this, it was necessary to derive a relationship between the S.P.R. and the idling speed of the chuck. Using the values listed in Table 4.9

Table 4.9: Iding speed versus swash plate ratio

Speed	2336	1981	1648	1406	1186
S.P.R.	1.00	0.75	0.50	0.25	0.00

the following equation was found to describe the relationship wherein the

$$S.P.R. = 8.6 \times 10^{-4} \text{ rpm} - 0.9711 \qquad \ldots(4.17)$$

with r = 0.99.

Thus, from the voltage record of the swash plate potentiometer and the potentiometer supply voltage, the data can be corrected to comply with a 10 volt excitation where necessary. The corrected voltage can be substituted in equation 4.15 to derive the swash plate ratio. The S.P.R. is then substituted in equation 4.17 to derive the idling speed (x-axis intercept) for that swash plate position. Finally, using the two sets of co-ordinates (x,o) and (786,80.7) in the general equation for a straight line

$$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1} \qquad \text{...(4.18)}$$

the equation for the required torque curve is derived.

CHAPTER 5

LABORATORY DRILLING TRIALS

5.1 Introduction

As previously noted, the aim of this study was to assess the feasibility of acquiring engineering geological data by monitoring rotary drilling performance during tunnelling site investigations and correlating this data with rock properties to predict ground conditions in advance of tunnelling operations. The project was orientated both towards probing ahead of tunnelling operations and the routine use of horizontal holes for tunnelling site investigation.

Earlier field trials by Imperial College researchers at Chinnor, Oxfordshire (in conjunction with the TRRL) and Meldon Quarry, Devon indicated that, in vertical holes at least, drilling performance can be suitably monitored[66,67,212]. However, in both instances, the significance of the recovered data could not be suitably assessed. In view of these difficulties, extensive laboratory drilling trials were undertaken prior to field investigations to permit correlation of drilling performance with known 'rock mass' properties and to isolate those properties that can be detected by drilling rig instrumentation. Accordingly, laboratory drilling trials were designed to meet the following requirements:

1. To provide a test facility for developing suitable instrumentation to monitor rotary drilling performance.
2. To establish the feasibility of drilling and collecting data from horizontally drilled boreholes.
3. To verify that relationships between drilling variables determined from a wide range of drilling equipment could be applied to the high performance Atlas Copco Diamec 250.
4. To produce a 'catalogue' of instrument response to known drilling conditions prior to field trials.
5. To assess the practicality of predicting rock strength from monitored parameters.

In order to pursue these objectives, an artificial rock mass constructed of blocks of reconstituted rock of known compressive strength and containing discontinuities of known orientation, aperture and in-filling was assembled on a test bed in the TRRL facilities at Crowthorne, Berkshire. Two horizontal holes were drilled in the block assembly and the drilling performance monitored. The first of these holes was used by TRRL scientific staff to evaluate a variety of downhole geophysical and other tools for acquiring rock mass information and to provide additional control for the drilling experiments.

While this test facility was being constructed, samples of limestone and sandstone from the Middle Limestone Group at Rogerley Quarry in Weardale were shipped to Craelius Diabor AB in Stockholm, Sweden. They were requested to perform drilling tests on these samples to verify penetration rate versus rotary speed (constant thrust) and penetration rate versus thrust (constant rotary speed) relationships over a specified range of drilling conditions. These tests would substantiate that the rationale governing the design of the drilling rig instrumentation, the design of the test bed and the subsequent drilling experiments were based on sound theoretical principles.

5.2 Description of the Experimental Layout

An array of concrete blocks with various aggregate contents and cement ratios were arranged on a concrete plinth to simulate diverse lithological conditions which might be encountered during normal site investigation drilling and/or probing in advance of tunnelling operations. Since the latter application was of principal interest in this investigation, the experimental design was structured to assess the feasibility of horizontally-orientated instrumented drilling. Individual blocks were arranged normal to the drill string with the exception of a central section whose specific design is treated in greater detail later.

The Diamec 250 was located at one end of the block array and secured to a rigid steel frame which was bolted to the laboratory floor of Bay 1 in the Tunnels and Underground Pipes Division of the TRRL.

5.2.1 Manufacture of the concrete blocks

In previous discussion, it was noted that blocks for the test bed should display a range of physical properties, particularly strength, and be arranged to simulate the characteristics of a jointed rock mass.

This was achieved simply and economically by casting blocks of concrete incorporating a specific aggregate from a range of several types. By this means, a variety of 'lithologies' was produced while differing cement/aggregate ratios ensured a range of strengths for a given aggregate type. The Civil Engineering Services of the TRRL prepared the concrete blocks. A TRRL Working Paper details the manufactured of the blocks[291] and this document forms the basis of the following account.

For each aggregate, three strengths of concrete was produced by modifying the preparation procedure for normal concrete mixes[292]. Three cement contents were chosen which in turn determined the coarse to fine aggregate contents. A constant coarse to fine aggregate ratio of 1.78:1 was chosen; the grading of the fine aggregate being Zone 2 in every case. An approximate 0.6 water to cement ratio was used although this occasionally varied to provide a workable mix. The mixing compositions are summarised in Table 5.1.

Table 5.1: Concrete Mix Composition

Mix designation	Percent Cement	Percent Coarse Aggregate	Percent Fine Aggregate
1	21	51	28
2	14	55	31
3	8	59	33

In all, seven aggregates were used to produce the concrete blocks. Considering the three different cement contents for the concrete produced from each aggregate, a total of 21 different blocks was available for the drilling trials. Table 5.2 lists the rock type, designation and source of each of the aggregates. Of the seven aggregates all but one, the siltstone,

Table 5.2: Origin of the Aggregates

Aggregate Designation	Rock Type	Source
L	flint	Laleham, Middlesex
R	quartzite	Rugeley, Staffordshire
BH	gritstone	Bayston Hill, Shropshire
H	limestone	Holcombe, Somerset
DR	siltstone	Dry Rigg Quarry, Yorkshire
CH	dolerite	Clee Hill, Shropshire
C	granite	Croft, Leicestershire

was available from stocks of angular roadstone held at the Laboratory. The siltstone was supplied by the quarry at Horton-in-Ribblesdale. The properties of the Portland cement used in the manufacture of the blocks are summarized in Appendix 2.

A number of considerations influenced the dimensions of the concrete blocks. In the first instance, a 60cm square area was deemed necessary to permit drilling of adequately spaced multiple boreholes through the assembly of blocks without encroaching upon the edge of a block. Such an arrangement also provided sufficient latitude for deflection of the drill string over the length of the block array should it occur. A final width of 71cm was decided upon in order that steel reinforcement could be incorporated in the block to aid loading of the blocks on the plinth and to ensure adequate resistance to the thrust imposed upon the block during drilling. The height of the blocks was 77cm, due allowance being made for the 15cm of concrete which would be used to embed the blocks upon the plinth. The thickness of the blocks averaged 20.5cm. This was deemed suitably thick for the drill to sample prior to passing into another block.

The ingredients of the concrete were mechanically mixed prior to being poured into wooden moulds containing the reinforcement. The concrete was compacted with a vibrating poker before the exposed surface was smooth-trowelled. All the blocks were cured under wet hessian for a period of 5 to 7 days prior to demoulding and subsequent storage under cover. Into the top of each block were cast two threaded steel sockets to receive eye-bolts for loading the blocks on the plinth.

The Laboratory carried out a number of tests on the physical characteristics of the aggregates and the concrete. The range of aggregate tests included:

1. grading
2. specific gravity
3. point load strength
4. slake durability
5. abrasivity

Each are discussed in turn.

A particle size distribution analysis was performed on coarse and fine aggregate samples in accordance with British Standard 812[293]. The results were then combined to produce a single grading curve, according to the appropriate mix proportion for the concrete, to represent the grading of the aggregate that was used in the manufacture of the blocks. The distribution curves are shown in Figures 5.1 and 5.2. In general, the curves are similar in as far as they are well graded through the fine sand to coarse gravel range.

Specific gravity determinations according to British Standard 812[294]

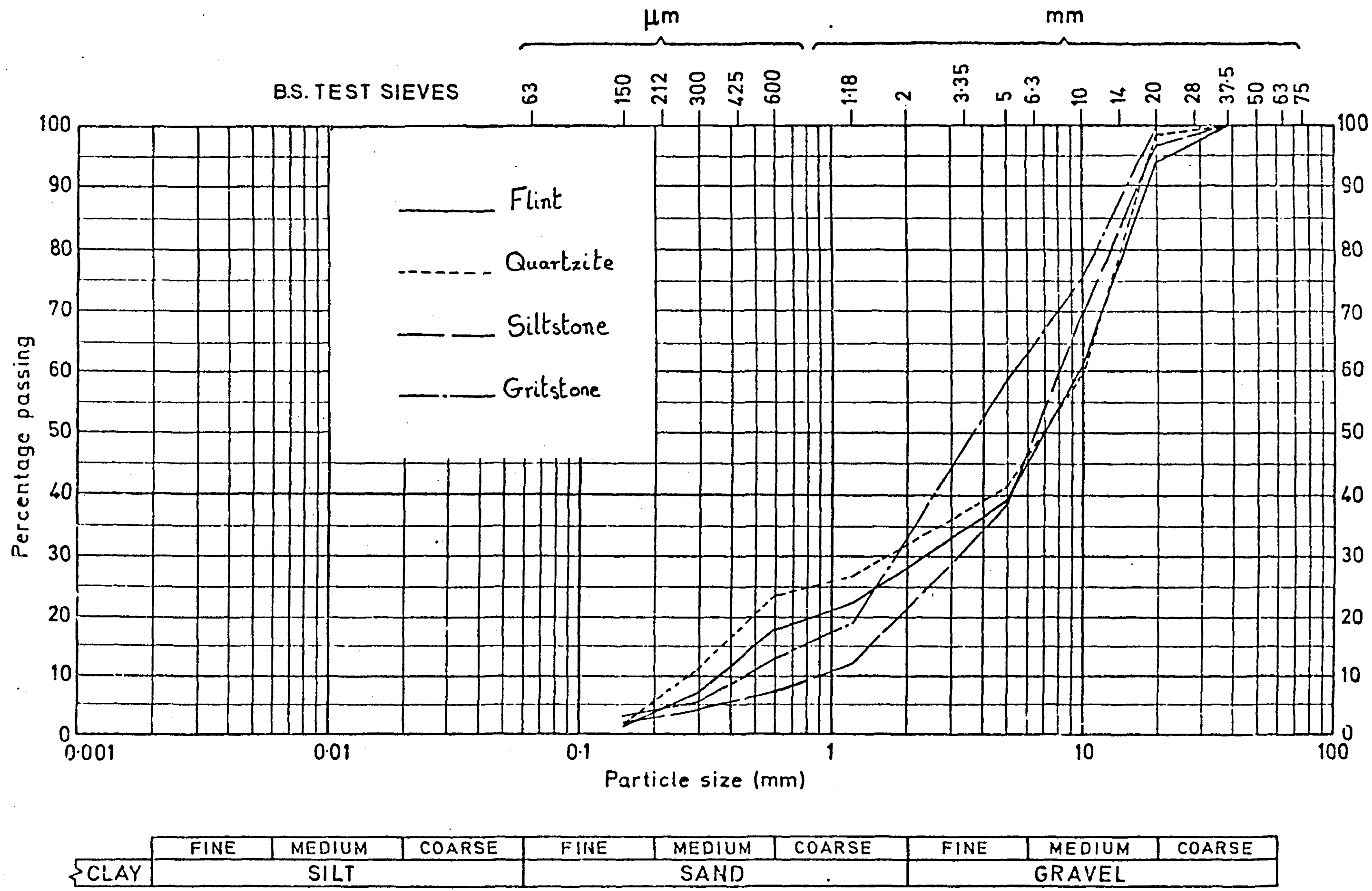


FIGURE 5.1: GRADING CURVES FOR AGGREGATES (Flint, Quartzite, Siltstone and Gritstone).

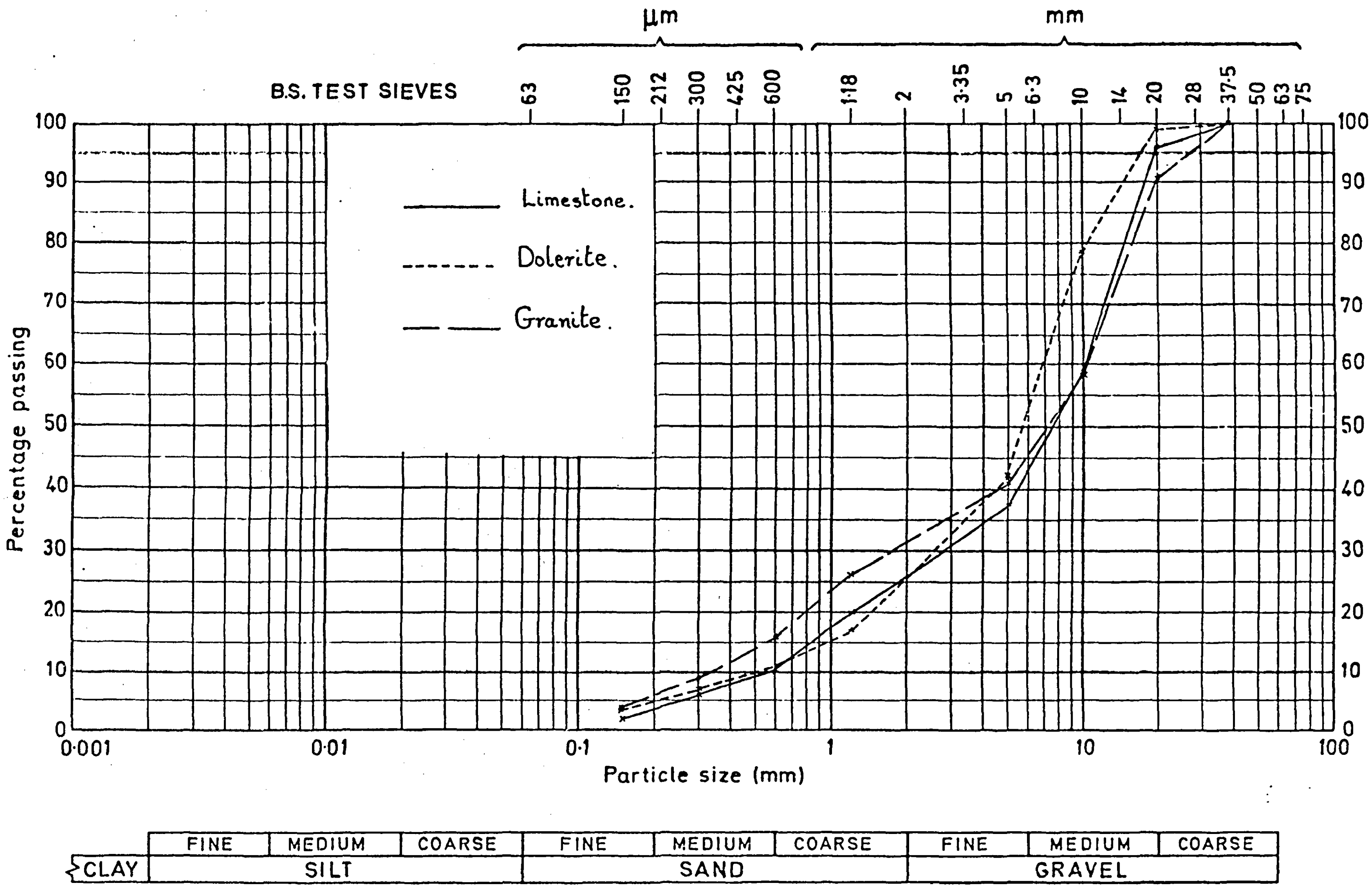


FIGURE 5.2: GRADING CURVES FOR AGGREGATES (Limestone, Dolerite and Granite).

were made for each of the aggregates. Three determinations were obtained for each aggregate type and the average value is recorded in Table 5.3. A consistent trend in noted in these results [291], the specific gravity ranging from 2.62 for flint, through 2.65 for quartzite (specific gravity of quartz = 2.65) and 2.70 for limestone (specific gravity of calcite = 2.71) to 2.87 for dolerite (composed of ferromagnesian minerals of high specific gravity).

Table 5.3: Properties of the Aggregates

Rock type	Designation of aggregate	Specific	Point load strength index I_s(50mm) MN/m^2	Slake durability index per cent	Abrasivity per cent per hour x 10^{-4}
Flint	L	2.62	11.3	99.9	82.2
Quartzite	R	2.65	9.3	100.0	94.7
Gritstone	BH	2.78	7.2	99.2	93.3
Limestone	H	2.70	6.4	99.6	69.9
Siltstone	DR	2.77	6.4	99.5	113.2
Dolerite	CH	2.87	7.4	99.4	84.7
Granite	C	2.66	9.8	99.5	110.5

The point load strength index, I_s, for each aggregate was determined on air-dry lumps of aggregate. The specimen size correction suggested by Franklin, Broch and Walton [295] and the ISRM [296] was applied to produce I_s(50mm) values. Table 5.3 lists the mean of 20 determinations for each aggregate type. The strength index varied from 11.3 MPa for the flint down to 6.4 MPa for the siltstone and the limestone. If the generally accepted relationship between point load index and uniaxial compressive strength is applied, namely:

$$\sigma_c = I_s \text{ (50mm) } \times 24$$

then, the compressive strength range was from 150 to 270 MPa. This places the flint, granite and quartzite in the category of 'extremely strong' rocks (> 200 MPa) while the remainder classify as 'very strong' (100 to 200 Mpa) according to the classification system proposed by the Engineering Group of the Geological Society of London [12]. These results should only be accepted as approximate, however, since the tests were performed on irregular lumps of aggregate of limited size. Bieniawski [152] has demonstrated that point load tests on irregular lumps of rock display considerably higher percentage deviation from the mean strength value than do either diametral or axial point load tests on core. In addition, some of the test pieces did not meet Bieniawski's minimum size recommendation of 42mm.

The slate durability index for each type of aggregate was determined in accordance with the procedure proposed by Franklin, Broch and Walton. Table 5.2 lists the mean value of four determinations for each of the aggregates. As expected for roadstone aggregate, the values are, for all intents and purposes, 100 percent, indicating that breakdown of the blocks caused by slaking of the aggregate will not occur as a result of drilling operations.

The Laboratory decided to devise its own measure of abrasivity of the aggregates with respect to metal machinery rather than use one of the many established methods [24]. Their test involved a one-inch bright mild steel cube being tumbled for three hours in a tumble-polishing machine along with a 900g charge of aggregate (with similar grading to that used in the concrete) saturated with water. Abrasivity was defined as the loss in weight/hour of the steel cube, expressed as a percentage of its initial weight. Twenty determinations for each aggregate were used to provide the mean values listed in Table 5.3. Given the novelty of the test procedure, it is only possible to make a relative comparison of the abrasive index as measured for each aggregate type. The lowest abrasivity index was for the limestone which is not surprising in view of its calcite content. In increasing order, the flint, dolerite, gritstone and quartzite had intermediate index values which were not unexpected except for the gritstone, which was anticipated to prove highly abrasive. As suspected, the granite proved to have a high abrasive index. Wholly unexpected was the maximum value recorded by the siltstone in view of the rock containing two relatively soft minerals; mica and chlorite.

The tests performed on the concrete included both density and strength determination. When the blocks were cast, six-inch test cubes were prepared from the same mix [297]. After twenty-four hours, the test cubes were removed from the mould, cured in water and tested after seven and twenty-eight days.

Upon curing, the cubes were surface dried and weighed. The density of the concrete was calculated and is presented in Table 5.4 as the mean of six determinations for each mix. As is evident, the density of the cubes varied from 2.40 Mg/m^3 for the weakest granite mix to 2.69 Mg/m^3 for the middle strength dolerite concrete.

Strength evaluation followed the desired period of curing. Each test cube was surface dried and its compressive strength determined according to British Standard 1881[298]. Half of the cubes were tested after seven days and the remainder at twenty-eight days. Values listed in Table 5.4 for each concrete mix at each of the two time intervals represents the mean of three strength determinations. With the exception of the flint mix, and, to a lesser extent, the siltstone mix, a consistent variation in strength is indicated for varying cement contents for each of the two time intervals. The 28-day strength ranged from 6.1 MPa for the BH3 (gritstone) mix to 67.0 MPa for the CH1 (dolerite) mix, corresponding to 'moderately weak' rock (5 to 12.5 MPa) through 'moderately strong' rock (12.5 to 50 MPa) to 'strong rock' rock (50 to 100 MPa) according to the classification scheme cited previously [12].

Generally, the mix ratios produced concretes of three distinct strengths within each aggregate group. The notable exceptions are the flint and siltstone mixes 1 and 2 which have contradictory strengths according to their cement, aggregate and water ratios. As the flint mixes were the first to be produced, they may very well have suffered from an error in batching. For example, mix DR1 (siltstone) was observed to be particularly wet during casting of the blocks.

One final feature of the blocks is worth mention as it proved awkward during the setting out of the blocks on the plinth. The aim during the casting of the blocks was to produce blocks with parallel faces. However, because of the weight of the concrete in the moulds (each block weighed approximate 280 kg after curing) the lower surface was bowed outwards while the upper one was smooth-trowelled. As a result it was only possible to arrange the blocks with every second set of opposing surfaces being parallel.

5.2.2 Design of the plinth

The main body of the plinth was 12 metres long by 1.6 metres wide by 0.6 metres high and comprised of a mass of concrete which was smooth-trowelled to produce a level surface. Set into the outer perimeter of the top surface was a 75mm wide collector drain designed to surround the array of concrete blocks (Figure 5.3). At either end of the plinth, the spent drilling fluid discharged from this drain into a gutter situated on the floor. This 15cm wide (30cm wide at each end) gutter was constructed of pre-cast concrete kerb stones to form a catchment at both ends and down one side of the plinth. Cracks between the kerb and the cement floor of the gutter were sealed with Sylglass tape. Gravity drainage from this catchment passed to a sediment

TABLE 5.4: PROPERTIES OF THE CONCRETE

Rock type used for aggregate	Designation of concrete	Density Mg/m^3	Compressive strength MN/m^2	
			7 days	28 days
Flint	L1	2.48	34.2	48.6
	L2	2.50	38.0	51.3
	L3	2.50	18.7	25.6
Quartzite	R1	2.53	50.5	56.8
	R2	2.53	34.2	43.7
	R3	2.43	7.8	10.4
Gritstone	BH1	2.51	31.1	41.1
	BH2	2.54	20.8	27.9
	BH3	2.41	4.2	6.1
Limestone	H1	2.54	51.0	61.1
	H2	2.56	47.9	55.1
	H3	2.60	25.8	32.0
Siltstone	DR1	2.45	28.3	38.1
	DR2	2.59	30.2	37.1
	DR3	2.60	20.6	21.9
Dolerite	CH1	2.66	45.2	67.0
	CH2	2.69	44.2	47.7
	CH3	2.54	13.6	18.6
Granite	C1	2.46	43.4	56.8
	C2	2.45	24.4	32.4
	C3	2.40	7.5	10.1

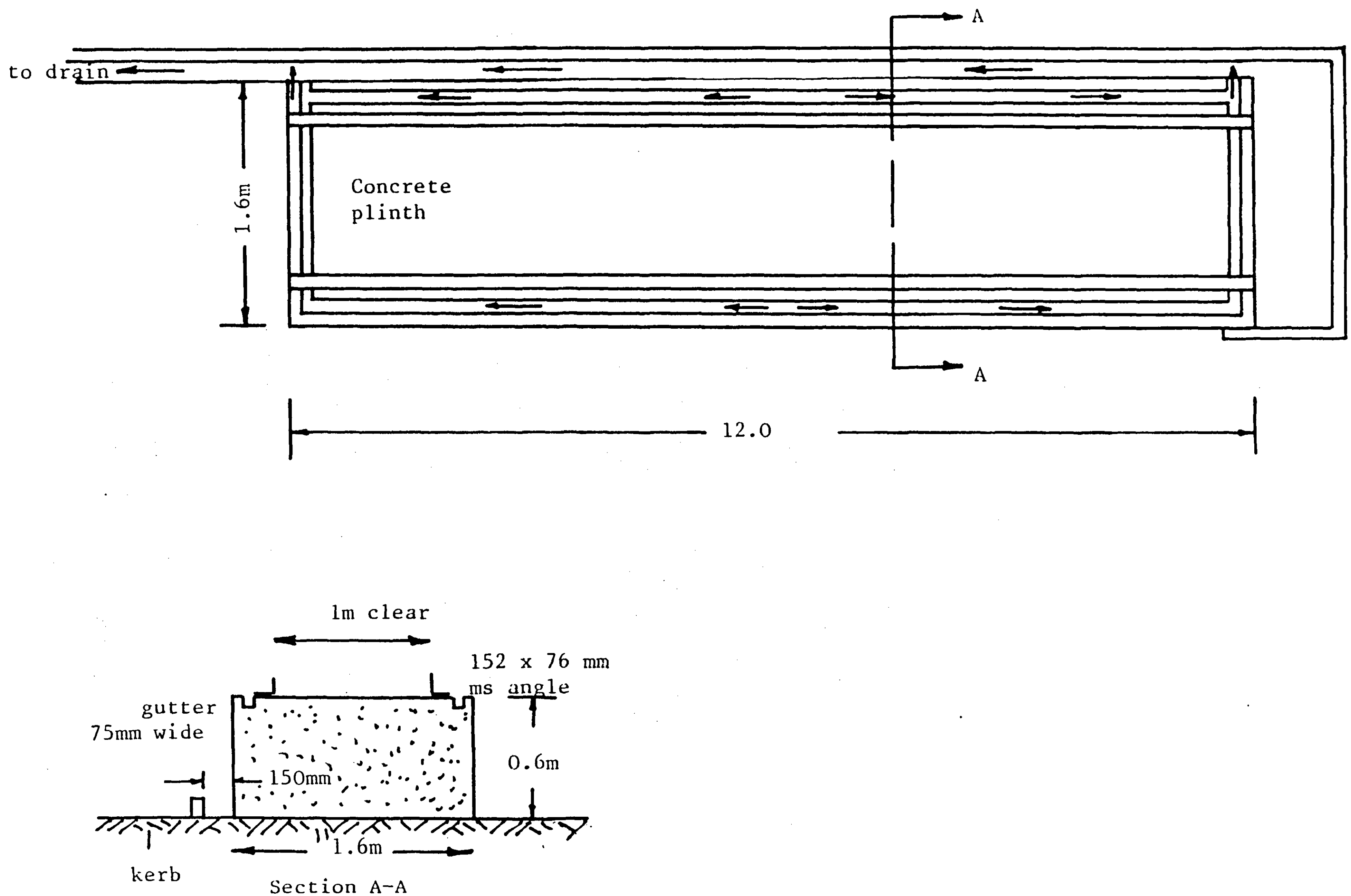


FIGURE 5.3 DESIGN OF THE PLINTH AT THE TRRL.

trap, containing three concrete slab baffles, prior to discharge into the main storm runoff drains.

When the blocks were placed on the plinth, the intention was to secure them by imbedding them in concrete. In order to do so, 152 x 76mm mild steel angle, rawl-bolted at one metre centres was used as shuttering. The angle was located in such a manner that an approximate gap of 0.15m existed between it and the blocks along both sides. At either end, the angle butted against the end blocks and bolted to that running along the sides of the plinth.

5.2.3 Design of the block array

Figure 5.4 depicts the arrangement of the blocks on the plinth. The layout of the 51 blocks was as follows:

i) Blocks 1 to 12 inclusive (unit 1) incorporated the strongest and the weakest blocks of each aggregate type with the exclusion of the quartzite.

ii) Blocks 13 to 24 (unit 2) were a repeat of the arrangement in unit 1.

iii) Blocks 25 to 30 (unit 3) made up the central zone of the array and were designed to simulate various ground conditions which might be encountered in drilling site investigations.

iv) Blocks 31-51 (unit 4) were designed to simulate a solid block of "rock" incorporating each lithological unit.

The blocks in the array were arranged so that suspected abrasive blocks were evenly distributed in order to ensure a sharp bit condition over the length of the drilling run.

Each block was hoisted into position on the plinth using a fork lift truck. The blocks were suspended on chains hooked through eyebolts that were screwed into sockets cast into the concrete blocks. The blocks were arranged so that the smooth-trowelled faces of individual blocks opposed each other where fissures of regulated aperture were required. The aperture was set by bonding strips of wood to the block face prior to bringing the next block to bear against it. The wood strips were 2,5,10 and 20mm thick. In each of units 1 and 2, one of the 10mm joints was filled with puddle clay to simulate a clay-filled joint. The remaining joints were left open.

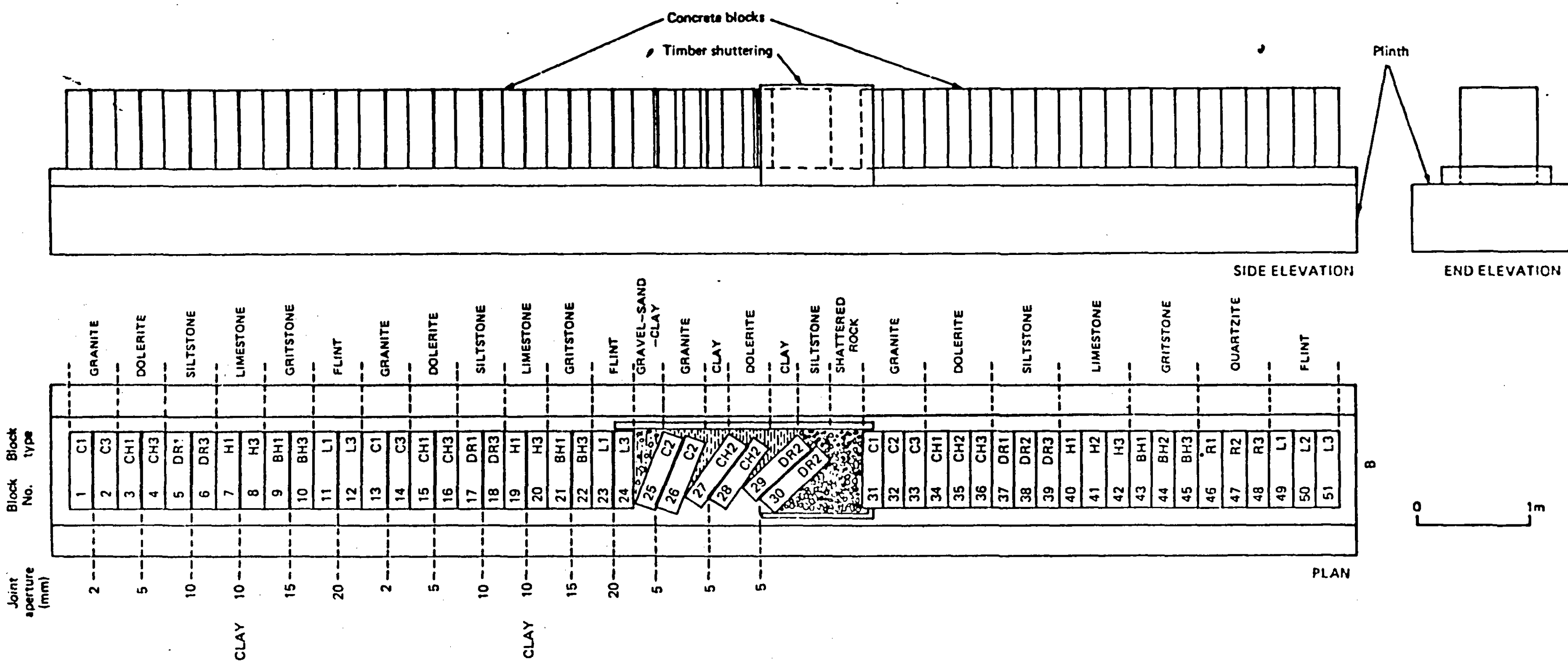


FIGURE 5.4 **ARRANGEMENT OF BLOCKS FOR LABORATORY TRIALS**

The central section (unit 3) involved a complex arrangement of "geological" situations. Blocks were orientated at 15^{o} (blocks 25 and 26), 30^{o} (blocks 27 and 28) and 45^{o} (blocks 29 and 30) from the normal with respect to the drill string. A 5mm aperture was established between each pair of inclined blocks.

After all the blocks had been placed on the plinth and concreted in place, wooden shuttering was erected around unit 3. In the wedge confined between blocks 24 and 25, a densely packed mixture of gravel, sand and clay was placed while the wedges between blocks 26 and 27 as well as blocks 28 and 29 were charged with puddle clay. Finally, a loosely cement-bonded gravel (particle size 3 to 5cm) filled the void between blocks 30 and 31 to simulate a shattered rock zone.

Table 5.5 summarizes the major features incorporated in the block array and their purpose with respect to the horizontal drilling trials at the TRRL. The fissure arrangement, including the clay filled joints, was to investigate the sensitivity of the drilling system in detecting joints of varying aperture, orientation and infill characteristics.

Repetition of the features built into units 1 and 2 were aimed at obtaining an indirect assessment of bit wear by comparing the drilling record for each of the two units. The existence of unit 4 at the far end of the plinth was expected to provide similar comparisons as well as giving an indication of friction losses over the length of the hole. The fact that 21 blocks were used in unit 4 was to meet the requirements of G. West who was involved in a simultaneous study on the application of borehole geophysics for tunnelling site investigation purposes. While the use of all block types for this portion of the array limited the available space on the remainder of the plinth, it nevertheless provided an excellent test for the drilling systems sensitivity to lithological change, ability to predict rock strength and the loss of sensitivity, if any, over the relatively short drill run involved. However, in order to incorporate the features represented in unit 3, it was necessary to modify the number and arrangement of blocks in units 1 and 2. The intermediate strength blocks of each aggregate group were omitted thus providing a high, and, hopefully, readily detectable, strength contrast between blocks of similar aggregate type. In addition, space restrictions required that one aggregate group be omitted from units 1 and 2. Quartzite aggregate blocks were eliminated as it was anticipated that they would probably be laborious to drill and cause considerable wear of the drill bit. In fact, subsequent drilling experience in unit 4 showed these expectations to be erroneous.

Table 5.5 shows that one of the aims of the drilling trials at the TRRL

Table 5.5: Experimental design for the TRRL Horizontal Drilling Trials

Feature	Purpose	Method
1. Blocks of various aggregate (cement ratios)	Investigate ability of drilling system (a) to sense lithological change and (b) attempt to predict strength of lithological unit based on drilling performance Also unit 4 check on loss of sensitivity with distance.	a) Monitor penetration rate under conditions of uniform thrust b) Monitor penetration rate at various thrust levels under uniform r.p.m. (Tsoutrelis)
2. Fissure array of different aperture and orientation.	a) Investigate the sensitivity of the drill system to joints of known aperture and to determine minimum sensible aperture. b) Determine the critical angle of orientation w.r.t. the drill string beyond which system ceases to detect a joint of constant aperture	Monitor torque, rpm, head displacement and water flow
3. Clay infill sand, gravel, clay zones.	Check the system's sensivity to high strength high permeability contrast zones and the limits of sensitivity	Monitor torque, rpm, head displacement water flow and pressures
4. Gravel (broken ground) zone	Determine characteristic response to fractured ground conditions	Monitor all system variables
5. Highly permeable and pressurized fissures.	a) Determine if the water monitoring system could sense the penetration of a fissure causing loss of fluid. b) Determine if zones of higher pressure and fluid gain were sensible	Monitor water flow and water pressure instrumentation.

was to investigate the possibility of using the drilling system to provide quantitative assessment of rock mass permeability by monitoring the water balance in the drillhole. Also, because of the potential threat posed by intersecting zones of high water pressure during tunnelling operations, pressurized fissures were allowed for in the construction of the block array. The technical support staff at the TRRL believed that the contact surface between the blocks and the plinth would be sealed by the cement holding the blocks in position. The gap between blocks was grouted with cement. Small standpipes were grouted into the joints between blocks 11/12, 21/22 23/24 and 27/28 to (a) act as zones of high permeability by allowing leakage of flushing fluid to occur or (b) provide a source of high pressure "groundwater" by pumping water into the standpipe.

Unacceptably high leakage of fluid from the block array was encountered on the first attempt to pressurize the system. The greatest loss was along the top surface of the plinth, although some leaks were apparent along the sides of the block assembly. Because the first drilling pass through the block array would prevent a repeat of the permeability/pressure investigations, it was necessary to try and seal the leaks prior to drilling. As a first attempt, a thin "ciment fondu" slurry was poured into each of those joints which provided access via a standpipe. Migration of the slurry was noted to have occurred through small leaks at the contact surface between the blocks and the plinth. The "ciment fondu" was allowed to cure overnight. Water tests the following day showed that the leakage remained excessive.

Another attempt to seal the base was made by pouring a thixotropic clay slurry (bentonite) into the block array, access being gained via the standpipes. When the clay was poured into the joint, migration of the slurry was hastened by applying air pressure to the joint. The clay was left overnight to gel. Tests showed that while the leakage across the base had been reduced, hitherto unencountered leaks on the sides of the block array were activated.

Finally, having decided that further attempts to seal the base in order that each joint could act independent of the others were futile, the decision was taken to try and seal the external leaks and thus contain the fluid within an interdependent array of blocks.

All of the steel angle shuttering was removed and the concrete brushed clean. Sylglas mastic followed by a bitumen compound was applied at the boundary between the upper surface of the plinth and the concrete used to contain the blocks. Also, since some small voids were noted in the concrete, the bitumen was used to coat the entire surface which was in contact with the shuttering. All hairline cracks which were visible on the exposed surface of the containing concrete were treated in a similar fashion. The mastic and bitumen were also used to coat every joint along the block array. Finally, strips of 51mm wide Sylglas mastic tape were applied along every contact and joint surface before the shuttering was bolted back into place. In spite of all these efforts, the block array continued to leak. No further attempts were made to stem the flow of water and it was decided to proceed with the laboratory drilling trials and hope that whatever information was forfeited could be retrieved during the field trials.

5.2.4 Equipment layout

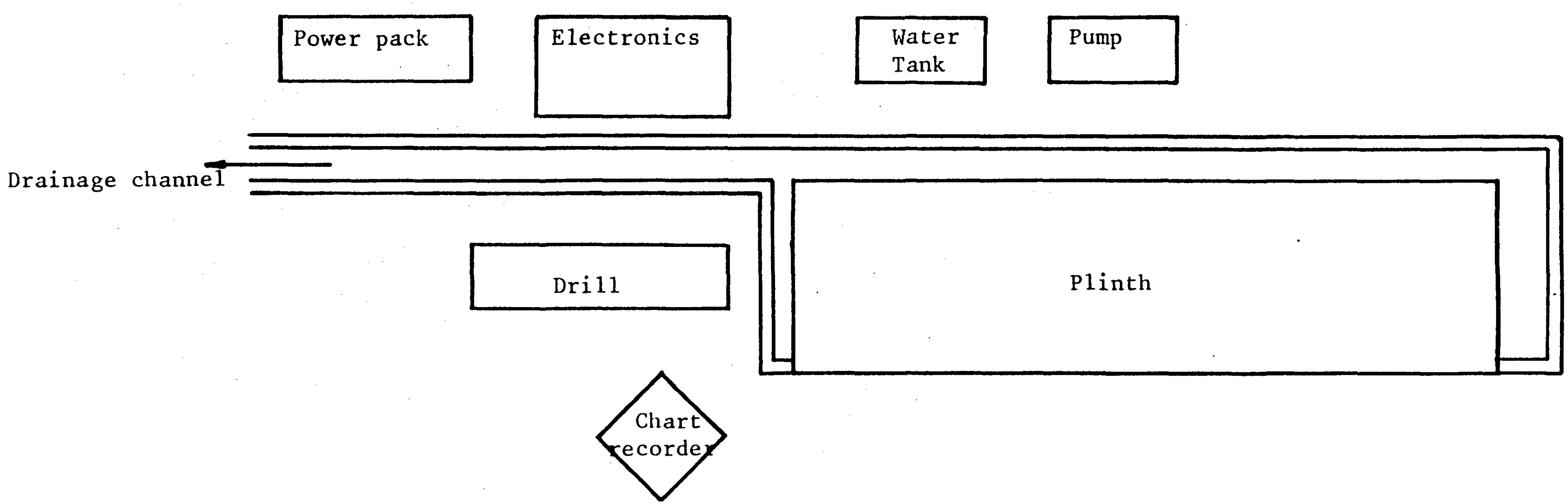
The drill unit was mounted on a steel frame which in turn was bolted to the concrete floor of the laboratory. This assembly was located at one end of the block array. The first hole was centrally located on the face of block 1 and the drill string was orientated by sighting along a centre-line drawn across the top surface of the blocks. The power pack was confined between the drainage channel and the outer wall of the laboratory which created a convenient path for the hydraulic lines to the drill unit (Figure 5.5).

The Boyles water pump and its attendant stilling tank were also located in the same general area. The intake strainer from the pump was placed in the tank and the intake hose was clamped to its lip. Water was drawn from the tank, passed through the pump and the venturi before being directed to the drill rod string via a hose with a swivel attachment. Spent water from the stilling tank was replenished from the mains suppy with the flow being regulated by a ballcock valve. The required 3 phase/415 volt electrical supply for the power pack and the water pump was obtained by running spurs from the laboratory mains supply; an isolator switch being provided for each of the electrical units.

The electronic equipment was housed in a cabinet located within easy reach of the drill control console (Figure 5.5). Electricity was supplied from an existing source. Immediately adjacent to the control console was the Rikadenki strip chart recorder, since this device was used to display ready information for the driller as well as to act as a diary for events noted by him.

When the major items of equipment had been suitably placed, the various transducers, potentiometers and flow meters were fitted to the system. This done, multicore cables were prepared and wired into place. It was also at this time that the swash plate potentiometer was connected to the drill rotation unit and an aluminium housing designed and manufactured to afford

FIGURE 5.5: EQUIPMENT LAYOUT FOR TRRL DRILLING TRIALS



it some degree of protection given that the potentiometer was in a very exposed location.

When all the sensors were located and ready, a considerable period of time was spent performing the calibration checks described in the last chapter. This also included an extensive overhaul of the Rikadenki recorder since it proved impossible to maintain calibration settings. The equipment was stripped down and thoroughly cleaned and lubricated. New drive belts were installed and the alignment of the twelve drive wheels were adjusted to prevent the belts from rubbing one against the other. This solved the calibration difficulties since the renewed tension on the belts combined with their freedom of movement, cured the errors introduced by belt slippage. The tension was also increased on the drive wires to the pen carriage and the carriage guide rails were cleaned and lubricated, particularly the bottom of the rail where grime could collect unseen. Thereafter, the chart recorder performed acceptably, although a regular programme of cleaning had to be maintained.

One of the biggest delays during this period was caused by a mechanical breakdown on the drill rig. During a calibration run the rubber muff which transmits hydraulic pressure to the mechanical chuck ruptured. The rubber muff is carried in a metal sleeve which fits tightly into a machined housing at the forward end of the rotation unit; access being gained by removing a cover plate[272]. Once exposed, it proved impossible to remove this assembly by conventional methods.

The problem was finally overcome by designing and having the Civil Engineering Services of the TRRL build a piece of equipment similar to a standard hub puller. The device consisted of a central steel shaft with cross-pieces at either end. One cross-piece had two pivoted lugs, one at each end, which engaged a lip on the inside diameter of the metal sleeve. The cross-piece at the other end travelled along a threaded portion of the central shaft. To remove the muff assembly, the central shaft was fed through the rod holder and rod guide before the cross-piece was applied and held in place by a washer and nut. The lugs were then engaged and the metal sleeve withdrawn by tightening the nut on the cross-piece at the opposite end causing it to bear against the rod guide. Thereafter, torque applied to the nut forced the withdrawal of the muff and its carrier sleeve. Once removed, a replacement was soon installed.

5.3 Swedish Drilling Programme

5.3.1 Introduction

Section 3.5 described numerous laboratory and field-based investigations of drilling performance employing a variety of drilling rigs and types of bit. On the basis of these studies, a number of fundamental relationships between drilling variables were outlined which constitute the theoretical rationale for this investigation. However, it is notable that the rotary speeds used in these earlier studies were normally 500 rpm or less, the only significant exception being the USBM investigations where rotary speeds up to 1100 rpm were employed. Reference to Table 4.1 shows the Diamec 250 capable of speeds far in excess of these values. Therefore, it was necessary to establish that the drilling relationships outlined in Chapter 3 remained valid at higher rotary speeds to ensure sensible interpretation of recorded drilling data.

5.3.2 Test programme

Samples of limestone and sandstone from the Middle Limestone Group at Rogerley Quarry in Weardale were shipped to Craelius Diabor AB in Stockholm, Sweden for testing on their newly commissioned Boman test drilling rig. Samples from Rogerley Quarry were chosen since this was the proposed site for the field drilling trials. While verifying the drilling relationships it would be possible to select the optimum drilling conditions for the forthcoming field trials.

Craelius were requested to conduct the following tests for each of the rock samples supplied:

1. Maintain a constant rotary speed of 1500 rpm while the thrust was varied through 2.5, 5.0, 7.5, 10.0 and 12.5 kN. Each thrust level was to be maintained for a minimum 14 cm penetration.

2. Maintain a constant thrust of 5.0 kN with the rotary speed kept at 250, 500, 750, 1000, 1250, 1500 and 2000 rpm while penetration rates are recorded.

All tests were performed using a sharp TT56 (copper matrix) Diaborit drill bit and resulting core was returned to Imperial College for uniaxial compressive strength testing.

5.3.3 Results

Tables 5.6 and 5.7 list the results obtained from the Boman drilling rig.

TABLE 5.6: EFFECT OF THRUST ON PENETRATION RATE AT CONTANT ROTARY SPEED (1500 rpm)

Thrust (kN)	Penetration Rate (cm/min)	
	Sandstone	Limestone
2.5	20.6	8.6
5.0	37.7	19.2
7.5	57.1	31.9
10.0	62.5	40.5
12.5	74.1	46.9

TABLE 5.7: EFFECT OF ROTARY SPEED ON PENETRATION RATE AT CONSTANT THURST (5 kN)

Rotary Speed (rpm)	Penetration Rate (cm/min)	
	Sandstone	Limestone
250	11.4	4.2
500	16.9	7.5
750	23.8	12.5
1000	27.6	17.6
1250	35.6	23.1
1500	36.7	28.3
2000	53.4	35.3

It is evident that drilling relationships described by previous researchers remain valid for the combinations of thrust and rotary speed considered in the Swedish test programme. Figure 5.6 is a graphical presentation of the thrust versus penetration rate results listed in Table 5.6.

An essentially linear increase in penetration rate with increasing thrust is apparent in Figure 5.6, particularly when the limestone is considered. The sandstone may display non-linearity at higher thrust values but the paucity of data combined with scatter of the data renders further analysis speculative. It is recognized that extrapolation of the regression line virtually through the origin in the case of the limestone and intersecting the ordinate axis at approximately 10 cm/min (zero thrust) in the case of the sandstone, ignores the necessity of a minimum level of thrust in order to initiate rock comminution.

The penetration rate (cm/min) versus thrust (kN) relationships given by the fitted straight lines are:

Sandstone: $R = 5.27F+10.86$ for $N = 1500$ rpm

Limestone: $R = 3.92F+0.05$ for $N = 1500$ rpm

While these results are insufficient for conclusive statements to be made on the R-F relationship, it is reasonable to expect that a linear region exists for these two variables and that region falls within a range of values that ensures acceptable drilling rates for the purposes of this investigation.

The effect of rotary speed (N) on penetration rate is shown in Figure 5.7 for conditions of constant thrust. Both the sandstone and the limestone show excellent linear characteristics over the range of rotary speed values. Straight line fits to the data produced the following relationships:

Sandstone: $R = 0.02N + 5.4$ for $F = 5.0$ kN

Limestone: $R = 0.02N - 0.95$ for $F = 5.0$ kN

This was an important result since monitoring anticipated changes in ground conditions during field trials would rely on observing variations in rotary speed and penetration rate under constant thrust conditions.

5.4 TRRL Drilling Trials

5.4.1 Drilling programme

The objectives of the laboratory drilling programme have been detailed elsewhere in this chapter but they are sufficiently important that they can bear repeating, namely:

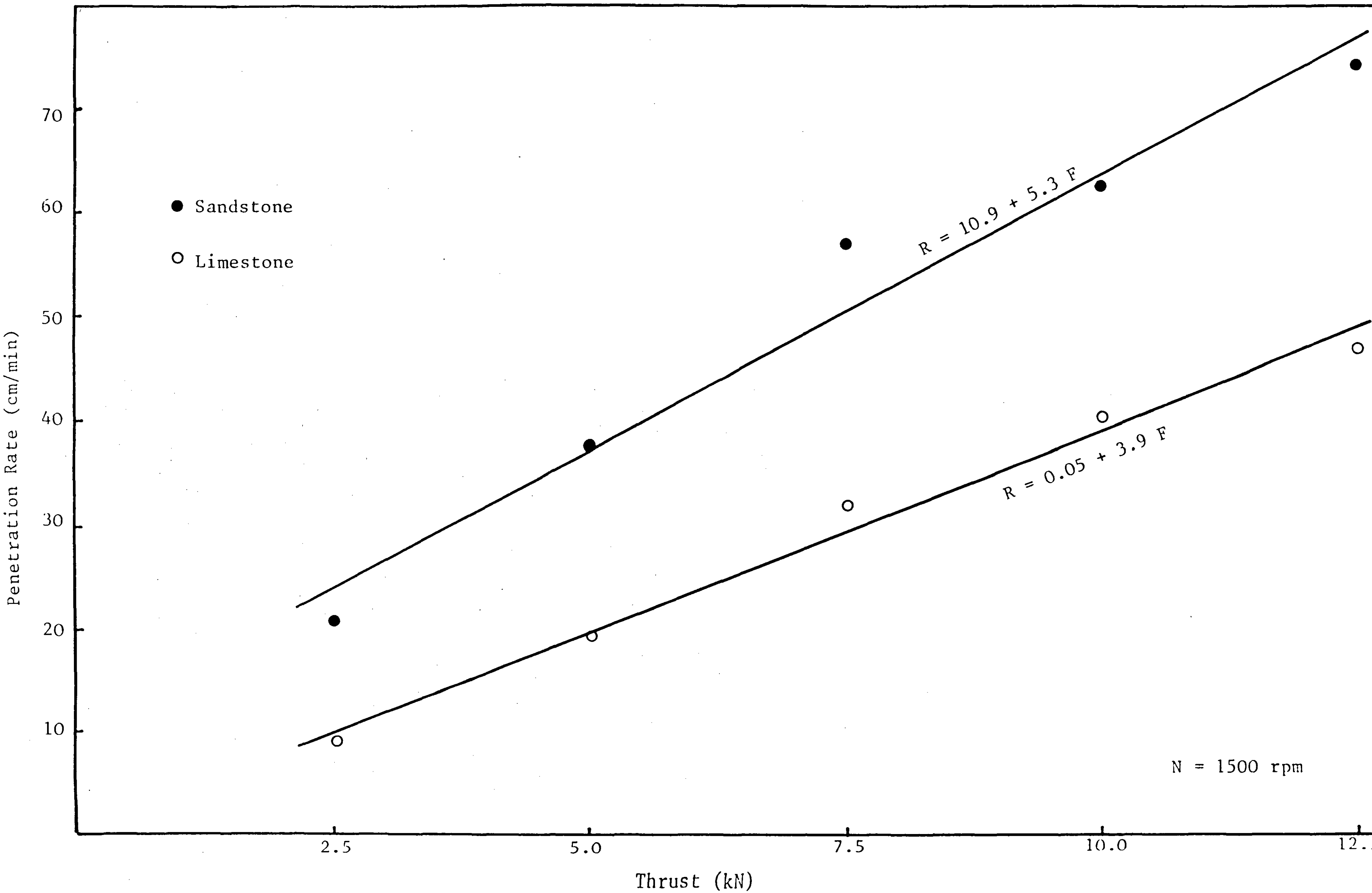


FIGURE 5.6: EFFECT OF THRUST ON PENETRATION RATE AT CONSTANT ROTARY SPEED

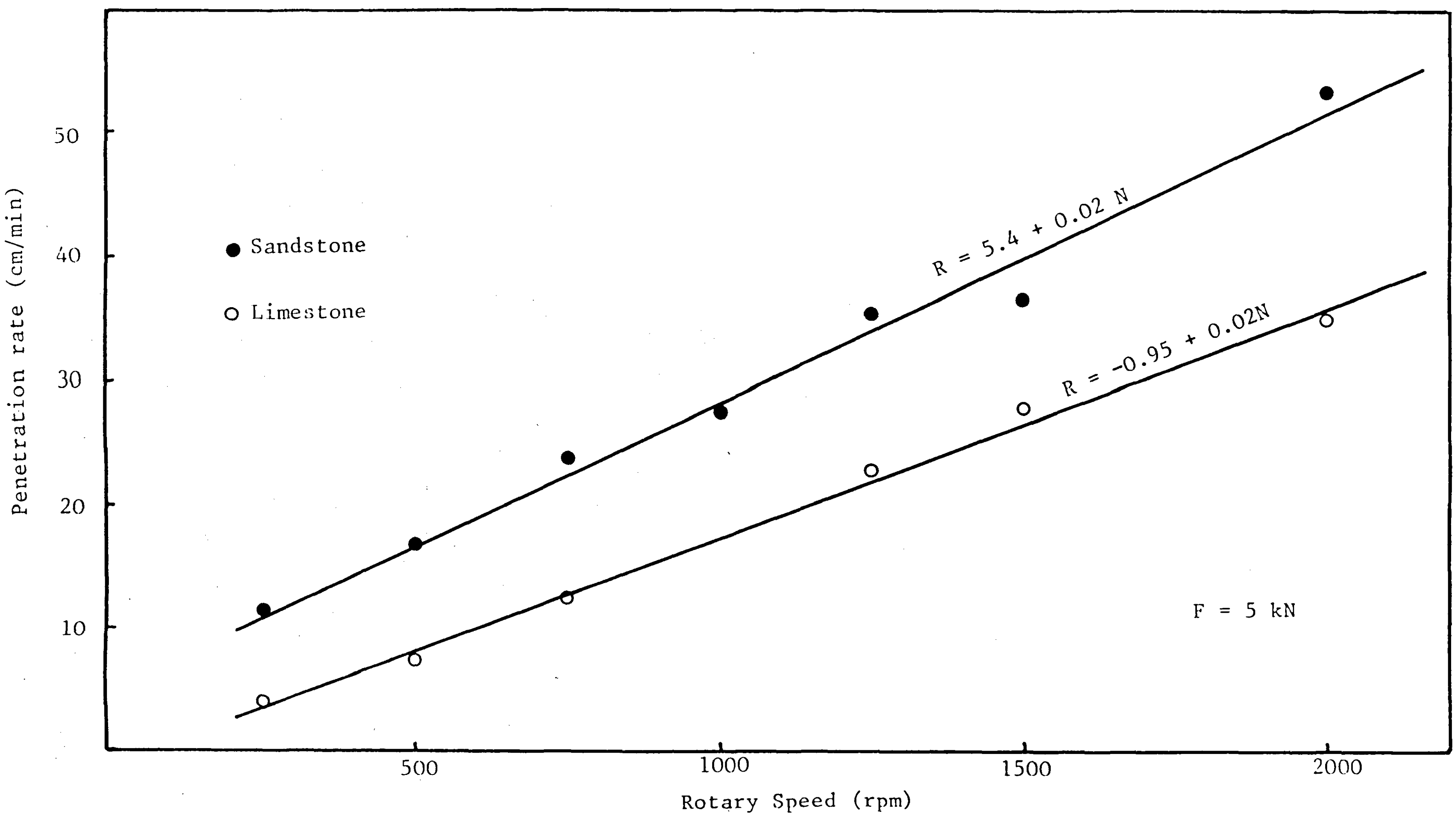


FIGURE 5.7: EFFECT OF ROTARY SPEED ON PENETRATION RATE AT CONSTANT THRUST

1. To develop instrumentation suited to routine monitoring of rotary drilling performance.
2. To establish the feasibility of drilling and collecting data from horizontally drilled boreholes.
3. To verify that essentially linear relationships between drilling variables, as outlined in the literature, could be applied to the high performance Diamec 250.
4. To recognise geological features encountered by the drill by means of their 'signature' as expressed in the drilling variables.
5. To assess the practicality of predicting rock strength from monitored parameters.

In furtherance of these various objectives, two fundamentally different drilling regimes were required. One drilling programme was dedicated to detecting simulated geological features incorporated in the concrete block array. In general, optimum drilling conditions were established and maintained by drilling at maximum values of rotary speed and thrust commensurate with penetration rates which would be acceptable under contract drilling situations. After acceptable values for the combination of independent variables were achieved, the operator intervened only when the drill rig was labouring under constraints imposed by changing downhole conditions which threatened to damage the equipment. In this manner, observed changes in the values of the dependent variables could be explained in relation to the geological features incorporated in the block array.

The other drilling regime was structured, *inter alia*, to obtain rate of penetration data for drill runs in each block type for a number of maintained thrust levels at a constant rotary speed (1500 or 1600 rpm). These data were to be used to assess a technique for back-calculating rock strength from recorded drilling performance. A secondary objective of this drilling regime was to attempt detection of structural features in the block array when they were potentially masked by alteration of independent drilling variables by the operator. A total of four boreholes, two for each drilling regime, were planned initially for the TRRL drilling trials. In view of the numerous difficulties encountered with the drilling and recording equipment, initial expectations were too ambitious. Nevertheless, the limited trials which were completed proved most informative and demonstrated that field trials were warranted subject to some improvements in the equipment.

A final series of tests were conducted in the TRRL to provide additional data for predicting rock strength from monitored drilling parameters. These tests were carried out after the field trials and involved drilling large blocks of natural stone to acquire data for back-calculation of rock strength. Table 5.8 lists the type of rocks involved.

TABLE 5.8: NATURAL STONE BLOCKS USED IN TRRL DRILLING TRIALS

Rock Type	County of Supplier	Number of Cores tested	Compressive Strength* (MN/m^2)
Sandstone A	Nottinghamshire	3	70.1
Sandstone B	Yorkshire	4	83.3
Carboniferous Limestone	Clwyd	6	89.3
Shap Granite	Cumbria	5	66.8
Merivale Granite	Devon	5	145.6
Whinsill Dolerite	Northumberland	3	190.5

* Measure by TRRL staff

5.4.2 Recording of drilling variables

In common with most prototype equipment, an intricate sequence of tasks had to be completed before, in this instance, drilling could commence or end. Table 5.9 summarises this procedure while Appendix 3 outlines the operation in greater detail.

While time consuming, the procedure outlined in Table 5.9 ensured that the recording equipment was functioning prior to a drill run. The visual display unit of the Mycalex was particularly useful during the pre-drilling checks since it could be used to observe the effect of any adjustment made to the recording equipment.

5.5 Data Processing

5.5.1 Basic system structure

Chapter 4 summarised the method of measurement of each of the drilling variables and the use made of each measurement. Of the variables discussed (Table 5.10), all were periodically sampled via the Mycalex logger and selected variables were continuously monitored using the Rikadenki strip chart recorder. At pre-selected intervals, normally from 2 to 5 seconds (10 seconds when drilling

TABLE 5.9: OPERATIONAL PROCEDURE FOR DRILL RIG INSTRUMENTATION

1. Warm-up period

   (a) Rotate chucks for approx. 20 minutes until normal operating oil temperature is reached (80^{o} C).
   (b) Switch on Mycalex and display all channels on the visual display unit.
   (c) Switch on Rikadenki
   (d) Check power-supply settings.

2. Pre-start routine

   (a) Check all Mycalex settings for position and off-set reading stability.
   (b) Check voltage supply on Mycalex and adjust if necessary to 10 volts.
   (c) Check zero adjustment and attenuator setting (normally 5v) on chart recorder - switch on pens.
   (d) Start water pump and check inlet pressure is being recorded.
   (e) Interface the venturis and check inlet water flow (bleed venturis if required).
   (f) Start paper punch.
   (g) Feed drill string to end of borehole, keeping bit just off the face, rotate the chucks and record off-set values on paper tape.
   (h) Start drilling.

3. Shut-down procedure

   (a) Back bit off rock, rotate chucks and record off-set value on paper tape.
   (b) Isolate the venturis prior to switching off the water pump.
   (c) Switch off paper punch and stop the chart recorder.

TABLE 5.10: INSTRUMENTION OF ATLAS-COPCO DIAMEC 250 ROTARY DRILL FOR HORIZONTAL DRILLING TRIALS

PARAMETER	METHOD OF MEASUREMENT	INFORMATION OBTAINED
Rotary speed	The output frequency from a tachometer coupled to the drive shaft of the motor is processed by a frequency to voltage converter and transmitted to the data logger as a D.C. voltage proportional to rotary speed.	Important drilling parameter for correlation with rock mass properties. Also used in determination of torque developed at the chuck.
Head displacement	A rotary potentiometer monitors the movement of the pulley over which the rotary head drive chain passes. Output voltage is directly proportional to the position of the rotary head.	Used to determine instantaneous penetration rates for correlation with rock mass properties.
Thrust	A 0-35 MN/m^2 pressure transducer used in conjunction with an instrumentation amplifier measures the oil pressure applied to the thrust piston.	Useful parameter for controlling drilling performance.
Inlet oil pressure	A 0-70 MN/m^2 pressure transducer used in conjunction with an instrumentation amplifier monitors the oil pressure at the control panel.	Used in the estimation of torque (see below).
Swash plate position	A rotary potentiometer coupled to the swash plate shaft gives an output voltage proportional to swash plate angle.	Swash plate position and rotary speed are used to determine the torque delivered to the drill chuck from calibration curves obtained using a Heenan-Froude dynamometer.
Torque	An electronic multiplier connected in division mode is used to derive an approximate torque value from inlet oil pressure and rotary speed.	Provides an approximate torque reading to assist the driller during drilling operations.
Water flow rates Inlet Outlet	The pressure drop across a venturi nozzle is measured by a differential pressure transducer and the signal processed by a square root extractor to produce a value of flow rate.	The net water balance in the borehole provides information on the groundwater conditions in the rock mass.
Inlet water pressure	A 0-1.7 MN/m^2 pressure transducer monitors the water supply to the drill string.	Useful in detecting discontinuities and as a correction to determine the effective thrust applied at the bit.
Outlet water pressure	A 0-0.7 MN/m^2 pressure transducer monitors the return water pressure as it passes through a stuffing box mounted on the rock face.	Useful in detecting discontinuities and sensing abnormal groundwater pressures.
Transducer and potentiometer supply voltages	Two precision voltage regulators ensure a stable supply. Any small fluctuations associated with the devices are recorded.	Recorded values of drilling parameters can be corrected for supply voltage fluctuations.

the natural stone blocks), depending on drilling conditions, the Mycalex logger would scan the array of 20 data channels and transfer recorded values to paper tape for subsequent computer processing. The intermittent sampling of the drilling operation was reflected in the logging system's response to downhole events. Early comparison with the continuous strip chart record showed that often Mycalex-recorded events were truncated, particularly during rapid penetration by the drill bit. However, these 'sampling errors' were greatly reduced by shortening the interval between data scans, thus improving the resolving power of the system.

By contrast, the chart recorder provided a continual indication that certain key sensors were functional during drilling operations and an accurate record of the drilling operation was maintained by recording events such as rechucks, core blockage or equipment failure. While it was never intended to use the strip chart records for detailed analysis, they proved an invaluable source of immediate information for the driller and provided an ideal diary of the drilling operation. This record was extremely useful during editing of the punch tape data.

5.5.2 Data editing

Data from the paper tape were read into a permanent file. The files were structured on the basis of individual core runs for a given borehole, subdivision within a core run being used to denote rechucks or other interuptions to drilling. For example, the file name T1.5.3 corresponds to TRRL Borehole 1, core number 5 following a second rechuck. This sytem of coding was used throughout the drilling trials.

Once established, the raw data were edited to:

1. Eliminate punching errors
2. Determine channel offset values from predrilling and post-drilling calibration runs.
3. Eliminate non-drilling portions of the file once step (2) was completed.

Once corrected, this edited file was placed in permanent store.

The frequency of punching errors varied from a few random events in a given file to innumerable errors which demanded many tedious hours of correction/elimination in order that the computer program would function. Errors normally consisted of a missing digit in the channel code, a missing blank between code elements, a missing polarity sign for voltage value or, on occasion, a missing digit in a variable value. Editing was also necessary when the data logger started to print in mid-scan, missing earlier channels in that particular time step. Where such errors were obvious, they were corrected. Otherwise, the time step was deleted from the record.

Also, at this stage, offset values for the measured variables were determined from the calibration runs before and after each coring interval. These offset values were used to establish a null position for each sensor relative to the calibration factors incorporated in the program. A record of these values was made for each drill run. Upon completion of the above tasks, all non-drilling portions of the file were deleted and the remaining data established as the permanent data file for that portion of borehole. However, a record of un-edited files was maintained for reference purposes.

5.5.3 Requirements of the computer program

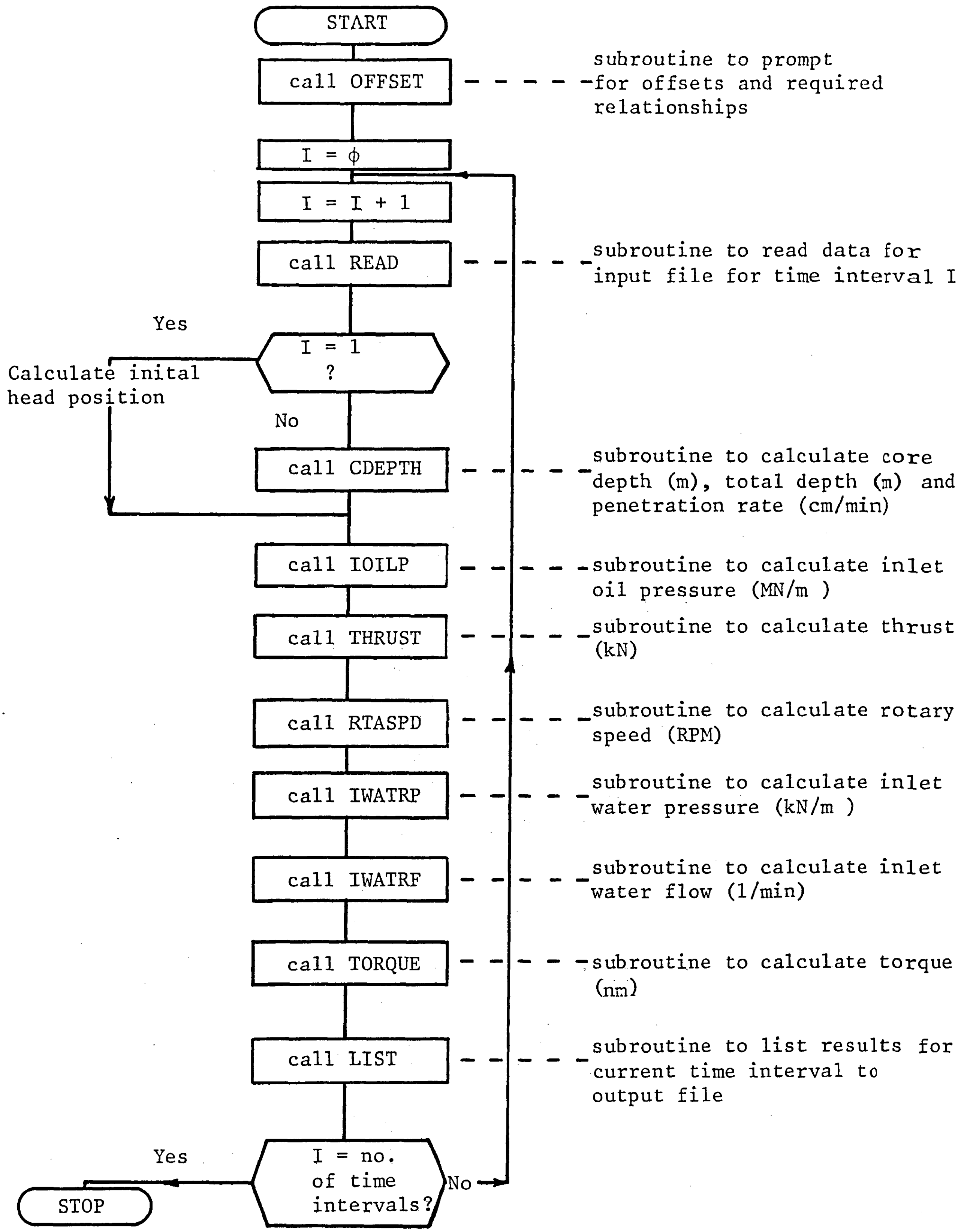
The captured data from the drilling rig instrumentation were expressed as voltages at assigned locations in the Mycalex data logger. At the end of a pre-determined time interval, the Mycalex would transfer data to a paper punch for storage and subsequent analysis by computer. Table 5.11 lists the channels and their corresponding variables.

TABLE 5.11: RECORDED VARIABLES

Channel	Variable
00	Real time
01	Rotary head displacement
02	Inlet oil pressure
03	Potentiometer supply voltage
04	Inlet water flow
05	Approximate torque
07	Thrust on bit
08	Transducer supply voltage
09	Rotary speed
11	Swash plate angle
18	Inlet water pressure

Figure 5.8 summarises the operation of the drilling data program. Broadly, the program was required to perform the following operations:

Figure 5.8; Flow chart for drilling data program



1) Allow for initial voltage offsets in the data prior to numerical processing.

2) Calculate penetration rate, rotary speed, thrust, torque, inlet water pressure, inlet water flow, and inlet oil pressure for each time interval based on specified calibration factors.

3) Maintain a continuous record of core depth and borehole depth in relation to the recorded variables.

A listing of the program is available in Appendix 4 along with a glossary of terms used.

5.5.4 *Program structure*

The program was structured with a main routine which was essentially a list of call instructions for subroutines which performed calculations to derive drilling parameters from the recorded voltages. One time interval of data was read as integer values, converted to real numbers for processing and the results transferred to the output file. The various subroutines are discussed in turn.

Subroutine *OFFSET*

Parameters: MXV, MNV, OILOV, TOV, ROV, WPOV, WFOV, N, K, TD, L, MIV and MAV.

This subroutine prompted the user for information that the program required during a given core run, namely:

1) The number of time intervals to be analysed.
2) The maximum voltage for the head displacement.
3) The minimum voltage for the head displacement.
4) Total depth at end of the previous core run.
5) The offset voltage for the inlet oil pressure.
6) The required thrust relationship.
7) The thrust offset voltage.
8) The required rotary speed relationship.
9) The rotary speed offset voltage.
10) The inlet water pressure offset voltage.
11) The inlet water flow offset voltage.
12) The minimum voltage for the swashplate setting.
13) The maximum voltage for the swash plate setting.

This subroutine also wrote the headings to the results file. Thereafter, the remaining subroutines were called for each time interval.

Subroutine *READ*

Parameters: TIME, CH 1, CH 2, CH 3, CH 4, CH 5, CH 7, CH 8, CH 9, CH 11, CH 18

(Channels 6 and 19 were not read since the outlet water balance from the boreholes failed to perform throughout the drilling operations).

This subroutine read the data from the input file for each time interval. Since, the raw data was stored as integers, this part of the program must float the data and multiply by 100 in order to provide correct voltage values.

Subroutine *CDEPTH*

Parameters: CRDTH, TIME, MXV, PTIME, CH 1, PRATE, MNV, TD, HLINT and HLNXT.

This subroutine calculated the depth drilled in metres since the last time interval and maintained a running total of borehole depth and core depth. The depth drilled during a particular core run was given by

$$\text{CRDTH} = 0.85 \frac{(\text{head displacement} - \text{minimum voltage})}{(\text{maximum voltage} - \text{minimum voltage})}$$

Therefore, the drilled interval became

$$\text{DLINT} = (\text{Present bit depth} - \text{previous bit depth})$$

The updated total depth was simply the previous total depth plus the drilled interval during the present time step. Similarly, the updated core depth was the previous core depth plus the drilled interval.

The penetration rate (cm/min) was calculated for each time interval as follows:

$$\text{PRATE} = [(\text{total depth} - \text{previous depth})/\text{time interval}] * 100 * 60$$

For the first time interval in each core run, the only calculation made in this subroutine was the depth drilled to date.

Subroutine *IOILP*

Parameters: CH2, ZERO, OILOV, CH8 and 1OP

The purpose of this subroutine was to maintain a continual check on inlet oil pressure variations. This information was required to provide an alternative means of determining torque based on the dynamometer tests described in Section 4.4 in the event of difficulties occurring with the swash plate potentiometer. The inlet oil pressure (MN/m^2) was determined from

$$\text{IOP} = \{[10 * \text{corrected voltage for CH2/CH8/} -0.2138]/0.001096\} * 0.006895$$

Subroutine *THRUST*

Parameters: CH7, CH8, TOV, K and THRST

This subroutine calculated the weight on bit (thrust) according to 1 of 4 different calibration relationships which resulted from various modifications to the thrust circuitry, namely:

x = (corrected voltage - 0.354326)/ 0.001755

x = (corrected voltage - 0.3883)/0.00201

x = (corrected voltage - 3.5385)/0.0070

x = (corrected voltage - 0.2753/0.0004

The x value (psi) derived from the appropriate equation was then used to determine the weight on bit (kN).

THRUST = (x-10) * 5.1431 * 4.448 * 0.001

Subroutine *RTASPD*

Parameters: ZERO, ROV, CH9, CH3, L, and RTSP

This subroutine calculated the speed of the rotary head (bit) in revolutions per minute using 1 of 2 calibration relationships:

RTSP = {[(CH9 - voltage offset)* 10/CH3]+ 0.082398} /0.003445

or

RTSP = {[(CH9 - voltage offset)* 10/CH3]- 0.4230 } /0.00308

Subroutine *IWATRP*

Parameters: WPOV, CH8, CH18 and IWP

This subroutine calculated inlet water pressure (kN/m^2) using the following relationship:

IWP = |{[(CHI8 - voltage offset)* 10/CH8] -0.7052} /0.03726|*6.895

Subroutine *IWATRF*

Parameters: WFOV, CH4, CH8 and lWF

Inlet water flow (l/min) was calculated by the following relationship:

IWF = {10**[(LY + 1.750046)/1.967213]} * 4.546

where

LY = $\log_{10}$(CH4 - voltage offset)*10/CH8

Subroutine *TORQUE*

Parameters CH3, CH11, MIV, MAV, ZERO, RTSP and TRQ

Torque values were determined for each time interval based on the angle of the swash plate and the rotary speed in accordance with the relationships detailed in Section 4.4.5.

The voltage reading at CH11 was corrected for supply voltage fluctuations to the rotary potentiometer on the swash plate shaft. The value employed in subsequent calculations corresponded to that which would result from the standardised 10 volt supply used during instrument calibration. This is carried out as follows:

Correct CH11 voltage = CH11* 10/CH3

In order to proceed with the torque calculation, the position of the swash plate must be determined, whereby:

Swash plate ratio = (CH11 corrected voltage-minimum swash plate voltage)/
(maximum swash plate voltage-minimum swash plate voltage)

Then, the idling speed (zero load) for the rotation unit was calculated to provide the abscissa intercept in Figure 4.28.

RPM = (swash plate ratio + 0.9711)/0.00086

Finally, the torque was calculated for the rotary speed which obtained at any time interval during drilling operations by the following formula:

TORQUE = {[(rotary speed - RPM)/(786 - RPM)]*80.7} /0.7376

Subroutine *LIST*

This subroutine printed out TIME, TD, CRDTH, PRATE, RTSP, THRST, TRQ, IWP, IWF and IOP for each time step to the output file.

5.5.5 Data presentation

Three different formats were used to present the data recovered during the drilling trials. Strip chart records from a Rikadenki recorder provided the most instantaneous, albeit fundamental, presentation of the drilling operation. Initially, six channels were used to record the following variables against time (chart speed = 50 mm/min.): thrust, torque, head displacement, rotary speed, inlet and outlet water pressure. Eventually, the two water pressure variables were dispensed with when they proved to be unreliable.

A complete record of the drilling operation was provided by a computer listing of all dependent and independent drilling variables monitored throughout the laboratory and field trials. This information was presented for each drill run using the file code outlined in Section 5.5.2., namely: borehole, core run and rechuck number. All variables are listed for pre-selected time intervals. With the exception of penetration rate, all variables are derived from voltages prevailing at each channel location during the data scan by the Mycalex. Penetration rate was based on the drilled interval over a known time period (two successive date scans).

Finally, a graphical presentation of downhole drilling situations was produced from the computer-derived listings described above. Five variables (the maximum on the Zeta plotter graphics package) including rotary speed, inlet water pressure, thrust, core depth and penetration rate were plotted against time for selected drill runs. In order to separate the traces within the 300 units allocated by the plotting program, the following scaling factors were used:

Variable	Scale Value	Units
Rotary speed	x 10	r.p.m.
Inlet water pressure	− 100	kN/m^2
Thrust	÷ 10	kN
Core depth	÷ 294.12	m
Penetration rate	÷ 2	cm/min

5.6 Results of the Laboratory Drilling Trials

The volume of data recovered during the TRRL drilling trials renders impractical an exhaustive consideration of each drill run. For the purpose of detailed discussion, a representative selection of drilling records are analysed for boreholes 1 and 2. The remaining drilling records are presented in Appendix 5. A selection of computer graphs are also considered in this section. The record is incomplete because computing time costs restricted the availability of Zetaplot graphs.

5.6.1 TRRL Borehole 1

Drilling record 1.3.1

The strip chart record for the 0.91 to 1.76 metres drilled interval is shown in Figure 5.9. Since the water monitoring equipment was non-operational only four drilling variables are represented, namely: thrust, torque, rotary speed and head displacement. Nevertheless, the record contains a number of interesting features.

For example, the effect of fissures, orientated normal to the drill string, are clearly apparent. When the drill bit encountered a fissure with a perceptible gap, there was a pronounced change in the slope of the head displacement curve. In this instance, the head displacement curve tends to the horizontal because a substantial change in the location of the rotary head on the drill frame (represented on the x-axis of Figure 5.9) has occurred over a very small time interval (y-axis). In fact, the slope of the head displacement curve represents the rate of penetration of the drill bit, the slope of the curve tending to zero with increasing rate of penetration.

After approximately 1 minute 18 seconds drilling time, a 10mm wide fissure was encountered between blocks 5 and 6. Unfortunately, a faulty switch on the recorder resulted in the head displacement record being interrupted on the strip chart. Hence, the abrupt change in the slope of the head displacement curve was not recorded; however, other drilling variable responses were captured. In particular, the effect on rotary speed was notable, there being a slight initial increase in rotary speed prior to a pronounced deceleration. At the same time, the torque and thrust displayed marked responses. Initially, thrust and torque decreased in value when the fissure was encountered but this was followed by pronounced reversals in response.

Since this fissure was open rather than clay-filled, this behaviour must correspond with the bit entering the non-resistant void causing the rotary speed to increase since frictional resistance at the bit (drag) fell momentarily to zero. Although torque, as measured on the chart recorder, was a function of rotary speed (Section 4.3.7), it was reasonable to expect a similar decrease over the width of the fissure since the major resistive force contributing to torque no longer existed.

Upon encountering the opposing face of block 6, sharp reversals in the trends for rotary speed, torque and thrust were recorded. Rotary speed decreased markedly as the bit dug into the concrete, thrust increased as load on the drill bit was re-established and torque increased in response to mounting resistance to drilling.

FIGURE 5.9 RECORD OF TRRL DRILL RUN 1.3.1 (0.91 to 1.76metres).

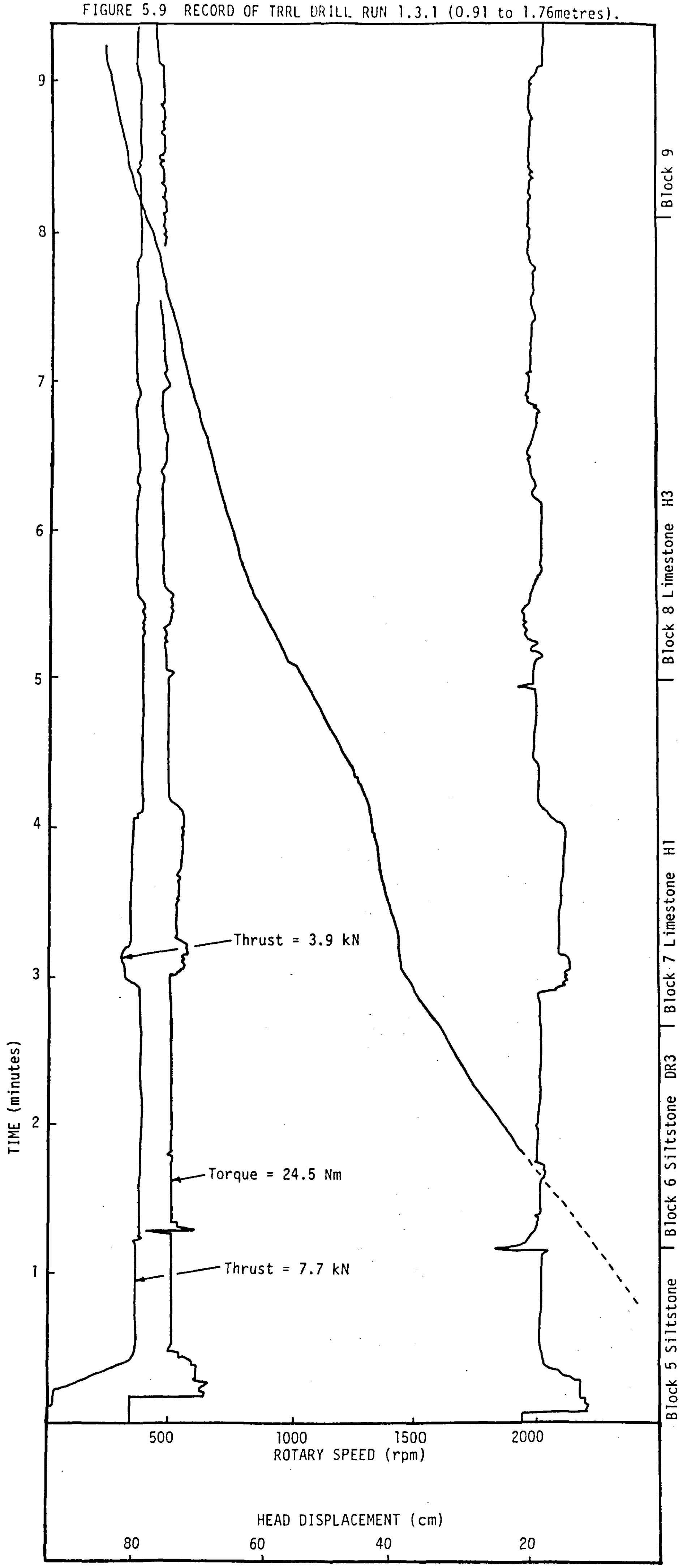


Figure 5.10 shows a computer-drawn graph of drill run TRRL 1.3.1 wherein thrust, rate of penetration, core depth, inlet water pressure and rotary speed are represented. The fissure intersection is outlined prominantly in this record. Once initial drilling conditions were established with thrust equal to 7.74 kN, rotary speed approximately 1950 rpm, inlet water pressure averaging about 25 kN/m^2, the rate of penetration was effectively 14.5 cm/sec. The block 5/6 fissure intersection stands out as a distinctive spike on the penetration rate trace and coincides with a near vertical displacement in the core depth trace, a downward trending ripple in the thrust plot and an abrupt decrease in rotary speed. Thereafter, the trends which existed prior to encountering the fissure were re-established with only minor variations occurring.

Another 'fissure' occurs after approximately 2 minutes 26 seconds elapsed drilling time. In this case (block 6/7 interface), the block faces were designed so that no appreciable gap would exist. However, in attempting to marry up two non-planar surfaces (see Section 5.2.1), a small but sensible aperture existed. Only very slight ripples in each of the traces hint at the presence of this joint. It is doubtful whether these tight joints and their subtle disturbance of the instrumentation sensors would be recognised under field drilling conditions. In the listing of computed values presented in Table 5.12, it was difficult to decide with certainty which time interval represented this event although it was thought to be 45938. The computer graph offered no assistance since it was drawn from the periodic data listed in the table.

A second 10mm wide fissure was encountered after 4 minutes 56 seconds drilling time (time interval 46204) and while the response of the system variables was similar to the block 5/6 joint, slight variations were observed. It should be borne in mind that this fissure was packed with clay to simulate a clay-filled joint. In this instance, head displacement through the fissure was less rapid. Table 5.12 indicates a 18.6 cm/min rate of penetration for this joint (block 7/8 interface) compared with 50.6 cm/min for the one at 1.06m depth. No initial increase in rotary speed was noted despite the bit passing through a material with lower drilling resistance than the confining limestone blocks. Similarly, the drop in rotary speed was less pronounced when the bit encountered 'rock' again. Only a slight drop in thrust and a brief increase in torque occurred. The presence of the clay infill dampened the response of the instrumentation and tended to blur the contrasting conditions at the block 7/8 interface.

FIGURE 5.10 COMPUTER RECORD OF TRRL DRILL RUN 1.3.1 (0.91 to 1.76 metres)

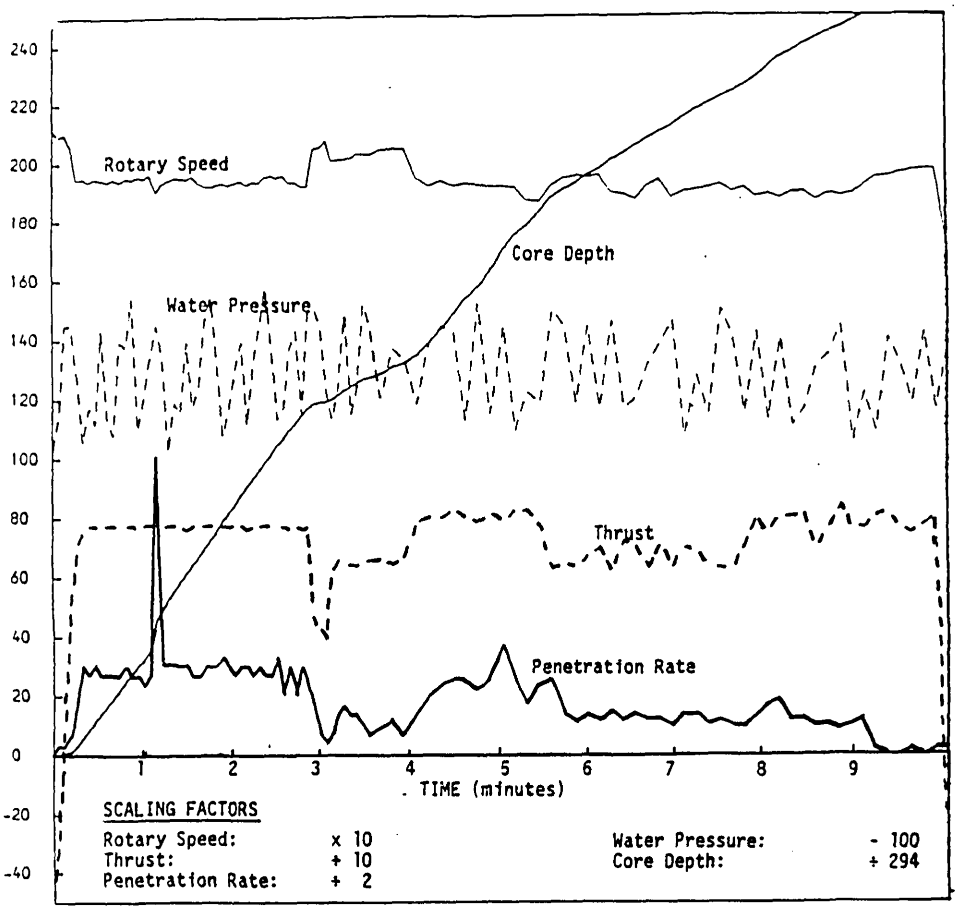


TABLE 5.12 COMPUTED VALUES FOR TRRL 1.3.1 DRILLING VARIABLES

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAT. RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M^2)	H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M^2)
45710	[illegible]	[illegible]	[illegible]	2114.37	-4.55	[illegible]	3.41	[illegible]	[illegible]
45714	0.91	[illegible]	1.69	[illegible]	[illegible]	14.11	[illegible]	[illegible]	[illegible]
45718	0.91	[illegible]	1.69	2099.41	1.07	13.68	[illegible]	27.75	7.14
45722	0.91	0.004	3.37	[illegible]	4.58	16.87	44.95	39.91	7.44
45726	0.92	0.012	4.43	1944.52	[illegible]	[illegible]	[illegible]	[illegible]	5.77
45730	0.93	0.020	13.15	1947.43	7.60	23.25	5.27	23.14	9.34
45734	0.94	0.029	13.49	1938.69	7.73	23.67	17.0[illegible]	[illegible]	9.55
45738	0.95	0.039	17.18	1951.33	7.73	[illegible]	11.47	47.25	[illegible]
45742	0.96	0.048	13.49	1944.52	7.73	[illegible]	43.[illegible]	41.73	[illegible]
45746	0.97	0.057	13.49	1938.69	7.73	23.67	13.30	25.46	9.34
45750	0.98	0.066	13.49	1947.43	7.73	25.23	7.7[illegible]	3.41	9.28
45754	0.99	0.075	13.49	1938.69	7.73	23.67	39.37	3.40	9.34
45758	1.00	0.085	15.18	1950.35	7.74	24.62	37.41	36.43	9.35
45802	1.0[illegible]	0.094	13.49	1949.37	7.74	22.34	54.17	37.12	9.22
45806	1.0[illegible]	0.103	13.49	1954.22	7.62	23.15	9.37	3.41	9.30
45810	1.02	0.111	11.81	1952.28	7.74	22.12	20.66	3.40	9.1[illegible]
45814	1.03	0.12[illegible]	13.49	1951.03	7.74	24.24	33.67	27.28	9.03
45818	1.06	0.154	50.59	1933.72	7.74	27.14	44.86	43.61	10.17
45822	1.0[illegible]	0.165	18.55	1932.86	7.74	24.39	33.69	47.69	9.54
45826	1.09	0.178	16.86	1941.60	7.74	24.35	2.04	51.81	9.22
45830	1.10	0.188	15.18	1950.35	7.74	23.70	18.80	50.05	9.10
45834	1.11	0.196	15.18	1949.37	7.62	21.20	14.96	43.33	9.11
45838	1.12	0.209	15.19	1946.45	7.62	21.42	39.18	23.31	6.98
45842	1.13	0.217	13.49	1936.18	7.74	23.27	16.94	3.40	6.97
45846	1.14	0.226	13.49	1932.86	7.74	24.99	24.38	3.40	6.91
45850	1.15	0.236	15.18	1921.20	7.74	25.85	46.72	3.40	9.41
45854	1.16	0.246	15.18	1921.20	7.73	25.35	54.20	14.78	9.53
45858	1.17	0.256	15.18	1927.03	7.73	25.42	31.93	46.29	9.34
45902	1.18	0.268	16.86	1932.86	7.74	24.99	7.63	52.43	9.29
45906	1.19	0.278	15.18	1927.03	7.73	25.42	17.05	49.63	9.47
45910	1.20	0.287	13.49	1932.86	7.74	24.99	29.97	41.66	9.16
45914	1.21	0.297	15.18	1938.69	7.74	24.56	39.28	13.93	9.22
45918	1.22	0.307	15.18	1920.03	7.62	22.97	11.23	4.84	9.[illegible]
45922	1.23	0.316	13.49	1935.77	7.74	24.78	31.83	3.40	9.[illegible]
45926	1.24	0.326	15.18	1932.86	7.74	24.99	44.86	3.40	9.16
45930	1.25	0.335	13.49	1950.35	7.74	23.70	57.89	7.71	9.03
45934	1.25	0.344	13.49	1956.18	7.74	23.27	37.41	45.86	6.78
45938	1.27	0.355	16.87	1947.43	7.74	23.92	13.21	52.31	9.10
45942	1.27	0.362	10.12	1956.18	7.73	23.27	17.05	48.55	6.77
45946	1.28	0.372	15.18	1931.80	7.61	22.33	37.41	38.83	9.[illegible]
45950	1.29	0.379	10.12	1929.95	7.73	25.21	43.09	3.40	9.15
45954	1.30	0.389	15.18	1917.27	7.62	23.64	14.96	4.64	9.17
45958	1.31	0.397	11.81	1918.29	7.74	26.16	50.45	3.4[illegible]	9.3[illegible]
46002	1.31	0.403	4.43	2040.52	4.59	16.62	50.45	3.40	7.90
46006	1.31	0.405	3.37	2050.35	4.33	15.20	44.85	40.25	7.58
46010	1.32	0.406	1.69	2072.75	3.94	14.69	22.52	51.57	7.26
46014	1.32	0.408	3.37	2034.80	6.17	17.00	13.21	51.44	7.39
46018	1.32	0.413	6.75	2008.04	6.55	19.41	24.47	45.03	8.01
46022	1.33	0.418	8.43	2011.63	6.43	16.36	48.55	25.03	7.53
46026	1.33	0.423	6.75	2015.46	6.43	15.11	15.07	4.84	7.83
46030	1.34	0.427	6.75	2025.13	6.43	15.23	24.38	4.84	7.[illegible]
46034	1.34	0.431	5.06	2028.13	6.44	15.[illegible]	52.23	4.84	7.55
46038	1.34	0.433	3.37	2026.12	6.56	16.	44.86	3.40	7.52
46044	1.35	0.437	4.[illegible]	2043.61	6.56	16.	20.65	5.17	7.45

The drilled interval between 1.27 and 1.50m demonstrated the effect that operator adjustment of an independent variable(thrust)had upon the other major drilling variables. Reference to Table 5.13 shows the following average values obtained over this section of block 7.

Table 5.13 Relationship between drilling parameters in concrete block 5 (TRRL 1.3.1).

Time (min)	Sample size	Thrust (kN)	Rotary Speed (rpm)	Penetration Rate (cm/m)	Torque (N m)
2.53	5	7.7	1931	12.5	24.1
2.90	2	4.1	2063	2.5	15.4
3.20	4	6.4	2021	6.7	15.8
4.10	6	8.1	1924	11.8	23.5

The values demonstrated the importance of thrust in the rotary diamond drilling operation. When thrust was insufficient, penetration rates were correspondingly low. The high rotary speed and relatively low torque were also indicative of low thrust levels. With increased thrust, the rotary speed fell and the torque increased as the resistance to drilling mounted with the greater penetration of the cutting elements into the rock.

The strip chart record for this drill run highlighted another important feature of drill rig instrumentation, namely: fault diagnosis. At the beginning of the log, the on/off switch controlling the head displacement circuit developed a fault which meant no record of rotary head advance was obtained. This was quickly remedied. Fortunately, the data was available from the Mycalex recording. Although in this instance, the fault involved the instrumentation rather than the drilling rig, the benefit of early fault detection is demonstrated.

Drilling record 1.3.2

This short drill run was interrupted by a core blockage at 2.04m. However, some interesting responses are present in the record. Figure 5.11 commences with the setting of the thrust equal to 7.5 kN. Torque and rotary speed show characteristic adaptation to this change. The rate of penetration averaged 10.2 cm/min over the remaining portion of block 9. At 1.95m depth, a 15mm wide fissure denotes the passage of the bit into block 10. The fissure was marked by a sharp drop in rotary speed, an

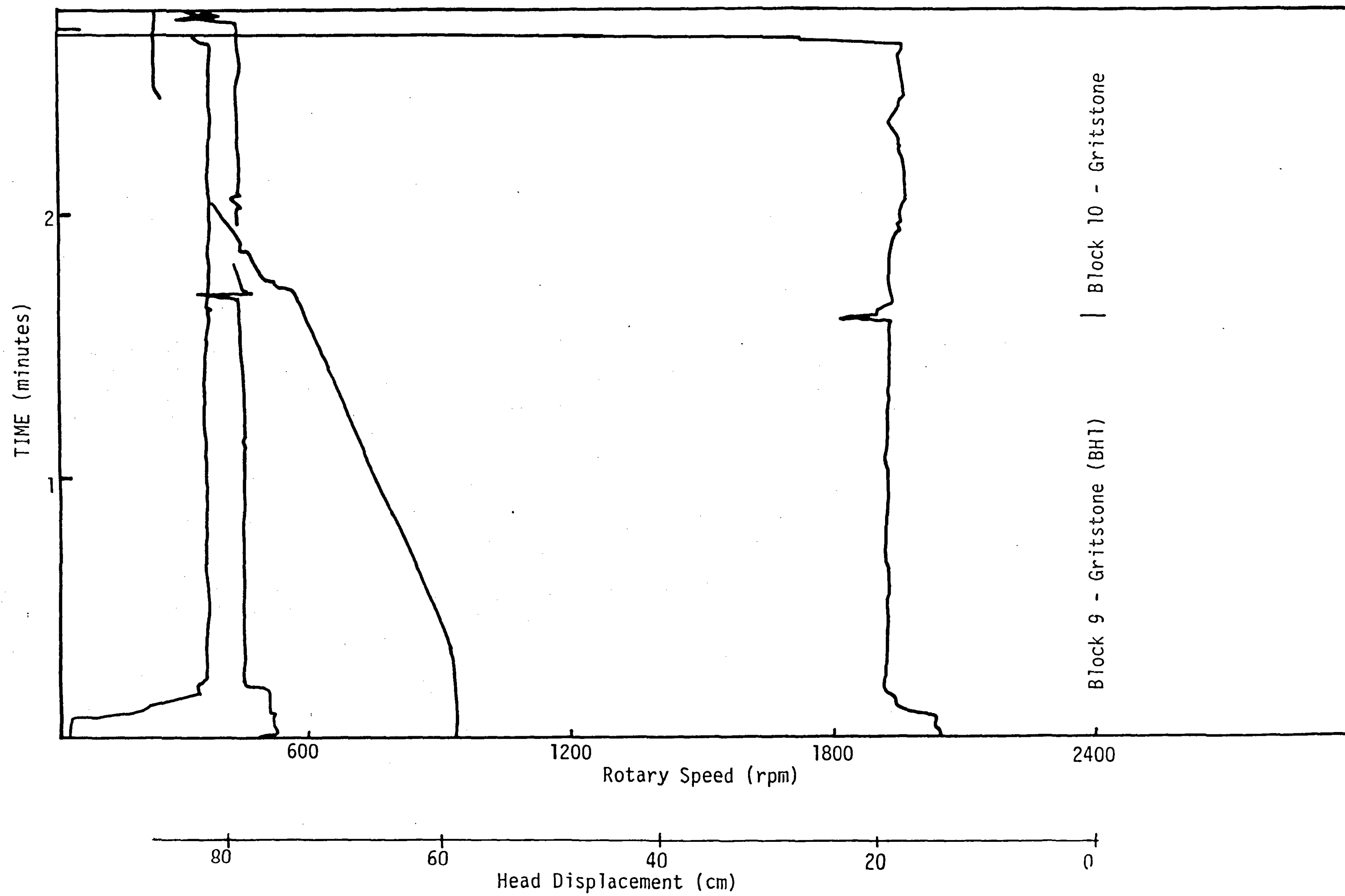


FIGURE 5.11 RECORD OF TRRL DRILL RUN 1.3.2 (1.76 to 2.04 metres)

FIGURE 5.12 CORE RECOVERY FROM TRRL BOREHOLE 1

initial reduction in thrust and torque followed by slight increases over the pre-fissure levels, and a pronounced horizontal shift in the head displacement trace on the strip chart record. Although the initial increase in rotary speed at a fissure was not noted, the other variable responses compared favourably with those observed in the previous record.

In block 10, the average thrust level was maintained yet the rotary speed and rate of penetration increased while torque values dropped slightly, suggesting less resistant drilling conditions. Penetration rates of 10.2 cm/min. and 15.8 cm/min. in block 9 and 10 respectively reflected the stark contrast in strength between blocks 9 (41.1 MN/m^3) and 10 (6.1 MN/m^2). This variation was also the cause of the core blockage which terminated the drill run. In Figure 5.12, a photographic record of the core retrieved from borehole 1 is shown. Other than the small core stub in block 10 which caused the blockage, the remainder of the block was represented only by fragments of aggregate.

Drilling record 1.3.4

The influence of drilling fluid circulation is shown in Figure 5.13. For the 1¼ minutes drilling time, very slow advance was made through flint aggregate block 11. Drilling was characterised by fluctuating rotary speed and torque as the drill rig struggled to make headway in the flint. Some improvement in rate of penetration was obtained by increasing the flow of water to the bit to enhance hole cleaning. Although the improvement in rate of advance declined slightly, the better hole cleaning was reflected in smoother rotary speed and torque traces. The core barrel had several scores along its length when removed from the hole, which suggested that a flint particle(s) had wedged in the annulus, possibly at the point where the rotary speed dropped to its lowest values.

After approximately 3 minutes drilling, a large aperture fissure (20 mm) was encountered between flint blocks 11 and 12 (Figure 5.4). Very pronounced deflections occurred in the drilling variable traces. Initially, the torque value dropped in response to the zero load condition at the bit, followed by a sharp increase as the bit contacted the face of block 12. The rotary speed fell abruptly when this contact was made. These extreme values were not recorded by the data logger since the fissure was crossed between data scans. The thrust value dropped over the aperture of the fissure prior to increasing when the bit struck block 12.

Finally, reference to Appendix 5 shows that despite a marked variation in strength between blocks 11 and 12, 48.6 MN/m^2 and 25.6 MN/m^2 respectively, no appreciable difference in penetration rate occurred. Apparently the

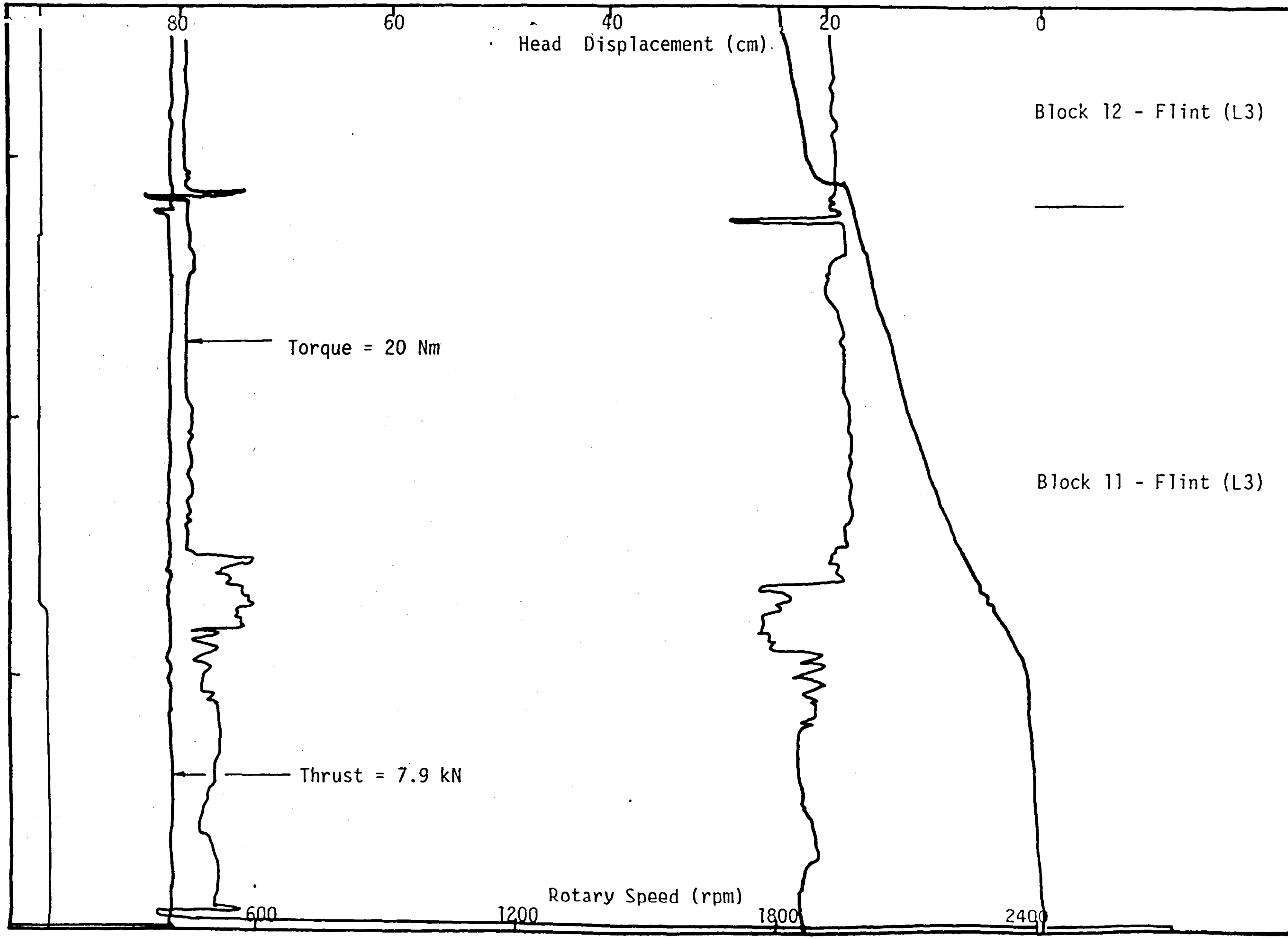


FIGURE5.13: RECORD OF TRRL DRILL RUN 1.3.4 (2.17 to 2.42 metres)

character of the flint rather than the strength of the concrete dictated the rate of advance in these blocks.

Drilling record 1.5.1

Figure 5.14 depicts the drilling record for coring run 1.5.1. The record is slightly in excess of 10 minutes duration and contains a number of interesting features despite pen interaction which caused interruptions in the traces.

The initial portion of the coring run involved routine drilling in block 19 (H1, limestone aggregate). Under 10 kN thrust, uniform rates of penetration of 6.8 to 8.3 cm/minute are maintained throughout the block until the clay-filled fissure between blocks 19 and 20.

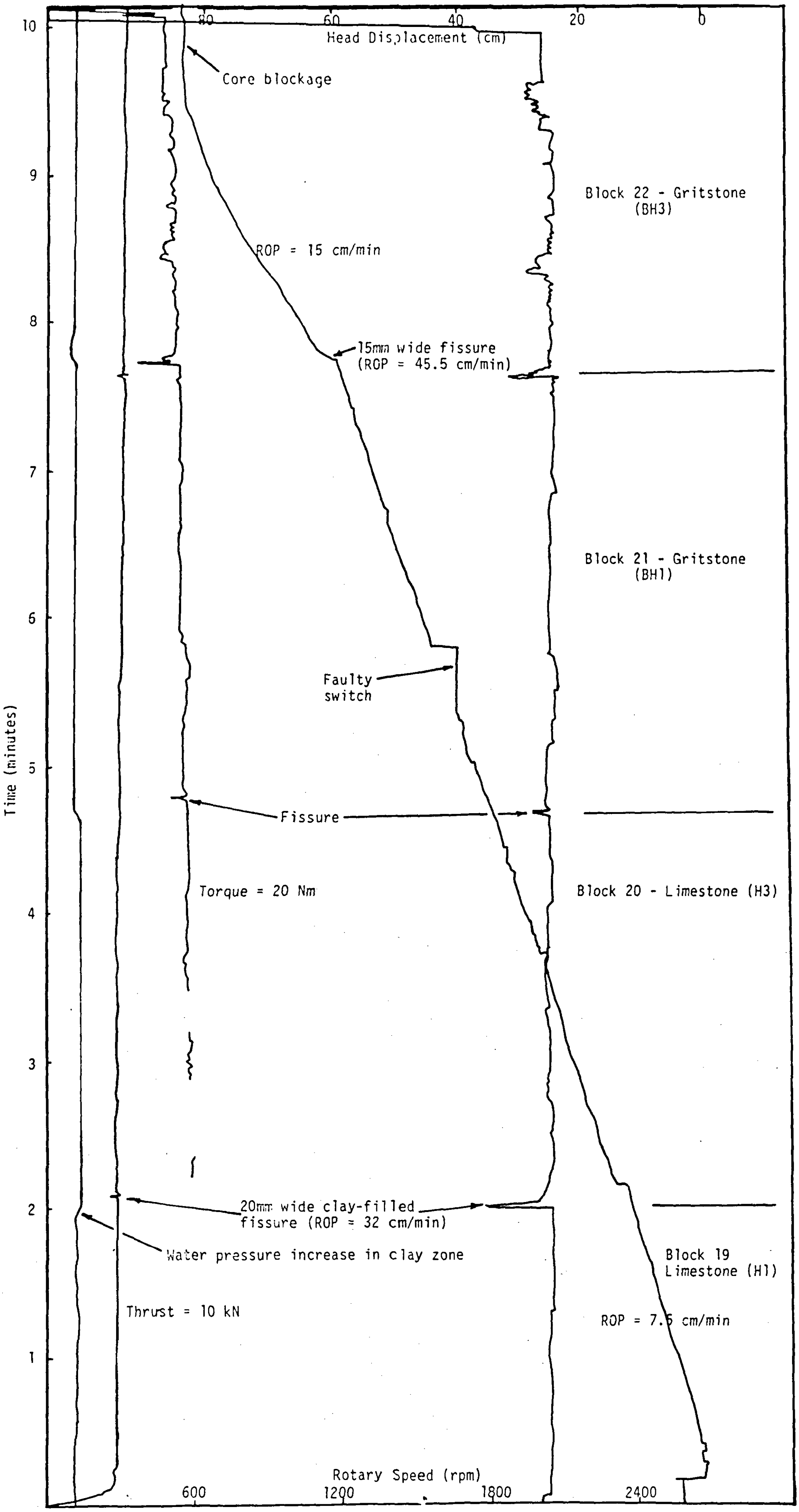
The fissure is marked by characteristic deflections of the principal drilling variable traces about 2½ minutes into the drill run. The head displacement tended to the horizontal as the penetration rate increased from 6.8 to 32.0 cm/min. A marked drop in rotary speed was evident on the strip chart record when the bit encountered the face of block 20. The Mycalex record (Appendix 5) was less informative with respect to rotary speed, showing a mere 35 rpm variation over the fissure, indicating that the event occurred largely within a scanning interval. The thrust trace also behaved as expected, a slight drop in value when the fissure is encountered followed by a slight increase when the opposite block is struck before establishing a fixed level. The torque trace was non-functional during this time.

Another feature of the clay-filled fissure concerned the inlet water pressure. Figure 5.14 shows an increase in pressure as the bit surges through the clay. The pressure returned gradually to its pre-fissure value as block 20 was drilled. The numerical record indicates 50.6 kN/m^2 over the clay-filled fissure but this value may not necessarily be indicative of the fissure as inlet water pressure values recorded by the Mycalex tended to be erratic.

Drilling through block 20 proved uneventful. No variation in rate of penetration occurred between blocks 19 and 20, despite drilling in a weaker limestone aggregate block (H3) under similar conditions of thrust and rotary speed.

After approximately 5 minutes, another block interface was crossed (blocks 20/21) but with considerably less effect upon the recorded variables than the previous one. No perceptible fissure aperture was indicated on the head displacement trace in Figure 5.14. This accords well with the block

FIGURE 5.14 RECORD OF TRRL DRILL RUN 1.5.1 (3.89 to 4.73 metres)



arrangement discussed in Section 5.2.3 since no gap between the block was intended at this location. Nevertheless, the boundary was signalled by characteristic disturbances in the rotary speed and torque traces. In addition, the inlet water pressure dropped slightly, presumably as a result of the storage capacity provided by the fissure.

Some of these features are apparent in Figure 5.15 which shows the computed results for the drilling run. The block boundary is indicated by the small rate of penetration peak standing slightly proud of the values prevailing in block 20. This subdued response is in marked contrast to the pronounced peak representing the clay-filled fissure between blocks 19 and 20. Figure 5.15 also shows that no pronounced rate of penetration change occurred when the drill bit encountered the gritstone aggregate of block 21. Apart from a faulty switch indication on the head displacement channel (Figure 5.14) about 5½ minutes into the record, nothing of particular note occurred until the fissure between blocks 21 and 22 was crossed.

This 15mm wide fissure separated two gritstone aggregate blocks with substantially different 28 day compressive strengths (Table 5.4), 41 MPa for block 21 compared with 6 MPa for block 22. The open fissure and the strength contrast exerted strong control over the observed drilling variable response. The strip chart record was characterised by pronounced displacements in the rotary speed, head displacement and torque traces. The inlet water pressure dropped slightly in value as the fissure was crossed. The fissure is represented on the computer graph at approximately 8 minutes by a high rate of penetration peak (45.5 cm/min.).

Drilling in the weaker block resulted in rates of penetration averaging about 15 cm/min. for unchanged conditions of thrust and rotary speed. This was maintained until erratic rotary speed and thrust signalled a core blockage which was expressed in reduced rate of penetration.

<u>Drilling record 1.5.3</u>

The most striking feature encountered in the 4.77 to 5.00 metre interval was the 20mm wide fissure between blocks 23 and 24. Prior to this event, drilling was extremely slow through the flint. Coupled with poor rate of penetration was a system fault at 2½ minutes elapsed drilling time. The paper punch jammed necessitating shutdown while the fault was rectified. This problem is apparent in Figure 5.16 and the computer graph in Appendix 5. The numerical record notes the event at 102402.

Slow drilling resulted over the thickness of block 23. However, the

FIGURE 5.15 COMPUTER RECORD OF TRRL DRILL RUN 1.5.1 (3.89 to 4.73 metres)

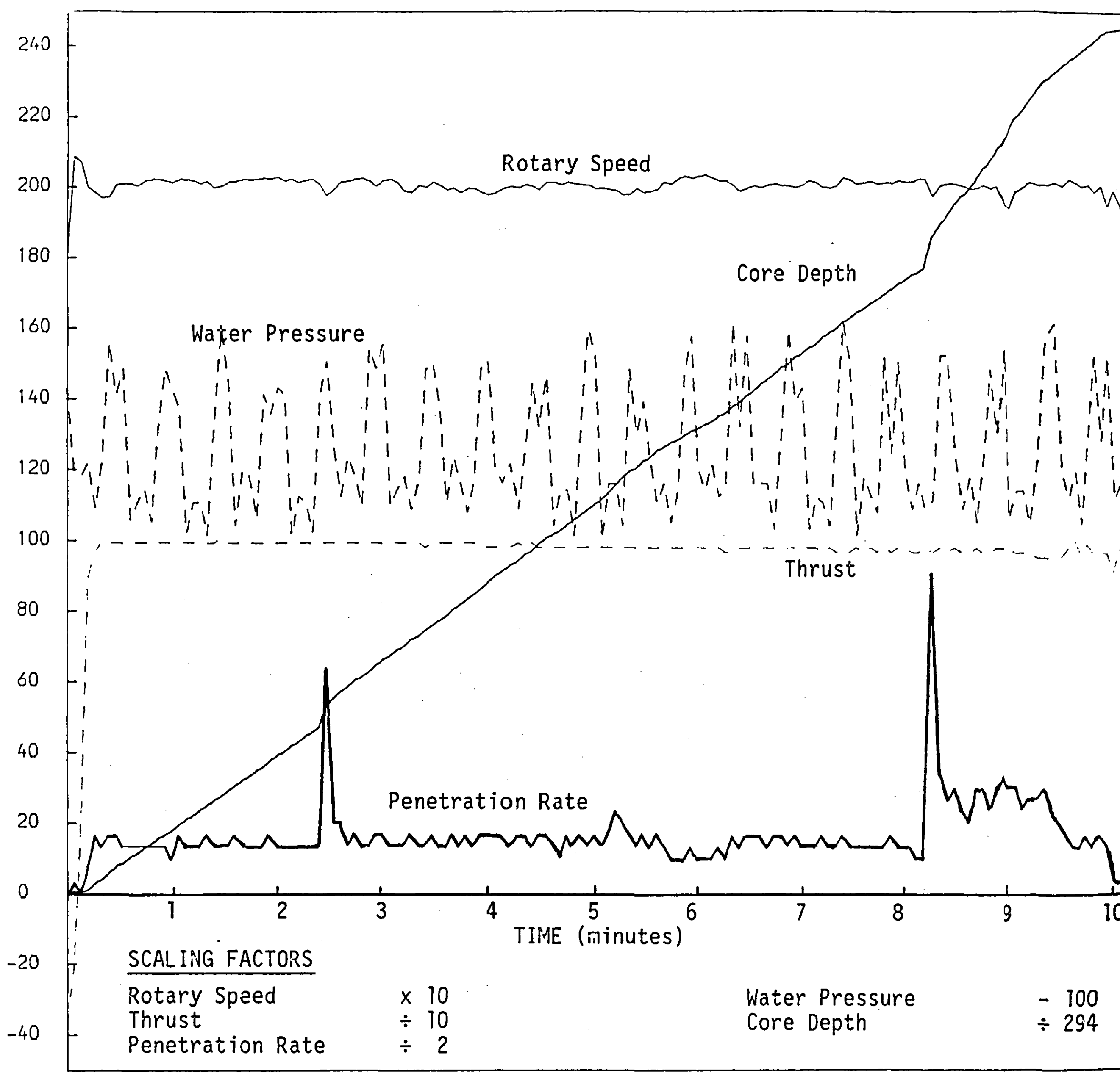
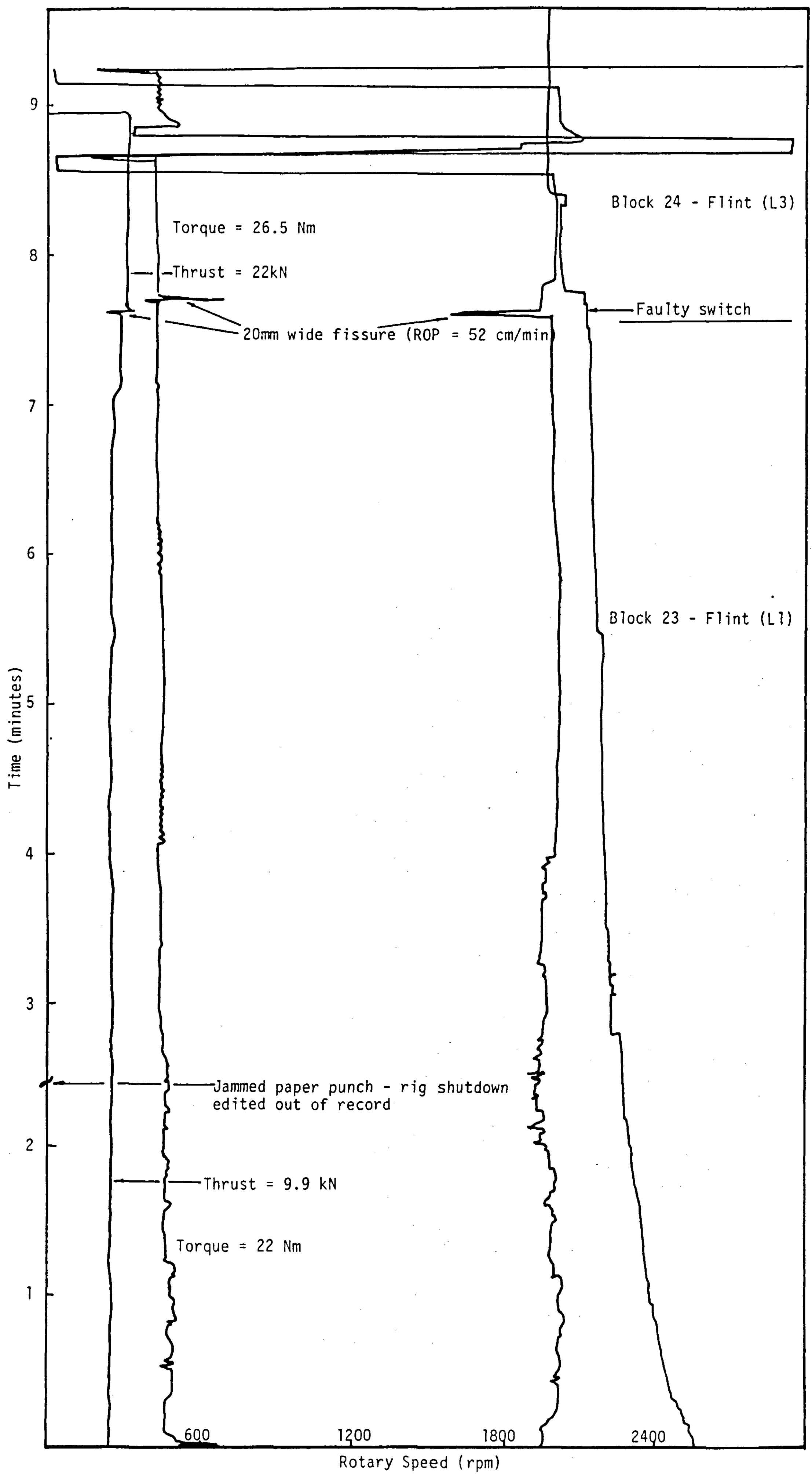


FIGURE 5.16 RECORD OF TRRL DRILL RUN 1.5.3 (4.77 to 5.00 metres)



fissure was marked by very pronounced deflections in the drilling variables, particularly rotary speed, torque and displacement. Average rate of penetration rose from less than 1.7 cm/min. to over 50 cm/min. The torque and thrust traces show an initial drop in level as the bit traverses the open fissure followed by a pronounced increase in value in the case of torque, less so with thrust, as the bit engages the face of block 24. Shortly after this event, the drilling run was stopped because of a combination of a punch tape jam and a core blockage.

Drilling record 1.6

This drilling record graphically illustrated the difficulties posed when drilling flint aggregate blocks. Drilling was slow but routine through flint block 24 with the rate of penetration gradually falling from initial values of 8.5 - 10.0 cm/min. to 5.1 cm/min. After 100 seconds elapsed drilling time, the drill bit passes into the wedge of mixed gravel/sand/clay between blocks 24 and 25. This feature is well marked on Figure 5.17 by pronounced deflections in the head displacement, rotary speed, torque and inlet water pressure traces. The thrust record on this plot was reconstructed from numerical data in Appendix 5 since a system fault precluded direct recording. Hence, the thrust trace does not display the expected reduction in value which would normally result from drilling into this zone. The variations which occurred around two minutes were caused by intervention by the driller to ease the drilling difficulties which followed drilling of this 'mixed ground'.

At the first indications of rough drilling, the driller altered the swash plate angle thereby reducing the rotary speed to prevent damage to the drill bit. Also, the thrust was reduced from 9.5 kN to 6.8 kN to allow the bit to better engage the inclined granite block on the opposite side of the 'mixed ground' zone. These adjustments are evident in Figure 5.18, the gravel/sand/clay wedge being defined by the prominent rate of penetration peak. Nevertheless, even in the granite block (25), the drill rig was in distress. Particles flushed from the mixed ground zone were evidently wedging the barrel in the small annulus between the barrel and the borehole wall. The net effect was repeated snatching of the drill string in the hole causing rapid fluctuations in torque and rotary speed and a tendency for the bit to advance in very short, frequent surges. Rather than terminate the core run, the driller attempted to free the drill string by a number of adjustments to the thrust. This apparently succeeded when the snatching was largely eliminated after approximately 1½ minutes of nerve-wracking drilling. However, after 5 minutes drilling time, a pronounced solitary snatch of the string announced

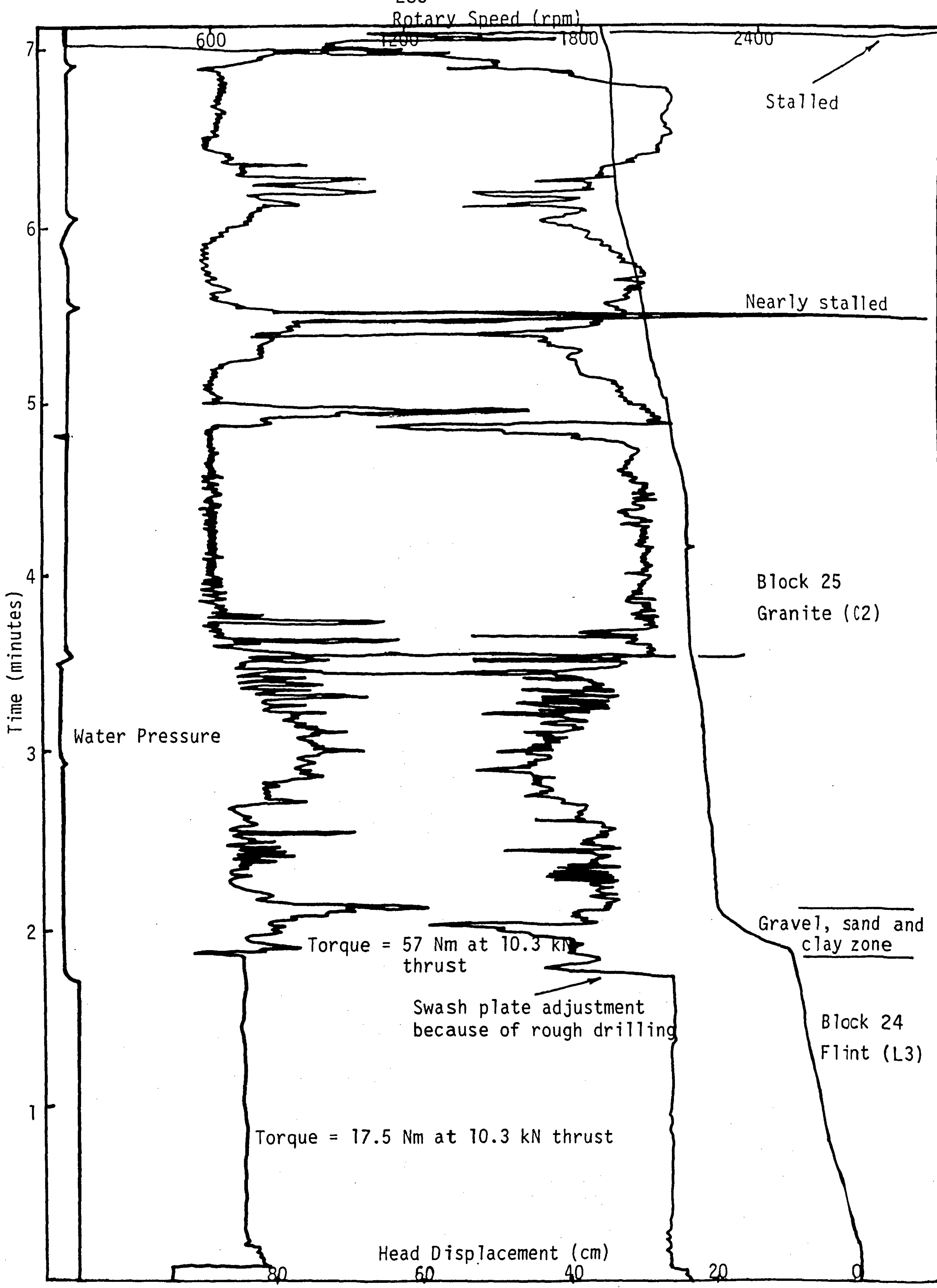
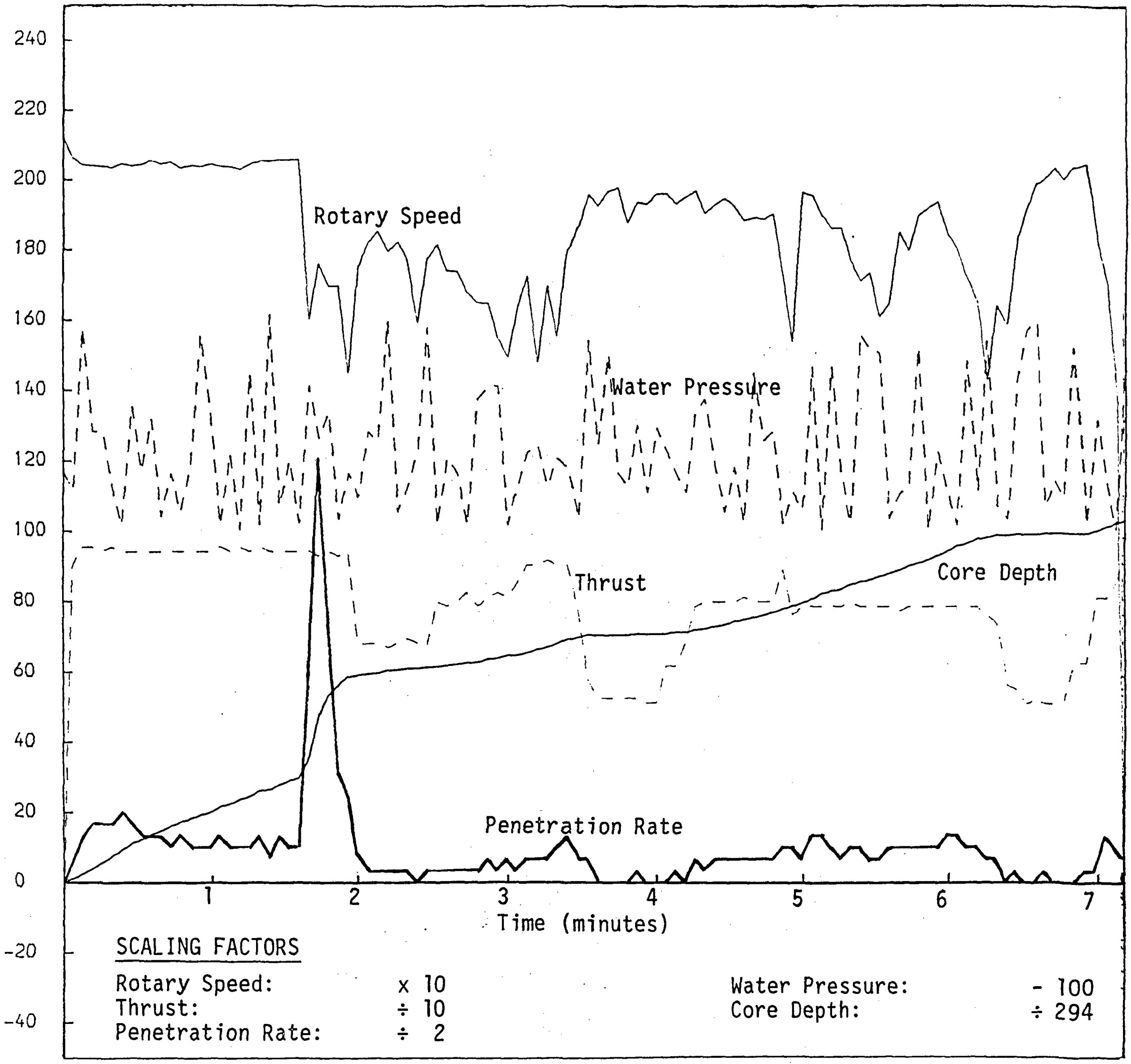


FIGURE 5.17 RECORD OF TRRL DRILL RUN 1.6 (5.06 to 5.41 metres)

FIGURE 5.18 COMPUTER RECORD OF TRRL DRILL RUN 1.6 (5.06 to 5.41 metres)



the onset of the problem once again. Ultimately, the resistance to drilling was such that the system pressure increased to a critical level causing the pressure compensator in the power pack to trip - the drill rig had stalled. This coincided with the drill string jamming in the borehole. When the string was finally worked free after some 45 minutes, inspection of the core barrel showed evidence of scoring, presumably by flint particles from the mixed ground. Thereafter, a regular routine of flushing the hole was adopted on tripping in to ensure aggregate particles were not allowed to accumulate in the annulus.

Drilling record 1.7.1

The drilled interval on this record (5.41 to 5.81 metres) represented the first opportunity to study the response of the instrumentation to an inclined fissure. However, before studying this aspect of the record some other features should be noted, namely:

1. The rotary speed trace was inoperative.
2. The inlet water pressure sensor was functional with pressure increasing from right to left.
3. The swash plate was set in its mid-position.
4. The break in the record after 50 seconds drilling was necessitated by a stoppage to tighten a loose water swivel.

Following the interruption to tighten the swivel, drilling proceeded at a rate of penetration averaging less than 5 cm/min. The 5 mm wide fissure at 5.49 metres depth is distinguished in Figure 5.19 by a pronounced break of slope in the head displacement curve, a transient increase in torque and a decrease in water pressure since the fissure acted as a drain. It should be noted that as drilling proceeded in block 26, the pressure gradually rose as the fissure was left behind. No response was noted in the thrust, presumably since the 15^{o} angle of the blocks ensured that the bit was in contact with rock throughout its passage across the fissure.

The rate of penetration in block 26 remained some 3 to 4 times higher than the previous block, although they were similar concrete formulations. No explanation is offered to explain this anomaly.

At 5.75 metres, the bit penetrated the clay zone between blocks 26 and 27. As usual, the head displacement trace shows a near horizontal displacement as the penetration rate increased from 18.5 to 45.5 cm/min. No clear indication of the clay zone was discernible in either the torque or the thrust record.

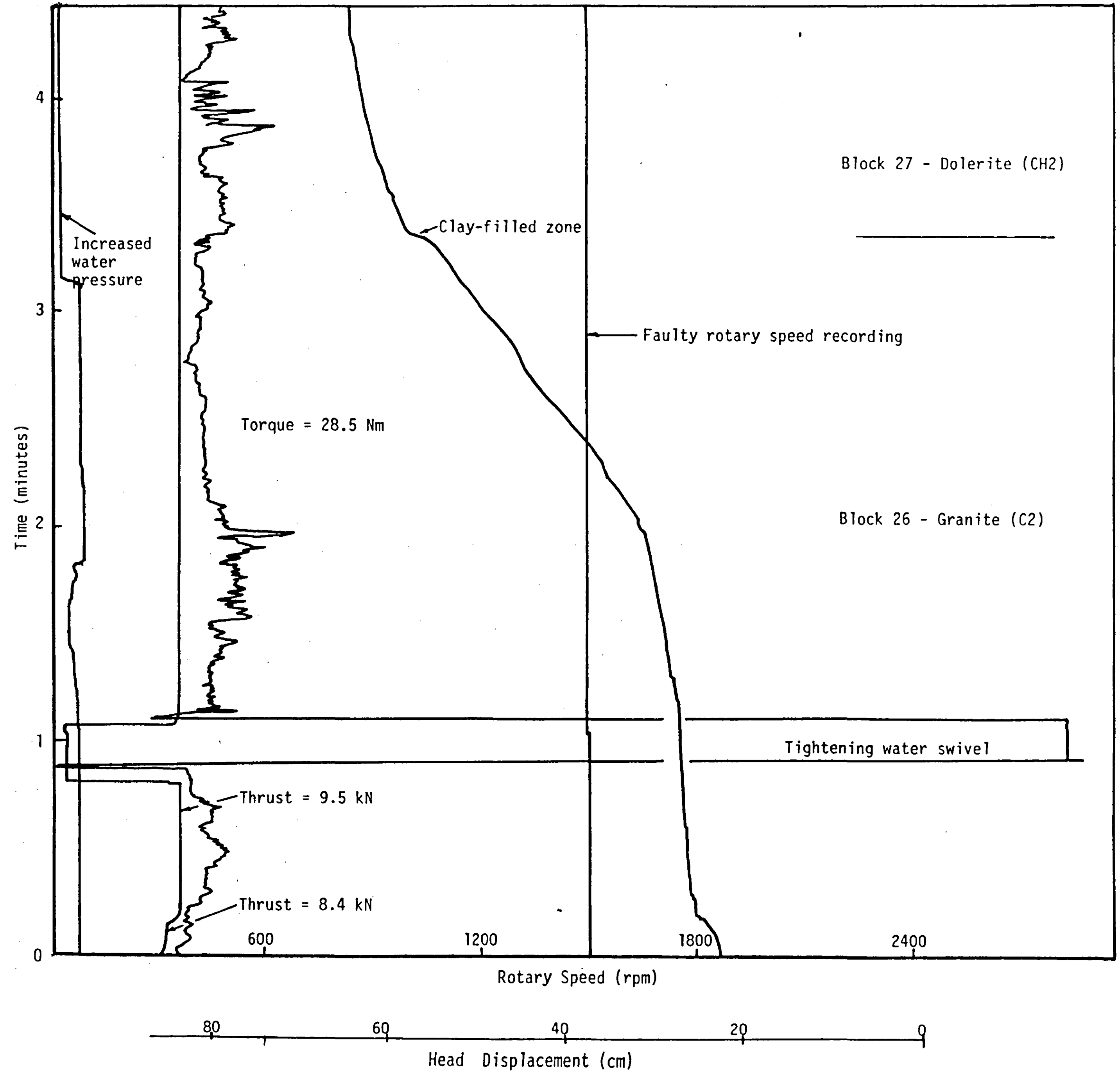


FIGURE 5.19 RECORD OF TRRL DRILL RUN 1.7.1 (5.41 to 5.81 metres)

The inlet water pressure provided an important clue to the nature of the infill. As soon as the clay was encountered, the water pressure rose sharply indicating that the fissure was sealed with an impermeable material. Also, as drilling proceeded in block 27, the drill string started to snatch in the hole and there was a marked drop in penetration rate - all of which pointed to a blocked bit. Indeed, when the bit was pulled, the water course between the core catcher and the bit was choked with clay.

Drilling record 1.8.2

Further characterisation of the effect of a clay zone upon the drilling parameters was obtained from the wedge of clay between blocks 28 and 29. Figure 5.20 starts with the bit advancing in excess of 20 cm/min through dolerite block 28 at a modest thrust of 7.7 kN. The rotary speed trace was *non-operational but reference to* Appendix 5 indicates rotary speed and torque averaging 1900 rpm and 28 Nm respectively.

When the bit encountered the clay zone, an abrupt increase in torque occurred, values reaching a peak of 58 Nm. Similarly, the penetration rate averaged 36 cm/min over the zone while the rotary speed dropped by some 25% to 1490 rpm. These effects are shown clearly in Figure 5.21. As in the previously described example of a clay seam, the water pressure rose abruptly when the clay was encountered, although the pressure values are difficult to define exactly. An additional indicator of the resistance offered by the clay to effective drilling was seen in the increased inlet oil pressure values through the clay zone, presumably mirroring the increased torque. Thereafter, the penetration rate falls rapidly towards zero and snatching of the drill string indicates a blocked bit and dry drilling conditions. This was verified when the bit was pulled.

Drilling record 1.10

Figure 5.22 shows the drill bit advancing initially at an average rate of 18.5 cm/min in siltstone block 30. Thrust was moderately high at 8.5 kN, rotary speed averaged 1975 rpm (except for some brief decelerations corresponding to particularly resistant lumps of aggregate) and torque values hovered around 23.5 Nm. Prior to entering the course gravel zone between blocks 30 and 31, the rate of penetration had fallen to 15 cm/min, but otherwise conditions remained essentially unchanged.

After 1.2 minutes, the bit broke out of block 30 into the gravel zone. This change was anticipated during drilling by a gradual increase in

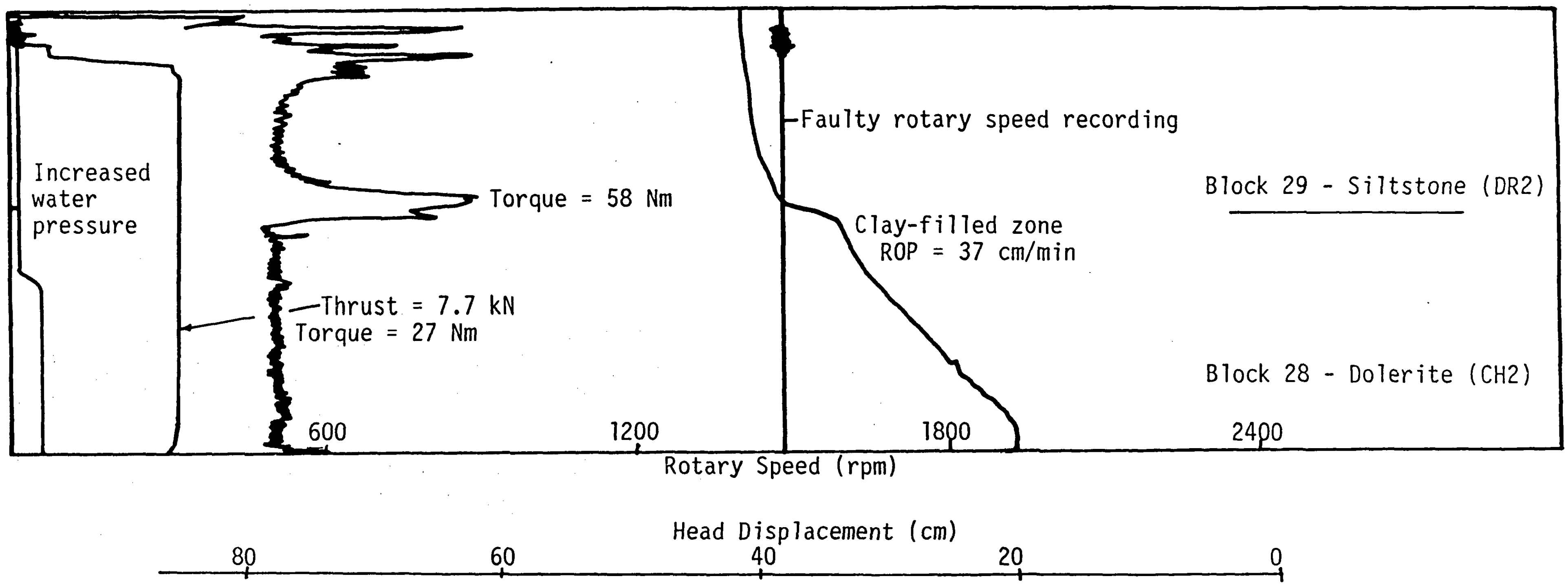
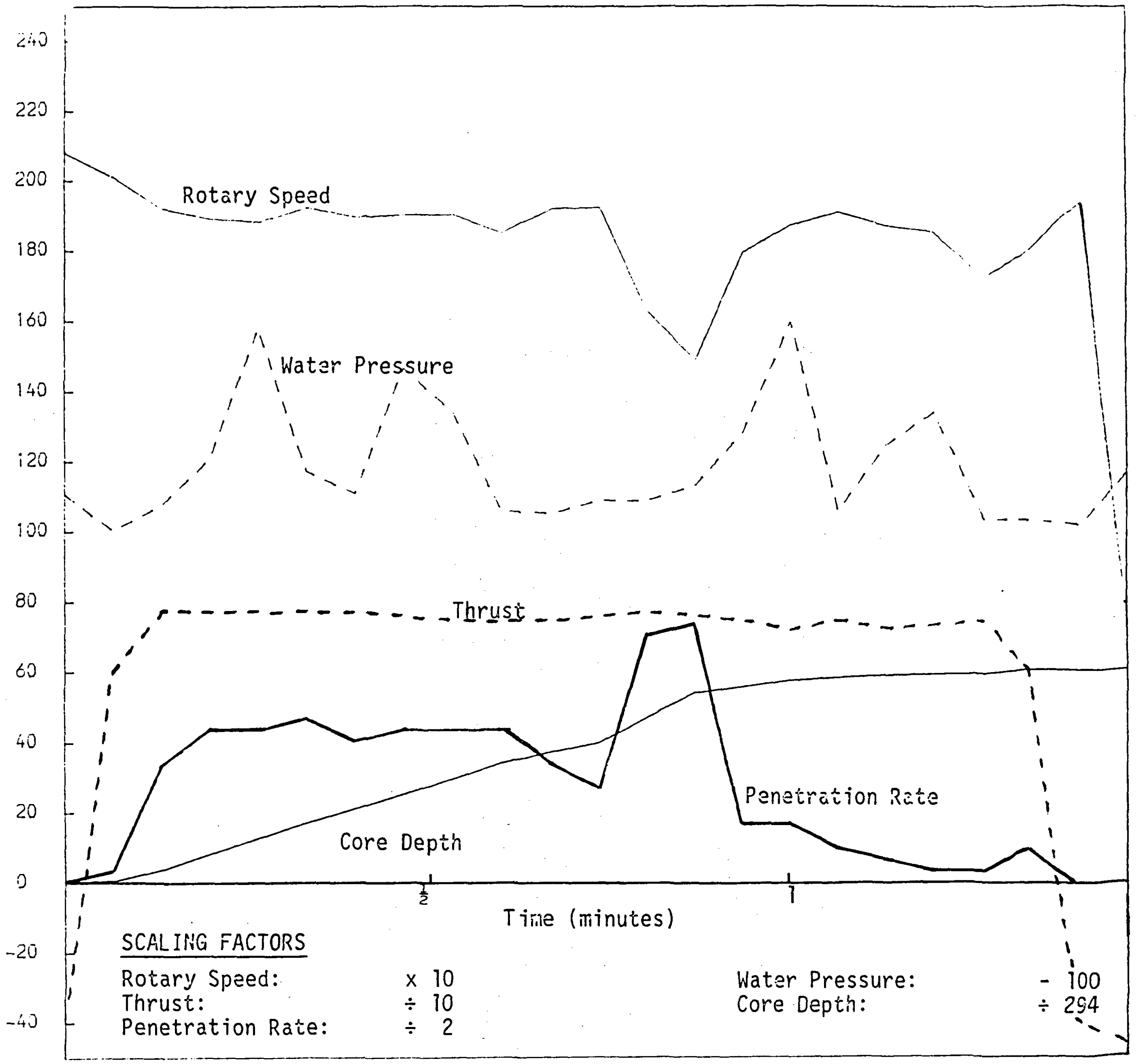


FIGURE 5.20 RECORD OF TRRL DRILL RUN 1.8.2 (6.09 to 6.30 metres)

FIGURE 5.21 COMPUTER RECORD OF TRRL DRILL RUN 1.8.2 (6.09 to 6.30 metres)



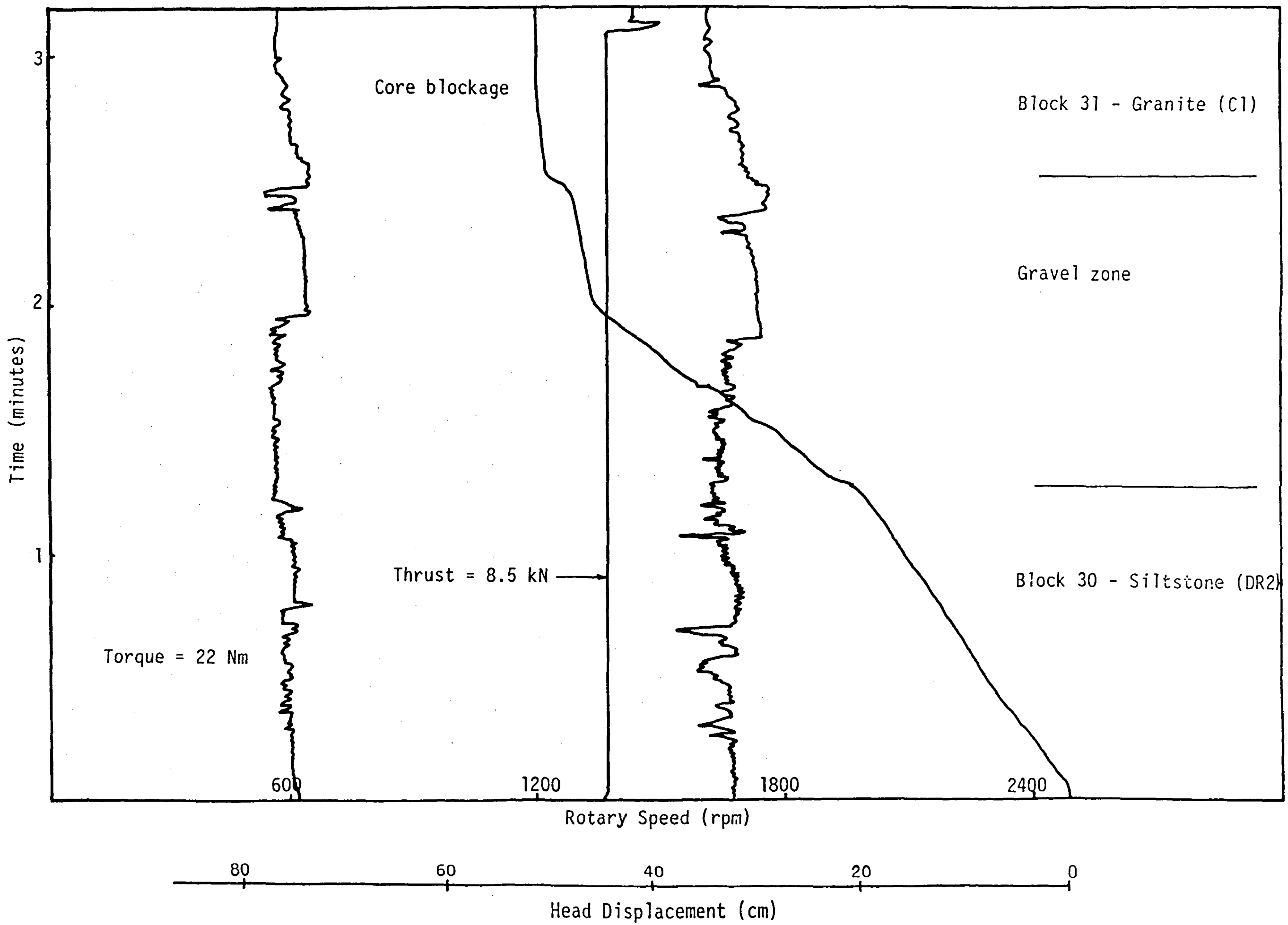


FIGURE 5.22 RECORD OF TRRL DRILL RUN 1.10 (6.73 to 7.22 metres)

penetration rate as the bit was required to cut progressively less rock on bottom once the 45^{o} inclined block was initially breached. Once into the 'broken ground' zone, the bit's progress varied. Initially the rate of penetration was high, averaging 32 cm/min, but then fell off sharply when the bit encountered a substantial lump of aggregate. Reference to Figure 5.12 shows that this was one of only a small number of lumps eventually recovered from this zone and the only one displaying evidence of prolonged exposure to the drill bit. This piece eventually wedged in the barrel to cause a core blockage, but not before a short-lived increase in penetration rate at 2½ minutes. The blockage resisted attempts to free it downhole so the drill run was terminated after some 3 minutes drilling.

These events are well displayed in the appropriate computer plot in Appendix 5. In particular, the penetration rate depicts the high levels obtained prior to the bit encountering the lump of aggregate. The sudden increase in penetration once the lump was drilled is marked by the isolated penetration peak at 2½ minutes before the run was terminated by the blockage. The changes of slope of the core depth trace provide supportive evidence for this analysis. The remainder of the broken ground zone was drilled in the next run with no further difficulty.

Table 5.14 represents a condensed record of the borehole 1 drilling programme. Entries in the table correspond to short periods of time during a drill run when the values of thrust and rotary speed were constant. This was a natural response to the drilling conditions rather than engineered by the operator. The significance of this data is discussed later in this chapter.

Drilling record 1.14.2

The response of the drilling system to the rear section of the block array is represented in Figure 5.23. This zone was designed primarily to assess the utility of various slimhole logging tools for acquiring geotechnical information. In order to mount the maximum number of concrete blocks showing various aggregate and strength variations, the blocks were packed tightly together with no fissures being allowed in the layout. This drill record shows that it is nevertheless possible to distinguish block boundaries.

Only four variables are recorded on this plot, namely: head displacement, rotary speed, torque and thrust. Initially, the bit was advancing at 6.74 cm/min. in block 44 (medium strength gritstone) with thrust of 6.8 kN, rotary speed of 1990 rpm and torque of 22 Nm. At 10.19 m, a break of slope in the head displacement curve signalled passage of the bit into block 45 (low

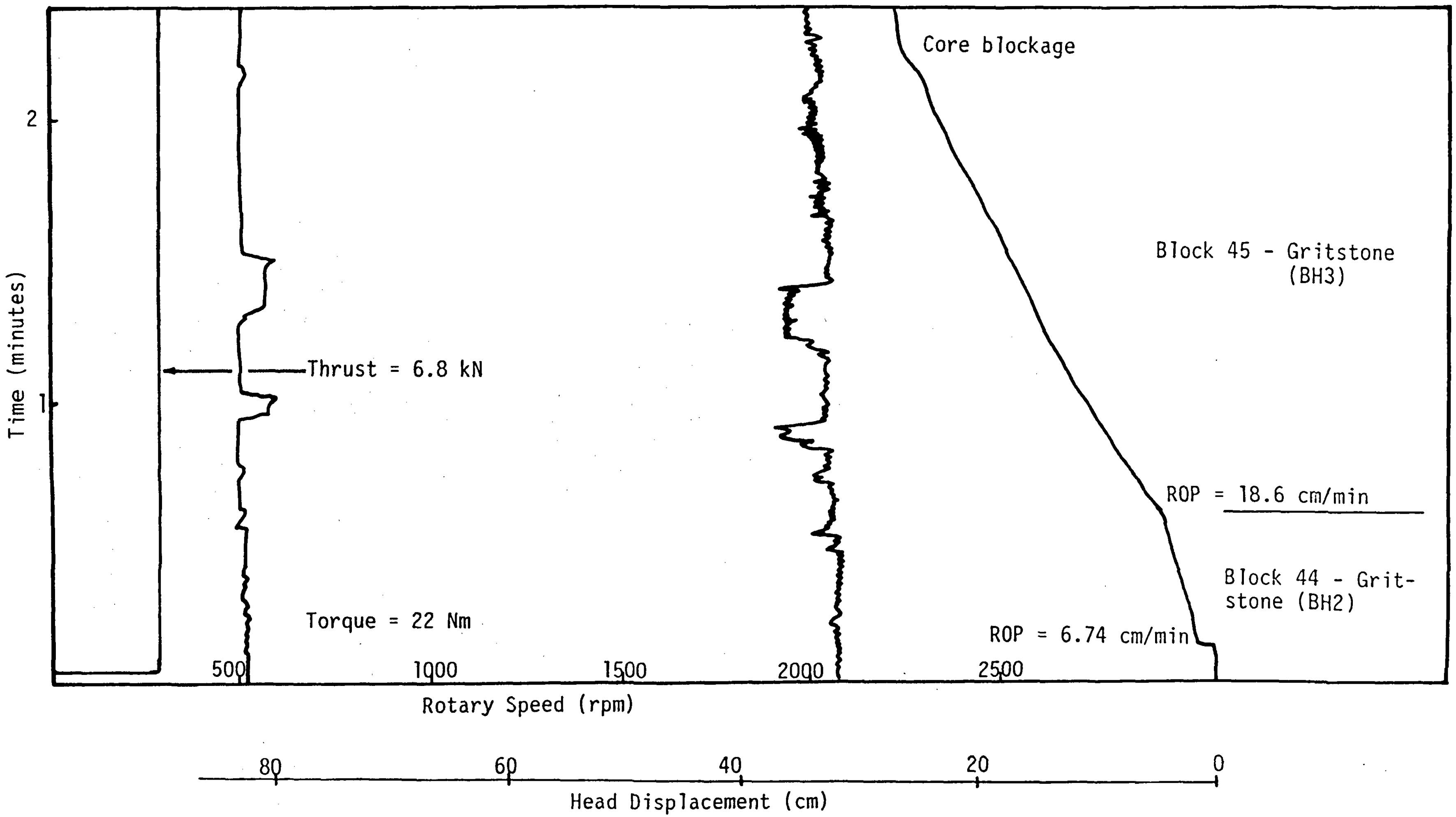


FIGURE 5.23 RECORD OF TRRL DRILL RUN 1.14.2 (10.13 to 10.40 metres)

TABLE 5.14: DRILLING TEST RESULTS FOR TRRL BOREHOLE 1

File Number	Block Number	Block Code	Material	Depth (m)	Rotary Speed (rpm)	Thrust (kN)	Torque (Nm)	Penetration rate (cm/min)
1.1.1	1	C1	Granite	0.03-0.06	1465	10.5	-	8.4
				0.07-0.07	1538	7.7	-	1.7
				0.07-0.09	1519	9.5	-	3.6
				0.10-0.14	1495	10.2	-	6.4
				0.15-0.16	1469	10.5	-	9.6
	2	C3	Granite	0.22-0.24	1533	7.9	-	4.9
				0.26-0.32	1533	7.9	-	2.7
				0.38-0.42	1479	9.3	-	6.4
	3	CH1	Dolerite	0.42-0.46	1475	9.3	-	4.8
1.1.2	3	CH1	Dolerite	0.58-0.59	2028	6.7	19.2	3.8
1.2	3	CH1	Dolerite	0.60-0.62	1939	8.3	25.7	12.9
	4	CH3	Dolerite	0.74-0.80	1923	8.3	26.8	14.3
					1930	8.3	23.4	11.8
1.3.1	5	DR1	Siltstone	0.94-1.03	1948	7.7	24.4	13.6
	6	DR3	Siltstone	1.08-1.25	1937	7.7	24.2	15.0
	7	H1	Limestone	1.27-1.31	1930	7.7	24.1	12.5
		H1	Limestone	1.33-1.34	2021	6.4	15.8	6.8
1.3.3	10	BH3	Gritstone	2.07-2.13	1884	6.5	28.1	23.8
1.3.4	11	L1	Flint	2.27-2.33	1946	7.9	19.54	8.3

File Number	Block Number	Block Code	Material	Depth (m)	Rotary Speed (rpm)	Thrust (kN)	Torque (Nm)	Penetration (cm/min)
1.4.1	12	L3	Flint	2.45-2.49	1915	8.1	27.4	14.9
		L3	Flint	2.50-2.56	1958	8.1	24.3	8.0
		L3	Flint	2.56-2.58	1989	8.1	22.0	6.1
		L3	Flint	2.58-2.59	1999	7.3	21.3	4.8
	13	C1	Granite	2.60-2.61	1986	7.3	22.2	5.7
		C1	"	2.61-2.69	1971	7.2	23.4	5.4
		C1	"	2.69-2.74	1933	7.4	26.1	5.7
		C1	"	2.77-2.78	1926	7.4	26.6	4.5
		C1	"	2.78-2.79	1927	6.7	26.6	5.1
	14	C3	Granite	2.88-2.92	1981	7.0	22.5	9.5
		C3	"	2.94-2.96	1965	6.5	38.8	7.3
	15	CH1	Dolerite	3.01-3.03	1969	7.3	23.5	5.1
				3.09-3.10	1932	7.5	26.2	4.7
				3.13-3.14	1946	7.1	25.1	3.8
				3.14-3.15	1959	6.6	24.2	3.7
1.4.2	16	CH3	Dolerite	3.28-3.45	1975	9.7	23.0	7.1
	17	DR1	Siltstone	3.46-3.54	1963	9.7	24.7	6.3
				3.56-3.57	1970	9.5	22.5	6.3
1.4.1	18	DR3	Siltstone	3.65-3.66	1937	9.8	24.9	8.9
				3.68-3.69	1986	9.4	21.4	5.5
				3.71-3.75	1943	9.8	24.4	8.8
1.5.1	19	H1	Limestone	3.90-4.05	2014	10.0	20.2	7.0
	20	H3	Limestone	4.08-4.18	2005	9.9	19.6	7.6
				4.18-4.27	2000	9.8	20.7	7.7
	21	BH1	Gritstone	4.29-4.49	2009	9.8	19.7	7.0

File Number	Block Number	Block Code	Material	Depth (m)	Rotary Speed (rpm)	Thrust (kN)	Torque (Nm)	Penetration (cm/min)
	22	BH3	Gristone	4.56-4.65	1990	9.7	21.0	13.8
1.5.3	23	L1	Flint	4.83-4.88	1968	9.9	23.5	3.8
				4.90-4.91	1934	9.8	26.0	2.3
	24	L3	Flint	4.98-5.01	1948	11.2	24.2	3.1
1.5.4	24	L3	Flint	5.01-5.03	1999	10.7	21.3	4.0
				5.04-5.06	2034	10.6	18.7	2.7
1.6	24	L3	Flint	5.09-5.13	2046	9.4	17.9	6.6
				5.15-5.16	2058	9.4	17.0	5.1
	25	C2	Granite	5.26-5.27	1810	6.8	5.2	1.7
				5.28-5.29	1650	9.1	14.5	4.4
				5.30-5.32	1908	8.0	15.0	3.2
				5.33-5.39	1813	7.9	10.9	5.1
1.7.1	25	C2	Granite	5.46-5.49	1475	9.4	30.6	4.5
	26	C2	Granite	5.50-5.72	1493	9.4	28.5	16.4
	27	CH2	Dolerite	5.75-5.79	1493	9.3	31.1	8.0
1.7.2	27	CH2	Dolerite	5.81-5.83	1508	8.9	25.5	3.4
1.8.1	27	CH2	Dolerite	5.91-5.99	1975	7.6	21.7	14.8
				6.00-6.01	1963	7.6	22.1	5.4
1.8.2	28	CH2	Dolerite	6.10-6.17	1904	7.7	28.2	20.9
				6.19-6.21	1892	7.5	29.1	20.2

File Number	Block Number	Block Code	Material	Depth (m)	Rotary Speed (rpm)	Thrust (kN)	Torque (Nm)	Penetration (cm/min)
1.9	29	DR2	Siltstone	6.32-6.42	2001	8.0	21.2	16.9
	30	DR2	Siltstone	6.65-6.69	2005	7.8	18.0	13.8
1.10	30	DR2	Siltstone	6.75-6.92	1948	8.6	25.0	16.0
1.11.1	31	C1	Granite	7.27-7.37	2013	8.4	20.3	18.4
				7.38-7.44	1984	8.6	22.4	15.9
	32	C2	Granite	7.46-7.53	1983	8.6	22.5	14.0
				7.54-7.59	1984	8.8	22.4	11.4
1.11.2	33	C3	Granite	7.77-7.81	1582	8.7	50.9	15.5
1.12.1	34	CH1	Dolerite	7.98-8.14	1926	8.6	25.7	11.3
1.12.1	35	CH2	Dolerite	8.18-8.28	1896	8.5	26.0	12.6
	36	CH3	Dolerite	8.47-8.52	1817	9.3	32.4	11.2
1.13	38	DR2	Siltstone	8.92-8.95	1744	9.3	52.4	9.6
	39	DR3	Siltstone	8.96-9.10	1783	9.0	66.5	8.9
				9.11-9.15	2015	8.9	20.1	10.1
	40	H1	Limestone	9.16-9.19	2012	9.0	19.6	12.1
				9.20-9.27	2050	9.0	17.0	5.5
1.14.1				9.32-9.37	1772	6.8	11.6	6.3
	41	H2	Limestone	9.38-9.42	1780	6.8	12.6	6.0
				9.44-9.46	1751	6.7	8.9	4.1
				9.49-9.53	1776	6.8	12.0	5.1
				9.54-9.56	2010	6.8	18.4	6.2

File Number	Block Number	Block Code	Material	Depth (m)	Rotary Speed (rpm)	Thrust (kN)	Torque (Nm)	Penetration rate (cm/min)
	42	H3	Limestone	9.57-9.61	1941	6.7	23.6	5.8
	43	B1	Gritstone	9.80-9.83	1860	6.9	29.7	5.5
				9.89-9.90	2012	7.2	18.4	4.2
	44	B2	Gritstone	10.08-10.09	1975	8.2	21.1	3.4
1.14.2	44			10.14-10.18	1986	6.8	22.2	6.8
1.14.2	45	B3	Gritstone	10.20-10.36	1939	6.8	25.7	12.9
1.15.1	46	R1	Quartzite	10.42-10.45	1952	6.8	24.7	4.4
				10.45-10.51	1922	7.8	26.9	6.8
				10.53-10.62	1937	7.8	25.8	7.0
	47	R2	Quartzite	10.64-10.75	1957	7.8	24.3	6.2

strength gritstone). Thereafter, the rotary speed and torque was less regular and on occasion was subject to marked deflections. The most notable indicator of 'lithological' variation was the penetration rate which gradually dropped from a peak value of 18.6 to 11.8 cm/min. before a core blockage stopped the run. Reference to Figure 5.12 shows that no core was recovered from this block, only lumps of aggregate. The breakage of the block can explain a number of the observed responses in the record, including the higher penetration rates, rotary speed fluctuations and blockage of the bit.

5.6.2 TRRL Borehole 2

The attempt to obtain a minimum of three rates of penetration under constant rotary speed conditions for various levels of thrust and torque when drilling individual blocks in borehole 2, meant that operator induced variations were imposed upon those produced by the design of the block array. This added factor complicated both the pattern of the recovered data as well as the interpretation of the drilling records. Nevertheless, if it is borne in mind that the effects of two major elements of the design of the block array, fissures and 'lithology', are superimposed upon routine adjustments to the drilling rig then recognition of one from another is made easier.

Drilling record 2.2.1

Figure 5.24 shows a low rate of penetration (1.35 cm/min), stemming from an average thrust level of 5.1 kN at 1600 rpm, which characterised the initial drilling conditions in granite aggregate block 2. After approximately two minutes, the thrust was increased to 7.7 kN and the swash plate was adjusted via the manual over-ride to restore the rotary speed to 1600 rpm. This accounts for the large increase in the torque (from 4.3 to about 15.0 Nm) and the drop in rotary speed prior to its restoration to 1600 rpm. These adjustments resulted in a rate of penetration which fluctuated between 10.8 and 12.1 cm/min.

A further increase of the thrust level to 10.6 kN at three minutes coincided with the fissure between blocks 2 and 3, due allowance being made for the pen offsets on the graph. The fissure was crossed while the operator was adjusting the swash plate setting. The fissure can be recognized by the large peaks appearing on the rotary speed and torque traces and to a lesser extent on the thrust trace. As in the examples described for borehole 1, the head displacement curve tends towards the horizontal as the fissure aperture is traversed.

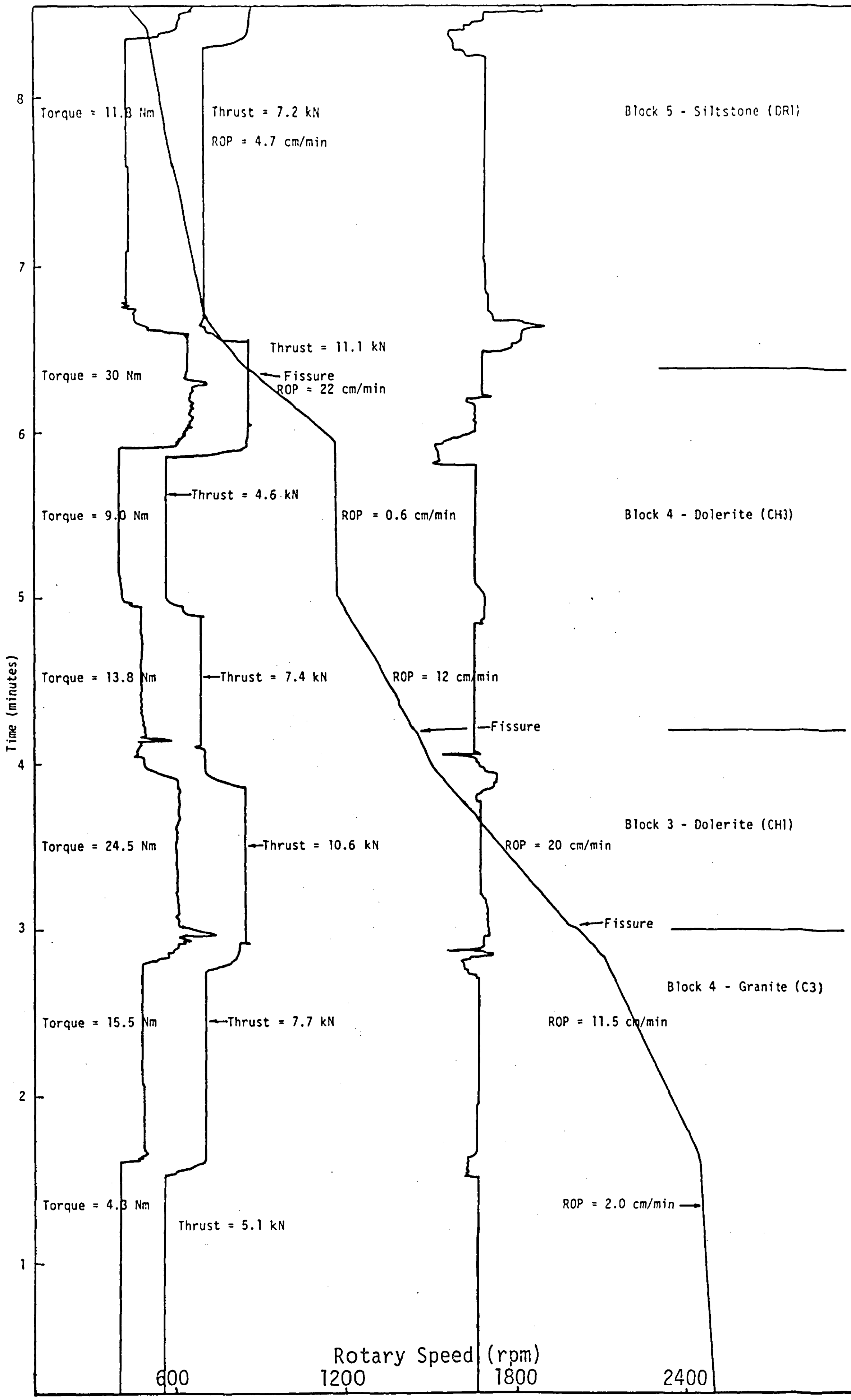


FIGURE 5.24 RECORD OF TRRL DRILL RUN 2.2.1 (0.21 to 1.06 metres)

Progress through block 3 (dolerite) averaged some 20 cm/min. under the drilling conditions outlined above. At approximately four minutes elapsed drilling time, the driller lowered the thrust level to 7.4 kN. The immediate consequence of this action was a rise in rotary speed to about 1675 rpm. Adjustment of the swash plate to restore the 1600 rpm condition also caused a small increase in torque. Just as these adjustments were completed, another block boundary was encountered. This fissure is located at approximately 4½ minutes into the record and displays all the characteristic features of an open fissure which were outlined in Section 5.6.1.

With the thrust level at 7.4 kN, rotary speed slightly low at 1575 rpm and torque around 13.8 Nm, the rate of penetration in the weakest dolerite block averaged some 12 cm/min. At 5 minutes, the thrust was reduced further to 4.6 kN with a resulting increase in rotary speed until the necessary adjustments to the swash plate were effected. The low level of thrust was inadequate for effective drilling in the dolerite with an advance rate of 0.6 cm/min averaged over this interval.

About one minute later, the thrust was increased to 11.1 kN which resulted in a rate of penetration of about 29 cm/min once the control condition was established. Unfortunately, no sooner had this condition been achieved than the bit passed into block 5. This is marked by the break of slope in the head displacement curve at 0.85 metres depth (6.3 minutes).

The remainder of this record was confined to drilling in the siltstone block. Initial penetration rates at 11.1 kN averaged 22 cm/min. before the thrust setting was lowered to 7.2 kN. Over this thrust interval, the penetration rate fluctuated between 4.1 and 5.4 cm/min. After nearly two minutes drilling at these settings, the thrust was increased again to 11.1 kN but control condition was not established before a rechuck was required.

Drilling record 2.4.2

A second and final example of the type of information recovered from the drilling regime implemented in borehole 2 is provided by Figure 5.25. Drilling conditions were fixed initially at 5.8 kN thrust, 1585 rpm and 6.6 Nm torque which produced approximately 2.1 cm/min rate of penetration in block 11. After one minute, thrust levels were raised to 9.0 kN. When the rotary speed was adjusted upwards from 1561 to 1622 rpm, the resultant torque was 12.7 Nm and the rate of advance rose to 4.7 cm/min through this flint block. A further increase in thrust to 12.1 kN at 1615 rpm produced rates of penetration normally between 10.8 and 14.8 cm/min. This condition prevailed until the 20mm wide fissure between blocks 11 and 12 was met.

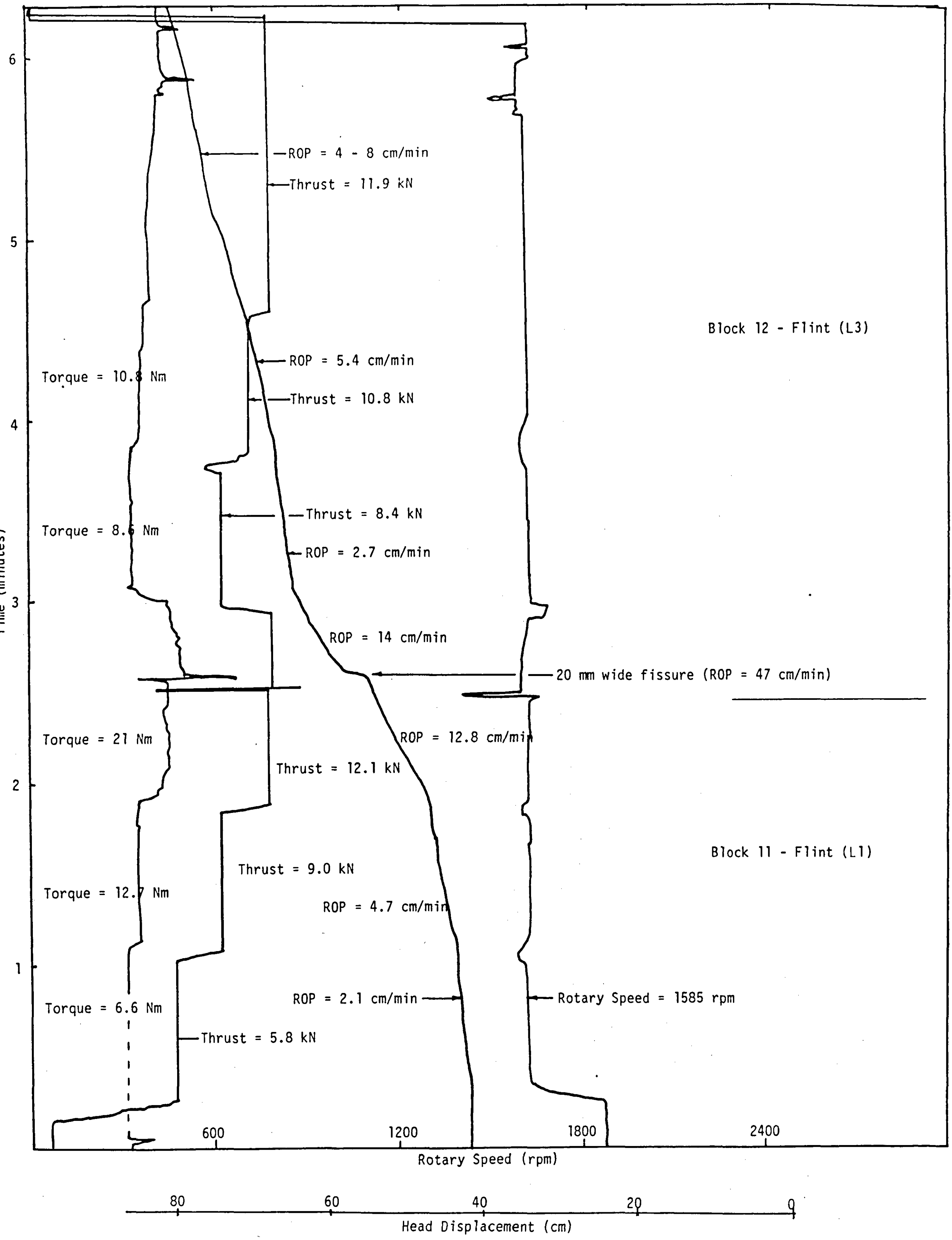


FIGURE 5.25 RECORD OF TRRL DRILL RUN 2.4.2 (2.23 to 2.61 metres)

The fissure was encountered 2½ minutes from the start of drilling and it displayed to perfection the features which represent an open joint, namely:

1. A pronounced displacement of the rotary head.
2. A slight increase in rotary speed immediately followed by an abrupt fall as the opposing block face was struck.
3. A large drop-off in thrust level, followed by an even larger increase as the next block was encountered before returning to the pre-disturbance level.
4. A sharp decline in torque before an abrupt increase in excess of the pre-disturbance level followed by an eventual return to the mean level.

Reference to the numerical record in Appendix 5 shows the pronounced effect this wide fissure had on the thrust value. The fissure was encountered in mid-scan during time interval 21162925. No influence of the fissure was apparent in the head displacement readings (first channel scanned) during this interval, yet by the time the thrust was recorded (seventh channel) the value had fallen from 12.1 to 5.6 kN. During the next time scan, the effect of the fissure on head displacement was complete, resulting in a rate of penetration in excess of 47 cm/min while the thrust has returned to its original setting of 12.1 kN.

Once across the fissure, advance rates in block 12 were about 14 cm/min for the conditions which prevailed before the disturbing effect of the block boundary. At 2.45 metres, the thrust was decreased to 8.4 kN and the rotary speed adjusted to 1589 rpm. As expected, both the torque and rate of advance decreased, being 8.6 Nm and 2.7 cm/min respectively.

After approximately four minutes, the thrust was raised to 10.8 kN and the rotary speed adjusted via the swash plate over-ride to 1615 rpm to yield penetration rates in the region of 5.4 cm/min and torque values around 10.8 Nm. After a further 30 seconds drilling, the thrust was finally raised to 11.9 kN with the rotary speed hovering around 1600 rpm. Yet, the rate of penetration remained low, fluctuating between 4.0 and 8.1 cm/min until drilling was halted in order to make a connection.

Thrust versus penetration rate data for these two records, as well as the average value for the drilling variables for those other blocks within which it was possible to establish uniform thrust and rotary speed conditions in borehole 2, are presented in Table 5.15.

TABLE 5.15: DRILLING TEST RESULTS FOR TRRL BOREHOLE 2

File Number	Block Number	Block Code	Material	Depth (m)	Rotary Speed (rpm)	Thrust (kN)	Torque (Nm)	Penetration rate (cm/min)
2.2.1	2	C3	Granite	0.21-0.23	1604	5.1	5.4	1.6
				0.25-0.37	1601	7.7	13.0	11.4
	3	CH1	Dolerite	0.46-0.59	1592	10.7	26.1	19.6
	4	CH3	Dolerite	0.65-0.74	1578	7.4	13.4	12.4
				0.75-0.75	1578	4.6	8.5	0.5
				0.76-0.83	1523	11.2	29.6	24.3
	5	DR1	Siltstone	0.85-0.91	1585	11.1	29.7	23.6
				0.93-1.00	1595	7.2	11.7	4.7
				1.01-1.06	1540	11.1	30.4	21.1
2.2.2	6	DR3	Siltstone	1.12-1.23	1607	7.9	17.5	13.0
	7	H1	Limestone	1.33-1.38	1572	11.8	37.3	26.3
				1.39-1.40	1583	4.4	12.8	0.6
				1.41-1.42	1598	5.5	5.5	2.0
				1.42-1.44	1591	6.8	11.3	5.1
				1.46-1.52	1599	8.8	18.6	12.5
	8	H3	Limestone	1.55-1.57	1606	8.8	17.2	13.5
				1.61-1.69	1602	11.8	36.0	25.3
2.3.2	8			1.69-1.70	1579	5.7	5.7	3.0

File Number	Block Number	Block Code	Material	Depth (m)	Rotary Speed (rpm)	Thrust (kN)	Torque (Nm)	Penetration rate (cm/min)
	9	BH1	Gritstone	1.74-1.75	1588	8.0	14.6	11.4
				1.77-1.80	1608	9.1	21.4	14.1
				1.86-1.90	1608	12.1	39.2	26.5
2.4.1	9			1.83-1.85	1585	5.6	7.6	3.4
	10	BH3	Gritstone	1.99-2.06	1595	8.3	13.1	20.7
					1569	5.1	5.2	1.1
	11	L1	Flint	2.18-2.21	1611	11.8	31.7	22.3
2.4.2	11			2.24-2.25	1584	5.8	6.6	2.1
				2.25-2.27	1621	9.0	12.8	4.6
				2.28-2.28	1616	8.9	10.7	5.4
				2.30-2.35	1615	12.1	19.5	11.0
	12	L3	Flint	2.41-2.44	1604	12.1	21.4	13.5
				2.45-2.47	1590	8.4	8.5	2.9
				2.48-2.51	1609	10.8	11.5	5.2
				2.52-2.60	1595	11.9	13.9	5.6
2.5.1	13	C1	Granite	2.62-2.63	1606	6.9	3.7	3.4
				2.63-2.64	1598	6.8	3.8	2.2
				2.64-2.67	1603	8.2	7.9	4.8
				2.68-2.71	1606	10.1	13.5	10.4
				2.74-2.79	1590	12.4	24.8	17.5

File Number	Block Number	Block Code	Material	Depth (m)	Rotary Speed (rpm)	Thrust (kN)	Torque (Nm)	Penetration rate (cm/min)
2.5.1	14	C3	Granite	2.87-2.95	1591	9.1	15.0	16.5
				2.69-2.97	1591	6.0	3.4	1.5
	15	CH1	Dolerite	3.05-3.09	1627	12.9	28.7	22.0
				3.11-3.15	1606	9.0	13.2	12.5
				3.16-3.21	1590	7.1	8.6	3.1
				3.21-3.22	1580	7.0	9.3	2.5
	16	CH3	Dolerite	3.25-3.31	1595	9.9	20.5	17.8
				3.33-3.36	1593	12.7	39.7	26.2
				3.38-3.42	1586	7.5	12.7	5.5
2.5.2	17	DR1	Siltstone	3.47-3.48	1604	7.0	9.7	4.5
				3.49-3.52	1593	8.4	10.8	6.5
				3.53-3.57	1596	10.1	20.7	12.9
				3.59-3.65	1581	13.1	37.5	23.6
2.6	18	DR3	Siltstone	3.74-3.75	1622	5.7	5.7	4.3
				3.75-3.80	1654	7.1	7.7	4.7
				3.81-3.87	1652	9.0	12.9	12.5
	19	H1	Limestone	3.93-4.06	1649	12.0	16.5	15.2
				4.08-4.10	1664	8.1	17.4	10.2

5.6.3 Drilling trials in natural rock blocks

The drilling records from borehole 2 demonstrate clearly the difficulties of obtaining three values for rate of penetration at selected thrust levels before the bit passes into another block. Also, the concrete blocks offered a limited range of strength variation for testing hypotheses concerned with rock strength prediction from drilling data. A number of drilling runs were made using large natural rock blocks which were available at the TRRL in order to overcome these difficulties.

The rock blocks were located at the front of the concrete block array after some ten or more of these blocks had been removed. No anchoring was required since the rock blocks were sufficiently heavy to resist movement. In addition, they were dressed on all faces and hence butted up firmly to the concrete blocks. In all, nine holes were drilled in six different rock types (see Table 5.8).

The computer derived results of the tests are given in Appendix 5. Only numerical data is presented and this is in a modified format since the circuitry was completely restructured following the field trials (Figure 5.26). The new circuit monitored only voltage supply, head displacement, rotary speed, thrust and torque. Laboratory calibration of the circuitry had shown the voltage supply to remain stable but it was monitored as a precaution since a number of faults were occurring in the equipment. The remaining variables were neglected as they were unnecessary for this aspect of the study. As before, all variables were logged in real time, the data being handled by minor modification of the existing computer program.

Table 5.16 lists the average value of the drilling variables for each portion of a rock block wherein conditions of uniform thrust and rotary speed were maintained. This information, after some editing, provided the input data for subsequent strength prediction calculations which are discussed later in this chapter.

5.6.4 Relationships between drilling parameters

In Chapter 3, simple drilling theory suggested that a number of linear relationships should exist between the major drilling variables thrust, rotary speed, penetration rate and torque. A number of laboratory drilling experiments and field trials were discussed in support of these relationships. Using the data set out in Tables 5.14, 5.15 and 5.16, an attempt to determine the appropriate relationships for the present laboratory drilling trials was made.

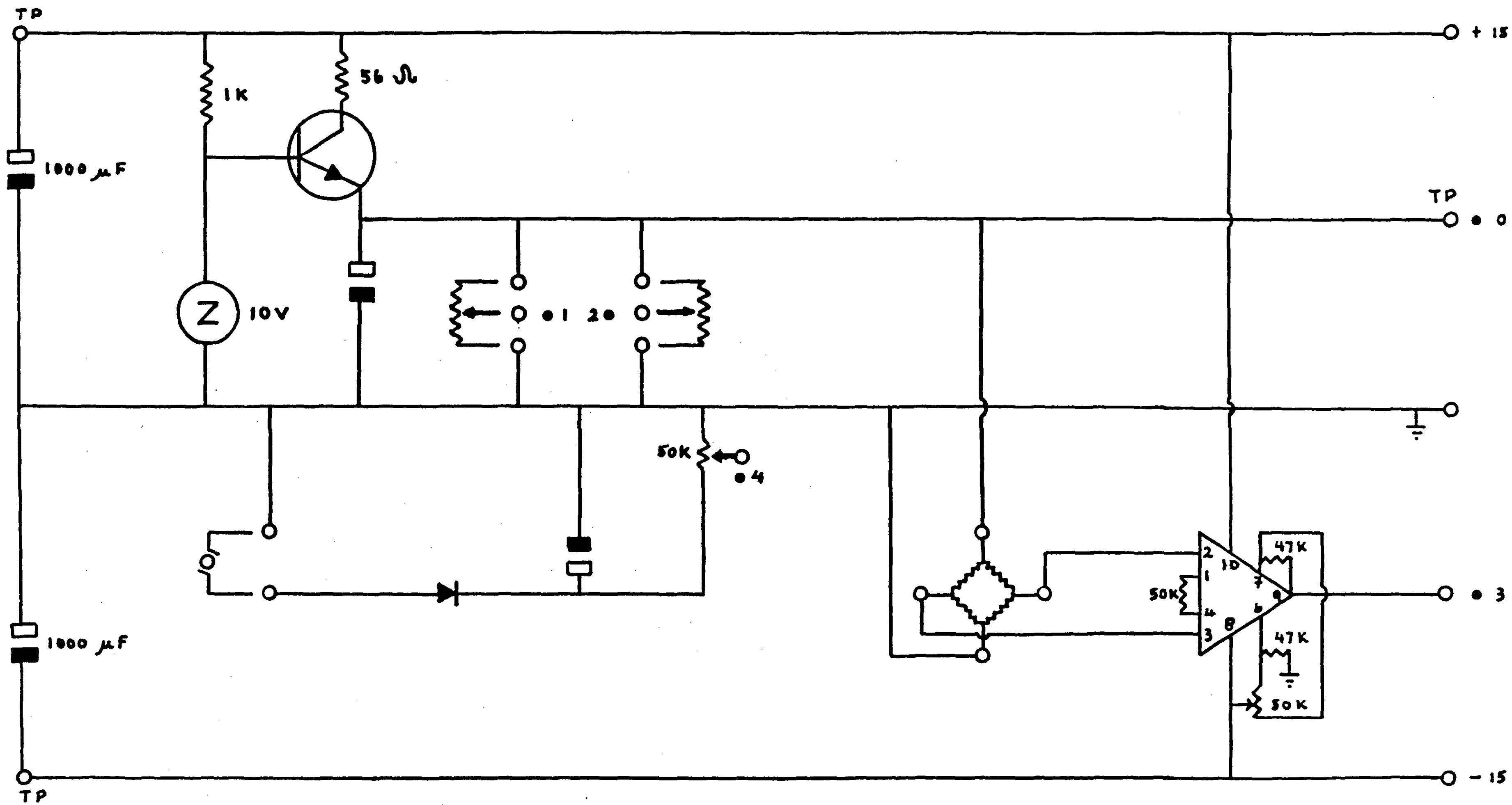


FIGURE 5.26 MODIFIED CIRCUITRY FOR INSTRUMENTED DRILLING TRIALS IN NATURAL ROCK

TABLE 5.16: RESULTS OF THE NATURAL ROCK BLOCK DRILLING TRIALS

	Time	Number of intervals	Distance drilled (cm)	Rate of penetration (cm/min)	Rotary speed (rpm)	Torque (Nm)	Thrust (kN)
Limestone							
	161040	7	9.9	8.4	1468	55	3.6
	161200	4	9.8	14.8	1487	47	7.6
	161250	9*	27.1	20.1	1483	-	11.6
	161440	4	8.6	12.9	1491	23	6.2
Granite (Merivale)							
(1)	231320	4	12.0	17.9	1509	57	2.4
	231410	4	15.7	23.5	1480	94	4.2
	231500	2	12.1	25.9	1488	115	5.5
	231530	3	8.8	12.5	1496	45	2.7
	21610	3	11.0	17.0	1495	60	5.3
(2)	125.20	4	1.9	4.4	1466	57	1.1
	125200	5	5.0	6.9	1482	55	2.7
	125300	4	7.7	11.6	1495	54	4.7
	125350	6	13.4	13.5	1518	50	7.2
	125500	6	15.4	15.3	1506	51	11.0
	125610	7	20.2	17.3	1495	44	13.5
Sandstone (Lindley)							
	122650	5	19.4	23.3	1511	46	4.5
	122750	3	16.4	32.9	1518	31	6.1
	122820	2	11.5	34.5	1523	73	7.0
	122900	2	12.7	38.1	1538	126	8.1
Sandstone (Gregory)							
	160610	4	19.4	29.0	1487	51	2.5
	160650	3	20.4	40.9	1466	33	5.0
	160730	3	23.0	45.9	1497	8	5.3
Dolerite							
(1)	14310	4	13.3	19.9	1505	36	2.8
	14350	3	12.1	24.3	1513	18	4.5
	14440	3	13.9	27.9	1511	38	5.9
	14520	3	14.8	29.7	1483	38	6.1

	Time	Number of intervals	Distance drilled (cm)	Rate of penetration (cm/min)	Rotary speed (rpm)	Torque (Nm)	Thrust (kN)
(2)	121140	4	13.3	19.9	1505	36	2.8
	121230	3	5.5	11.1	1469	42	6.2
	121310	2	5.2	15.7	1475	37	8.6
	121340	3	8.6	17.3	1455	39	8.7
	121420	5	18.7	22.5	1465	27	10.6
	121520	2	7.7	23.1	1469	-	10.1
	121540	4	15.4	23.1	1501	9	9.4
	121650	3	11.7	23.4	1465	10	7.9
Granite (Shap)							
(1)	363050	3	2.2	4.3	1507	47	0.4
	363130	6	10.0	10.1	1487	49	3.6
	363240	5	14.0	16.8	1516	37	6.6
	363340	5	18.6	23.4	1483	31	9.5
	363510	3	12.3	24.6	1567	81	10.6
(2)	124620	4	18.2	27.3	1545	133	6.3
	124700	3	13.7	27.4	1506	114	6.9
	124730	4	18.5	27.7	1509	85	8.6
	124820	2	7.5	22.4	1552	12	9.7
	124840	5	16.5	19.7	1533	14	12.7

*Time intervals 161310, 161330 and 161340 were not used in the determination of average values.

N.B. Torque values are suspect in a number of instance.

TABLE 5.17: THRUST-PENETRATION RATE RELATIONSHIPS IN TRRL BOREHOLE 2

Aggregate	Relationship	Critical Thrust	r^2	Block Numbers
Limestone*	R = -11.5+2.4F		0.67	All
Siltstone*	R = 18.6 +2.2F		0.37	All
Limestone(5)	R = 17.2+3.6F	4.8	0.97	7
(10)	R = -14.2+3.1F		0.88	7,8,19
Siltstone(7)	R = -22.1+3.7F	6.0	0.90	5,17
(11)	R = -16.8+3.2F		0.86	5,6,17,18
Gritstone(4)	R = -16.9+3.5F	4.8	0.99	9
Flint (4)	R = -6.9+1.4F	4.9	0.93	11
(3)	R = -3.8+0.8F	4.8	0.97	12
Granite (5)	R = -15.8+2.6F	6.1	0.98	13
(9)	R = -11.9+2.5F		0.73	2,13,14
Dolerite (3)	R = -15.3+3.6F	4.3	0.99	4
(4)	R = -19.5+3.3F	5.9	0.97	15
(3)	R = -23.2+4.0F	5.8	0.98	16
(10)	R = -17.0+3.3F		0.88	4,15,16

* Represents data from TRRL boreholes 1 and 2

N.B. Number in brackets represents number of data points used in least squares analysis.

Penetration rate versus thrust

Figures 5.27 and 5.28 depict thrust versus penetration rate relationships for limestone and siltstone aggregate blocks respectively. Note the distinction between the data points derived from routine drilling operations in borehole 1 as opposed to those from the strictly controlled drilling conditions prevailing in borehole 2. As might be expected, when all the data points are considered, the results show more scatter than those associated solely with borehole 2. The main contributory cause of the increased scatter was the wider variation in rotary speed which was a natural consequence of the drilling practice adopted in borehole 1. However, despite the scatter in the data in these two figures, a direct relationship between thrust and rate of penetration is evident.

Table 5.17 indicates the effect of the scatter on the goodness of fit for a straight line through the data points with and without the data from borehole 1. The best indicator of degree of fit is the r^2 value listed in the table. For $r^2 = 1$ the variation in the two variables is wholly explained one in terms of the other and for $r^2 = 0$, the opposite applies. It is apparent that one or more additional influences are contributing to the dispersion of the combined data for the limestone and siltstone blocks in boreholes 1 and 2. When the analysis is restricted to the controlled drilling conditions exercised in borehole 2, the goodness of fit for the data improves substantially (Figures 5.29 to 5.34).

With the exception of the flint and the granite aggregates, there is little variation between the blocks. The slope of the curves are similar being of the order of 3.5 for given blocks. Defining critical thrust as the x-axis intercept, most blocks require some 4.8 kN threshold load before penetration occurs. The three remaining aggregates had threshold values around 6.0 kN. It may only be a coincidence that two of these, the siltstone and the granite, had the highest abrasivity values (Table 5.3). Drilling these blocks with insufficient thrust should quickly dull the bit. This may partially explain the high thrust values required for the dolerite since these blocks followed the granite in the block array. Although data is limited, there is an apparent tendency towards a curvilinear relationship at low thrust levels.

Further evidence of a linear relationship between thrust and rate of penetration was provided by the drilling trials in the rock blocks. Figures 5.35 to 5.40 are derived from the data presented in Table 5.16. Before a brief discussion of these graphs is undertaken, certain aspects of the rock block drilling trials are outlined in Table 5.18 as they have a bearing on

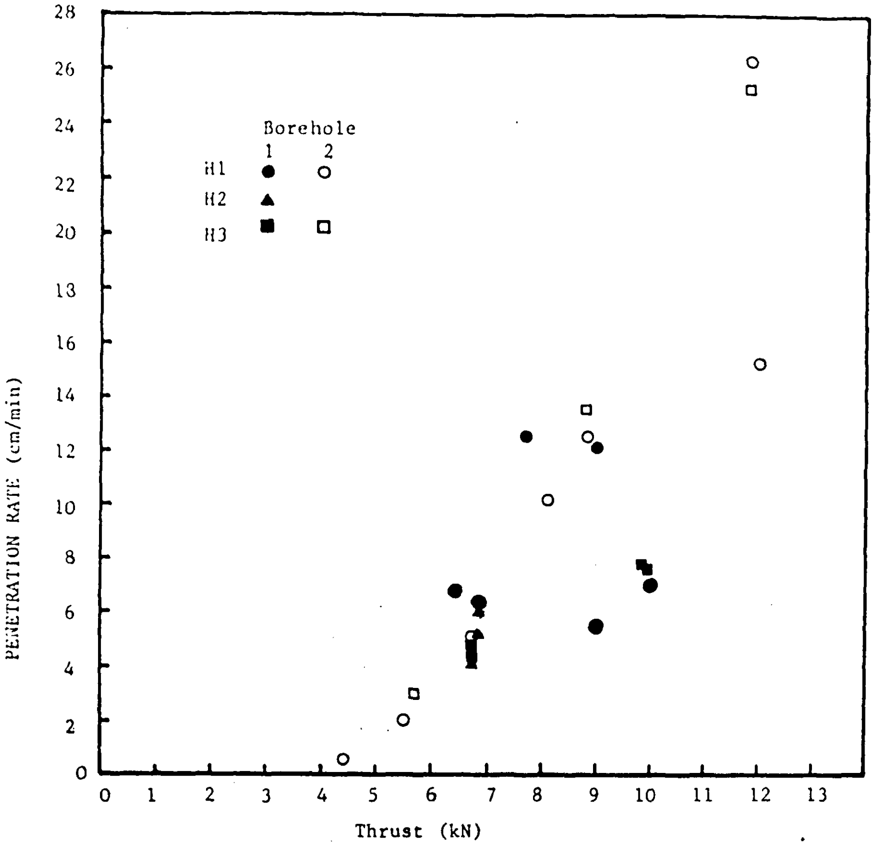


FIGURE 5.27: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE IN LIMESTONE AGGREGATE CONCRETE USING DATA FROM TABLES 5.14 AND 5.15.

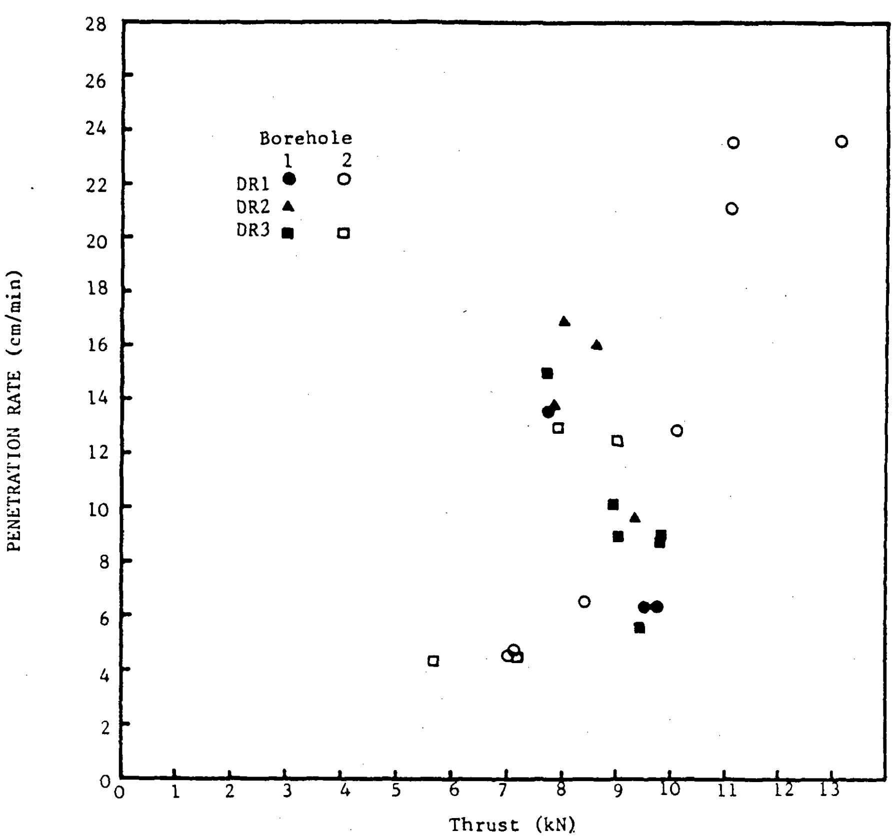


FIGURE 5.28: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE IN SILTSTONE AGGREGATE CONCRETE USING DATA FROM TABLES 5.14 AND 5.15.

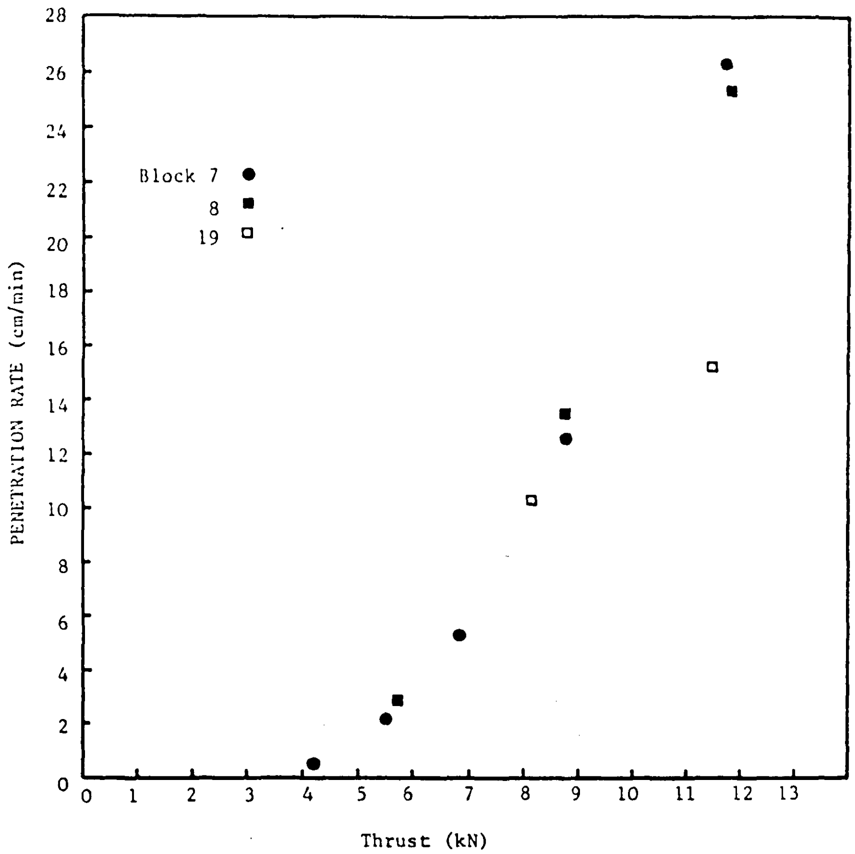


FIGURE 5.29: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE FOR LIMESTONE AGGREGATE BLOCKS IN TRRL BOREHOLE 2.

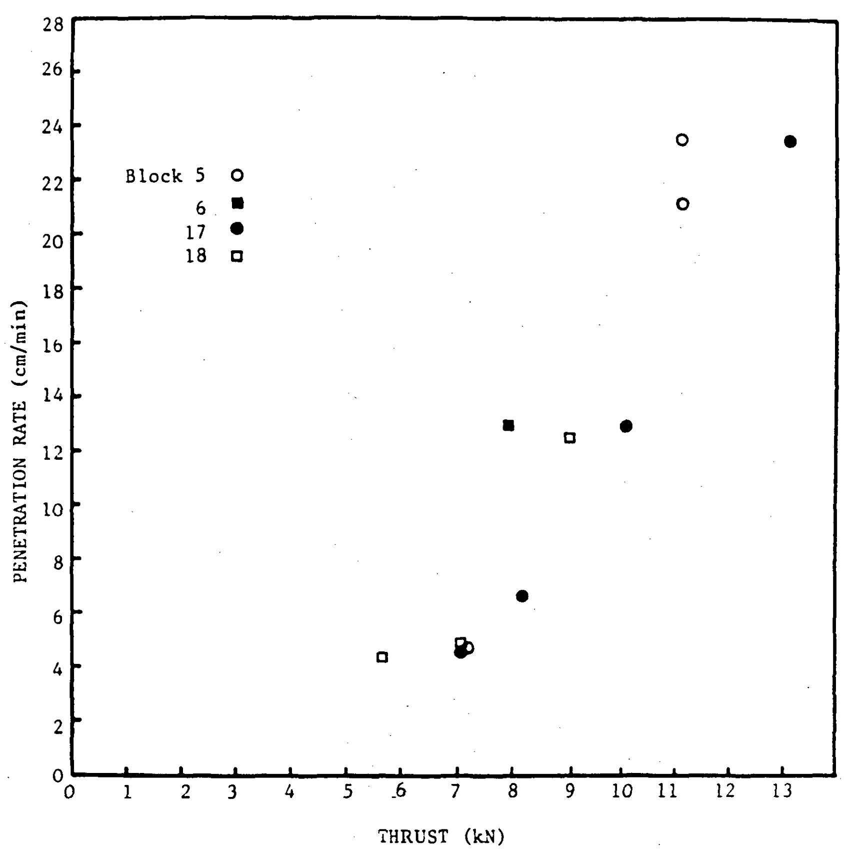


FIGURE 5.30: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE FOR SILTSTONE AGGREGATE BLOCKS IN TRRL BOREHOLE 2.

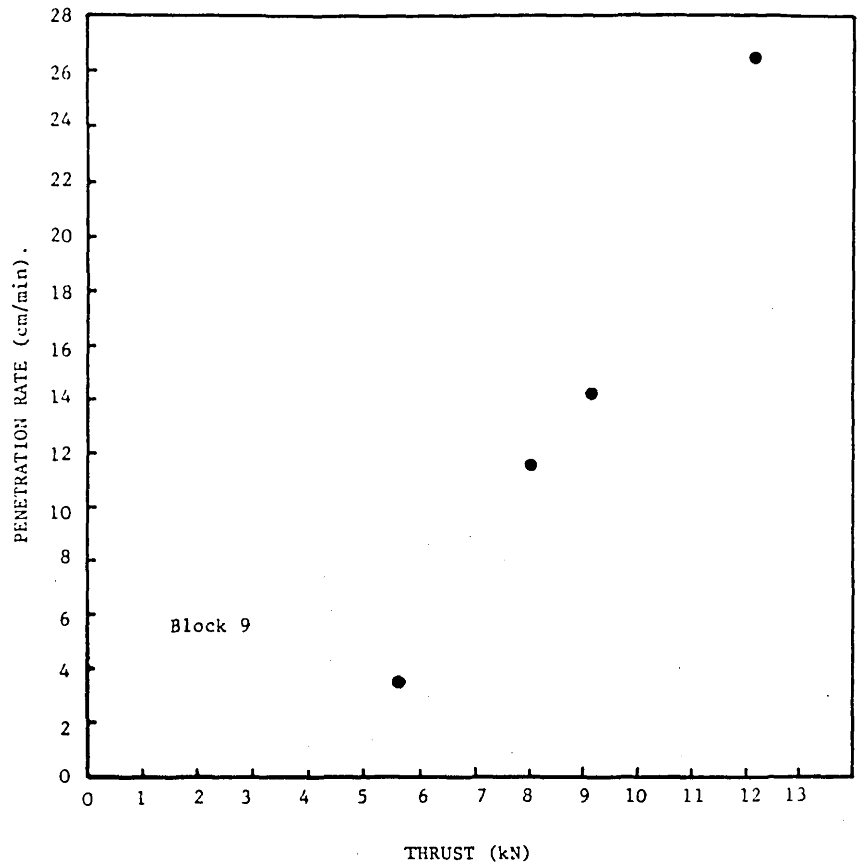


FIGURE 5.31: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE FOR GRITSTONE AGGREGATE BLOCKS IN TRRL BOREHOLE 2.

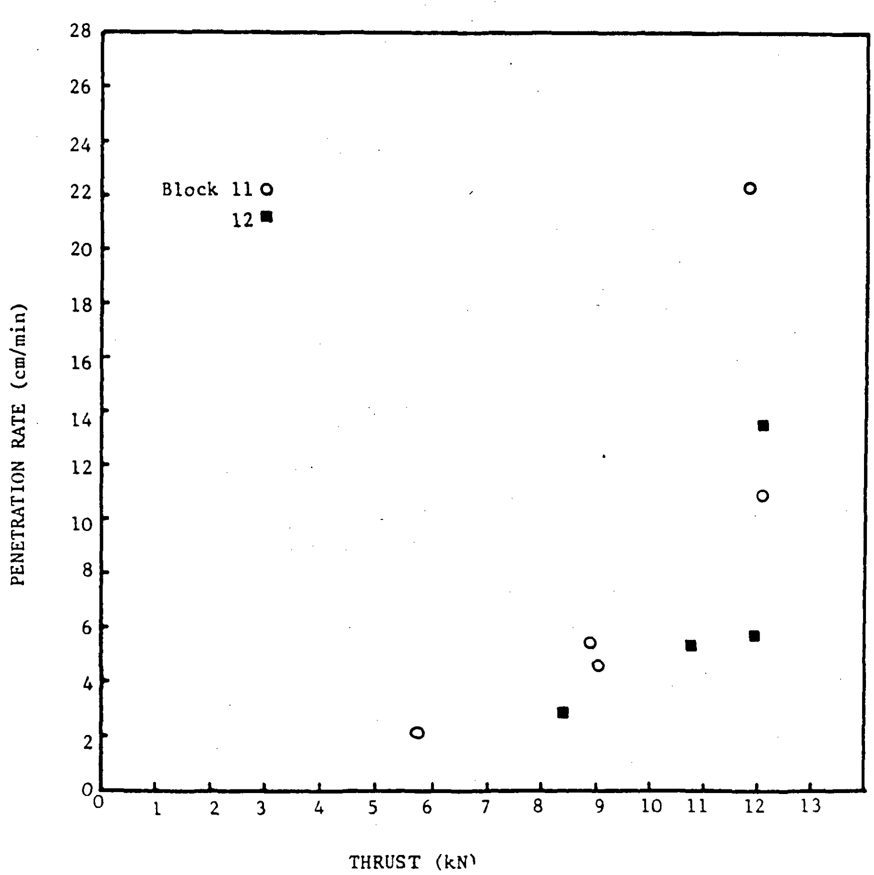


FIGURE 5.32: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE FOR FLINT AGGREGATE BLOCKS IN TRRL BOREHOLE 2.

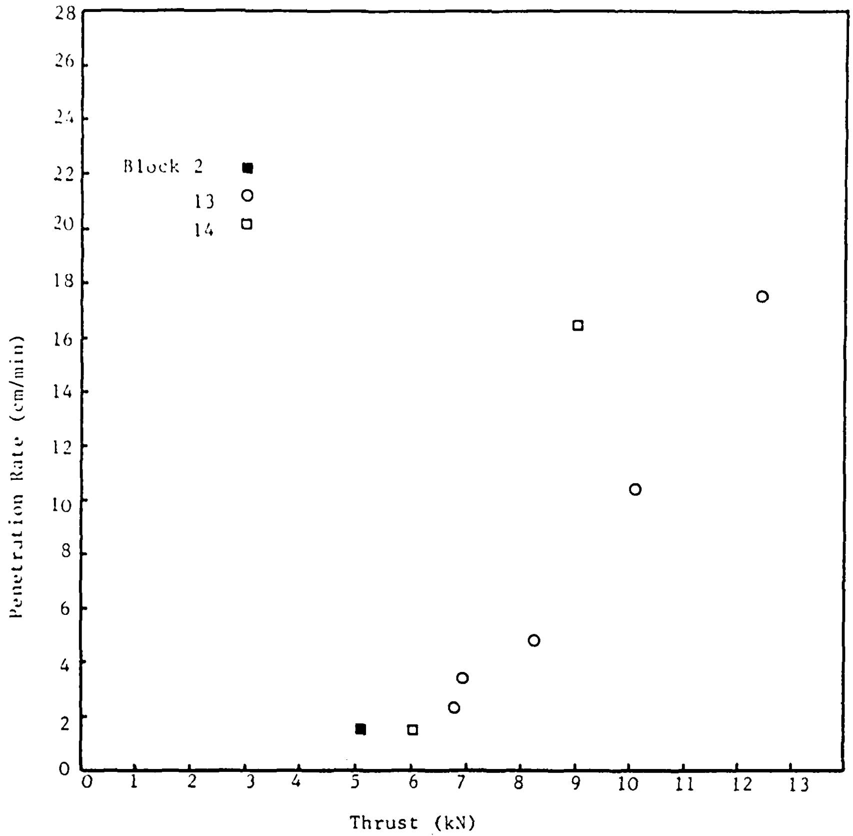


FIGURE 5.33: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE FOR GRANITE AGGREGATE BLOCKS IN TRRL BOREHOLE 2.

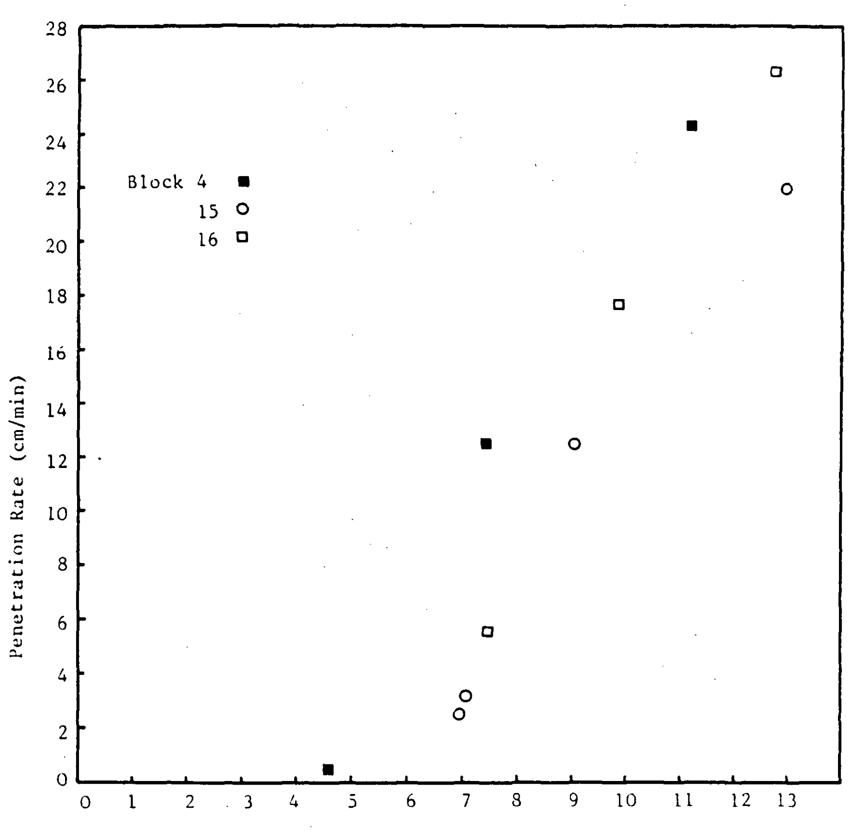


FIGURE 5.34: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE FOR DOLERITE AGGREGATE BLOCKS IN TRRL BOREHOLE 2

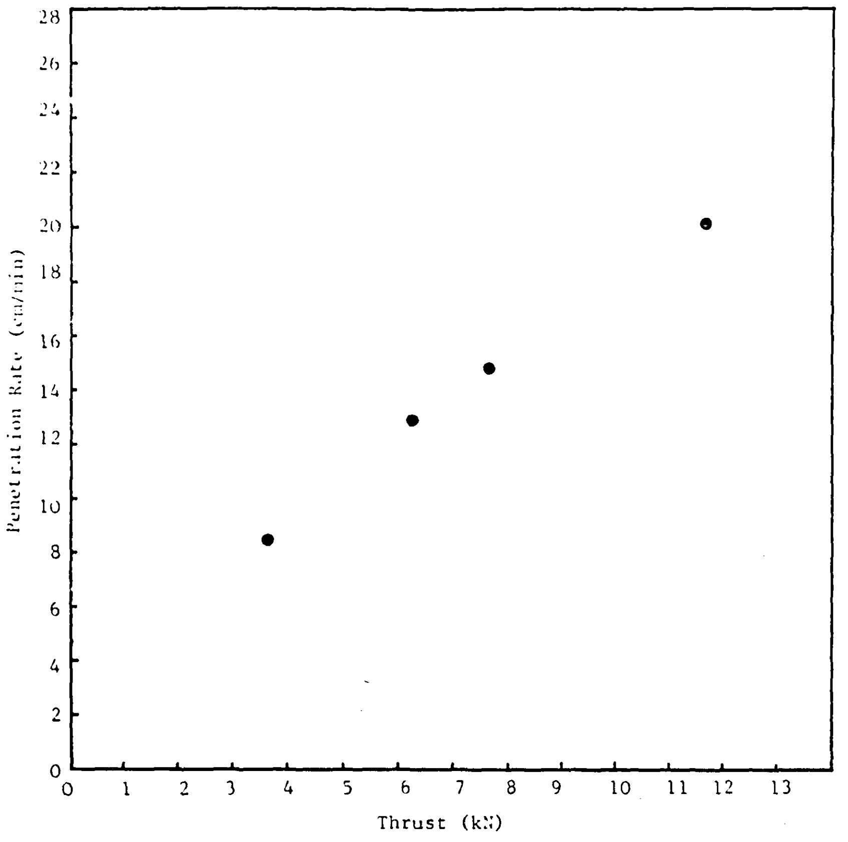


FIGURE 5.35: RELATIONSHIP BETWEEN THRUST AND PENETRATION IN CARBONIFEROUS LIMESTONE (AVERAGE SPEED = 1482 rpm)

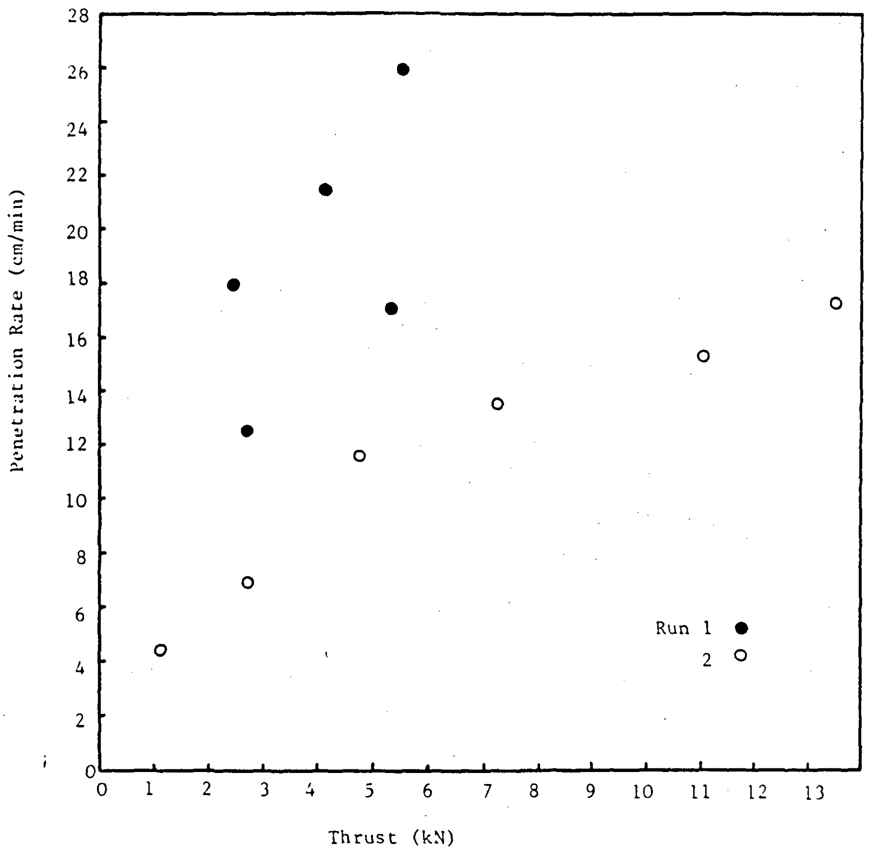


FIGURE 5.36 RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE IN MERIVALE GRANITE (AVERAGE SPEED = 1494 rpm)

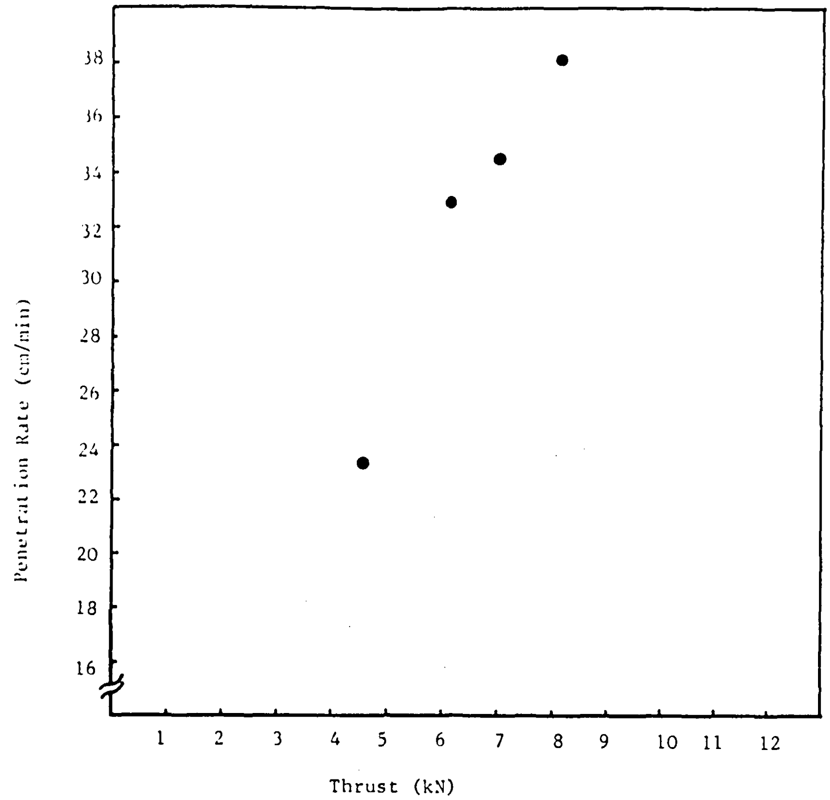


FIGURE 5.37: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE IN LINDLEY SANDSTONE (AVERAGE SPEED = 1523 rpm)

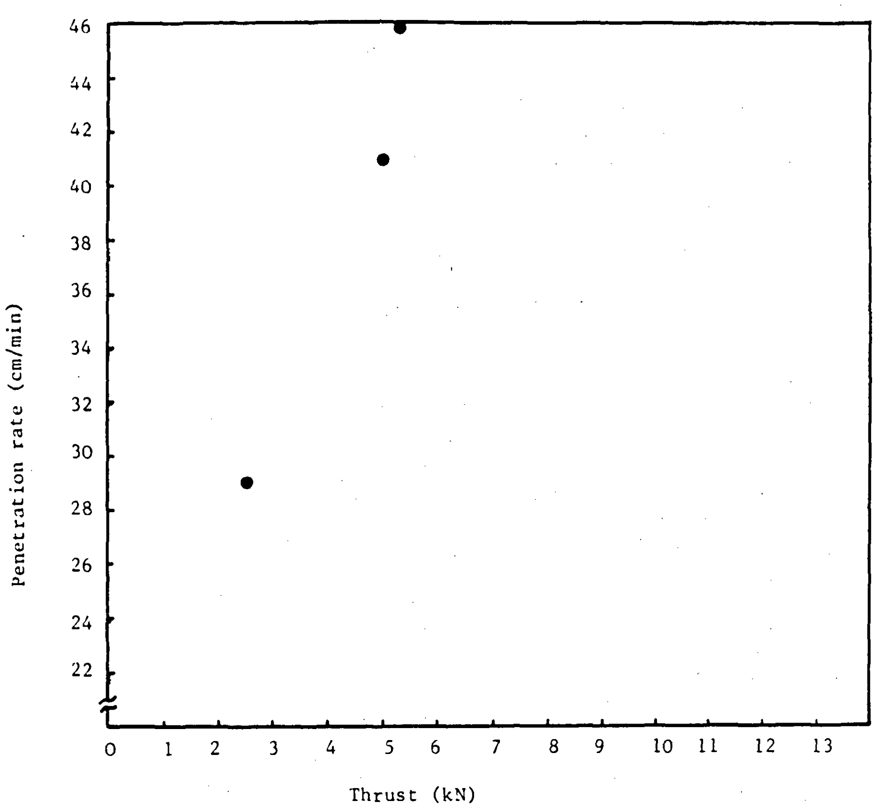


FIGURE 5.38: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE IN GREGORY SANDSTONE (AVERAGE SPEED = 1483 rpm)

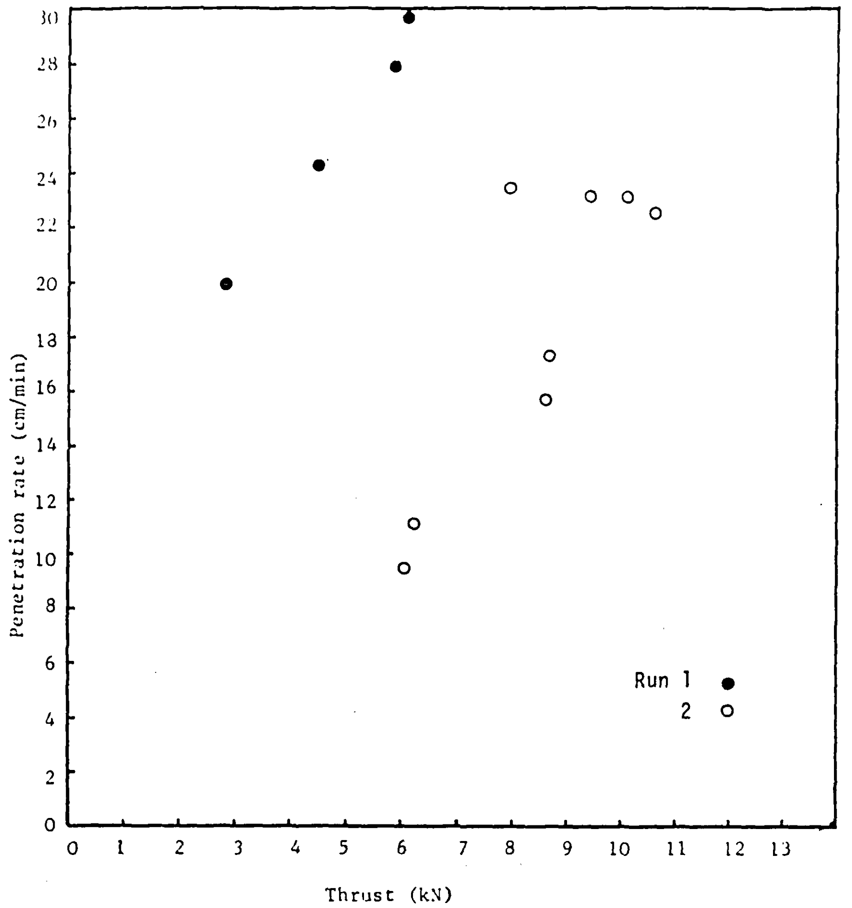


FIGURE 5.39: RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE FOR WHINSILL DOLERITE (AVERAGE SPEED = 1503 and 1469 rpm)

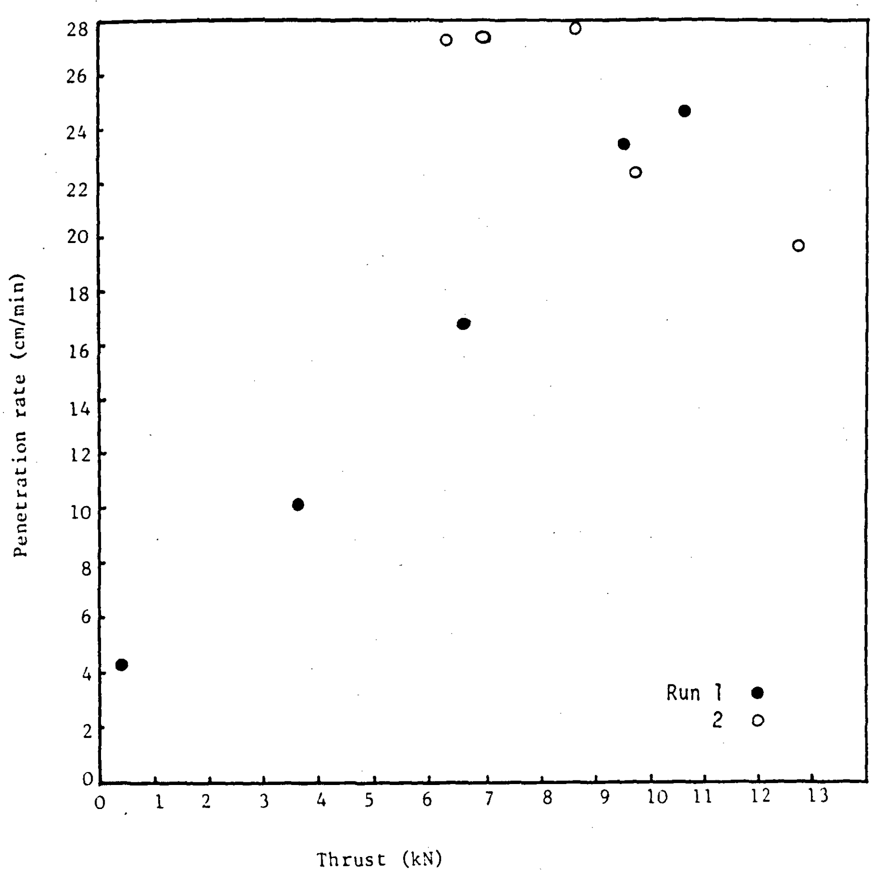


FIGURE 5.40 RELATIONSHIP BETWEEN THRUST AND PENETRATION RATE FOR SHAP GRANITE (AVERAGE SPEED = 1512 and 1529 rpm)

TABLE 5.18: SUMMARY OF DRILLING TRIALS IN NATURAL ROCK BLOCKS

Rock Type	Day	Comments	Results
Limestone	1	Thrust circuitry modified and re-calibrated following this drill run.	Good uniform drilling
Merivale Granite	3	Two blocks drilled on same day but not immediately one after the other.	Rapid drilling but erratic rates of penetration which may reflect proportion of quartz to feldspar or the presence of a fracture in the block.
Dolerite	3	Delay in loading next three blocks on plinth.	Good rate of advance since self-sharpening condition was easily maintained.
Gregory Sandstone	8	Thrust circuitry re-calibrated after this run.	Very high rates of penetration since weakly cemented grains are plucked rather than abraded. Bit in excellent condition.
Lindley Sandstone	10	More competent sandstone than previous one.	High rates of penetration, bit in excellent condition after run.
Shap Granite	10		Good advance rates. Core shows uniform distribution of minerals throughout.
Dolerite	12	Place in front to dress bit after granite run.	Similar rates of advance to previous run.
Merivale Granite	12	Redrilled because of fracture in previous block.	More uniform variation in rate of penetration but slower drilling overall.
Shap Granite	12	Provide comparison with Merivale granite using same thrust calibration.	Progressively lower penetration rates with increasing thrust points to bit dulling which was observed when the bit was pulled.

TABLE 5.19: THRUST-PENETRATION RATE RELATIONSHIPS IN THE NATURAL ROCK BLOCKS

Rock Type	Relationship	r^2	Sample Size
Carboniferous Limestone	R = 3.6 + 1.5 F	0.99	4
Merivale Granite (1)	R = 10.2 + 2.3 F	0.38	5
(2)	R = 4.9 + F	0.92	6
Lindley Sandstone	R = 6.2 + 4.1 F	0.95	4
Gregory Sandstone	R = 15.0 + 5.5 F	0.96	3
Whinsill Dolerite (1)	R = 11.9 + 2.8 F	0.98	4
(2)	R = -8.8 + 3.1 F	0.92	7
Shap Granite (1)	R = 3.2 + 2.1 F	1.00	5
(2)	R = 36.4 - 1.3 F	0.83	5

the results. In all nine holes were drilled in six different rock types. The blocks were drilled in the order of presentation and were grouped on the plinth in the manner suggested by the table.

Table 5.19 lists the results of the least squares analysis for the thrust versus penetration rate data. Whilst most of the rocks display a linear relationship, most curves are displaced to the left resulting in positive y-axis intercepts signifying bit advance under zero load. This is a non-sensical result which suggests that offset values and/or the calibration of the circuitry were erroneous. Certainly the thrust circuitry posed problems during this period as Table 5.18 implies. In general, an initial thrust of some 4 kN was required before effective cutting ensued. The notable exceptions were the two sandstones where bit advance proceeded at lower thrust values. Because of the uncertainty concerning the thrust values, there is little to be gained in attempting to analyse these curves further.

Penetration rate versus torque

Figure 5.41 represents the only 'sensible' result from a comparison of achieved rates of penetration against computed torque values for both of the boreholes drilled in the concrete blocks and those drilled in rock. In this instance the curve has been fitted by eye. Nothing more remains to say about it other than it bears more than passing resemblance to those described in Chapter 3. However, in view of the difficulties associated with measuring torque throughout this investigation, coupled with this solitary example of the anticipated relationship, a sceptical acceptance of it being other than a coincidental fit is advised.

5.6.5 Detection of lithology

The Diamec 250 responded in a characteristic fashion to certain down-hole phenomena, this response providing, in effect, a signature of the bore-hole feature in question. Once such characteristic response involved a change in lithology, if the different concrete block compositions can be termed such.

Where the following conditions applied, namely:

1. a constant thrust level was maintained over the lithological boundary,
2. the disturbing effect upon the drilling variables of any physical break (fissure) between the lithological units could be ignored as a transient and unrelated response,
3. a contrast in 'drilling resistance' existed from one unit to another

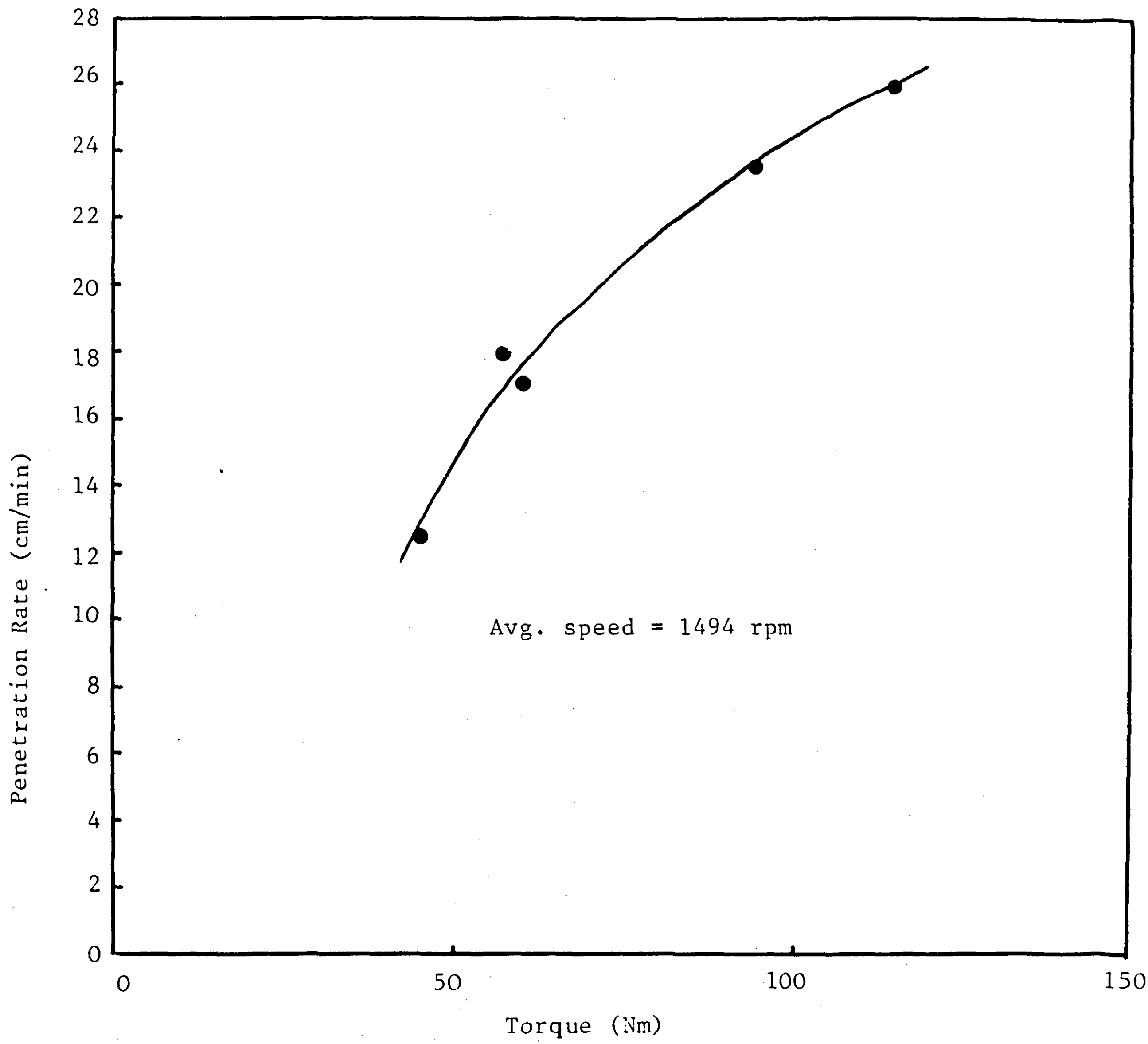


FIGURE 5.41: TORQUE VERSUS PENETRATION RATE IN MERIVALE GRANITE

then, moving from 'strong' to 'weak' rock caused the drilling variables to respond in a predictable manner. First and foremost, there was an obvious increase in rate of penetration accompanied by increased rotary speed and reduced torque as restraints to drilling were eased. For example, the reader might recall the 50% improvement in penetration recorded in passing from block 9 to 10 in drilling record 1.3.2, which was discussed earlier. Equally, drilling records of 1.5.1 and 1.14.2 could be used to note similar variations moving from block 21 to 22 and 44 to 45 respectively. Also, Table 5.14 contains similar examples, one being across the block 2/3 boundary. In this instance the effect on penetration rate was reversed as the bit passed from a weaker to a stronger block.

A notable exception to this general trend was flint. Drilling records 1.3.4 and 1.6 have detailed concrete blocks comprised of this aggregate. Table 5.14 catalogues the very slow rate of advance made in these blocks irrespective of the block strength. The rate of penetration, other than those occasions when the block disintegrated rather than drilled, was dictated solely by the proportion of flint being cut by the bit. When the flint concentration was high, the rate of penetration was very low and vice versa.

The author has observed this relationship at its most extreme during drilling trials at Meldon Quarry. These drilling trials, supervised by J.M. Boyd and performed by experienced contract drillers, involved drilling a 76mm borehole using an impregnated diamond bit in a thinly interbedded chert /limestone formation known locally as the 'streaky'. Whenever the chert was drilled, the rate of penetration was exceedingly low, often obtaining only a few centimeters in an hour. This may relate to the crypto-crystalline structure of chert (flint) which tended to produce a sticky paste when drilled, which masked the small diamond chips in the impregnated bit. Chert is better drilled using a roller bit to exploit the brittle behaviour of this material to best advantage.

Table 5.20 provides a general summary of the types of 'signatures' to be expected from the drilling variables when moving from weak to strong rock and vice versa, from rock to clay and unconsolidated sands and/or gravels. The table should be viewed solely as an approximate guide as a number of factors have not been considered. Nevertheless, the comments made in the table are supported by evidence from the drilling trials and are representative within that particular context.

TABLE 5.20: DRILLING VARIABLE RESPONSE TO SELECTED LITHOLOGICAL VARIATIONS

LITHOLOGY	PENETRATION RATE	ROTARY SPEED	TORQUE	DRILLING FLUID	BIT	DRILLING RECORD
Weak to strong rock	Lower	Lower	Higher	Depends on primary and secondary permeability, fluid type and density	Dulling if thrust insufficient for increased drilling resistance	1.3.2 1.5.1 1.14.2
Strong to weak rock	Higher	Higher	Lower	As above	May require lower thrust for best drilling and to prevent excessive vibration	1.1.1
Clay (good circulation)	Higher	Higher	Lower	Some rise in pressure	May need to restrict penetration rate to avoid blocked bit	1.5.1
(poor circulation)	Initially higher but drops off	Higher but starts to snatch if bit blocks	Initially lower but high peaks if bit blocks	Little or no circulation if bit blocks, increased pressure	Blocked water courses leads to dry drilling, snatching and possible twist-off	1.8.2
Unconsolidated sands and gravels	Higher but variable depending on particle size and hole stability	Higher but may be variable	Lower but may be erratic	Lost circulation if drilling overbalanced	Damaged bit if thrust and rotary speed too high	1.6 1.10

5.6.6 Fissure detection

One of the most successful aspects of the laboratory drilling trials was the ability to detect the fissures which were built into the block array. In certain circumstances, it proved possible to determine whether the fissures were open or infilled and to estimate their aperture. The task of locating fissures was eased by the majority of them trending normal to the drillstring. Inclined fissures could be inferred from the recorded drilling variables, although it is debatable if this could be done under field conditions as their approximate location would be unknown.

Locating fissures in the block array

Discussion of the drilling records in Sections 5.6.1 and 5.6.2 has demonstrated that fissures having a perceptible aperture, even when infilled, have characteristic effects upon the drilling variables which can be used as a diagnostic aid to their detection. In the simplest case of an open fissure at 90^{o} to the borehole long axis, all or most of the following events will occur as the fissure is crossed:

1. A shortlived but pronounced increase in rate of penetration.
2. A small increase in rotary speed over the void followed by a sharp decrease as rock is contacted again with ultimate restoration of the pre-fissure mean levels.
3. A drop in torque in the void followed by a sharp increase on re-establishing contact with rock before returning to pre-fissure levels.
4. A drop in water pressure at least until the storage capacity of the fissure/surrounding rock is satisfied or the fissure is sealed by drilled cuttings carried over in the circulation losses.
5. An initial drop in the thrust level if the aperture is sufficiently large, followed by a sharp increase in value on contacting rock again, whereafter the thrust assumes its pre-set level. In fissures of small aperture, it is probable that the thrust will display no variation.

When the fissure was infilled, the net effect of the infilling material was to dampen the response of the drilling variables, often to the extent that no variation occurred. The one variable which could always be relied upon to tag fissures was the head displacement (rate of penetration). Even when the response was dampened by infill, there was normally sufficient change in the rate of penetration to define block boundaries.

The above criteria were used to identify fissures in the concrete block array using a combination of strip chart records and numerical data. Likely fissures were selected initially on the basis of penetration rate from either or both records, then the other criteria were applied. The depth of the fissure was estimated based on the computed data. Finally, these fissures were tabulated and their estimated depths compared with their known location in the block array. The results of this investigation are summarised in Tables 5.21 and 5.22 for boreholes 1 and 2 respectively. Those fissures which were not identified are denoted by (e) in the tables as an estimated location.

While it was impossible to suspend knowledge of the block array and the average thickness of the blocks, the exact location of the fissures were only noted once the estimates had been made. For most purposes, this was almost an unnecessay precaution as the fissures stand out boldly in the record and this, coupled with diary entries when drilling, made most identification a formality.

<u>Inclined fissures</u>

The first inclined fissure encountered in borehole 1 was described previously in drilling record 1.7.1 above. This was a 5mm wide fissure located between blocks 25 and 26 and inclined 15^{o} from the normal to the drillstring. The fissure was marked by a sharp break of slope in the head displacement curve, an increase in torque and a drop in water pressure. No change in thrust was noted since the 15^{o} angle coupled with the 5mm aperture and 56mm bit ensured that the bit never encountered a void.

A 30^{o} inclined fissure was crossed in drilling run 1.8.1 but, apart from rate of penetration values above the levels prevailing before and after the feature was drilled, no indication of its presence exists. Had the approximate location of this fissure not been known, it is doubtful that it could have been isolated in the drilling record.

Drilling record 1.9 contains the results of drilling across the 45^{o} fissure between blocks 29 and 30. This fissure was located solely on the evidence provided by the penetration rate record. From a rate of 13.5 cm/min at 6.61m, the penetration increased to 20.2cm/min at 6.64m before returning to 13.5cm/min at 6.65m. This suggested a 4cm wide zone existed over which drilling restraints are eased. This compares favourably with the 5.8 centimetres which was calculated for the 56mm bit over this feature.

TABLE 5.21: TRRL BOREHOLE 1 FISSURE INTERSECTIONS

File Reference	Block Intersection	Computed Depth (m)	Measured Depth(m)	Time Reference
CORE 1				
1.1.1	1/2	0.22	0.208	2 5104
	2/3	0.42	0.422(e)	2 5548
	T.D. 0.50m			
1.1.2	-	-	-	-
	T.D. 0.59m			
CORE 2				
1.2	3/4	0.63(e)	0.635	4 3702
	T.D. 0.81m			
CORE 3	Corrected for non-recorded run to pass reamer through rod holder (10cm)			
1.3.1	5/6	1.06	1.067	4 5818
	6/7	1.27	1.292	4 5938
	7/8	1.49	1.500	5 0204
	8/9	1.71	1.733	5 0508
	T.D. 1.76m			
1.3.2	9/10	1.95	1.948	5 1444
	T.D. 2.04m			
1.3.3	10/11	2.16	2.171	5 2108
	T.D. 2.17m			
1.3.4	11/12	2.39	2.384	5 2548
	T.D. 2.42m			
CORE 4				
1.4.1	12/13	2.60(e)	2.613	17 2500
	13/14	2.81	2.820	17 2844
	14/15	2.97	3.032	17 3036
	15/16	3.23	3.245	17 3624
	T.D. 3.27m			
1.4.2	16/17	3.46(e)	3.458	18 2214
	17/18	3.64	3.668	18 2446
	18/19	3.88	3.890	18 2834
	T.D. 3.89m			

File Reference	Block Intersection	Computed (Depth(m)	Measured Depth(m)	Time Reference
CORE 5				
1.5.1	19/20	4.07	4.099	10 0626
	20/21	4.29	4.322	10 0910
	21/22	4.52	4.535	10 1214
	T.D. 4.73m			
1.5.2	22/23	4.75	4.758	10 1922
	T.D. 4.77m			
1.5.3	23/24	4.97	4.969	10 3026
	T.D. 5.00m			
1.5.4	-	-	-	-
	T.D. 5.06			
CORE 6				
1.6	24/25	5.16-5.26	5.19-5.32	13 3054
	T.D.5.41			
CORE 7				
1.7.1	26/26	5.49	5.525(15°)	14 5802
	26/27	5.72-5.76	5.75-5.79	14 5926
1.7.2	-	-	-	-
	T.D. 5.89m			
CORE 8				
1.8.1	27/28	6.03	6.026 (30°)	13 2354
	T.D. 6.09			
1.8.2	28/29	6.22-6.28	6.27-6.34	13 3026
	T.D. 6.30			
CORE 9				
1.9	29/30	6.64	6.643 (45°)	71 61324
	T.D. 6.73m			
CORE 10				
1.10	30/31	6.93-7.27	6.95-7.25	717 0300
	T.D. 7.22m			
CORE 11				
1.11.1	31/32	7.46	7.459	717 2806
	32/33	7.68	7.670	717 3050
	T.D. 7.73m			

File Reference	Block Interaction	Computed Depth (m)	Measured Depth (m)	Time Reference
1.11.2	-	-	-	-
	T.D. 7.80m			
1.11.3	Depth corrected for core stub			
	T.D. 7.86m			
CORE 12				
1.12.1	33/34	7.87	7.881	14 4856
	34/35	8.10	8.098	14 5056
	35/36	8.30	8.306	14 5556
	36/37	8.53	8.525	15 0922
	T.D. 8.66m			
1.12.2	37/38	-	8.739	15 1900
	Damage paper tape - no record			
	T.D. 8.79m			
1.12.3	-	-	-	-
	T.D. 8.91m			
CORE 13				
1.13	38/39	8.96	8.952	114 3232
	39/40	9.16	9.168	114 3444
	T.D. 9.29m			
CORE 14				
1.14.1	40/41	9.38(e)	9.374	115 5214
	41/42	9.57(e)	9.584	115 5610
	42/43	9.80(e)	9.794	116 0110
	43/44	10.01(e)	10.004	116 0650
	T.D. 10.13m			
1.14.2	44/45	10.19	10.212	116 2550
CORE 15				
1.15.1	45/46	10.42	10.421	117 1740
	46/47	10.63	10.628	117 2102
	47/48	10.83(e)	10.842	117 2430
	T.D. 11.03m			
1.15.2	48/49	11.06	11.050	117 4546
	49/50	11.26(e)	11.258	117 4902
	T.D. 11.38m			

File Reference	Block Intersection	Computed Depth(m)	Measured Depth(m)	Time Reference
CORE 16				
1.16.1	50/51	11.45	11.464	118 2718
	T.D. 11.54m			
1.16.2	-	-	-	-
	T.D. 11.62m			
CORE 17				
1.17	-	-	-	-
	T.D. 11.70m			

TABLE 5.22: TRRL BOREHOLE 2 FISSURE INTERSECTIONS

File Reference	Block Intersection	Computed Depth(m)	Measured Depth(m)	Time Reference
CORE 1	1/2	-	0.208	-
	T.D. 0.21m First block used to spud hole - no record			
CORE 2				
2.2.1	2/3	0.43	0.422	9143645
	3/4	0.64(e)	0.635	9143755
	4/5	0.85	0.847	9144005
	T.D. 1.07m			
2.2.2	5/6	1.09	1.067	9144320
	6/7	1.29	1.292	9144435
	T.D. 1.38m			
CORE 3				
2.3.1	7/8	1.51	1.500	145835
	T.D. 1.68m			
2.3.2	8/9	1.74	1.733	150155
	T.D. 1.93m			
CORE 4	(redrilling a core stub)			
2.41	9/10	1.97	1.948	21161405
	10/11	2.16	2.171	21161520
	T.D. 2.23m			
2.42	11/12	2.40	2.384	1162930
	12/13	2.61	2.613	1163310
	T.D. 2.61m			
CORE 5				
2.5.1	13/14	2.81	2.820	7154540
	14/15	3.03	3.032	7154720
	15/16	3.24	3.245	7155025
	T.D. 3.43m			
2.5.2	16/17	3.46	3.458	7160420
	17/18	3.67(e)	3.668	7160615
	T.D. 3.74m			
CORE 6				
2.6	18/19	3.92	3.890	31935
	19/20	4.12	4.099	32105
	T.D. 4.13m			

Table 5.22 contd.

File Reference	Block Intersection	Computed Depth(m)	Measured Depth(m)	Time Reference
CORE 7	20/21	-	4.322	-
	21/22	4.54	4.535	-
	T.D. 4.54m	Water spray shorted circuitry - no record		
CORE 8	22/23	4.77	4.758	9145725
	23/24	4.97	4.969	9146010
	T.D. 5.00m			
	Drilling terminated because of major mechanical problems			

Estimation of fissure aperture

The use of head displacement variations to tag fissure locations also provided a rough estimate of fissure aperture. Reference to a numerical record, say file 1.3.4, indicates a fissure at time reference 52548. Prior to the fissure, the bit was advancing 8mm/time interval. In the time step containing the fissure it is reasonable to assume that most of the interval was devoted to drilling the concrete block since the step across the fissure is virtually instantaneous. Thus, adding 8mm to the core depth value given in time interval 52540 gives a base value of 0.195m. The core depth at the end of the next time interval which included the fissure was 0.224m, yielding an approximate aperture of 29mm for the fissure. This compares favourably with the 'real' value of 20mm for the block 11/12 boundary.

Table 5.23 compares estimated fissure apertures using the method outlined above with the exception of block boundaries 24/25 onwards. These four values were obtained without making allowance for drilling rates before and after the 'fissure'. The infilling materials in these zones slowed the drill bit sufficiently to minimise the percentage of time available to cut the concrete blocks.

It is quite evident that fissure apertures estimated using this method can be exaggerated, particularly at smaller aperture values. Two possible explanations can account for this error. The greater the time allotted between scanning intervals, the greater the potential error in estimating the fissure width since the head displacement associated with this feature will be incorporated within a value which includes advance through concrete. Estimates of the depth attributed to drilling in the blocks rather than

TABLE 5.23 ESTIMATED FISSURE APERTURES

Block Boundary	Aperture (mm)	Estimated Aperture (mm) TRRL 1	TRRL 2
1/2	2	11	-
3/4	5	-	7
5/6	10	25	24
7/8	10	10	10
9/10	15	28	101*
11/12	20	29	30
13/14	2	12	11
15/16	5	11	15
17/18	10	22	-
19/20	10	17	15
21/22	15	26	-
23/24	20	33	15
24/25†	130(123)	100	-
26/27	40(9)	40	-
28/29	70(30)	54	-
30/31	300(275)	295	-

* Block 10 was extremely weak and broke up when drilled

† Bracketed values represent the distance over which the bit is not in contact with either concrete block

crossing the fissure may not be truly represented by averaging values from earlier scanning intervals. During manufacture of the blocks, preparation of the finished faces often produced a veneer of cement largely devoid of aggregate on this face. The fissures within the array were bounded by two such finished faces in each instance. This tended to result in a slight increase in penetration rate over these thin zones. The net effect of this cement veneer would be to underestimate the distance drilled in the block, hence exaggerating the fissure aperture. Another common occurrence resulting from this cement veneer was a tendency for the block to fail a few millimetres back of the face rather than allow the drill bit to cut its own path. These 'breakouts' were seen when the concrete block array was partially disassembled to perform the tests on the rock blocks. This breakout tendency was confined to the face of the block through which the bit was progressing towards the fissure. Nevertheless, it could explain partially the overestimation of fissure aperture in Table 5.23.

5.6.7 Correlation of drilling performance with rock strength

One of the principal aims of this investigation was to assess the validity of selected techniques for back-calculating rock strength from recorded drilling parameters. Of the many techniques reported in the literature, two have been singled out for particular attention because of the apparent success which the methods have demonstrated, both in the laboratory and the field.

Paone and Bruce method

These U.S. Bureau of Mines investigators developed an equation for predicting penetration rate(R) for given rock types using impregnated diamond bits, namely:

$$R = \frac{2\pi N(T-\mu Fr)}{SA - F} \tag{5.1}$$

where
- N is the rotary speed (rpm)
- T is the torque (kNm)
- F is the thrust (kN)
- S is the drilling strength of the rock (MN/m^2)
- A is the cross-sectional area of the bit kerf (m^2)
- r is the mean radius of the bit (m)
- μ is the friction coefficient between the bit and the rock

Paone and Bruce obtained good correlation between theoretical predictions and drilling trials on a number of rock types when $\mu = 0.4$ and S was equated with the uniaxial compressive strength of the rock. It is of particular interest to test the correlation of the predictions of this equation using recorded laboratory drilling data with the equation re-cast in order to predict drilling strength,

$$S = \frac{2\pi N(T-\mu Fr)}{RA} + \frac{F}{A} \tag{5.2}$$

Strengths predicted from the application of equation (5.2) can be compared with those determined from unconfined compressive tests. For the Craelius TT56 bit used $r = 0.0254$m and $A = 0.000837m^2$. Assuming $\mu = 0.4$, the following values of S were predicted from the results presented in Tables 5.15 and 5.16.

Material	Depth(m)	Strength (MN/m^2)		
		Predicted		Measured
Concrete				
Dolerite (3)	0.46-0.59	-5024	1591†	33.6
Limestone (7)	1.33-1.38	-3691	1674	30.2/41.3
Gritstone (10)	1.99-2.06	-4110	758	6.1*
Rock				
Dolerite	0.05-0.15	432	2044	299
	0.19-0.27	-1290	841	
	0.40-0.49	-885	1545	
	0.59-0.69	-891	1424	

Bracketed numbers refer to concrete blocks

*Value represents a 28 day cube test since no core recovery in this block

†Values in this column derived from equation (5.3).

Obviously, the calculated drilling strength values bear no relation to the measured unconfined compressive strengths of the concrete or the rock block. Quite apart from the negative values for strength predicted from equation 5.2, the absolute values are considerably in error suggesting that the theory bears little relation to practice. Even using a simplified equation suggested by Paone and Bruce

$$S = \frac{2\pi NT}{RA} \tag{5.3}$$

proved inaccurate. While the values tend to be more realistic, they still grossly overestimate the drilling strength of the materials. The positive values derived from equation (5.3) demonstrates the sensitivity of the more detailed equation to the value assigned to torque. Almost invariably, the high speed low torque performance characteristics of the Diamec 250 resulted in a negative value for drilling strength using equation (5.2). Assuming that the thrust, torque, rotary speed and penetration rate measurements are not grossly inaccurate, it must be concluded that the work balance equation derived by Paone and Bruce is over-simplified and their theory is not applicable to the performance characteristics of the drill used in these trials. It is thought unlikely that the torque applied at the bit varies substantially from that measured at the motor in view of the shallow depths which are considered. The only remaining explanation requires that the torque measurements are erroneous, the validity of the other drilling parameters having been judged acceptable. However, the maximum torque available for the gear train used throughout these drilling trials was approximately 0.10 kN/m before the pressure compensator in the power pack induced a stall condition. In many instances, this maximum value would be insufficient to produce a positive drilling strength value using equation (5.2).

Tsoutrelis method

Section 3.6.2 discussed in detail a technique described by Tsoutrelis for back-calculating the uniaxial compressive strength of rock from recorded drilling parameters. It was suggested that for a given rock type and constant rotary speed, rate of penetration and thrust at the commencement of drilling before wear affects the bit performance are related by the equation

$$R_o = k\ (F - F_o) \qquad (5.4)$$

Based on experimental evidence, Tsoutrelis suggested that for a given rock type and bit design, the parameter $k_o = k/n$ was constant. From laboratory drilling trials, Tsoutrelis defined a unique relationship between k_o and uniaxial compressive strength, namely:

$$\sigma_c = \frac{A}{k_o + B} \qquad (5.5)$$

where A and B represent constants for the drill bit.

Tables 5.15 and 5.17 were used to derive values of k_o for selected blocks and Table 5.24 to determine their respective z values as follows:

Block	$k_o(10^{-5})$	z
4	2.25	52.7
5	2.82	29.1
7	2.20	33.2
8	2.42	32.8
9	2.17	29.8
11	0.86	28.1
12	0.49	37.6
13	1.62	20.5
15	1.92	21.5
16	2.44	52.7
17	2.00	29.1
18	1.54	36.9

where $z = 10^4/\sigma_c$ (5.6)

TABLE 5.24: UNIAXIAL COMPRESSIVE STRENGTHS OF THE CONCRETE BLOCKS USED IN THE TRRL LABORATORY DRILLING TRIALS

Aggregate Type	Block Number	Uniaxial Compressive Strength (MN/m^2)	Cube Test (MN/m^2) 7 day	28 day
Granite				
C1	1	50.9	44.4	56.8
	13	47.0 53.0		
	31	43.1 44.9		
C2	25	34.5	24.4	32.4
	26	23.9		
	32	31.0		
C3	2	7.5	7.5	10.1
	14	14.9 13.3		
	33	–		
Dolerite				
CH1	3	33.6	45.2	67.0
	15	61.2 35.6		
	34	59.8 37.4		
CH2	27	–	44.2	47.4
	28	35.1 35.6		
	35	30.5		
CH3	4	17.2	13.6	18.6
	16	20.0		
	36	–		
Siltstone				
DR1	5	37.7	28.3	38.1
	17	27.4 35.9		
	37	–		
DR2	29	33.6	30.2	37.1
	30	–		
	38	–		
DR3	6	23.6	20.6	21.9
	18	20.7 35.3		
	39	premature failure		
Limestone				
H1	7	30.2 41.3	51.0	61.1
	19	28.8 30.8		
	40	27.3 29.8		
H2	41	34.1 27.6	47.9	55.1
H3	8	27.3 37.4	25.8	32.0
	20	premature failure		
	42	25.0		

Table 5.24 contd.

Aggregate Type	Block Number	Uniaxial Compressive Strength (MN/m^2)		Cube Test (MN/m^2) 7 day	28 day
Gritstone					
BH1	9	29.6	30.1	31.1	41.1
	21	34.9			
	43	32.2	37.6		
BH2	44	20.8	33.3	20.8	27.9
BH3	10	-		4.2	6.1
	22	-			
	45	-			
Flint					
L1	11	40.4		34.2	48.6
	23	30.3	34.0		
	49	-			
L2	50	30.7	31.2	38.0	51.3
L3	12	25.5	22.1	18.7	25.6
	24	27.7	28.8		
	51	-			
Quartzite					
R1	46	58.4	32.7	50.5	56.8
R2	47	25.7	27.6	34.2	43.7
R3	48	-		7.8	10.4

The z values were based on the averaged uniaxial compressive strength measurements derived from all blocks of a given formulation, for example, block type C1 involving cores from blocks 1, 13 and 31. By this means, more representative strength values were employed.

The k_o and z values were plotted in order to filter out spurious data (Figure 5.42) as a number of the R-F relationships from which k_o derives were based upon a minimum number of data points. Blocks 4 and 5 were eliminated since the regression lines were effectively computed on the basis of two points. Block 16 results were discarded since only three data points existed and the R-F curves suggested the onset of stall conditions. Again only three points were

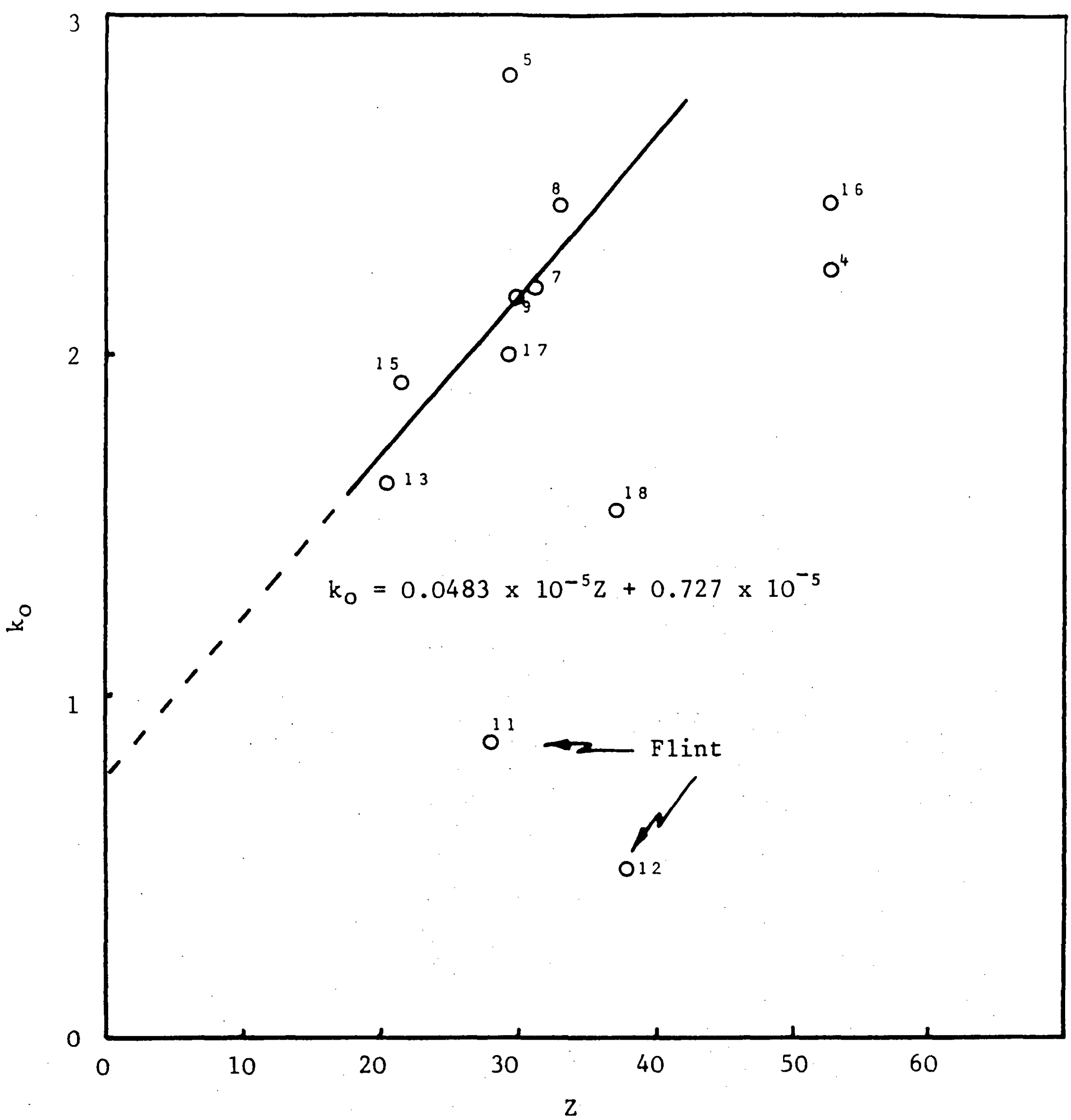


FIGURE 5.42: RELATIONSHIP OF k_o TO Z FOR CONCRETE BLOCKS

available for block 18 and these indicated a high degree of scatter, hence this point was discounted. Of the remaining values, blocks 11 and 12 clearly demonstrated the peculiar response of flint to rotary diamond drilling and therefore were eliminated.

The seven remaining data points were used to define the $k_o - z$ relationship for the concrete blocks, in order to derive the constants for the TT56 drill bit. Tsoutrelis proposed a straight line relationship between these two variables whose general equation was

$$k_o = Az + B \tag{5.7}$$

In Tsoutrelis' case, the y-axis intercept was negative. The concrete block data yielded bit constants

$$A = 0.0444 \times 10^{-5}$$

and

$$B = 0.8190 \times 10^{-5}$$

These values, according to Tsoutrelis, are constant for a given type of bit. This being true, these constants should apply to the drilling trials on the natural rock blocks as the same bit type was employed in both instances. While it is recognised that the thrust values recorded during these latter trials are questionable, the back-calculation of strength relies only on the slope derived from the R-F plots (k) and the rotary speed for a given block of rock.

The comparison of measured versus back-calculated strength values in Table 5.25 shows that the calculated strengths grossly underestimate those derived from laboratory tests by an order of magnitude in most cases. Several reasons may contribute to failure of the Tsoutrelis method in this instance, including:

1. The technique may not apply to high rotary speed drilling with impregnated diamond bits as the method was developed using tungsten carbide coring bits up to maximum speeds of 260 rpm.
2. Applying the bit constants derived from drilling concrete to the natural rock blocks assumes that the k_o values of the latter are valid despite difficulties with the thrust measurements.
3. Tsoutrelis may be wrong in asserting that the bit constants are independent of rock type.
4. Prolonged drilling even with an impregnated diamond bit, may introduce wear effects which went unnoticed.

TABLE 5.25: BACK-CALCULATED STRENGTH VALUES USING TSOUTRELIS' METHOD FOR NATURAL ROCK BLOCKS

Rock Type	k	N (rpm)	k ($x10^{-5}$)	Compressive Strength (MN/m^2)		
				Author	TRRL	Calculated
<u>Rock Blocks</u>						
Carboniferous Limestone	0.0142	1482	0.9582	93.1 (4)	89.3 (6)	24.5
Merivale Granite	0.0225	1494	1.5053	92.4 (4)	145.6(5)	18.7
	0.0097	1494	0.6470			29.7
Lindley Sandstone	0.0397	1523	2.6053	118.8(8)	83.3 (4)	12.7
Gregory Sandstone	0.0544	1483	3.6664	33.6(7)	70.1 (3)	9.7
Dolerite	0.0276	1503	1.8378	239.4(10)	190.5(3)	16.4
	0.0302	1471	2.0549			15.2
Shap Granite	0.0202	1512	1.3351	70.0 (16)	66.8(5)	20.2
<u>Kielder Samples</u>						
Limestone	0.0384	1500	2.5595	148.0 (13)	-	12.9
Sandstone	0.0517	1500	3.4458	176.9 (37)	-	10.2

*Bracketed figures refer to the number of samples tested.

5.6.8 Results of borehole logging

The author[24], in a report to the Construction Industry Research and Information Association, advocated the use of slimhole geophysical tools for geotechnical logging purposes during site investigation for major structures. Information gathered from this type of investigation would supplement that gained from standard site investigation techniques, plus provide the additional benefit of representing a wide zone of rock around the borehole. As mentioned previously, the TRRL used the horizontal holes drilled during this investigation to conduct a series of trials of geophysical and other borehole logging devices to assess their potential for probing ahead of tunnels via horizontal boreholes. The results of this investigation have been reported in detail by West[26]. Those findings of interest to the present investigation are discussed briefly.

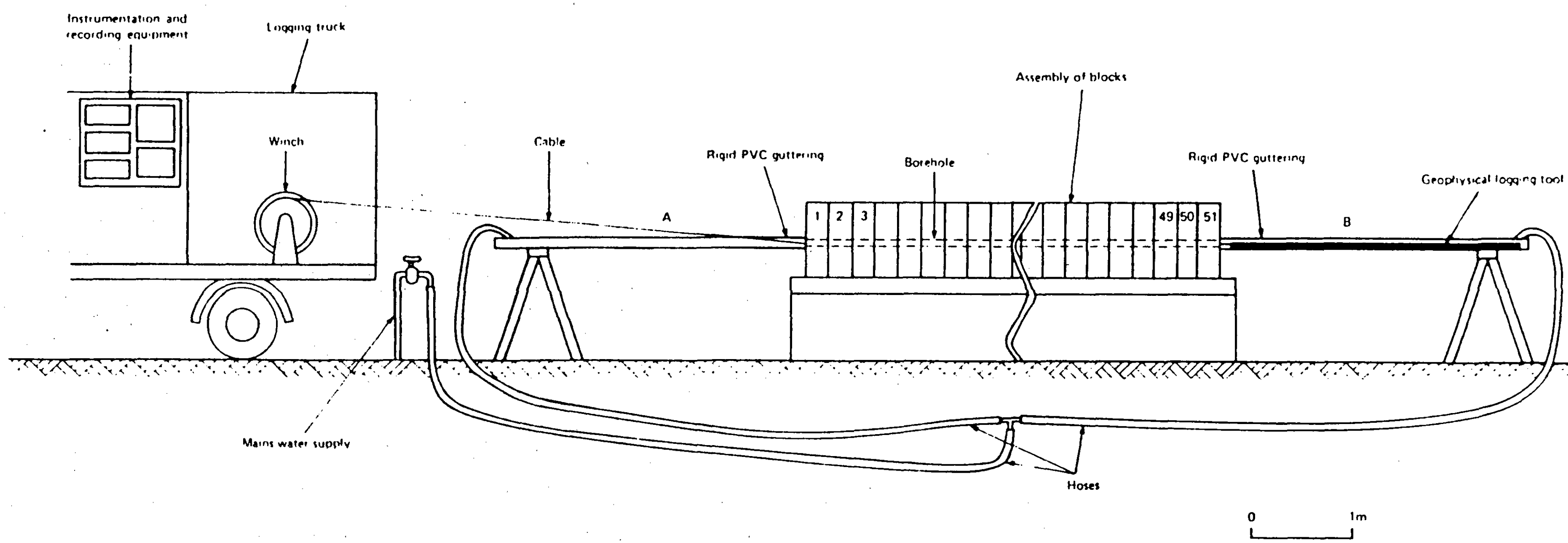
Logging technique

The geophysical borehole logging was conducted by BPB Instruments Limited, a company with experience in the manufacture of geophysical tools and logging of deep vertical boreholes for coal exploration. Figure 5.43 depicts the arrangement of equipment in order to carry out the geophysical logging. Each end of the block array was fitted with a 3m length of guttering (closed at one end) to provide a trough for filling the borehole with water as required by particular tools. The logging unit was located at A and all logging tools were pulled at a speed of 2.5m/min from B to A. All logging tools were approximately 3m long and 48mm in diameter. Unfortunately, the BPB sonic velocity probe required centralizers which exceeded the borehole diameter and thus could not be run. The following tools were run:

1. A natural gamma, gamma-gamma and caliper combination tool.
2. Neutron-neutron tool.
3. Neutron-gamma tool.
4. Resistivity and self-potential tool.

In addition, a Rees 60 borehole television camera consisting of a 51mm diameter, 200mm long miniature television camera with a wide angle lens (20mm to ∞), a self-illumination unit, a control unit, a television monitor (625 line b/w) and a videotape recorder was used to inspect the block array. The camera had two heads available, one forward-looking and another with a 45° angled mirror for sideways scanning. The camera was advanced down the hole from A to B on drain rods and its passage was recorded on videotape.

FIGURE 5.43 METHOD OF CONDUCTING GEOPHYSICAL LOGGING (After West, 1980).



Because BPB's sonic velocity tool could not be run, Mr. B. New of the TRRL developed a velocity tool to log the 56mm diameter borehole (Figure 5.44). Two ceramic piezoelectric transducers were mounted in stainless steel cases fitted with brass pads with the same radius of curvature as the borehole wall. The transducers were mounted 140mm apart in a Delrin holder, the spacing permitting measurement of individual block velocities. The transducers were decoupled from each other by fitting them in floating mountings. A manually operated levering system loaded the transducers against the borehole wall. The transmitter was connected to a pulse generator with a repetition rate of ten pulses/second. The receiver was connected to a cathode ray oscilloscope. Signal quality was good, permitting transit times to be read to an accuracy of 1μs.

The tool was positioned within a block during measurement. If the tool was straddling a joint, no signal was detected by the receiver. Transit time measurements for each block were made travelling in each direction. Comparison of the paired readings indicated that 85% or more were within 1μs of each other, a difference of 2.5% in velocity.

Geophysical logging

West stated that the gamma-gamma log was the only geophysical tool which supplied useful information for tunnelling ground investigation, providing a good measure of rock density.

A long and a short-spacing density log is produced by the gamma-gamma tool. Figure 5.45 shows the long-spacing density log. Three important lower density peaks stand out from the background, namely:

Peak	Density (Mg/m^3)	Feature
C	1.87	Gravel/sand/clay zone
D	1.39	Shattered rock zone
E	2.16	Block 10 and 11

While the resolution of the long-spacing density log (0.5m) does not permit the density of individual blocks to be measured, it does give 'zone' densities which compare favourably with direct measurements on core.

The short-spacing density log (Figure 5.46) indicates very low densities at C and D corresponding to the structural features noted in the previous log. The low density peak (E) corresponding to blocks 10 and 11 was also represented. The peak was better defined than in the previous log and appeared

FIGURE 5.44 ULTRASONIC VELOCITY TOOL (After West, 1980).

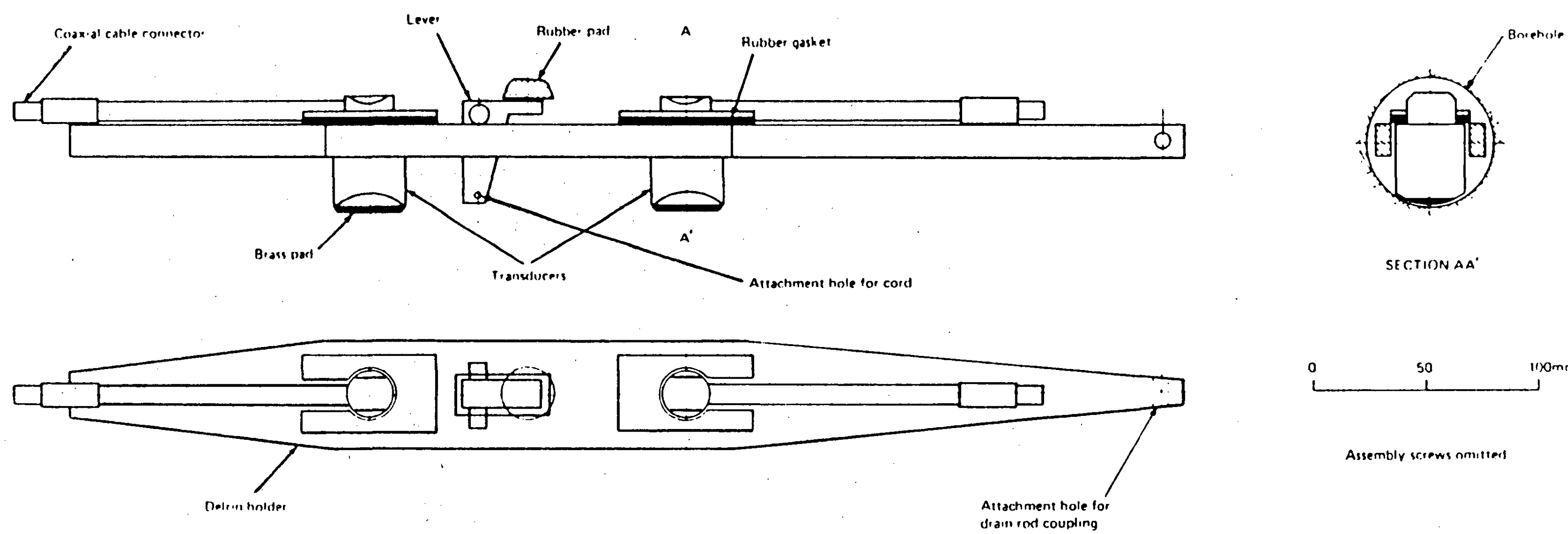


FIGURE 5.45 GAMMA-GAMMA (LONG SPACING DENSITY) LOG (After West, 1980).

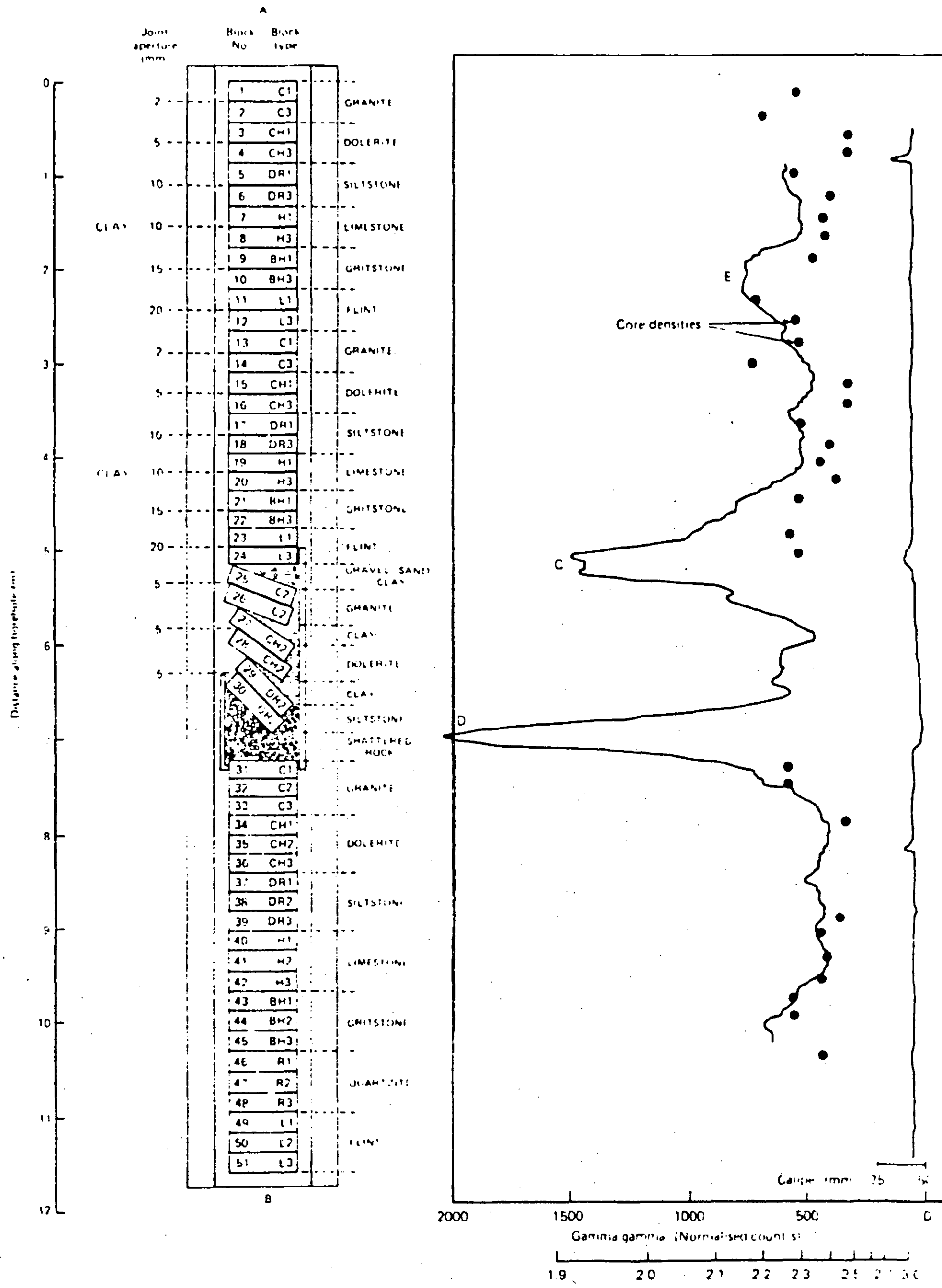
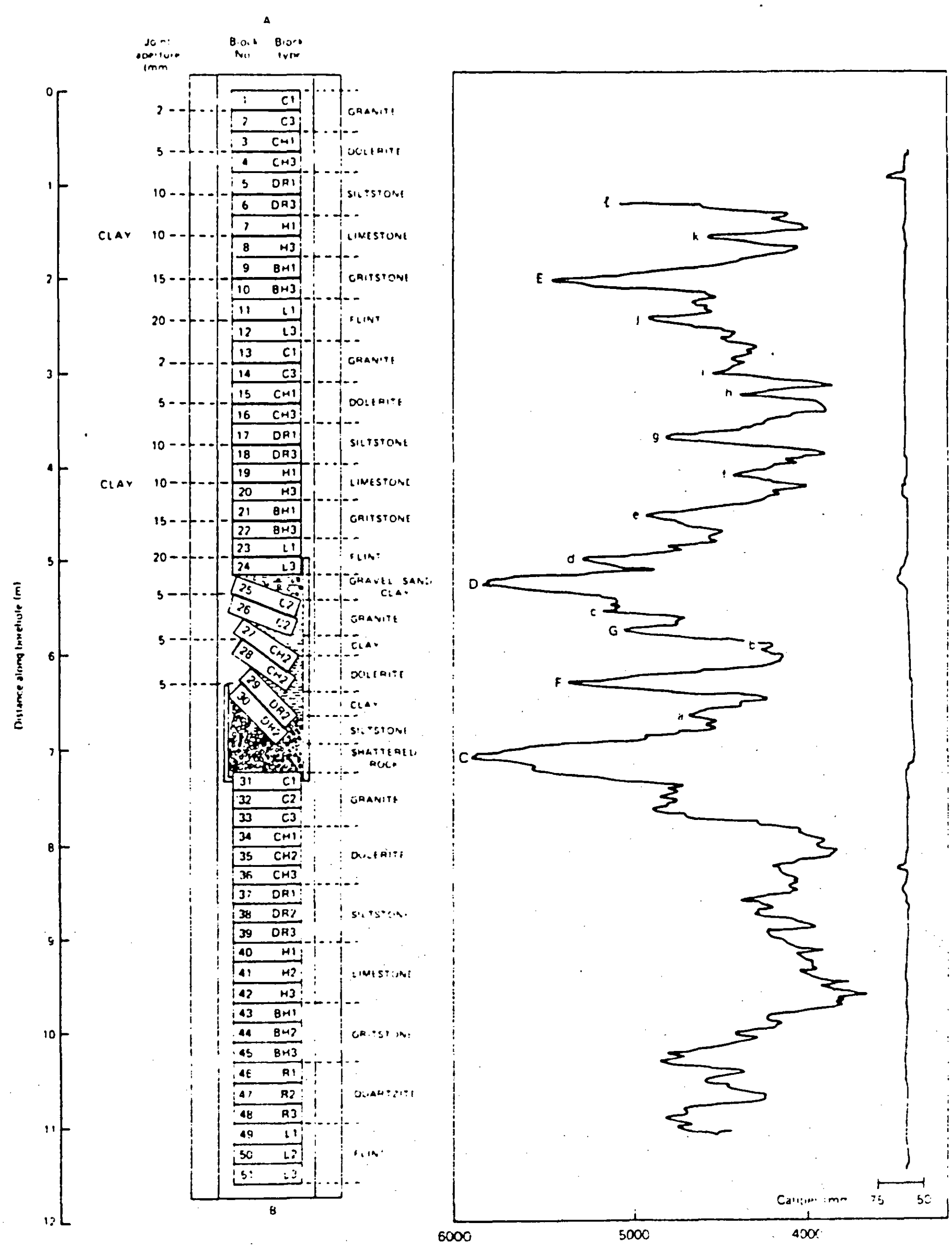


FIGURE 5.46 GAMMA-GAMMA (SHORT SPACING DENSITY) LOG (After West, 1980).



associated with block 10 rather than 11. The lower density, possibly corresponding to voids, might offer an explanation for the higher rate of penetration in this block, which was noted in drilling record 1.3.2 earlier. Peaks F and G are associated with the two clay-filled zones in the inclined block area of the array. West also noted that peaks a to l , including E, were associated with open joints in the array. However, comparable sized peaks occur in the 'tight joint' end of the block array at joints 45/46, 46/47 and 48/49. West stated that this cast doubt on the use of this log as an indicator of open joints; however, these same joints were sensed as 'open' by the drill rig instrumentation. Thus, not only was the short-spacing density log useful as an open joint detector, but the instrumented drilling rig, at least in the case of normal trending joints, was equally sensitive to these small-scale features.

Borehole television

Bearing in mind that the dry-hole conditions were optimal, examination of the borehole with the television camera was reasonably successful. Normal trending joints appeared as white circles, the thickness varying directly with the aperture. Inclined joints tended to be 'tear-drop shaped'.

The depth of the joints in the borehole were recorded using the tape measure attached to the instrument cable. Depths were recorded when a circular image filled the monitor screen. When compared with direct measurements, approximately 90% of the camera measurements were within 0.01m or less.

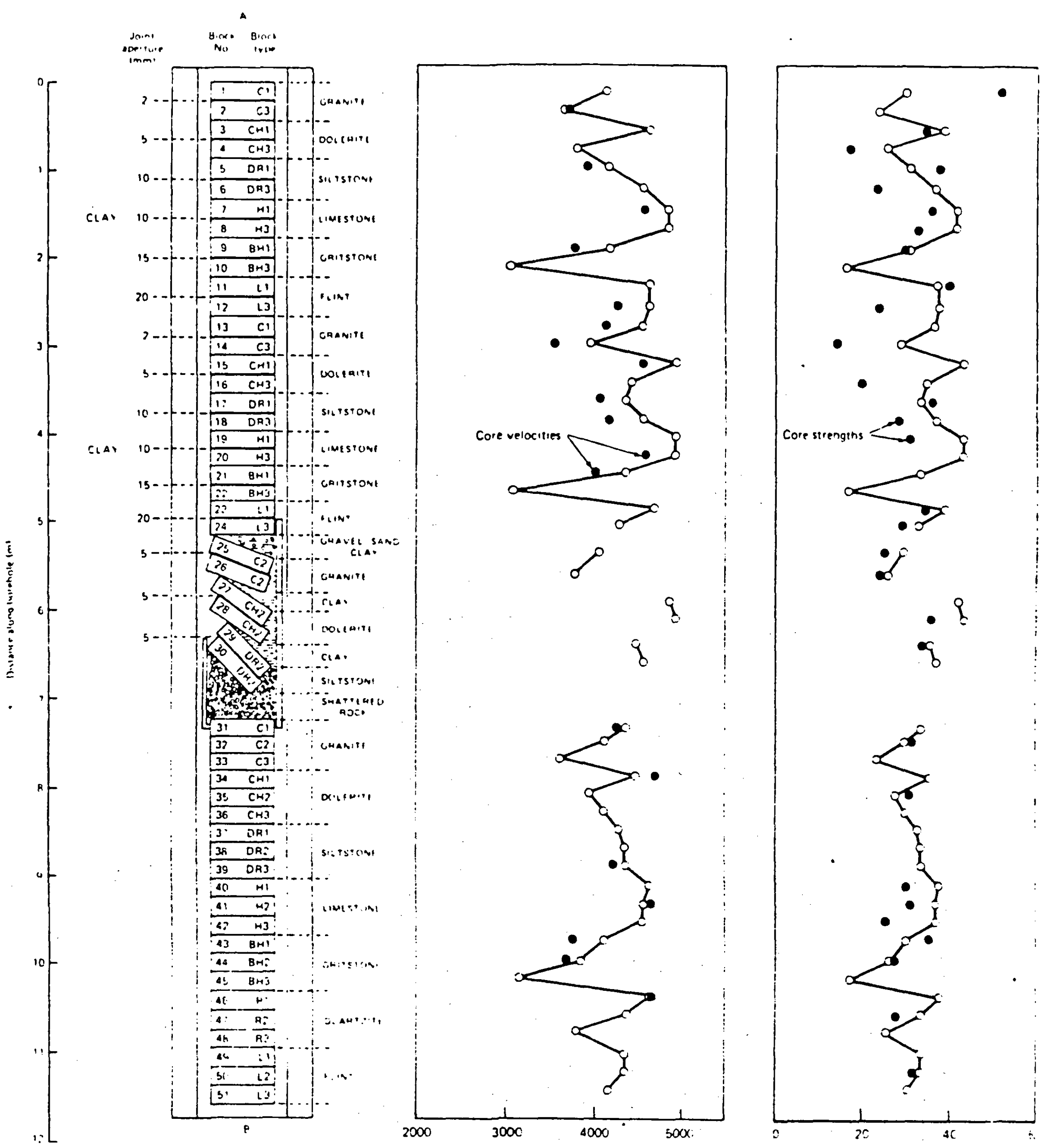
The side-scanning mirror permitted selective viewing of various features along the borehole. Joint apertures were apparent and reasonable estimates of their widths were practicable, provided sharp boundaries existed. One of the most serious drawbacks with this equipment concerns the near impossibility of orientating the image and hence, the joint trace. That aside, the camera did discern individual aggregate particles within the concrete blocks, individual pieces of rock in the shattered rock zone and score marks on the wall of the borehole caused by the drill string.

Ultrasonic velocity and rock strength

Figure 5.47 shows that the sonic wave velocity of the concrete ranges from 3000 to 6000 m/s. Direct velocity determination on core (solid circles) compare favourably with those determined by the velocity tool. More important, however, was the relationship between the velocity and the strength of the medium. West stated that the uniaxial compressive strength, σ_c, of the concrete blocks can be related to the compressional wave velocity, C_p, as follows:

$$\sigma_c = 1.77\ C_p^2 \qquad (5.8)$$

FIGURE 5.47 ULTRASONIC VELOCITY AND COMPRESSIVE STRENGTH LOG (After West, 1980).



This semi-empirical relationship provides the basis for the strength log plotted in Figure 5.47 wherein log-derived values are plotted as open circles, while compressive test values on core are displayed as solid circles on the same log. In general, there was fair to good agreement between the two measures of strength. Compression test results range from 14 to 51 MN/m^2 while the velocity-based values vary from 16 to 43 MN/m^2. Even where the agreement between values was weakest, the overall trends matched with respect to whether the strength was increasing or decreasing. The ultrasonic velocity tool appeared capable of predicting the general strength category of the material. If this capability is verified over a wide range of rock strengths, then the tool could be useful for probing ahead or pre-tunnelling site investigation applications.

5.7 Summary

In the introduction to this chapter, a number of objectives were specified for the laboratory drilling trials, including:

1. To develop instrumentation to monitor rotary drilling performance.
2. To prove the feasibility of drilling and collecting data from horizontal boreholes.
3. To verify that established relationships between drilling variables were applicable to the Diamec 250 drilling rig,
4. To produce a catalogue of 'signatures' for instrumentation responses to known ground conditions for eventual use in field applications.
5. To assess the practicality of predicting rock strength from monitored parameters.

Apart from difficulties associated with predicting rock strengths, the laboratory drilling trials must be considered successful since most of the objectives were achieved. While the instrumentation proved unreliable on occasion, as a prototype installation, it established that it was possible to fully instrument a rotary drilling rig, produce accurate records of drilling variables and interpret the results in a manner likely to be of considerable assistance to geotechnical engineers involved in site investigation drilling for tunnelling and other construction purposes.

CHAPTER 6

FIELD DRILLING TRIALS

6.1 Introduction

In order to demonstrate the practicality of drilling horizontal boreholes under conditions comparable with those which might be anticipated during routine tunnelling site investigation or probing ahead operations, underground field trials were carried out. It was originally intended to drill in the experimental tunnel beneath Rogerley Quarry in Weardale. This tunnel was constructed to assess design and construction requirements for the 32km Kielder water tunnel which would pass through alternating sandstone, limestone and mudstone rocks in conveying water from the River Tyne to the Tees. Unfortunately, dangerous roof conditions in the fissile mudstone section of the tunnel forced abandonment of this site. After several months search, an alternative site was secured near Bath, Wiltshire.

6.2 Site of the Underground Drilling Trials

6.2.1 Location and geology

The underground drilling trials were conducted in a disused underground Bath Stone quarry at Corsham, where the Great Oolite Limestone was won in underground galleries 30m below surface[299]. The Great Oolite Series is of Jurassic age and in the Bath area subdivides into:

- Bradford Clay
- Upper Rags (including Bradford Coral Bed, Ancliff Oolite and Corsham Coral Bed)
- Bath Oolite
- Twinhoe Beds
- Combe Down Oolite

The Series consists primarily of white to pale yellow, shelly oolitic limestones and free-stones which often display well developed current bedding[300,301]. In the Corsham area, the Bath Oolite is normally 9 to 10m thick. The Bradford Clay which overlies the workings forms an ideal waterproofing layer for the stone mines. Percolating surface water is arrested and diverted by this impervious horizon rendering the mines relatively dry.

The mine was operated on a room and pillar basis, the size of the pillar being dependent on the miner's assessment of the roof conditions and/or the quality of the stone. As a result, pillars are irregularly spaced and shaped.

Another characteristic feature of the pillars was a downward tapered profile caused by the sawyers setting outer saw cuts at an angle in order to obtain larger blocks from the lower beds. This practice was known as robbing the picker since he was paid by the width of the roof bed that was removed by pickaxe in order to insert the saws[299].

6.2.2 Location of the drill rig

The gallery at the test site was approximately 8m wide and some 5m high and was located on the northernmost extremity of the workings. The rig was located in a convenient recess in the gallery wall. The arrangement of the drill and the recording equipment at the site is shown in Figure 6.1. This layout had a number of advantages, including:

1. A 19m long 'pillar' was available for drilling with access afforded at each end of the borehole.
2. Major geological features encountered by the drill bit were verified by simply mapping their exposure in the gallery.

The drill rig was set up in the recess about 0.75 from the rock face to permit manipulation of tools into the borehole. The rig frame was secured to the gallery floor by eight anchors which were grouted in place since the floor was formed from compacted rock rubble.

The power pack and water pump were set up about a third of the distance down the pillar to minimise noise. A special circulation tank with filter screens was employed to guard against possible irregularities in mine water supply. A 50m run of pipe was installed to supply water to this tank by tapping into an existing service. Both 3-phase and single phase power supplies were run some 30m from existing junction boxes to power the drilling equipment and the instrumention respectively. Also, additional lighting was installed above the drill platform and at the downhole end of the pillar.

Finally, a 1m deep sump was dug into the rubble floor by the rock face to provide a soak-away for spent drilling fluid. Two shallower pits were dug at a later date, one mid-way along the pillar and the other at the downhole end, to accommodate drilling fluid losses from the rock mass.

6.3 Drilling Programme

In all, four boreholes were drilled at the Corsham site with the maximum

FIGURE 6.1 SITE OF THE UNDERGROUND DRILLING TRIALS

distance between centres being less than 0.5m. The first borehole was drilled without monitoring the rig performance in order to permit TRRL staff to log the borehole with minimum delay. Thereafter three boreholes were drilled using the drilling data logging equipment. Of these three boreholes, only two will be discussed for the purposes of this study since the information gained from the last borehole merely confirmed that obtained from the earlier drill runs.

Most drilling runs were performed under conditions of constant thrust except in instances when 'friction tests' or strength tests were being conducted. Friction tests involved substituting a 'bull-nosed' solid steel insert in place of the drill bit. This non-drilling assembly was then run to bottom and various conditions of thrust similar to those which prevailed during normal drilling were imposed. As the drill blank was offering little resistance to rotation, any build-up in resistive forces with increased thrust could be ascribed to friction between the drillstring and the borehole wall. In fact, no change was noted suggesting that the flushing rate combined with the stiff drillstring contributed to the development of minimal friction in this rock. The friction tests were conducted in Borehole 2 at 4.5 and 16.7m and in Borehole 3 at 6.3 and 11.9m.

The strength tests were similar to those conducted during the laboratory drilling trials. As before, a number of different thrust levels were selected while adjustments were made to the swept-volume of the motor to maintain a constant rotary speed. In Borehole 2, strength tests were conducted during drill runs 9 and 13, while in Borehole 3 similar tests were performed during drill runs 4,6,8,12,13 and 14.

In each instance, the boreholes were drilled using HM matrix TT56 thin-wall coring bits. After completion of Borehole 3, a N-size diamond coring bit suitably adapted to carry a 15cm long steel pilot was used to open the hole out to 76mm in order to log the borehole with an impression packer. This operation proceeded without difficulty until severe vibration about 4.5m depth required incorporating a stabilizer in the drill string. At 9m depth, severe vibration started again accompanied by snatching in the hole. One particularly severe snatch brought the drill rig to a dead stop from 1900 rpm. At this point, the drill string was pulled back to the barrel and the borehole washed down employing rotation. Nevertheless, at 9m depth snatching occurred again and could not be suppressed by reducing rotary speed using the over-ride. Finally, since no more stabilizers were available, the gear train in the gear box was changed to permit lower rotary speeds, but to no avail. Thus, hole opening was ended when only half complete.

6.4 Data Logging, Processing and Presentation

Almost the same instrumentation which was used in the concrete block drilling trials at the TRRL was used in the Bath Stone quarry. The only change concerned the water flow monitors which were dispensed with early in the underground drilling trials because the same pressure pulse problems which troubled the laboratory trials continued at Corsham. With this exception, the operational procedure outlined in Section 5.4.2 was followed to permit an equipment warm-up period prior to recording off-set values in advance (and following) of each drill run. As before, all monitored values were stored on punch tape as interval data normally collected each four seconds. The chart recorder was employed again to provide an immediate display for the operator.

Data handling/editing followed precisely the procedure detailed in Section 5.5 of the previous chapter with one exception, and hence needs no repetition. The only variation which occurred concerned the polarity of the power supplied to the various sensors. During the hook-up of the equipment, one or two transducers had the polarity reversed compared with the laboratory. Once recognized, this change was easily accommodated for by slightly modifying the off-set voltage subroutine in the computer program. Otherwise, the program remained unchanged since regular calibration checks on the sensors showed they remained stable.

Data presentation adopted the same three formats outlined in Section 5.5.5, namely:

1. Strip chart records
2. Computer tabulation of drilling variables
3. Computer drawn graphs

The only variation was the change in the drilling file reference to reflect the new location. The sequence of borehole number, core run and rechuck remained unchanged.

6.5 Examples of Recorded Output

As in the case of the laboratory experiments, the volume of data from the Corsham drilling trials precluded an exhaustive study of the information contained in the individual coring runs. For purposes of discussion, a selection of the more eventful records are analysed. However, a complete record of the recovered data is presented in Appendix 6.

6.5.1 Drilling record 3.3.1

An example of a strip chart record from Borehole 3 is shown in Figure 6.2. Thrust, torque, rotary speed, head displacement (penetration) and water pressure are continuously plotted against drilling time. The rate of penetration at any depth is given by the slope of the head displacement - time curve, higher penetration rates being characterised by a horizontally-tending slope. Figure 6.2 shows drilling proceeding uniformly at an approximate penetration rate of 35cm/min, a rotary speed of 2000 rpm and a thrust of 3.1 kN. At 2.30 metres depth, a rapid acceleration in head displacement occurred corresponding to a penetration rate of 117 cm/min over a drilled interval of 8cm. Momentarily, the rotary speed dropped to 1900 rpm, the torque increased to 17.5 Nm while the thrust and inlet water pressure remained unchanged. Experience has shown this type of drilling response to indicate a discontinuity or cavity.

Thereafter, the drilling parameters tended to their former levels until a second fissure was encountered by the drill at 2.64 metres. A momentary decrease of some 200 rpm was accompanied by a small drop in the thrust and inlet water pressure values as the drill bit traversed a 7cm void. Returns were lost to this discontinuity, the flush water discharging from the exposure of this joint in the gallery wall. Beyond this joint, penetration rates gradually decreased from 40 to 15 cm/min. Finally, a smaller fissure was traversed at 2.97m depth. The recorded drilling parameters display the characteristic signature of this type of geological feature. The record ends at 3.02m as the rotary head of the drill has reached the bottom of the drill carriage and a rechuck is required.

The irregular nature of the discontinuities in the Great Oolite Limestone at Corsham was demonstrated by the apparent absence of the major joint/cavity at 2.64 in the record for borehole 2 (File 2.4.1). It should be borne in mind that boreholes 2 and 3 were less than 0.3m apart. This behaviour was confirmed by discontinuities exposed in the gallery. Over very short distances, wide clay-filled joints closed to leave only a tight joint trace on the gallery wall.

6.5.2 Drilling record 2.10.1

Figure 6.3 provided a good impression of the typical drilling conditions at Corsham. This record shows a uniform rate of advance, 20 to 25 cm/min, under a thrust of 2.6 kN and a rotary speed around 2000 rpm. The only interruption in this pattern occurred at 8.5m depth as a fissure was crossed.

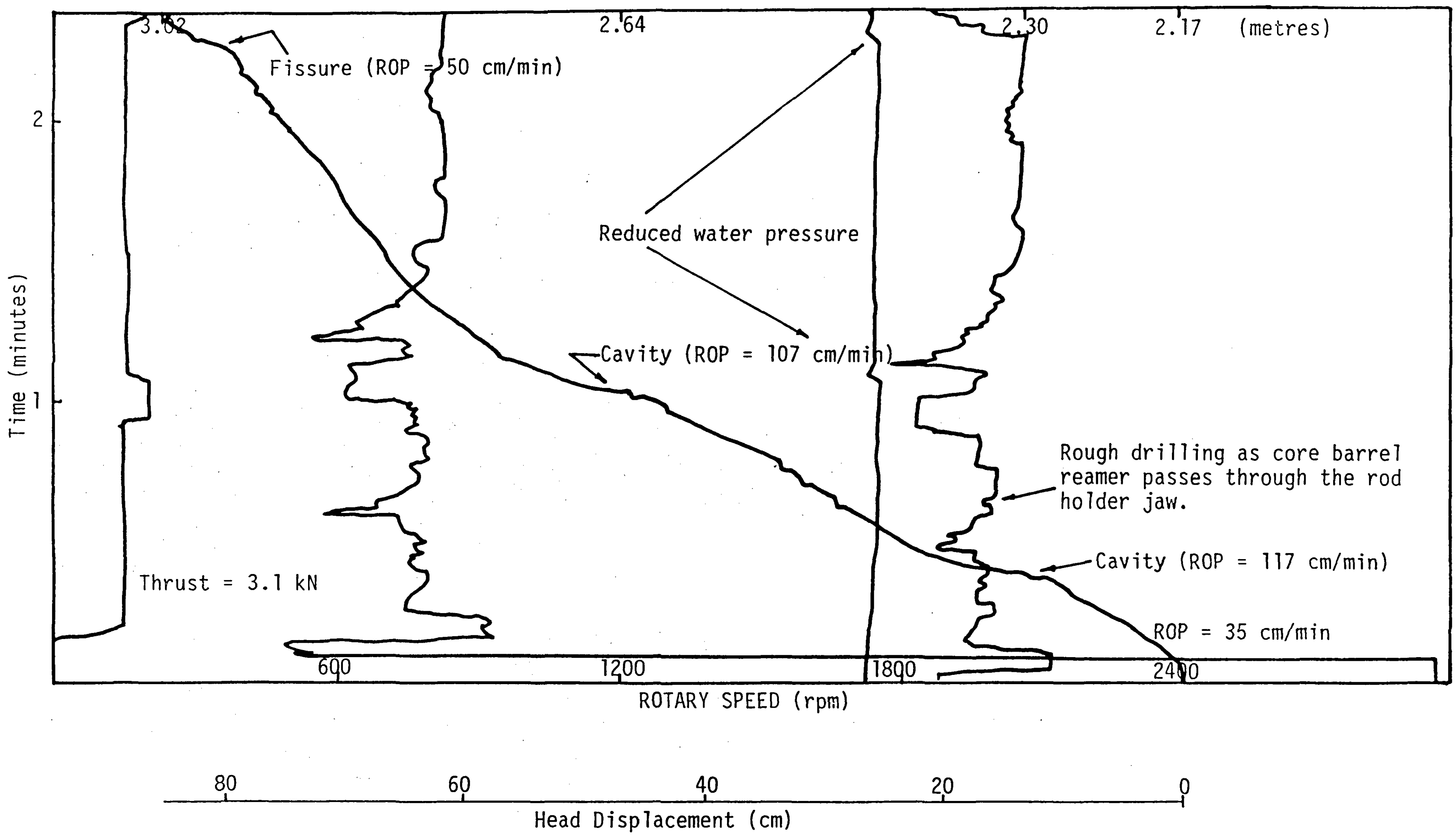
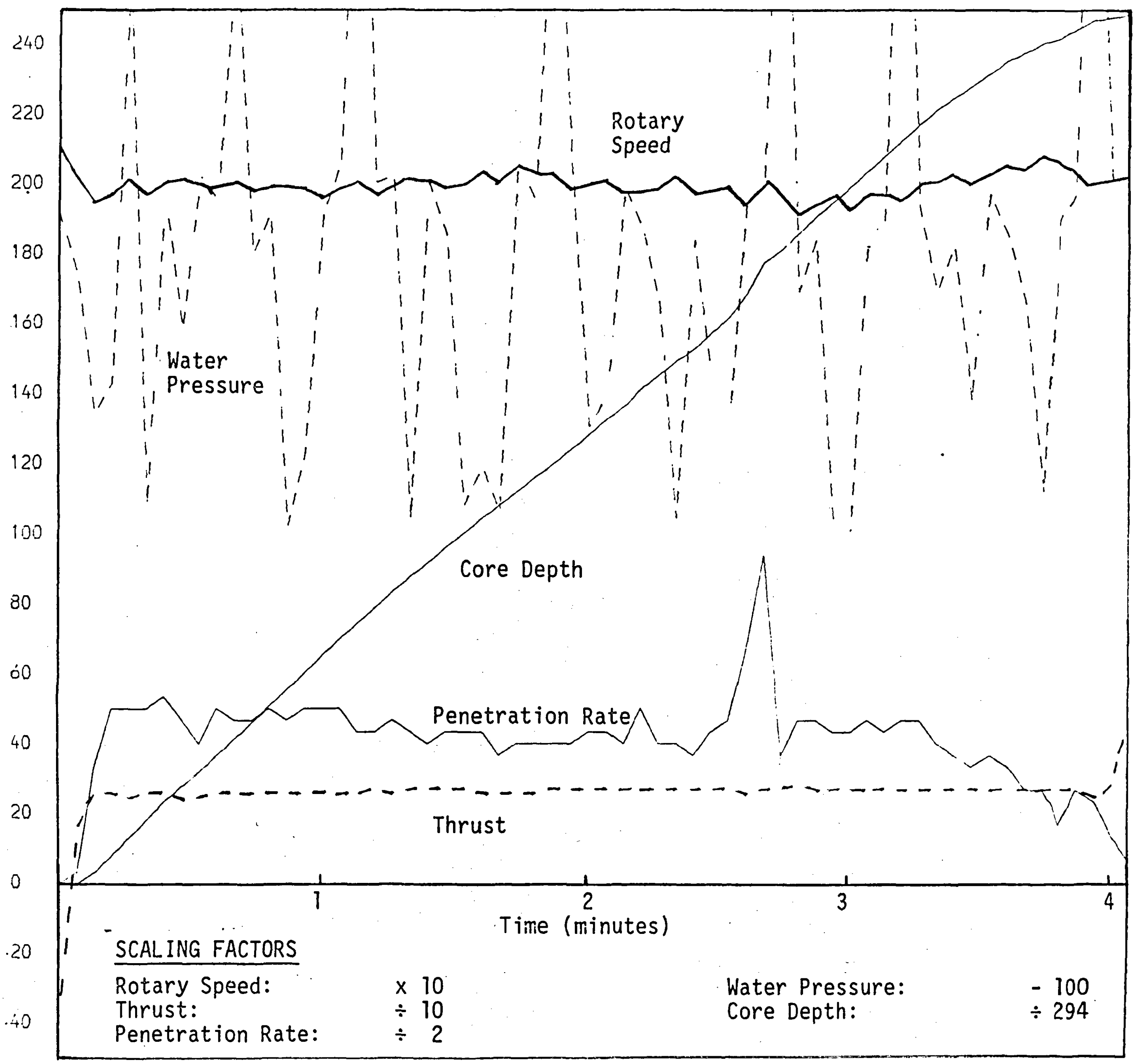


FIGURE 6.2 RECORD OF CORSHAM DRILL RUN 3.3.1 (2.17 to 3.02 metres)

FIGURE 6.3 COMPUTER RECORD OF CORSHAM DRILL RUN 2.10.1 (7.93 to 8.78 metres)



Although the numerical record (Appendix 6) indicated a fissure aperture of some 5cm width, the relatively low increase in rate of penetration, coupled with a moderate drop in rotary speed and thrust for such a 'large fissure' suggested otherwise. In fact, only a portion of the high penetration rate zone was a true fissure. The remainder of the zone was associated with heavily oxidised and corroded rock on either side of the fissure. This weak material accounted, in part, for the higher rate of penetration.

Thereafter, the drilling variables assumed their previous values with thrust constant at 2.72 kN, rotary speed ranging generally from 1950 to 2000 rpm and penetration rate gradually declining from 23.5 to 13.0 cm/m until the run was halted for a re-chuck.

6.5.3 Drilling record 2.10.2

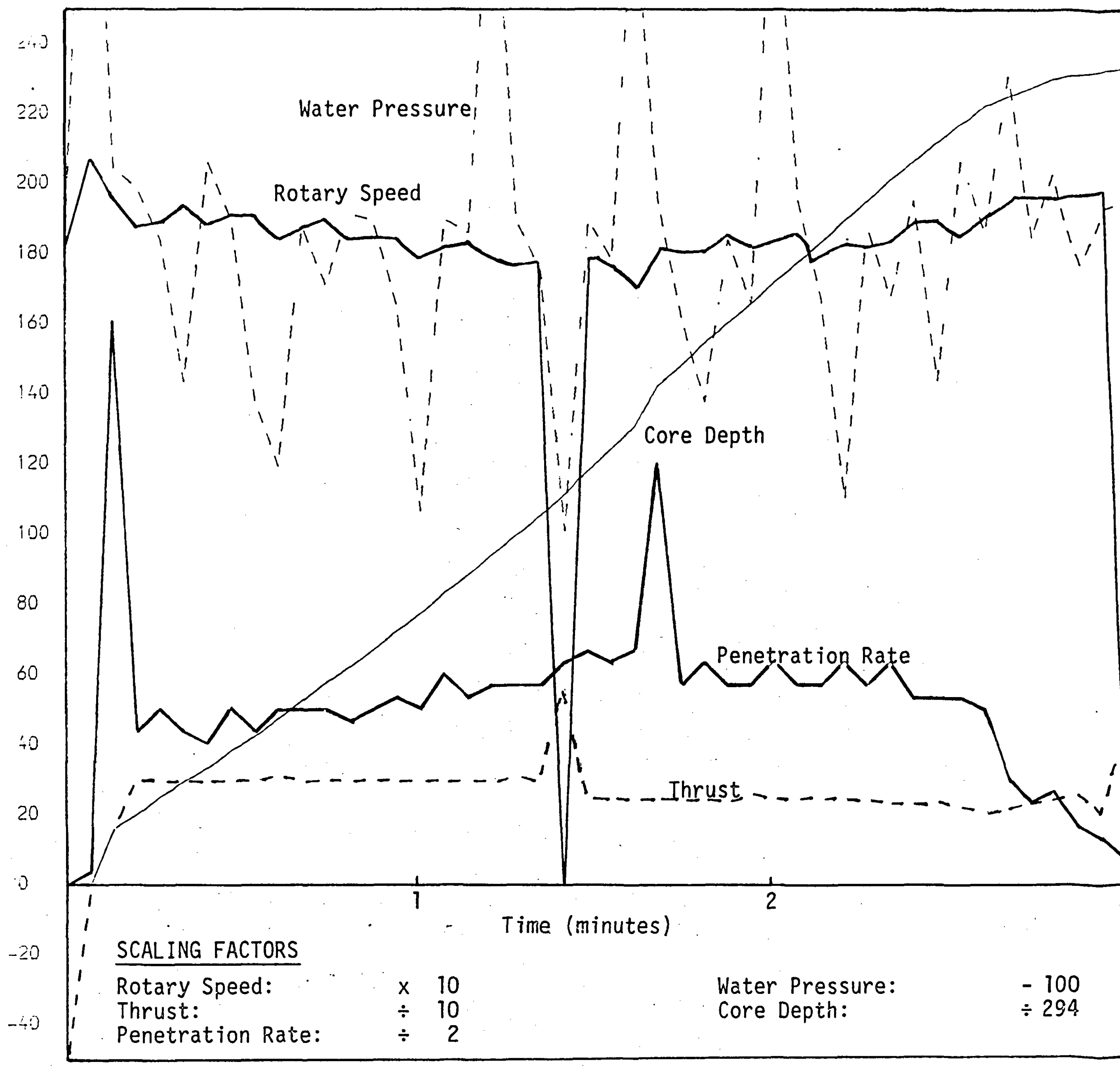
Drilling had just commenced when the bit traversed a 5cm wide fissure at 8.78m depth. Other than the prominant rate of penetration peak at the start of the record in Figure 6.4, the drilling variable responses are masked by the operator making initial adjustments to the thrust. The penetration rate over this 5cm interval was 80.5 cm/min. When the bit re-entered the limestone, this rate dropped back to about 25 cm/min at 3 kN thrust and an average rotary speed around 1840 rpm. After 1½ minutes drilling time, the operator caused a short but rapid increase in load to try and effect increased rate of penetration by sharpening the bit down-hole. There appeared to be some improvement in cutting rate since the rate of penetration rose to 33.0 cm/min at a lower thrust setting of 2.5 kN.

Unfortunately, the validity of this trend could not be established since another fissure at 9.27m interrupted the bit's advance. This fissure caused some of the characteristic responses in the drilling variables apart from increased rate of penetration (60.4 cm/min). The rotary speed dropped as did the inlet water pressure, although this latter effect is seen to best effect on the strip chart record in Appendix 6. Thereafter, the rate of advance was slightly reduced from the pre-fissure levels until the core run was stopped because of a blockage in the barrel.

6.5.4 Drilling record 2.11.1

Figure 6.5 shows the strip chart record of the drilling variables over the 9.57 to 10.41m interval. The most distinctive feature was the 7cm wide fissure at 9.72m over which the penetration rate soared from about 32 to 104 cm/min. Reference to the strip chart record demonstrates pronounced deviations in every recorded variable. The head displacement curve indicates

FIGURE 6.4 COMPUTER RECORD OF CORSHAM DRILL RUN 2.10.2 (8.78 to 9.57 metres)



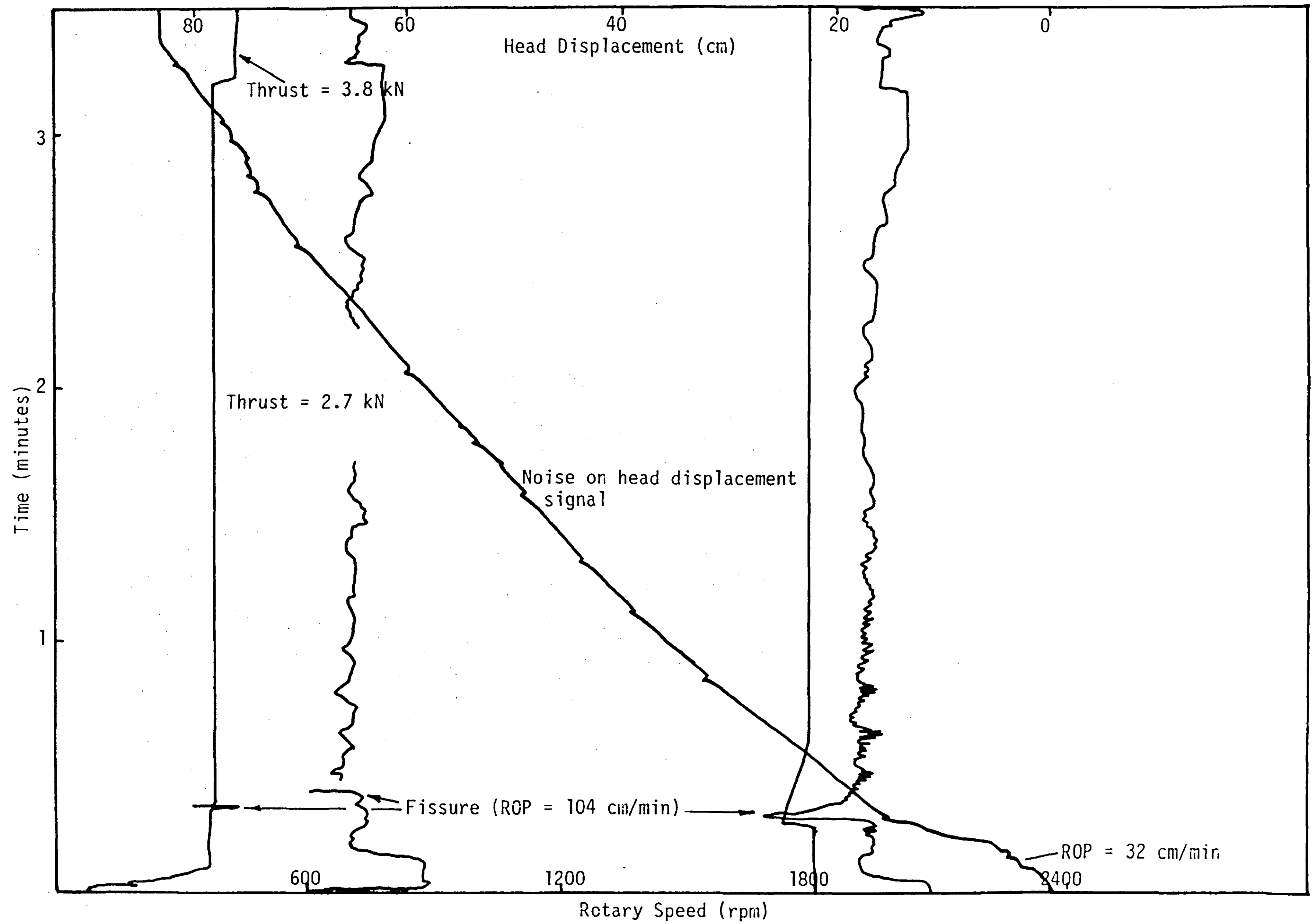


FIGURE 6.5 RECORD OF CORSHAM DRILL RUN 2.11.1 (9.57 to 10.41 metres)

a sharp increase in penetration rate which is momentarily interrupted before another surge forward by the drill bit. This behaviour is attributable to either partial infill of the fissure or, more likely, a rock bridge. The recorded variables sensed this as a single event since it occurred between data scans.

Having crossed the fissure, there was a dramatic drop in rotary speed when the bit engaged rock again. Also, consistent with observations in the previous chapter, other drilling variable responses included:

1. A pronounced reduction in torque when the bit entered the void.
2. A decrease in thrust as the bit met no resistance to advance across the fissure followed by a sharp increase in thrust when contact with rock is re-established. Thereafter, the thrust returns to the pre-fissure value of 2.59 kN.
3. An abrupt drop in the inlet water pressure value as the storage capacity of the fissure acts as a pressure sink before entry of the bit into rock introduces a back-pressure and water pressure values are gradually restored as the bit advances further into the rock.

Drilling conditions beyond the fissure are uneventful. Penetration rates over the remainder of the coring run decline slowly from about 35 cm/min to some 22 cm/min when the run was halted for a re-chuck.

The ability of the drilling rig instrumentation to detect these four major joints over a distance of about 1m indicated that joint spacing could be measured with sufficient accuracy that rock mass classification indices and primary support requirements could be estimated.

6.5.5 Drilling record 3.8.4

Figure 6.6 is the computer plot of the 8.17 to 9.02m drilled interval in borehole 3. The principal aim in this section of hole was to obtain data for the back-calculation of rock strength, hence the incremental rise in the thrust level over the coring run. As this aspect of the underground drilling trials is discussed later, it is not considered here. The fissure indicated after some 2½ minutes elapsed drilling time is the feature of interest. This fissure (depth = 8.56m) is the same as that detected in borehole 2 (file number 2.10.1). As is frequently the case with the computer plots, the fissure was best represented by the short duration increase in rate of penetration where a rate of 70 cm/min represents the fissure and 30 cm/min corresponds with the rock mass on either side of the fissure.

Also, the core depth trace, equivalent to head displacement on a strip

FIGURE 6.6 COMPUTER RECORD OF CORSHAM DRILL RUN 3.8.4 (8.17 to 9.02 metres)

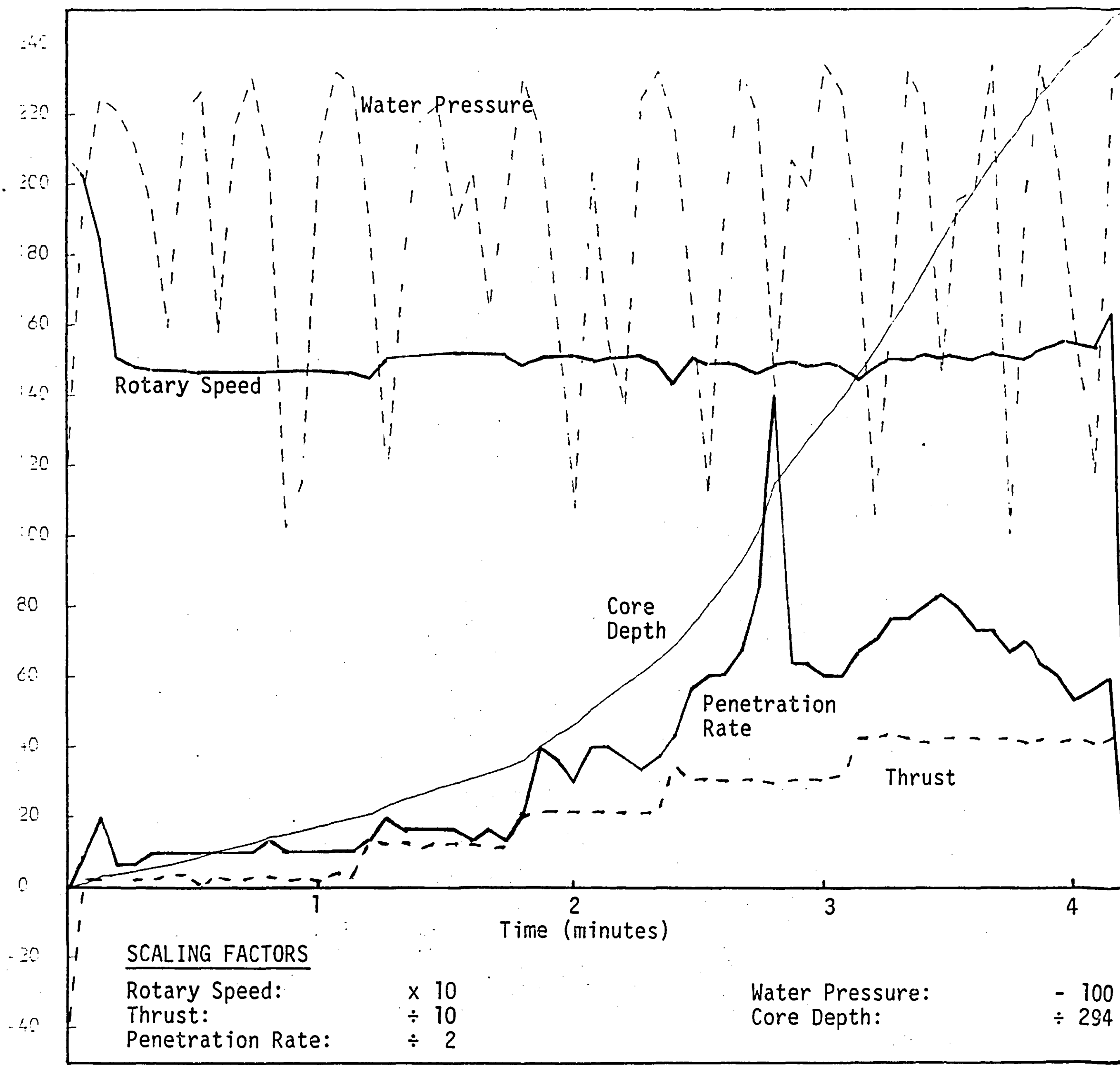


chart record, showed a marked depth increase over a short time interval. The thrust trace showed a slight drop in value which may be explained by the fissure, although the variation suggested on this plot could equally be explained as rounding errors in the thrust voltage signal.

A clearer representation of the drilling variable response was obtained from the strip chart record in Appendix 6. Prior to encountering the fissure, the drilling record shows a predictable head displacement response to regular increases in thrust given rotary speeds adjusted to a minimal 1500 rpm. At the fissure, the following events occurred:

1. A sharp break of slope in the head displacement curve.
2. A reduced rotary speed immediately after the fissure was crossed.
3. An increased torque when the bit encountered rock on the opposite side of the fissure.
4. A sharp drop in thrust over the void followed by an abrupt increase at the opposite rock face before returning to the nominal setting of 3.1 kN.
5. A slight increase in water pressure, presumably when the bit struck the rock surface on the opposite side of the fissure.

There is nothing new in these responses, having been observed repeatedly during the drilling trials. However, it is worth noting once again the extra detail which is obtained from continuous recording of drilling variables.

6.5.6 *Drilling record 3.9*

To complete this demonstration on the repeatability of results between boreholes, consider the intensity of fracturing indicated in Figure 6.7 for the interval 9.02 to 9.65m.

Shortly after initial drilling conditions were established, a major joint/cavity was penetrated around 9.20m depth. This was preceded by a smaller 'fissure' immediately beforehand (about 9.09m), although in all probability it comprised part of the larger feature and likely represented a small rock bridge. The void was substantial, representing a width of some 12cm, and caused marked fluctuations in each of the plotted variables. The rate of penetration across this feature was a remarkable 165 cm/min.

Some 20cm later, another discontinuity was registered, largely as a result of an abrupt, short duration increase in the slope of the head displacement curve as the bit stepped across the fissure. The variation

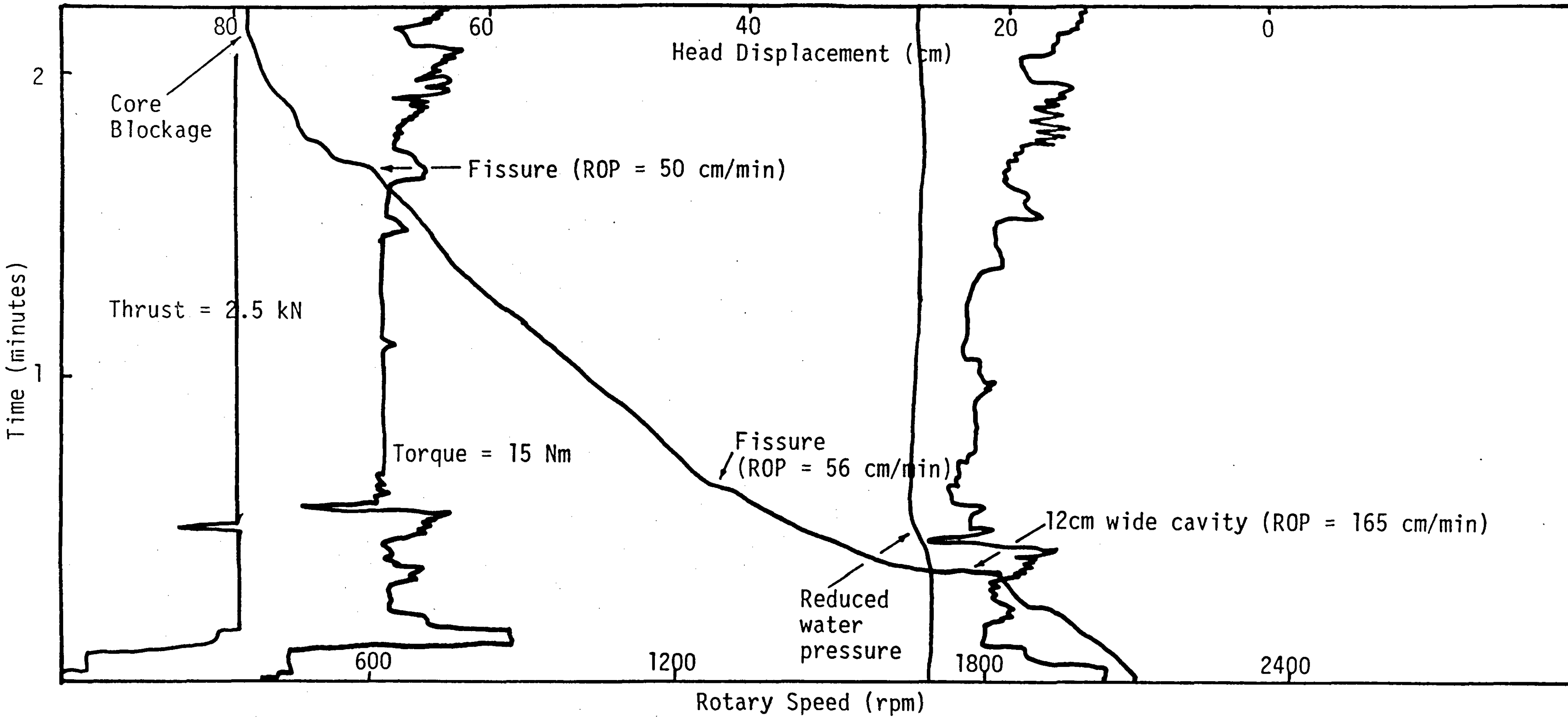


FIGURE 6.7 RECORD OF CORSHAM DRILL RUN 3.9 (9.02 to 9.65 metres)

in rate of penetration on this occasion represented a two-fold increase over those prevailing in the rock. From this point until the next fissure intersection at 9.60m, drilling was relatively straightforward except for some variation in rotary speed. After the fissure was crossed, indications from the drilling variables indicated a bit blockage and drilling was stopped in order to trip the barrel.

It is interesting to compare the strip chart record with the computer graph for this core run. The fissure locations in Figure 6.8 are unmistakable. The large discontinuity at 9.20m showed a number of interesting features, including:

1. A rate of penetration which went off scale indicating both the width of the fissure and the fact that it contained no infilling.

2. A thrust value which decreased to near zero, again indicating a large open void where the only resistance to advancing the bit was in overcoming the inertia of the drill string.

3. A rise in rotary speed resulting from a freely rotating bit.

Finally, the size of the void was confirmed by the near vertical slope of the core depth curve over a distance representing 18% of the total cored depth.

The effects on the drilling variables at the remaining two fissure intersections were less pronounced and are restricted to the rate of penetration, core depth and arguably the rotary speed traces. This is partly a consequence of the logger sampling the prevailing values before and after penetrating the fissure, rather than during the event, thus allowing certain variables to return to their normal levels. Also, where the fissure is small enough, certain variables do not have sufficient time to respond to the momentarily changed conditions (rotary speed, thrust, etc.).

6.5.7 Drilling record 2.16.2

There was no apparent loss of instrument sensitivity with depth. This is demonstrated by considering Figure 6.9 which shows the computer-processed drilling record for an 0.85m interval of Borehole 2. From 16.66 to 17.51m drilling progressed smoothly with penetration rate slowly increasing from 25 to 40 cm/min, while rotary speed slightly decreased under constant thrust conditions. Without warning the drill string surged forward at a rate of penetration in excess of 240 cm/min through a partly clay-filled

FIGURE 6.8 COMPUTER RECORD OF CORSHAM DRILL RUN 3.9 (9.02 to 9.65 metres)

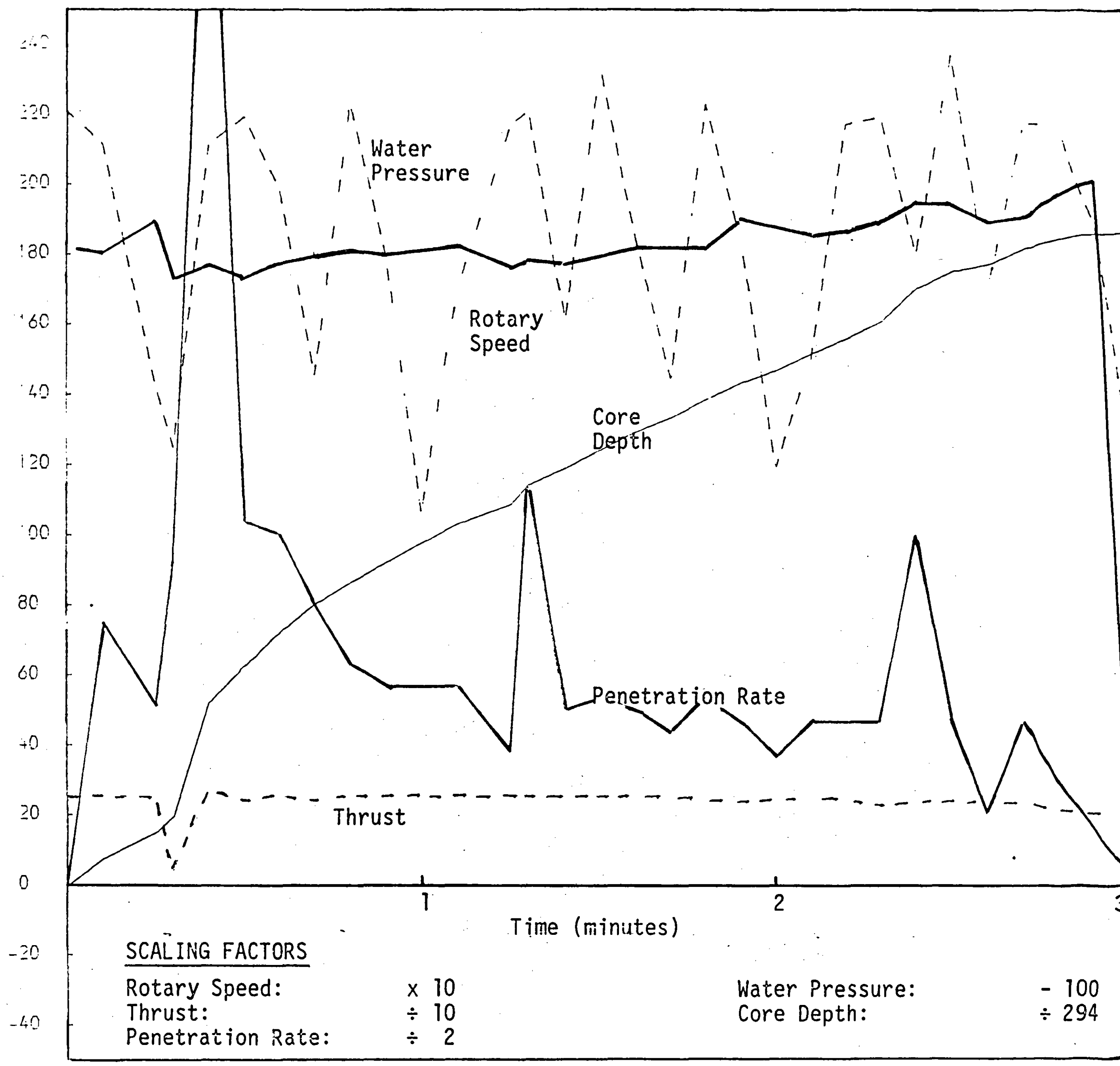
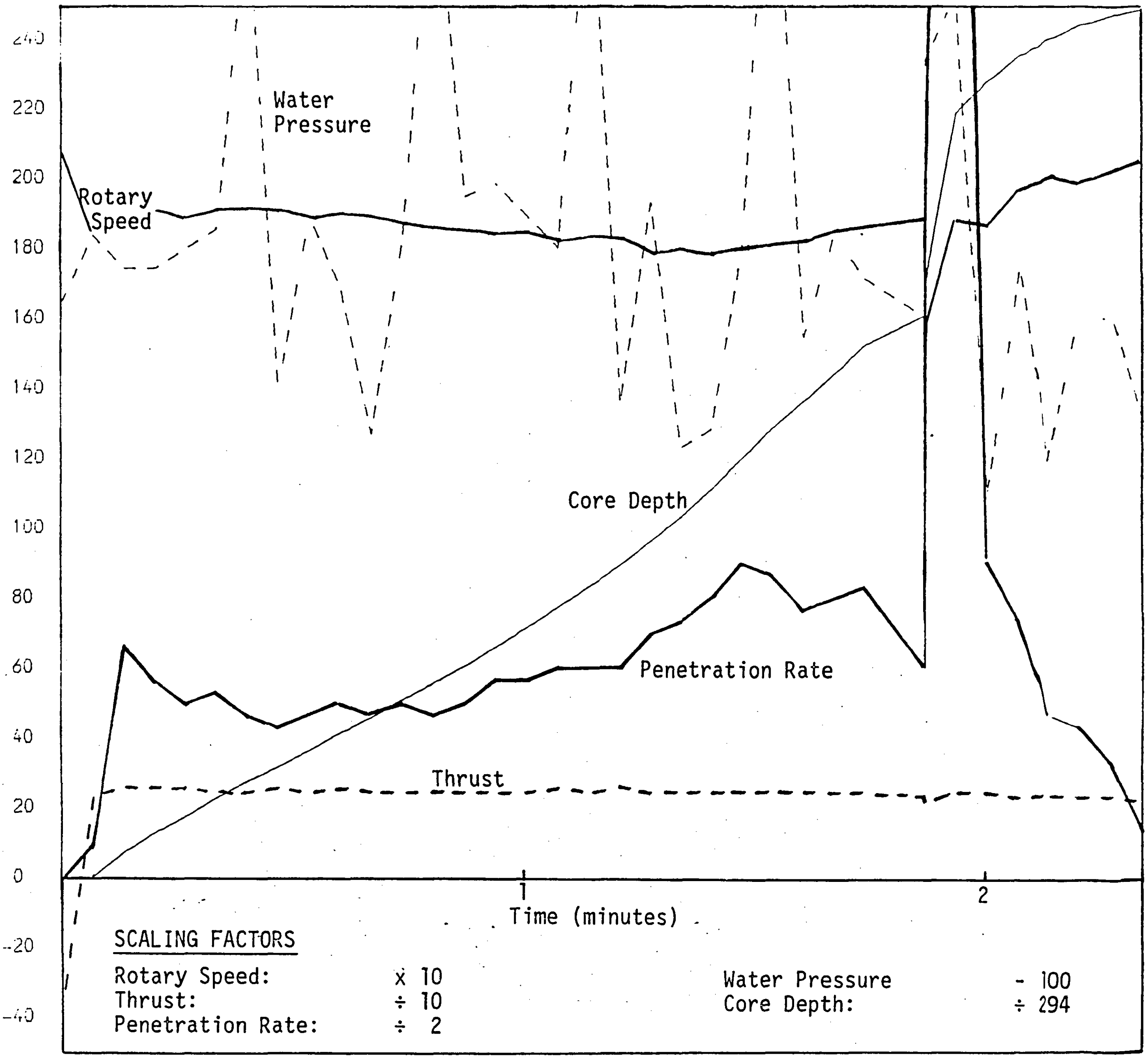


FIGURE 6.9 COMPUTER RECORD OF CORSHAM DRILL RUN 2.16.2 (16.66 to 17.51 metres)



zone of some 20cm width at a depth of 17.24m. The surge is marked by characteristic pulses in the other recorded parameters. For example, the thrust dropped slightly over the void as reduced resistance to advance was encountered. The rotary speed fell initially through the partial clay infill, but rose again in the void.

Figure 6.10 provides further evidence of the effects of the cavity on the drilling variables. The cavity is plainly visible as a near horizontal head displacement trace some 2 minutes into the record. This is accompanied by the previously noted responses in the thrust and rotary speed. Equally significant, the inlet water pressure responded in a manner indicative of the partially infilled nature of the void. When the bit first entered the cavity, the water pressure rose. As the reader will recall from the laboratory trials, this was a characteristic response to clay infill. Almost immediately following this rise, the water pressure dropped and remained below the pre-cavity levels. Previous experience has demonstrated that this response was indicative of an open conductive cavity. During this period, it was noted that water was discharging from the gallery wall. When the barrel was pulled, a small clay plug was recovered in the core.

6.5.8 Drilling record 3.15

The cavity described above was encountered in Borehole 3 and is shown in Figure 6.11. The fissure signature should be recognisable at 17.25m. In particular, note the response of the rotary speed, water pressure and thrust. All show a marked disturbance when the discontinuity is encountered. The aperture in this instance is only 12cm in spite of the close proximity of boreholes 2 and 3.

Another 12cm wide fissure, not seen in the previous hole, was clearly indicated at 17.61m. This fissure was clay-filled as indicated by increased water pressure resulting from a blocked bit. Erratic torque and rotary speed values caused by snatching of the drill string in the clay zone and high frictional forces at the bit resulted from drilling without circulation. After 0.5 minutes drilling with a dry bit, the drill string stuck in the hole. Early recognition of drilling without circulation in horizontal boreholes is imperative as there is a marked tendency for stuck pipe to occur.

6.6 Detection of Discontinuities

The drilling records described in the previous section illustrated the ability of an instrumented drilling rig to locate discontinuities in the rock pillar at Corsham. Figure 6.12 shows a portion of the pillar used

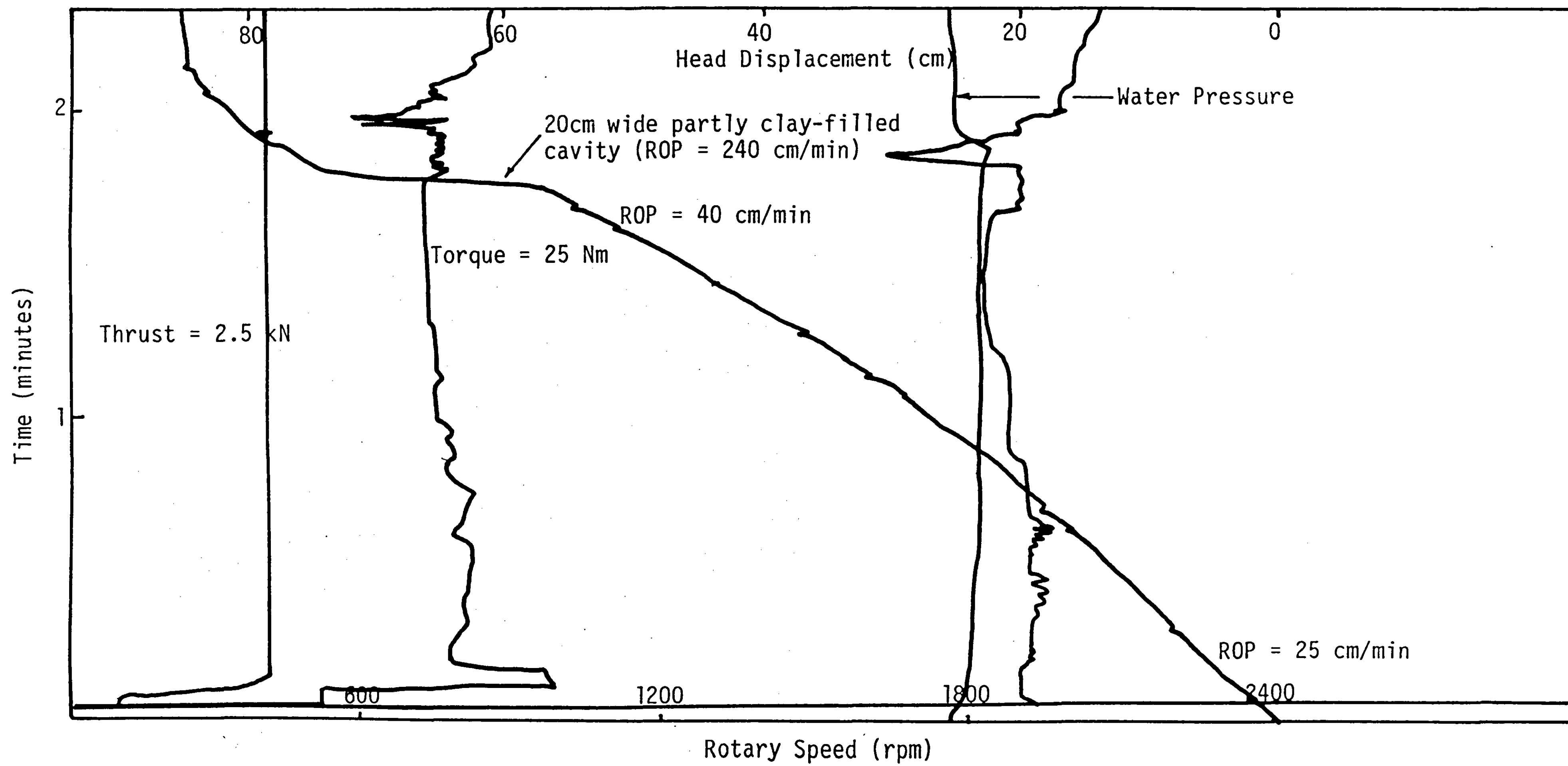


FIGURE 6.10 RECORD OF CORSHAM DRILL RUN 2.16.2 (16.66 to 17.51 metres)

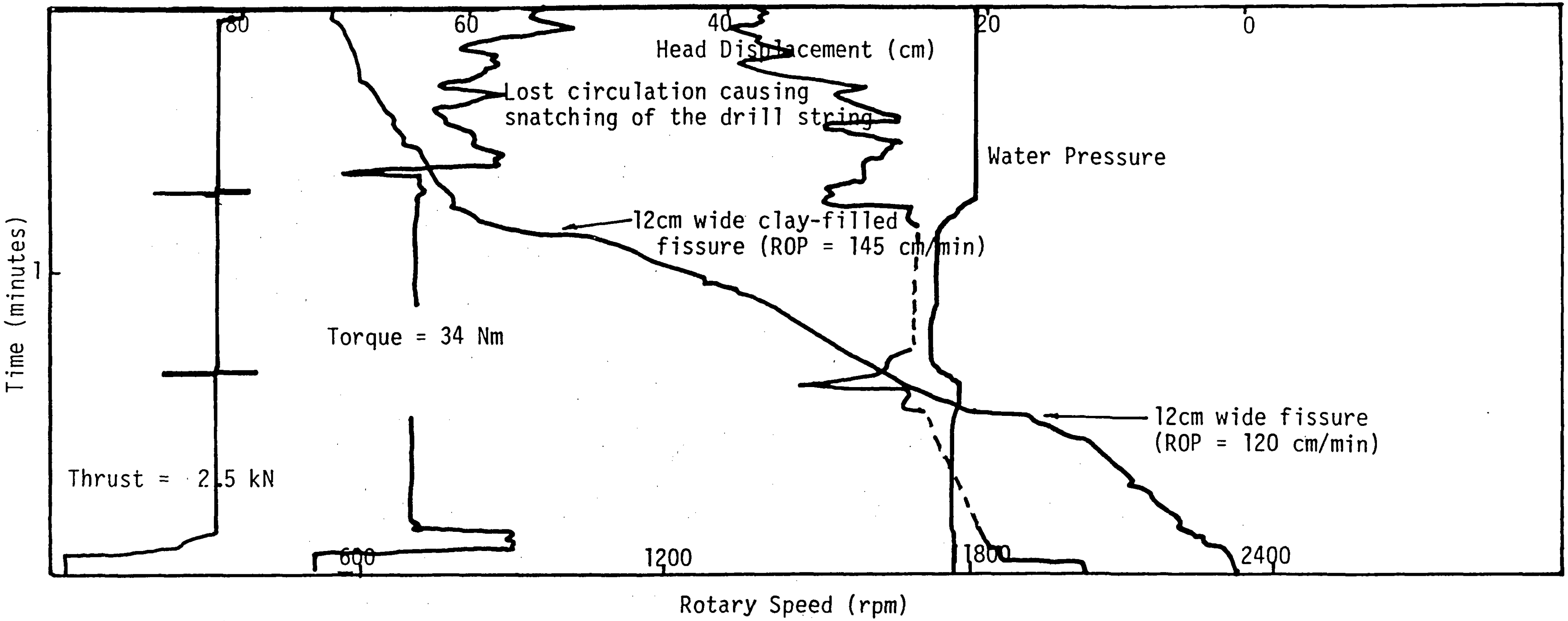


FIGURE 6.11 RECORD OF CORSHAM DRILL RUN 3.15 (17.11 to 17.80 metres)

FIGURE 6.12 THE GALLERY AT CORSHAM

for the drilling trials. At intervals along the pillar, *en echelon* surfaces are visible extending from the floor to the roof of the gallery. These represent natural release surfaces and were exploited by the miners when they were winning the stone. The whitewash on several of these surfaces has been removed, in particular in the middle of the photograph near the gallery roof. These major joints extended through the pillar and evoked a marked response in the rig instrumentation when encountered during drilling. These are persistent features, it being possible to trace them across the roof and on the opposite wall of the gallery. Also, water conducting joints are visible to the right of the power pack (light brown stains on the wall).

Figure 6.13 plots the joints exposed along the gallery wall. On average, there was a major joint every 1½ to 2m along the pillar, except for a central zone from 9.5 to 16.5m where no joints existed.

When other discontinuities were considered, a distinctive pattern emerged. Figure 6.14 plots the poles of discontinuities logged in the gallery. These features fall into three distinct classes, namely:

1. The major joints trending normal to the borehole axis at approximately 246° azimuth and 87° dip.
2. Another family of joints at approximately right angles to the former orientated at 340° azimuth and 75° dip (some planar surfaces were saw cuts while others were natural features).
3. Bedding planes dipping locally 20° towards the south at 193° (visible in Figure 6.1).

6.6.1 Discontinuity logging techniques

Various fracture logging techniques were employed at Corsham including

1. Analysis of strip chart and computer-processed drilling data.
2. Borehole television logging employing a Rees 60 camera as described by West[302].
3. Impression packer logging as outlined by Barr and Hocking[99].

The use of the drilling records to locate discontinuities has been discussed in detail in Section 5.6.6 and requires no further explanation. Suffice to say that little difficulty was experienced in locating fissures trending normal or thereabouts to the borehole. As for inclined fissures, there were occasions when the drilling data suggested their presence but without corroborative evidence from other sources, no foolproof criteria existed upon which to base a judgement.

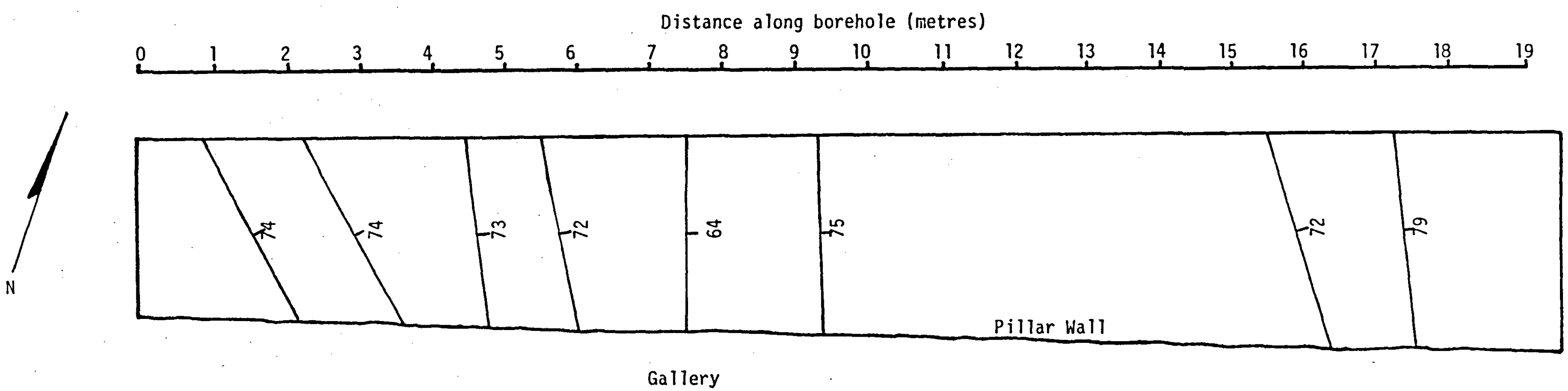


FIGURE 6.13 MAJOR DISCONTINUITIES IN THE UNDERGROUND GALLERY AT CORSHAM

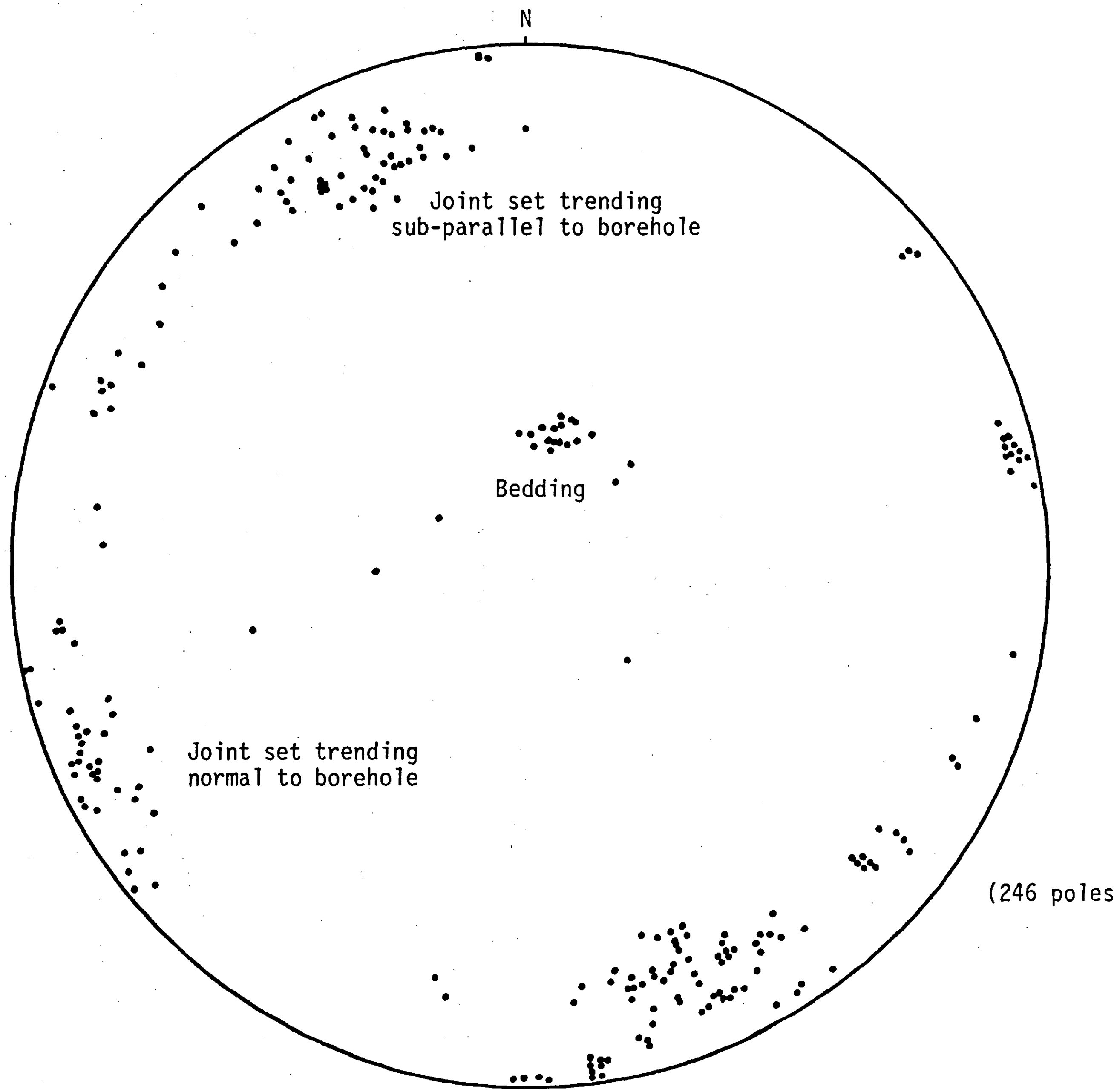


FIGURE 6.14 STRUCTURAL DISCONTINUITIES IN THE PILLAR AT CORSHAM

6.6.2 Detection of fissures using drilling records

Table 6.1 lists the discontinuities inferred from the recorded drilling variables in boreholes 2 and 3. Estimated apertures are given also, although it must be understood that these values are probably overestimated. Considering that the boreholes are located at the same height and separated by only 20cm, agreement between the two records was understandably good. This was true especially for the larger features where it was possible to detect the same discontinuity in both boreholes. While the existence of certain fissures could be disputed between observers, the overall result was an accurate record of fissure distribution in the pillar.

6.6.3 Borehole television logging

Borehole 2 was logged with the Rees 60 closed circuit television camera described in the previous chapter. The control unit, the monitor and the recorder were set up at the downhole end of the bore. A surveyor's measuring tape was attached to the camera which was then advanced down the borehole using drain rods. Still photographs were taken of the monitor screen as required, and the passage down the hole was recorded on videotape. Runs were made with the camera looking forwards, then the side-scanning head was fitted and particular sections of the borehole wall were examined. Fracture locations were recorded according to depth, fracture inclination, aperture and infill.

6.6.4 Borehole impression packer logging

In addition to logging borehole 2 with the television camera, approximately 8m of Borehole 3 was logged using an N-size impression packer. Because of the packer size, it was necessary to ream the hole to accommodate the logging tool (due to shortage of stabilisers, reaming operations were suspended at 8.5m depth because of severe vibration of the drill string).

A pneumatically inflatable rubber packer forms the basis of this simple borehole tool. The central packer is plugged by stoppers screwed to receive end guides to centralise the instrument in the borehole and accept airline terminations. Overlying the internal packer were two metal shells suitably curved to conform to the radius of the borehole. These shells were backed by a resilient foam material which was in turn wrapped with a thermoplastic film known as Parafilm 'M'. When the packer was inflated, the stainless steel shells were forced onto the borehole walls and the rubber lining with the thermoplastic film forced into any irregularities which existed on the wall of the borehole. After a short period of time,

TABLE 6.1: DETECTION OF DISCONTINUITIES AT CORSHAM USING THE INSTRUMENTED DRILLING RIG

BOREHOLE 2

File	Depth (m)	Aperture (mm)
2.1.1	0.05	31
2.1.2	0.11	49
	0.21	-
2.2	1.07*	-
	1.36*	11
2.3	-	-
2.4.1	2.38	49
2.4.2	3.00	18
2.5	4.13	8
2.6.1	4.55	5
2.6.2	4.58	23
	4.73	54
2.7.1	5.40	32
	5.74	-
2.7.2	6.50	13
2.8	7.07	8
	7.11	8
2.9	-	-
2.10.1	8.50	37
2.10.2	8.83	54
	9.06*	3
	9.27	18
2.11.1	9.72	48

BOREHOLE 3

File	Depth (m)	Aperture (mm)
3.1	0.03	-
	0.20	
3.2.1	1.32	10
3.2.2	1.71*	4
3.3.1	2.38	47
	2.71	42
	3.00	24
3.3.2	3.10*	-
	3.18	5
	3.31	10
	3.37*	4
3.4.1	3.43*	-
	4.12	7
3.4.2	-	-
3.4.3	4.56	70
3.5	4.86	10
	5.36	-
	5.40	20
3.6.1	6.06	5
3.6.2	6.32	5
3.7	6.41	7
	6.54	34
3.8.1	7.42	3
3.8.2	No record	
3.8.3	-	-

BOREHOLE 2			BOREHOLE 3		
File	Depth (mm)	Aperture (mm)	File	Depth (m)	Aperture (mm)
2.11.2	-	-			
			3.8.4	8.56	22
2.12.1	-	-	3.9	9.20	94
2.12.2	-	-		9.41	-
				9.60	17
2.13.1	11.68*	3	3.10.1	-	-
2.13.2	-	-	3.10.2	10.55*	5
2.13.3	-	-	3.11.1	-	-
2.14.1	13.98*	3	3.11.2	-	-
	14.03*	3			
			3.12.1	11.90	35
2.14.2	-	-			
			3.12.2	-	-
2.14.3	15.34	8			
			3.12.3	13.57	47
2.15.1	15.50	13			
	15.92*	-	3.12.4	-	-
	15.96	-			
	16.27	-	3.13.1	-	-
2.15.2	16.62	5	3.13.2	15.68	11
2.16.1	-	-	3.14.1	-	-
2.16.2	17.07*	3	3.14.2	16.69	6
	17.24	220		16.90	7
2.16.3	17.54	15	3.15	17.29	198
	17.68	20		17.61	108
	17.71	-			
			3.16	17.85	34
2.17.1	18.29	-		18.15	98
	18.57	6			
			3.17.1	-	-
2.17.2	-	-			
			3.17.2	-	-

the packer was vented, the plates being mechanically retracted, and the instrument was removed from the borehole.

The action of forcing the resilient foam against the borehole wall allowed the foam to deform and partially intrude into fissures, vugs and other borehole irregularities. This penetration into voids resulted in the deformation of the thermoplastic film, producing an accurate representation of the particular void or fissure.

Orientation of the structures was accomplished simply by using the top of the borehole as datum and overlapping successive impressions of the borehole wall, thereby producing a continuous record of geological structure.

6.6.5 Comparison of fissure logging techniques

The borehole television log, compiled as described above, is shown in Figure 6.15(a). Three kinds of feature were distinguished: minor joints, major joints and cavities. These are shown on the log together with joints that could only be seen in part of the borehole wall. Minor joints were recorded when the television image was a thin white line around the borehole wall, major joints were recorded when the television image was a thick white line, or when a definite joint aperture could be seen, and cavities were recorded when a large void could be seen.

West[26] reported that from the television log a joint spacing log was derived which showed the mean joint spacing and the number of joints per metre for each metre of the borehole. The mean joint spacing was seen to vary from 200mm to over 1m, thus falling into the joint spacing categories of 'wide' (200 to 600mm) and 'very wide' (600mm to 2m) of the classification system of the Geological Society Engineering Group Working Party[12] . There is a section of the borehole in which there are no joints for almost 5m.

If minor joints are disregarded, it can be seen that there are only 10 major joints and cavities along the whole 19m length of borehole, giving an overall mean joint spacing of almost 2m and that the length of borehole without joints rises to almost 8m. These values are consistent with the fact that the galleries in the underground workings are mostly unsupported over wide spans.

The other logging methods show good agreement with the television survey. Bearing in mind that fracture records (a) and (b) represent Borehole 2, while records (c) and (d) correspond to Borehole 3, all major structural features are represented. Slight variations in position occur one hole

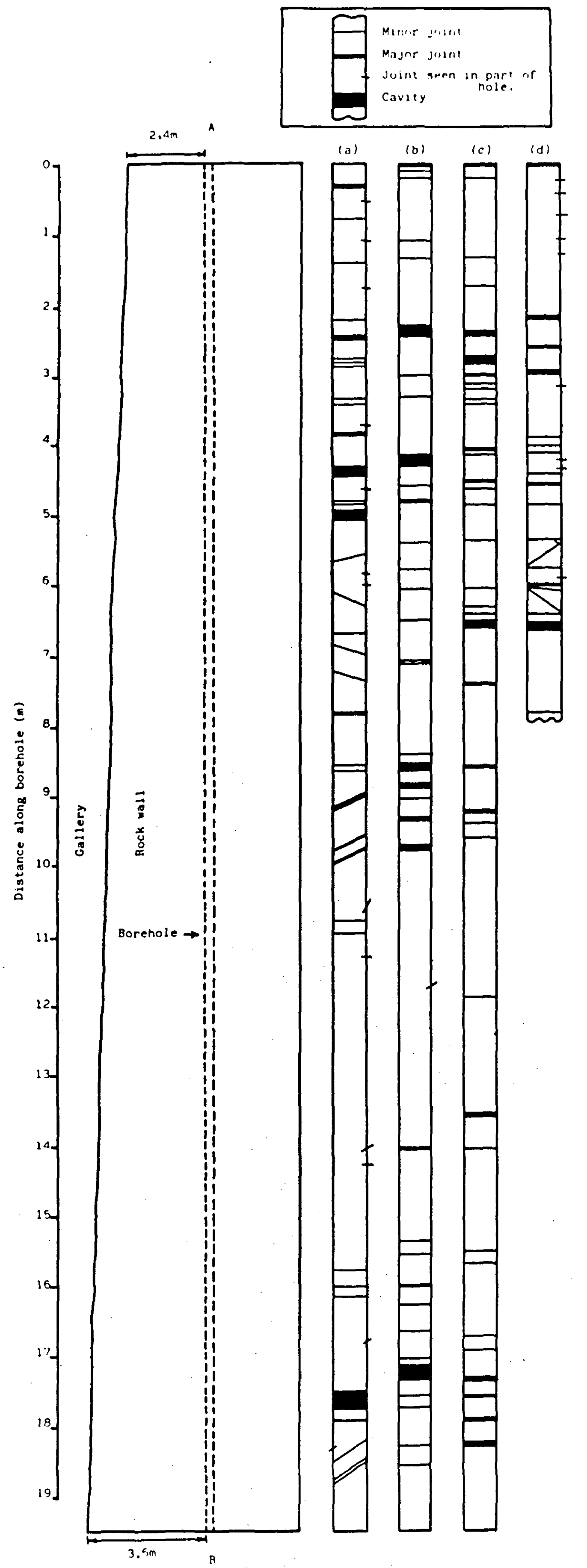


FIGURE 6.15 FRACTURE LOG FOR CORSHAM BOREHOLE 2: a) TV camera and b) drill record and CORSHAM BOREHOLE 3: c) drill record and d) impression packer

to another because of irregularity of the discontinuities, sampling error in the drill record and variations in depth measurement between techniques. Also it is difficult to decide when variation in drilling parameters represents a highly inclined fissure or changing intact rock properties. Nevertheless, analysis of recorded drilling data provided useful information on fissure distribution, approximate aperture and infill.

6.7 Estimation of Rock Strength

In Section 5.6.7 of the previous chapter, two techniques for back-calculating rock strength from drilling parameters were assessed using laboratory derived data, albeit with limited success. Nevertheless, a series of strength determination drilling runs were conducted at Corsham during the course of the underground trials to assess the applicability of these techniques for routine site investigation purposes.

6.7.1 Paone and Bruce Method

Using equations 5.2 and 5.3, data from a representative drilling test were selected from Table 6.2 for analysis according to the method outlined in Chapter 5. Three samples from data file C2.13.1 were chosen to assess the predictive capability of the technique; namely those beginning at 28102946, 28103042 and 28103142. These samples represented drilled intervals of 0.09, 0.19 and 0.17 metres respectively. Back-calculated versus measured rock strengths (see Table 6.3) were as follows:

Time	Depth Interval (m)	Strength (MN/m^2)		
		Predicted		Measured
28102946	11.73 - 11.83	1.19	2.19†	12.6*
28103042	11.87 - 12.07	0.42	1.40	12.1
28103142	12.14 - 12.31	-0.25	0.76	17.4

† Values in this column are derived from equation (5.3)

* Averaged measured values over the drilled interval

As in Chapter 5, the TT56 bit constants were $r = 0.0254m$ and $A = 8.37 \times 10^{-4} m^2$ with an assumed value for $\mu = 0.4$. The calculated strength values were, at least, an order of magnitude too low using equation 5.2 and only marginally improved using the condensed formula. One feature of note

TABLE 6.2: DRILLING STRENGTH TEST DATA FROM BOREHOLES 2 AND 3 AT CORSHAM

File	Time	Number of intervals	Distance Drilled (m)	Rate of Penetration (cm/min)	Rotary Speed (rpm)	Torque (Nm)	Thrust (kN)
C2.9	27151836	12	0.115	15.9	1485	27.2	1.45
	27151924	13	0.186	22.9	1446	31.8	2.46
	27152036	9	0.154	28.5	1488	26.9	3.31
	27152120	6	0.030	8.9	1467	29.4	2.03*
	27152144	6	0.066	19.5	1474	28.5	4.27*
C2.13.1	28102858	10	0.019	3.3	1491	26.5	0.14*
	28102946	11	0.096	14.5	1473	28.7	1.29
	28103042	13	0.193	23.7	1450	31.4	2.20
	28103142	8	0.172	37.0	1506	24.8	3.27
	28103218	6	0.083	25.7	1482	27.6	2.27
	28103246	5	0.040	15.7	1506	24.8	2.22*
C3.4.1	4102318	10	0.063	9.0	1470	23.6	1.33
	4102402	10	0.123	20.6	1497	22.0	2.50
	4102446	12	0.204	27.9	1504	21.2	3.43
	4102538	8	0.140	29.7	1516	19.7	4.35*
	4102610	6	0.117	34.0	1480	24.1	4.27*
C3.4.3	4102928	6	0.088	26.4	1510	27.8	2.98
C3.6.1	4111632	11	0.034	5.2	1496	35.0	0.85
	4111720	5	0.015	5.4	1492	35.4	1.17
	4111740	12	0.078	10.3	1524	32.0	2.14
	4111832	5	0.050	19.1	1531	31.5	2.98*
	4111852	9	0.121	22.3	1523	33.1	3.11*
	4111932	6	0.135	40.2	1536	30.8	4.19
	4112008	5	0.127	48.2	1509	33.6	5.18
C3.8.1	4152650	12	0.078	10.5	1500	-	0.19*
	4152742	12	0.112	15.3	1493	-	1.38*
	4152838	13	0.162	20.0	1481	-	2.47
	4152934	9	0.188	34.6	1519	-	2.47
	4153010	6	0.158	45.7	1512	-	4.47

File	Time	Number of Intervals	Distance Drilled	Rate of Penetration (cm/min)	Rotary Speed	Torque (Nm)	Thrust (kN)
C3.8.4	4154824	15	0.054	4.9	1472	31.6	0.26*
	4154928	8	0.037	8.1	1516	26.2	1.17
	4155004	8	0.085	18.4	1508	27.1	2.14
	4155040	7	0.199	30.8	1493	28.8	3.06†
	4155120	11	0.250	37.2	1497	27.7	4.22
C3.12.2	5105224	7	0.036	9.1	1470	28.5	0.48*
	5105256	10	0.086	14.4	1488	26.2	1.87
	5105344	10	0.155	25.6	1506	24.3	3.12
	5105436	7	0.151	37.1	1481	27.2	3.82
	5105508	6	0.156	47.2	1497	25.3	4.87
C3.13.1	5112248	8	0.046	10.0	1486	32.6	0.34*
	5112324	11	0.111	16.7	1495	31.1	1.67
	5112412	9	0.119	22.3	1499	27.8	2.44
	5112452	7	0.125	30.8	1463	31.4	3.59
	5112532	10	0.211	36.0	1520	25.9	4.72*

* Spurious value -- not used in calculations

† Effect of a fissure eliminated from data

TABLE 6.3: UNCONFINED COMPRESSIVE STRENGTH OF BATH LIMESTONE VERSUS DEPTH IN BOREHOLE 3 AT CORSHAM

Sample	Depth (m)	Strength (MPa)	Sample	Depth (m)	Strength (MPa)	Sample	Depth (m)	Strength (MPa)
1	0.48	14.1	41*	8.05	18.6	81*	16.97	20.6
2*	0.57	24.4	42	8.14	21.1	82	17.13	9.2
3	0.66	14.1	43*	8.29	25.0	83*	17.62	17.9
4*	0.75	21.7	44	8.38		84	17.72	11.6
5	0.84	10.3	45*	8.47	68.6	85*	17.82	21.9
6*	0.96	19.2	46	8.61		86	18.08	22.8
7	1.05	15.0	47*	8.74	18.6	87*	18.17	26.7
8*	1.14	33.8	48	8.83		88	18.28	30.8
9	1.46	11.2	49*	8.99	24.2	89*	18.37	21.1
10*	1.55	24.6	50	9.56		90	18.46	22.8
11	1.71	12.1	51*	9.77	80.9	91*	18.55	19.9
12*	1.80	49.3	52	9.88		92	18.65	-
13	1.94	10.7	53*	10.08	23.1	93*	18.73	25.4
14	2.03	11.6	54	10.22		94	18.83	25.8
15	2.23	13.5	55*	10.31	36.4	95*	19.00	21.5
16*	2.81	29.9	56	10.40	12.5			
17	2.94	18.6	57*	10.49	58.8			
18*	3.44	33.0	58	10.58	10.1			
19	3.54	13.2	59*	10.67	21.7			
20*	3.62	25.0	60	10.76	9.5			
21	3.72	21.3	61	11.00	14.1			
22*	3.81	26.4	62*	11.20	15.7			
23	3.90	11.9	63	11.30	9.7			
24*	4.05	36.6	64	11.39	9.5			
25	4.47	8.2	65	11.48	10.6			
26	4.65	7.9	66	11.70	12.5			
27	4.80	13.4	67	11.85	12.7			
28	4.98	-	68	12.12	12.1			
29	5.07	20.1	69*	12.21	21.4			
30	5.37	13.4	70	12.30	13.3			
31	5.62	-	71*	12.39	30.5			
32	5.71	16.8	72	12.48	16.5			
33	5.80	18.6	73*	12.63	25.2			
34	6.68	11.1	74	12.90	-			
35*	6.90	24.5	75*	13.41	46.9			
36	7.04	21.2	76	13.81	12.8			
37*	7.13	32.0	77*	13.96	28.8			
38	7.21	17.6	78	14.18	11.0			
39*	7.39	17.1	79	14.27	-			
40	7.49	10.3	80	14.36	49.2			

*Water saturated sample

concerned the predicted values being lower in this instance compared with the laboratory trials. This could be attributable to the Bath limestone's tendency to disintegrate partially through plucking of ooliths from the weak calcite cement rather than relying solely upon diamond abrasion. The enhanced rate of penetration which results being interpreted by the formulae as weaker rock than actually exists. However, further speculation along these lines was not warranted by the poor quality of the strength predictions. As in the case of the TRRL trials, the Paone and Bruce Analysis failed to predict rock strength from recorded drilling parameters.

6.7.2 Tsoutrelis analysis

During the course of drilling the boreholes at Corsham, eight coring runs were made with the rotary speed held constant at approximately 1500 rpm whilst the thrust was maintained at various selected levels in order to record the resulting rate of penetration. The results of these tests are given in Table 6.2.

For each of the strength determination drilling runs, plots of penetration rate versus thrust were compiled to filter out spurious data based on the established linear relationship which existed between these two drilling variables under constant rotary speed conditions. Conscious of the risk of introducing bias at this stage of the data preparation, the author asked Mr. J. Peak (Cambridge University) to view these initial plots since he had no knowledge of the objectives of the drilling trials. He was instructed to isolate spurious data based on the linear nature of R-F plots and the upper and lower restrictions which applied to thrust levels during rotary diamond drilling. Based largely upon his recommendations, the data points listed in Table 6.2 were selected for least squares line fitting.

In most instances, data points were rejected because they resulted from insufficient or excessive thrust. As a result, the data points departed from the linear trends established over the normal operating range for the drilling rig. Examples of spurious data caused by working at the extreme operating limits of the drill are shown in Figure 6.16. Drilling run C3.12.2 was linear except for point (49, 9.1) which was discounted in subsequent analysis. Run C2.13.1 had two points rejected at (14, 3.3) and (224, 16). Drilling at too low levels of thrust was common during these strength determination runs because the thrust gauge on the driller's control console was inaccurate below 250 kg. Another feature of drilling at lower thrust levels concerned the depth interval over which readings were recorded. Normally, the driller gauged the time at a particular drill setting by listening to the data transfer

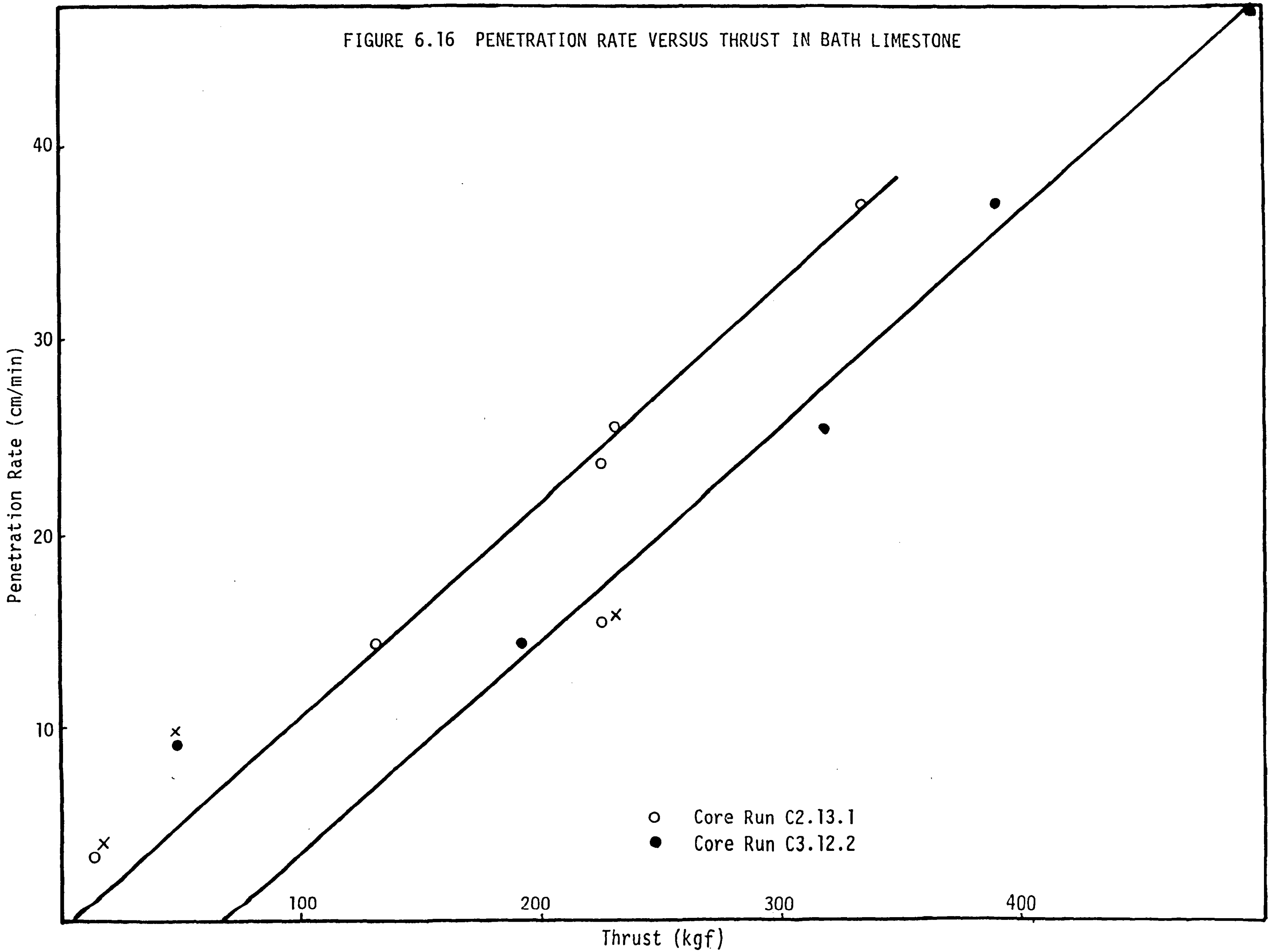


FIGURE 6.16 PENETRATION RATE VERSUS THRUST IN BATH LIMESTONE

to the tape punch until approximately one minute had elapsed before changing the drill setting. In retrospect, a minimum depth limit might have been a better basis for deciding when to change thrust levels since most of the rejected data points involved very short drilling runs.

The next step in the procedure for back-calculation of strength involved fitting straight lines to the data sets to obtain slope values, k in the Tsoutrelis analysis. These values were divided by the average rotary speed which obtained during the drilled intervals for the data points used in the analysis to yield k_o values. In addition, z values were determined for each run by averaging the measured strength values of the rock samples obtained over the total drilled interval of the strength determination run.

These values were plotted as shown in Figure 6.17 in order to derive the relationship between k_o and z for the range of rock types depicted. The values obtained for the natural rock blocks drilled at the TRRL were also included in an attempt to extend the strength range under consideration.

Whilst the Bath limestone data, with the exception of run C2.9, proved to be distributed linearly, the natural rock blocks fell into essentially two distinct groups. In keeping with the apparent linear trend in the Corsham data, a straight line was fitted to the data using points 1, 7, 3.8.1 and 3.8.4 yielding the relationship.

$$k_o = 1.74 \times 10^{-5} + 1.033 \times 10^{-5} z \qquad (6.1)$$

with $r^2 = 0.99$. Substituting σ_c for z gives

$$\sigma_c = \frac{103.3}{k_o - 1.74} \qquad (6.2)$$

Table 6.4 lists the back-calculated strengths for the rock types shown in Figure 6.17.

The accuracy of strength prediction varied. In general, unconfined compressive strengths for the Bath limestone were estimated to within ±5% of the measured value. The one notable exception was drilling run C2.9 which was over-estimated by some 85%. However, the initial k value for this data set had to be determined from only three thrust-penetration rate couplets. Comparison with other samples of Bath limestone in the same strength range (i.e. C3.8.1) indicated that the k value was anomalously low. It was reasonable to assume that the C2.9 sample was unrepresentative of the Great Oolite.

Only two of the strength estimates for the natural rock blocks drilled at the TRRL were accurate, those being Lindley sandstone and Kielder limestone. The remainder suffered from gross inaccuracies resulting from a number of contributory sources. Estimates for the higher strength rocks were increasingly

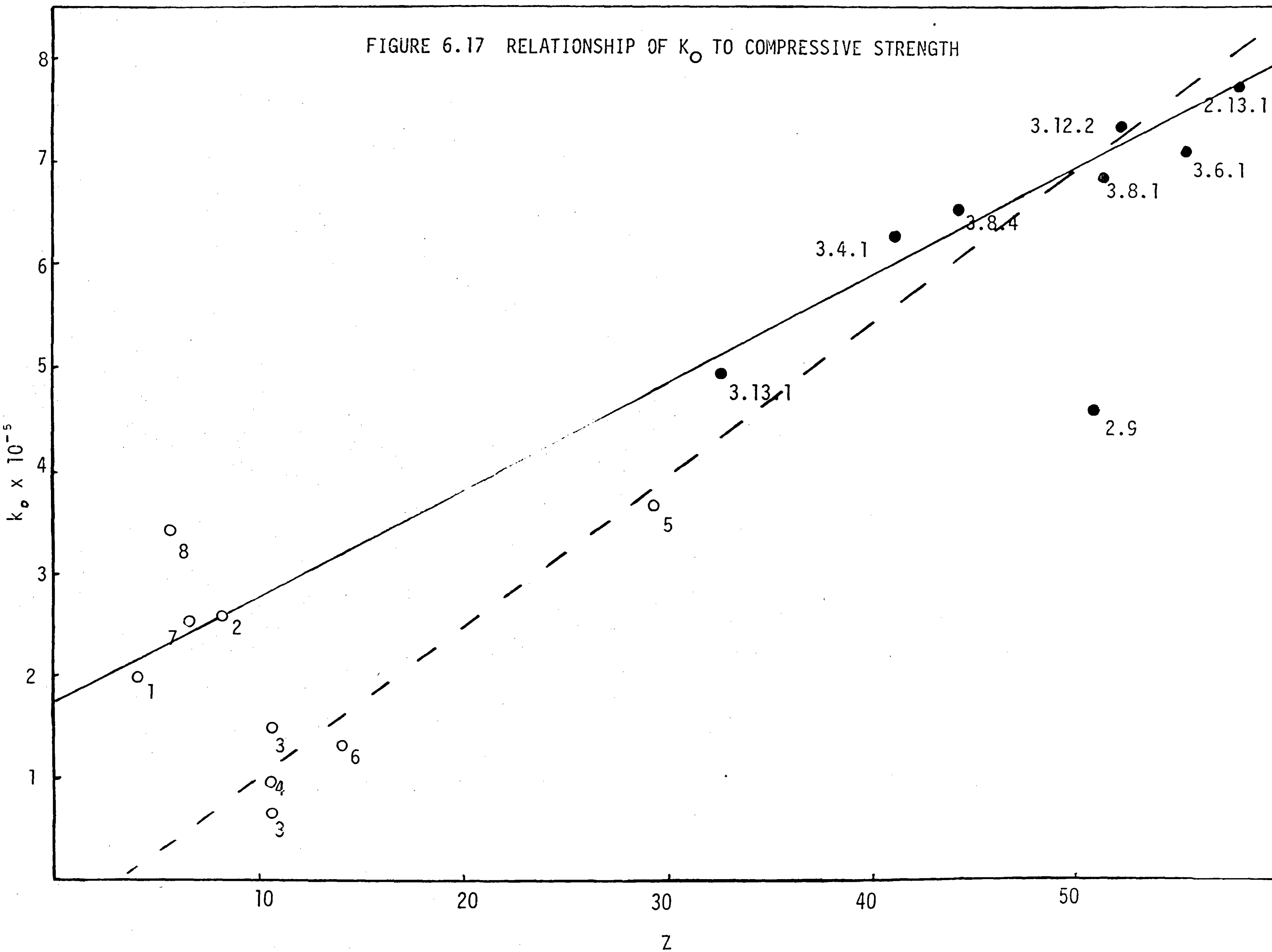


FIGURE 6.17 RELATIONSHIP OF K_O TO COMPRESSIVE STRENGTH

TABLE 6.4: BACK-CALCULATED STRENGTH VALUES USING THE TSOUTRELIS METHOD

Ref. No.	Rock Type	k	N rpm	k_o ($x10^{-5}$)	Rock Strength (MN/m^2)	
					Measured	Calculated
1	Whin sill dolerite*	0.0289	1487	1.95	239	492
2	Lindley sandstone	0.0397	1523	2.61	119	119
3	Merivale granite	0.0225 0.0097	1494 1495	1.51 0.65	92	-
4	Carboniferous limestone	0.0142	1482	0.96	93	-
5	Gregory sandstone	0.0544	1483	3.67	34	54
6	Shap granite	0.0202	1512	1.34	70	-
7	Kielder limestone	0.0384	1500	2.56	148	126
8	Kielder sandstone	0.0517	1500	3.45	177	60
2.9	Bath limestone	0.0678	1473	4.60	19.3	36.1
2.13.1	" "	0.1140	1478	7.72	17.0	17.3
3.4.1	" " †	0.941	1495	6.29	23.9	22.7
3.6.1	" "	0.1074	1511	7.10	17.7	19.3
3.8.1	" "	0.1026	1501	6.84	19.1	20.3
3.8.4	" "	0.0982	1504	6.53	22.2	21.6
3.12.2	" "	0.1098	1493	7.36	18.8	18.4
2.13.1	" "	0.0735	1486	4.95	30.1	32.1

* Based on combined data from two runs

† Includes one reading from C3.4.3

sensitive to variations in the k_o values used in the analysis. For example, in Table 6.4 the calculated strength of dolerite for $k_o = 1.95$ was 492 MN/m^2. By contrast, assumed values of k_o equal to 2.00 and 1.90 resulted in calculated strengths of 398 and 646 MN/m^2 respectively. Similar variations in k_o value for the Bath limestone had negligible effect on the calculated strength value, normally less than ± 1% in contrast to 20 to 30% for the rock blocks.

Another obvious sources of error concerned the Gregory sandstone. The k value for the F versus R relationship was derived from three data points only. This was a recognised shortcoming with this particular block of rock but was necessitated by insufficient drilling data. Doubt must attend the validity of the derived k_o value as a result.

Three other rock types including Carboniferous limestone (4), Merivale (3) and Shap granites (6) produced negative strength estimates based on the bit constants given by equation 6.1 above. The quartz content of the granites must be singled out as a source of difficulty in obtaining uniform rates of penetration for given drilling conditions. During drilling of the granite blocks, repeated accelerations and decelerations occurred in response to varying mineralogy at the bit. In one instance, a marked acceleration in rotary speed coupled with increased rate of penetration was related to a large feldspar phenocryst in the recovered Shap granite core. Reference to Figures 5.35 to 5.40 will confirm the variability of data recovered from the granites compared with the other rock types, suggesting a strong influence of mineralogy and texture on recorded drilling performance.

A possible explanation for the Carboniferous limestone being grouped with the granites in Figure 6.17 relates to the limestone being the first block drilled in the strength determination tests. These tests were drilled using a new TT56-HM drill bit similar to that used at Corsham. The new bit may not have 'drilled itself in' during the comparatively short run in the limestone block. This meant that a minimum exposure of diamonds was available at the bit face. It is doubtful if the low abrasivity of the Carboniferous limestone would adequately dress the bit over the 1 metre run. The linear response noted in Figure 5.35 suggests that the bit remained undressed as no break of slope occurred to indicate enhanced diamond exposure leading to improved rate of penetration. On the other hand, the irregular data associated with the first Merivale granite (Figure 5.36) run could be attributed to gradual dressing of the bit since this block followed the limestone during the trials.

Finally, difficulties with the thrust which were also noted in the laboratory trials appear to be confined largely to errors in the offset value used during conversion from recorded voltages to engineering units. Although this type of error produced an incorrect y-axis intercept for the thrust versus penetration rate relationship, no error in the Tsoutrelis analysis resulted since this method relied solely upon the slope of the best fit line (k).

6.7.3 Ultrasonic velocity determination of strength

Following completion of the first borehole in the quarry at Corsham (see Section 6.3), staff from the TRRL surveyed the hole with a number of logging tools including the ultrasonic velocity tool which was used in the laboratory trials. On this occasion, an amplifier was interposed between the receiver and the oscilloscope to improve the strength of the displayed signal. This resulted in frequent recognition of shear wave, as well as compressional wave arrivals.

Logging of the borehole was achieved by advancing the tool along the length of the hole on drain rods. The location of the tool in the borehole was monitored by attaching a measuring tape midway between the transducers. Velocity measurements were made every 0.14m, since this represented the spacing between the transducers, until the entire length of the borehole was logged. A record was maintained of positions where no signal was received for correlation with fracture locations derived from various logging techniques.

Ultrasonic velocity data for borehole 1 is recorded in Figure 6.18. With the exception of a low value at location C (approximately 17.8m), and locations where no signal was detected, seismic wave velocities ranged from 2500 to 4000 m/s. Velocities determined from right cylindrical specimens cut from core obtained from this borehole (solid circles) agreed favourably with those measured by the logging tool.

West[302] has shown that the equation relating uniaxial compressive strength (C_o) to compressional wave velocity (C_p) for the oolitic limestone at Corsham takes the form

$$C_o = 1.20\, C_p^2 \qquad (6.3)$$

This relationship was used to derive the strength log presented in Figure 6.18. Also shown are the uniaxial compressive strengths of right cylinders of core (solid circles) determined by conventional testing methods. Agreement between the calculated strengths using equation 6.3 and measured values is good, some 80% of the values separated by no more than 3 MN/m^2.

Ignoring the low value at C, the strength of the oolitic limestone ranged from 8 to 20 MN/m^2. According to the Geological Society Engineering Group Working Party classification, the limestone would be considered moderately weak (5 to 12.5 MN/m^2) to moderately strong (12.5 to 50 MN/m^2).

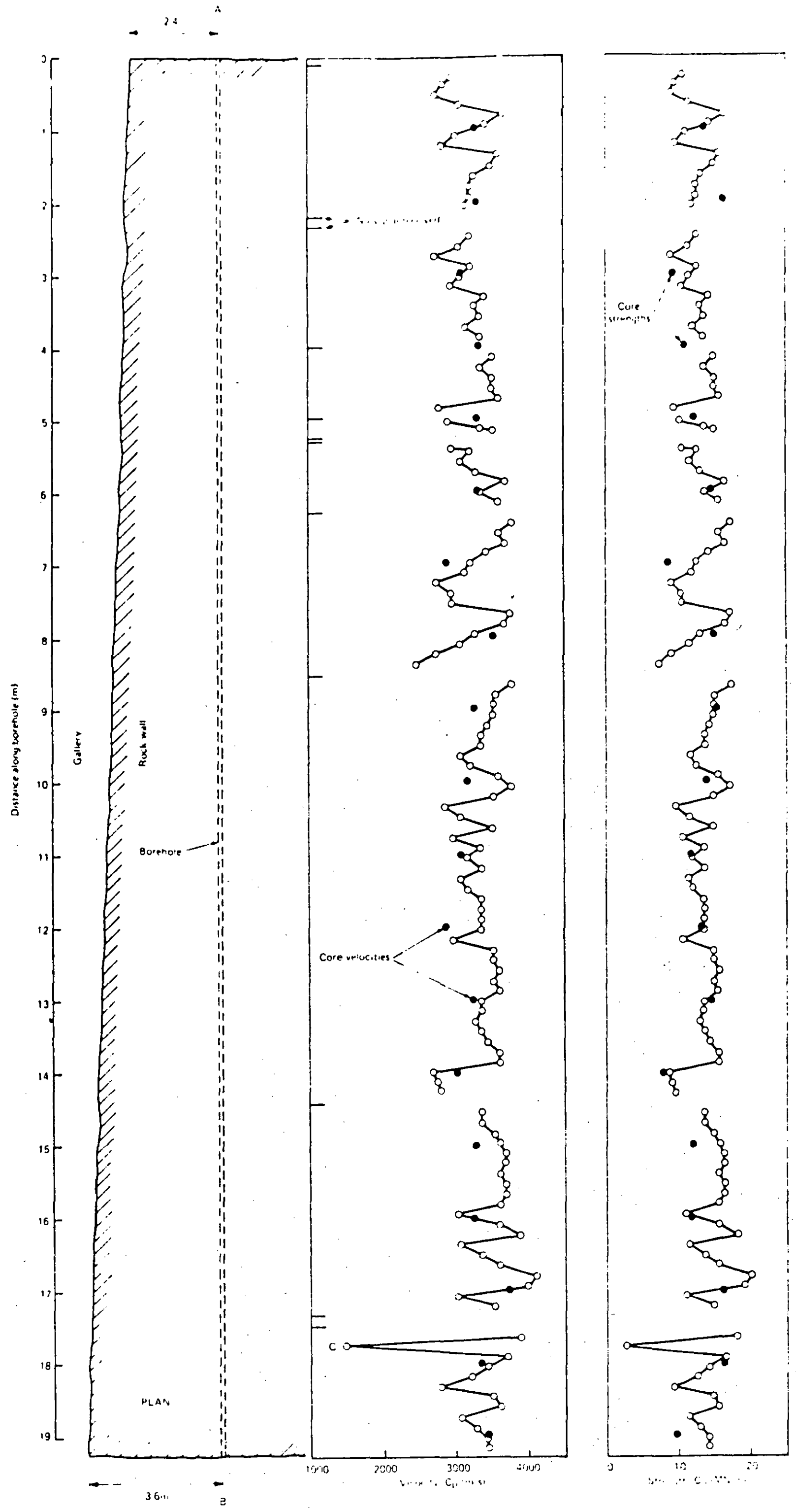


FIGURE 6.18 ULTRASONIC VELOCITY AND COMPRESSIVE STRENGTH LOGS IN THE GREAT OOLITE, CORSHAM

It is worth noting for purposes of comparison that the Tsoutrelis method also produced values which fall within the moderately strong range, albeit in an adjacent borehole.

Finally, reference to Figure 6.15 demonstrated that for those locations at which no signal was received, there was a strong correlation with discontinuities which were detected by techniques previously described. When the transducers straddled an open joint, the receiver would not register a signal since none would be transmitted across the joint.

6.8 Summary

The field trials of the instrumented drilling rig at Corsham proved generally successful bearing in mind the problem of logistics which attend investigations of this type and the relatively high incidence of equipment failure associated with prototype systems. The main objectives of the Corsham trials were achieved, namely:

1. To prove the serviceability of an instrumented drilling rig in a horizontal borehole performing under near-normal operational constraints.
2. To prove that 'signatures' of rock mass characteristics which were established in the laboratory drilling trials could be used to infer ground conditions during routine site investigations.
3. To demonstrate that the additional cost of instrumenting a drilling rig was justified by providing improved site investigation data and an economic and reliable means of probing ahead of tunnelling operations.

The implications of the laboratory and field drilling trials and recommendations for further development of instrumented drilling are discussed in the next chapter.

CHAPTER 7 - SUMMARY AND CONCLUSIONS

7.1 Summary

The principal objective of this investigation was a theoretical and experimental appraisal of the applicability of instrumented horizontal drilling to tunnelling site investigation. Knowledge of the prevailing ground conditions at the pre-tunnelling stage of construction or as a consequence of probing ahead of an advancing face would prove extremely useful to the tunnelling engineer concerned with selecting a tunnel route and design, deciding upon a method of excavation, anticipating support requirements, minimising environmental impact of the operation and ensuring safety of personnel.

Traditional tunnelling site investigation practice involving sinking of widely-spaced vertical boreholes along the proposed tunnel line has acknowledged shortcomings when the limited amount of ground information acquired is contrasted with the effort, time and money spent to obtain it. Some individuals in the tunnelling industry have argued that traditionally conceived site investigations are woefully inadequate when judged on this cost effectiveness basis. Only in the vicinity of tunnel portals where special attention is devoted to obtaining additional geotechnical data using inclined or horizontal drilling techniques can the engineer expect something other than a patchy insight into the prevailing ground conditions.

The literature records numerous case histories which illustrate the consequences of driving tunnels into unknown ground. The risks associated with this questionable practice are especially acute when mechanised excavation is involved, FFTBM's being particularly prone to encountering difficulty in unexpected rock conditions. This difficulty is aggravated by restricted access to the working face afforded by these machines which impairs the contractor's ability to respond to unstable or changing ground. While effort has been directed at improving access to the tunnel face and placing of support close to the cutting head, most tunnelling engineers would agree that prior knowledge of problematical ground offered the best solution to this problem.

A number of authorities have supported the need for improved data acquisition during pre-tunnelling site investigation and probing ahead operations. The use of drilling equipment outfitted with robust instrumentation to record drilling variables while advancing inclined and horizontal boreholes has been suggested as a means of attaining this objective. Reported experience with instrumented drilling sustained the view that routine monitoring of rotary drilling performance was a viable enterprise, although correlation of recorded values with conditions encountered downhole remained speculative and their relationship to TBM performance was problematical. For purposes of tunnelling site investigation, this study indicated that long horizontal boreholes have been drilled successfully since circa 1954.

In some instances, these boreholes were logged with a range of downhole probes to provide geotechnical data for design purposes. An extensive range of this type of equipment is available to provide the geotechnical engineer with a choice of core or open-hole drilling supplemented by borehole logging tools. In addition, technical advances in directional drilling technology requires engineers and contractors to reconsider their approach to tunnelling site investigation. The author believes that a combination of recorded drilling performance, directional drilling and borehole logging is technically feasible and represents an alternative means of addressing the demands placed upon site investigation for modern tunnelling projects. Costwise, this technique will require additional funding for site investigation. However, the expenditure will provide improved pre-tunnelling knowledge of the ground, tunnel designs suited to the prevailing ground conditions, equipment selection capable of dealing with known geological conditions along the tunnel route, safer excavation and reduced project cost.

Although the drilling of long horizontal boreholes for ground exploration by coring was an important aspect of this study, the use of rig instrumentation to predict rock conditions was of paramount interest. Many researchers have postulated that measurement of drilling variables such as rotary speed, thrust, torque, rate of penetration, bit-wear and drilling fluid hydraulics would provide a useful insight into conditions at the rock/bit interface as they respond to variations in lithology and structure. Evidence was presented supporting the expectation that monitoring of drilling variables would provide additional information on the location of discontinuities, energy requirements for rock cutting and various rock properties including strength. Results from previous instrumented drilling trials indicated that records of drilling performance would assist engineering geologists and geotechnical engineers in the interpretation of site investigation data. These early trials demonstrated that the rig performance changes in response to variations in downhole conditions. However, the correlation of the drilling rig response with downhole conditions was primarily a speculative art depending upon imagination as much as engineering skill. Hence, diagnostic criteria were required to define geological features expressed in the recorded variables if instrumented drilling was to contribute to tunnelling site investigation.

The purpose of the experimental part of this investigation was to discover useful diagnostic criteria in the laboratory and to use them to demonstrate that recorded drilling variables can define geological features encountered by the drill bit. Laboratory drilling trials were carried out using a concrete block array to model common rock mass conditions including: variations in lithology, open and infilled fissures, clay seams, highly permeable sand and gravel inclusions and broken ground. In addition, blocks of dolerite, granite, limestone and sandstone were drilled. Both the block model and the natural rock blocks were used to achieve the following objectives.

1. To provide a test facility to develop instrumentation suited to monitoring rotary drilling performance.
2. To establish techniques for drilling and collecting data from horizontally drilled boreholes.
3. To verify relationships between drilling variables for the Atlas Copco Diamec 250 drilling rig.
4. To produce a catalogue of instrument response to known drilling conditions.
5. To assess the feasibility of determining rock strength from recorded drilling parameters.
6. To provide a facility to evaluate the geotechnical data gathering capability of a number of geophysical borehole probes.

These trials were carried out at the TRRL facilities at Crowthorne, Berkshire.

A commercially available Diamec 250 rotary drilling rig was selected for instrumentation. Sensors with associated signal conditioners were installed on this unit to monitor rotary speed, thrust, torque and rate of penetration achieved at the top of the hole, flowrates and pressures associated with the drilling fluid and supply voltages to various sensors. The output from this instrumentation was sampled continuously by a multi-pen recorder and intermittently by a data logger which transferred the information to paper tape for computer analysis.

It had been intended to conduct field drilling trials in an experimental tunnel in Weardale in order to compare drilling performance with that achieved by TBM's on the nearby Keilder Water Scheme. However, deteriorating roof conditions rendered this site unsafe. Eventually, a new site was secured near Corsham, Wiltshire. The drilling rig was situated underground in a recess in a mine boundary wall from whence four 19m long boreholes were drilled in the Jurassic Bath Limestone. The recorded output from the drilling rig was used to interpret the ground conditions encountered by the drill bit using the characteristic response defined in the laboratory experiments. This interpretation was judged against structural features expressed on the walls and roof in the gallery, recovered core and information derived from borehole impression packer traces, closed circuit television and ultrasonic velocity measurements in the boreholes.

A summary of the more pertinent observations from the laboratory and field drilling trials is presented below.

7.2 EXPERIMENTAL RESULTS

Instrumentation of the Diamec 250 was relatively straightforward with the exception of torque which proved extremely difficult and never wholly satisfactory. Some problems were experienced with monitoring of the drilling fluid because pressure pulses introduced into the circulating system by the flush pump distorted the data. The most frustrating aspect of the data gathering concerned the repeated failure of the prototype signal conditioning equipment and the data logger, the latter being particularly vulnerable to ingress of moisture. Consequently, by tunnelling industry standards, an unacceptable proportion of rig time was devoted to servicing the logging equipment. The various sensors performed admirably, only being disturbed once installed to check their calibration following repairs to the supporting electronics. The electronics package incurred numerous system faults occasioned by inadequate protection against humidity, the use of an outmoded but available logging unit and over-sophistication of the signal conditioning unit. The current generation of commercially available logging equipment would eliminate these difficulties at minimal cost. Finally, the use of paper tape storage and main frame computing facilities to process drilling data was too restrictive for industry use. Fortunately, the necessity to do so has been superseded by the advent of desk top computers which allow immediate processing of recovered data. Despite these difficulties, much useful information was obtained from the drilling trials.

The linear relationship between penetration rate and thrust for constant rotary speed and between rotary speed and penetration rate for constant thrust noted by previous investigators remain valid for the substantially higher rotary speeds associated with the Diamec 250.

Changes in the value of monitored drilling variables under conditions of uniform thrust correspond with variations in the downhole conditions encountered by the drill bit. Laboratory drilling trials established characteristic responses for known drilling conditions which provided effective signatures against which field drilling data was compared to decide upon geotechnical features encountered in the borehole.

Lithological variations, drilling under constant thrust, were marked by reduced rate of penetration, lower rotary speed and higher torque when moving from weak to strong rock and vice versa.

When clay zones were encountered penetration rate and rotary speed increased while torque decreased, provided there was adequate circulation of drilling fluid. Passage of the bit into clay was accompanied normally by a rise in water pressure. Alternatively, with poor circulation, the penetration rate increased initially before falling to a lower value. The rotary speed increased but snatches occurred when the bit was blocked by clay. Similarly, the torque reduced initially but showed marked excursions during snatching of the drill string.

Unconsolidated sands and gravels were characterised by high rates of penetration, increased but possibly variable rotary speed and lower but possibly erratic torque readings caused by debris lodging in the annulus between the drill string and the borehole wall. Normally, returns were lost or reduced through these deposits and this was accompanied by reduced water pressure. If these thief zones are wide, borehole instability can occur. For example, washouts or sloughing can make tripping difficult.

Fissures trending normal to the drill string were readily and accurately located. Inclined fissures became progressively difficult to discern as they tended to parallel the borehole long axis. Only when inclined fissures presented a perceptible aperture to the drill bit were their presence decided with certainty.

Open fissures 'normal' to the drill string provided many diagnostic clues regarding their presence. First, there was a transient but pronounced rate of penetration increase. If the fissure was sufficiently wide, a small increase in rotary speed occurred over the void followed by an abrupt deceleration upon re-establishing contact with rock before the pre-fissure values are restored. An opposite effect occurred with the torque readings. Also, water pressure values dropped occasionally until the storage capacity of the fissure was satisfied. In fissures having large apertures, the thrust values would drop slightly as the bit travers ed the void. This was followed by a sharp increase at the opposing fissure wall before restoration of the pre-set level.

Estimates of fissure aperture were possible using successive core depth readings. The accuracy of these estimates was improved by reducing the scanning interval, encountering wider fissures and intersecting normal trending fissures.

Rate of penetration followed by thrust and rotary speed were the most informative drilling parameters for site investigation data acquisition. Drilling fluid flowrate and pressure measurements, although never wholly reliable during these trials, proved useful for detecting impervious clay zones and highly permeable open fissures, sand or gravel lenses.

Torque values provided limited quantitative information during these trials since the author lacked confidence in the readings. The strip chart recordings did provide useful qualitative data to corroborate suspected clay zones, loggy hole conditions and, in conjuction with thrust and rate of penetration, can indicate excessive bit wear.

The continuous strip chart recorder was an invaluable aid to drilling. The driller had an instantaneous record of the drilling operation at his disposal which alerted him to potentially important events which occurred downhole. This information prompted him to seek additional data to confirm or deny events of geotechnical significance rather than relying upon his ability to recall events at a later date. Equally, an engineer familiar with the drilling operation can use the chart to review the day's drilling and question the driller about events of geotechnical interest.

Prediction of rock strength from drilling parameters proved inconclusive. In these trials, strength predictions based upon Paone and Bruce's drilling theory bear no relationship to recorded drilling performance. This statement is based upon torque values which were believed accurate for the particular drill settings established during the various laboratory and field drilling trials. Strength predictions using the Tsoutrelis empirical technique proved inconclusive when applied to the concrete blocks. This was because the drilling performance was determined by the aggregate properties rather than the strength characteristics of the concrete. However, a similar analysis provided acceptable strength predictions in the Bath Limestone and, by extrapolation, in those natural rock blocks characterised by uniform mineralogy and low abrasivity.

The correlation of compressive wave velocity with uniaxial compressive strength offered promise of a rapid, if approximate, assessment of rock strength. However, the trial of the ultrasonic velocity tool was conducted in ideal borehole conditions and in rock and concrete exhibiting limited strength variations. The ability of the device to function in normal borehole environments (flooded, out of gauge and/or mudcaked) and geological situations exhibiting lithological and porosity variations remains to be established.

Successful acquisition of geotechnical data from horizontal boreholes using conventional logging tools was demonstrated using a borehole television camera, an ultrasonic velocity tool, a borehole impression packer and a range of nuclear and geophysical tools. The only concession required for their use in horizontal as opposed to vertical boreholes was the necessity to run the tools on rods rather than wireline.

Borehole inspection with the camera was successful, although it must be acknowledged that viewing conditions in all boreholes were ideal. Optical resolution would be considerably impaired by the 'opaque' conditions normally prevailing in fluid-filled boreholes. Such conditions would occur in horizontal boreholes since there would be no guarantee that they would be free draining since there is a natural tendency for the hole to drop below the level of the borehole collar.

The impression packer is not subject to 'blinding' in murky water. In fact, it performs better in a wet borehole since the parafilm releases more readily from the borehole wall. Details of fissure orientation, aperture and occasionally infilling material were more readily determined using this device, as opposed to the television camera. It was possible to distinguish score marks left on the borehole wall by the drill string as well as the textural features of the limestone from the parafilm impressions. However, both the impression packer and the television camera would ultimately require wellbore survey data to correct fissure orientations since long boreholes tend to deviate from their intended path.

The value of nuclear and geophysical borehole probes for geotechnical data aquisition remained unproven. Of the various tools tested in the concrete block array at the TRRL, only the gamma-gamma probe produced results of note. In particular, the short-spacing density log produced by this tool distinguished low density zones and open joints in the block array. The apparent failure of the other borehole probes to provide 'useful' data was difficult to reconcile with their proven capability in the coal and petroleum industries.

7.3 CONCLUSIONS

The progress of tunnelling works, particularly when driven by tunnel boring machines, remain vulnerable to unexpected variation in ground conditions. Until the disparity between the quality of ground information obtained from site investigation and that required for increasingly ambitious tunnelling projects driven by expensive plant is addressed, the industry will continue to pay an unnecessarily high cost for ignorance of the ground into which they advance. This investigation has attempted to demonstrate that instrumented horizontal drilling would improve the quality of tunnelling site investigation. Although a direct comparison of drilling rig and tunnelling machine performance was thwarted by inaccessibility to the proposed site in Weardale, a number of conclusions regarding the usefulness of instrumented horizontal diamond drilling for pre-tunnelling site investigation and probing ahead of the working face are warranted.

1. Horizontal drilling technology should be reviewed in light of the modern drill rigs and directional drilling technology available for use in tunnelling site investigation drilling. If this technology can be adapted, considerable rock mass data would be gained from along the tunnel axis and extraneous drilling from surface or unnecessary probing ahead could be greatly reduced.

2. Improved site investigation data would result from instrumented drilling rigs being used to drill long horizontal boreholes. Records of drilling performance would assist engineering geologists and geotechnical engineers to interpret and assess the results of site investigation drilling for tunnelling and other construction purposes.

3. Drilling records yield data which provide, at least, a rudimentary appreciation of fracture spacing, unstable ground, lithological variation, qualitative strength estimates and ground water conditions. This information would contribute to improved estimates of machine advance rates, support requirements, overbreak, ground treatment and other potentially costly aspects of rock tunnelling.

4. The application of horizontal drilling technology should pose no unsurmountable technical problems for an industry which developed mechanised tunnelling equipment.

5. Instrumented horizontal drilling will reduce, but not eliminate, uncertainties about ground conditions along a proposed tunnel route. Nevertheless, use of this technique will greatly increase the quantity and quality of data available to the geotechnical engineer and permit selective use of probing ahead techniques to provide more information on suspected problem areas.

7.4 RECOMMENDATIONS FOR FUTURE RESEARCH

Although instrumented drilling rigs can provide better quality site investigation data, developments in associated areas of interest would improve further the quality of data available to the tunnelling industry. The following recommendations for future research are suggested:

1. The potential benefits offered by geophysical techniques, and possibly ground probing radar, should be evaluated on an actual tunnelling project to allow comparison between predicted and encountered rock conditions. Interpretation of the geophysical data should be carried out by experienced log analysts, thus recognising that deciphering logs is a combination of art, science and experience.

2. Acquisition of structural data will continue to rely upon exploratory boreholes for the foreseeable future. Therefore, a need exists for a dependable, inexpensive borehole survey device in order to compensate for borehole deviation when mapping structural features.

3. The obscure relationships which are deemed to exist between hardness, abrasivity and machineability require clarification if reliable predictions of advance rates and cutter consumption for TBM's are to be realised. This assumes that an indirect measure of these performance characteristics can be made from rock index properties.

4. Further trials are required to establish the validity of Tsoutrelis' strength estimation technique.

5. Horizontal instrumented drilling for tunnelling site investigation must be assessed on a tunnelling project(s) to estimate whether the benefits it provides warrant the additional costs. Further laboratory or non-tunnelling field trials offers little scope for improving knowledge in this area.

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INSTRUMENTED HORIZONTAL DRILLING
FOR
TUNNELLING SITE INVESTIGATION

by

Matthew Valet Barr

A thesis submitted to the University of London (Imperial College of Science and Technology) for the Degree of Doctor of Philosophy in the Faculty of Engineering.

VOLUME 2
(APPENDICES)

June, 1984

APPENDIX I: DYNAMOMETER TRIALS

Program for dynamometer data

```
      PROGRAM TORCALC (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)
C      PROGRAM FOR THE FORMULATION OF TORQUE AND POWER CURVES FOR THE
C      DIAMEC 250 FOLLOWING DYNAMOMETER TRIALS IN MECHANICAL ENGINEERING
C
C
C
    1 N=0
      DRRPM=0.0
      DYRPM=0.0
      OP250=0.0
      OPMTR=0.0
      DLOAD=0.0
      BHP=0.0
      TORQ=0.0
      SWASH=0.0
      DESHP=0.0
      TORK1=0.0
      TORK2=0.0
C
  100 FORMAT (4F7.2)
  102 FORMAT (1H1,1X,46H   OP250    OPMTR    DRRPM    DYRPM    DLOAD    BHP,
     135H    TORQUE    DESHP    TORK1    TORK2 )
  104 FORMAT (2X,10(F7.2,1X))
  106 FORMAT (F2.1)
C
    5 READ (5,106) SWASH
   10 READ (5,100) OP250, OPMTR, DRRPM, DLOAD
C
C      SEGREGATION OF DATA DECKS
      IF(OP250.EQ.-8888.0) GOTO 1
      CONTINUE
C
C      PROGRAM TERMINATION CARD
      IF(OP250.EQ.-9999.0) GOTO 99
      CONTINUE
C
C      COUNTER FOR LINE PRINTER CONTROL
      N=N+1
C
C      CHECKS FOR DATA VALIDITY
      IF((   OP250.LT.0.0)
     1 .OR.(OP250.GT.3000.0)
     2 .OR.(OPMTR.LT.0.0)
     3 .OR.(OPMTR.GT.3000.0)
     4 .OR.(DRRPM.LT.0.0)
     5 .OR.(DRRPM.GT.2200.0)
     6 .OR.(DLOAD.LT.0.0)
     7 .OR.(DLOAD.GT.30.0)) STOP
C
C      CONVERSION OF DRILL RPM TO DYNAMOMETER RPM BASED ON 60/22 PULLEY RATIO
      DYRPM=DRRPM*60.0/22.0
C
C      CALCULATION OF BRAKE HORSEPOWER USING DYNAMOMETER CONSTANT OF 4000
      BHP=DYRPM*DLOAD/4000.0
C
C      CALCULATION OF DRILL TORQUE (FT/LB) WITH ADJUSTMENT TO COMPENSATE
C      FOR PULLEY RATIO
      TORQ=(60.0*BHP*550.0)/(22.0*DYRPM*0.1047)
C
C      ASSIGNING DISPLACEMENT VALUES BASED ON THE SWASH PLATE POSITION
      IF(SWASH.EQ.0.0) DISPL=1.030
      IF(SWASH.EQ.1.0) DISPL=1.275
      IF(SWASH.EQ.2.0) DISPL=1.520
      IF(SWASH.EQ.3.0) DISPL=1.765
      IF(SWASH.EQ.4.0) DISPL=2.010
C
      DESHP=1.275855*OPMTR/1714.0
C
C      TORK1 BASED ON HP*5252/RPM
      TORK1=DESHP*5252.0/DRRPM
C
C      TORK2 BASED ON DISPLACEMENT*OIL PRESSURE/24 PI
      TORK2=(DISPL*OPMTR)/(24.0*3.14159)
C
C      LOOP CONTROL STATEMENTS
      IF(N.EQ.1) GOTO 101
      IF(N.GT.1)GOTO 103
C
  101 WRITE (6,102)
  103 WRITE (6,104) OP250, OPMTR, DRRPM, DYRPM, DLOAD, BHP, TORQ,
     1DESHP, TORK1, TORK2
      GOTO 10
   99 STOP
      END
```

APPENDIX 1
DYNAMOMETER TRIALS

APPENDIX 2
REPORT OF TESTS OF PORTLAND CEMENT

R.H. HARRY STANGER
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File No 2247/77 Test No. 3995

APPENDIX 2

REPORT OF TESTS OF PORTLAND CEMENT

Received from yourselves on the 8th July, 1977.

The sample of cement marked "Blue Circle Cement" was tested for physical properties and chemical composition in accordance with BS 12:Part 2:1971 for ordinary Portland cement as instructed by your Order No. E5689 dated the 24th May, 1977.

MECHANICAL TESTS in accordance with British Standard 12 : Part 2 : 1971

SPECIFIC SURFACE

SPECIFICATION MINIMUM	m^2/kg
Ordinary Portland	225
Rapid Hardening	325
Portland Blast Furnace	225
Low Heat Portland	320
Sulphate Resisting	250

Specific Surface 327 m^2/kg

SETTING TIME

SPECIFICATION

Initial .. 45 minutes (minimum)

Final . 10 hours (maximum)

Initial = 110 minutes

Final = 2hrs 35mins

Standard Consistency 25.5 %

COMPRESSIVE STRENGTH

SPECIFICATION MORTAR, MN/m^2

Minimum at	3 days	7 days
Ordinary Portland	15	23
Rapid Hardening Portland	21	28
Portland Blast Furnace	15	23
Low Heat Portland	8	14
Sulphate Resisting	15	23

CONCRETE, MN/m^2

Minimum at	3 days	7 days
Ordinary Portland	8	14
Rapid Hardening Portland	12	17
Portland Blast Furnace	8	14
Low Heat Portland	5	7
Sulphate Resisting	8	14

MORTAR 3 DAYS MN/m^2	MORTAR 7 DAYS MN/m^2	CONCRETE 3 DAYS MN/m^2	CONCRETE 7 DAYS MN/m^2
42.0	53.5	21.0	32.0
41.0	53.0	20.5	32.0
40.0	52.0	20.5	31.5
41.0	53.0	20.5	32.0

Water Used in Gauging

MORTAR 10% of weight of materials
CONCRETE 0.6 water - cement ratio

SOUNDNESS

SPECIFICATION	EXPANSION	
To expand not more than 10 mm; nor more than 5 mm after 7 days' aeration if previous test fails	As received =	1 mm
	After 7 days' aeration =	mm

CHEMICAL ANALYSIS

	SPECIFICATION Max[illegible] BS 12	BS 146	[illegible]	BS 4027	Per cent
Silica (SiO_2)	—	—	—	—	20.90
Insoluble Residue	1.5	1.5	1.5	1.5	0.60
Alumina (Al_2O_3)	—	—	—	—	4.92
Ferric Oxide (Fe_2O_3)	—	—	—	—	2.00
Lime (CaO)	—	—	—	—	65.06
Magnesia (MgO)	4.0	7.0	4.0	4.0	1.06
Sulphuric Anhydride (SO_3)	—	[illegible]	—	2.5	3.12
Loss on Ignition	3.0	3.0	3.0	3.0	1.34
Undetermined	—	—	—	—	1.00
TOTAL					100.00
Alkalies: K_2O ......%					Per cent
Na_2O ......% Total as Na_2O					
Free Lime					1.24
Total Sulphur Expressed as SO_3	2.5 3.0	6.75	2.5 3.0		3.12
Sulphur present as Sulphide (S)	—	1.5	—	—	Nil
Lime Saturation Factor	Min 0.66 Max 1.02	—	—	Min 0.66 Max 1.02	0.96
Alumina - iron Ratio	Min [illegible]	—	Min 0.66	—	
Tricalcium Aluminate	—	—	—	3.5	9.7 %

3 copies to: Dept. of the Environment,
Transport & Road Research Laboratory,
Old Wokingham Road,
Crowthorne,
Berkshire. RG11 6AU

Attn: Mrs. J. Horning

Specific gravity = 3.16

The results of the physical tests comply with the requirements of BS 12:Part 2: 1971 for ordinary Portland cement. The total sulphur expressed as SO_3 content of 3.12% slightly exceeds the maximum permitted figure of 3.0. The remaining composition complies with the Specification.

N Greig

For R. H. HARRY STANGER 29.7.77:SMH

APPENDIX 3
START-UP/STOP PROCEDURE FOR DRILL RUNS

APPENDIX 3: START/STOP PROCEDURE FOR DRILLING RUNS

OPERATION OF VENTURI NOZZLES

1. Start-up

(a) Open main water supply

(b) Ensure venturi valves are closed

(c) Turn on main power supply for pump

(d) Ensure through flow exists via the by-pass and bleed valve - turn on pump

(e) Open up-stream valve of venturi

(f) Open down-stream valve

(g) Close the by-pass

(h) Regulate supply via bleed valve

(i) Open by-pass mini-valve at differential transducer

(j) Open up-stream (hp) mini-valve

(k) Open down-stream (lp) mini-valve

(l) Close by-pass mini-valve

(m) Adjust flow to obtain desired pressure

2. Shut-down

(a) Open by-pass mini-valve

(b) Shut down-stream mini-valve

(c) Shut up-stream mini-valve

(d) Open by-pass valve

(e) Close down stream valve

(f) Close upstream valve

(g) Shut down pump

MYCALEX

(a) Patchboard pins - RO

(b) Scan limit - 20

(c) Scale - Auto

(d) Scan - On

(e) Speed - Select

(f) Interval - Select

(g) Demand - Ignore

(h) Punch - On

DATA DYNAMICS PUNCH

(a) Check supply of paper tape

(b) Switch on

(c) Run out - label core run

RIKADENKI CHART RECORDER

(a) Zero pens

(b) Set attenuator voltage control at 5 volts

(c) Check ink supply

(d) Select chart speed

WEIR 423D/423 POWER SUPPLY

(a) Switch on (red buttons) simultaneously

(b) Select 0-30 setting

(c) Set voltage supply at 10 volts and check with Mycalex

HYDRAULIC POWER PACK

(a) Check oil level

(b) Mains switch-on

(c) Pump switch on (wait for switch to trip prior to drilling)

BOYLES BB 7-12 RED PUMP

(a) Mains switch-on

(b) Check that screen is submerged

(c) Ensure a through flow exists

(d) Pump should be primed if not used in last 12 hours (see manual)

(e) Switch on

APPENDIX 4
PROGRAM LISTING

APPENDIX 4

DRILLING DATA PROGRAM

```
      REAL ZERO,CRDTH,CH1,CH2,CH3,CH4,CH5,CH7,CH8,CH9,CH11,CH18,TD,HLINT
      REAL MXV,MNV,OILCV,ROV,TOV,WPOV,WFOV,MIV,MAV,IWP,THRST,PRATE,HLNXT
      INTEGER TIME,N,PTIME,K,L
      DATA ZERO/0.0/,PTIME/0/

      CALL OFFSET(MXV,MNV,OILCV,TCV,RCV,WPOV,WFOV,N,K,TD,L,MIV,MAV)

      CRDTH = ZERO

      DO 10 I=1,N

C  CALL SUBROUTINE TO READ IN DATA

      CALL READ(TIME,CH1,CH2,CH3,CH4,CH5,CH7,CH8,CH9,CH11,CH18)
      IF(CH8.EQ.ZERO) CH8 = 10.00

20    FORMAT(/'THE TIME INTERVAL IS:                 ',I8)
      WRITE(1,20)TIME
      WRITE(6,20)TIME

C  CALL SUBROUTINE TO CALCULATE DEPTH DRILLED AND PENETRATION R ATE

      IF(I.EQ.1)GOTO 30
      CALL CDEPTH(CRDTH,TIME,MXV,PTIME,CH1,PRATE,MNV,TD,HLINT,HLNXT)
      GOTO 40
30    HLINT = ((CH1-MNV)/(MXV-MNV))*0.85

C  CALL SUBROUTINE TO CALCULATE THE INLET OIL PRESSURE

40    CALL IOILP(CH2,ZERO,OILCV,CH8)

C  CALL SUBROUTINE TO CALCULATE THRUST

      CALL THRUST(CH7,CH8,TOV,K,THRST)

C  CALCULATE ROTARY SPEED

      CALL RTASPD(ZERO,RCV,CH9,CH3,L,RTSP)

C  CALCULATE INLET WATER PRESSURE

      CALL IWATRP(WPOV,CH8,CH18,IWP)

C  CALCULATE INLET WATER FLOW

      CALL IWATRF(WFOV,CH4,CH8)

C  CALCULATE TORQUE

      CALL TORQUE(CH11,CH3,MIV,MAV,ZERO,RTSP)
```

GLOSSARY OF PROGRAM NAMES

NAME	TYPE	DESCRIPTION
CH1	Real	Channel 1 of input data
CH2	Real	" 2 " " "
CH3	Real	" 3 " " "
CH4	Real	" 4 " " "
CH5	Real	" 5 " " "
CH7	Real	" 7 " " "
CH8	Real	" 8 " " "
CH9	Real	" 9 " " "
CH11	Real	" 11 " " "
CH18	Real	" 18 " " "
CRDTH	Real	Core depth (metres)
CV	Real	Corrected voltage for inlet oil pressure
CVCH11	Real	Corrected voltage for torque
DLINT	Real	Drilled interval
HLINT	Real	Previous depth of drill bit in rig
HLMXT	Real	Present depth of drill bit in rig
IOP	Real	Inlet oil pressure (MN/metres^2)
IWF	Real	Inlet water flow (litres/minute)
IWP	Real	Inlet water pressure (kN/metres^2)
K	integer	The number of the required thrust relationship
L	integer	The number of the required rotary speed relationship
LY	Real	$Logarithm_{10}$ of Y
MAV	Real	Maximum voltage for swash plate ratio
MJV	Real	Minimum voltage for swash plate ratio
MNV	Real	Minimum value for depth calibration factor
MXV	Real	Maximum value for depth calibration factor
N	integer	Number of time intervals
N1	integer	Integer value of channel 1 in input data
N2	integer	" " " 2 " "
N3	integer	" " " 3 " "
N4	integer	" " " 4 " "
N5	integer	" " " 5 " "
N7	integer	" " " 7 " "
N8	integer	" " " 8 " "
N9	integer	" " " 9 " "
N11	integer	" " " 11 " "
N18	integer	" " " 18 " "

NAME	TYPE	DESCRIPTION
OILOV	Real	Offset voltage for inlet oil pressure
PDEPTH	Real	Depth at end of previous time interval
PRATE	Real	Penetration rate (cm/minute)
PTIME	integer	Time of previous time interval
ROV	Real	Offset value for rotary speed
RPM	Real	Revs/min of a time interval
RTSP	Real	Rotary speed (rpm)
SPR	Real	Swash plate ratio
TCV	Real	Corrected voltage for thrust
TD	Real	Total depth (metres)
THRST	Real	Thrust (Kn)
TIME	integer	Time (seconds)
TMINT	Real	Time interval in seconds
TOV	Real	Offset value for thrust
TRQ	Real	Torque (Nm)
WFOV	Real	Offset value for inlet water flow
WPOV	Real	Offset value for inlet water pressure
X	Real	Intermediate stage in calculation of thrust
Y	Real	Initial step in calculation of inlet water flow
ZERO	Real	Constant value of ϕ.ϕ

```
      PRINT LIST OF RESULTS

      CALL LIST(TD,FRATE,RTSP,THRST,IWP)

C     PLOT GRAPH

C     CALL PLOT(CRDTH,TRQ,IWP,FRATE,THRST,RTSP)

10    CONTINUE
      STOP
      END


      SUBROUTINE OFFSET(MXV,MNV,OILOV,TOV,ROV,WPOV,WFOV,N,K,TD,
     1 L,MIV,MAV)
C     ----------------------------------------------------------------

      REAL MXV,MNV,OILOV,TOV,ROV,WPOV,WFOV,MIV,MAV,TD
      INTEGER N,K,L
100   FORMAT('HOW MANY TIME INTERVALS TO BE ANALYSED? E.G :'/
     1       '354'/)
110   FORMAT(I3)
      WRITE(1,100)
      READ(1,110)N

115   FORMAT('TYPE MAX. VALUE FOR DEPTH CALIBRATION FACTOR, E.G '/
     1       '8.40 ,(WHICH IS IN VOLTS)'/)
120   FORMAT(F4.2)
      WRITE(1,115)
      READ(1,120)MXV

125   FORMAT('NOW TYPE THE MIN. VALUE, E.G'/
     1       '0.84'/)
      WRITE(1,125)
      READ(1,120)MNV

127   FORMAT('TYPE THE LAST CORE RUN DEPTH IN METRES,E.G.'/
     1       '02.15'/)
      WRITE(1,127)
128   FORMAT(F5.2)
      READ(1,128)TD

135   FORMAT('TYPE OFFSET VOLTAGE FOR INLET OIL PRESSURE, E.G'/
     1       '+0.03'/)
140   FORMAT(F5.2)
      WRITE(1,135)
      READ(1,140)OILOV

150   FORMAT('WHICH THRUST RELATIONSHIP IS REQUIRED:'/
     1       ' 1) Y=0.354326 + 0.001755X '/
     2       ' 2) Y=0.3883 + 0.00201X '/
     3       ' 3) Y=3.5385 + 0.0070X '/
     4       ' 4) Y=0.2753 + 0.0004X '/
     5       'JUST TYPE 1,2,3 OR 4 AS APPROPRIATE'/)
155   FORMAT(I1)
      WRITE(1,150)
      READ(1,155)K
```

```
160   FORMAT('TYPE OFFSET VALUE FOR THRUST, E.G. '/
     1         '-0.02'/)
      WRITE(1,160)
      READ(1,140)TOV

170   FORMAT('WHICH ROTARY SPEED RELATIONSHIP IS REQUIRED?:'/
     1         ' 1)  Y= -0.082398 + 0.003445X '/
     2         ' 2)  Y= 0.4230 + 0.00308X '/)
      WRITE(1,170)
      READ(1,155)L

175   FORMAT('TYPE OFFSET VALUE FOR ROTARY SPEED, E.G. '/
     1         '-0.01'/)
      WRITE(1,175)
      READ(1,140)ROV

180   FORMAT('TYPE IN OFFSET VALUE FOR INLET WATER PRESSURE,E.G'/
     1         '-0.36'/)
      WRITE(1,180)
      READ(1,140)WPOV

190   FORMAT('TYPE IN OFFSET VALUE FOR INLET WATER FLOW,E.G'/
     1         '+0.98'/)
      WRITE(1,190)
      READ(1,140)WFOV

196   FORMAT('TYPE MIN. VOLTAGE FOR SWASH PLATE RATIO,E.G'/
     1         '+2.93'/)
      WRITE(1,196)
      READ(1,140)MIV
197   FORMAT('TYPE MAX. VOLTAGE FOR SWASH PLATE RATIO,E.G'/
     1         '+3.17'/)
      WRITE(1,197)
      READ(1,140)MAV

198   FORMAT(5X,'DEPTH',1X,'PENETRATION',3X,'ROTARY',
     1         5X,'THRUST',2X,'INLET WATER'/
     2         2X,8('-'),1X,'RATE(CM/MIN)',2X,'SPEED(RPM)',
     3         2X,'(KN)',3X,'PRESSURE(KN/M**2)'/
     4         11X,12('-'),2X,10('-'),1X,6('-'),2X,17('-')/)
      WRITE(7,198)

      RETURN
      END

      SUBROUTINE READ(TIME,CH1,CH2,CH3,CH4,CH5,CH7,CH8,CH9,CH11,CH18)
C     -----------------------------------------------------------------

      REAL CH1,CH2,CH3,CH4,CH5,CH7,CH8,CH9,CH11,CH18
      INTEGER TIME,N1,N2,N3,N4,N5,N7,N8,N9,N11,N18

900   FORMAT(1X,I8,4X,I4,4(7X,I4)/)
      READ(5,900)TIME,N1,N2,N3,N4,N5
910   FORMAT(16X,I4,2(7X,I4)/)
      READ(5,910)N7,N8,N9
920   FORMAT(5X,I4/)
```

```
      READ(5,920)N11
  930 FORMAT(27X,I4/)
      READ(5,930)N18

C  CONVERT TO REAL CHANNEL NUMBERS

      CH1=FLOAT(N1)/100.
      CH2=FLOAT(N2)/100.
      CH3=FLOAT(N3)/100.
      CH4=FLOAT(N4)/100.
      CH5=FLOAT(N5)/100.
      CH7=FLOAT(N7)/100.
      CH8=FLOAT(N8)/100.
      CH9=FLOAT(N9)/100.
      CH11=FLOAT(N11)/100.
      CH18=FLOAT(N18)/100.

      IF (CH3.LE.100.) CH3 = CH3 + 10.
      IF (CH8.LE.100.) CH8 = CH8 + 10.

      RETURN
      END


      SUBROUTINE CDEPTH(CRDTH,TIME,MXV,PTIME,CH1,PRATE,MNV,TD
     1 ,HLINT,HLNXT)
C     ------------------------------------------------------

      REAL PDEPTH,PRATE,MXV,CH1,MNV,TD,CRDTH,HLINT,HLNXT,DLINT
      INTEGER TIME,PTIME

C  CALCULATE DEPTH

      PDEPTH = TD
      HLNXT = ((CH1-MNV)/(MXV-MNV))*0.85
      DLINT = HLINT - HLNXT
      TD = TD + DLINT
      CRDTH = CRDTH + DLINT
      HLINT = HLNXT

  240 FORMAT('THE DEPTH IN THIS CORE RUN IS:       ',F7.2,' METRES')
      WRITE(6,240)CRDTH

  220 FORMAT('THE DEPTH SO FAR IS:                 ',F7.2,' METRES')
      WRITE(6,220)TD

C  CALCULATE THE PENETRATION RATE

      PRATE = 100 * 60 *  ((TD - PDEPTH)/(TIME - PTIME))
      PTIME = TIME

  230 FORMAT('THE PENETRATION RATE IS:             ',F9.4,' CM/MIN')
      WRITE(6,230)PRATE

      RETURN
      END
```

```
      SUBROUTINE IOILP(CH2,ZERO,OILOV,CH8)
C     ------------------------------------

      REAL CV,OV,ZERO,IOP,CH2,CH8,OILOV

C  CALCULATE CORRECT VOLTAGE

      CV=CH2-OILOV

C  CALCULATE INLET OIL PRESSURE

      IOP = (((10.*CV/CH8)-0.2138)/0.001096)*0.006895

320   FORMAT('THE INLET OIL PRESSURE IS:                    ',F6.3,' MN/M**2')
      WRITE(6,320)IOP

      RETURN
      END


      SUBROUTINE THRUST(CH7,CH8,TOV,K,THRST)
C     --------------------------------------

      REAL TOV,TCV,X,THRST,CH7,CH8
      INTEGER K

C  CALCULATE CORRECT VOLTAGE

      TCV = (CH7-TOV)*10./CH8

C  SELECT THRUST RELATIONSHIP

      GOTO(1,2,3,4),K

1     X = (TCV-0.354326)/0.001755
      GOTO 10

2     X = (TCV-0.3883)/0.00201
      GOTO 10

3     X = (TCV-3.5385)/0.0070
      GOTO 10

4     X = (TCV-0.2753)/0.0004

10    THRST = (X-10.)*5.1431*4.448*0.001

540   FORMAT('THE THRUST IS:                                ',F5.2,' KN')
      WRITE(6,540)THRST

      RETURN
      END


      SUBROUTINE RTASPD(ZERO,ROV,CH9,CH3,L,RTSP)
C     ------------------------------------------

      REAL ZERO,RCV,RTSP,CH9,CH3
```

```
      INTEGER L
C  ALLOW FOR CH3 BEING ZERO
      IF(CH3.EQ.ZERO) CH3 = 10.00
C  SELECT REQUIRED RELATIONSHIP
      GOTO(1,2),L
1     RTSP = (((CH9-ROV)*10./CH3)+0.382398)/0.003445
      GOTO 640
2     RTSP = (((CH9-ROV)*10./CH3)-0.4230)/0.00308
640   FORMAT('THE ROTARY SPEED IS:                    ',F9.3,' RPM')
      WRITE(6,640)RTSP
      RETURN
      END

      SUBROUTINE IWATRP(WPOV,CH8,CH18,IWP)
C     ----------------------------------------
      REAL IWP,WPOV,CH8,CH18
C  CALCULATE THE INLET WATER PRESSURE
      IWP = ((((CH18-WPOV)*10./CH8)-0.7052)/0.03726)*6.895
720   FORMAT('THE INLET WATER PRESSURE IS:            ',F6.1,' KN/M**2')
      WRITE(6,720)IWP
      RETURN
      END

      SUBROUTINE IWATRF(WFOV,CH4,CH8)
C     --------------------------------
      REAL Y,IWF,WFOV,CH4,CH8,LY
C  INITIAL STEP
      Y = (CH4-WFOV)*10./CH8
      IF(Y.LT.0.0)Y=-Y
      IF(Y.EQ.0.0)GOTO 25
C  CALCULATE INLET WATER FLOW
      LY=ALOG10(Y)
      IWF=(10**((LY+1.750046)/1.967213))*4.546
420   FORMAT('THE INLET WATER FLOW IS:                ',F6.2,' LITRES/MIN')
      WRITE(6,420)IWF
      GOTO 30
25    FORMAT('INVALID DATA FOR INLET WATER FLOW')
      WRITE(6,25)
```

```
30    RETURN
      END

      SUBROUTINE TORQUE(CH11,CH3,MIV,MAV,ZERO,RTSP)
C     ----------------------------------------

      REAL CH11,CH3,MIV,MAV,ZERO,RPM,RTSP,TRQ,SPR

      IF(CH3.LE.ZERO)CH3=CH3+10.
      IF(CH11.LE.ZERO)CH11=CH11+10.

      SPR=(((CH11+10.)/CH3)-MIV)/(MAV-MIV)

      IF(SPR.EQ.1.00) TRQ = 121.5737 - 0.05203*RTSP
      IF(SPR.EQ.0.75) TRQ = 132.8274 - 0.06732*RTSP
      IF(SPR.EQ.0.50) TRQ = 156.2922 - 0.09482*RTSP
      IF(SPR.EQ.0.25) TRQ = 180.9540 - 0.12870*RTSP
      IF(SPR.EQ.0.00) TRQ = 241.0608 - 0.20320*RTSP
      IF(SPR.EQ.1.00.OR.SPR.EQ.0.75.OR.SPR.EQ.0.50)GOTO 800
      IF(SPR.EQ.0.25.OR.SPR.EQ.0.00)GOTO 800

      RPM = (SPR + 0.9711)/0.00086
      TRQ = (((RTSP-RPM)/(786.-RPM))+80.7)/0.7376

800   FORMAT('THE TORQUE IS:                        ',F7.2,
     1       'NEWTON/METRES'/)
      WRITE(6,800)TRQ

      RETURN
      END

      SUBROUTINE LIST(TD,PRATE,RTSP,THRST,IWP)
C     ------------------------------------------

      REAL PRATE,RTSP,THRST,IWP,TD

900   FORMAT(2X,F7.2,6X,F5.2,7X,F7.2,3X,F5.2,6X,F7.1)
      WRITE(7,900)TD,PRATE,RTSP,THRST,IWP

      RETURN
      END

      SUBROUTINE PLOT(CRDTH,TRQ,IWP,PRATE,THRST,RTSP)
C     ---------------------------------------------

      REAL CRDTH
      INTEGER T,I,P,TH,R,S,PLTR,PLTRQ,PLTIWP,PLTPRT,PLTHRT,PLTRSP
      INTEGER PLTR(125)
      DATA T/'T'/,I/'I'/,P/'P'/,TH/'L'/,R/'R'/,S/' '/

      DO 10 J=1,125
      PLTR(J) = S
10    CONTINUE

      PLTRQ = TRQ/2
```

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      PLTR(PLTRQ) = I

      PLTIWP = IWF/2
      PLTR(PLTIWP) = I

      PLTPRT = IFIX(PRATE)
      PLTR(PLTPRT) = P

      PLTHRT = THRST/2
      PLTR(PLTHRT) = TH

      PLTRSP = RTSP/20
      PLTR(PLTRSP) = R

2.    FORMAT(F7.2,125(I1))
      WRITE(8,20)CRDTH,(PLTR(K),K=1,125)

      RETURN
      END
```

APPENDIX 5
THE TRRL DRILLING RECORDS

USER: EX9069 -AT SYSTEM

NR_T1.1.1

LABEL: PRT003 -FORM

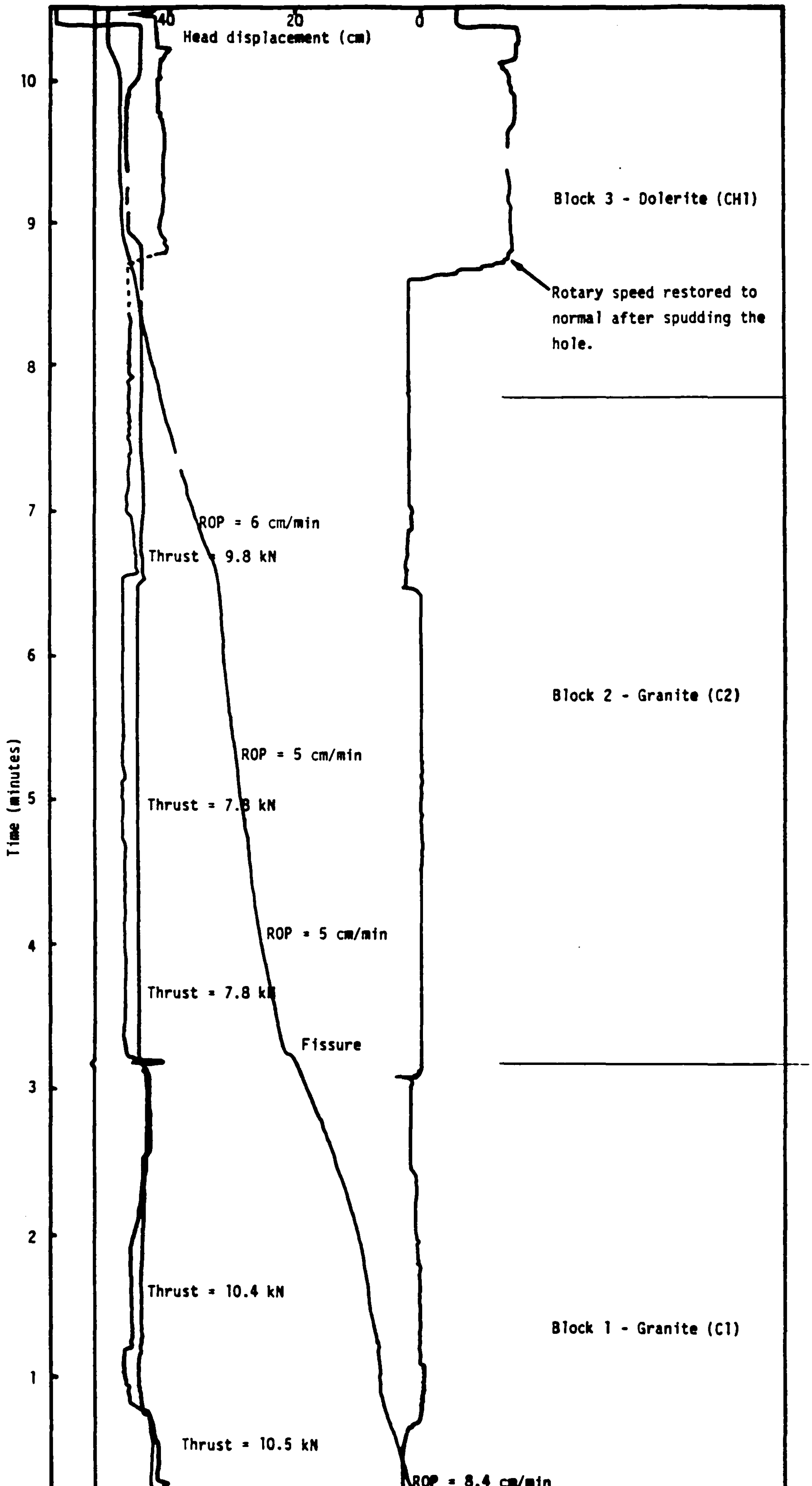
SPOOLED: 82-01-21.19:06
STARTED: 82-01-21.19:25, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
24756	[illegible]	0.000	0.00	1304.03	11.76	71.77	3.14	38.74	2.13
24800	0.01	0.005	11.81	1440.46	11.50	61.86	37.69	5.94	5.41
24804	0.01	0.015	8.43	1437.36	11.63	62.07	16.13	4.83	5.60
24808	0.02	0.020	8.43	1452.07	11.63	61.02	32.13	9.78	5.47
24812	0.03	0.026	8.43	1460.78	10.45	60.39	2.43	42.35	5.13
24816	0.03	0.031	8.43	1457.88	10.45	[illegible]	14.28	55.57	5.13
24820	0.04	0.037	8.43	1449.17	10.45	7.02	6.85	57.84	5.09
24824	0.04	0.043	8.43	1463.69	10.45	4.78	28.41	54.87	5.03
24828	0.05	0.048	8.43	1469.49	10.45	3.88	26.55	49.65	4.78
24832	0.05	0.054	8.43	1472.39	10.45	3.43	56.25	47.47	4.71
24836	0.06	0.058	6.75	1481.10	10.45	2.39	6.85	45.55	4.46
24840	0.06	0.063	6.75	1533.35	8.36	5.98	17.99	44.41	3.89
24844	0.06	0.064	1.69	1533.35	8.36	5.98	1.28	34.58	3.26
24848	0.07	0.066	3.37	1539.16	7.83	6.87	46.97	4.83	3.32
24852	0.07	0.067	1.69	1544.96	7.70	7.77	27.27	4.83	3.01
24856	0.07	0.069	1.69	1536.25	7.70	6.43	52.54	27.69	3.07
24900	0.07	0.070	1.69	1533.35	7.70	5.98	5.00	47.61	[illegible]
24904	0.07	0.071	1.69	1507.23	9.14	1.94	14.28	57.05	3.14
24908	0.07	0.073	3.37	1515.94	9.53	3.29	0.57	56.71	3.64
24912	0.08	0.075	3.37	1518.84	9.53	3.74	37.69	54.04	3.56
24916	0.08	0.079	5.06	1521.74	9.53	4.18	28.41	50.48	3.58
24920	0.08	0.081	3.37	1518.84	9.53	3.74	30.27	48.14	3.51
24924	0.08	0.083	3.37	1518.84	9.53	3.74	12.42	45.97	3.58
24928	0.09	0.085	3.37	1518.84	9.53	3.74	12.42	43.54	3.51
24932	0.09	0.088	3.37	1518.84	9.53	3.74	11.71	23.26	3.51
24936	0.09	0.090	3.37	1521.74	9.67	4.18	43.26	4.83	3.51
24940	0.09	0.093	5.06	1515.94	9.80	3.29	19.84	6.88	3.51
24944	0.10	0.096	3.37	1518.84	9.93	3.74	19.13	36.20	3.58
24948	0.10	0.099	5.06	1507.23	9.93	1.94	14.28	52.60	3.70
24952	0.10	0.103	6.75	1501.42	9.93	1.05	14.28	58.50	3.83
24956	0.11	0.107	5.06	1497.05	10.04	3.09	15.54	56.91	4.08
25000	0.11	0.112	8.43	1489.81	9.93	0.74	48.83	52.96	4.14
25004	0.12	0.116	5.06	1488.35	10.04	4.39	35.93	50.33	4.27
25008	0.12	0.121	8.43	1486.91	9.93	1.19	9.85	48.14	4.27
25012	0.13	0.126	6.75	1491.25	10.04	3.96	14.13	46.36	4.33
25016	0.13	0.132	8.43	1488.35	10.04	4.39	4.86	39.21	4.27
25020	0.14	0.136	6.75	1485.45	10.04	4.83	35.93	17.09	4.39
25024	0.14	0.143	10.12	1466.59	10.06	4.33	52.54	51.49	4.46
25028	0.15	0.148	8.43	1466.59	10.45	4.33	41.41	45.27	4.65
25032	0.16	0.155	10.12	1469.49	10.45	3.88	6.14	47.47	4.71
25036	0.16	0.162	10.12	1469.49	10.45	3.88	16.13	46.66	4.59
25040	0.17	0.168	8.43	1472.39	10.32	3.43	5.00	40.19	4.59
25044	0.17	0.173	8.43	1473.85	10.43	6.56	35.93	24.84	4.58
25048	0.18	0.180	10.12	1473.85	10.43	6.56	12.28	3.40	4.64
25052	0.19	0.187	10.12	1479.65	10.56	5.70	41.50	26.79	4.58
25056	0.19	0.193	10.12	1475.30	10.32	2.99	1.28	48.01	4.46
25100	0.20	0.199	8.43	1492.71	9.80	0.30	16.13	56.49	4.14
25104	0.22	0.216	25.30	1510.13	6.49	2.39	3.14	56.26	4.30
25108	0.22	0.219	5.06	1536.25	7.83	6.43	33.98	55.10	3.01
25112	0.22	0.224	6.75	1536.25	7.83	6.43	24.70	51.74	2.88
25116	0.22	0.225	1.69	1534.74	7.95	2.54	45.20	48.91	2.94
25120	0.23	0.229	6.75	1530.45	7.83	5.53	10.56	45.41	2.95
25124	0.23	0.233	5.06	1530.45	7.83	5.53	16.13	45.26	2.95
25128	0.24	0.236	5.06	1533.35	7.83	5.98	6.14	37.74	3.07

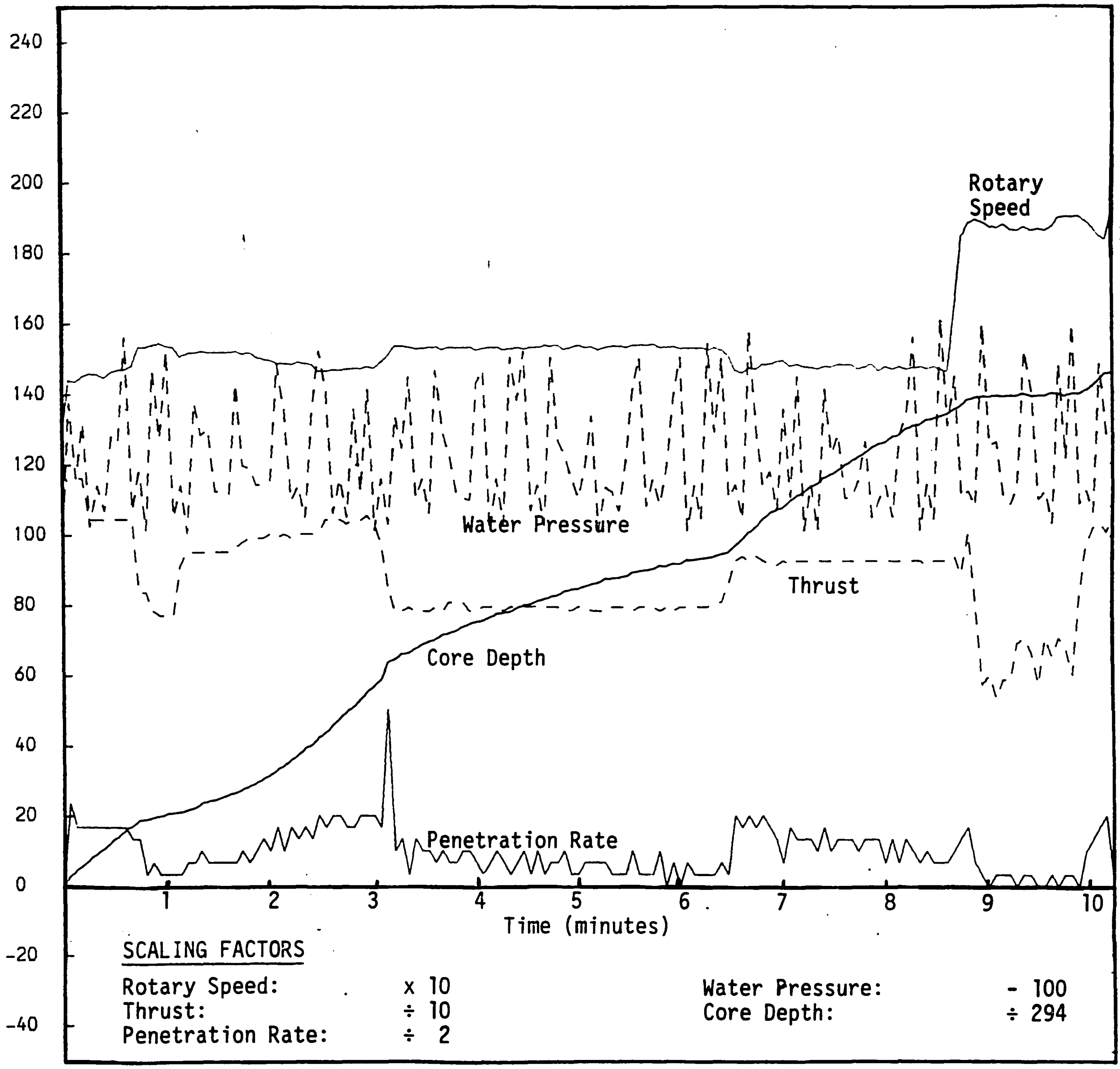
	TOTAL	CORE	PENETRATN	ROTARY			INLET H20	I. H20	PAGE
25132	0.24	0.238	3.37	1534.74	7.95	2.54	47.[illegible]	18.[illegible]	3.[illegible]
25136	0.24	0.242	5.06	1527.55	7.83	5.08	29.12	27.4[illegible]	3.[illegible]1
25140	0.24	0.244	3.37	1531.84	8.08	2.11	22.95	45.1[illegible]	3.[illegible]7
25144	0.25	0.246	3.37	1531.84	8.08	2.11	12.28	55.07	3.[illegible]7
25148	0.25	0.250	5.06	1531.84	8.08	2.11	10.42	58.[illegible]	2.54
25152	0.25	0.253	5.06	1533.35	7.83	5.98	9.85	57.61	2.88
25156	0.25	0.255	3.37	1527.55	7.83	5.08	43.26	53.44	2.95
25200	0.26	0.256	1.69	1528.94	7.95	1.68	47.06	51.34	3.13
25204	0.26	0.259	3.37	1531.84	7.95	2.11	0.71	48.65	3.07
25208	0.26	0.262	5.06	1533.35	7.97	5.98	16.13	48.67	2.95
25212	0.26	0.264	3.37	1527.55	7.83	5.08	3.14	41.44	2.95
25216	0.27	0.265	1.69	1528.94	7.95	1.68	50.77	14.76	3.07
25220	0.27	0.268	3.37	1531.84	7.95	2.11	38.24	20.98	3.[illegible]
25224	0.27	0.271	5.06	1530.45	7.97	5.53	52.54	40.82	2.95
25228	0.27	0.272	1.69	1531.84	7.95	2.11	6.71	53.42	3.[illegible]
25232	0.28	0.275	5.06	1533.35	7.97	5.98	14.28	57.95	2.95
25236	0.28	0.277	1.69	1537.64	7.95	2.98	2.56	58.36	2.82
25240	0.28	0.279	3.37	1536.25	7.95	1.24	50.77	55.54	2.88
25244	0.28	0.281	3.37	1539.16	7.95	1.67	26.65	53.78	2.82
25248	0.28	0.284	5.06	1527.55	7.83	5.08	22.65	49.06	2.95
25252	0.29	0.286	1.69	1533.35	7.83	5.98	16.13	49.45	2.28
25256	0.29	0.287	1.69	1537.64	7.95	2.98	10.42	48.25	2.94
25300	0.29	0.289	3.37	1533.35	7.95	0.81	19.24	38.72	2.94
25304	0.29	0.291	3.37	1534.86	7.83	4.55	33.96	13.00	3.07
25308	0.29	0.293	3.37	1526.15	7.83	3.26	1.28	32.51	2.88
25312	0.30	0.296	3.37	1531.96	7.83	4.14	13.57	48.80	2.82
25316	0.30	0.297	1.69	1536.25	7.95	1.24	12.28	54.72	2.68
25320	0.30	0.298	1.69	1536.25	7.95	1.24	6.71	59.35	2.88
25324	0.30	0.299	1.69	1533.35	7.95	0.81	21.10	57.36	2.82
25328	0.30	0.302	5.06	1537.77	7.83	5.03	41.41	52.23	2.69
25332	0.30	0.304	1.69	1539.16	7.95	1.67	50.77	53.06	2.75
25336	0.30	0.305	1.69	1539.16	7.95	1.67	8.12	46.49	2.75
25340	0.31	0.306	1.69	1542.06	7.95	2.09	15.99	56.34	2.69
25344	0.31	0.309	5.06	1534.86	7.83	4.58	8.71	60.24	2.59
25348	0.31	0.309	0.00	1533.35	7.95	0.81	19.24	57.02	2.75
25352	0.31	0.311	3.37	1534.86	7.83	4.58	39.55	53.80	2.69
25356	0.31	0.311	0.00	1530.45	7.95	0.38	50.77	51.58	2.75
25400	0.31	0.314	3.37	1530.45	7.95	0.38	1.15	45.43	2.75
25404	0.31	0.315	1.69	1530.45	7.95	0.38	14.13	48.51	2.75
25408	0.32	0.316	1.69	1530.45	7.95	0.38	4.41	41.42	2.65
25412	0.32	0.317	1.69	1527.55	7.95	0.05	54.48	26.99	2.63
25416	0.32	0.318	1.69	1530.45	8.08	0.38	28.96	17.44	2.63
25420	0.32	0.320	3.37	1524.64	8.08	0.47	50.77	40.01	2.69
25424	0.32	0.322	1.69	1510.13	8.61	2.61	10.42	53.78	2.65
25428	0.33	0.328	10.12	1468.03	5.27	5.59	14.28	60.67	3.77
25432	0.33	0.334	8.43	1460.76	9.39	9.89	4.41	58.25	3.76
25436	0.34	0.341	10.12	1475.30	9.26	7.75	58.18	54.72	3.57
25440	0.35	0.346	8.43	1472.39	9.39	8.18	30.37	50.20	3.45
25444	0.35	0.353	10.12	1484.01	9.26	6.47	13.68	48.51	3.51
25448	0.36	0.359	8.43	1485.47	9.14	2.93	17.99	48.01	3.26
25452	0.36	0.363	6.75	1491.28	9.14	2.05	6.85	46.66	2.95
25456	0.37	0.365	3.37	1495.62	9.26	4.75	35.93	40.17	3.13
25500	0.37	0.371	8.43	1479.66	9.14	3.82	10.56	31.72	3.01
25504	0.38	0.376	6.75	1484.01	9.26	6.47	45.2[illegible]	38.22	3.19
25508	0.38	0.380	6.75	1478.20	9.26	7.32	1.15	52.[illegible]	3.13
25512	0.38	0.385	6.75	1475.30	9.26	7.75	14.13	59.13	3.26
25516	0.39	0.388	5.06	1472.39	9.26	8.18	1.15	58.[illegible]	3.32
25520	0.39	0.394	8.43	1478.20	9.26	7.32	41.5[illegible]	55.65	3.19

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
25524	0.40	0.397	5.06	1478.20	9.26	7.32	22.95	51.46	3.26
25528	0.40	0.401	6.75	1484.01	9.26	6.47	28.52	51.95	3.32
25532	0.41	0.406	6.75	1484.01	9.26	6.47	10.42	48.25	3.19
25536	0.41	0.410	6.75	1484.01	9.26	6.47	10.42	46.83	3.13
25540	0.41	0.414	5.06	1472.39	9.26	8.18	15.54	41.72	3.19
25544	0.42	0.418	6.75	1478.20	9.26	7.32	26.66	26.79	3.19
25548	0.42	0.423	6.75	1480.91	9.26	5.04	4.86	30.49	3.36
25552	0.43	0.427	6.75	1466.59	9.26	9.04	9.97	48.78	3.38
25556	0.43	0.429	3.37	1478.20	9.26	7.32	14.13	55.89	3.13
25600	0.43	0.434	6.75	1472.39	9.26	8.18	4.86	58.03	3.38
25604	0.44	0.436	3.37	1478.20	9.26	7.32	28.52	56.14	3.26
25608	0.44	0.441	6.75	1472.39	9.26	8.18	34.08	54.96	3.26
25612	0.44	0.444	5.06	1475.30	9.26	7.75	56.33	52.33	3.19
25616	0.45	0.446	3.37	1478.20	9.26	7.32	1.15	46.91	3.19
25620	0.45	0.450	5.06	1473.84	9.14	4.70	14.26	48.93	3.26
25624	0.45	0.452	3.37	1478.20	9.26	7.32	4.41	43.66	3.26
25628	0.45	0.454	3.37	1472.39	9.26	8.18	61.85	31.51	3.32
25632	0.46	0.456	3.37	1463.69	9.26	9.46	30.82	29.23	3.45
25636	0.46	0.460	5.06	1640.75	9.39	27.41	45.29	39.37	4.33
25640	0.46	0.464	6.75	1845.77	8.88	32.42	10.55	52.69	8.31
25644	0.47	0.470	8.43	1886.45	10.06	29.46	12.42	58.94	8.31
25648	0.47	0.472	3.37	1896.20	8.10	2.21	8.00	39.71	8.31
25652	0.47	0.473	1.69	1887.49	5.73	3.05	60.04	3.40	8.43
25656	0.47	0.473	0.00	1875.88	5.99	4.18	25.26	11.49	8.36
25700	0.47	0.474	1.69	1871.92	5.36	30.52	26.45	44.58	8.51
25704	0.47	0.473	1.69	1881.68	5.87	3.61	10.56	53.44	8.44
25708	0.47	0.474	1.69	1867.17	5.86	5.02	8.57	59.13	8.61
25712	0.47	0.474	0.00	1864.27	6.91	5.30	13.68	57.47	8.55
25716	0.48	0.476	1.69	1874.83	7.05	30.31	52.54	53.68	8.44
25720	0.47	0.474	1.69	1864.27	6.66	5.30	41.41	44.98	8.69
25724	0.47	0.474	0.00	1870.07	5.74	4.74	9.85	48.93	8.56
25728	0.47	0.474	0.00	1864.27	7.05	5.30	12.42	47.87	8.56
25732	0.48	0.476	1.69	1875.88	6.53	4.18	3.14	42.20	8.50
25736	0.48	0.476	0.00	1902.00	7.05	1.65	48.83	33.47	8.18
25740	0.47	0.474	1.69	1904.90	6.79	1.37	21.70	25.32	8.06
25744	0.48	0.476	1.69	1904.90	6.00	1.37	59.97	31.12	7.99
25748	0.48	0.476	0.00	1907.81	8.23	1.09	8.71	51.11	7.93
25752	0.48	0.479	5.06	1893.29	9.67	2.49	12.42	58.50	8.25
25756	0.48	0.483	6.75	1875.88	10.19	4.18	6.14	58.17	8.12
25800	0.49	0.489	8.43	1852.66	10.32	6.42	48.83	52.60	8.31
25804	0.50	0.496	10.12	1841.04	10.66	7.54	28.41	52.47	8.81
25808	0.50	0.497	1.69	1928.13	10.45	0.87	32.13	51.86	7.74



RECORD OF TRRL DRILL RUN 1.1.1 (0.00 to 0.50 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.1.1 (0.00 to 0.50 metres)



USER: EX9069 -AT SYSTEM

NF_TI.2

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WWWWW W   W  WWW    WWW    WWW  WWW
W      W W  W   W  W   W  W    W   W
W       W   W   W  W   W  W    W   W
WWWW    W    WWWW  W W W  WWWW  WWWW
W      W W      W  W   W  W   W    W
W     W   W    W   W   W  W   W   W
WWWWW W   W WWW     WWW    WWW  WWW


W   W WWWW       WWWWW   W         WWW
WW  W W   W        W    WW        W   W
W W W W   W        W     W            W
W  WW WWWW         W     W           W
W   W W            W     W          W
W   W W            W     W    WW   W
W   W W    WWWWW   W    WWW   WW  WWWWW

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LABEL: PRT004 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:25, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
43642	0.59	0.000	0.00	2076.17	-3.15	15.68	13.68	99.99	7.35
43646	0.59	0.002	3.37	2050.04	5.99	17.56	19.24	99.99	7.54
43650	0.60	0.009	10.12	1919.42	8.34	27.07	48.91	99.99	9.56
43654	0.61	0.019	15.18	1951.35	8.34	24.75	37.79	99.99	9.18
43658	0.62	0.028	13.49	1945.54	8.34	25.17	56.33	15.96	8.99
43702	0.63	0.038	15.18	1931.03	8.34	26.22	41.50	45.24	9.31
43706	0.64	0.047	13.49	1925.22	8.34	26.54	21.10	50.20	9.25
43710	0.65	0.057	15.18	1916.52	8.34	27.28	13.68	38.72	45.05
43714	0.66	0.066	13.49	1919.42	8.34	27.37	11.83	46.22	9.50
43718	0.67	0.078	16.86	1909.69	8.10	24.53	35.84	39.07	9.51
43722	0.68	0.087	13.49	1897.23	8.21	27.29	54.45	21.67	9.75
43726	0.69	0.097	15.18	1900.13	8.34	27.08	19.24	99.99	9.69
43730	0.70	0.108	16.86	1902.00	8.23	23.60	24.70	3.40	9.70
43734	0.71	0.119	16.87	1887.49	8.23	24.72	41.41	3.40	9.45
43738	0.72	0.129	15.18	1846.85	8.10	27.34	48.83	3.40	9.51
43742	0.73	0.141	16.86	1911.73	8.34	26.22	61.89	12.99	9.81
43746	0.74	0.150	13.49	1916.52	8.23	22.46	30.27	45.83	9.38
43750	0.75	0.156	10.12	1911.73	8.21	26.22	19.24	52.08	9.25
43754	0.76	0.165	13.49	1916.52	8.23	22.48	28.41	3.40	9.32
43758	0.76	0.173	11.81	1932.02	8.34	24.72	54.48	99.99	9.31
43802	0.77	0.182	13.49	1928.13	8.23	21.59	50.69	8.45	8.94
43806	0.78	0.189	10.12	1940.72	8.34	24.08	54.48	22.71	8.99
43810	0.79	0.197	11.81	1940.72	8.21	24.08	30.37	47.98	9.16
43814	0.79	0.204	10.12	1943.62	8.34	23.86	15.54	52.33	8.87
43818	0.80	0.211	11.81	1936.84	8.23	20.92	13.57	51.36	8.88
43822	0.81	0.219	11.81	1359.19	-3.15	67.77	8.00	43.83	9.13

USER: EX9369 -AT SYSTEM

NR_T1.3.1

EX9369

NR_T1.3.1

LABEL: PRT005 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:25, ON: PR0 BY: PR0

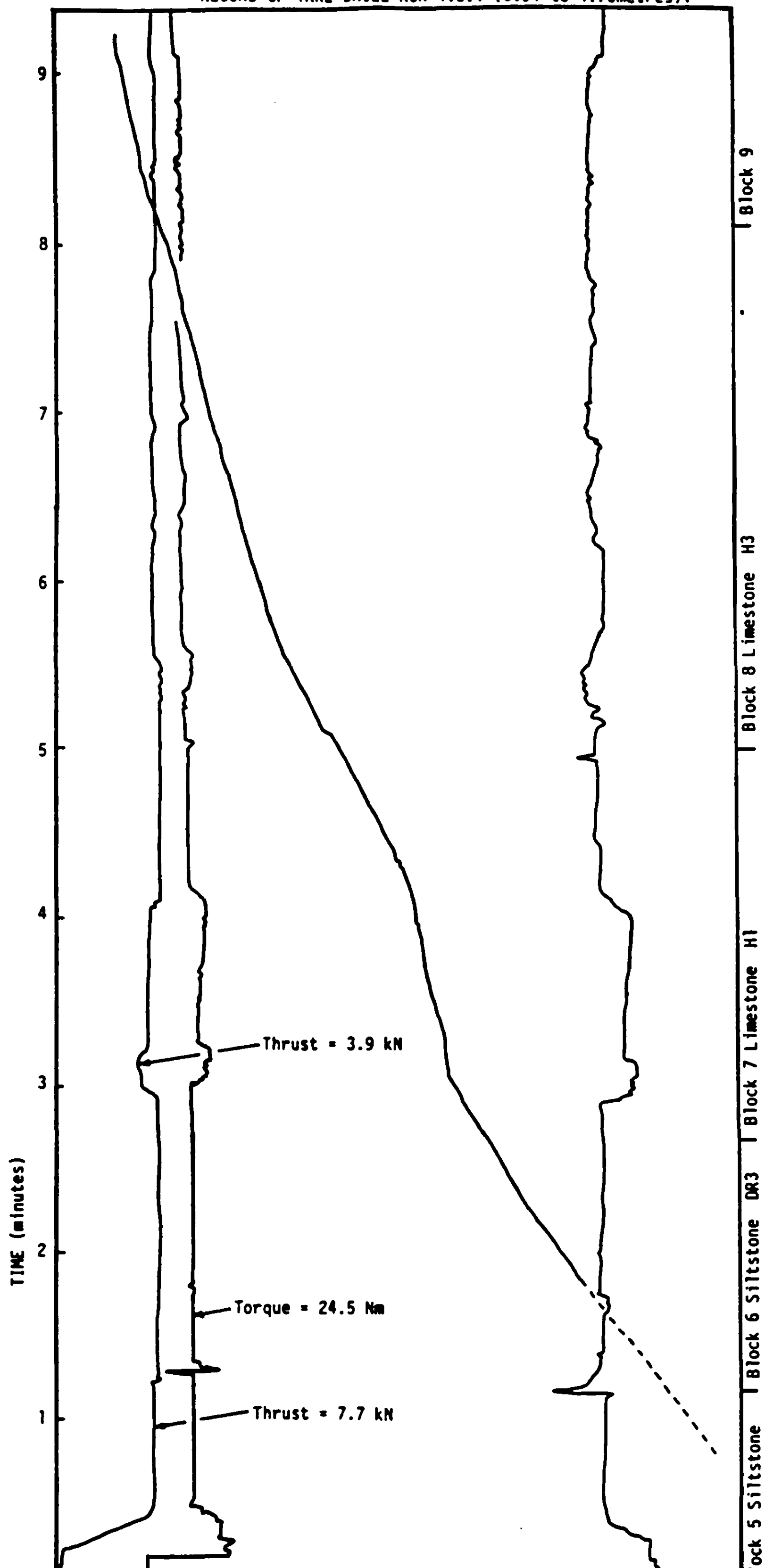
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
45710	0.91	0.000	0.00	2114.37	-4.55	12.62	3.41	37.12	6.94
45714	0.91	0.001	1.69	2093.99	-2.88	14.11	13.33	32.54	6.87
45718	0.91	0.002	1.69	2099.81	1.07	13.66	45.03	27.25	7.18
45722	0.91	0.004	3.37	2056.14	4.58	16.87	44.95	39.91	7.44
45726	0.92	0.010	8.43	1944.02	6.94	25.24	25.21	48.06	8.77
45730	0.93	0.020	15.18	1947.43	7.60	25.33	5.27	53.14	9.34
45734	0.94	0.029	13.49	1938.69	7.73	25.67	17.05	50.66	9.53
45738	0.95	0.039	15.18	1950.35	7.73	24.82	11.47	47.25	9.28
45742	0.96	0.048	13.49	1944.52	7.73	25.24	43.09	41.79	9.40
45746	0.97	0.057	13.49	1938.69	7.73	25.67	13.35	25.46	9.34
45750	0.98	0.066	13.49	1947.43	7.73	25.33	7.75	3.40	9.28
45754	0.99	0.075	13.49	1938.69	7.73	25.67	39.37	3.40	9.34
45758	1.00	0.085	15.18	1950.35	7.74	24.82	37.41	36.43	9.35
45802	1.00	0.094	13.49	1949.37	7.74	22.34	54.17	37.12	9.22
45806	1.01	0.103	13.49	1954.22	7.62	23.15	9.37	3.41	9.30
45810	1.02	0.111	11.81	1952.28	7.74	22.12	20.66	3.40	9.10
45814	1.03	0.120	13.49	1961.03	7.74	24.04	33.69	27.28	9.03
45818	1.06	0.154	50.59	1903.72	7.74	27.14	44.86	43.61	10.17
45822	1.08	0.166	18.55	1932.86	7.74	24.99	33.69	47.68	9.54
45826	1.09	0.178	16.86	1941.60	7.74	24.35	2.94	51.81	9.22
45830	1.10	0.188	15.18	1950.35	7.74	23.70	18.80	50.05	9.10
45834	1.11	0.198	15.18	1949.37	7.62	21.20	14.96	43.33	9.11
45838	1.12	0.208	15.18	1946.45	7.62	21.42	39.18	23.31	8.98
45842	1.13	0.217	13.49	1956.18	7.74	23.27	16.94	3.40	8.97
45846	1.14	0.226	13.49	1932.86	7.74	24.99	24.38	3.40	8.91
45850	1.15	0.236	15.18	1921.20	7.74	25.85	46.72	3.40	9.41
45854	1.16	0.246	15.18	1921.20	7.73	25.85	54.25	14.78	9.53
45858	1.17	0.256	15.18	1927.03	7.73	25.42	31.93	46.29	9.34
45902	1.18	0.268	16.86	1932.86	7.74	24.99	7.63	52.43	9.29
45906	1.19	0.278	15.18	1927.03	7.73	25.42	17.05	49.63	9.47
45910	1.20	0.287	13.49	1932.86	7.74	24.99	29.97	41.66	9.16
45914	1.21	0.297	15.18	1938.69	7.74	24.56	39.28	13.93	9.22
45918	1.22	0.307	15.18	1926.03	7.62	22.97	11.23	4.84	9.05
45922	1.23	0.316	13.49	1935.77	7.74	24.78	31.83	3.40	9.02
45926	1.24	0.326	15.18	1932.86	7.74	24.99	44.86	3.40	9.16
45930	1.25	0.335	13.49	1950.35	7.74	23.70	57.89	7.71	9.03
45934	1.25	0.344	13.49	1956.18	7.74	23.27	37.41	46.86	8.78
45938	1.27	0.355	16.87	1947.43	7.74	23.92	13.21	52.31	9.10
45942	1.27	0.362	10.12	1956.18	7.73	23.27	17.05	48.85	8.77
45946	1.28	0.372	15.18	1931.86	7.61	22.53	37.41	38.80	9.03
45950	1.29	0.379	10.12	1929.95	7.73	25.21	43.09	3.40	9.15
45954	1.30	0.389	15.18	1917.27	7.62	23.64	14.96	4.84	9.17
45958	1.31	0.397	11.81	1918.29	7.74	26.06	50.45	3.40	9.35
46002	1.31	0.403	8.43	2046.52	4.59	16.62	50.45	3.40	7.90
46006	1.31	0.405	3.37	2052.35	4.33	16.20	44.86	40.25	7.58
46010	1.32	0.406	1.69	2072.75	3.94	14.69	22.52	51.57	7.26
46014	1.32	0.408	3.37	2004.80	6.17	17.00	13.21	51.44	7.39
46018	1.32	0.413	6.75	2008.64	6.55	19.41	24.49	45.03	8.01
46022	1.33	0.418	8.43	2010.53	6.43	16.56	48.58	28.63	7.83
46026	1.33	0.423	6.75	2016.46	6.43	16.11	15.07	4.84	7.83
46030	1.34	0.427	6.75	2028.13	6.43	15.23	24.38	4.84	7.9[illegible]
46034	1.34	0.431	5.06	2028.13	6.44	15.[illegible]	52.23	4.84	7.65
46038	1.34	0.433	3.37	2026.12	6.56	18.	44.86	3.40	7.52
46044	1.35	0.437	4.[illegible]	2043.61	6.56	16.	20.65	5.[illegible]17	7.45

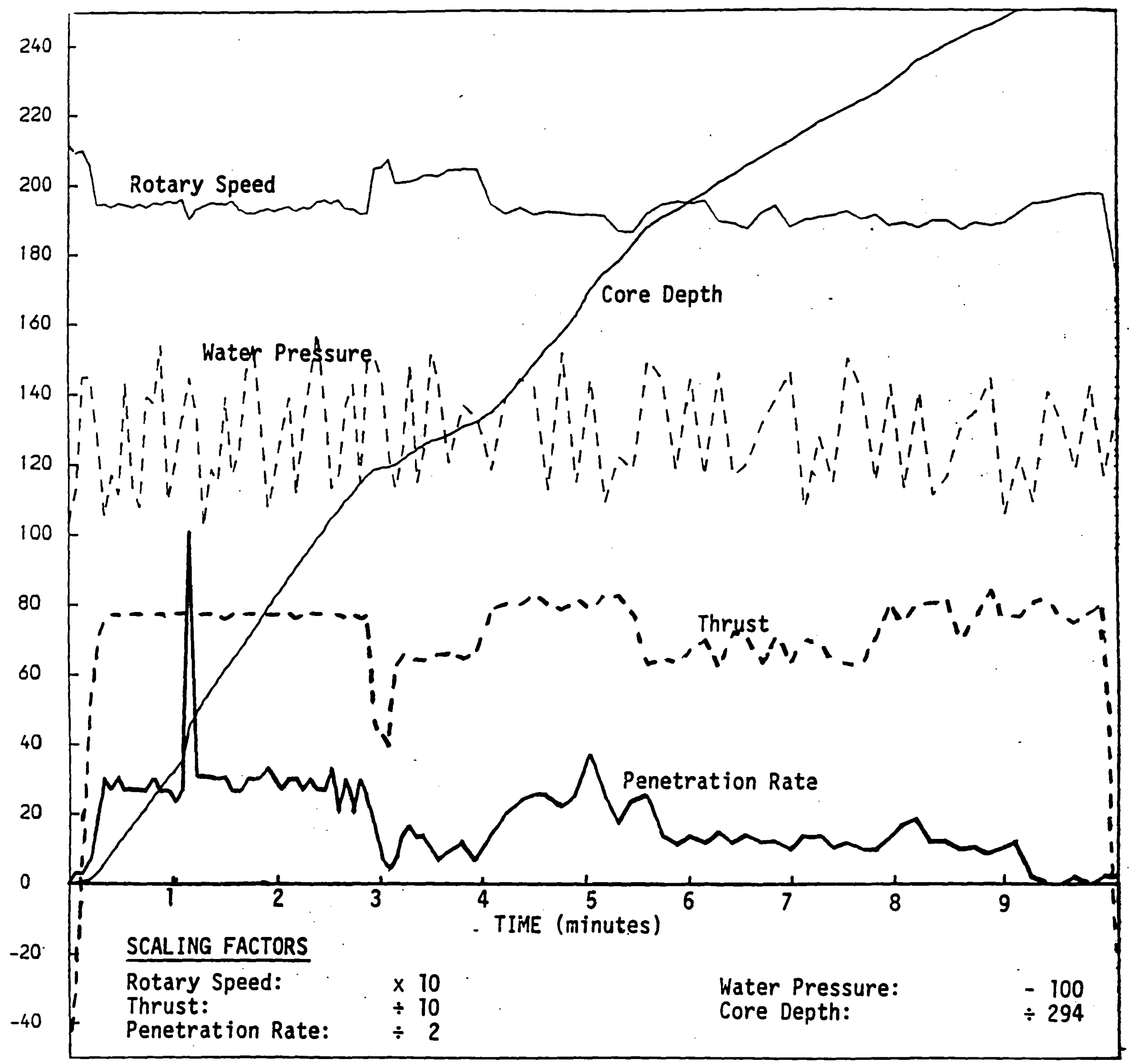
-445-

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 2
46052	1.34	0.445	5.90	2045.54	6.44	13.90	37.32	11.52	7.21
46100	1.36	0.450	3.37	2045.64	6.70	13.90	33.5[illegible]	4.84	7.14
46108	1.37	0.459	6.75	1945.46	7.89	22.57	15.68	4.84	8.47
46116	1.38	0.472	10.12	1920.19	8.02	27.01	39.28	50.68	8.97
46124	1.40	0.488	11.81	1937.70	8.00	22.59	44.86	41.81	8.84
46132	1.42	0.505	12.65	1919.18	8.29	20.82	42.82	4.85	9.18
46140	1.43	0.522	12.65	1920.93	8.03	21.45	12.98	4.85	8.67
46148	1.45	0.536	10.96	1924.12	7.66	25.63	52.37	48.98	8.71
46156	1.46	0.553	12.65	1917.27	8.15	23.64	14.96	45.50	8.65
46204	1.49	0.578	18.55	1918.29	7.87	26.36	44.86	3.40	8.91
46212	1.50	0.595	12.65	1914.36	8.28	23.86	9.37	4.84	8.35
46220	1.52	0.606	8.43	1869.53	8.28	28.35	22.41	40.29	9.30
46228	1.53	0.622	11.81	1867.68	7.75	27.40	18.60	50.58	9.49
46236	1.55	0.639	12.65	1921.29	6.33	21.90	50.20	35.36	8.81
46244	1.56	0.648	6.75	1944.47	6.45	23.90	44.65	3.41	8.42
46252	1.57	0.655	5.90	1953.26	6.30	23.49	18.8[illegible]	18.18	8.15
46300	1.57	0.664	6.75	1949.37	6.72	21.20	44.77	51.22	8.69
46308	1.58	0.672	5.90	1956.17	6.98	19.19	16.71	47.46	8.23
46316	1.59	0.682	7.59	1895.82	6.19	22.65	46.57	4.85	8.36
46324	1.60	0.690	5.90	1889.98	7.23	26.83	16.82	3.41	8.73
46332	1.61	0.699	6.75	1875.38	7.11	24.25	20.44	40.61	9.16
46340	1.62	0.707	5.90	1922.10	6.31	24.42	31.73	52.34	8.60
46348	1.63	0.715	5.90	1941.55	7.11	24.11	39.03	37.33	8.36
46356	1.63	0.722	5.06	1881.22	6.31	27.48	46.64	3.41	8.73
46404	1.64	0.731	6.75	1899.77	6.97	24.96	7.50	3.41	8.79
46412	1.65	0.740	6.75	1907.50	6.85	21.74	27.90	49.58	8.61
46420	1.66	0.747	5.06	1913.34	6.44	25.08	14.96	52.83	8.66
46428	1.66	0.754	5.90	1925.52	6.31	24.20	50.37	31.39	8.47
46436	1.67	0.761	5.06	1901.66	6.31	25.95	41.05	3.41	8.60
46444	1.68	0.768	5.06	1914.36	7.09	27.43	15.07	7.71	8.34
46452	1.69	0.777	6.75	1884.14	8.02	27.26	42.91	49.55	8.79
46500	1.70	0.788	8.43	1892.90	7.50	22.88	12.98	46.50	8.87
46508	1.71	0.801	9.28	1878.30	8.03	24.02	40.96	4.85	8.74
46516	1.72	0.808	5.90	1898.74	8.02	26.17	11.23	3.41	8.73
46524	1.73	0.816	5.90	1898.74	8.15	26.17	16.82	40.43	8.60
46532	1.73	0.823	5.06	1872.46	6.98	28.14	31.63	50.86	8.80
46540	1.74	0.830	5.06	1892.90	7.64	22.88	35.36	36.46	8.61
46548	1.75	0.835	4.22	1884.14	8.41	27.26	44.77	3.41	8.66
46556	1.75	0.842	5.06	1892.90	7.62	26.61	5.64	3.41	8.79
46604	1.76	0.850	5.90	1921.09	7.65	21.90	22.19	48.42	8.62
46612	1.76	0.851	0.84	1947.40	8.04	19.87	9.12	51.64	7.67
46620	1.76	0.851	0.00	1953.24	8.17	19.42	40.87	32.41	7.61
46628	1.76	0.851	0.00	1962.01	7.64	18.74	31.63	4.85	7.66
46636	1.76	0.850	0.84	1971.74	7.49	20.71	18.68	36.27	7.40
46644	1.76	0.850	0.00	1977.58	7.77	16.26	42.82	51.12	7.34
46652	1.76	0.849	0.84	1974.66	8.02	20.49	16.82	47.03	7.33
46700	1.76	0.850	0.84	1716.46	-4.45	40.73	37.13	4.85	5.96

RECORD OF TRRL DRILL RUN 1.3.1 (0.91 to 1.76metres).



COMPUTER RECORD OF TRRL DRILL RUN 1.3.1 (0.91 to 1.76 metres)



USER: EX9069 -AT SYSTEM

NR_T1.3.2

EX9069

NR_T1.3.2

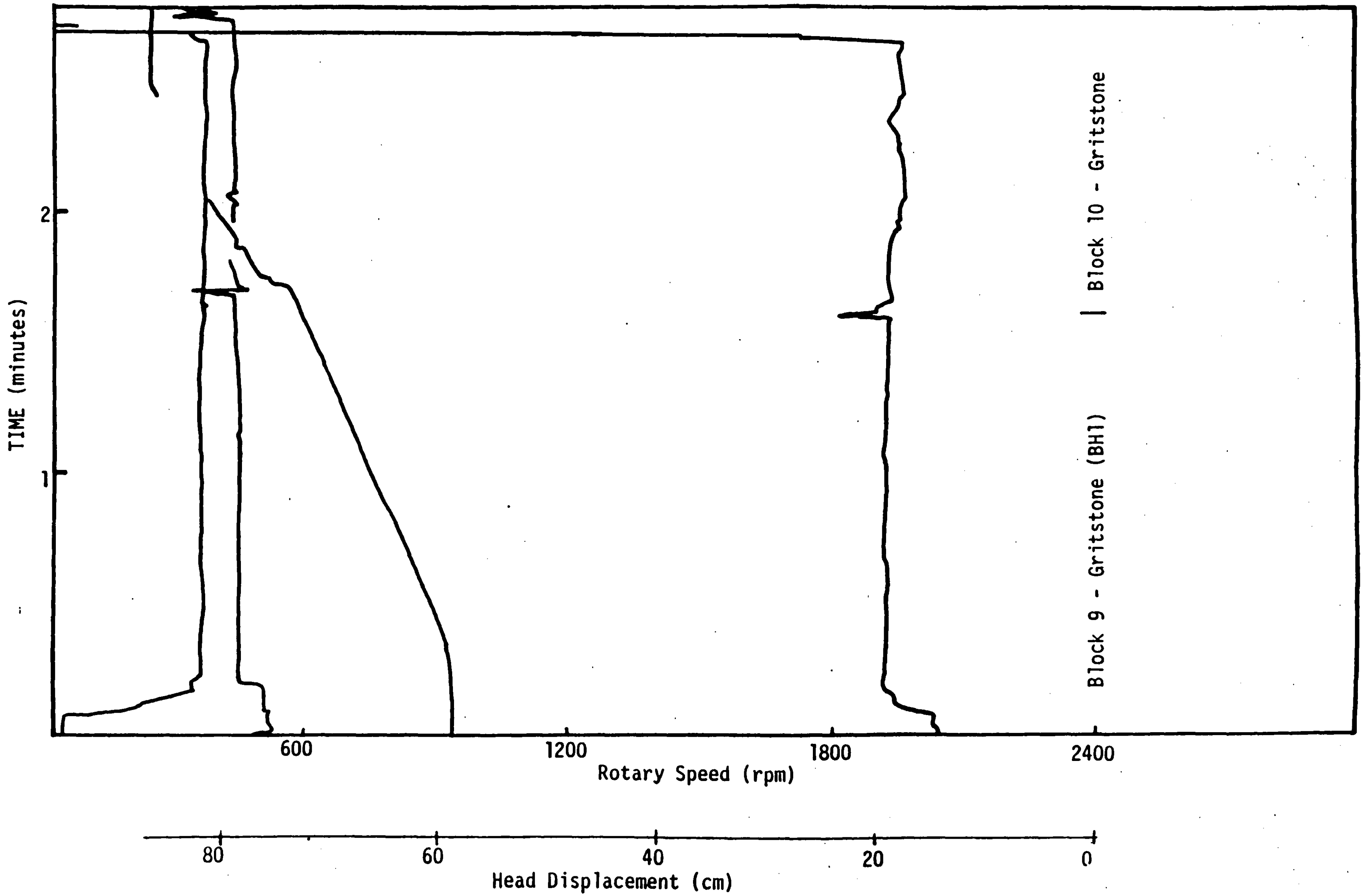
LABEL: PRT006 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:25, ON: PRO BY: PRO

O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

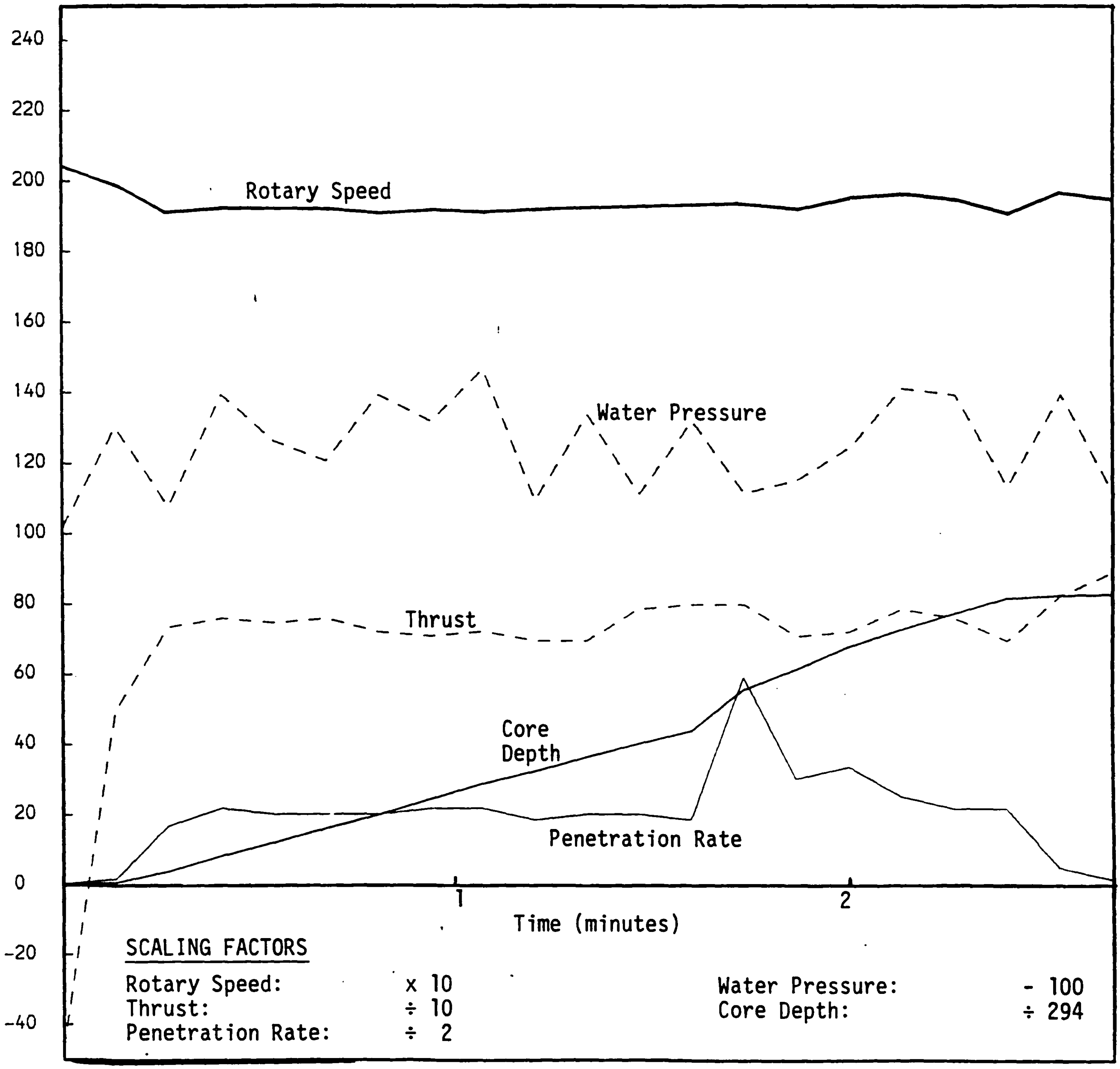
TOTAL CORE PENETRATN ROTARY INLET H2O I. H2O PAGE

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
51300	1.76	0.000	0.00	2043.61	-4.72	18.04	2.04	4.64	8.69
51308	1.76	0.001	0.84	1991.15	4.98	21.96	36.07	48.86	8.62
51316	1.77	0.012	8.43	1929.54	7.34	27.76	7.75	50.15	8.52
51324	1.79	0.027	10.96	1924.12	7.60	26.72	39.37	17.11	8.20
51332	1.80	0.040	10.12	1924.12	7.47	26.72	26.35	4.84	8.14
51340	1.81	0.054	10.12	1924.12	7.60	26.72	20.77	15.49	8.14
51348	1.83	0.067	10.12	1909.54	7.21	27.78	39.37	50.53	8.33
51356	1.84	0.082	10.96	1921.20	7.09	26.94	31.83	41.66	8.21
51404	1.86	0.097	10.96	1912.46	7.22	27.57	45.72	4.84	8.21
51412	1.87	0.109	9.28	1924.12	6.95	26.72	9.49	4.84	8.15
51420	1.88	0.123	10.12	1927.03	6.95	26.51	33.69	48.61	7.96
51426	1.90	0.136	10.12	1929.95	7.87	26.30	11.35	48.21	7.83
51436	1.91	0.148	9.28	1932.86	7.99	26.09	31.93	4.84	7.76
51444	1.95	0.188	29.51	1935.77	7.99	25.88	11.47	4.84	7.69
51452	1.97	0.208	15.18	1921.20	7.07	26.94	15.14	44.46	7.62
51500	1.99	0.230	16.87	1956.18	7.21	24.40	24.49	50.79	7.32
51506	2.01	0.247	12.65	1967.83	7.86	23.55	41.23	38.94	7.13
51516	2.02	0.262	10.96	1950.35	7.60	24.82	39.37	4.84	7.32
51524	2.04	0.277	10.96	1906.63	6.94	28.00	13.33	28.39	7.63
51532	2.04	0.280	2.53	1968.79	8.24	23.48	39.46	51.01	7.12
51540	2.04	0.281	0.84	1953.26	8.91	22.15	11.47	48.06	7.25



RECORD OF TRRL DRILL RUN 1.3.2 (1.76 to 2.04 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.3.2 (1.76 to 2.04 metres)



USER: EX9069 -AT SYSTEM

NR_T1.3.3

LABEL: PRT007 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:25, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
52036	2.04	0.000	0.00	2033.74	3.53	18.76	28.31	42.82	6.68
52044	2.07	0.027	21.64	878.54	6.16	27.70	1.93	1.91	8.58
52052	2.10	0.057	22.77	1870.86	6.41	30.59	50.51	37.93	8.55
52100	2.13	0.093	26.98	1901.85	6.81	25.96	35.65	4.84	8.43
52108	2.16	0.118	18.55	1968.23	5.90	20.68	13.33	4.84	7.19
52116	2.16	0.120	1.69	1973.75	7.07	21.97	39.37	51.16	7.51
52124	2.16	0.121	0.84	1932.86	8.38	24.76	17.[illegible]	45.73	7.89
52132	2.16	0.124	1.69	1953.26	7.99	23.26	43.[illegible]9	4.84	8.[illegible]1
52140	2.16	0.125	0.84	1929.95	7.73	24.98	9.61	4.84	7.59
52148	2.17	0.126	0.84	1894.97	8.78	27.56	24.49	45.17	8.52
52156	2.17	0.127	0.84	1874.57	7.65	29.06	15.19	51.16	6.71
52204	2.17	0.127	0.00	1854.17	7.73	30.57	48.67	19.81	8.96
52212	2.17	0.128	0.84	1857.09	8.12	35.36	28.21	4.84	9.02
52220	2.17	0.129	0.84	1874.57	8.14	29.56	20.65	29.71	9.10

USER: FX9069 -AT SYSTEM

NK_T1.3.4

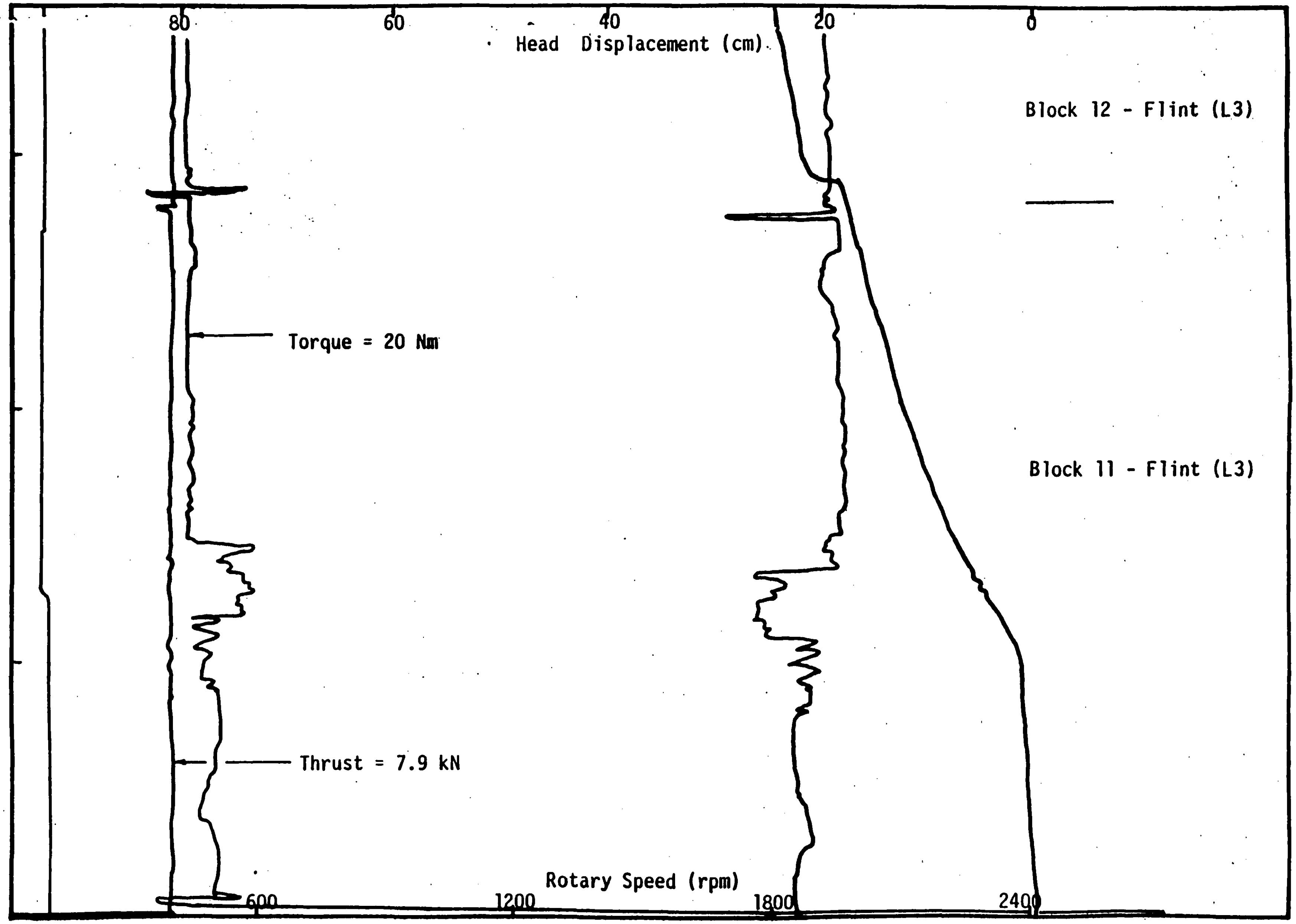
LABEL: PRT008 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:25, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

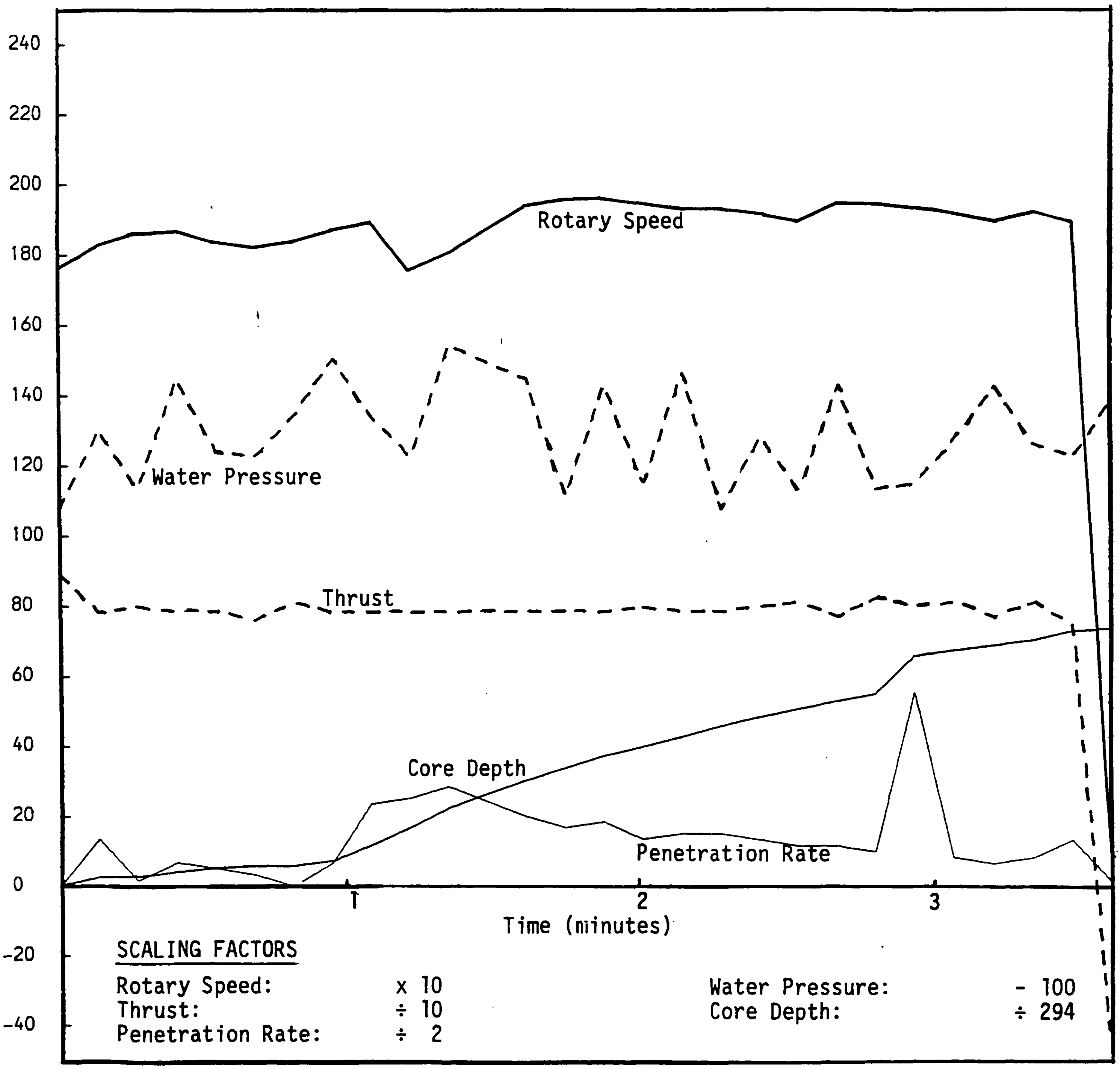
	TOTAL	CORE	PENETRATN	ROTARY				INLET H2O	I. H2O	PAGE 1

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (N.M)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
52252	2.17	0.000	0.00	1764.99	8.91	35.06	7.75	4.84	8.9[illegible]
52300	2.18	0.008	6.75	1829.04	7.86	33.20	30.[illegible]7	44.4[illegible]	9.21
52308	2.18	0.009	0.84	1862.14	7.98	30.01	13.4[illegible]	45.67	9.[illegible]6
52316	2.16	0.013	3.37	1669.80	7.86	27.10	44.9[illegible]	25.35	8.39
52324	2.19	0.017	2.53	1837.78	7.66	32.80	24.4[illegible]	4.84	9.[illegible]9
52332	2.19	0.019	1.69	1823.22	7.60	33.86	22.63	31.95	9.15
52340	2.19	0.019	0.00	1838.87	8.10	32.92	33.[illegible]	[illegible].35	9.[illegible]7
52348	2.19	0.024	3.37	1872.72	7.86	28.26	50.5[illegible]	33.31	6.46
52356	2.21	0.039	11.81	1893.10	7.85	26.74	33.98	4.84	9.[illegible]1
52404	2.23	0.056	12.65	1756.26	7.85	36.95	22.74	18.16	9.77
52412	2.25	0.075	14.34	1805.75	7.85	33.26	54.32	53.59	9.27
52428	2.27	0.102	10.12	1942.59	7.86	19.39	44.95	4.84	7.25
52436	2.28	0.114	8.43	1960.06	7.86	18.03	11.47	4.84	7.25
52444	2.30	0.126	9.28	1962.97	7.86	17.80	43.09	50.02	7.25
52452	2.30	0.135	6.75	1949.39	7.96	21.42	15.31	47.36	7.18
52500	2.32	0.145	7.59	1930.95	7.86	20.30	46.81	4.84	7.38
52508	2.33	0.155	7.59	1930.95	7.86	20.30	7.75	4.84	7.38
52516	2.33	0.164	6.75	1916.39	7.99	21.43	28.21	40.39	7.44
52524	2.34	0.172	5.90	1896.01	8.12	23.01	13.33	49.24	8.01
52532	2.35	0.180	5.90	1946.41	7.73	18.94	43.09	4.84	7.51
52540	2.36	0.187	5.06	1946.49	8.24	21.64	13.45	3.40	7.25
52548	2.39	0.224	27.83	1933.86	7.95	20.07	15.17	42.99	7.51
52556	2.40	0.229	4.22	1919.30	8.12	21.20	28.21	50.66	7.51
52604	2.40	0.234	3.37	1897.04	7.72	25.38	43.17	35.33	7.62
52612	2.41	0.239	4.22	1923.22	8.11	23.45	26.45	3.40	7.98
52620	2.42	0.248	6.75	1896.01	7.47	23.01	22.63	33.69	7.82
52628	2.42	0.250	0.84	23.92	-4.85	166.32	39.37	51.29	-1.41



RECORD OF TRRL DRILL RUN 1.3.4 (2.17 to 2.42 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.3.4 (2.17 to 2.42 metres)



USER: EX9069 -AT SYSTEM

NR_T1.4.1

LABEL: PRT009 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:25, ON: PRO BY: PRC

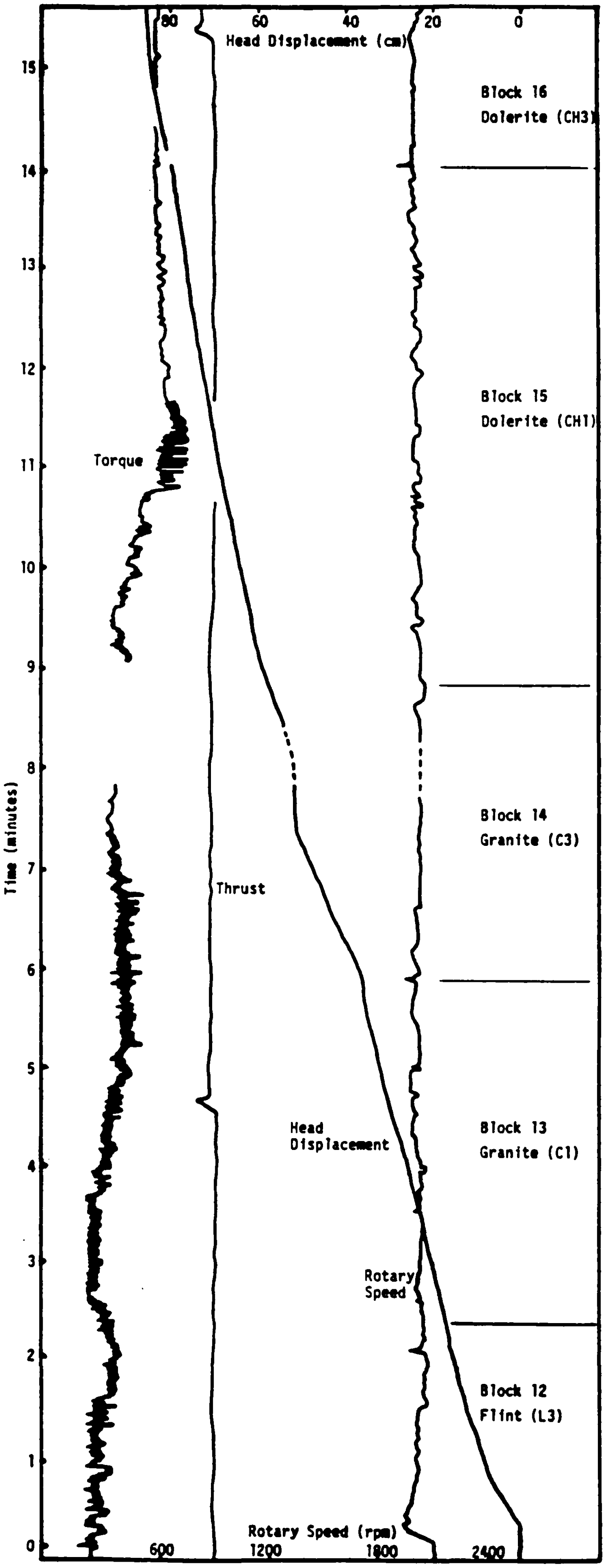
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
172252	2.42	0.000	0.00	2075.67	-4.06	15.71	47.0[illegible]	99.99	6.91
172256	2.42	0.001	1.69	2055.27	0.25	17.20	47.06	99.99	6.98
172300	2.42	0.002	1.69	2055.27	3.51	17.20	43.35	99.99	7.16
172304	2.42	0.004	3.37	1982.41	6.91	22.49	22.95	24.35	7.35
172308	2.43	0.013	13.49	1892.06	8.21	29.05	4.41	99.99	8.93
172312	2.45	0.027	20.24	1894.97	8.08	28.84	6.27	99.99	9.56
172316	2.46	0.038	16.86	1897.89	8.08	28.63	17.34	26.04	9.12
172320	2.47	0.049	16.87	1912.46	8.08	27.57	32.22	99.99	9.06
172324	2.48	0.058	13.49	1921.20	8.08	26.94	52.62	99.99	8.99
172328	2.49	0.065	10.12	1929.95	8.08	26.30	61.89	99.99	6.87
172332	2.49	0.073	11.81	1935.77	8.08	25.88	56.33	17.79	8.60
172336	2.50	0.078	6.75	1944.52	8.08	25.24	41.50	22.71	8.68
172340	2.50	0.083	8.43	1962.00	8.08	23.97	28.52	35.47	8.43
172344	2.51	0.089	8.43	1964.92	8.08	23.76	19.24	39.37	8.30
172348	2.51	0.094	8.43	1976.58	8.08	22.91	11.83	37.72	8.11
172352	2.52	0.101	10.12	1959.09	8.08	24.18	11.83	37.55	8.36
172356	2.53	0.108	10.12	1941.60	8.08	25.45	24.81	33.64	8.43
172400	2.53	0.114	8.43	1944.52	8.08	25.24	37.79	26.99	8.24
172404	2.54	0.120	10.12	1953.26	8.08	24.61	50.77	99.99	8.43
172408	2.55	0.126	8.43	1964.92	8.08	23.76	52.62	99.99	6.17
172412	2.55	0.130	6.75	1950.35	8.08	24.82	37.79	99.99	6.43
172416	2.55	0.134	5.06	1964.92	8.08	23.76	22.95	99.99	8.17
172420	2.56	0.137	5.06	1970.75	8.08	23.34	8.12	99.99	8.17
172424	2.56	0.141	5.06	2011.55	8.08	20.37	6.27	99.99	7.61
172428	2.56	0.143	3.37	1982.41	8.08	22.49	21.10	99.99	7.48
172432	2.57	0.147	6.75	1988.23	8.08	22.07	21.10	28.35	7.86
172436	2.57	0.153	8.43	1976.58	8.08	22.91	34.06	33.83	7.92
172440	2.58	0.157	6.75	1985.32	8.08	22.28	47.06	30.07	7.80
172444	2.58	0.161	5.06	2002.81	7.30	21.01	58.18	99.99	7.54
172448	2.58	0.163	3.37	2023.21	7.30	19.53	37.79	99.99	7.67
172452	2.59	0.165	3.37	2014.46	7.30	20.16	22.95	4.83	7.54
172456	2.59	0.170	6.75	1956.18	7.30	24.40	9.97	99.99	7.54
172500	2.60	0.175	8.43	1988.23	7.30	22.07	8.12	15.17	7.86
172504	2.60	0.179	5.06	1991.15	7.30	21.86	17.39	99.99	7.67
172508	2.60	0.182	5.06	1982.41	7.30	22.49	30.37	99.99	7.67
172512	2.61	0.186	5.06	1988.23	7.30	22.07	50.77	99.99	7.86
172516	2.61	0.189	5.06	1982.41	7.30	22.49	61.89	99.99	7.80
172520	2.61	0.192	5.06	1982.41	7.17	22.49	58.18	17.79	7.80
172524	2.62	0.196	5.06	1985.32	7.17	22.28	39.64	29.01	7.86
172528	2.62	0.199	5.06	1967.83	7.17	23.55	26.66	31.31	8.11
172532	2.62	0.204	6.75	1953.26	7.17	24.61	15.54	38.06	7.98
172536	2.63	0.207	5.06	1947.43	7.17	25.03	6.27	38.06	8.36
172540	2.63	0.210	5.06	1950.35	7.17	24.82	15.54	38.22	8.24
172544	2.63	0.215	6.75	1962.00	7.17	23.97	21.10	34.20	8.05
172548	2.64	0.218	5.06	1964.92	7.17	23.76	41.50	22.15	7.98
172552	2.64	0.221	5.06	1962.00	7.04	23.97	50.77	22.43	8.05
172556	2.64	0.224	3.37	1964.92	7.04	23.76	52.62	99.99	7.92
172600	2.65	0.227	5.06	1973.66	7.17	23.13	39.64	99.99	7.86
172604	2.65	0.230	5.06	1970.75	7.30	23.34	13.68	99.99	7.80
172608	2.65	0.235	6.75	1973.66	7.17	23.13	9.97	20.39	7.54
172612	2.66	0.238	5.06	1979.49	7.17	22.70	9.97	99.99	7.54
172616	2.66	[illegible]	5.06	1979.49	7.17	22.70	21.10	95.99	7.80
17[illegible]2[illegible]	2.67	[illegible]	[illegible]6	1973.66	7.17	2[illegible]	39.64	99.99	7.8[illegible]
172624	2.67	[illegible]	[illegible]	1967.83	7.17	2[illegible]	58.18	99.99	7.86

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
172628	2.67	0.253	6.75	1982.41	7.17	22.49	52.04	3.4	7.61
172632	2.68	0.256	5.06	1976.58	7.17	22.91	51.77	99.99	7.61
172636	2.68	0.261	6.75	1970.75	7.17	23.34	32.22	32.88	7.61
172640	2.68	0.264	5.06	1967.83	7.17	23.55	19.24	38.72	7.86
172644	2.69	0.265	6.75	1996.98	7.17	21.43	19.24	37.55	7.61
172648	2.69	0.271	3.37	1962.00	7.30	23.97	22.95	37.55	7.67
172652	2.69	0.274	5.06	1956.18	7.43	24.40	13.68	39.37	7.86
172656	2.70	0.278	5.06	1932.86	7.43	26.09	21.10	34.75	8.05
172700	2.70	0.282	6.75	1929.95	7.43	26.30	45.22	99.99	8.24
172704	2.71	0.286	5.06	1929.95	7.17	26.30	54.48	99.99	8.11
172708	2.71	0.290	6.75	1921.20	7.30	26.94	47.06	99.99	8.36
172712	2.71	0.295	6.75	1924.12	7.30	26.72	32.22	99.99	8.36
172716	2.72	0.298	5.06	1929.95	7.62	26.30	11.83	99.99	8.17
172720	2.72	0.302	6.75	1924.12	7.17	26.72	4.41	99.99	8.05
172724	2.73	0.307	6.75	1918.29	7.56	27.15	13.68	99.99	8.36
172728	2.73	0.310	5.06	1935.77	6.25	25.88	22.95	99.99	8.24
172732	2.73	0.313	3.37	1897.89	7.30	28.63	39.64	99.99	8.11
172736	2.74	0.317	6.75	1894.97	6.91	28.84	47.06	99.99	8.61
172740	2.74	0.320	5.06	1894.97	7.04	28.84	54.48	99.99	8.61
172744	2.74	0.324	5.06	1915.37	6.91	27.36	60.04	99.99	8.36
172748	2.75	0.327	5.06	1924.12	7.43	26.72	39.64	99.99	7.54
172752	2.75	0.331	5.06	1970.75	6.65	23.34	17.39	99.99	7.54
172756	2.75	0.334	5.06	1970.75	7.17	23.34	8.12	99.99	7.61
172800	2.76	0.337	5.06	1976.58	6.91	22.91	8.12	99.99	7.42
172804	2.76	0.341	5.06	1964.92	7.30	23.76	17.39	99.99	7.48
172808	2.76	0.344	5.06	1956.18	7.43	24.40	34.08	99.99	7.67
172812	2.77	0.347	5.06	1941.60	6.39	25.45	56.33	99.99	7.80
172816	2.77	0.350	3.37	1921.20	7.43	26.94	60.04	99.99	8.05
172820	2.77	0.353	5.06	1921.20	7.43	26.94	52.62	3.40	8.17
172824	2.78	0.356	5.06	1935.77	7.43	25.88	43.35	28.57	7.98
172828	2.78	0.360	5.06	1932.86	6.65	26.09	24.81	39.85	7.86
172832	2.78	0.363	5.06	1912.46	6.65	27.57	9.97	36.70	7.98
172836	2.79	0.367	5.06	1932.86	6.78	26.09	9.97	40.01	7.98
172840	2.79	0.371	6.75	1897.89	6.39	28.63	11.83	38.55	7.54
172844	2.81	0.387	23.61	1956.18	6.78	24.40	26.66	34.20	7.73
172848	2.81	0.392	8.43	1944.52	7.17	25.24	43.35	99.99	7.54
172852	2.82	0.399	10.12	1935.77	6.52	25.88	50.77	6.44	7.61
172856	2.83	0.406	10.12	1918.29	7.17	27.15	43.35	99.99	7.92
172900	2.83	0.413	10.12	1927.03	6.52	26.51	26.66	99.99	7.92
172904	2.84	0.419	10.12	1953.35	7.43	24.82	11.83	99.99	7.80
172908	2.84	0.425	8.43	1967.83	6.52	23.55	8.12	99.99	7.48
172912	2.85	0.431	8.43	1970.75	7.43	23.34	4.41	99.99	7.16
172916	2.86	0.435	6.75	1967.83	7.04	23.55	17.39	99.99	7.29
172920	2.86	0.441	8.43	1964.92	6.39	23.76	34.08	3.40	7.29
172924	2.87	0.446	8.43	1947.43	7.30	25.03	56.33	99.99	7.35
172928	2.87	0.451	6.75	1932.86	6.39	26.09	61.89	99.99	7.67
172932	2.88	0.458	10.12	1979.49	6.52	22.70	56.33	99.99	7.10
172936	2.89	0.465	11.81	1982.41	7.30	22.49	39.64	18.14	7.10
172940	2.89	0.471	8.43	1982.41	6.52	22.49	26.66	37.21	6.98
172944	2.90	0.477	8.43	1988.23	7.56	22.07	15.54	40.17	6.91
172948	2.90	0.482	8.43	1985.32	6.52	22.28	8.12	38.72	7.04
172952	2.91	0.489	10.12	1973.66	7.56	23.13	11.83	33.83	6.98
172956	2.92	0.496	10.12	1982.41	6.52	22.49	21.10	30.07	7.10
173000	2.92	0.501	8.43	1979.49	7.43	22.70	43.35	33.07	7.04
173004	2.93	0.506	6.75	1973.66	6.25	23.13	52.62	99.99	7.04
173008	2.93	0.513	10.12	1970.75	7.43	23.34	54.48	18.14	7.35
173012		0.517	6.75	1962.00	6.52	23.97	39.64	99.99	7.16
173016		.522	6.75	1941.60	6.65	25.45	24.81	99.99	7.73

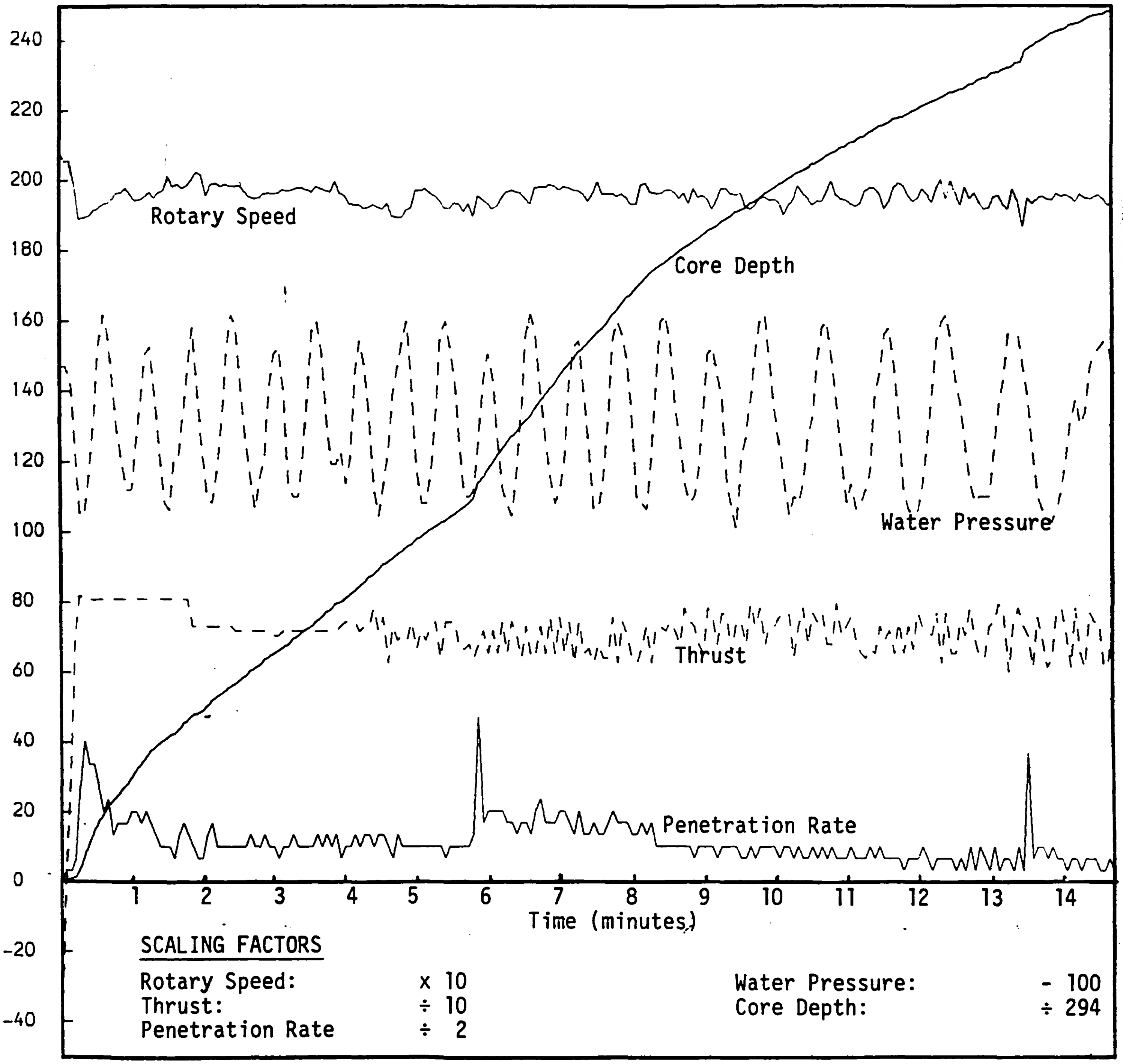
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
173020	2.95	0.527	8.43	1964.92	6.25	23.76	6.27	99.99	7.23
173024	2.95	0.532	6.75	1996.98	6.78	21.43	6.27	99.99	6.79
173028	2.96	0.536	6.75	1962.00	6.39	23.97	15.54	99.99	7.04
173032	2.96	0.542	8.43	1962.00	6.39	23.97	30.37	99.99	7.23
173036	2.97	0.549	10.12	1962.00	7.56	23.97	54.48	99.99	7.23
173040	2.97	0.554	8.43	1956.18	6.25	24.40	60.04	99.99	7.29
173044	2.98	0.560	8.43	1962.00	7.43	23.97	56.33	15.17	7.16
173048	2.99	0.566	8.43	1950.35	7.04	24.82	48.91	99.99	7.23
173052	2.99	0.570	6.75	1932.86	6.39	26.09	32.22	99.99	7.42
173056	2.99	0.575	6.75	1932.86	6.25	26.09	8.12	99.99	7.67
173100	3.00	0.580	8.43	1988.23	6.65	22.07	8.12	6.87	6.91
173104	3.00	0.585	6.75	1994.06	7.30	21.64	6.27	99.99	6.85
173108	3.01	0.590	8.43	1967.83	6.25	23.55	21.1[illegible]	99.99	6.66
173112	3.01	0.594	5.06	1964.92	7.30	23.76	41.50	99.99	7.16
173116	3.02	0.597	5.06	1964.92	7.30	23.76	60.04	99.99	7.10
173120	3.02	0.600	5.06	1970.75	7.17	23.34	61.89	99.99	7.04
173124	3.02	0.604	5.06	1973.66	7.43	23.13	54.48	9.13	7.[illegible]4
173128	3.03	0.607	5.06	1967.83	7.17	23.55	35.93	32.30	6.98
173132	3.03	0.611	5.06	1950.35	6.78	24.82	26.66	38.06	7.23
173136	3.03	0.614	5.06	1964.92	7.82	23.76	13.68	38.88	7.23
173140	3.04	0.617	5.06	1935.77	7.43	25.88	8.12	33.83	7.42
173144	3.04	0.620	3.37	1976.58	7.30	22.91	9.97	37.38	7.48
173148	3.04	0.623	5.06	1953.26	6.78	24.61	17.39	36.53	7.04
173152	3.05	0.626	5.06	1956.18	6.52	24.40	34.08	18.14	7.23
173156	3.05	0.630	5.06	1947.43	7.62	25.03	50.77	31.71	7.23
173200	3.05	0.633	5.06	1918.29	7.56	27.15	52.62	99.95	7.73
173204	3.06	0.635	3.37	1944.52	6.78	25.24	45.20	13.90	7.23
173208	3.06	0.639	5.06	1976.58	7.69	22.91	37.79	99.99	6.72
173212	3.06	0.642	5.06	1976.58	7.56	22.91	13.68	99.99	6.79
173216	3.07	0.645	5.06	1962.00	6.52	23.97	6.27	99.99	7.04
173220	3.07	0.649	5.06	1959.09	7.43	24.18	[illegible]	99.99	7.10
173224	3.07	0.651	3.37	1964.92	7.43	23.76	21.10	99.99	7.04
173228	3.07	0.653	3.37	1924.12	6.78	26.72	26.66	99.99	7.48
173232	3.08	0.657	5.06	1918.29	7.95	27.15	37.79	99.99	7.01
173236	3.08	0.659	3.37	1929.95	7.30	26.30	50.77	99.99	7.48
173240	3.08	0.662	5.06	1950.35	7.82	24.82	60.04	99.99	7.23
173244	3.09	0.666	5.06	1953.26	6.78	24.61	61.89	31.71	7.16
173248	3.09	0.669	5.06	1944.52	7.30	25.24	48.91	3.40	7.04
173252	3.09	0.672	5.06	1944.52	7.30	25.24	34.05	35.47	7.10
173256	3.09	0.675	3.37	1938.69	7.56	25.67	24.81	30.49	6.79
173300	3.10	0.678	5.06	1900.80	7.69	28.42	13.68	36.70	7.23
173304	3.10	0.681	5.06	1929.95	7.69	26.30	4.41	37.89	6.98
173308	3.10	0.684	3.37	1944.52	6.39	25.24	9.97	36.35	7.42
173312	3.11	0.687	5.06	1985.32	7.30	22.28	8.12	34.38	6.41
173316	3.11	0.689	3.37	1964.92	7.82	23.76	13.68	37.38	6.91
173320	3.11	0.691	3.37	1950.35	6.78	24.82	26.66	33.83	6.55
173324	3.11	0.695	5.06	1929.95	7.69	26.30	32.22	35.83	7.35
173328	3.12	0.697	3.37	1941.60	7.43	25.45	48.91	20.09	7.23
173332	3.12	0.700	5.06	1941.60	7.69	25.45	58.18	95.59	7.35
173336	3.12	0.703	3.37	1967.83	6.78	23.55	60.04	99.99	6.91
173340	3.13	0.706	5.06	1999.89	6.78	21.22	48.91	99.99	6.53
173344	3.13	0.708	3.37	1959.09	7.95	24.18	35.93	25.06	6.91
173348	3.13	0.711	3.37	1947.43	7.04	25.03	21.10	99.99	7.10
173352	3.13	0.713	3.37	1944.52	7.30	25.24	8.12	10.38	6.98
173356	3.14	0.716	5.06	1932.86	7.56	26.09	13.68	38.88	7.23
173400	3.14	0.718	3.37	1927.03	6.91	26.51	6.27	37.72	7.42
173404	3.14	0.721	3.37	1935.77	6.52	25.88	8.12	36.53	7.29
173408	3.14	0.723	3.37	1970.75	6.39	23.34	11.83	33.83	6.98

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
173412	3.15	0.726	5.06	1979.49	6.55	22.7	17.34	38.22	6.72
173416	3.15	0.729	3.37	1979.49	6.52	22.72	39.64	35.29	6.41
173420	3.15	0.732	5.06	1962.00	7.30	23.97	45.20	10.38	6.72
173424	3.15	0.734	3.37	1921.20	6.91	26.94	56.33	99.99	7.42
173428	3.16	0.736	3.37	1941.60	7.17	25.45	56.14	99.99	7.29
173432	3.16	0.739	3.37	1982.41	6.52	22.49	47.96	99.99	6.72
173436	3.16	0.741	3.37	1994.96	7.43	21.64	32.22	99.99	6.35
173440	3.16	0.742	1.69	1985.32	6.52	22.28	11.83	99.99	6.41
173444	3.16	0.744	3.37	1959.09	7.30	24.18	6.27	99.99	6.79
173448	3.17	0.747	3.37	1941.60	6.65	25.45	4.41	26.04	7.16
173452	3.17	0.749	3.37	1950.35	7.69	24.82	6.27	99.99	7.16
173456	3.17	0.752	5.06	1976.58	7.30	22.91	13.68	99.99	6.53
173500	3.17	0.754	3.37	1962.00	7.17	23.97	24.81	99.99	6.79
173504	3.18	0.756	1.69	1938.69	7.04	25.67	39.64	99.99	6.91
173508	3.18	0.758	3.37	1979.49	7.69	22.76	54.48	99.99	6.22
173512	3.18	0.760	3.37	2005.72	6.25	20.80	60.94	99.99	7.16
173516	3.18	0.762	3.37	1950.35	7.69	24.82	61.83	99.99	6.66
173520	3.18	0.765	3.37	1999.89	6.52	21.22	54.48	6.87	6.53
173524	3.19	0.766	1.69	1967.83	6.52	23.55	43.35	22.98	6.60
173528	3.19	0.768	3.37	1929.95	7.43	26.33	35.93	32.69	6.91
173532	3.19	0.769	1.69	1982.41	7.04	22.49	24.81	38.55	6.65
173536	3.19	0.772	5.06	1950.35	7.82	24.82	13.68	40.64	6.79
173540	3.19	0.774	1.69	1964.92	6.91	23.76	8.12	40.95	6.85
173544	3.20	0.777	5.06	1938.69	6.39	25.67	9.97	35.11	7.16
173548	3.20	0.779	3.37	1918.29	6.39	27.15	9.97	36.70	7.35
173552	3.20	0.780	1.69	1921.20	7.30	26.94	9.97	37.38	7.23
173556	3.20	0.784	5.06	1953.26	7.43	24.61	22.95	34.20	6.72
173600	3.20	0.785	1.69	1959.09	7.95	24.18	35.93	33.45	6.79
173604	3.21	0.787	3.37	1932.86	7.69	26.09	43.35	33.45	7.04
173608	3.21	0.789	3.37	1918.29	5.99	27.15	56.33	26.04	7.23
173612	3.21	0.790	1.69	1976.58	7.43	22.91	56.33	22.71	6.85
173616	3.21	0.794	5.06	1941.60	7.62	25.45	56.33	99.99	6.98
173620	3.22	0.795	1.69	1868.74	7.30	30.75	47.06	29.86	6.79
173624	3.23	0.807	18.55	1950.35	7.04	24.82	37.79	27.45	7.04
173628	3.23	0.810	3.37	1935.77	6.12	25.88	22.95	99.99	6.98
173632	3.23	0.813	5.06	1947.43	7.56	25.03	9.97	99.99	7.10
173636	3.24	0.816	5.06	1956.18	6.91	24.40	6.27	99.99	6.60
173640	3.24	0.819	3.37	1947.43	6.12	25.03	4.41	99.99	6.85
173644	3.24	0.822	5.06	1944.52	6.39	25.24	2.55	99.99	6.75
173648	3.24	0.824	3.37	1962.00	7.69	23.97	6.27	25.56	6.85
173652	3.25	0.826	3.37	1956.18	7.82	24.40	11.83	95.99	6.79
173656	3.25	0.827	1.69	1959.09	7.17	24.18	21.10	99.99	6.72
173700	3.25	0.830	3.37	1953.26	6.12	24.61	32.22	15.57	6.79
173704	3.25	0.832	3.37	1941.60	7.82	25.45	37.79	99.99	6.91
173708	3.25	0.833	1.69	1962.00	6.52	23.97	30.37	99.99	6.53
173712	3.26	0.835	3.37	1953.26	6.12	24.61	34.08	21.29	6.66
173716	3.26	0.838	3.37	1950.35	7.69	24.82	47.06	25.80	6.79
173720	3.26	0.840	3.37	1956.18	7.43	24.40	50.77	99.99	6.85
173724	3.26	0.841	1.69	1962.00	7.43	23.97	52.62	99.99	6.53
173728	3.26	0.842	1.69	1950.35	6.12	24.82	54.48	99.99	6.72
173732	3.26	0.844	3.37	1935.77	6.25	25.88	52.62	95.99	6.79
173736	3.27	0.845	1.69	1941.60	7.56	25.45	45.20	28.57	7.04



RECORD OF TRRL DRILL RUN 1.4.1
(2.42 to 3.27 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.4.1 (2.42 to 3.27 metres)



USER: EX9069 -AT SYSTEM

NR_T1.4.2

EX9069

NR_T1.4.2

LABEL: PRT010 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:26, ON: PRC BY: PRO

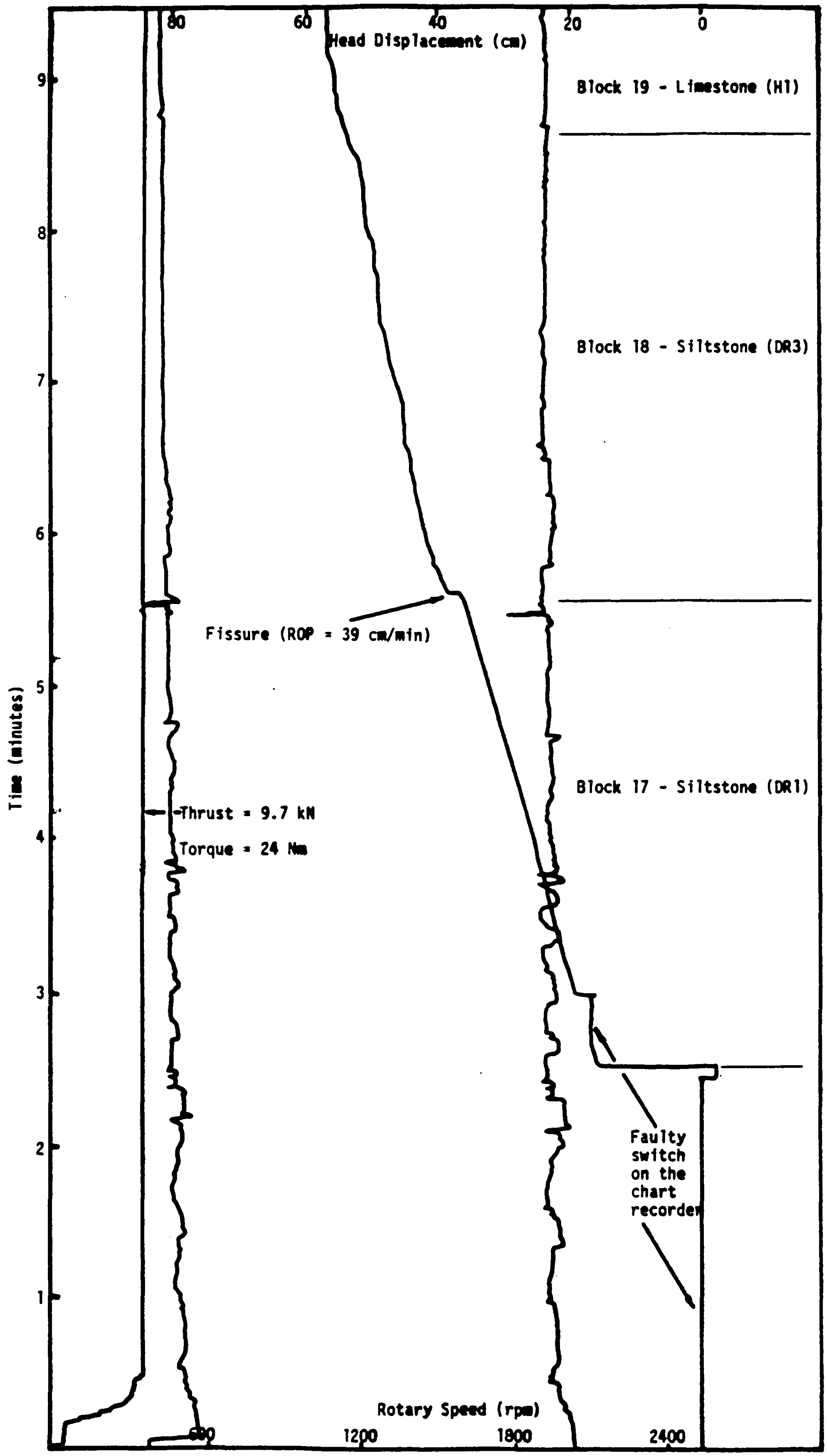
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TOTAL CORE PENETRATN ROTARY INLET H2O I. H2O

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
181949	3.27	0.000	0.00	1992.09	9.65	21.79	51.89	25.80	7.86
181954	3.28	0.008	8.43	1983.35	9.65	22.42	4.41	99.99	7.98
181958	3.28	0.015	10.12	1995.00	9.65	21.58	17.37	9.13	7.86
182002	3.29	0.020	8.43	1992.09	9.65	21.79	43.35	99.99	7.92
182006	3.29	0.025	6.75	1977.53	9.65	22.84	61.89	99.99	8.11
182010	3.30	0.029	6.75	1974.62	9.65	23.06	56.18	99.99	8.17
182014	3.30	0.034	6.75	1945.50	9.65	25.17	50.77	10.72	8.43
182018	3.31	0.039	8.43	1945.50	9.65	25.17	26.66	37.38	8.55
182022	3.31	0.044	6.75	1962.97	9.65	23.90	13.68	38.88	8.30
182026	3.32	0.049	8.43	1977.53	9.65	22.84	11.65	40.80	7.98
182030	3.33	0.055	8.43	1971.71	9.65	23.27	19.24	36.70	8.05
182034	3.33	0.061	8.43	2000.82	9.65	21.15	17.39	39.05	7.80
182038	3.34	0.069	11.81	1997.91	9.65	21.36	41.50	24.04	7.67
182042	3.35	0.075	10.12	1995.00	9.65	21.58	60.04	99.99	7.73
182046	3.35	0.081	8.43	1960.06	9.65	24.11	56.18	99.99	7.98
182050	3.36	0.087	8.43	1945.50	9.65	25.17	32.22	99.99	8.36
182054	3.36	0.091	6.75	1945.50	9.65	25.17	6.27	99.99	8.43
182058	3.37	0.096	6.75	1957.15	9.65	24.33	9.97	99.99	8.30
182102	3.37	0.101	8.43	1983.35	9.65	22.42	22.95	99.99	7.98
182106	3.38	0.106	6.75	1968.79	9.65	23.48	43.35	99.99	7.92
182110	3.38	0.111	8.43	1995.00	9.65	21.58	60.04	99.99	7.80
182114	3.39	0.116	6.75	2018.29	9.65	19.88	61.89	99.99	7.42
182118	3.39	0.121	8.43	1980.44	9.65	22.63	50.77	18.48	7.67
182122	3.40	0.127	8.43	2021.20	9.65	19.67	22.95	31.71	7.23
182126	3.40	0.132	6.75	2018.29	9.65	19.88	13.68	38.72	7.35
182130	3.41	0.137	8.43	2018.29	9.65	19.88	13.66	38.55	7.48
182134	3.41	0.144	10.12	1971.71	9.52	23.27	15.54	32.69	8.05
182138	3.42	0.148	6.75	1962.97	9.65	23.90	22.95	34.57	7.98
182142	3.42	0.154	8.43	1933.86	9.65	26.02	47.06	12.51	8.24
182146	3.43	0.157	5.06	1942.59	9.65	25.38	56.33	99.99	8.36
182150	3.43	0.161	5.06	1954.24	9.65	24.54	45.22	22.43	8.11
182154	3.44	0.165	6.75	2003.73	9.65	20.94	21.10	34.93	7.73
182158	3.44	0.169	5.06	1983.35	9.65	22.42	8.12	43.64	7.54
182202	3.44	0.173	6.75	1939.68	9.65	25.59	15.54	40.01	8.11
182206	3.45	0.178	6.75	1937.76	9.65	24.87	22.95	34.57	8.36
182210	3.45	0.181	5.06	1951.33	9.65	24.75	39.64	30.49	8.17
182214	3.46	0.186	6.75	1992.09	9.65	21.79	58.13	30.90	7.42
182218	3.46	0.190	6.75	1974.62	9.65	23.06	61.89	99.99	7.73
182222	3.46	0.195	6.75	1965.88	9.65	23.69	39.64	99.99	7.80
182226	3.47	0.199	6.75	1948.41	9.65	24.96	6.27	99.99	8.11
182230	3.47	0.204	6.75	1919.30	9.65	27.07	8.12	99.99	8.36
182234	3.48	0.207	5.06	1971.71	9.65	23.27	17.39	99.99	7.92
182238	3.48	0.212	8.43	1992.09	9.65	21.79	47.06	99.99	7.54
182242	3.49	0.217	6.75	1933.86	9.65	26.02	58.18	99.99	7.98
182246	3.49	0.220	5.06	1922.21	9.65	26.86	60.04	99.99	8.49
182250	3.49	0.224	5.06	1997.91	9.65	21.36	41.50	99.99	7.73
182254	3.50	0.228	6.75	1962.97	9.65	23.90	22.95	36.87	7.42
182258	3.50	0.232	5.06	1955.21	9.65	23.59	6.27	44.24	8.36
[illegible]302	3.50	0.235	5.06	1943.58	9.65	24.44	8.12	40.48	8.17
182306	3.51	0.238	5.06	1977.53	9.65	22.84	26.62	34.01	7.67
182310	3.51	0.243	6.75	1974.62	9.65	23.56	45.20	34.75	7.73
182314	3.52	0.246	5.06	1962.97	9.52	23.90	60.04	99.99	7.73
[illegible]318	3.52	[illegible].251	6.75	1960.06	9.65	24.11	60.04	99.99	7.80
[illegible]322	3.53	[illegible]	6.75	1943.58	9.65	24.44	34.08	99.99	7.80

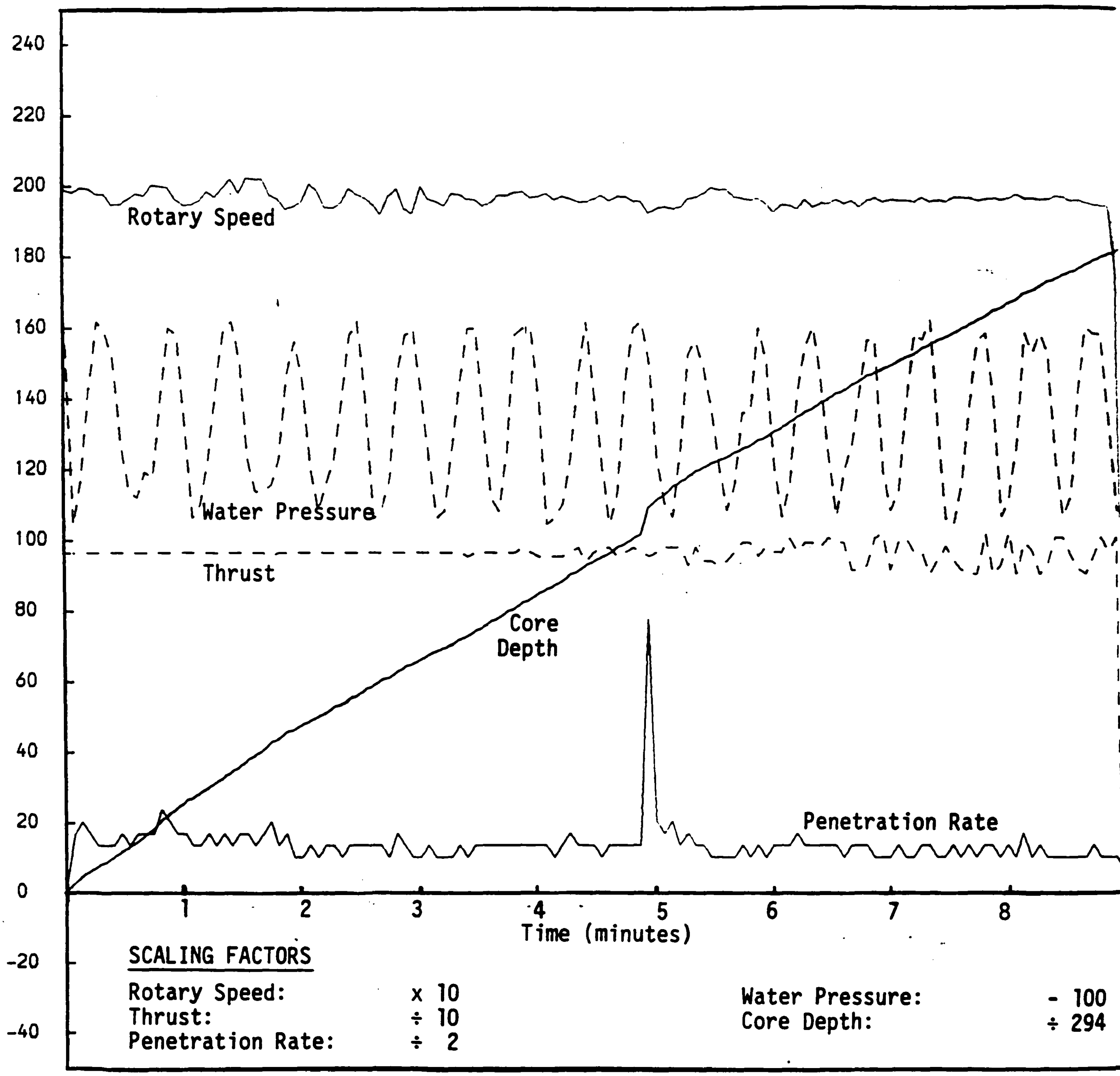
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
182326	3.53	0.260	6.75	1952.30	9.65	23.80	11.83	99.99	7.92
182330	3.53	0.264	6.75	1972.66	9.65	22.31	6.12	99.99	7.73
182334	3.54	0.269	6.75	1972.66	9.65	22.31	24.81	99.99	7.54
182338	3.54	0.273	6.75	1981.39	9.65	21.67	58.18	99.99	7.48
182342	3.55	0.278	6.75	1983.35	9.78	22.42	60.04	99.99	7.35
182346	3.55	0.282	6.75	1966.85	9.65	22.73	60.04	4.83	7.67
182350	3.56	0.287	6.75	1969.75	9.52	22.52	39.64	32.32	7.67
182354	3.56	0.291	6.75	1978.48	9.52	21.88	4.41	35.47	7.54
182358	3.56	0.295	5.06	1961.03	9.52	23.16	6.27	40.64	7.92
182402	3.57	0.299	6.75	1969.75	9.52	22.52	9.97	39.53	7.61
182406	3.57	0.305	8.43	1963.94	9.65	22.95	22.95	31.31	7.42
182410	3.58	0.309	6.75	1955.21	9.78	23.59	47.06	26.76	7.67
182414	3.58	0.314	6.75	1955.21	9.39	23.59	61.69	99.99	7.92
182418	3.59	0.318	6.75	1963.94	9.65	22.95	41.57	99.99	7.73
182422	3.59	0.322	5.06	1972.66	9.78	22.31	21.10	99.99	7.73
182426	3.60	0.326	6.75	1958.12	9.78	23.37	4.41	99.99	7.54
182430	3.60	0.331	6.75	1969.75	9.52	22.52	13.68	99.99	7.48
182434	3.61	0.335	6.75	1969.75	9.65	22.52	45.2	99.99	7.48
182438	3.61	0.340	6.75	1958.12	9.78	23.37	60.04	99.99	7.61
182442	3.61	0.344	6.75	1955.21	9.65	23.59	61.89	99.99	7.42
182446	3.64	0.370	38.79	1923.22	9.52	25.94	50.77	6.87	7.86
182450	3.65	0.377	10.12	1934.85	9.65	25.08	22.95	35.29	7.98
182454	3.65	0.382	8.43	1940.67	9.78	24.65	9.97	99.99	7.80
182458	3.66	0.389	10.12	1934.85	9.78	25.08	6.27	99.99	7.80
182502	3.66	0.394	6.75	1937.76	9.78	24.87	24.81	99.99	7.92
182506	3.67	0.399	8.43	1961.03	9.26	23.16	52.62	99.99	7.42
182510	3.67	0.404	6.75	1966.85	9.78	22.73	56.33	99.99	7.42
182514	3.68	0.408	6.75	1975.57	9.39	22.09	48.91	99.99	7.35
182518	3.68	0.412	5.06	1993.02	9.39	20.81	37.79	10.95	7.16
182522	3.68	0.415	5.06	1987.21	9.26	21.24	21.10	25.56	7.29
182526	3.69	0.418	5.06	1987.21	9.39	21.24	8.12	37.38	7.16
182530	3.69	0.422	5.06	1966.85	9.65	22.73	15.54	36.18	7.16
182534	3.70	0.426	6.75	1961.03	9.91	23.16	35.93	22.71	7.48
182538	3.70	0.429	5.06	1958.12	9.91	23.37	35.93	99.99	7.54
182542	3.70	0.434	6.75	1961.03	9.52	23.16	60.04	99.99	7.48
182546	3.71	0.437	5.06	1946.49	9.78	24.23	50.77	99.99	7.61
182550	3.71	0.442	6.75	1923.22	9.65	25.94	21.10	99.99	7.86
182554	3.72	0.446	6.75	1943.58	9.65	24.44	6.27	99.99	7.61
182558	3.72	0.451	6.75	1940.67	10.04	24.65	15.54	99.99	7.73
182602	3.73	0.456	8.43	1931.94	9.65	25.30	41.57	99.99	7.73
182606	3.73	0.461	6.75	1958.12	9.91	23.37	54.48	99.99	7.61
182610	3.74	0.465	6.75	1937.76	9.91	24.87	60.04	99.99	7.54
182614	3.74	0.470	6.75	1946.49	9.78	24.23	45.20	11.49	7.54
182618	3.74	0.474	6.75	1946.49	10.04	24.23	22.95	38.98	7.54
182622	3.75	0.479	6.75	1958.12	9.91	23.37	6.27	35.65	7.35
182626	3.75	0.482	5.06	1946.49	9.91	24.23	19.24	37.21	7.42
182630	3.76	0.487	6.75	1955.21	9.13	23.59	26.66	39.53	7.54
182634	3.76	0.491	6.75	1937.76	9.13	24.87	41.53	22.15	7.54
182638	3.77	0.496	6.75	1955.21	9.26	23.59	56.33	99.99	7.73
182642	3.77	0.499	5.06	1963.94	10.04	22.95	56.33	99.99	7.29
182646	3.77	0.503	5.06	1952.30	10.17	23.80	19.24	99.99	7.48
182650	3.78	0.506	5.06	1958.12	9.13	23.37	8.12	99.99	7.35
182654	3.78	0.510	6.75	1955.21	9.91	23.59	13.68	99.99	7.35
182658	3.78	0.514	5.06	1955.21	10.04	23.59	37.79	99.99	7.29
182702	3.79	0.517	5.06	1952.30	9.65	23.80	58.18	99.99	7.29
182706	3.79	0.522	6.75	1963.94	9.65	22.95	56.33	95.99	7.42
182710	3.80	0.526	6.75	[illegible]	9.00	23.80	[illegible].89	99.99	7.35
182714	3.80	0.530	5.06		9.39	23.59	22	37.38	7.29

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. HID	PAGE 3
182718	3.8	0.533	5.06	1952.30	9.78	23.81	4.41	41.88	7.29
182722	3.81	0.537	6.75	1963.94	9.39	22.95	4.41	43.08	7.23
182726	3.81	0.541	5.06	1963.94	9.13	22.95	15.54	31.13	7.23
182730	3.82	0.545	6.75	1961.03	9.00	23.16	37.79	99.99	7.16
182734	3.82	0.549	5.06	1955.21	9.00	23.59	56.33	26.13	7.29
182738	3.82	0.553	6.75	1958.12	10.17	23.37	58.18	95.99	7.23
182742	3.83	0.558	6.75	1961.03	9.00	23.16	39.64	99.99	7.10
182746	3.83	0.561	5.06	1956.12	9.26	23.37	6.27	99.99	7.16
182750	3.84	0.566	6.75	1961.03	10.17	23.16	11.83	99.99	7.20
182754	3.84	0.569	5.06	1972.66	9.00	22.31	26.66	99.99	6.98
182758	3.84	0.575	8.43	1961.03	9.91	23.16	58.18	99.99	7.35
182802	3.85	0.578	5.06	1961.03	9.65	23.16	52.62	31.13	7.10
182806	3.85	0.582	6.75	1958.12	9.00	23.37	58.18	99.99	7.23
182810	3.86	0.586	5.06	1956.12	9.26	23.37	52.62	99.99	7.16
182814	3.86	0.589	5.06	1966.85	10.04	22.73	22.95	95.99	7.04
182818	3.86	0.593	5.06	1966.85	10.04	22.73	6.27	95.99	7.04
182822	3.87	0.596	5.06	1958.12	9.52	23.37	11.83	99.99	7.10
182826	3.87	0.599	5.06	1958.12	9.13	23.37	41.50	99.99	7.16
182830	3.87	0.603	5.06	1952.30	9.00	23.80	60.04	99.99	7.23
182834	3.88	0.607	6.75	1946.49	9.52	24.23	58.18	95.99	7.23
182838	3.88	0.611	5.06	1943.58	10.04	24.44	56.18	99.99	7.23
182842	3.88	0.614	5.06	1943.58	9.65	24.44	34.08	26.13	7.35
182846	3.89	0.617	5.06	1751.61	10.04	38.53	8.12	43.08	7.29
182850	3.89	0.620	3.37	23.92	-3.41	165.35	6.39	46.33	-1.41



RECORD OF TRRL DRILL RUN 1.4.2 (3.27 to 3.89 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.4.2 (3.27 to 3.89 metres)



USER: EX9069 -AT SYSTEM

NR_T1.5.1

EX9069

NR_T1.5.1

LABEL: PRT011 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:26, ON: PR0 BY: PR0

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
100358	3.89	0.000	0.00	1815.60	-3.07	34.61	43.59	30.74	7.66
100402	3.89	0.001	1.69	2086.10	-2.10	14.96	16.91	28.64	9.40
100406	3.89	0.001	0.00	2071.55	1.70	16.01	16.29	23.29	8.71
100410	3.89	0.003	3.37	1998.84	8.91	21.30	22.01	27.26	9.28
100414	3.90	0.009	8.43	1984.30	9.69	22.35	8.95	27.06	10.16
100418	3.90	0.013	6.75	1969.75	9.96	23.41	22.63	32.15	10.10
100422	3.91	0.019	8.43	1972.66	9.96	23.20	56.11	34.44	10.10
100426	3.91	0.025	8.43	2007.57	9.96	20.66	41.23	33.88	9.59
100430	3.92	0.029	6.75	2010.47	9.96	20.45	48.67	29.05	9.53
100434	3.92	0.034	6.75	2010.47	9.96	20.45	5.89	24.34	9.47
100438	3.93	0.038	6.75	2004.66	9.96	20.87	10.85	21.90	9.28
100442	3.93	0.043	6.75	2016.29	9.96	20.33	14.57	24.06	9.34
100446	3.94	0.047	6.75	2022.11	9.96	19.61	5.27	25.10	9.09
100450	3.94	0.052	6.75	2022.11	9.96	19.61	31.93	29.70	9.21
100454	3.95	0.056	6.75	2019.20	9.96	19.82	48.67	27.95	9.02
100458	3.95	0.060	5.06	2013.38	9.96	20.24	43.09	31.15	9.09
100502	3.96	0.065	8.43	2022.11	9.96	19.61	37.51	31.76	9.09
100506	3.96	0.070	6.75	2022.11	9.96	19.61	2.17	19.81	8.96
100510	3.96	0.074	6.75	2019.20	9.96	19.82	10.85	14.36	8.96
100514	3.97	0.079	6.75	2010.47	9.96	20.45	10.85	3.40	9.02
100518	3.97	0.084	8.43	2016.29	9.94	20.03	1.42	27.02	9.01
100522	3.98	0.089	6.75	1998.84	9.94	21.30	33.85	22.73	9.14
100526	3.98	0.093	6.75	2004.66	10.07	20.87	59.90	28.38	9.14
100530	3.99	0.098	6.75	2013.38	9.94	20.24	45.03	27.71	9.01
100534	3.99	0.103	8.43	2016.29	9.94	20.03	4.16	29.04	8.82
100538	4.00	0.108	6.75	2022.11	9.94	19.61	20.00	24.84	8.70
100542	4.00	0.112	6.75	2022.11	9.94	19.61	18.14	23.27	8.63
100546	4.01	0.117	6.75	2022.11	9.94	19.61	6.02	26.31	8.76
100550	4.01	0.121	6.75	2025.02	9.94	19.39	41.32	32.91	8.70
100554	4.02	0.127	8.43	2025.02	9.94	19.39	35.74	29.89	8.63
100558	4.02	0.132	6.75	2027.93	9.94	19.18	43.17	32.53	8.63
100602	4.03	0.136	6.75	2019.20	9.94	19.82	41.32	27.25	8.63
100606	4.03	0.141	6.75	2022.11	9.94	19.61	1.42	10.39	8.76
100610	4.04	0.145	6.75	2013.38	9.94	20.24	12.56	17.46	8.76
100614	4.04	0.150	6.75	2019.20	9.94	19.82	10.71	25.04	8.63
100618	4.04	0.154	6.75	2022.11	9.94	19.61	2.30	23.00	8.51
100622	4.05	0.159	6.75	2007.57	9.94	20.66	41.32	30.52	8.57
100626	4.07	0.180	32.04	1975.57	9.94	22.99	50.61	30.52	9.83
100630	4.08	0.187	10.12	1993.02	9.94	21.72	26.45	31.54	8.95
100634	4.08	0.193	10.12	2013.38	9.94	20.24	12.56	27.25	8.57
100638	4.09	0.198	6.75	2016.29	9.94	20.03	23.71	26.78	8.51
100642	4.09	0.204	8.43	2022.11	9.94	19.61	18.14	29.68	8.45
100646	4.10	0.208	6.75	2025.02	9.94	19.39	9.73	29.68	8.38
100650	4.10	0.212	6.75	2016.29	9.94	20.03	54.32	33.11	8.45
100654	4.11	0.218	8.43	2001.75	9.94	21.08	48.75	31.74	8.51
100658	4.11	0.224	8.43	2019.20	9.94	19.82	56.18	32.72	8.51
100702	4.12	0.228	6.74	2022.11	9.94	19.61	9.73	29.04	8.38
100706	4.12	0.233	6.74	2013.38	9.94	20.24	14.42	39.89	8.38
100710	4.13	0.237	6.74	1987.21	9.94	19.31	18.14	49.35	8.63
100714	4.13	0.243	8.43	1984.30	9.94	22.35	8.85	44.72	8.76
100718	4.14	0.247	6.74	2004.66	9.94	18.00	17.16	40.21	8.70
100722	4.14	0.252	6.74	1998.84	9.81	18.44	48.75	34.23	8.51
100726	4.15	0.257	8.43	2013.38	9.94	17.35	50.61	13.47	8.45
100730	4.15	0.262	6.74	2004.66	9.94	18.00	37.60	3.40	8.45

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
100734	4.16	0.266	6.74	1993.02	9.94	18.65	10.71	3.40	8.57
100738	4.16	0.272	8.43	1995.93	9.94	21.51	23.71	3.40	8.51
100742	4.17	0.277	6.74	1984.30	9.94	19.53	16.0	3.4	8.76
100746	4.17	0.282	8.43	1995.93	9.94	18.65	7.87	3.40	8.76
100750	4.16	0.287	6.74	1995.93	9.94	18.65	17.14	40.07	8.45
100754	4.18	0.292	8.43	1984.30	9.81	22.35	50.61	24.84	8.57
100758	4.19	0.298	8.43	1978.46	9.81	22.78	50.61	3.40	8.76
100802	4.19	0.304	8.43	1984.30	9.81	19.53	20.84	3.40	8.76
100806	4.20	0.309	8.43	1995.93	9.81	18.66	16.20	3.40	8.58
100810	4.20	0.314	6.74	2001.75	9.81	21.08	21.85	3.40	8.45
100814	4.21	0.319	8.43	1998.84	9.94	21.30	8.85	3.40	8.32
100818	4.21	0.325	8.43	2007.57	9.81	20.66	26.45	3.40	8.19
100822	4.22	0.329	6.74	2001.75	9.94	21.08	45.05	3.40	8.19
100826	4.23	0.335	8.43	1993.02	9.81	21.72	32.03	3.40	8.26
100830	4.23	0.341	8.43	2013.38	9.81	20.24	46.84	3.40	8.26
100834	4.24	0.345	6.74	2013.38	9.81	20.24	4.16	19.16	8.07
100838	4.24	0.349	5.06	2007.57	9.81	20.66	14.42	38.59	8.13
100842	4.24	0.354	8.43	2013.38	9.81	20.24	14.42	44.58	8.20
100846	4.25	0.359	6.74	2010.47	9.81	20.45	1.42	40.03	8.07
100850	4.25	0.364	8.43	2007.57	9.81	20.66	35.74	36.91	8.00
100854	4.26	0.369	6.74	2005.58	9.81	19.91	59.90	3.40	8.19
100858	4.26	0.374	8.43	1996.86	9.81	20.55	52.46	3.40	8.13
100902	4.27	0.379	6.74	1996.86	9.81	20.55	0.44	3.40	8.13
100906	4.27	0.385	8.43	1993.96	9.81	20.77	16.28	3.40	8.26
100910	4.28	0.392	11.80	1991.05	9.81	20.98	16.28	3.40	8.82
100914	4.29	0.399	10.12	1979.43	9.81	21.83	4.16	3.40	8.45
100918	4.29	0.405	8.43	1979.43	9.81	21.83	48.75	3.40	8.45
100922	4.30	0.409	6.74	1996.86	9.81	20.55	30.17	3.40	8.13
100926	4.30	0.415	8.43	1985.24	9.81	21.41	39.46	3.40	8.26
100930	4.31	0.415	6.74	1988.15	9.81	21.19	22.74	3.40	8.26
100934	4.31	0.425	8.43	1993.96	9.81	20.77	10.71	5.94	8.13
100938	4.32	0.429	6.74	2014.35	9.81	19.28	16.28	39.41	8.00
100942	4.32	0.433	5.06	2008.49	9.81	19.70	5.13	40.53	7.81
100946	4.33	0.436	5.06	2023.01	9.81	18.64	13.45	39.89	7.75
100950	4.33	0.440	5.06	2031.73	9.81	18.00	46.89	30.52	7.56
100954	4.33	0.444	6.74	2025.92	9.81	18.42	58.04	3.40	7.50
100958	4.34	0.447	5.06	2028.83	9.81	18.21	20.83	3.40	7.56
101002	4.34	0.451	5.06	2034.64	9.81	17.78	14.42	3.40	7.31
101006	4.34	0.454	5.06	2025.92	9.81	18.42	21.85	3.40	7.43
101010	4.35	0.459	6.74	2017.20	9.81	19.06	12.56	3.40	7.69
101014	4.35	0.462	5.06	2017.20	9.68	19.06	15.31	3.40	7.62
101018	4.36	0.468	8.43	2005.58	9.68	19.91	61.75	3.40	7.75
101022	4.36	0.472	6.74	1988.15	9.81	21.19	32.03	3.40	7.88
101026	4.37	0.478	8.43	1996.86	9.81	20.55	58.04	3.40	7.94
101030	4.37	0.483	8.43	2002.67	9.81	20.13	15.31	3.40	7.81
101034	4.38	0.489	8.43	1999.77	9.81	20.34	16.28	20.42	7.81
101038	4.38	0.494	6.74	2005.58	9.81	19.91	16.28	41.31	7.88
101042	4.39	0.499	8.43	2008.49	9.81	19.70	3.27	39.89	7.75
101046	4.39	0.505	8.43	2005.58	9.68	19.91	30.17	32.14	7.69
101050	4.40	0.509	6.74	2002.67	9.81	20.13	59.90	4.84	7.69
101054	4.40	0.515	8.43	1999.77	9.81	20.34	39.46	3.40	7.62
101058	4.41	0.519	6.74	2005.58	9.81	19.91	43.17	3.40	7.62
101102	4.41	0.524	6.74	2017.20	9.81	19.06	3.27	13.92	7.62
101106	4.42	0.528	6.74	2011.39	9.81	19.49	12.56	32.91	7.43
101110	4.42	0.534	8.43	1999.77	9.68	20.34	10.71	41.92	7.75
101114	4.4	0.539	6.74	1996.86	9.81	20.55	4.16	34.42	7.69
101118	4.	0.543		2002.67	9.68	20.13	33.88	27.25	7.62
101122	4.	0.549		[illegible]	9.68	18.42	61.75	3.40	7.50

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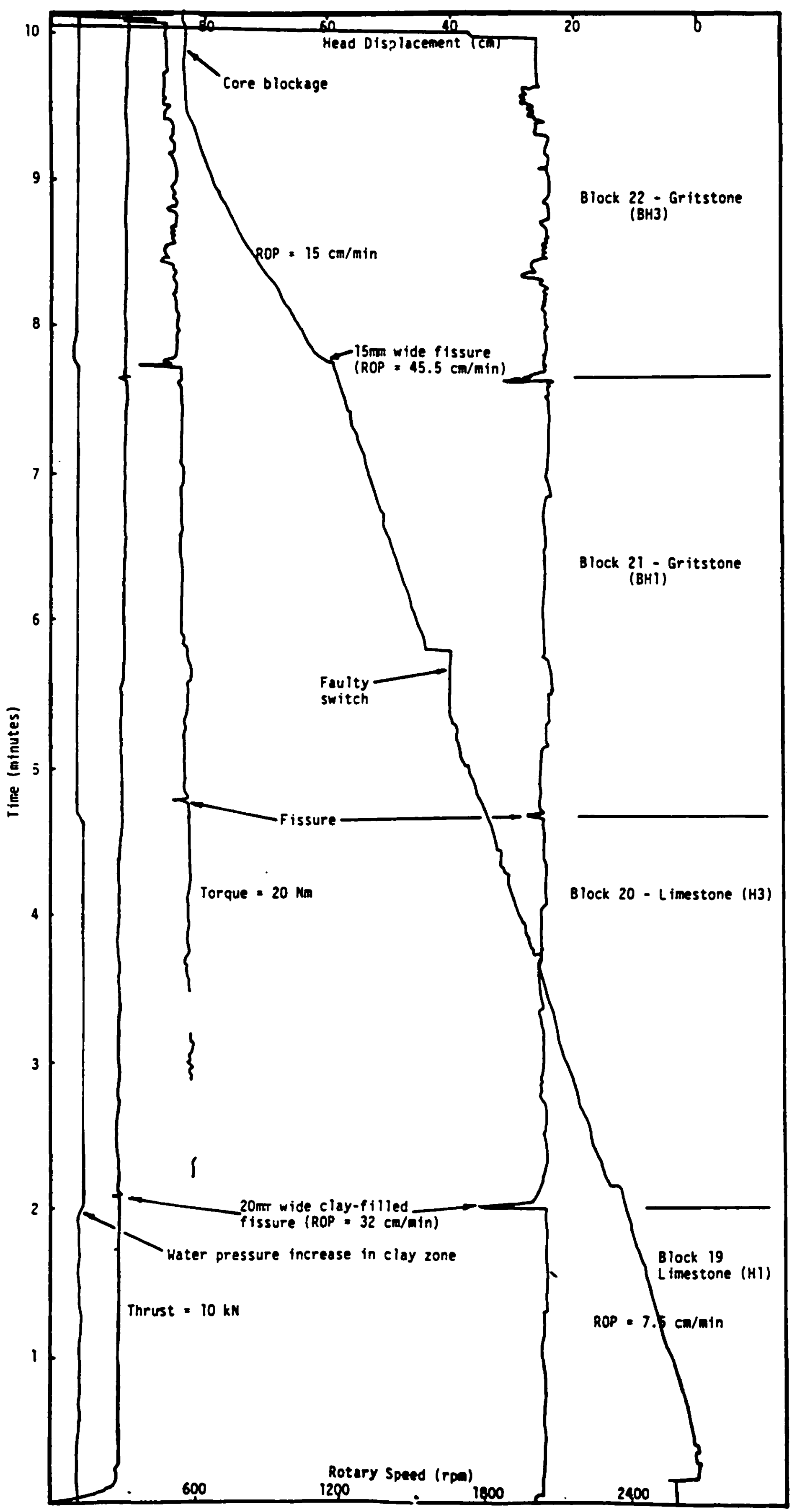
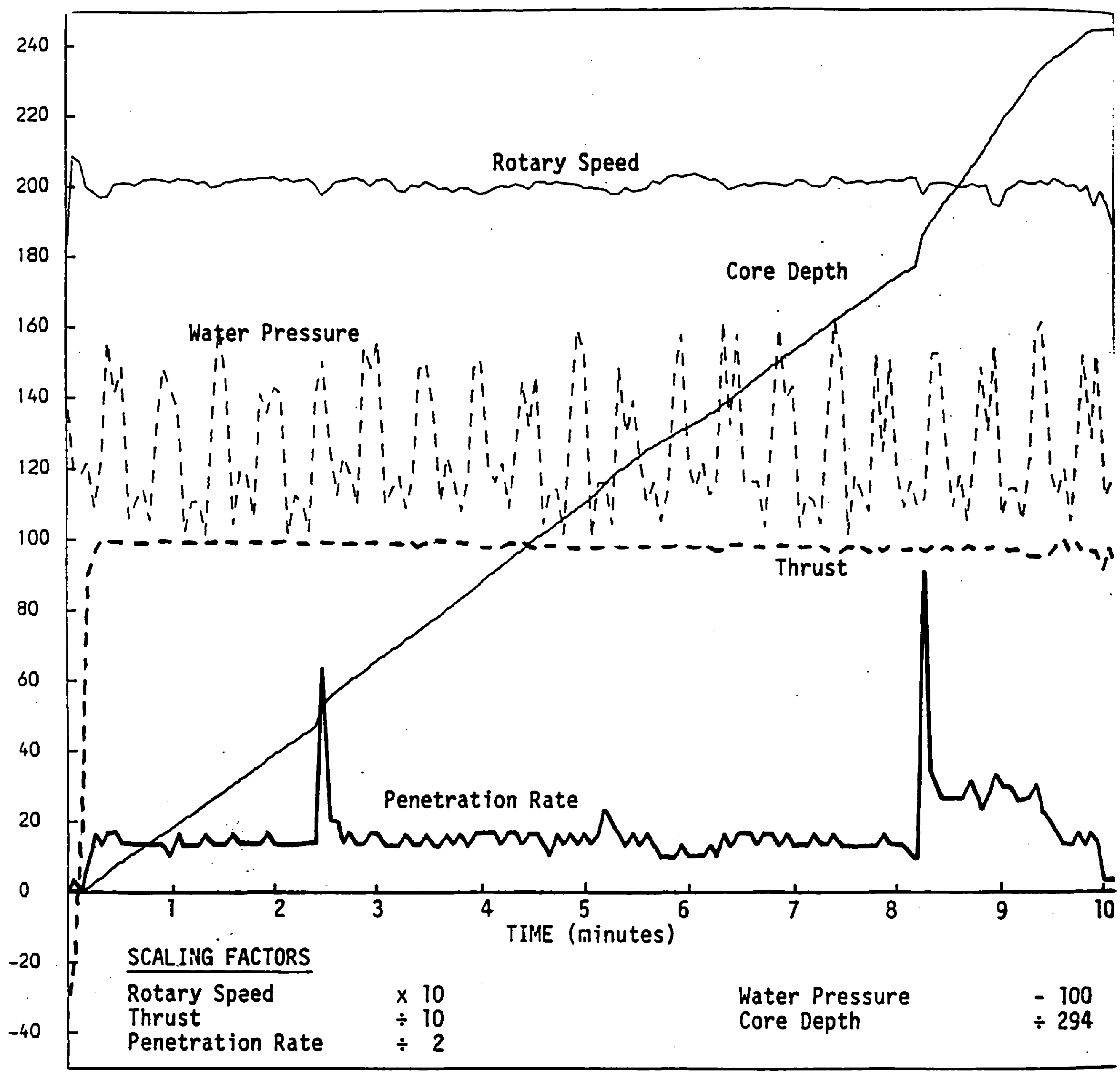
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 3
101126	4.44	0.553	6.74	2020.11	9.68	18.85	50.41	3.40	7.01
101130	4.45	0.558	6.74	2008.49	9.81	19.70	1.42	3.40	7.43
101134	4.45	0.562	6.74	2011.39	9.68	19.49	18.14	3.40	7.50
101138	4.46	0.567	6.74	2014.30	9.81	19.28	12.56	3.40	7.43
101142	4.46	0.571	6.74	2008.49	9.68	19.70	7.87	3.40	7.37
101146 –	4.47	0.576	6.74	2011.39	9.81	19.49	52.46	3.40	7.43
101150	4.47	0.581	8.43	2011.39	9.68	19.49	24.60	3.40	7.37
101154	4.48	0.586	6.74	2017.20	9.81	19.06	50.61	3.40	7.37
101158	4.48	0.590	6.74	2014.30	9.81	19.28	19.62	3.40	7.31
101202	4.49	0.595	6.74	2014.30	9.68	19.28	6.85	20.11	7.37
101206	4.49	0.598	5.06	2023.01	9.68	18.64	16.28	36.56	7.25
101210	4.49	0.602	5.06	2023.01	9.81	18.64	8.85	41.68	7.50
101214	4.52	0.632	45.53	1973.62	9.68	22.26	11.59	34.97	6.32
101218	4.53	0.643	16.86	2005.58	9.81	19.91	52.46	21.02	7.50
101222	4.54	0.652	13.49	2008.49	9.68	19.70	52.46	3.40	7.43
101226	4.55	0.662	15.18	2008.49	9.81	19.70	26.45	3.40	7.37
101230	4.56	0.670	11.80	2002.67	9.68	20.13	8.65	3.40	7.37
101234	4.57	0.677	10.12	1996.86	9.68	20.55	18.14	3.40	7.31
101238	4.58	0.687	15.18	1996.86	9.80	20.55	5.00	3.40	7.55
101242	4.59	0.697	15.18	2005.58	9.67	19.91	22.85	3.40	7.68
101246	4.59	0.705	11.80	1996.86	9.67	20.55	48.83	3.40	7.43
101250	4.60	0.715	15.18	2002.67	9.80	20.13	30.27	3.40	7.49
101254	4.62	0.726	16.86	1947.47	9.80	24.18	54.40	3.40	7.62
101258	4.63	0.736	15.18	1941.66	9.80	24.61	6.14	3.40	8.18
101302	4.64	0.747	15.18	1988.15	9.67	21.19	14.28	31.72	7.67
101306	4.64	0.754	11.80	1999.77	9.67	20.34	14.28	42.20	7.30
101310	4.65	0.763	13.49	2014.30	9.67	19.28	5.00	39.71	7.24
101314	4.66	0.772	13.49	2008.49	9.53	19.70	22.85	32.51	7.17
101318	4.67	0.783	15.18	2008.49	9.53	19.70	58.11	99.99	7.30
101322	4.68	0.790	11.80	2014.30	9.53	19.28	61.82	3.40	7.05
101326	4.69	0.797	10.12	2005.58	9.53	19.91	19.13	3.40	7.36
101330	4.69	0.803	8.43	2023.92	9.80	17.65	12.42	3.40	6.86
101334	4.70	0.807	6.74	2014.30	10.06	19.28	19.84	3.40	6.86
101338	4.70	0.812	6.74	2003.60	9.67	19.15	5.00	3.40	7.11
101342	4.71	0.817	8.43	2009.40	9.93	18.72	30.27	3.40	7.05
101346	4.71	0.822	6.74	1989.08	9.67	20.23	52.54	3.40	7.24
101350	4.72	0.828	8.43	2006.50	9.67	18.94	28.41	3.40	6.98
101354	4.72	0.832	6.74	1948.45	9.65	23.24	52.62	3.40	7.86
101358	4.72	0.833	1.69	1991.99	9.13	20.01	11.83	3.40	7.86
101402	4.72	0.834	1.69	1954.25	9.78	22.81	15.99	3.40	8.30
101406	4.73	0.835	1.69	1896.20	9.00	27.11	17.84	3.40	8.30
101410	4.73	0.836	1.69	1916.52	10.17	25.61	3.01	3.40	8.68

RECORD OF TRRL DRILL RUN 1.5.1 (3.89 to 4.73 metres)

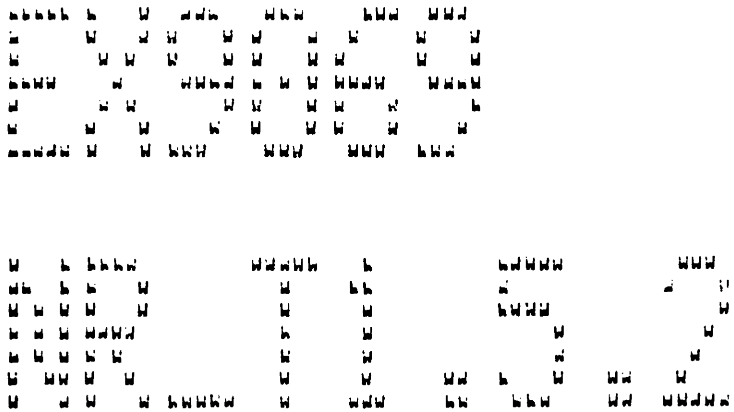


COMPUTER RECORD OF TRRL DRILL RUN 1.5.1 (3.89 to 4.73 metres)



USER: EX9669 -AT SYSTEM

NT1.52



LABEL: PRT012 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:26, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
101918	4.75	-0.000	0.00	1897.23	9.52	26.68	4.86	4.83	8.99
101922	4.76	0.005	8.43	1918.83	9.78	27.84	33.37	4.83	8.36
101926	4.76	0.010	6.74	1908.83	9.65	27.84	50.77	4.83	8.68
101930	4.76	0.012	3.37	1900.13	9.91	28.47	6.27	4.83	8.60
101934	4.77	0.013	1.69	1900.13	9.91	26.47	43.35	4.83	8.67
101938	4.77	0.014	1.69	1911.73	9.78	27.33	14.13	22.43	8.60
101942	4.77	0.015	1.69	1923.32	9.78	26.78	17.34	36.73	8.43
101946	4.77	0.017	1.69	1923.32	9.91	25.78	15.99	45.52	8.49
101950	4.77	0.017	0.00	1914.63	9.91	27.41	3.7[illegible]	4.83	8.55
101954	4.77	0.018	1.69	1908.83	9.91	27.84	54.06	4.83	8.87
101958	4.77	0.018	0.00	1935.93	9.78	28.05	45.[illegible]	4.83	8.68
102002	4.77	0.018	0.00	1908.83	9.91	27.64	13.66	4.83	8.74

PAGE 1

USER: EX9569 -AT SYSTEM

NR_T1.5.3

LABEL: PRT013 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:27, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
102134	4.77	-0.000	0.00	1917.53	10.04	27.20	3[illegible]	24.56	6.80
102138	4.78	0.008	11.80	1915.02	10.04	19.42	60.04	11.49	33.14
102142	4.79	0.017	13.49	1903.03	9.91	28.26	47.[illegible]	4.83	8.24
102146	4.80	0.025	11.80	1958.12	9.78	24.25	19.24	4.83	7.92
102150	4.80	0.031	8.43	1961.32	9.78	22.57	19.69	4.83	7.54
102154	4.81	0.035	6.74	1973.52	9.78	22.99	23.41	4.83	7.42
102158	4.81	0.039	5.06	1959.72	9.78	23.41	4.85	4.83	7.29
102202	4.82	0.043	6.74	1987.12	9.91	22.15	26.66	4.83	7.98
102206	4.82	0.046	5.06	1995.82	9.91	21.52	56.33	4.83	7.35
102210	4.82	0.050	5.06	1987.12	9.91	22.15	26.66	4.83	7.35
102214	4.83	0.053	5.06	1963.92	9.91	23.83	35.93	4.83	7.61
102218	4.83	0.057	5.06	2001.62	9.91	21.09	17.39	4.83	7.42
102222	4.83	0.060	5.06	1998.72	9.91	21.30	15.99	4.83	7.23
102226	4.83	0.062	3.37	2007.42	9.91	20.67	21.55	30.70	7.54
102230	4.84	0.066	5.06	1972.62	9.91	23.20	10.42	30.90	7.48
102234	4.84	0.068	3.37	1981.32	9.91	22.57	8.12	7.79	7.54
102238	4.84	0.070	3.37	2004.52	9.91	20.88	43.35	4.83	7.16
102242	4.84	0.072	3.37	1961.02	9.91	24.04	58.18	4.83	7.23
102246	4.85	0.073	1.69	1955.22	9.91	24.47	39.64	4.83	7.67
102250	4.85	0.076	3.37	1934.92	9.91	25.94	21.13	4.83	8.11
102254	4.85	0.078	3.37	1943.62	9.91	25.31	12.28	21.58	7.86
102258	4.85	0.079	1.69	1946.52	9.91	25.10	14.13	32.49	7.92
102302	4.85	0.081	3.37	1961.02	9.91	24.04	12.28	24.56	7.73
102306	4.86	0.085	5.06	1949.42	9.91	24.89	6.27	4.83	7.54
102310	4.86	0.087	3.37	1926.22	9.91	26.57	37.79	4.83	7.61
102314	4.86	0.088	1.69	1969.72	9.91	23.41	60.04	4.83	7.92
102318	4.86	0.089	1.69	1969.72	9.90	23.41	54.55	4.83	7.47
102322	4.86	0.091	3.37	1972.62	9.90	23.20	17.50	4.83	7.35
102326	4.87	0.094	3.37	1932.02	9.90	26.15	12.13	4.83	7.66
102330	4.87	0.097	5.06	1946.52	9.90	25.10	19.54	4.83	7.85
102334	4.87	0.099	3.37	1914.63	9.90	27.41	10.28	4.83	6.10
102338	4.87	0.100	1.69	1911.73	9.90	27.63	15.65	4.83	8.23
102342	4.87	0.103	3.37	1882.73	9.90	29.73	58.25	4.83	8.10
102346	4.88	0.104	1.69	1929.12	9.90	26.36	30.47	4.83	7.98
102350	4.88	0.105	1.69	1885.63	9.90	29.52	21.21	4.83	8.23
102402	4.88	0.109	2.25	1859.53	9.90	31.42	19.54	5.93	8.29
102522	4.88	0.113	0.25	1903.03	9.90	28.26	37.88	34.37	8.04
102526	4.89	0.115	3.37	1923.32	9.77	26.78	60.11	7.69	8.35
102530	4.89	0.117	3.37	1932.02	9.77	26.15	52.79	4.83	8.04
102534	4.89	0.120	3.37	1929.12	9.77	26.36	17.50	4.83	7.98
102538	4.89	0.121	1.69	1934.92	9.90	25.94	17.69	4.83	7.98
102542	4.89	0.122	1.69	1937.82	9.90	25.73	21.40	4.83	7.72
102546	4.90	0.124	3.37	1943.62	9.77	25.31	8.43	4.83	7.53
102550	4.90	0.125	1.69	1932.02	9.90	-26.15	28.62	4.83	7.60
102554	4.90	0.126	1.69	1940.72	9.77	25.52	47.14	4.83	7.60
102558	4.90	0.126	0.00	1932.02	9.77	26.15	58.26	18.13	7.72
102602	4.90	0.127	1.69	1917.53	9.77	27.20	48.99	4.83	7.60
102606	4.90	0.129	1.69	1923.32	9.90	26.78	28.62	4.83	8.10
102610	4.90	0.129	0.00	1917.53	10.03	27.20	10.28	4.83	7.98
102614	4.90	0.130	1.69	1920.43	10.03	26.99	25.10	4.83	7.91
102618	4.90	0.131	1.69	1923.32	9.90	26.78	15.84	4.83	7.72
102622	4.90	0.131	0.00	1911.73	9.90	27.63	2.68	4.83	7.72
102626	4.90	0.132	1.69	1920.43	[illegible]	26.99	45.29	4.83	7.85
102630		132	0.00	1920.43	[illegible]	26.99	34.18	4.83	7.60

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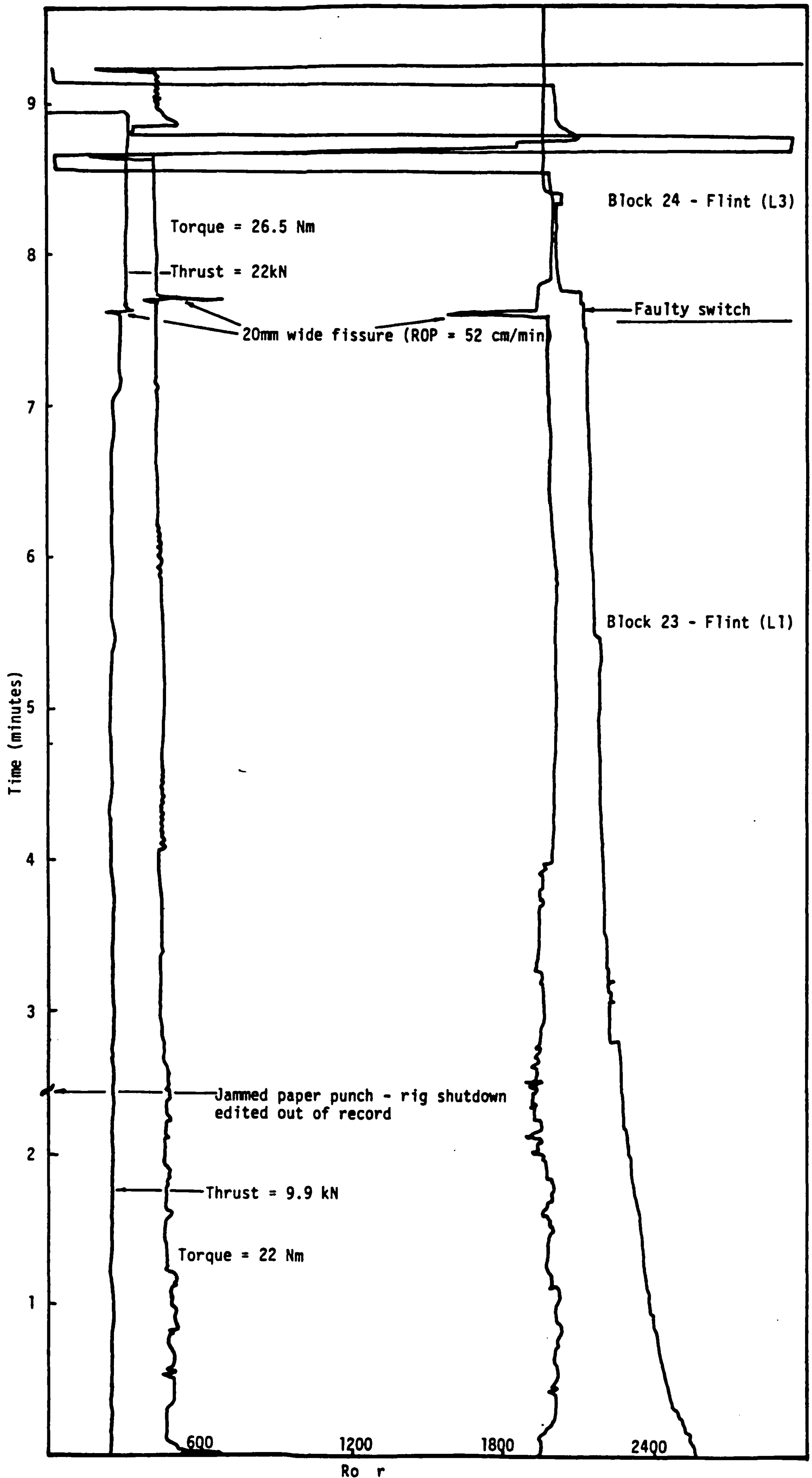
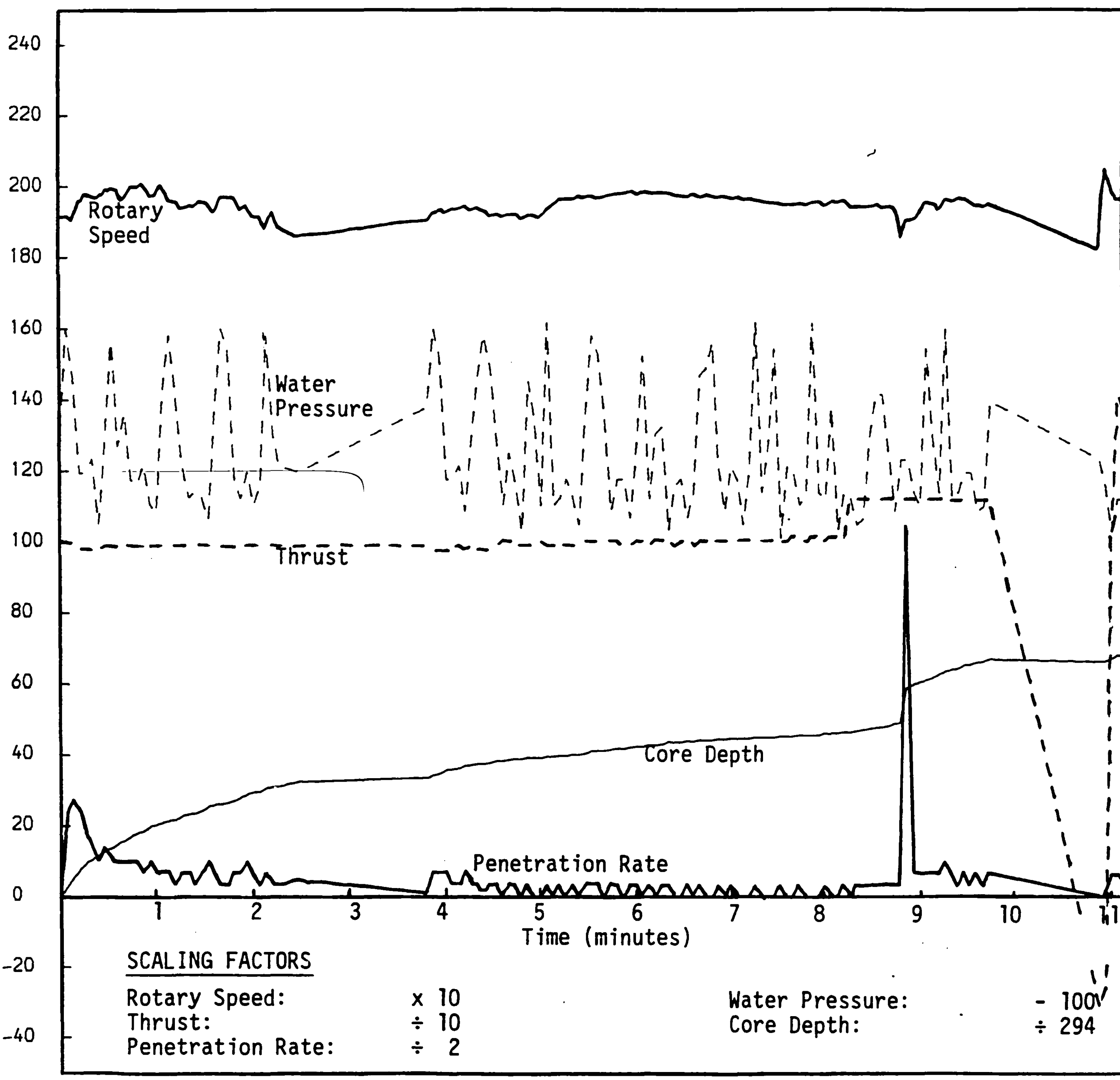
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 2
102634	4.95	0.132	0.00	1914.63	10.03	27.41	13.09	4.83	7.72
102638	4.90	0.133	1.69	1937.82	9.90	25.73	61.96	4.83	7.53
102642	4.90	0.133	0.00	1949.42	9.90	24.89	10.39	4.83	7.55
102646	4.91	0.134	1.69	1963.92	9.90	23.83	12.13	26.98	7.41
102650	4.91	0.134	0.00	1963.92	9.90	23.83	17.69	42.46	6.97
102654	4.91	0.135	1.69	1966.82	9.90	23.62	12.13	41.85	7.03
102658	4.91	0.135	0.00	1975.52	9.90	22.99	4.54	41.85	7.03
102702	4.91	0.136	1.69	1972.62	10.03	23.20	36.07	25.85	6.97
102706	4.91	0.138	1.69	1975.52	10.03	22.99	58.26	4.83	6.97
102710	4.91	0.139	1.69	1969.72	10.03	23.41	52.72	4.83	7.03
102714	4.91	0.139	0.00	1972.62	10.03	23.20	34.18	4.83	6.97
102718	4.91	0.140	1.69	1978.42	10.03	22.78	8.43	4.83	6.90
102722	4.91	0.141	1.69	1982.27	10.03	21.63	17.69	4.83	6.84
102726	4.91	0.141	0.00	1985.16	9.90	21.42	17.69	4.83	6.72
102730	4.91	0.142	1.69	1988.06	9.90	21.20	6.58	4.83	6.78
102734	4.92	0.143	1.69	1982.27	10.03	21.63	26.77	4.83	6.78
102738	4.92	0.143	0.00	1984.22	10.03	22.36	52.71	4.83	6.78
102742	4.92	0.144	1.69	1981.32	9.90	22.57	11.95	4.83	6.78
102746	4.92	0.144	0.00	1981.32	10.03	22.57	30.47	4.83	6.78
102750	4.92	0.145	1.69	1984.22	10.03	22.36	32.32	4.83	6.78
102754	4.92	0.147	1.69	1982.27	10.03	21.63	2.87	3.39	6.78
102758	4.92	0.147	0.00	1978.42	9.90	22.78	15.84	32.67	6.72
102802	4.92	0.147	0.00	1975.52	10.03	22.99	17.69	46.47	6.76
102806	4.92	0.148	1.69	1973.57	10.03	22.27	6.58	43.35	6.76
102810	4.92	0.148	0.00	1978.42	9.90	22.78	13.86	38.54	6.78
102814	4.92	0.149	1.69	1973.57	10.03	22.27	47.14	26.98	6.90
102818	4.92	0.149	0.00	1979.37	10.03	21.84	48.99	4.83	6.72
102822	4.92	0.149	0.00	1976.47	10.03	22.05	56.40	4.83	6.76
102826	4.92	0.150	1.69	1970.68	10.03	22.48	21.21	4.83	6.78
102830	4.92	0.150	0.00	1970.68	10.03	22.48	6.43	4.83	6.84
102834	4.92	0.151	1.69	1967.76	10.03	22.69	21.40	4.83	6.84
102838	4.92	0.151	0.00	1970.68	10.03	22.48	17.69	4.83	6.90
102842	4.92	0.151	0.00	1964.88	10.03	22.91	4.72	4.83	6.90
102846	4.92	0.151	0.00	1966.82	10.03	23.62	21.21	4.83	6.90
102850	4.92	0.152	1.69	1964.88	10.03	22.91	61.96	4.83	6.84
102854	4.92	0.152	0.00	1959.09	10.03	23.33	13.80	4.83	6.84
102858	4.92	0.152	0.00	1956.19	10.03	23.54	26.77	4.83	6.90
102902	4.92	0.152	0.30	1953.30	10.03	23.76	54.55	4.83	7.03
102906	4.93	0.153	1.69	1950.40	10.03	23.97	0.83	4.83	6.97
102910	4.93	0.153	0.00	1947.50	10.03	24.18	21.40	4.83	7.03
102914	4.93	0.153	0.00	1947.50	10.16	24.18	19.54	4.83	7.09
102918	4.93	0.154	1.69	1953.30	10.03	23.76	10.28	4.83	7.03
102922	4.93	0.154	0.00	1947.50	10.03	24.18	13.80	4.83	7.09
102926	4.93	0.154	0.00	1953.30	10.16	23.76	61.96	4.83	6.90
102930	4.93	0.154	0.00	1959.09	10.16	23.33	13.80	4.83	6.90
102934	4.93	0.156	1.69	1947.50	10.03	24.18	11.95	4.83	6.90
102938	4.93	0.156	0.00	1956.19	10.16	23.54	37.88	4.83	6.97
102942	4.93	0.156	0.00	1956.19	10.16	23.54	2.87	4.83	6.90
102946	4.93	0.157	1.69	1959.09	10.03	23.33	13.99	27.44	6.90
102950	4.93	0.157	0.00	1944.60	11.20	24.39	12.13	40.31	6.90
102954	4.93	0.158	1.69	1944.60	11.20	24.39	4.72	43.49	7.03
102958	4.93	0.159	1.69	1944.60	11.20	24.39	6.39	27.65	7.03
103002	4.93	0.160	1.69	1944.60	11.20	24.39	28.62	21.28	6.97
103006	4.93	0.161	1.69	1947.50	11.20	24.18	41.58	4.83	7.03
103010	4.93	0.162	1.69	1938.81	11.20	24.82	41.58	4.83	7.03
103014	4.94	0.163	1.69	1944.60	11.20	24.39	24.91	4.83	7.03
103018	4.94	0.165	1.69	1938.81	11.20	24.82	8.43	4.83	7.09
103022	4.94	0.166	1.69	1851.90	11.20	31.20	23.25	4.83	7.39

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
103026	4.97	0.200	52.28	1906.94	11.20	27.16	23.25	4.83	7.53
103030	4.97	0.203	3.37	1909.84	11.20	26.94	13.99	4.83	7.41
103034	4.98	0.205	3.37	1924.55	11.20	25.85	10.05	4.83	7.41
103038	4.98	0.207	3.37	1956.15	11.20	23.54	54.55	4.83	6.72
103042	4.98	0.209	3.37	1959.42	11.20	23.97	28.62	4.83	6.78
103046	4.98	0.212	3.37	1935.91	11.20	25.33	13.86	4.83	6.97
103050	4.99	0.215	5.06	1964.88	11.20	22.91	66.11	4.83	6.78
103054	4.99	0.217	3.37	1959.59	11.20	23.33	11.95	4.83	6.72
103058	4.99	0.218	1.69	1964.88	11.20	22.91	13.99	19.77	6.78
103102	4.99	0.271	3.37	1961.99	11.20	23.12	19.54	38.70	6.72
103106	4.99	0.222	1.69	1953.30	11.20	23.76	19.54	42.61	6.72
103110	5.00	0.224	3.37	1944.60	11.20	24.39	6.43	42.16	6.97
103114	5.00	0.225	1.69	1944.60	11.20	24.39	10.09	40.31	6.84
103118	5.00	0.227	3.37	1953.30	11.20	23.76	39.73	33.43	6.84
103226	5.00	0.225	0.20	1828.73	-3.15	32.90	23.25	4.83	5.20
103230	5.00	0.225	0.00	2254.69	-2.37	16.32	15.84	4.83	5.71
103234	5.00	0.227	3.37	1990.96	10.16	20.99	2.68	4.83	6.09
103238	5.00	0.230	3.37	1967.78	11.20	22.69	41.58	4.83	6.53
103242	5.00	0.231	1.69	1964.88	11.20	22.91	36.03	4.83	6.65

RECORD OF TRRL DRILL RUN 1.5.3 (4.77 to 5.00 metres)



COMPUTER RECORD OF TRRL DRILL RUN 1.5.3 (4.77 to 5.00 metres)



USER: EX9069 -AT SYSTEM

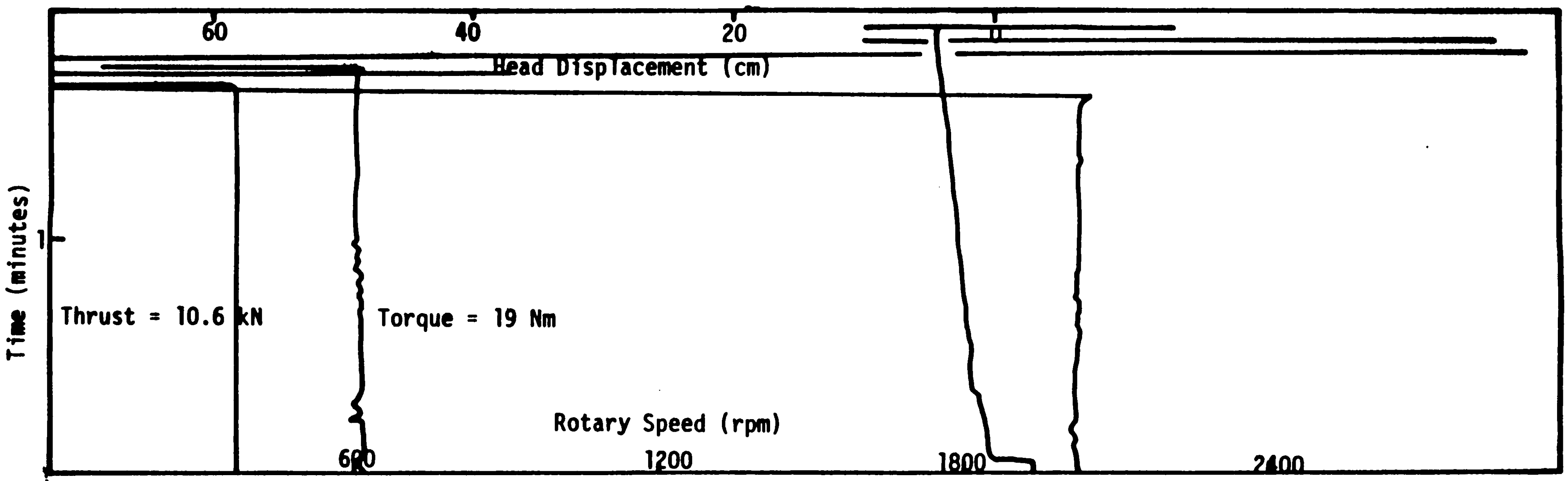
NR_T1.5.4

LABEL: PRT014 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:27, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
123212	5.00	-0.000	0.00	1953.28	11.10	24.61	41.41	25.68	9.32
123216	5.01	0.007	10.12	1947.47	10.84	25.03	52.54	22.99	9.69
123220	5.01	0.013	8.43	1947.47	10.84	25.03	10.56	13.00	9.82
123224	5.01	0.016	5.06	1967.81	10.71	23.55	17.99	17.45	9.63
123228	5.02	0.017	1.69	1970.71	10.71	23.34	8.71	15.58	9.51
123232	5.02	0.021	5.06	1982.34	10.71	22.50	24.70	21.88	9.36
123236	5.02	0.023	3.37	2002.67	10.71	21.02	50.69	25.81	9.07
123240	5.02	0.026	5.06	2008.49	10.71	20.63	15.42	22.99	8.75
123244	5.03	0.029	3.37	2037.54	10.71	16.48	45.12	26.30	8.37
123248	5.03	0.032	5.06	2017.20	10.71	19.96	30.27	20.71	8.50
123252	5.03	0.034	3.37	2002.67	10.71	21.02	5.60	4.83	8.50
123256	5.04	0.038	5.06	2034.54	10.58	18.70	16.13	4.83	8.57
123300	5.04	0.040	3.37	2034.64	10.58	18.70	17.99	24.31	8.25
123304	5.04	0.041	1.69	2034.64	10.58	18.70	5.00	26.30	8.25
123308	5.04	0.043	3.37	2034.64	10.58	18.70	19.13	26.77	8.18
123312	5.04	0.044	1.69	2040.45	10.58	18.27	56.23	31.32	8.18
123316	5.04	0.047	3.37	2034.64	10.58	18.70	37.54	31.32	8.25
123320	5.05	0.048	1.69	2025.92	10.58	19.33	50.69	20.71	8.12
123324	5.05	0.050	3.37	2031.73	10.58	18.91	19.13	18.82	8.25
123328	5.05	0.052	3.37	2031.73	10.58	18.91	12.42	19.15	8.12
123332	5.05	0.053	1.69	2031.73	10.58	18.91	19.84	25.32	8.18
123336	5.05	0.054	1.69	2031.73	10.58	18.91	14.26	29.45	8.12
123340	5.05	0.057	3.37	2034.64	10.58	18.70	9.85	27.00	8.06
123344	5.06	0.058	1.69	2037.54	10.58	18.45	13.57	27.23	8.06
123348	5.06	0.059	1.69	2037.54	10.58	18.48	48.83	29.88	7.87



RECORD OF TRRL DRILL RUN 1.5.4 (5.00 to 5.06 metres)

USER: EX7169 -AT SYSTEM

NR_T1.6

LABEL: PRT015 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:27, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (KN/M**2)
132918	5.06	0.000	0.00	2117.28	-1.75	12.59	16.43	45.83	7.13
132922	5.06	0.002	3.37	2061.95	9.34	15.71	11.47	44.31	7.51
132926	5.07	0.007	6.74	2044.49	9.56	17.98	57.97	22.18	8.[illegible]7
132930	5.07	0.012	8.43	2041.58	9.56	18.19	28.21	99.99	8.20
132934	5.08	0.018	8.43	2038.67	9.43	18.40	28.21	99.99	8.2[illegible]
132938	5.08	0.024	8.43	2035.76	9.56	18.61	12.71	99.99	8.2[illegible]
132942	5.09	0.030	10.12	2047.41	9.43	17.77	1.55	99.99	8.14
132946	5.10	0.036	8.43	2041.58	9.43	18.19	35.65	99.99	8.36
132950	5.10	0.040	6.74	2044.49	9.43	17.98	17.[illegible]	99.99	8.20
132954	5.10	0.045	6.74	2056.14	9.43	17.13	31.93	99.99	7.69
132958	5.11	0.049	6.74	2047.41	9.43	17.77	4.05	99.99	8.[illegible]1
133002	5.11	0.053	5.06	2053.23	9.43	17.35	16.43	37.27	8.01
133006	5.12	0.057	6.74	2035.76	9.43	18.61	5.27	45.73	8.[illegible]1
133010	5.12	0.061	5.06	2041.58	9.43	18.19	18.91	44.0[illegible]	8.[illegible]8
133014	5.12	0.064	5.06	2041.58	9.43	18.19	56.11	33.50	8.[illegible]8
133018	5.13	0.067	5.06	2047.41	9.43	17.77	33.79	99.99	7.95
133022	5.13	0.072	6.74	2041.58	9.56	18.19	1.55	99.99	7.95
133026	5.14	0.075	5.06	2038.67	9.43	18.40	22.01	99.99	8.01
133030	5.14	0.079	5.06	2032.85	9.56	18.83	0.31	99.99	8.[illegible]1
133034	5.14	0.082	5.06	2047.41	9.43	17.77	44.95	99.99	8.01
133038	5.15	0.087	6.74	2056.14	9.56	17.13	1.55	99.99	7.70
133042	5.15	0.089	3.37	2056.14	9.43	17.13	61.69	99.99	7.70
133046	5.15	0.093	6.74	2059.05	9.43	16.92	7.13	35.70	7.63
133050	5.16	0.097	5.06	2059.05	9.43	16.92	20.15	45.87	7.70
133054	5.16	0.100	5.06	2059.05	9.43	16.92	2.17	44.89	7.57
133058	5.18	0.118	26.98	1601.95	9.43	18.95	41.23	31.76	11.62
133102	5.22	0.159	60.71	1762.08	9.29	1.19	26.45	99.99	11.22
133106	5.24	0.180	32.04	1698.03	9.43	8.30	33.79	99.99	12.55
133110	5.25	0.190	15.18	1698.03	9.29	8.30	3.27	99.99	12.15
133114	5.26	0.198	11.80	1447.64	9.43	36.06	16.43	99.99	13.96
133118	5.26	0.200	3.37	1750.43	6.81	2.49	9.61	99.99	12.75
133122	5.26	0.201	1.69	1826.13	6.80	5.91	28.31	99.99	11.10
133126	5.26	0.202	1.69	1855.25	6.80	9.13	25.57	99.99	10.47
133130	5.26	0.204	1.69	1797.02	6.68	2.68	59.83	99.99	10.79
133134	5.26	0.205	1.69	1823.22	6.61	5.58	5.27	99.99	12.69
133138	5.27	0.206	1.69	1776.64	6.94	0.42	12.71	15.99	12.20
133142	5.27	0.206	0.00	1593.21	6.81	19.92	22.63	99.99	10.60
133146	5.27	0.207	1.69	1773.72	6.68	0.10	57.97	99.99	11.43
133150	5.27	0.208	1.69	1814.49	7.99	4.62	1.55	99.99	10.73
133154	5.27	0.209	1.69	1741.70	7.86	3.45	20.77	99.99	12.00
133158	5.27	0.210	1.69	1738.79	7.99	3.78	16.43	99.99	12.19
133202	5.27	0.211	1.69	1680.56	8.25	10.23	1.55	99.99	11.74
133206	5.27	0.212	1.69	1648.53	7.86	13.78	37.51	12.53	13.[illegible]
133210	5.27	0.215	3.37	1648.53	8.12	13.78	41.23	95.99	13.51
133214	5.28	0.216	1.69	1552.45	8.25	24.44	41.23	99.99	13.39
133218	5.28	0.218	3.37	1494.22	8.12	30.89	1.55	99.99	13.26
133222	5.28	0.219	1.69	1633.97	8.52	15.40	12.71	99.99	13.20
133226	5.28	0.221	3.37	1727.14	9.04	5.07	22.63	99.99	12.88
133230	5.28	0.224	3.37	1479.66	9.[illegible]4	32.50	24.49	99.99	12.12
133234	5.29	0.226	3.37	1698.03	5.17	8.30	12.71	99.99	10.73
133238	5.29	0.229	5.06	1552.45	5.04	24.44	20.77	99.99	10.67
133242	5.29	0.234	6.74	1794.11	5.04	2.36	18.29	21.99	11.05
133246	5.30	0.236	3.37	1869.80	7.60	10.75	3.41	43.58	10.67
133250	5.30	0.238	3.37	1957.15	5.76	20.43	54.25	22.47	10.04

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
133254	5.30	0.238	0.00	1925.12	5.24	16.65	24.40	99.99	9.15
133258	5.30	0.238	0.00	1968.79	5.24	21.72	50.53	99.99	10.98
133302	5.30	0.238	0.00	1977.53	5.24	22.69	16.43	99.99	6.71
133306	5.30	0.238	0.00	1878.54	5.24	11.72	12.71	99.99	8.33
133310	5.30	0.239	1.69	1933.85	5.24	17.85	30.07	99.99	8.77
133314	5.30	0.239	0.00	1930.95	5.11	17.53	10.85	99.99	8.83
133318	5.30	0.239	0.00	1960.06	5.11	20.75	29.45	99.99	8.77
133322	5.30	0.239	0.00	1960.06	6.16	20.75	22.63	99.99	8.71
133326	5.30	0.241	1.69	1930.95	6.16	17.53	16.43	99.99	8.27
133330	5.30	0.241	0.00	1951.33	6.81	19.79	10.60	31.76	8.77
133334	5.30	0.243	3.37	1968.79	7.86	21.72	33.79	23.55	9.28
133338	5.30	0.244	1.69	1904.74	7.99	14.62	37.51	99.99	9.72
133342	5.31	0.246	3.37	1928.03	7.99	17.20	18.91	99.99	8.39
133346	5.31	0.248	3.37	1945.53	7.99	19.14	5.27	99.99	8.20
133350	5.31	0.251	3.37	1925.12	7.99	16.88	16.29	99.99	8.58
133354	5.31	0.253	3.37	1884.36	8.12	12.36	2.17	99.99	9.02
133358	5.32	0.255	3.37	1890.18	7.99	13.01	44.95	99.99	9.78
133402	5.32	0.257	3.37	1887.27	7.99	12.69	25.73	99.99	9.09
133406	5.32	0.260	3.37	1901.83	7.99	14.30	28.21	99.99	8.77
133410	5.32	0.263	5.06	1732.96	8.91	4.42	1.55	99.99	11.68
133414	5.33	0.266	5.06	1537.89	7.60	26.05	10.85	18.51	14.90
133418	5.33	0.269	3.37	1962.97	7.86	21.08	5.80	32.74	7.89
133422	5.33	0.273	6.74	1954.24	7.86	20.11	46.81	99.99	7.76
133426	5.34	0.278	6.74	1901.83	7.86	14.30	0.31	99.99	8.64
133430	5.34	0.281	5.06	1861.07	7.86	9.78	46.81	99.99	9.34
133434	5.34	0.283	3.37	1861.07	7.86	9.78	16.43	99.99	9.47
133438	5.35	0.287	5.06	1773.72	7.99	0.10	2.17	99.99	9.91
133442	5.35	0.290	5.06	1712.58	7.86	6.68	56.11	99.99	11.36
133446	5.35	0.292	3.37	1732.96	7.86	4.42	51.76	99.99	11.93
133450	5.35	0.295	3.37	1610.68	7.86	17.98	50.53	99.99	12.63
133454	5.36	0.298	5.06	1645.62	7.86	14.11	3.41	12.03	12.56
133458	5.36	0.301	5.06	1852.34	7.73	8.81	10.85	40.86	9.97
133502	5.36	0.305	5.06	1799.93	7.86	3.00	13.33	27.72	9.47
133506	5.37	0.308	5.06	1898.92	7.86	13.98	52.39	99.99	9.21
133510	5.37	0.311	5.06	1919.30	7.86	16.24	0.31	99.99	8.52
133514	5.37	0.315	5.06	1936.77	7.86	18.17	22.63	99.99	8.33
133518	5.38	0.319	6.74	1846.51	7.86	8.17	10.85	10.97	9.40
133522	5.38	0.324	6.74	1799.93	7.86	3.00	1.55	40.70	10.23
133526	5.39	0.327	5.06	1727.14	7.86	5.07	48.67	4.84	10.79
133530	5.39	0.331	5.06	1654.35	7.86	13.14	11.47	99.99	12.63
133534	5.39	0.333	3.37	1430.17	7.60	37.99	54.25	99.99	12.94
133538	5.39	0.335	3.37	1639.80	7.34	14.75	7.13	99.99	13.01
133542	5.39	0.335	0.00	1587.39	5.63	20.56	3.41	99.99	10.54
133546	5.40	0.336	1.69	1834.87	5.50	6.87	43.05	99.99	10.10
133550	5.40	0.336	0.00	1922.21	5.11	16.56	57.34	99.99	8.83
133554	5.40	0.336	0.00	1989.18	5.24	23.98	59.83	99.99	7.89
133558	5.40	0.337	1.69	2006.64	5.11	25.92	7.13	99.99	7.38
133602	5.40	0.337	0.00	2032.85	5.11	28.82	14.57	34.44	7.06
133606	5.40	0.337	0.00	2000.82	5.11	25.27	9.61	28.17	7.13
133610	5.40	0.337	0.00	2032.85	6.29	28.82	52.39	99.99	7.00
133614	5.40	0.338	1.69	2044.49	6.29	30.12	2.17	99.99	6.75
133618	5.40	0.340	1.69	1820.31	8.12	5.26	31.93	99.99	7.57
133622	5.40	0.344	6.74	1706.76	8.12	7.33	12.71	99.99	11.43
133626	5.41	0.347	5.06	1401.05	8.52	41.22	0.31	99.99	12.82
133630	5.41	0.350	3.37	23.92	9.04	193.95	52.39	99.99	16.99

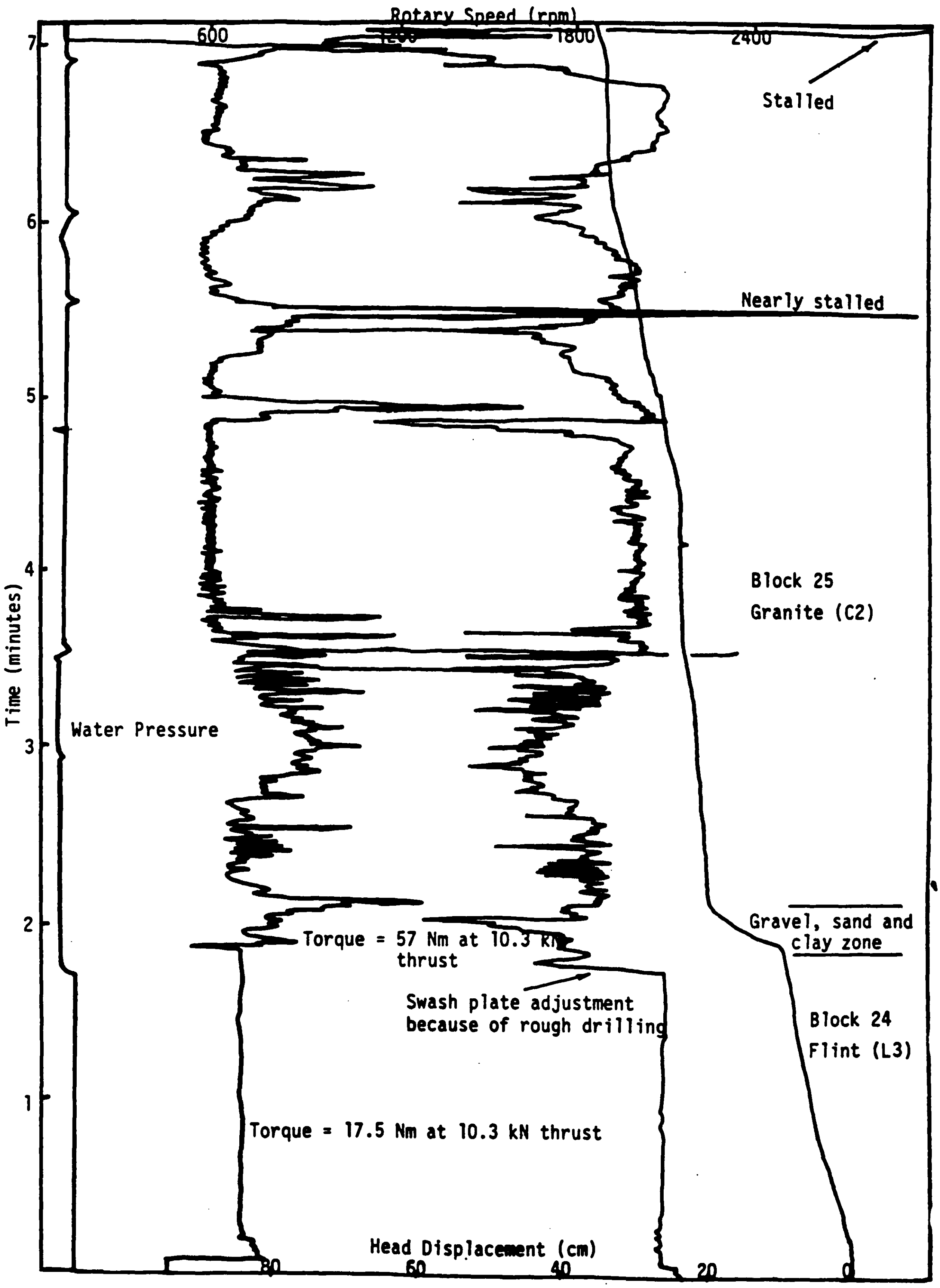
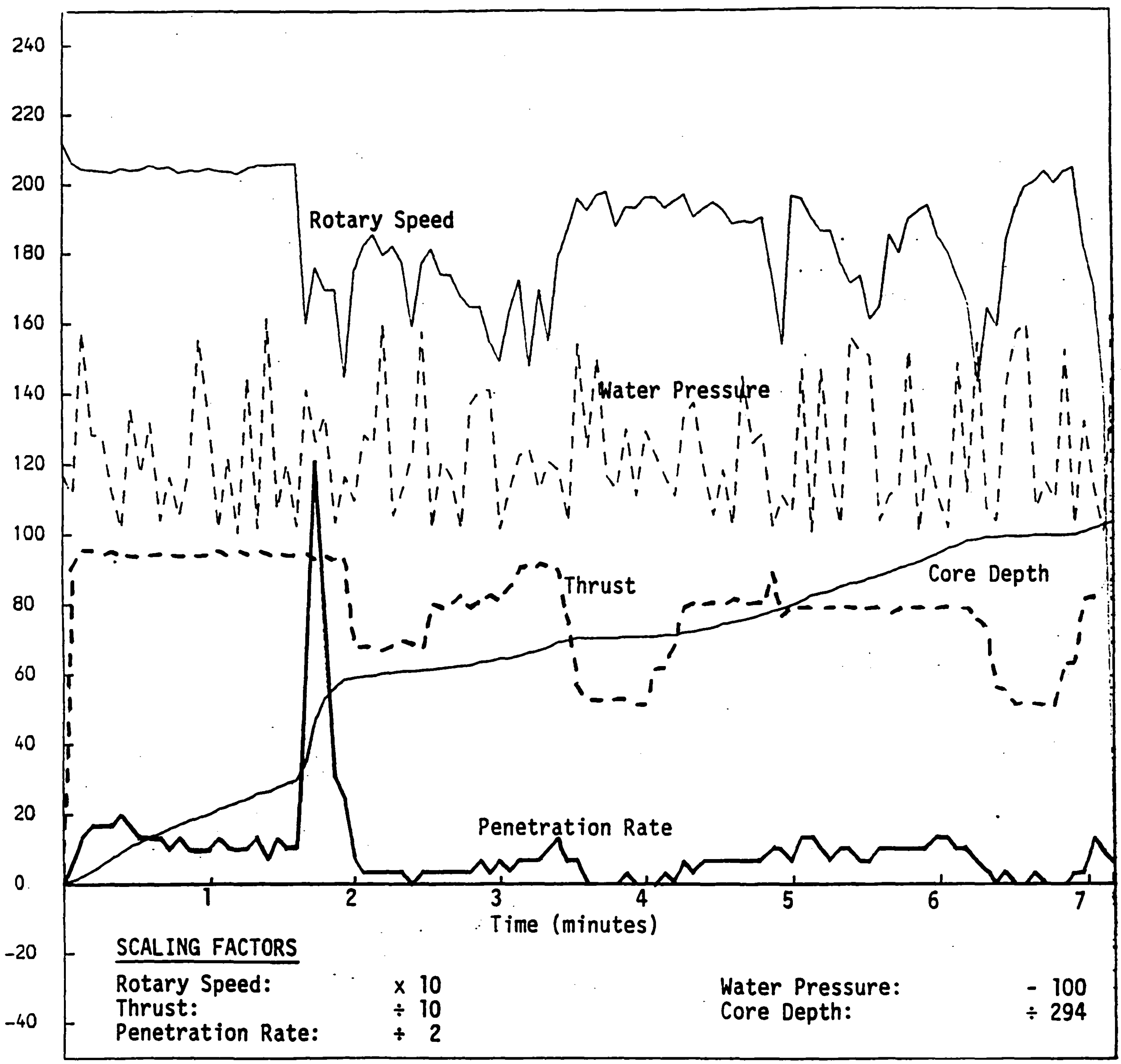


FIGURE 5.17 RECORD OF TRRL DRILL RUN 1.6 (5.06 to 5.41 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.6 (5.06 to 5.41 metres)



USER: EX9069 -AT SYSTEM

NP_T1.7.1

LABEL: PRT016 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:27, ON: PRO BY: PRC

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
145606	5.41	-0.000	0.00	1518.93	8.36	21.07	59.97	32.12	4.27
145610	5.43	0.012	18.55	1539.29	8.36	16.61	45.12	30.51	4.33
145614	5.44	0.021	13.49	1524.74	8.36	20.36	15.42	30.51	4.33
145618	5.44	0.027	8.43	1510.20	9.93	22.12	8.71	25.57	4.90
145622	5.45	0.031	6.74	1518.93	9.93	21.07	0.57	26.77	5.66
145626	5.45	0.033	1.69	1501.47	9.53	23.17	37.69	28.59	5.34
145630	5.45	0.034	1.69	1481.11	9.53	25.62	3.14	22.99	5.65
145634	5.45	0.035	1.69	1495.66	9.67	23.87	41.41	31.12	6.04
145638	5.45	0.036	1.69	1510.20	9.53	22.12	6.85	28.37	5.34
145642	5.45	0.036	0.00	1501.47	9.53	23.17	19.84	21.88	5.72
145646	5.45	0.037	1.69	1513.11	9.53	21.77	8.71	3.41	6.16
145650	5.45	0.038	1.69	1521.83	9.53	20.71	15.42	22.72	4.78
145654	5.45	0.039	1.69	1533.47	9.53	23.89	58.11	28.14	4.52
145658	5.46	0.040	1.69	38.46	-4.32	194.94	43.26	28.81	-1.53
145702	5.46	0.040	0.00	23.92	-4.32	196.60	17.28	30.51	-1.35
145706	5.46	0.040	0.00	23.92	-4.32	196.60	14.28	27.46	-1.35
145710	5.46	0.040	0.00	605.63	-4.32	130.05	1.28	22.99	-1.35
145714	5.46	0.044	5.06	1478.21	9.40	30.21	28.41	25.81	5.22
145718	5.46	0.046	3.37	1489.84	9.40	24.88	26.56	27.69	5.53
145722	5.46	0.046	3.37	1498.57	9.40	27.88	6.14	26.81	5.09
145726	5.47	0.052	5.06	1498.57	9.40	27.36	4.28	28.59	5.53
145730	5.47	0.054	3.37	1481.11	9.40	29.88	16.13	8.45	5.72
145734	5.47	0.057	5.06	1484.02	9.40	29.54	8.71	6.88	6.42
145738	5.48	0.061	5.06	1489.84	9.40	28.88	17.28	33.84	5.47
145742	5.48	0.063	3.37	1478.21	9.40	30.21	58.11	35.13	6.86
145746	5.48	0.066	5.06	1478.21	9.40	30.21	35.84	29.45	6.48
145750	5.48	0.070	5.06	1431.67	9.40	35.53	6.85	34.95	6.54
145754	5.49	0.073	5.06	1481.11	9.40	29.88	19.84	27.00	6.42
145758	5.49	0.076	5.06	1405.49	9.40	38.53	1.28	32.51	7.11
145802	5.50	0.084	11.80	1446.21	9.40	33.87	39.55	34.40	5.60
145806	5.51	0.094	15.18	1484.02	9.40	29.54	1.28	36.74	6.04
145810	5.52	0.102	11.80	1492.75	9.40	28.55	58.11	35.13	5.79
145814	5.53	0.111	13.49	1492.75	9.53	28.55	5.00	36.89	5.47
145818	5.54	0.121	15.18	1498.57	9.53	27.88	10.56	33.84	5.47
145822	5.55	0.130	13.49	1489.84	9.40	28.88	5.00	33.09	5.28
145826	5.56	0.143	18.55	1495.66	9.40	28.21	22.85	34.58	5.15
145830	5.57	0.156	20.24	1492.75	9.40	28.55	50.65	33.09	4.96
145834	5.58	0.169	18.55	1504.38	9.40	27.21	46.97	37.40	5.09
145838	5.60	0.182	20.24	1486.93	9.40	29.21	5.00	36.20	5.22
145842	5.61	0.194	18.55	1501.47	9.40	27.55	8.71	34.95	4.84
145846	5.62	0.205	15.18	1504.38	9.40	27.21	6.85	31.32	4.84
145850	5.63	0.214	13.49	1516.02	9.40	25.88	11.71	33.84	4.78
145854	5.64	0.221	11.80	1510.20	9.40	26.55	43.26	34.95	4.65
145858	5.65	0.234	18.55	1498.57	9.40	27.88	8.00	30.71	5.03
145902	5.66	0.246	18.55	1495.66	9.40	28.21	30.27	33.47	5.03
145906	5.67	0.259	18.55	1489.84	9.40	28.88	12.42	30.51	5.15
145910	5.69	0.271	18.55	1481.11	9.40	29.88	0.57	31.52	5.03
145914	5.70	0.282	16.86	1486.93	9.40	29.21	39.55	30.09	5.03
145918	5.71	0.293	16.86	1510.20	9.40	26.55	2.43	34.40	4.90
145922	5.72	0.306	18.55	1472.39	9.40	30.87	45.83	29.24	4.71
145926	5.75	0.336	45.53	1484.02	9.27	29.54	24.70	30.51	5.03
145930	5.76	0.343	10.12	1478.21	9.27	30.21	10.56	7.70	6.35
145934	5.76	0.349	8.43	1457.85	9.27	32.54	4.28	3.49	6.16
145938	77	0.356	11.80	1484.02	9.27	29.54	48.83	13.09	5.72

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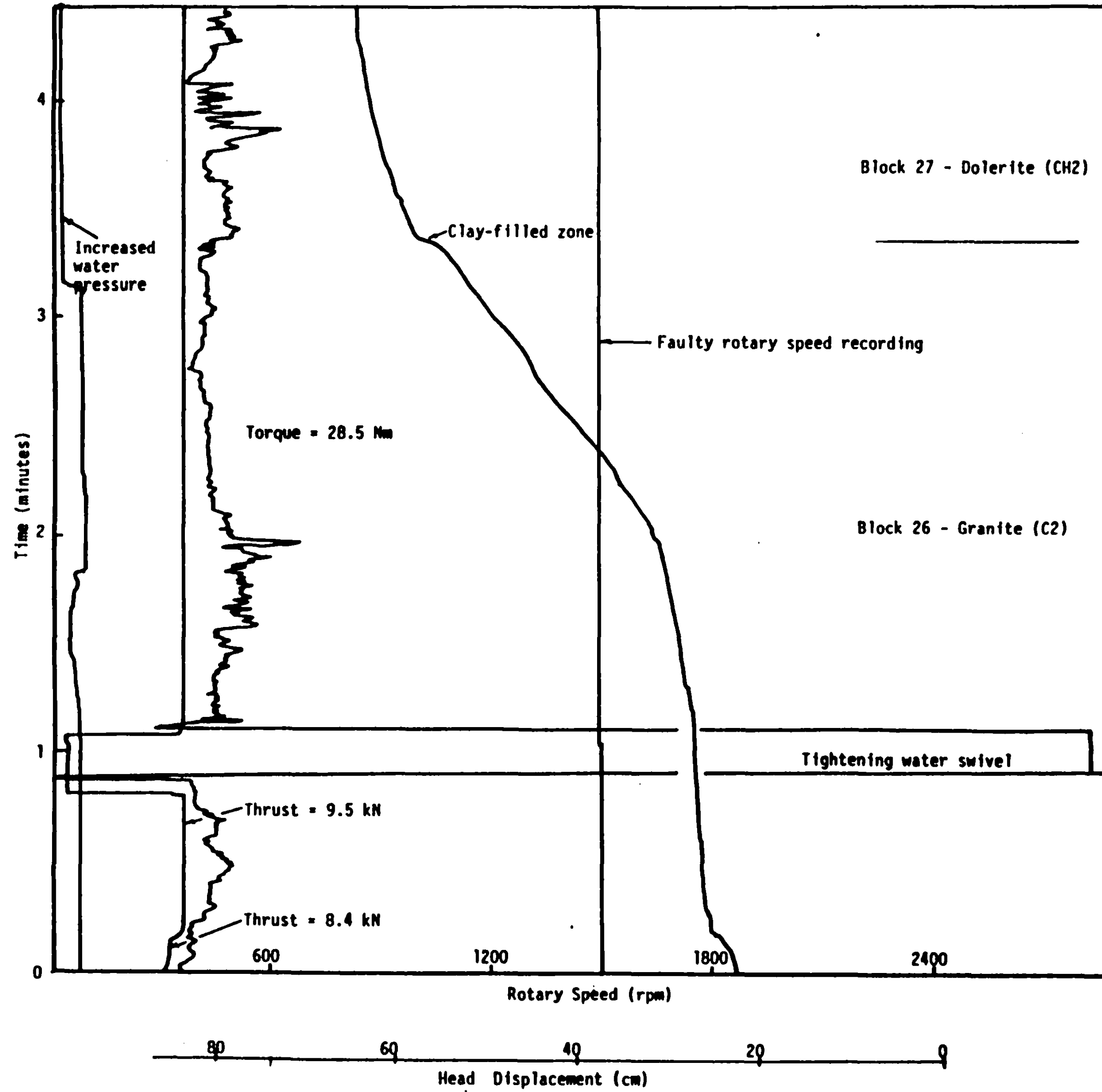
	TOTAL	COAL	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
145942	5.77	0.360	5.06	1463.66	9.27	31.87	43.25	16.73	5.97
145946	5.78	0.364	6.74	1489.84	9.27	28.88	22.85	20.44	5.34
145950	5.78	0.370	8.43	1481.11	9.27	29.88	5.05	3.40	5.59
145954	5.79	0.376	8.43	1446.21	9.27	33.87	16.13	3.40	5.91
145958	5.79	0.379	5.06	1463.66	9.27	31.87	8.00	26.30	5.66
150002	5.80	0.381	5.00	1484.02	9.40	29.34	9.85	35.84	6.42
150006	5.80	0.385	5.06	1472.39	9.40	30.47	25.41	35.49	6.10
150010	5.80	0.387	3.37	1507.29	9.40	26.88	55.25	32.51	4.96
150014	5.81	0.390	5.06	1486.93	9.40	29.21	2.57	5.94	5.03
150018	5.81	0.392	3.37	1475.30	9.40	30.54	8.71	3.40	5.50
150022	5.81	0.395	3.37	1443.30	9.27	34.20	32.13	3.45	6.46
150026	5.81	0.397	3.37	1481.11	9.27	29.88	50.65	16.73	5.53
150030	5.81	0.398	1.69	1472.39	9.27	30.87	9.65	21.30	5.79



RECORD OF TRRL DRILL RUN 1.7.1 (5.41 to 5.81 metres)

USER: EX5069 -AT SYSTEM

NR_T1.7.2

EX5069

NR_T1.7.2

LABEL: PRT017 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:27, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
----	-----	-----	---------	------	------	------	---------	-------	---------
110302	5.81	-0.000	0.00	1517.43	8.10	24.31	6.85	38.57	3.70
110306	5.81	0.006	8.43	1526.15	8.62	23.35	14.26	33.28	3.70
110310	5.81	0.008	3.37	1514.52	8.88	24.65	35.44	29.24	4.27
110314	5.82	0.009	1.69	1511.62	8.88	24.99	6.85	99.99	4.27
110318	5.82	0.010	1.69	1508.71	8.75	25.33	3.14	3.45	4.46
110322	5.82	0.013	3.37	1479.66	8.88	28.71	33.98	99.99	5.22
110326	5.82	0.015	3.37	1531.96	8.75	22.62	56.27	11.53	4.71
110330	5.82	0.018	5.06	1514.52	8.88	24.65	17.28	27.92	4.14
110334	5.83	0.020	3.37	1491.28	8.88	27.35	30.27	21.01	4.71
110338	5.83	0.025	6.74	1520.33	8.88	23.97	14.26	23.26	3.73
110342	5.83	0.026	1.69	1491.28	8.88	27.35	10.56	9.14	4.52
110346	5.83	0.028	3.37	1511.62	9.14	24.99	26.56	26.81	3.96

USER: EX9269 -AT SYSTEM

NR_T1.7.3

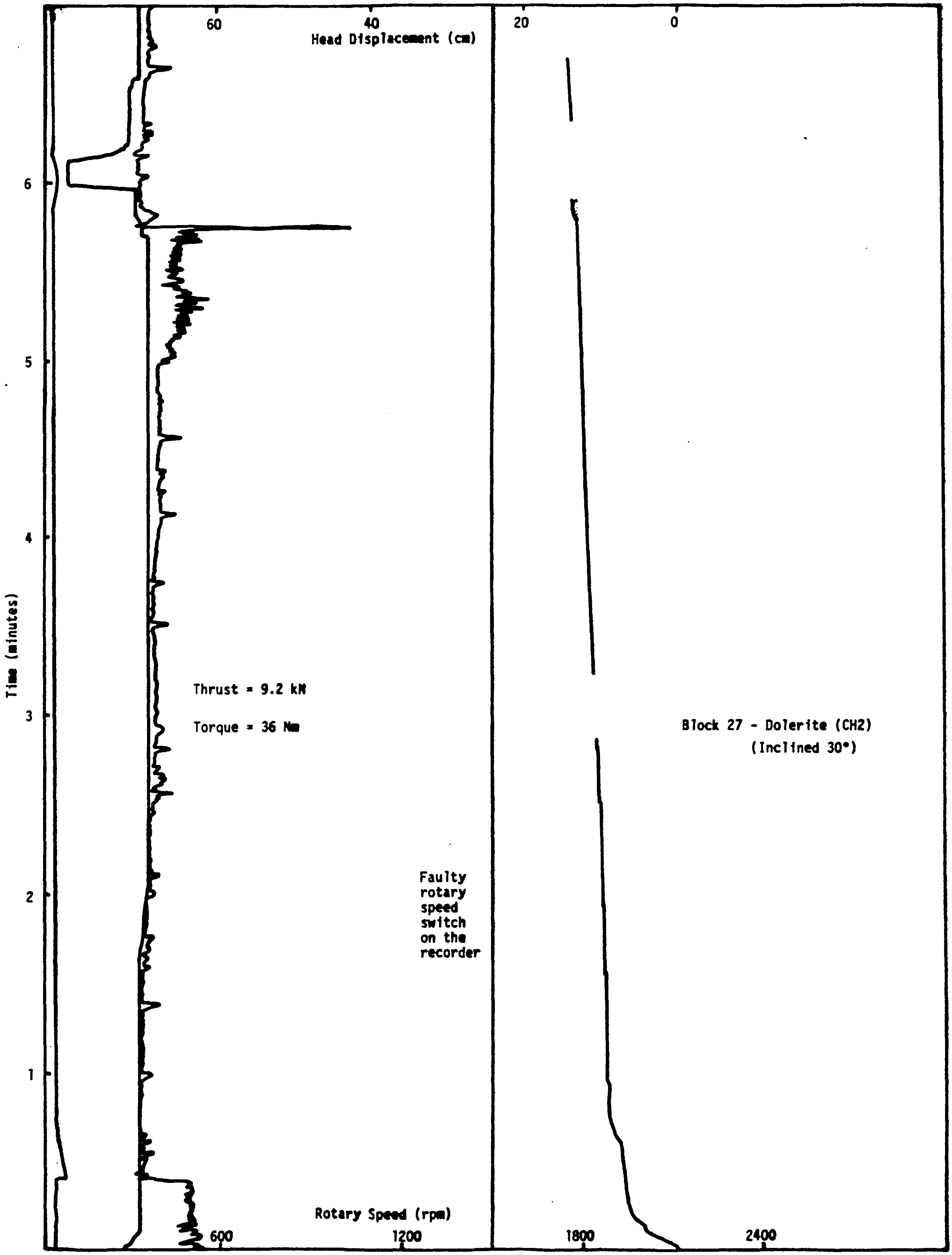
LABEL: PRT018 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:27, ON: PRO BY: PRC

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
111808	5.83	-0.000	0.00	1933.74	7.56	25.59	32.22	4.83	6.56
111812	5.83	0.002	3.37	1931.03	7.30	26.22	26.66	4.83	6.55
111816	5.83	0.003	1.69	1600.12	7.17	30.26	35.93	4.83	4.01
111820	5.83	0.005	3.37	1518.84	7.17	37.00	2.56	4.83	3.51
111824	5.83	0.007	1.69	1533.35	7.16	35.57	0.83	4.83	3.37
111828	5.84	0.011	6.74	1524.64	7.16	36.43	2.87	47.42	3.57
111832	5.84	0.017	8.43	1536.25	7.16	35.28	24.91	26.51	3.19
111836	5.84	0.019	3.37	1530.45	7.03	35.85	61.96	4.83	3.13
111840	5.85	0.020	1.69	1536.25	7.16	35.28	23.36	4.83	3.32
111844	5.85	0.020	0.00	1527.55	7.16	36.14	48.99	4.83	3.32
111848	5.85	0.021	1.69	1489.81	7.16	39.87	15.65	4.83	3.38
111852	5.85	0.021	0.00	1521.74	7.16	36.71	1.02	4.83	3.38
111856	5.85	0.022	1.69	1521.74	7.16	36.71	17.50	4.83	3.44
111900	5.85	0.022	0.00	1524.64	7.03	36.43	56.40	4.83	3.50
111904	5.85	0.023	1.69	1524.64	7.16	36.43	19.36	4.83	3.38
111908	5.85	0.023	0.00	1521.74	7.16	36.71	15.65	4.83	3.38
111912	5.85	0.023	0.00	1478.20	7.16	41.02	53.85	44.94	3.44
111916	5.85	0.025	1.69	1533.35	7.03	35.57	6.39	48.22	3.57
111920	5.85	0.025	0.00	1515.94	7.42	37.29	4.72	47.42	3.50
111924	5.85	0.025	0.00	1524.64	8.33	36.43	0.83	39.35	3.44
111928	5.85	0.026	1.69	1515.94	8.33	37.29	21.21	9.13	3.57
111932	5.85	0.026	0.00	1507.23	8.33	38.15	60.11	41.09	3.68
111936	5.85	0.027	1.69	1510.13	9.24	37.86	10.09	4.83	4.07
111940	5.85	0.027	0.00	1513.03	9.11	37.57	41.58	4.83	3.44
111944	5.85	0.027	0.00	1515.94	9.11	37.29	24.91	4.63	3.38
111948	5.85	0.028	1.69	1513.03	9.24	37.57	2.68	4.83	3.69
111952	5.85	0.028	0.00	1501.42	9.24	38.72	6.39	4.83	3.82
111956	5.86	0.029	1.69	1481.10	9.11	40.73	36.03	4.83	3.69
112000	5.86	0.029	0.00	1507.23	9.24	38.15	48.99	4.83	3.63
112004	5.86	0.030	1.69	1513.03	9.24	37.57	4.54	4.83	3.76
112008	5.86	0.031	1.69	1515.94	9.11	37.29	30.47	11.49	3.50
112012	5.86	0.031	0.00	1510.13	9.11	37.86	32.32	44.36	3.76
112016	5.86	0.031	0.00	1501.42	9.24	38.72	1.02	49.01	3.76
112020	5.86	0.032	1.69	1501.42	9.24	38.72	6.58	46.47	4.01
112024	5.86	0.032	0.00	1521.74	9.24	36.71	0.83	43.20	4.26
112028	5.86	0.034	1.69	1478.20	9.24	41.02	23.06	39.19	4.26
112032	5.86	0.035	1.69	1489.81	9.24	39.87	58.26	4.83	4.45
112036	5.86	0.035	0.00	1495.62	9.11	39.29	2.68	4.83	3.94
112040	5.86	0.036	1.69	1489.81	9.11	39.87	60.11	4.83	4.51
112044	5.86	0.037	1.69	1475.30	9.24	41.30	13.80	4.83	4.07
112048	5.86	0.037	0.00	1498.52	9.11	39.01	0.83	4.83	4.01
112052	5.86	0.038	1.69	1489.81	9.24	39.87	17.50	4.83	3.94
112056	5.86	0.038	0.00	1501.42	8.46	38.72	52.70	4.83	4.13
112100	5.87	0.039	1.69	1501.42	8.46	38.72	23.06	4.83	4.13
112104	5.87	0.039	0.00	1498.52	8.46	39.01	6.39	33.62	4.07
112108	5.87	0.040	1.69	1495.62	8.59	39.29	56.40	40.78	3.94
112112	5.87	0.041	1.69	1507.23	8.59	38.15	11.95	47.15	3.88
112116	5.87	0.041	0.00	1507.23	8.46	38.15	4.72	49.92	3.94
112120	5.87	0.043	1.69	1452.07	8.46	43.60	4.72	41.40	3.82
112124	5.87	0.043	0.00	1505.75	8.59	37.59	8.24	46.47	3.82
112128	5.87	0.044	1.69	1495.95	8.59	38.17	34.18	4.83	4.01
112132	5.87	0.044	0.00	1497.05	8.46	38.46	39.73	4.83	4.07
112136	5.87	0.045	1.69	1485.45	8.46	39.61	8.43	11.49	4.39
112140	.87	0.045	0.00	1497.05	9.11	38.46	56.40	40.15	3.82

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
112144	5.87	0.046	1.69	1494.15	9.37	38.74	8.24	44.79	3.94
112148	5.87	0.047	1.69	1491.25	9.37	39.33	4.72	47.29	4.13
112152	5.87	0.048	1.69	1485.45	9.37	39.51	4.72	48.75	4.20
112156	5.87	0.048	0.00	1479.65	9.11	40.19	4.54	42.76	4.26
112200	5.87	0.048	0.00	1482.55	8.59	39.91	23.0[illegible]	3.39	4.20
112204	5.88	0.049	1.69	1491.25	8.46	39.33	50.85	4.83	4.26
112208	5.88	0.049	0.00	1485.45	8.59	39.51	6.58	4.83	4.20
112212	5.88	0.050	1.69	1491.25	8.46	39.33	50.85	4.83	4.39
112216	5.88	0.050	0.00	1497.05	8.72	38.46	28.62	4.83	4.01
112220	5.88	0.052	1.69	1491.25	8.46	39.33	2.68	4.83	4.13
112224	5.88	0.052	0.00	1508.55	8.46	37.39	4.54	4.83	4.51
112228	5.88	0.053	1.69	1491.25	8.59	39.33	28.62	4.83	4.13
112232	5.88	0.053	0.00	1485.45	8.59	39.51	54.55	11.49	4.26
112236	5.88	0.054	1.69	1497.05	8.59	38.46	0.83	4.83	4.26
112240	5.88	0.055	1.69	1497.05	8.59	38.46	10.09	45.15	4.07
112244	5.88	0.055	0.00	1491.25	8.59	39.33	43.44	44.08	4.07
112248	5.88	0.056	1.69	1473.95	8.59	41.06	4.54	48.88	4.13
112252	5.88	0.056	0.00	1456.45	8.98	42.51	6.58	50.56	4.76
112256	5.88	0.057	1.69	1459.65	9.37	43.09	4.72	45.36	4.70
112300	5.88	0.058	1.69	1450.65	8.98	43.09	11.95	38.70	5.39
112304	5.89	0.059	1.69	1456.45	5.24	42.51	45.29	49.27	5.58
112308	5.89	0.059	0.00	1424.55	9.24	45.69	37.89	39.51	4.83
112312	5.89	0.061	1.69	1430.35	9.11	45.11	36.03	39.99	5.71
112316	5.89	0.061	0.00	1296.96	9.11	58.42	41.58	35.09	3.32
112320	5.89	0.062	1.69	1151.96	9.24	72.89	8.24	20.69	2.81
112324	5.89	0.062	0.00	1140.36	9.11	74.05	6.58	4.83	2.94
112328	5.89	0.063	1.69	1146.16	9.24	73.47	4.54	4.83	2.94
112332	5.89	0.063	0.00	1120.06	9.11	76.07	23.06	4.83	3.57
112336	5.89	0.064	1.69	1186.76	6.63	69.42	54.55	4.83	1.93
112340	5.89	0.067	5.06	1198.36	5.59	68.26	15.84	4.83	1.93
112344	5.89	0.066	1.69	1209.96	5.59	67.10	15.65	22.14	1.55
112348	5.89	0.067	1.69	1201.26	5.98	67.97	36.03	20.99	1.68



RECORD OF TRRL DRILL RUN 1.7.3 (5.83 to 5.89 metres)

USER: EX9069 -AT SYSTEM

NP_T1.8.1

EX9069

NP_T1.8.1

LABEL: PRT019 -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:28, ON: PRJ BY: PRJ

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (KN/M**2)
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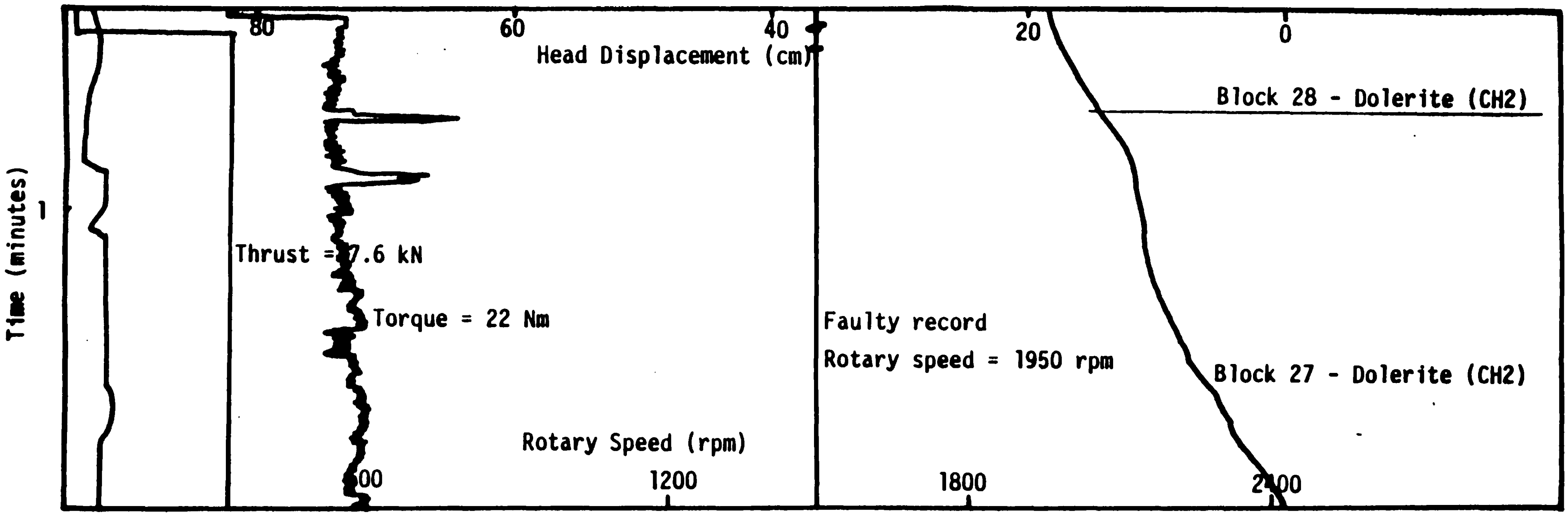
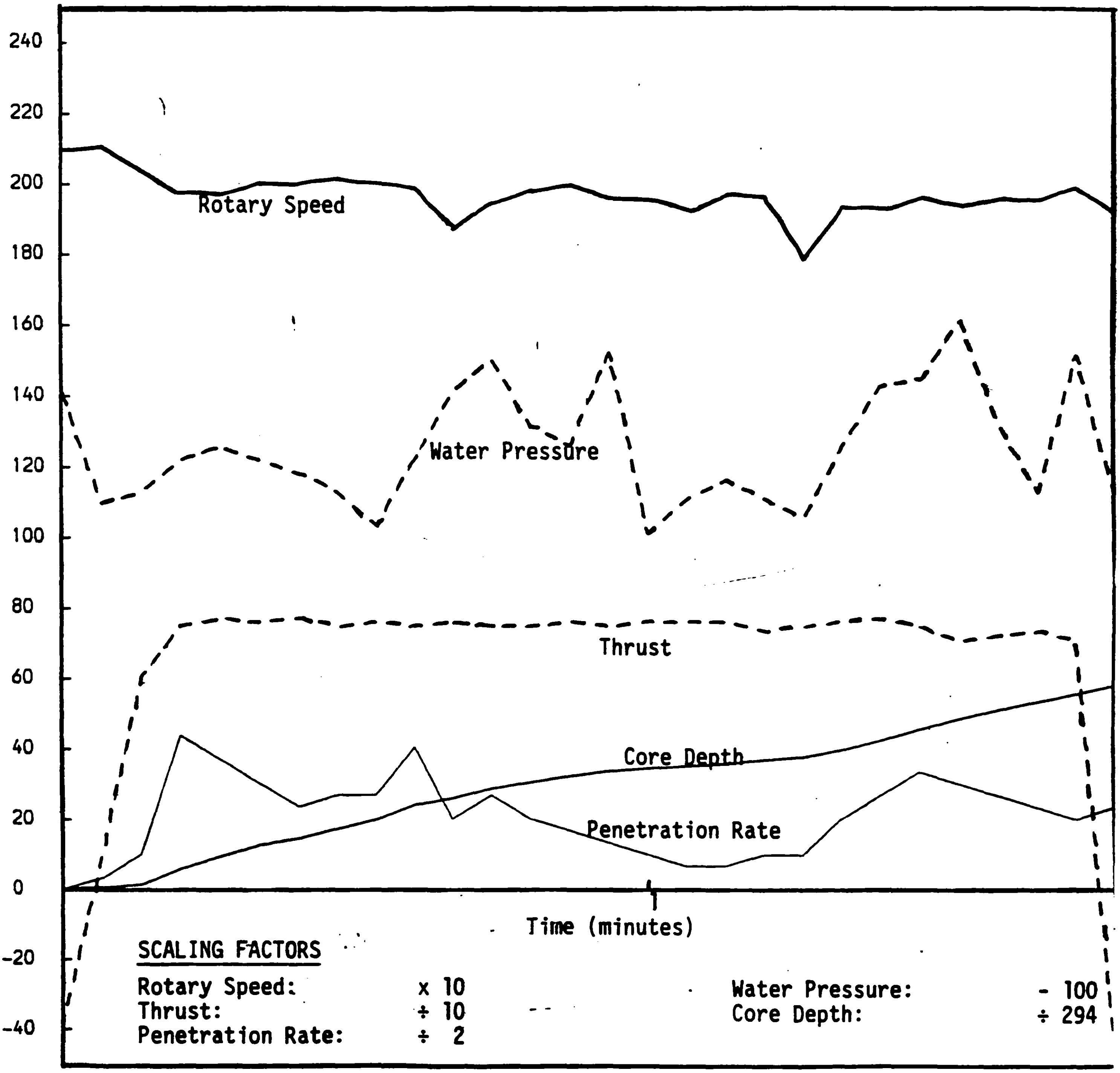
132230	5.89	0.000	0.00	2098.98	-3.93	14.02	41.14	45.62	7.52
132234	5.89	0.001	1.69	2107.73	6.92	13.39	9.49	50.56	7.39
132238	5.89	0.004	5.06	2043.61	6.04	18.04	12.85	50.05	7.14
132242	5.91	0.019	21.92	1973.66	7.48	23.13	22.16	53.41	8.72
132246	5.92	0.031	18.55	1967.83	7.74	23.55	25.84	47.68	9.22
132250	5.93	0.042	15.18	2003.73	7.60	20.94	22.01	40.39	6.83
132254	5.94	0.049	11.80	2000.82	7.73	18.33	18.29	39.27	6.71
132258	5.95	0.058	13.49	2014.46	7.48	18.26	12.85	25.61	8.65
132302	5.96	0.067	13.49	2002.81	7.61	19.13	3.54	31.77	6.59
132306	5.97	0.081	20.24	1988.23	7.46	20.21	22.52	41.19	6.91
132310	5.98	0.088	10.12	1868.74	7.61	29.07	41.14	13.02	8.97
132314	5.99	0.097	13.49	1944.52	7.48	23.45	50.45	4.84	9.10
132318	5.99	0.103	10.12	1982.41	7.48	20.64	31.83	4.84	8.59
132322	6.00	0.109	8.43	1996.98	7.61	19.56	26.24	4.84	8.53
132326	6.00	0.114	6.74	1962.00	7.48	22.15	52.31	4.84	9.10
132330	6.01	0.117	5.06	1959.09	7.61	22.37	1.68	16.75	9.35
132334	6.01	0.119	3.37	1924.12	7.61	24.96	10.99	23.57	9.79
132338	6.01	0.121	3.37	1970.75	7.61	21.50	16.57	17.48	9.67
132342	6.01	0.125	5.06	1962.00	7.35	22.15	10.99	40.41	9.16
132346	6.02	0.128	5.06	1784.23	7.48	35.34	5.77	4.84	12.07
132350	6.02	0.135	10.12	1935.77	7.61	24.10	26.24	44.33	8.84
132354	6.03	0.144	13.49	1928.03	7.73	23.79	43.09	41.79	9.15
132358	6.05	0.155	16.86	1964.92	7.48	21.94	44.86	4.84	10.61
132402	6.06	0.165	15.18	1941.60	7.09	23.67	61.62	4.84	9.60
132406	6.06	0.174	13.49	1962.00	7.22	22.15	31.83	4.84	8.91
132410	6.07	0.182	11.80	1953.26	7.35	22.80	13.21	4.84	8.97
132414	6.08	0.189	10.12	1994.06	7.09	19.77	52.31	4.84	6.84
132418	6.09	0.197	11.80	1915.37	-4.85	25.61	11.35	4.84	8.40



RECORD OF TRRL DRILL RUN 1.8.1 (5.89 to 6.09 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.8.1 (5.89 to 6.09 metres)



USER: EX9069 -AT SYSTEM

NR_T1.8.2

EX9069

NR_T1.8.2

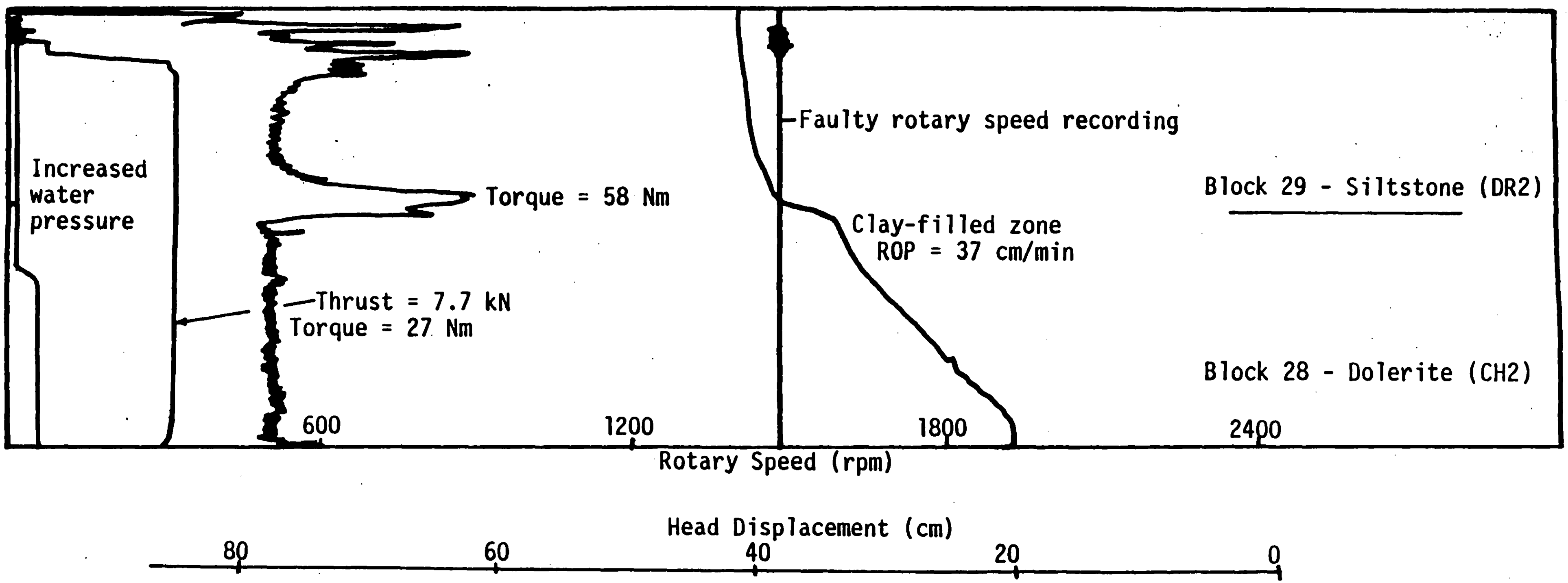
LABEL: PRT02C -FORM

SPOOLED: 82-01-21.19:07
STARTED: 82-01-21.19:28, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

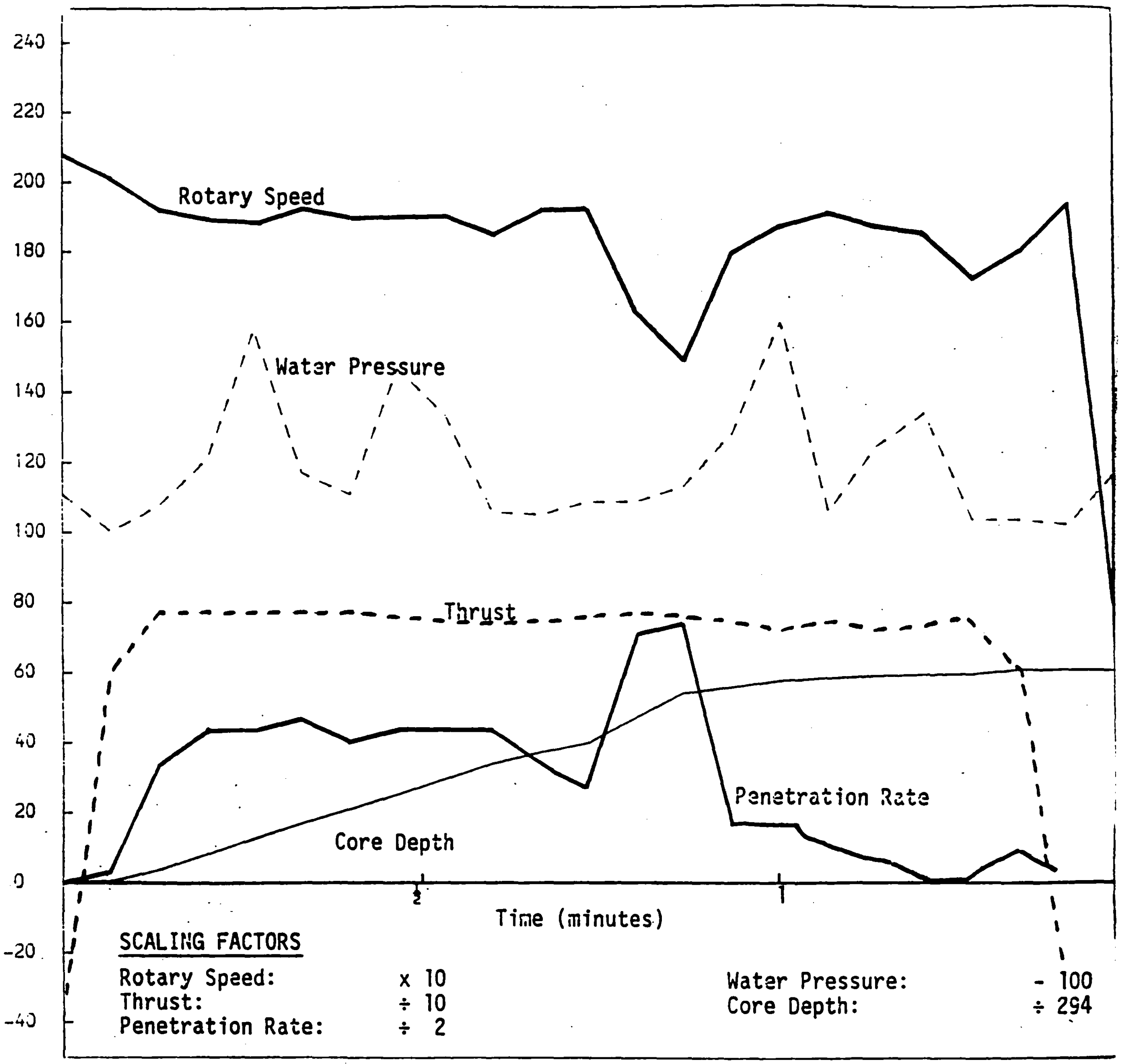
-508-

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
132942	6.09	0.000	0.00	2081.50	-3.93	15.29	10.85	48.19	6.94
132946	6.09	0.001	1.69	2011.55	6.03	20.37	0.31	45.45	7.00
132950	6.10	0.012	16.86	1921.20	7.73	26.94	7.75	45.55	9.[illegible]9
132954	6.12	0.027	21.92	1892.06	7.73	29.05	20.77	36.76	9.97
132958	6.13	0.042	21.92	1883.31	7.73	29.69	57.97	40.39	9.76
133002	6.15	0.057	23.61	1924.12	7.73	26.72	17.05	18.51	9.15
133006	6.16	0.071	20.24	1897.89	7.73	28.63	10.85	39.27	9.09
133010	6.18	0.085	21.92	1903.72	7.60	28.21	46.81	44.89	9.47
133014	6.19	0.100	21.92	1903.72	7.47	28.21	33.79	51.91	9.28
133018	6.20	0.115	21.92	1851.26	7.47	32.02	5.89	55.97	9.47
133022	6.22	0.126	16.86	1921.20	7.47	26.94	5.27	57.22	9.21
133026	6.22	0.135	13.49	1924.12	7.60	26.72	8.99	56.32	8.96
133030	6.25	0.159	35.42	1626.85	7.73	48.32	8.99	55.51	9.09
133034	6.27	0.183	37.10	1489.87	7.60	58.27	13.33	51.04	13.77
133038	6.28	0.189	8.43	1795.88	7.47	36.04	28.21	50.28	10.79
133042	6.28	0.195	8.43	1871.66	7.21	33.54	59.83	44.46	9.72
133046	6.29	0.198	5.06	1909.54	7.47	27.78	5.89	38.61	9.47
133050	6.29	0.200	3.37	1868.74	7.21	30.75	24.49	11.51	9.59
133054	6.29	0.201	1.69	1851.26	7.34	32.02	33.79	24.39	9.97
133058	6.29	0.202	1.69	1723.02	7.47	41.33	3.41	29.48	10.67
133102	6.30	0.206	5.06	1804.63	6.03	35.41	3.41	3.40	13.58
133106	6.30	0.206	0.00	1938.69	-3.93	25.67	2.17	3.40	8.46
133110	6.30	0.206	0.00	746.69	-4.59	112.26	17.05	3.40	7.00



RECORD OF TRRL DRILL RUN 1.8.2 (6.09 to 6.30 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.8.2 (6.09 to 6.30 metres)



USER: EX9069 -AT SYSTEM

NR_T1.9

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WWWW     W     WWWW  W W W  WWWW    WWWW
W       W W       W  WW  W  W   W      W
W      W   W     W   W   W  W   W     W 
WWWWW  W   W   WW     WWW    WWW    WW  
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LABEL: PRT021 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:28, ON: PRO BY: PRO

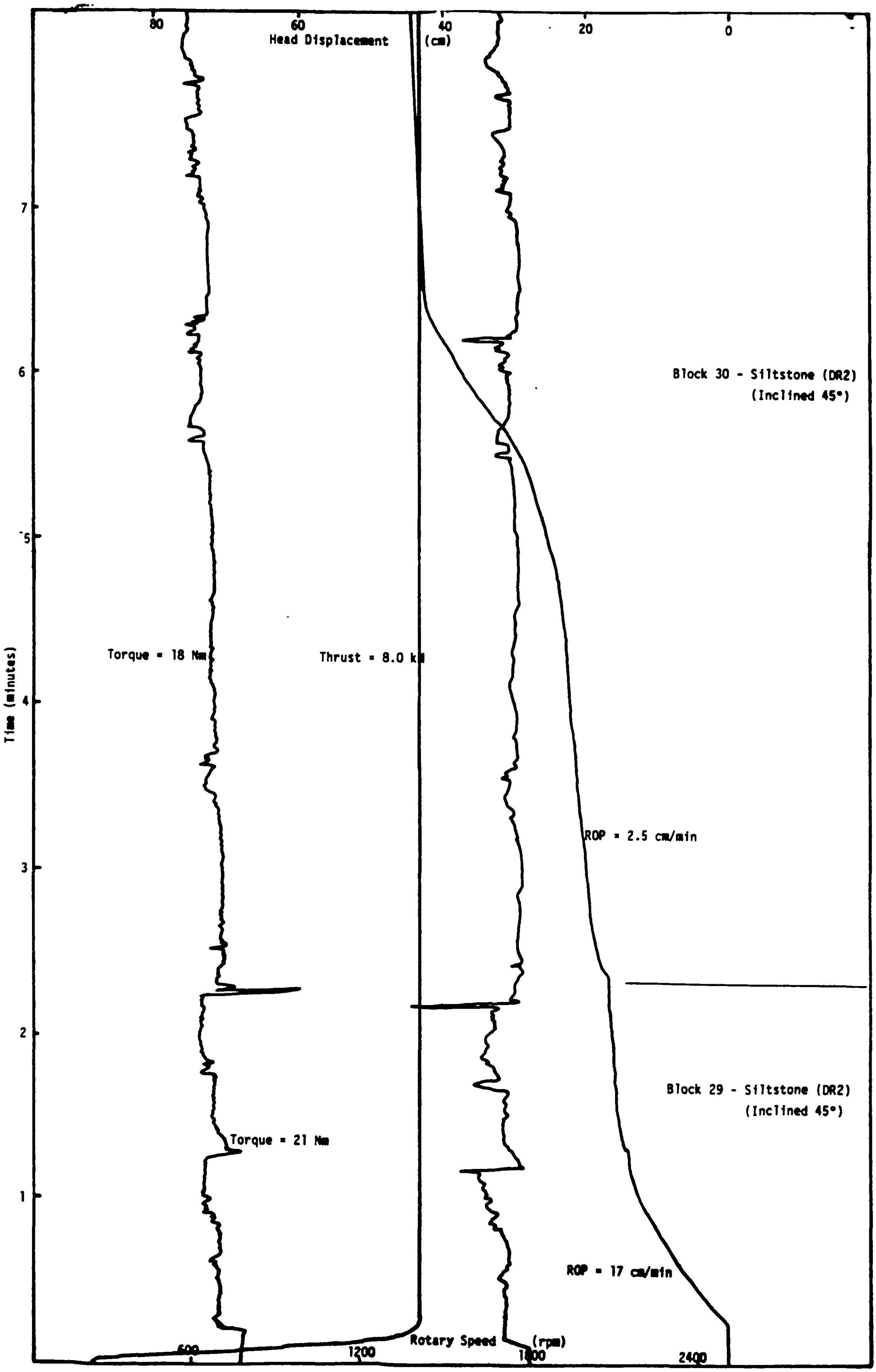
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

-512-

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
17160744	6.30	0.000	0.00	2108.63	-1.29	13.32	10.30	28.91	8.19
17160748	6.30	0.002	3.37	2111.56	4.76	13.11	11.56	44.42	7.93
17160752	6.31	0.008	8.43	2006.00	7.53	20.78	9.00	99.99	6.50
17160756	6.32	0.024	23.61	2001.14	8.06	21.20	37.04	99.99	9.71
17160800	6.34	0.036	18.55	1997.21	8.06	21.41	55.73	99.99	9.06
17160804	6.35	0.047	16.86	2008.94	7.92	20.56	23.95	99.99	9.52
17160808	6.36	0.058	16.86	2000.14	8.06	21.20	7.82	99.99	9.52
17160812	6.37	0.071	18.55	2000.14	7.92	21.20	51.99	99.99	9.46
17160816	6.38	0.081	15.18	1985.48	8.06	22.27	16.48	99.99	9.97
17160820	6.39	0.091	15.18	2023.60	7.92	19.50	15.30	22.80	9.61
17160824	6.40	0.101	15.18	2017.73	7.94	19.92	15.45	21.09	6.96
17160828	6.41	0.111	15.18	1994.27	8.07	21.63	11.71	99.99	9.41
17160832	6.42	0.120	13.49	1979.61	8.07	22.69	8.68	99.99	9.28
17160836	6.43	0.128	11.80	1956.16	8.07	24.40	44.43	99.99	10.23
17160840	6.43	0.134	8.43	1912.18	8.07	27.59	59.40	99.99	10.42
17160844	6.44	0.138	6.74	1909.24	8.07	27.81	21.97	99.99	10.30
17160848	6.44	0.142	5.06	1906.31	8.07	28.02	4.22	99.99	10.61
17160852	6.44	0.144	3.37	1888.72	8.07	29.30	59.40	99.99	10.87
17160856	6.45	0.147	5.06	2052.92	7.94	17.37	2.35	99.99	8.13
17160900	6.45	0.152	6.74	2020.66	7.94	19.71	11.71	99.99	8.51
17160904	6.45	0.154	3.37	1991.34	7.94	21.84	5.13	99.99	9.21
17160908	6.46	0.155	1.69	1985.48	7.94	22.27	36.94	99.99	9.41
17160912	6.46	0.156	1.69	1991.34	7.94	21.84	21.97	99.99	9.28
17160916	6.46	0.157	1.69	1997.21	7.94	21.41	15.45	99.99	9.02
17160920	6.46	0.157	0.00	2002.14	7.94	21.06	30.42	99.99	9.15
17160924	6.46	0.159	1.69	1919.96	7.94	27.03	59.40	99.99	9.02
17160928	6.46	0.160	1.69	1966.92	7.94	23.62	7.01	3.41	9.28
17160932	6.46	0.161	1.69	1919.96	7.94	27.03	9.83	23.89	9.66
17160936	6.46	0.162	1.69	1925.83	7.94	23.89	9.83	18.90	10.42
17160940	6.46	0.163	1.69	1914.09	7.95	24.77	1.26	99.99	10.85
17160944	6.46	0.163	0.00	1958.11	7.94	24.26	36.94	99.99	9.72
17160948	6.46	0.164	1.69	1961.05	7.95	21.25	59.32	99.99	9.48
17160952	6.47	0.166	3.37	1960.64	7.95	20.73	34.96	99.99	9.67
17160956	6.47	0.169	3.37	2033.52	7.96	16.80	6.37	99.99	8.28
17161000	6.48	0.177	11.80	2054.09	7.82	15.28	44.34	99.99	7.89
17161004	6.48	0.181	6.74	2071.71	7.83	13.97	14.26	99.99	7.90
17161008	6.48	0.183	3.37	2065.84	7.83	14.40	4.49	99.99	7.83
17161012	6.49	0.186	3.37	2051.15	7.83	15.49	0.74	99.99	7.90
17161016	6.49	0.188	3.37	2054.09	7.83	15.28	12.38	99.99	8.09
17161020	6.49	0.189	1.69	2054.09	7.83	15.28	48.00	99.99	7.90
17161024	6.49	0.190	1.69	2074.65	7.83	13.75	8.63	99.99	7.77
17161028	6.49	0.192	3.37	2073.79	7.83	14.82	41.99	99.99	7.64
17161032	6.49	0.193	1.69	2059.96	7.83	14.84	18.05	99.99	7.77
17161036	6.50	0.196	3.37	2077.59	7.83	13.53	61.13	99.99	7.58
17161040	6.50	0.198	3.37	2074.65	7.83	13.75	16.13	36.38	7.58
17161044	6.50	0.199	1.69	2074.65	7.83	13.75	11.99	34.95	7.58
17161048	6.50	0.201	3.37	2067.91	7.83	15.25	13.87	36.03	7.77
17161052	6.50	0.204	3.37	2051.15	7.83	15.49	2.62	39.59	7.77
17161056	6.50	0.205	1.69	2045.27	7.83	15.93	10.51	4.86	7.90
17161100	6.51	0.206	1.69	2033.52	7.83	16.80	61.13	99.99	8.02
17161104	6.51	0.207	1.69	2030.58	7.83	17.02	28.87	99.99	7.96
17161108	6.51	0.208	1.69	2015.89	7.83	18.11	34.88	15.66	6.66
17161112	6.51	0.208	0.00	2012.95	7.96	18.33	25.53	7.74	8.34
17161116	6.51	0.210	3.37	1983.57	7.96	20.51	61.13	30.87	8.09

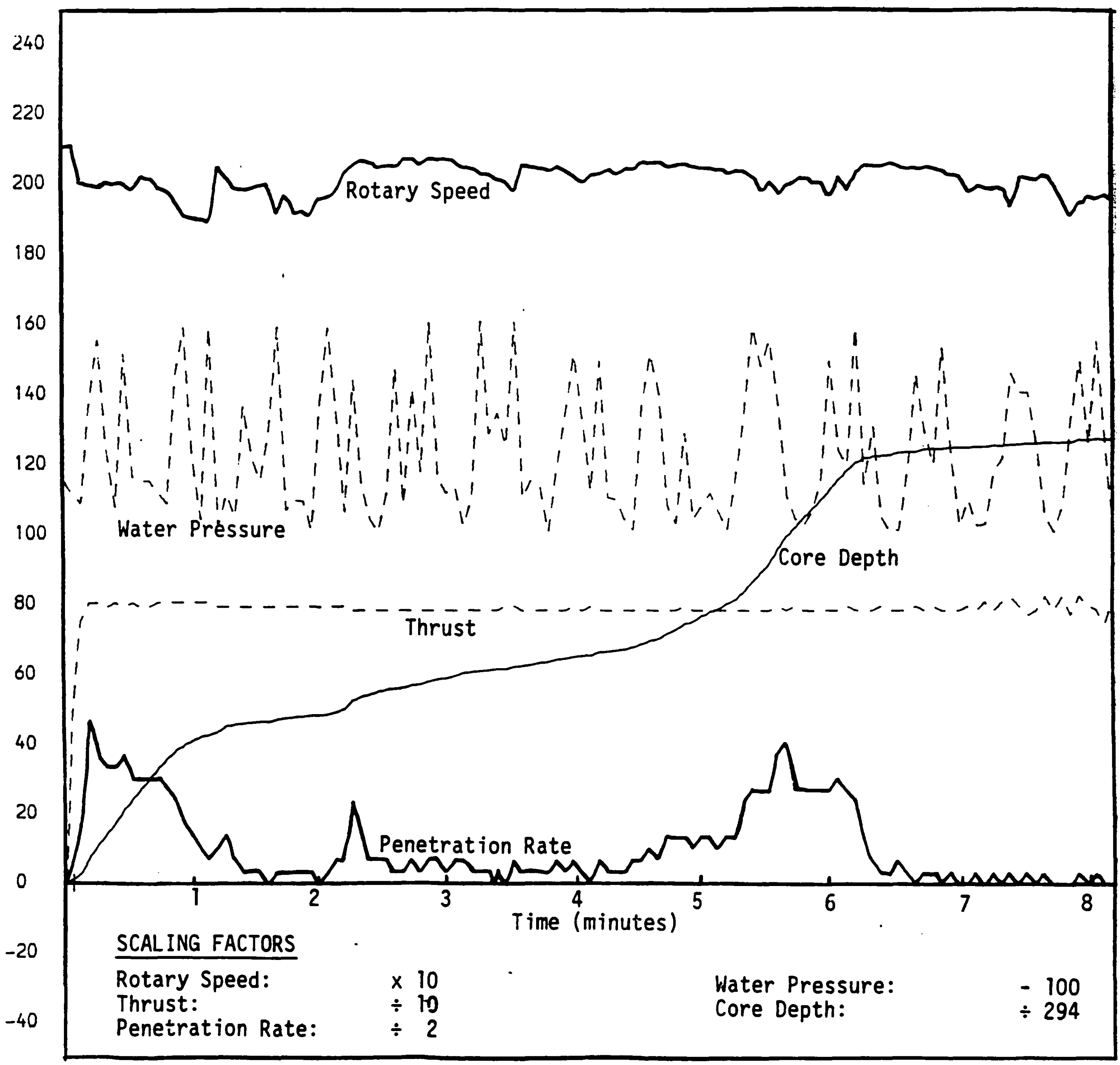
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 2
17161120	6.51	0.211	1.69	2059.96	7.82	14.84	10.63	99.99	8.33
17161124	6.51	0.212	1.69	2054.97	7.82	14.20	15.59	34.56	7.57
17161128	6.51	0.214	1.69	2049.10	7.83	14.64	13.87	29.17	7.77
17161132	6.51	0.215	1.69	2039.40	7.83	16.37	9.74	15.66	7.90
17161136	6.52	0.217	3.37	2052.03	7.83	14.42	19.88	99.99	7.64
17161140	6.52	0.218	1.69	2040.29	7.82	15.30	34.98	99.99	7.70
17161144	6.52	0.220	3.37	2025.62	7.95	16.40	51.83	99.99	7.82
17161148	6.52	0.221	1.69	2010.94	7.82	17.50	33.10	99.99	8.08
17161152	6.52	0.221	0.00	2028.55	7.95	16.18	12.50	99.99	8.08
17161156	6.52	0.224	3.37	2034.42	7.82	15.74	49.96	99.99	7.95
17161200	6.52	0.225	1.69	2043.23	7.82	15.08	10.63	99.99	7.70
17161204	6.53	0.226	1.69	2028.55	7.82	16.18	9.98	99.99	7.89
17161208	6.53	0.227	1.69	2046.16	7.82	14.86	4.36	99.99	7.70
17161212	6.53	0.229	3.37	2049.10	7.82	14.64	1.26	99.99	7.44
17161216	6.53	0.232	3.37	2063.77	7.82	13.54	36.85	99.99	7.44
17161220	6.53	0.235	5.06	2060.84	7.82	13.76	51.83	99.99	7.31
17161224	6.54	0.237	3.37	2063.77	7.82	13.54	40.59	99.99	7.31
17161228	6.54	0.242	6.74	2052.03	7.82	14.42	8.10	99.99	7.38
17161232	6.55	0.246	6.74	2057.90	7.82	13.98	3.13	99.99	7.25
17161236	6.55	0.251	6.74	2057.90	7.95	13.98	29.36	29.59	7.38
17161240	6.55	0.254	5.06	2052.03	7.82	14.42	4.36	38.75	7.44
17161244	6.56	0.259	6.74	2046.16	7.82	14.86	8.10	38.42	7.38
17161248	6.56	0.263	6.74	2040.29	7.82	15.30	11.85	38.75	7.57
17161252	6.57	0.266	5.06	2046.16	7.82	14.86	6.23	23.90	7.63
17161256	6.57	0.271	6.74	2031.49	7.82	15.96	1.26	95.99	7.38
17161300	6.58	0.275	6.74	2040.29	7.82	15.30	16.25	21.10	7.51
17161304	6.58	0.283	11.80	2037.36	7.82	15.52	34.98	99.99	7.44
17161308	6.59	0.292	13.49	2019.75	7.82	16.84	59.32	99.99	7.63
17161312	6.60	0.301	13.49	1978.66	7.82	19.92	48.09	99.99	7.70
17161316	6.61	0.310	13.49	2008.01	7.82	17.72	55.58	13.52	7.57
17161320	6.62	0.323	18.55	1969.85	7.95	20.59	36.85	36.71	8.33
17161324	6.64	0.336	20.24	1999.20	7.82	18.38	10.63	32.86	8.21
17161328	6.65	0.345	13.49	2013.88	7.95	17.28	4.36	27.82	7.70
17161332	6.65	0.354	13.49	2019.75	7.82	16.84	2.48	40.85	7.57
17161336	6.66	0.363	13.49	2005.07	7.82	17.94	6.88	39.92	7.63
17161340	6.67	0.372	13.49	2008.01	7.82	17.72	16.25	42.70	7.57
17161344	6.68	0.381	13.49	1966.92	7.82	20.81	49.96	37.92	7.76
17161348	6.69	0.391	15.18	2022.68	7.82	16.62	23.74	38.25	7.82
17161352	6.70	0.400	13.49	1984.53	7.96	19.48	19.88	45.07	8.41
17161356	6.71	0.408	11.80	2036.46	7.83	16.58	59.25	43.17	9.43
17161400	6.71	0.413	6.74	2054.97	7.82	14.20	14.37	44.90	7.30
17161404	6.71	0.415	3.37	2052.03	7.83	14.42	31.13	99.99	7.13
17161408	6.72	0.416	1.69	2054.97	7.96	14.20	4.88	99.99	7.07
17161412	6.72	0.417	1.69	2063.77	7.82	13.54	0.61	25.93	7.06
17161416	6.72	0.419	3.37	2052.03	7.82	14.42	1.26	37.92	7.00
17161420	6.72	0.420	1.69	2046.16	7.82	14.86	18.12	25.69	7.19
17161424	6.72	0.420	0.00	2046.16	7.95	14.86	46.21	34.19	7.19
17161428	6.72	0.422	1.69	2052.03	7.82	14.42	29.36	42.70	7.06
17161432	6.72	0.423	1.69	2046.16	7.95	14.86	19.99	46.04	7.00
17161436	6.72	0.423	0.00	2040.29	7.82	15.30	53.71	44.47	7.19
17161440	6.72	0.424	1.69	2025.62	7.82	16.40	23.74	42.24	7.76
17161444	6.72	0.424	0.00	2025.62	7.82	19.35	2.48	48.50	7.51
17161448	6.72	0.424	0.00	1978.66	7.95	19.92	9.98	48.23	7.38
17161452	6.72	0.425	1.69	1996.27	7.82	18.60	2.48	42.99	7.82
17161456	6.72	0.425	0.00	1990.40	8.08	19.04	3.13	34.37	6.14
17161500	6.73	0.426	1.69	1993.33	7.82	18.82	16.12	18.91	8.08
17161504	6.73	0.426	0.00	1984.53	6.08	19.48	21.86	95.99	7.82
17161508	6.73	0.427	1.69	1937.57	8.21	23.01	46.21	99.99	8.52

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 5
17161512	6.73	0.427	0.00	2022.68	7.95	16.62	40.59	99.99	7.70
17161516	6.73	0.428	1.69	2019.75	7.69	16.54	40.59	99.99	7.36
17161520	6.73	0.428	0.00	2016.81	7.63	17.06	25.51	99.99	7.45
17161524	6.73	0.429	1.69	2028.55	8.23	16.18	4.88	24.51	8.28
17161528	6.73	0.429	0.00	1995.33	7.83	19.64	0.74	34.02	7.77
17161532	6.73	0.429	0.00	1954.19	8.23	22.69	8.63	39.43	8.22
17161536	6.73	0.429	0.00	1911.15	7.70	24.99	33.09	33.64	8.92
17161540	6.73	0.431	1.69	1948.32	8.23	23.13	49.88	45.92	8.47
17161544	6.73	0.431	0.00	1968.88	7.96	21.69	25.50	44.93	8.02
17161548	6.73	0.432	1.69	1963.01	7.83	22.04	55.55	45.92	8.02
17161552	6.73	0.432	0.00	1974.76	7.43	21.16	23.63	50.74	7.83
17161556	6.73	0.432	0.00	1963.01	8.10	22.04	0.74	44.35	8.15



RECORD OF TRRL DRILL RUN 1.9 (6.30 to 6.73 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.9 (6.30 to 6.73 metres)



USER: EX9069 -AT SYSTEM

NR_T1.10

EX9069

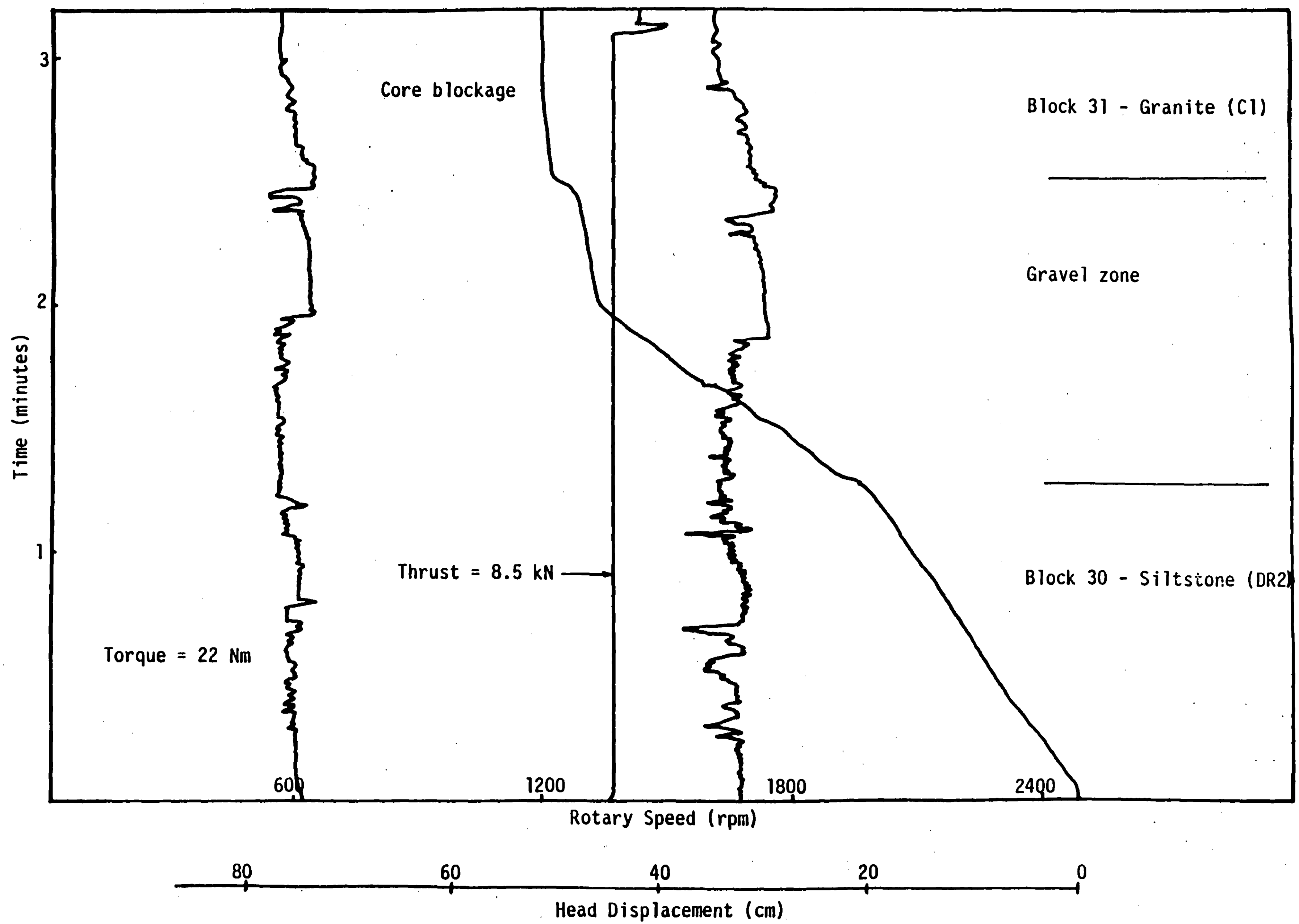
NR_T1.10

LABEL: PRT022 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:28, ON: PRO BY: PRO

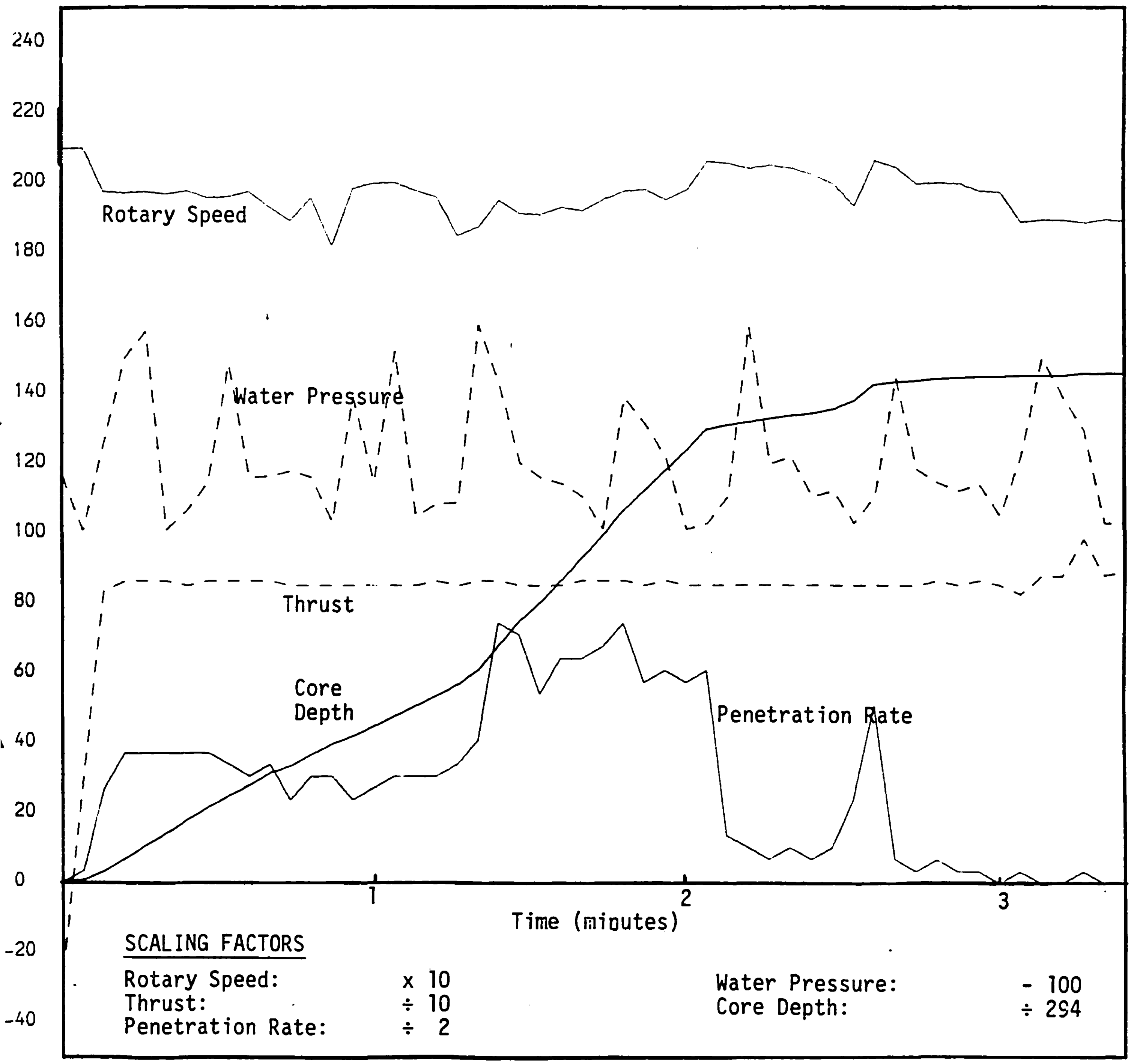
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
17170140	6.73	0.000	0.00	2098.16	-2.60	14.08	15.8[illegible]	46.64	7.2[illegible]
17170144	6.73	0.001	1.69	2098.16	2.94	14.08	0.74	42.11	7.37
17170148	6.74	0.010	13.49	1971.82	6.36	23.26	25.50	99.99	8.62
17170152	6.75	0.022	18.55	1968.88	8.62	23.47	49.68	99.99	8.98
17170156	6.76	0.035	18.55	1971.82	8.64	23.26	57.37	99.99	8.99
17170200	6.78	0.047	18.55	1965.95	8.62	23.69	0.74	99.99	8.98
17170204	6.79	0.060	18.55	1974.76	8.49	23.05	6.37	99.99	9.17
17170208	6.80	0.072	18.55	1954.19	8.62	24.54	14.26	23.65	9.49
17170212	6.81	0.083	16.86	1957.13	8.62	24.33	48.[illegible]	99.99	8.98
17170216	6.82	0.093	15.18	1971.82	8.62	23.26	15.74	15.66	6.85
17170220	6.83	0.105	16.86	1927.75	8.62	26.46	16.13	40.87	9.17
17170224	6.84	0.112	11.80	1889.56	8.49	29.24	17.62	41.03	10.32
17170228	6.85	0.123	15.18	1954.19	8.49	24.54	15.74	38.10	8.53
17170232	6.86	0.133	15.18	1819.04	8.49	34.36	3.01	99.99	9.24
17170236	6.87	0.141	11.80	1980.64	8.49	22.62	38.63	99.99	8.61
17170240	6.88	0.150	13.49	1995.33	8.49	21.55	14.26	99.99	8.41
17170244	6.89	0.160	15.18	1998.26	8.49	21.34	51.75	99.99	6.53
17170248	6.90	0.170	15.18	1974.76	8.49	23.05	4.49	99.99	8.73
17170252	6.91	0.180	15.18	1957.13	8.62	24.33	8.24	32.09	6.98
17170256	6.92	0.191	16.86	1848.42	8.49	32.22	8.63	33.26	8.85
17170300	6.93	0.205	20.24	1871.93	8.62	30.52	59.25	47.72	9.17
17170304	6.96	0.229	37.10	1948.32	8.62	24.97	42.38	49.84	9.24
17170308	6.98	0.253	35.42	1910.12	8.49	27.74	19.86	47.44	9.43
17170312	7.00	0.271	26.98	1907.19	8.49	27.96	15.74	47.72	9.04
17170316	7.02	0.292	32.04	1927.75	8.49	26.46	13.87	53.48	8.73
17170320	7.04	0.314	32.04	1918.94	8.64	27.10	10.26	41.83	8.86
17170324	7.07	0.336	33.73	1951.26	8.64	24.75	1.00	34.04	9.05
17170328	7.09	0.361	37.10	1974.76	8.64	23.05	38.54	37.96	9.05
17170332	7.11	0.380	28.67	1980.64	8.50	22.62	31.03	26.20	6.67
17170336	7.13	0.400	30.36	1951.26	8.64	24.75	21.64	26.45	8.67
17170340	7.15	0.419	28.67	1977.70	8.50	22.83	1.09	42.74	6.48
17170344	7.17	0.440	30.36	2059.96	8.50	16.86	2.75	40.73	7.91
17170348	7.17	0.444	6.74	2054.09	8.50	17.28	10.38	35.12	7.40
17170352	7.18	0.447	5.06	2039.40	8.50	18.35	59.18	40.58	7.59
17170356	7.18	0.450	3.37	2048.21	8.50	17.71	19.77	47.74	7.46
17170400	7.18	0.453	5.06	2039.40	8.50	18.35	21.64	48.81	7.46
17170404	7.19	0.455	3.37	2021.77	8.50	19.63	10.26	49.73	7.59
17170408	7.19	0.459	5.06	1995.33	8.49	21.55	11.99	43.47	7.96
17170412	7.20	0.467	11.80	1933.63	8.49	26.03	2.62	32.48	8.15
17170416	7.21	0.483	25.30	2062.90	8.49	16.64	10.51	4.86	7.20
17170420	7.22	0.486	3.37	2042.33	8.49	18.14	44.25	38.27	6.88
17170424	7.22	0.487	1.69	1995.33	8.49	21.55	18.00	44.64	8.02
17170428	7.22	0.489	3.37	1998.26	8.62	21.34	14.26	51.25	8.15
17170432	7.22	0.490	1.69	1995.33	8.49	21.55	11.99	45.64	8.15
17170436	7.22	0.491	1.69	1974.76	8.62	23.05	13.87	43.32	8.15
17170440	7.22	0.491	0.00	1971.82	8.49	23.26	4.88	36.38	8.28
17170444	7.22	0.492	1.69	1886.62	8.23	29.45	21.75	8.49	8.92
17170448	7.22	0.492	0.00	1892.49	8.76	29.02	49.88	99.99	9.43
17170452	7.22	0.492	0.00	1892.49	8.76	29.02	38.63	99.99	9.30
17170456	7.22	0.494	1.69	1886.62	9.81	29.45	29.25	99.99	9.30
17170500	7.22	0.494	0.00	1895.43	8.76	28.81	2.62	26.19	9.30
17170504	7.22	0.494	0.00	1892.49	8.89	29.02	2.62	35.85	9.43



RECORD OF TRRL DRILL RUN 1,10 (6.73 to 7.22 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.10 (6.73 to 7.22 metres)



USER: EX9069 -AT SYSTEM

NR_T1.11.1

EX9069

NR_T1.11.1

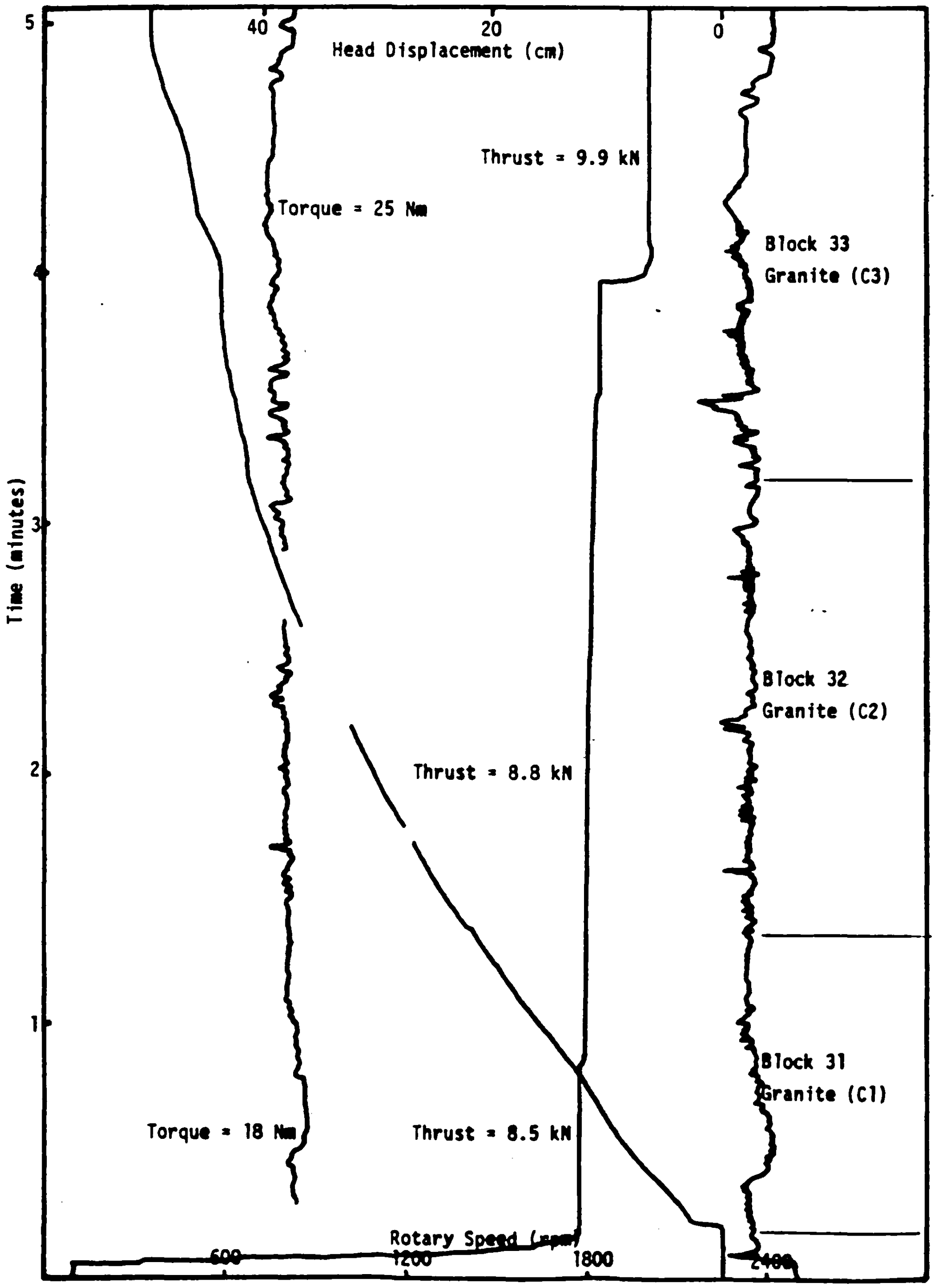
LABEL: PRT023 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:28, ON: PRO BY: PRG

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

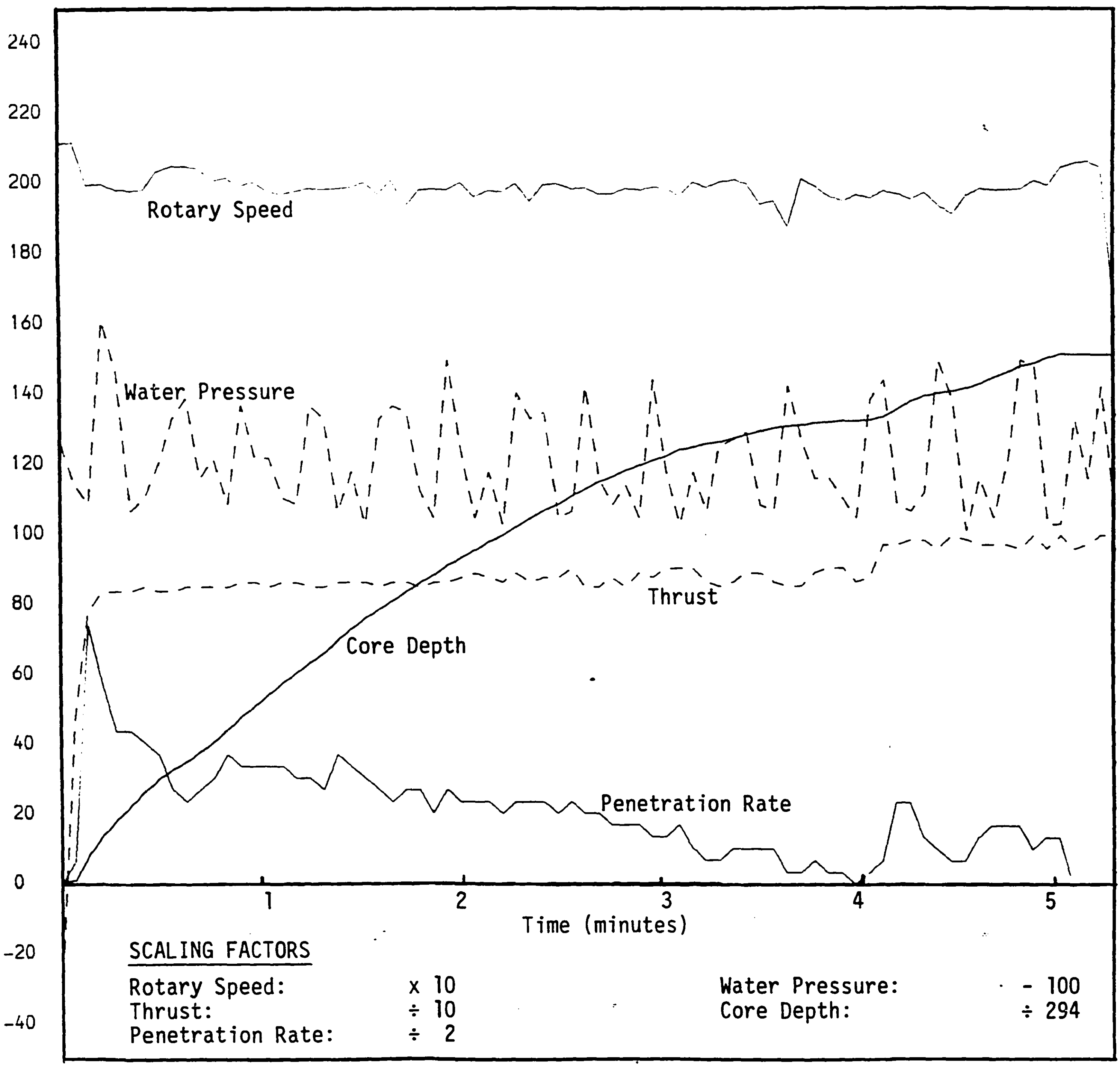
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
17172646	7.22	0.000	0.00	2114.96	-2.60	12.86	25.45	56.72	6.96
17172650	7.22	0.002	3.37	2117.90	4.68	12.65	14.16	57.18	6.70
17172654	7.25	0.027	37.05	1994.38	7.84	21.52	8.51	30.77	5.93
17172658	7.27	0.046	28.63	1997.32	8.37	21.41	61.06	36.05	8.35
17172702	7.28	0.061	21.90	1982.62	8.37	22.47	46.04	41.05	8.35
17172706	7.30	0.075	21.90	1976.74	8.37	22.90	6.51	34.22	8.29
17172710	7.31	0.089	20.21	1979.68	8.50	22.69	10.26	41.52	8.35
17172714	7.32	0.101	18.53	2032.61	8.37	18.84	19.77	45.52	7.97
17172718	7.33	0.110	13.47	2047.32	8.37	17.77	32.91	45.83	7.59
17172722	7.34	0.118	11.79	2047.32	8.50	17.77	38.54	38.63	7.52
17172726	7.35	0.127	13.47	2041.44	8.50	18.20	15.89	39.45	7.59
17172730	7.36	0.137	15.16	2006.15	8.50	20.77	21.52	42.74	7.78
17172734	7.37	0.149	18.53	2014.97	8.50	20.12	8.51	31.70	7.84
17172738	7.38	0.161	16.84	1991.44	8.64	21.83	36.66	99.99	8.10
17172742	7.39	0.172	16.84	2003.20	8.64	20.98	21.64	99.99	7.97
17172746	7.40	0.183	16.84	1976.74	8.50	22.90	21.64	99.99	8.29
17172750	7.41	0.194	16.84	1967.91	8.64	23.54	10.26	15.27	8.35
17172754	7.42	0.204	15.16	1976.74	8.64	22.90	8.51	32.10	8.16
17172758	7.43	0.214	15.16	1985.56	8.50	22.26	36.66	33.28	8.23
17172802	7.44	0.223	13.47	1982.62	8.50	22.47	32.91	45.24	8.23
17172806	7.46	0.236	18.53	1985.56	8.64	22.26	6.51	43.49	8.29
17172810	7.47	0.247	16.84	1988.50	8.64	22.05	17.77	41.36	8.10
17172814	7.48	0.257	15.16	2003.20	8.64	20.98	2.88	39.61	8.16
17172818	7.49	0.266	13.47	1970.85	8.50	23.33	32.91	25.47	8.23
17172822	7.49	0.274	11.79	2009.09	8.64	20.55	36.66	99.99	8.03
17172826	7.50	0.283	13.47	1935.56	8.64	25.89	34.78	99.99	7.78
17172830	7.51	0.292	13.47	1982.62	8.50	22.47	12.14	30.47	8.16
17172834	7.52	0.299	10.11	1985.56	8.64	22.26	4.75	36.40	7.97
17172838	7.53	0.308	13.47	1982.62	8.64	22.47	49.80	36.75	7.97
17172842	7.54	0.316	11.79	2003.20	8.77	20.98	23.52	41.98	7.91
17172846	7.54	0.323	11.79	1962.03	8.90	23.97	4.63	42.74	7.91
17172850	7.55	0.331	11.79	1979.68	8.77	22.69	17.77	42.44	7.84
17172854	7.56	0.338	10.11	1976.74	8.64	22.90	2.88	37.10	8.10
17172858	7.57	0.346	11.79	2000.26	8.90	21.19	40.41	9.83	7.97
17172902	7.57	0.354	11.79	1950.27	8.64	24.83	32.91	99.99	8.16
17172906	7.58	0.362	11.79	1997.32	8.77	21.41	34.78	99.99	7.84
17172910	7.59	0.368	10.11	2000.26	8.77	21.19	4.63	99.99	7.72
17172914	7.60	0.376	11.79	1985.56	9.03	22.26	6.63	36.22	7.84
17172918	7.60	0.383	10.11	1988.50	8.50	22.05	42.29	40.10	8.10
17172922	7.61	0.390	10.11	1970.85	8.50	23.33	16.01	39.94	8.10
17172926	7.62	0.395	8.42	1970.85	8.77	23.33	8.38	44.23	8.03
17172930	7.62	0.401	8.42	1985.56	8.50	22.26	14.01	41.21	7.84
17172934	7.63	0.406	8.42	1982.62	8.90	22.47	4.75	33.08	7.91
17172938	7.63	0.411	6.73	1988.50	8.77	22.05	44.17	11.02	7.97
17172942	7.64	0.415	6.73	1985.56	9.03	22.26	17.89	99.99	7.97
17172946	7.64	0.421	8.42	1964.97	9.03	23.76	2.88	41.83	8.23
17172950	7.64	0.424	5.05	2003.20	9.03	20.98	17.77	41.98	8.16
17172954	7.65	0.427	3.37	1988.50	8.64	22.05	6.51	39.61	8.03
17172958	7.65	0.429	3.37	2003.20	8.50	20.98	25.40	25.47	7.46
17173002	7.65	0.432	5.05	2009.09	8.64	20.55	27.27	99.99	7.59
17173006	7.66	0.436	5.05	2000.26	8.90	21.19	29.15	95.99	7.46
17173010	7.66	0.439	5.05	1941.44	8.90	25.47	8.38	43.79	7.97
17173014	7.66	0.442	5.05	1950.27	8.64	24.83	6.63	48.01	8.29
17173018	7.66	0.444	1.68	1876.74	8.50	30.17	42.29	47.60	6.59

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
17173022	7.66	0.445	1.68	2012.03	8.52	20.34	27.17	47.63	8.36
17173026	7.67	0.447	3.37	1991.44	8.92	21.83	15.9[illegible]	46.11	7.72
17173030	7.67	0.448	1.68	1964.97	9.05	23.76	16.04	41.38	8.04
17173034	7.67	0.449	1.68	1950.27	9.05	24.83	10.4[illegible]	43.21	8.17
17173038	7.67	0.449	0.00	1967.91	8.65	23.54	4.63	39.31	8.04
17173042	7.67	0.450	1.68	1959.09	8.78	24.18	38.44	33.87	8.17
17173046	7.67	0.453	3.37	1579.68	9.71	22.69	44.08	34.43	7.47
17173050	7.68	0.460	11.79	1970.85	9.71	23.33	8.38	37.63	7.85
17173054	7.69	0.468	11.79	1956.15	9.84	24.40	6.65	37.98	8.24
17173058	7.69	0.473	6.73	1973.79	9.84	23.12	12.14	44.39	8.04
17173102	7.70	0.476	5.05	1938.50	9.58	25.68	49.71	38.14	8.17
17173106	7.70	0.478	3.37	1914.97	9.97	27.39	38.44	45.46	8.75
17173110	7.70	0.461	3.37	1967.91	9.84	23.54	1.01	46.81	8.43
17173114	7.71	0.485	6.73	1985.56	9.71	22.26	16.04	43.21	7.66
17173118	7.71	0.491	8.42	1982.62	9.71	22.47	4.77	41.23	7.72
17173122	7.72	0.456	8.42	1582.62	9.71	22.47	19.66	33.48	7.72
17173126	7.72	0.502	8.42	1985.56	9.58	22.26	49.71	24.98	7.66
17173130	7.73	0.505	5.05	2039.09	9.97	20.55	47.84	25.73	7.98
17173134	7.73	0.510	6.73	1994.38	9.58	21.62	2.75	37.63	7.79
17173138	7.73	0.514	6.73	2047.32	9.97	17.77	2.89	44.54	6.96
17173142	7.73	0.514	0.00	2059.08	9.58	16.92	32.81	40.12	6.57
17173146	7.73	0.514	0.00	2064.97	9.71	16.49	15.9[illegible]	43.21	6.57
17173150	7.73	0.514	0.00	2050.26	9.97	17.56	42.2[illegible]	39.31	6.45
17173154	7.73	0.514	0.00	1653.23	9.97	46.41	8.53	41.54	6.83



RECORD OF TRRL DRILL RUN 1.11.1 (7.22 to 7.73 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.11.1 (7.22 to 7.73)



USER: EX9069 -AT SYSTEM

NR_T1.11.2

LABEL: PRT024 -FORM

SPOOLED: 82-01-21.19:28
STARTED: 82-01-21.19:28, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
17173522	7.73	0.000	0.00	2058.20	-2.33	16.98	14.16	99.99	8.24
17173526	7.73	0.000	0.00	2002.27	2.30	21.09	14.16	99.99	7.15
17173530	7.73	0.003	5.05	1943.39	7.46	25.32	14.16	99.99	7.92
17173534	7.74	0.015	16.84	1796.19	6.52	35.32	14.16	99.99	10.62
17173538	7.76	0.029	21.89	1643.10	9.58	45.25	14.16	99.99	11.56
17173542	7.77	0.042	18.53	1363.43	8.65	66.19	14.16	99.99	12.45
17173546	7.78	0.048	10.11	1189.73	8.65	80.08	14.16	99.99	11.17
17173550	7.78	0.053	6.73	1843.29	8.65	32.60	14.16	99.99	9.96
17173554	7.80	0.067	21.90	1805.02	8.78	35.38	14.16	99.99	9.70
17173558	7.81	0.081	20.21	1710.81	8.52	40.19	14.16	99.99	10.85
17173602	7.82	0.085	11.79	1575.39	7.46	52.06	14.16	99.99	12.71
17173606	7.82	0.091	3.37	1598.94	9.84	48.56	14.16	99.99	12.00
17173610	7.82	0.069	3.37	23.92	-1.94	166.45	14.16	99.99	-1.41
17173614	7.83	0.072	25.27	23.92	-1.94	166.45	14.16	99.99	-1.41

USER: EX5069 -AT SYSTEM

NR_T1.11.3

LABEL: PRT025 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:29, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
17174206	7.84	-0.000	0.00	1945.44	8.55	25.54	2.89	99.99	8.43
17174210	7.85	0.003	5.05	1884.51	8.25	29.67	21.55	99.99	8.66
17174214	7.85	0.006	3.37	1855.57	8.52	31.74	4.77	99.99	9.24
17174218	7.85	0.008	3.37	1863.90	8.78	31.10	30.93	99.99	9.26
17174222	7.85	0.010	3.37	1878.62	8.25	30.33	29.19	99.99	10.41
17174226	7.86	0.013	5.05	1728.48	8.12	40.94	10.26	99.99	11.49
17174230	7.86	0.016	3.37	1696.09	8.65	43.29	12.25	99.99	11.68
17174234	7.86	0.017	1.68	1719.65	8.65	41.58	6.65	28.32	12.77
17174238	7.86	0.018	1.68	1640.16	8.39	47.35	30.93	99.99	11.24
17174242	7.86	0.019	1.68	1613.66	8.12	49.28	23.41	99.99	13.47
17174246	7.86	0.019	0.00	1498.85	8.65	57.62	47.84	99.99	12.32
17174250	7.86	0.019	0.00	833.51	8.12	105.96	4.77	99.99	13.22

USER: EX9089 -AT SYSTEM

NR_T1.12.1

EX9089

NR_T1.12.1

LABEL: PRT026 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:32, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (KN/M**2)
20144852	7.86	-0.000	0.00	1955.40	8.42	24.82	4.32	99.99	9.33
20144856	7.87	0.013	20.21	1947.50	8.42	25.03	4.32	99.99	9.08
20144900	7.88	0.021	11.79	1959.09	8.42	24.18	4.32	99.99	9.01
20144904	7.89	0.030	13.47	1964.88	8.42	23.76	4.32	99.99	9.01
20144908	7.90	0.035	8.42	1973.57	8.29	23.13	0.63	99.99	8.76
20144912	7.90	0.041	8.42	1959.09	8.29	24.18	1.22	21.82	8.95
20144928	7.93	0.068	10.11	1933.02	8.68	26.08	4.32	99.99	9.[illegible]
20144932	7.94	0.076	11.79	1930.12	8.68	26.29	4.32	99.99	9.27
20144936	7.94	0.084	11.79	1941.71	8.55	25.45	2.47	99.99	9.01
20144940	7.95	0.092	11.79	1935.91	8.55	25.87	2.47	35.58	9.14
20144944	7.96	0.099	11.79	1947.50	8.55	25.03	4.32	99.99	8.89
20144948	7.97	0.108	13.47	1943.62	8.44	23.42	4.45	3.39	8.84
20144952	7.98	0.114	8.42	1947.50	8.55	25.03	2.47	99.99	8.89
20144956	7.98	0.122	11.79	1938.81	8.55	25.66	4.91	99.99	9.77
20145020	8.03	0.167	11.23	1924.33	8.55	26.71	1.22	99.99	2.67
20145024	8.04	0.176	13.47	1911.73	8.57	25.79	1.39	3.39	9.02
20145028	8.04	0.181	8.42	1906.94	8.55	27.97	1.22	99.99	9.27
20145032	8.05	0.190	13.47	1911.73	8.57	25.79	0.76	3.39	9.15
20145036	8.06	0.197	10.11	1915.64	8.44	24.54	1.39	3.39	9.02
20145040	8.07	0.205	11.79	1921.43	8.44	24.10	1.09	3.39	8.90
20145044	8.07	0.212	10.11	1922.43	8.55	25.92	0.63	99.99	8.95
20145048	8.08	0.220	11.79	1906.94	8.57	25.19	2.61	3.39	8.91
20145052	8.09	0.226	10.11	1899.28	8.55	27.62	0.63	99.99	9.01
20145056	8.10	0.238	16.84	1902.17	8.55	27.41	2.47	99.99	9.20
20145100	8.11	0.245	11.79	1896.38	8.55	27.83	2.47	99.99	9.08
20145104	8.12	0.256	15.16	1906.94	8.57	25.19	8.15	3.39	8.90
20145108	8.12	0.263	11.79	1875.08	8.57	27.58	6.30	3.39	9.02
20145112	8.13	0.272	13.47	1895.36	8.44	26.06	10.00	3.39	9.[illegible]9
20145116	8.14	0.281	13.47	1909.84	8.44	24.97	4.45	3.39	8.96
20145120	8.15	0.290	13.47	1904.05	8.44	25.41	8.15	4.82	8.96
20145124	8.16	0.299	13.47	1892.46	8.44	26.28	11.85	3.39	8.96
20145128	8.17	0.307	11.79	1904.05	8.44	25.41	4.45	3.39	8.96
20145132	8.18	0.315	11.79	1892.46	8.57	26.28	6.30	3.39	8.90
20145136	8.18	0.324	13.47	1886.67	8.44	26.71	2.61	17.77	9.15
20145140	8.19	0.333	13.47	1880.87	8.57	27.15	1.09	3.39	9.28
20145144	8.20	0.341	11.79	1877.98	8.44	27.37	4.79	3.39	9.21
20145148	8.21	0.349	11.79	1895.36	8.44	26.06	4.79	32.83	8.96
20145152	8.22	0.355	10.11	1895.36	8.57	26.06	4.79	3.39	8.77
20145156	8.23	0.364	13.47	1912.74	8.57	24.76	4.79	29.39	8.65
20145200	8.23	0.372	11.79	1898.25	8.44	25.84	4.79	3.39	8.77
20145204	8.24	0.376	5.05	1886.67	8.44	26.71	8.49	15.94	9.09
20145208	8.24	0.377	1.68	1898.25	8.44	25.84	4.79	3.39	8.96
20145212	8.24	0.379	3.37	1895.36	8.44	26.06	2.94	3.39	8.96
20145216	8.24	0.379	0.00	1889.56	8.44	26.50	1.09	3.39	9.02
20145220	8.24	0.380	1.68	1886.67	8.44	26.71	1.09	3.39	9.02
20145224	8.24	0.381	1.68	1892.46	8.57	26.28	1.09	3.39	10.26
20145228	8.25	0.385	5.05	1950.40	8.44	21.93	2.61	3.39	8.71
20145232	8.25	0.388	5.05	1930.12	8.44	23.45	0.76	3.39	8.33
20145236	8.25	0.391	5.05	1935.91	8.44	23.01	1.09	3.39	8.52
20145240	8.25	0.394	3.37	1933.02	8.44	23.23	1.09	31.06	8.46
20145244	8.26	0.396	3.37	1941.71	8.44	22.58	1.09	3.39	8.27
20145248	8.26	0.397	1.68	1938.81	8.57	22.80	2.94	3.39	8.27
20145252	8.26	0.398	1.68	1941.71	8.44	22.58	4.45	35.77	8.27
20145256	8.26	0.39[illegible]	0.00	1938.81	8.44	22.80	2.94	3.39	8.33

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
20145300	8.26	0.398	0.00	1933.02	8.30	26.08	2.94	15.55	8.27
20145304	8.26	0.399	1.68	1931.11	8.44	22.38	0.76	21.96	8.27
20145308	8.26	0.399	0.00	1918.53	9.35	27.13	2.94	3.39	8.27
20145312	8.26	0.400	1.68	1912.74	9.74	27.55	2.61	3.39	8.52
20145316	8.26	0.400	0.00	1895.36	9.74	28.81	2.94	15.55	6.77
20145320	8.26	0.400	0.00	1886.67	8.56	26.71	2.61	3.39	8.46
20145324	8.26	0.400	0.00	1740.10	-3.81	35.90	6.30	3.39	8.46
20145328	8.23	0.372	42.11	1789.30	0.10	33.16	6.30	3.39	6.20
20145332	8.24	0.378	8.42	1916.64	7.78	26.35	4.45	3.39	5.55
20145336	8.26	0.403	37.05	1939.80	6.57	24.65	8.15	3.39	8.40
20145340	8.26	0.404	1.68	1931.11	8.57	25.28	6.30	3.39	8.08
20145344	8.27	0.405	1.68	1921.43	8.57	26.92	8.15	3.39	8.14
20145348	8.27	0.406	1.68	1915.64	8.70	27.34	4.45	3.39	8.52
20145352	8.27	0.407	1.68	1910.86	9.09	26.77	6.30	34.70	8.40
20145356	8.27	0.408	1.68	1902.17	9.74	27.41	6.30	3.39	8.52
20145400	8.27	0.408	0.00	1879.02	9.74	29.11	4.45	3.39	8.77
20145404	8.27	0.409	1.68	1873.23	9.74	29.54	2.61	3.39	8.96
20145408	8.27	0.410	1.68	1879.02	9.61	29.11	1.09	3.39	8.84
20145412	8.27	0.410	0.00	1890.60	9.87	28.26	0.76	36.99	6.65
20145416	8.27	0.412	1.68	1890.60	9.61	28.26	1.09	21.83	8.71
20145420	8.27	0.413	1.68	1898.25	9.48	28.50	0.76	3.39	8.56
20145424	8.27	0.413	0.00	1896.38	9.74	27.83	0.76	3.39	8.58
20145428	8.27	0.414	1.68	1907.96	9.61	26.98	0.76	3.39	8.40
20145432	8.28	0.415	1.68	1905.07	9.74	27.20	2.94	3.39	8.33
20145436	8.28	0.416	1.68	1902.17	9.48	27.41	0.76	14.32	8.27
20145440	8.28	0.416	0.00	1906.94	9.87	27.97	0.76	3.39	8.27
20145444	8.28	0.417	1.68	1906.94	9.87	27.97	1.09	3.39	8.21
20145448	8.28	0.418	1.68	1906.94	9.87	27.97	1.09	3.39	8.27
20145452	8.28	0.419	1.68	1904.05	9.61	28.18	4.45	3.39	8.33
20145456	8.28	0.421	1.68	1893.49	9.61	28.05	4.45	3.39	8.33
20145500	8.28	0.421	0.00	1893.49	9.74	28.05	6.30	3.39	8.40
20145504	8.28	0.422	1.68	1896.38	10.00	27.83	0.76	3.39	8.33
20145508	8.28	0.423	1.68	1899.28	9.87	27.62	6.30	3.39	8.21
20145512	8.28	0.423	0.00	1942.69	9.48	24.43	4.45	3.39	7.77
20145516	8.28	0.424	1.68	1945.58	9.22	24.22	8.15	3.39	7.64
20145520	8.29	0.425	1.68	1953.33	9.74	24.61	6.30	3.39	7.52
20145524	8.29	0.425	0.00	1939.80	9.61	24.65	2.61	3.39	7.71
20145528	8.29	0.426	1.68	1942.69	9.35	24.43	4.45	3.39	7.58
20145532	8.29	0.427	1.68	1936.90	9.61	24.86	0.76	15.94	7.58
20145536	8.29	0.427	0.00	1934.01	9.61	25.07	2.61	3.39	7.71
20145540	8.29	0.428	1.68	1928.22	9.87	25.50	0.76	3.39	7.83
20145544	8.29	0.428	0.00	1896.38	9.35	27.83	2.61	3.39	8.58
20145548	8.29	0.431	3.37	1905.07	9.61	27.20	2.94	3.39	7.69
20145552	8.29	0.433	3.37	1818.24	9.48	33.57	2.61	3.39	8.96
20145556	8.30	0.439	8.42	1763.26	8.57	37.61	0.76	3.39	10.22
20145600	8.30	0.441	3.37	1887.70	8.83	28.47	2.61	3.39	7.77
20145604	8.30	0.442	1.68	1899.28	8.44	27.62	2.61	3.39	8.21
20145612	8.30	0.442	0.00	1887.70	8.30	28.47	0.76	3.39	8.08
20145616	8.30	0.443	1.68	1870.34	8.83	29.75	2.61	3.39	8.40
20145620	8.30	0.443	0.00	1861.66	8.57	30.39	2.61	3.39	8.46
20145624	8.30	0.443	0.00	1858.76	8.30	30.60	0.76	3.39	8.58
20145628	8.30	0.443	0.00	1815.35	8.83	33.79	0.76	27.41	8.90
20145632	8.31	0.444	1.68	1867.44	8.96	29.96	0.76	28.97	8.71
20145636	8.31	0.444	0.00	1870.34	8.70	29.75	0.76	3.39	8.46
20145640	8.31	0.444	0.00	1867.44	8.57	29.96	0.76	3.39	8.40
20145644	8.31	0.445	1.68	1855.87	8.30	30.81	2.94	3.39	8.52
20145648	8.31	0.445	0.00	1847.19	8.44	31.45	0.76	3.39	8.46
20145652	8.31	0.445	0.00	1858.76	8.44	30.60	2.61	15.94	8.58

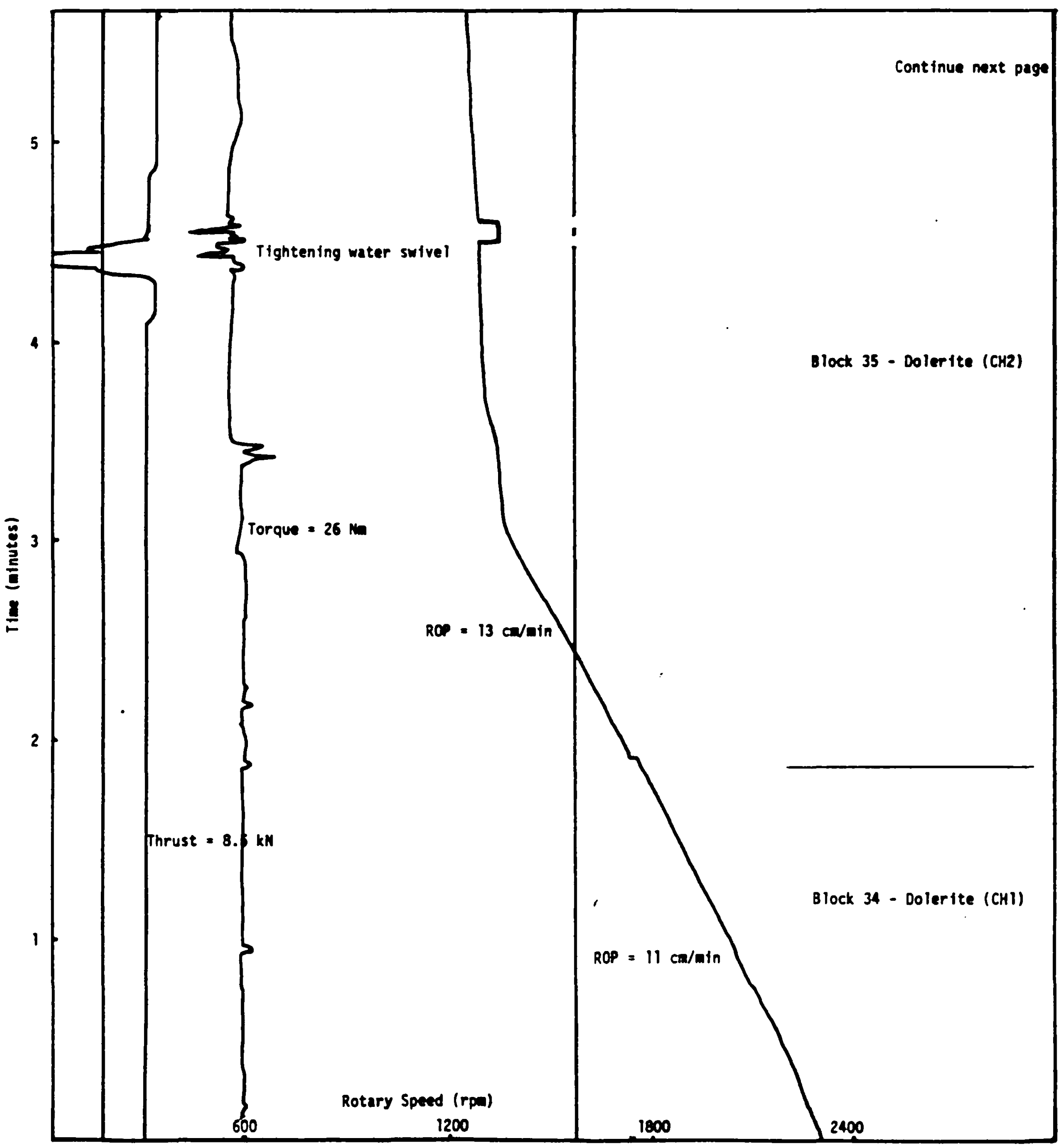
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
20145656	8.31	0.444	1.69	1862.71	9.85	31.19	3.07	99.99	8.45
20145700	8.31	0.446	3.37	1828.93	9.74	32.12	1.09	3.39	8.40
20145704	8.31	0.446	0.00	1864.55	9.74	29.32	0.76	8.43	8.27
20145708	8.31	0.448	1.68	1821.14	9.74	32.55	2.61	3.39	9.21
20145712	8.31	0.448	0.00	1812.46	9.35	33.19	1.09	3.39	9.22
20145716	8.31	0.446	1.69	1796.22	9.72	36.02	3.07	99.99	9.20
20145720	8.31	0.448	1.68	1787.55	9.72	36.05	1.22	99.99	9.45
20145724	8.31	0.449	1.68	1783.52	9.35	35.34	2.61	3.39	9.45
20145728	8.31	0.449	0.00	1771.94	9.48	36.20	4.45	3.39	9.46
20145732	8.31	0.450	1.68	1757.47	9.09	37.27	4.45	3.39	9.72
20145736	8.31	0.450	0.00	1786.41	9.48	35.13	2.61	3.39	9.40
20145740	8.31	0.450	0.00	1774.83	9.09	35.99	0.76	3.39	9.46
20145744	8.31	0.449	1.69	1761.52	9.46	38.54	0.63	99.99	9.71
20145748	8.31	0.451	3.37	1771.94	9.39	36.20	1.09	3.39	9.72
20145752	8.31	0.450	1.69	1770.20	9.72	37.91	1.22	99.99	9.52
20145756	8.31	0.451	1.68	1745.89	8.96	38.13	0.76	3.39	9.76
20145800	8.31	0.451	0.00	1740.10	9.74	38.56	2.61	3.39	9.64
20145804	8.31	0.451	0.00	1751.68	9.74	37.70	2.61	3.39	9.78
20145808	8.31	0.452	1.68	1792.20	9.35	34.70	2.61	3.39	9.34
20145812	8.31	0.452	0.00	1777.73	8.96	35.77	2.61	3.39	9.28
20145820	8.31	0.452	0.00	1769.05	9.35	36.42	0.76	3.39	9.34
20145824	8.31	0.453	1.68	1774.83	9.48	35.99	0.76	3.39	9.34
20145828	8.31	0.453	0.00	1774.83	9.09	35.99	1.09	3.39	9.34
20145832	8.32	0.454	1.68	1769.05	9.22	36.42	2.61	3.39	9.28
20145836	8.32	0.454	0.00	1763.26	9.48	36.84	2.61	3.39	9.34
20145840	8.32	0.454	0.00	1743.00	9.61	38.35	2.61	3.39	9.65
20145844	8.32	0.454	0.00	1732.61	9.59	40.64	1.22	99.99	9.71
20145848	8.32	0.455	1.68	1731.42	9.09	39.21	2.61	3.39	9.90
20145852	8.32	0.454	1.69	1718.16	9.85	41.69	1.22	99.99	10.02
20145856	8.32	0.455	1.68	1693.80	9.74	42.00	0.76	3.39	10.22
20145900	8.32	0.457	1.68	1705.38	9.35	41.14	0.76	3.39	10.03
20145904	8.32	0.457	0.00	1745.89	9.09	38.13	2.61	3.39	9.59
20145908	8.32	0.457	0.00	1786.41	9.35	35.13	2.61	3.39	9.40
20145912	8.32	0.457	0.00	1824.03	9.74	32.33	2.61	3.39	8.52
20145916	8.32	0.458	1.68	1835.61	9.48	31.47	0.76	3.39	8.33
20145920	8.32	0.459	1.68	1852.97	9.09	30.18	0.76	3.39	8.33
20145924	8.32	0.460	1.68	1847.19	9.09	30.61	2.61	3.39	8.14
20145928	8.32	0.461	1.68	1858.76	9.09	29.75	0.76	3.39	8.14
20145932	8.32	0.463	3.37	1847.19	9.61	30.61	1.09	3.39	8.33
20145936	8.33	0.466	3.37	1847.19	9.48	30.61	2.61	3.39	8.14
20145940	8.33	0.468	3.37	1852.97	9.09	30.18	2.61	3.39	8.14
20145944	8.33	0.470	3.37	1841.40	9.22	31.04	2.61	3.39	8.08
20145948	8.33	0.471	1.68	1826.93	9.61	32.12	0.76	3.39	8.40
20145952	8.33	0.471	0.00	1847.19	9.48	30.61	0.76	3.39	7.96
20145956	8.33	0.472	1.68	1841.40	9.22	31.04	2.61	3.39	8.14
20150000	8.33	0.473	0.00	1832.72	9.48	31.69	0.76	3.39	8.21
20150004	8.34	0.474	1.68	1829.82	9.09	31.90	4.45	3.39	8.27
20150008	8.34	0.474	0.00	1829.82	8.96	31.90	2.61	28.75	8.40
20150012	8.33	0.473	1.69	1828.02	9.72	33.71	2.47	99.99	8.45
20150016	8.34	0.474	1.68	1826.93	9.22	32.12	0.76	3.39	8.58
20150020	8.34	0.476	1.68	1829.82	9.61	31.90	0.76	3.39	8.46
20150024	8.34	0.474	1.69	1828.02	9.46	33.71	0.63	99.99	8.39
20150028	8.34	0.477	3.37	1870.34	9.09	28.89	2.61	3.39	8.40
20150032	8.34	0.477	0.00	1876.13	8.96	28.46	4.45	3.39	7.83
20150036	8.34	0.478	1.68	1858.76	9.35	29.75	0.76	3.39	7.83
20150040	8.34	0.478	0.00	1877.17	9.72	30.14	1.22	99.99	7.88
20150044	8.34	0.480	3.37	1864.55	8.96	29.32	2.61	3.39	7.71
20150048	8.34	0.481	1.68	1873.23	9.09	28.68	0.76	3.39	7.77

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
20150052	8.34	0.481	0.00	1874.28	9.20	30.37	1.22	99.99	7.76
20150056	8.34	0.483	3.37	1873.23	9.48	28.68	2.61	3.39	7.71
20150100	8.35	0.485	1.68	1875.13	9.09	28.46	2.61	3.39	7.71
20150104	8.35	0.486	1.68	1867.44	9.61	29.11	0.76	3.39	7.83
20150108	8.35	0.487	1.68	1861.66	9.48	29.54	0.76	3.39	7.77
20150112	8.35	0.489	3.37	1852.97	9.09	30.18	2.61	3.39	7.64
20150116	8.35	0.489	0.00	1858.76	9.09	29.75	2.61	3.39	7.77
20150120	8.35	0.490	1.68	1858.76	9.48	29.75	0.76	3.39	7.77
20150124	8.35	0.490	0.00	1856.93	9.33	31.61	1.22	99.99	8.01
20150128	8.35	0.492	3.37	1844.29	9.48	30.83	2.61	3.39	8.38
20150132	8.35	0.494	1.68	1867.44	9.48	29.11	0.76	3.39	8.14
20150136	8.35	0.494	0.00	1859.83	9.20	31.40	0.63	99.99	7.66
20150140	8.35	0.494	0.00	1862.72	9.72	31.19	2.47	99.99	7.82
20150144	8.36	0.496	3.37	1861.66	9.48	29.54	2.61	3.39	7.77
20150148	8.36	0.497	1.68	1864.55	9.48	29.32	2.61	3.39	7.64
20150152	8.36	0.498	1.68	1867.44	9.61	29.11	2.61	3.39	7.58
20150156	8.36	0.499	1.68	1873.23	9.61	28.68	0.76	3.39	7.64
20150200	8.36	0.498	1.69	1859.83	9.59	31.40	0.63	99.99	7.76
20150204	8.36	0.499	1.68	1856.93	9.07	31.61	4.91	99.99	7.76
20150208	8.36	0.500	1.68	1862.72	9.33	31.19	1.22	99.99	7.82
20150212	8.36	0.501	1.68	1847.19	9.74	30.61	2.61	3.39	7.69
20150216	8.36	0.501	0.00	1856.93	9.59	31.61	0.63	99.99	7.95
20150220	8.36	0.503	1.68	1524.45	9.07	55.76	1.22	99.99	8.07
20150224	8.37	0.508	8.42	1852.97	9.48	30.18	0.76	3.39	8.02
20150228	8.37	0.512	5.05	1824.03	9.09	32.33	2.61	3.39	7.89
20150232	8.38	0.515	5.05	1845.37	9.20	32.45	1.22	99.99	8.07
20150236	8.38	0.519	6.73	1783.52	9.61	35.34	0.76	3.39	8.46
20150240	8.38	0.519	0.00	1802.00	8.68	35.60	1.22	99.99	8.51
20150244	8.38	0.523	5.05	1844.29	8.17	30.83	0.76	3.39	7.71
20150248	8.38	0.524	1.68	1833.80	8.42	33.29	1.22	99.99	7.95
20150252	8.39	0.526	3.37	1793.33	8.94	36.23	0.63	99.99	8.01
20150256	8.39	0.530	5.05	1826.93	8.83	32.12	1.09	3.39	8.21
20150300	8.39	0.531	1.68	1833.80	8.42	33.29	1.22	99.99	7.88
20150304	8.39	0.533	3.37	1833.80	8.81	33.29	1.22	99.99	8.01
20150308	8.39	0.534	1.68	1841.40	8.96	31.04	0.76	3.39	7.71
20150312	8.40	0.535	1.68	1835.61	8.44	31.47	0.76	3.39	8.38
20150316	8.40	0.536	1.68	1606.98	-3.68	48.45	1.09	3.39	8.14
20150510	8.40	0.536	0.00	1813.57	8.81	34.76	4.91	99.99	8.32
20150514	8.40	0.537	1.68	1778.87	8.55	37.28	4.91	99.99	9.01
20150518	8.40	0.537	0.00	1775.98	8.68	37.49	3.07	99.99	9.01
20150522	8.40	0.537	0.00	1773.09	8.81	37.70	1.22	99.99	9.08
20150526	8.40	0.538	1.68	1804.89	8.16	35.39	4.91	99.99	8.76
20150530	8.40	0.540	1.68	1799.11	8.55	35.81	0.63	99.99	8.64
20150534	8.40	0.540	0.00	1807.78	8.68	35.18	3.07	99.99	8.58
20150538	8.40	0.541	1.68	1796.22	8.16	36.02	3.07	20.05	9.27
20150542	8.40	0.541	0.00	1819.35	8.68	34.34	1.22	99.99	8.64
20150546	8.40	0.541	0.00	1807.78	8.16	35.18	0.63	99.99	8.51
20150550	8.40	0.544	5.05	1900.30	8.17	25.73	0.76	3.39	7.71
20150554	8.41	0.547	5.05	1907.10	8.42	27.06	1.22	99.99	7.26
20150558	8.41	0.553	8.42	1897.41	8.29	28.57	1.22	99.99	7.19
20150602	8.42	0.556	5.05	1888.74	8.42	29.30	0.63	23.99	7.38
20150606	8.42	0.559	3.37	1881.11	8.16	28.97	0.63	99.99	8.20
20150610	8.42	0.560	1.68	1881.11	8.16	28.97	0.63	99.99	7.44
20150614	8.42	0.561	1.68	1880.06	8.70	27.25	1.09	3.39	7.58
20150618	8.42	0.562	1.68	1775.96	8.57	35.07	1.09	3.39	7.77
20150622	8.42	0.562	0.00	1885.85	8.64	26.82	2.61	3.39	7.71
20150626	8.42	0.562	0.00	1895.55	8.29	27.91	0.63	99.99	7.44
20150630	8.42	0.562	0.00	1886.88	8.42	28.55	2.47	99.99	7.26

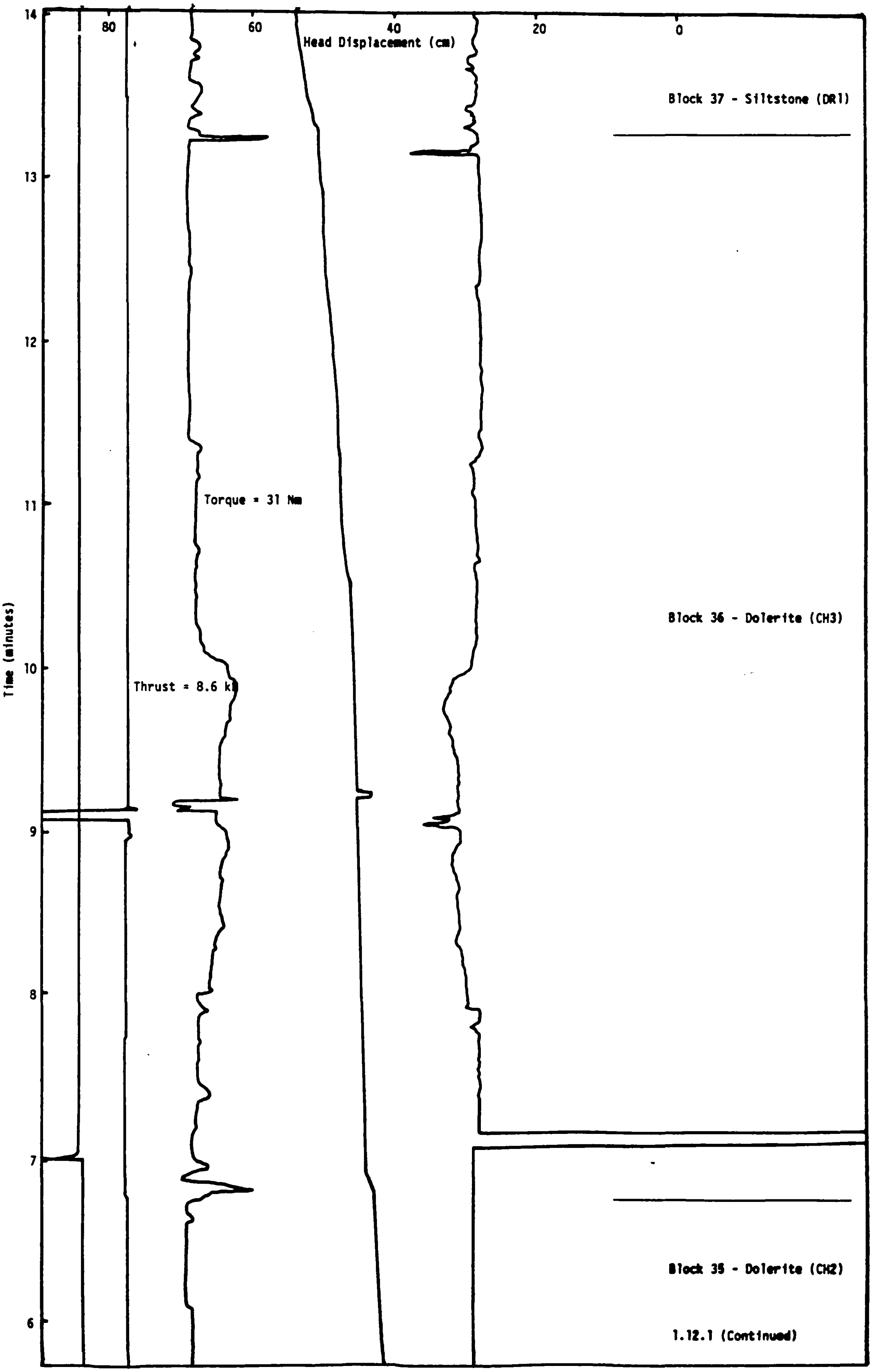
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
20150634	8.42	0.563	1.68	1854.04	8.70	29.21	0.76	3.39	7.64
20150638	8.43	0.564	1.68	1897.41	8.44	25.95	2.61	3.39	7.20
20150642	8.43	0.564	0.00	1891.63	8.04	26.39	1.65	3.39	7.39
20150646	8.43	0.564	0.00	1880.06	8.68	27.25	2.47	3.39	7.38
20150650	8.42	0.563	1.69	1878.22	9.33	29.18	0.63	99.99	7.51
20150654	8.43	0.565	3.37	1799.11	9.22	33.33	0.76	32.44	7.58
20150658	8.43	0.564	1.69	1843.56	9.46	31.73	1.22	99.99	7.95
20150702	8.43	0.567	3.37	1842.48	9.46	30.68	0.63	3.39	8.01
20150706	8.43	0.567	0.00	1828.02	9.61	31.16	0.76	3.39	7.69
20150710	8.43	0.568	1.68	1900.30	9.20	25.73	2.47	3.39	8.01
20150714	8.43	0.568	0.00	1926.32	9.07	23.78	0.63	3.39	6.82
20150718	8.43	0.569	1.68	1923.43	9.09	24.00	1.09	21.67	6.83
20150722	8.43	0.569	0.00	1909.99	9.32	25.85	1.35	99.99	7.16
20150726	8.43	0.570	1.68	1889.77	9.45	28.33	1.30	99.99	7.06
20150730	8.43	0.572	3.37	1900.30	9.07	25.73	2.47	3.39	7.15
20150734	8.43	0.573	1.68	1880.06	9.33	27.25	0.63	3.39	7.32
20150738	8.43	0.572	1.69	1881.11	9.72	28.97	1.22	99.99	7.44
20150742	8.43	0.573	1.68	1863.78	9.84	30.24	1.35	99.99	7.56
20150746	8.44	0.574	1.68	1872.44	9.58	29.61	3.19	99.99	7.62
20150750	8.44	0.576	1.68	1878.22	9.19	29.18	1.35	99.99	7.44
20150754	8.44	0.577	1.68	1875.33	9.19	29.39	0.50	99.99	7.56
20150758	8.44	0.578	1.68	1852.22	9.19	31.09	1.35	99.99	7.56
20150802	8.44	0.579	1.68	1865.61	8.94	28.34	2.47	3.39	7.51
20150806	8.44	0.580	1.68	1859.83	8.94	28.77	2.47	3.39	7.32
20150810	8.44	0.580	0.00	1866.66	9.06	30.03	1.35	99.99	7.69
20150814	8.44	0.581	1.68	1858.00	9.45	30.67	1.35	99.99	7.56
20150818	8.44	0.581	0.00	1846.45	9.58	31.52	0.50	99.99	7.75
20150822	8.44	0.583	3.37	1842.48	8.94	30.08	0.63	3.39	7.82
20150826	8.44	0.582	1.69	1858.00	9.84	30.67	1.35	99.99	7.56
20150830	8.44	0.583	1.68	1849.33	9.84	31.30	0.50	99.99	7.50
20150834	8.45	0.585	1.68	1875.33	9.06	29.39	1.35	99.99	7.37
20150838	8.45	0.586	1.68	1863.78	9.32	30.24	3.19	99.99	7.50
20150842	8.45	0.587	1.68	1803.12	9.45	34.70	5.04	99.99	8.06
20150846	8.46	0.596	13.47	1810.68	9.20	32.46	0.63	3.39	7.76
20150850	8.46	0.602	10.11	1825.13	9.59	31.38	0.63	3.39	8.26
20150854	8.47	0.607	6.73	1829.12	9.45	32.79	3.19	99.99	7.81
20150858	8.48	0.615	11.79	1802.00	9.07	33.12	0.63	3.39	8.14
20150902	8.48	0.622	10.11	1856.93	8.81	28.99	1.22	3.39	7.82
20150906	8.49	0.628	10.11	1830.91	9.20	30.95	1.22	3.39	7.95
20150910	8.50	0.637	13.47	1614.07	9.74	47.23	2.94	3.39	8.21
20150914	8.50	0.644	10.11	1883.99	9.71	28.76	1.35	99.99	7.12
20150918	8.51	0.654	15.16	1900.30	9.20	25.73	0.63	3.39	6.68
20150922	8.52	0.660	8.42	1832.00	9.45	32.58	1.35	99.99	7.50
20150926	8.52	0.662	3.37	1778.87	8.94	34.85	1.22	3.39	8.95
20150930	8.52	0.663	1.68	1767.31	9.33	35.72	0.63	3.39	8.70
20150934	8.52	0.663	0.00	1782.90	9.58	36.18	1.35	99.99	8.68
20150938	8.52	0.663	0.00	1791.57	9.45	35.55	1.35	99.99	8.69
20150942	8.53	0.665	3.37	1804.89	9.59	32.90	0.63	3.39	8.57
20150946	8.53	0.666	1.68	1807.78	9.48	32.68	0.76	3.39	7.96
20150950	8.53	0.666	0.00	1777.13	9.46	36.61	1.22	99.99	8.45
20150954	8.53	0.668	1.68	1777.13	9.72	36.61	1.22	99.99	8.45
20150958	8.53	0.670	3.37	1760.36	9.09	37.06	0.76	3.39	8.52
20151002	8.53	0.670	0.00	1794.46	9.46	35.33	3.07	99.99	8.39
20151006	8.53	0.672	3.37	1833.80	8.94	30.73	0.63	3.39	7.70
20151010	8.53	0.672	0.00	1826.23	9.19	33.00	1.35	99.99	7.88
20151014	8.53	0.673	1.68	1832.00	9.58	32.58	3.19	99.99	7.81
20151018	8.53	0.674	1.68	1800.23	9.19	34.91	3.19	99.99	8.06
20151022	8.54	0.675	1.68	1797.34	9.06	35.12	1.35	99.99	8.31

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H??	FAGL
20151026	8.54	0.677	1.68	1785.79	9.84	35.97	1.35	99.99	8.31
20151030	8.54	0.678	1.68	1759.80	9.58	37.86	1.35	99.99	8.54
20151034	8.54	0.679	1.68	1767.31	9.72	35.72	1.22	3.39	8.58
20151038	8.54	0.679	0.00	1814.67	9.71	33.85	3.19	99.99	7.94
20151042	8.54	0.680	1.68	1791.57	9.19	35.05	3.19	99.99	8.19
20151046	8.54	0.683	5.05	1787.55	9.59	34.20	2.47	3.39	8.20
20151050	8.54	0.683	0.00	1765.37	9.71	37.46	0.50	99.99	8.44
20151054	8.55	0.684	1.68	1723.94	9.07	38.98	0.63	3.39	9.14
20151058	8.55	0.686	1.68	1706.59	9.07	40.28	1.22	3.39	9.45
20151102	8.55	0.686	0.00	1728.02	9.97	40.21	1.35	99.99	9.07
20151106	8.55	0.688	3.37	1793.33	9.72	33.77	1.22	3.39	8.45
20151110	8.55	0.688	0.00	1762.68	9.84	37.57	3.19	99.99	8.38
20151114	8.55	0.690	3.37	1758.63	9.46	36.37	3.07	3.39	8.51
20151118	8.55	0.691	1.68	1741.29	8.94	37.68	1.22	13.87	8.64
20151122	8.55	0.692	1.68	1767.31	9.07	35.72	0.63	3.39	8.51
20151126	8.55	0.693	1.68	1770.20	9.07	35.50	0.63	3.39	8.39
20151130	8.56	0.695	1.68	1741.29	9.07	37.68	0.63	3.39	8.70
20151134	8.56	0.655	0.00	1670.26	9.58	44.46	1.35	99.99	9.13
20151138	8.56	0.657	3.37	1721.05	9.07	39.19	0.63	3.39	8.89
20151142	8.56	0.657	0.00	1756.91	9.71	38.09	3.19	99.99	8.63
20151146	8.56	0.659	3.37	1749.96	9.59	37.02	0.63	3.39	8.64
20151150	8.56	0.698	1.69	1730.91	9.06	40.00	1.35	99.99	8.75
20151154	8.56	0.699	1.68	1739.58	9.84	39.37	1.35	99.99	8.94
20151158	8.56	0.700	1.68	1722.25	9.19	40.64	3.19	99.99	9.07
20151202	8.56	0.702	3.37	1726.83	9.72	38.76	0.63	3.39	8.83
20151206	8.56	0.702	0.00	1774.24	9.58	36.82	1.35	99.99	8.31
20151210	8.56	0.704	1.68	1716.47	9.45	41.06	1.35	99.99	8.57
20151214	8.57	0.706	3.37	1742.47	9.19	39.15	3.19	99.99	8.50
20151218	8.57	0.707	1.68	1771.35	9.71	37.03	3.19	99.99	8.62
20151222	8.57	0.708	1.68	1811.79	9.19	34.06	1.35	99.99	8.19
20151226	8.57	0.710	3.37	1767.31	9.07	35.72	0.63	28.73	8.51
20151230	8.57	0.711	1.68	1814.67	9.32	33.85	1.35	99.99	7.88
20151234	8.58	0.715	5.05	1842.48	9.85	30.08	1.22	3.39	7.70
20151238	8.58	0.719	6.73	1820.45	9.45	33.43	1.35	99.99	7.44
20151242	8.59	0.725	8.42	1892.66	8.93	28.12	0.50	99.99	7.00
20151246	8.59	0.727	3.37	1858.00	9.71	30.67	1.35	99.99	7.00
20151250	8.59	0.732	6.73	1871.39	9.72	27.91	0.63	3.39	6.50
20151254	8.60	0.735	5.05	1874.28	8.94	27.69	0.63	3.39	6.50
20151258	8.60	0.737	3.37	1904.21	9.19	27.27	1.35	32.99	6.87
20151302	8.60	0.742	6.73	1888.74	9.85	26.60	0.63	3.39	6.75
20151306	8.61	0.746	6.73	1888.74	8.94	26.60	0.63	3.39	6.50
20151310	8.61	0.750	5.05	1885.85	9.72	26.82	1.22	3.39	6.56
20151314	8.61	0.753	5.05	1904.21	9.19	27.27	3.19	99.99	6.43
20151318	8.62	0.757	6.73	1874.28	9.46	27.69	1.22	3.39	6.69
20151322	8.62	0.763	8.42	1900.30	9.59	25.73	0.63	20.95	6.63
20151326	8.63	0.766	5.05	1894.52	8.94	26.17	0.63	3.39	6.37
20151330	8.63	0.770	5.05	1891.63	9.72	26.39	0.63	3.39	6.38
20151334	8.63	0.772	3.37	1849.33	9.71	31.30	1.35	99.99	6.56
20151338	8.64	0.775	5.05	1907.10	9.32	27.06	5.04	99.99	6.37
20151342	8.64	0.779	5.05	1909.99	9.06	26.85	1.35	99.99	6.56
20151346	8.64	0.783	6.73	1906.08	9.33	25.30	2.47	3.39	6.57
20151350	8.65	0.786	3.37	1907.10	9.19	27.06	0.50	99.99	6.50
20151354	8.65	0.788	3.37	1918.65	9.06	26.21	1.35	99.99	6.37
20151358	8.65	0.792	6.73	1872.44	9.84	29.61	1.35	99.99	6.56
20151402	8.66	0.794	3.37	1886.88	9.97	28.55	5.04	99.99	6.56
20151406	8.66	0.797	3.37	1904.21	9.06	27.27	0.50	99.99	6.62
20151410	8.66	0.799	3.37	1944.65	8.93	24.30	1.35	99.99	7.37
20151414	8.66	0.799	0.00	1950.42	9.84	23.88	1.35	99.99	5.93

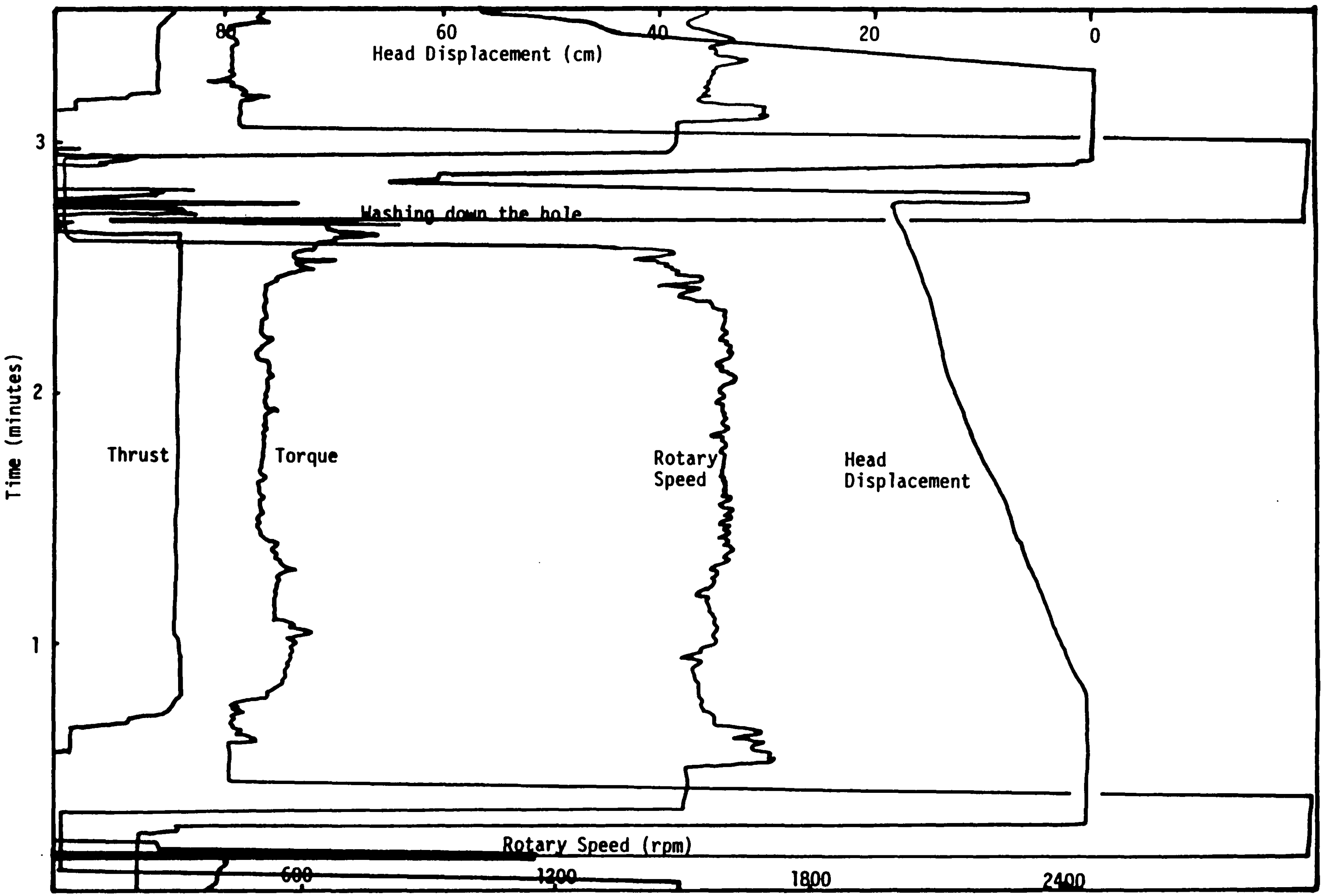
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 7
20151418	8.66	0.799	0.00	1947.34	5.19	24.09	3.10	99.99	5.87
20151422	8.66	0.799	0.00	1950.42	9.45	23.88	3.10	99.99	5.87
20151426	8.66	0.799	0.00	1953.31	9.84	23.57	1.30	99.99	5.87
20151430	8.66	0.799	0.00	1935.98	9.32	24.94	1.30	99.99	5.87



RECORD OF TRRL DRILL RUN 1.12.1 (7.86 to 8.66 metres)



80
60
40
20
0
Head Displacement (cm)
Block 37 - Siltstone (DR1)
Torque = 31 Nm
Block 36 - Dolerite (CH3)
Thrust = 8.6 k
Time (minutes)
14
13
12
11
10
9
8
7
6
Block 35 - Dolerite (CH2)
1.12.1 (Continued)



RECORD OF TRRL DRILL RUN 1.12.2 (8.66 to 8.89 metres)

USER: EX9069 -AT SYST_M

NR_T1.12.3

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EX9069 NR_T1.12.3

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LABEL: FRT027 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:33, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

-542-

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
20151828	8.89	0.000	0.00	1777.13	7.63	37.40	5.34	3.39	8.19
20151832	8.89	0.004	5.06	1725.14	8.28	41.18	5.34	3.39	8.19
20151836	8.90	0.008	5.06	1713.58	7.89	42.02	8.73	3.39	8.75
20151840	8.90	0.010	3.37	1684.70	7.63	44.12	10.57	3.39	8.69
20151844	8.90	0.012	3.37	1655.82	8.41	46.22	10.57	3.39	9.19
20151848	8.90	0.013	1.69	1687.59	8.41	43.91	10.57	3.39	9.32
20151852	8.90	0.015	1.69	1670.26	7.89	45.17	8.73	3.39	9.00
20151856	8.91	0.016	1.69	1401.64	8.67	64.68	6.88	3.39	9.38
20151900	8.91	0.018	3.37	1641.38	8.02	47.27	8.73	3.39	10.45
20151904	8.91	0.020	3.37	1618.27	8.54	48.94	8.73	3.39	10.01
20151908	8.91	0.021	1.69	1450.75	8.15	61.12	6.86	3.39	7.66
20151912	8.91	0.021	0.00	1447.86	7.76	61.33	8.73	3.39	8.50
20151916	8.91	0.022	1.69	1231.23	-2.77	77.06	8.73	3.39	11.07

USER: EX9J69 -AT SYSTEM

NR_T1.13

EX9J69

NR_T1.13

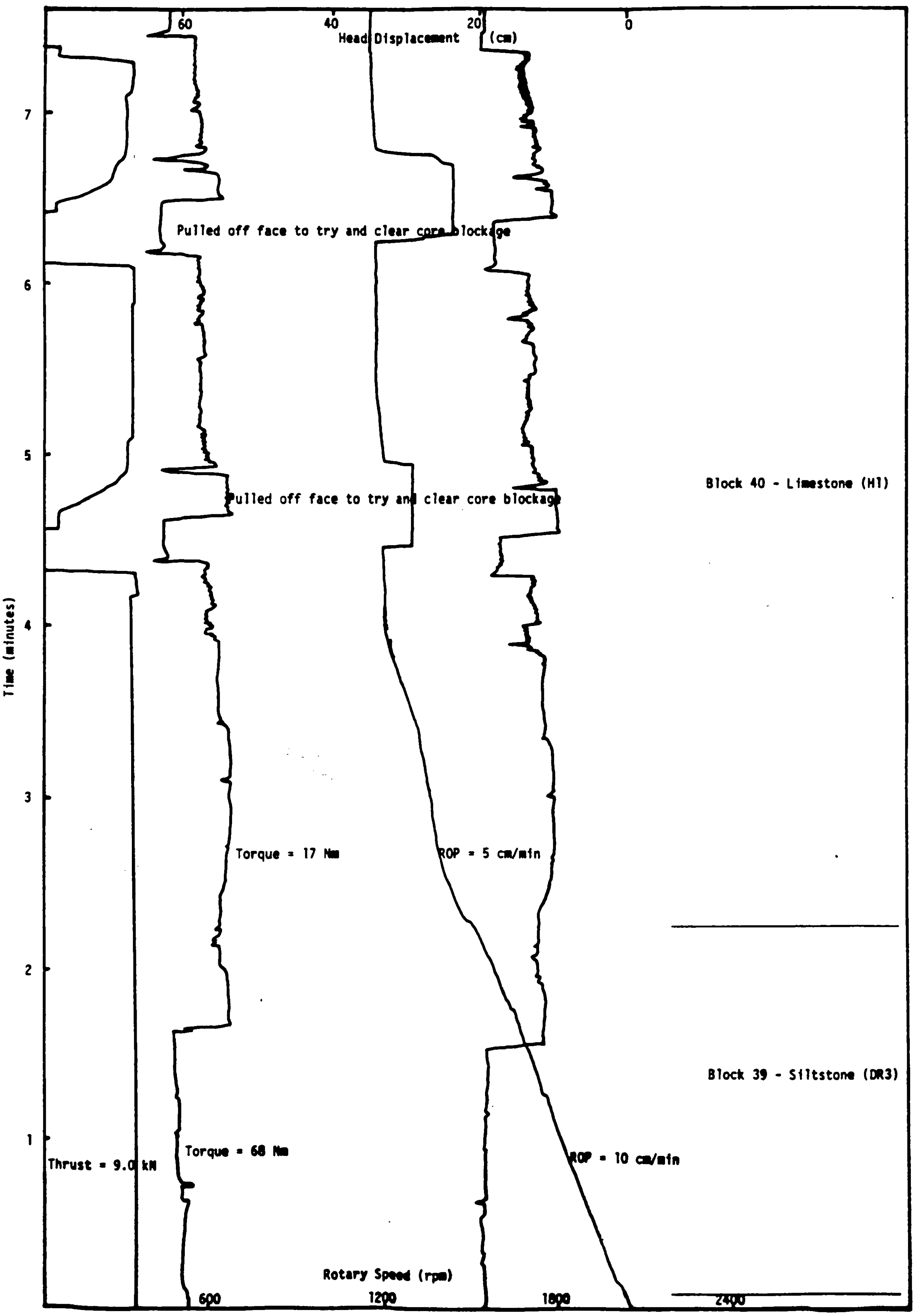
LABEL: PRT028 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:33, ON: PR0 BY: PR0

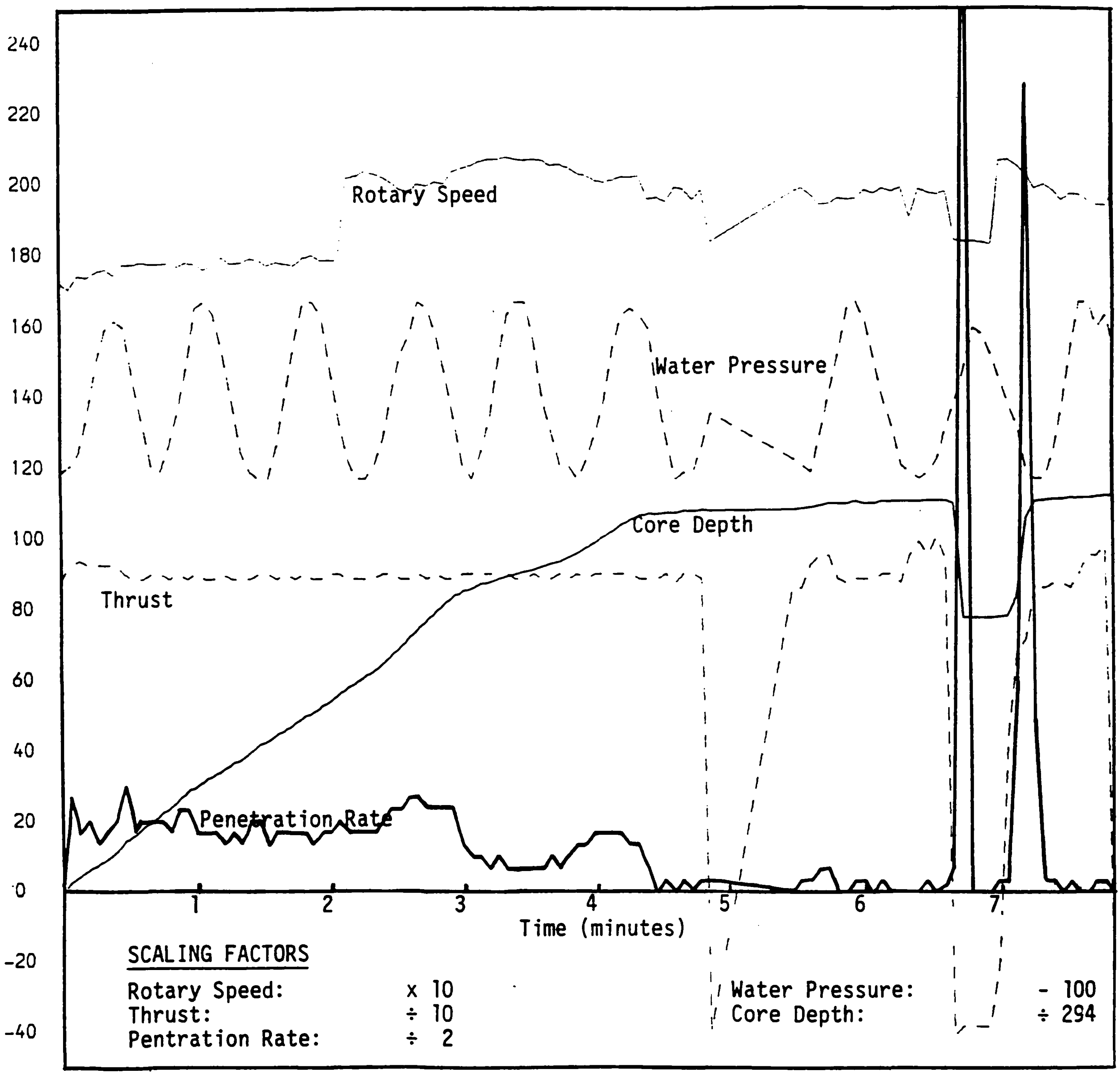
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (KN/M**2)
21143204	8.91	0.000	0.00	1724.23	8.69	41.25	19.02	99.99	7.59
21143208	8.92	0.009	13.49	1739.67	9.29	42.30	20.88	99.99	7.69
21143212	8.92	0.015	8.43	1744.61	9.42	39.77	24.61	99.99	7.75
21143216	8.93	0.021	10.12	1741.70	9.29	56.21	35.74	99.99	7.43
21143220	8.94	0.026	6.74	1756.26	9.29	58.74	50.61	99.99	7.25
21143224	8.94	0.031	8.43	1764.99	9.29	60.25	59.90	99.99	6.93
21143228	8.95	0.038	10.12	1747.52	9.29	57.22	61.75	99.99	6.99
21143232	8.96	0.048	15.18	1776.64	9.03	62.27	59.90	99.99	6.74
21143236	8.96	0.054	8.43	1776.64	8.89	62.27	45.03	99.99	6.74
21143240	8.97	0.061	10.12	1782.46	8.89	63.28	33.88	99.99	6.30
21143244	8.98	0.067	10.12	1779.55	9.03	62.77	20.88	99.99	6.30
21143248	8.98	0.074	10.12	1779.55	9.03	62.77	19.02	99.99	6.49
21143252	8.99	0.080	8.43	1782.46	8.89	63.28	26.45	99.99	6.49
21143256	9.00	0.088	11.80	1770.81	9.03	61.26	35.74	99.99	6.49
21143300	9.01	0.096	11.80	1782.46	8.89	63.28	48.75	99.99	6.42
21143304	9.01	0.101	8.43	1777.79	9.03	66.75	65.47	99.99	6.42
21143308	9.02	0.107	8.43	1763.25	8.89	64.16	67.33	99.99	6.68
21143312	9.02	0.112	8.43	1771.97	8.89	65.71	63.61	16.74	6.23
21143316	9.03	0.117	6.74	1798.15	9.03	70.36	52.46	99.99	6.17
21143320	9.03	0.123	8.43	1780.70	8.89	67.26	39.46	99.99	6.23
21143324	9.04	0.127	6.74	1783.61	8.89	67.78	24.60	99.99	6.05
21143328	9.04	0.134	10.12	1792.33	8.89	69.33	19.02	99.99	6.05
21143332	9.05	0.141	10.12	1792.33	9.03	69.33	17.16	99.99	5.92
21143336	9.06	0.145	6.74	1774.88	9.03	66.23	17.16	99.99	6.30
21143340	9.06	0.151	8.43	1783.61	8.89	67.78	26.45	99.99	6.23
21143344	9.07	0.156	8.43	1780.70	9.03	67.26	41.32	99.99	6.36
21143348	9.07	0.162	8.43	1774.88	8.89	66.23	56.18	99.99	6.23
21143352	9.08	0.168	8.43	1795.24	9.03	69.85	67.33	99.99	5.73
21143356	9.08	0.172	6.74	1803.97	8.89	71.40	67.33	99.99	5.67
21143400	9.09	0.178	8.43	1789.42	8.89	68.81	63.61	99.99	5.79
21143404	9.09	0.183	8.43	1789.42	9.03	68.81	48.75	99.99	5.92
21143408	9.10	0.190	10.12	1789.42	9.03	68.81	33.88	99.99	5.98
21143412	9.11	0.196	8.43	2021.20	8.89	19.67	22.74	99.99	8.51
21143416	9.11	0.201	8.43	2027.02	8.89	19.25	17.16	99.99	8.51
21143420	9.12	0.207	8.43	2038.67	8.89	18.40	17.16	99.99	8.38
21143424	9.12	0.212	8.43	2032.85	8.89	18.83	20.88	99.99	8.38
21143428	9.13	0.219	10.12	2024.11	9.03	19.46	28.31	99.99	8.32
21143432	9.14	0.227	11.80	2009.56	9.03	20.52	41.32	99.99	8.57
21143436	9.14	0.235	11.80	1989.18	8.89	22.00	52.46	99.99	9.01
21143440	9.15	0.244	13.49	1980.44	8.89	22.63	58.04	99.99	8.82
21143444	9.16	0.253	13.49	2004.66	9.03	19.91	67.33	99.99	8.70
21143448	9.17	0.261	11.80	1998.84	8.89	20.34	65.47	99.99	8.70
21143452	9.18	0.269	11.80	2009.56	9.03	20.52	58.04	99.99	8.57
21143456	9.19	0.277	11.80	2004.66	8.89	19.91	46.89	99.99	8.51
21143500	9.19	0.284	11.80	2039.56	8.89	17.35	33.88	99.99	8.19
21143504	9.20	0.289	6.74	2048.29	9.03	16.71	20.88	99.99	7.94
21143508	9.20	0.292	5.06	2056.14	9.03	17.13	17.16	99.99	7.75
21143512	9.21	0.296	5.06	2067.79	9.03	16.29	24.60	99.99	7.69
21143516	9.21	0.298	3.37	2073.61	9.03	15.86	33.88	12.52	7.56
21143520	9.21	0.301	5.06	2073.61	9.03	15.86	50.61	99.99	7.50
21143524	9.21	0.304	3.37	2079.43	9.03	15.44	63.61	99.99	7.50
21143528	9.22	0.306	3.37	2073.61	8.89	15.86	67.33	99.99	7.43
21143532	9.22	0.308	3.37	2070.70	8.89	16.08	67.33	99.99	7.50
21143536	9.22	0.310	3.37	2073.61	9.03	15.86	56.18	99.99	7.43

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
21143540	9.22	0.313	3.37	2071.55	8.89	15.00	39.46	99.99	7.[illegible]
21143544	9.23	0.316	5.06	2057.01	8.89	16.07	30.17	99.99	7.43
21143548	9.23	0.318	3.37	2059.92	9.03	15.85	20.88	99.99	7.56
21143552	9.23	0.322	5.06	2051.19	8.89	16.49	20.88	99.99	7.62
21143556	9.24	0.326	6.74	2036.65	9.03	17.56	17.16	99.99	7.69
21143602	9.24	0.331	6.74	2027.93	8.89	18.20	22.74	99.99	8.30
21143604	9.25	0.336	8.43	2016.29	9.03	19.06	30.17	99.99	8.00
21143608	9.25	0.342	8.43	2010.47	9.03	19.48	39.46	99.99	7.94
21143612	9.26	0.347	8.43	2016.29	9.03	19.06	54.32	99.99	8.07
21143616	9.26	0.353	8.43	2025.02	9.03	18.41	63.61	99.99	8.00
21143620	9.27	0.358	6.74	2025.02	9.03	18.41	65.47	99.99	7.94
21143624	9.27	0.362	6.74	2027.93	8.89	18.20	63.61	99.99	7.68
21143628	9.27	0.364	3.37	1963.94	8.89	22.90	59.9.	99.99	8.32
21143632	9.27	0.364	0.00	1966.85	8.89	22.69	41.32	99.99	8.57
21143636	9.28	0.365	1.69	1955.21	9.03	23.54	28.31	99.99	8.82
21143640	9.28	0.365	0.00	1995.93	8.76	20.55	17.16	99.99	8.38
21143644	9.28	0.367	1.69	1990.11	9.03	20.98	19.02	99.99	8.26
21143648	9.28	0.367	0.00	1961.03	9.03	23.11	19.02	99.99	8.63
21143652	9.28	0.368	1.69	1987.21	8.89	21.19	26.45	99.99	8.38
21143656	9.28	0.367	1.69	1841.78	-3.93	31.87	35.74	99.99	6.05
21143732	9.28	0.368	0.19	1981.39	8.63	21.62	22.74	99.99	8.13
21143736	9.28	0.369	1.69	1993.02	9.03	20.76	20.88	99.99	8.19
21143740	9.28	0.370	1.69	1972.66	9.29	22.26	19.02	99.99	8.19
21143744	9.28	0.372	3.37	1946.49	9.55	24.18	30.17	99.99	8.63
21143748	9.28	0.374	3.37	1949.39	9.55	23.97	41.32	99.99	8.57
21143752	9.28	0.374	0.00	1963.94	8.89	22.90	52.46	99.99	8.19
21143756	9.28	0.374	0.00	1961.03	8.76	23.11	65.47	99.99	8.26
21143800	9.29	0.376	1.69	1963.94	8.89	22.90	67.33	99.99	8.32
21143804	9.28	0.374	1.69	1987.21	8.89	21.19	61.75	99.99	8.45
21143808	9.28	0.374	0.00	1978.48	8.89	21.83	50.61	99.99	7.94
21143812	9.29	0.376	1.69	1993.02	9.03	20.76	39.46	15.59	7.88
21143816	9.29	0.376	0.00	1984.30	9.03	21.41	32.03	99.99	8.00
21143820	9.29	0.376	0.00	1995.93	8.76	20.55	20.88	99.99	8.19
21143824	9.29	0.376	0.00	1911.58	9.55	26.75	19.02	99.99	8.19
21143828	9.29	0.376	0.00	1990.11	9.94	20.98	17.16	99.99	8.07
21143832	9.29	0.377	1.69	1981.39	9.55	21.62	19.02	99.99	8.13
21143836	9.29	0.377	0.00	1975.57	10.07	22.05	22.74	99.99	8.13
21143840	9.29	0.377	0.00	1984.30	9.42	21.41	32.03	99.99	8.00
21143844	9.28	0.374	3.37	1844.69	-4.06	31.66	39.46	99.99	5.92
21143848	9.17	0.264	165.28	1841.78	-3.80	31.87	48.75	99.99	5.41
21143852	9.17	0.264	0.00	1841.78	-3.80	31.87	59.90	99.99	5.41
21143856	9.17	0.264	0.00	1838.87	-3.80	32.09	58.04	99.99	5.41
21143900	9.17	0.264	0.00	1833.05	-3.80	32.51	52.46	99.99	5.48
21143904	9.18	0.265	1.69	2071.55	-2.10	15.00	45.03	99.99	6.61
21143908	9.18	0.266	1.69	2074.46	4.31	14.78	37.60	99.99	6.55
21143912	9.19	0.284	26.98	2057.01	6.80	16.07	32.03	99.99	6.05
21143916	9.27	0.361	114.68	2033.74	7.19	17.77	19.02	99.99	7.06
21143920	9.29	0.377	23.61	1993.02	8.76	20.76	17.16	99.99	7.50
21143924	9.29	0.378	1.69	2004.66	8.63	19.91	17.16	99.99	7.62
21143928	9.29	0.379	1.69	1987.21	8.76	21.19	24.60	27.48	7.62
21143932	9.29	0.379	0.00	1961.03	8.76	23.11	37.60	99.99	7.56
21143936	9.29	0.380	1.69	1978.48	8.63	21.83	54.32	99.99	8.19
21143940	9.29	0.380	0.00	1978.48	9.03	21.83	67.33	26.78	7.75
21143944	9.29	0.380	0.00	1961.03	9.55	23.11	67.33	99.99	7.94
21143948	9.29	0.381	1.69	1949.39	9.55	23.97	59.90	99.99	8.19
21143952	9.29	0.382	1.69	1946.49	9.81	24.18	63.61	99.99	8.19
21143956	9.29	0.382	0.00	1981.39	-2.49	21.62	54.32	99.99	7.94


60
40
20
0
Head Displacement (cm)
Pulled off face to try and clear core blockage
Pulled off face to try and clear core blockage
Block 40 - Limestone (H1)
Time (minutes)
7
6
5
4
3
2
1
Torque = 17 Nm
ROP = 5 cm/min
Block 39 - Siltstone (DR3)
Thrust = 9.0 kN
Torque = 68 Nm
ROP = 10 cm/min
Rotary Speed (rpm)
600
1200
1800
2400

COMPUTER RECORD OF TRRL DRILL RUN 1.13 (8.91 to 9.29 metres)



USER: EX9069 -AT SYSTEM

NR_T1.14.1

LABEL: PRT029 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:33, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
21155046	9.29	0.000	1.69	1778.94	-1.05	12.42	24.60	99.99	6.49
21155050	9.29	0.001	1.69	1752.79	2.21	9.21	13.57	99.99	5.66
21155054	9.29	0.002	1.69	1752.79	4.71	9.21	19.02	99.99	4.72
21155058	9.29	0.003	1.69	1793.47	6.28	14.20	39.46	99.99	4.66
21155102	9.30	0.009	8.43	1749.88	7.57	8.85	67.39	99.99	5.91
21155106	9.31	0.016	10.12	1746.98	7.57	8.49	67.39	99.99	5.91
21155110	9.31	0.020	6.74	1755.69	6.92	9.56	41.41	99.99	6.29
21155114	9.32	0.026	8.43	1770.22	6.93	11.35	24.60	22.17	5.60
21155118	9.32	0.029	5.06	1752.79	6.79	9.21	15.42	95.99	5.72
21155122	9.32	0.034	6.74	1776.03	6.79	12.06	13.57	99.99	6.23
21155126	9.33	0.037	5.06	1749.88	6.79	8.85	22.85	99.99	5.72
21155130	9.33	0.040	5.06	1764.41	6.79	10.63	43.26	99.99	5.34
21155134	9.33	0.045	6.74	1796.37	6.66	14.55	58.11	99.99	5.47
21155138	9.34	0.048	5.06	1781.84	6.66	12.77	67.39	99.99	5.09
21155142	9.34	0.053	6.74	1781.84	6.66	12.77	54.40	99.99	5.09
21155146	9.35	0.056	5.06	1781.84	6.79	12.77	28.41	99.99	5.03
21155150	9.35	0.062	8.43	1770.22	6.79	11.35	17.28	99.99	5.09
21155154	9.36	0.067	8.43	1773.13	6.79	11.70	17.28	99.99	5.41
21155158	9.36	0.072	6.74	1767.32	6.79	10.99	37.69	95.99	5.28
21155202	9.37	0.076	6.74	1773.13	6.79	11.70	63.68	99.99	5.22
21155206	9.37	0.081	6.74	1773.13	6.79	11.70	65.54	95.99	5.28
21155210	9.37	0.084	5.06	1773.13	6.79	11.70	61.82	99.99	5.22
21155214	9.38	0.090	8.43	1776.03	6.79	12.06	41.41	99.99	5.28
21155218	9.38	0.093	5.06	1776.03	6.79	12.06	24.70	99.99	5.09
21155222	9.39	0.098	6.74	1778.94	6.79	12.42	13.57	20.10	5.09
21155226	9.39	0.101	5.06	1778.94	6.79	12.42	15.42	15.97	5.03
21155230	9.40	0.106	6.74	1773.13	6.79	11.70	19.13	99.99	5.03
21155234	9.40	0.110	6.74	1781.84	6.79	12.77	41.41	99.99	5.09
21155238	9.40	0.115	6.74	1781.84	6.79	12.77	59.97	99.99	5.03
21155242	9.41	0.118	5.06	1781.84	6.79	12.77	63.68	99.99	5.03
21155246	9.41	0.123	6.74	1784.75	6.79	13.13	61.82	99.99	5.09
21155250	9.42	0.127	6.74	1778.94	6.66	12.42	37.69	11.50	5.03
21155254	9.42	0.130	5.06	1784.75	6.79	13.13	15.42	99.99	4.90
21155258	9.42	0.134	5.06	1778.94	6.80	12.42	13.45	99.99	4.97
21155302	9.43	0.138	6.74	1784.75	6.66	13.13	28.41	26.06	4.84
21155306	9.43	0.141	3.37	892.71	-2.76	96.32	52.54	99.99	3.14
21155310	9.43	0.139	1.69	23.92	-2.75	202.91	67.33	99.99	-1.41
21155314	9.43	0.139	0.00	512.07	-2.10	143.02	63.61	99.99	-1.41
21155318	9.43	0.139	0.00	1700.49	-3.15	2.79	39.55	99.99	4.08
21155322	9.43	0.141	1.69	1781.84	-2.49	12.77	35.84	99.99	4.96
21155326	9.43	0.141	0.00	1776.03	1.82	12.06	22.85	99.99	4.78
21155330	9.43	0.142	1.69	1778.94	5.48	12.42	9.85	26.06	4.90
21155334	9.43	0.144	3.37	1761.50	6.53	10.28	17.28	99.99	5.09
21155338	9.44	0.146	3.37	1752.79	6.66	9.21	41.41	99.99	5.41
21155342	9.44	0.148	3.37	1749.88	6.66	8.85	67.39	3.40	5.47
21155346	9.44	0.152	5.06	1752.79	6.66	9.21	61.82	99.99	5.47
21155350	9.45	0.155	5.06	1746.98	6.66	8.49	54.40	23.26	5.47
21155354	9.45	0.157	3.37	1755.69	6.66	9.56	35.84	99.99	5.47
21155358	9.45	0.161	5.06	1746.98	6.66	8.49	26.56	99.99	5.47
21155402	9.45	0.163	3.37	1746.98	6.66	8.49	11.71	99.99	5.53
21155406	9.46	0.165	3.37	1755.69	6.79	9.56	11.71	99.99	5.47
21155410	9.46	0.169	5.06	1744.07	6.66	8.14	22.85	99.99	5.41
21155414	9.46	0.172	5.06	1755.69	6.66	9.56	45.12	99.99	5.34
21155418	9.46	0.174	3.37	1746.98	6.66	8.49	56.25	99.99	5.41

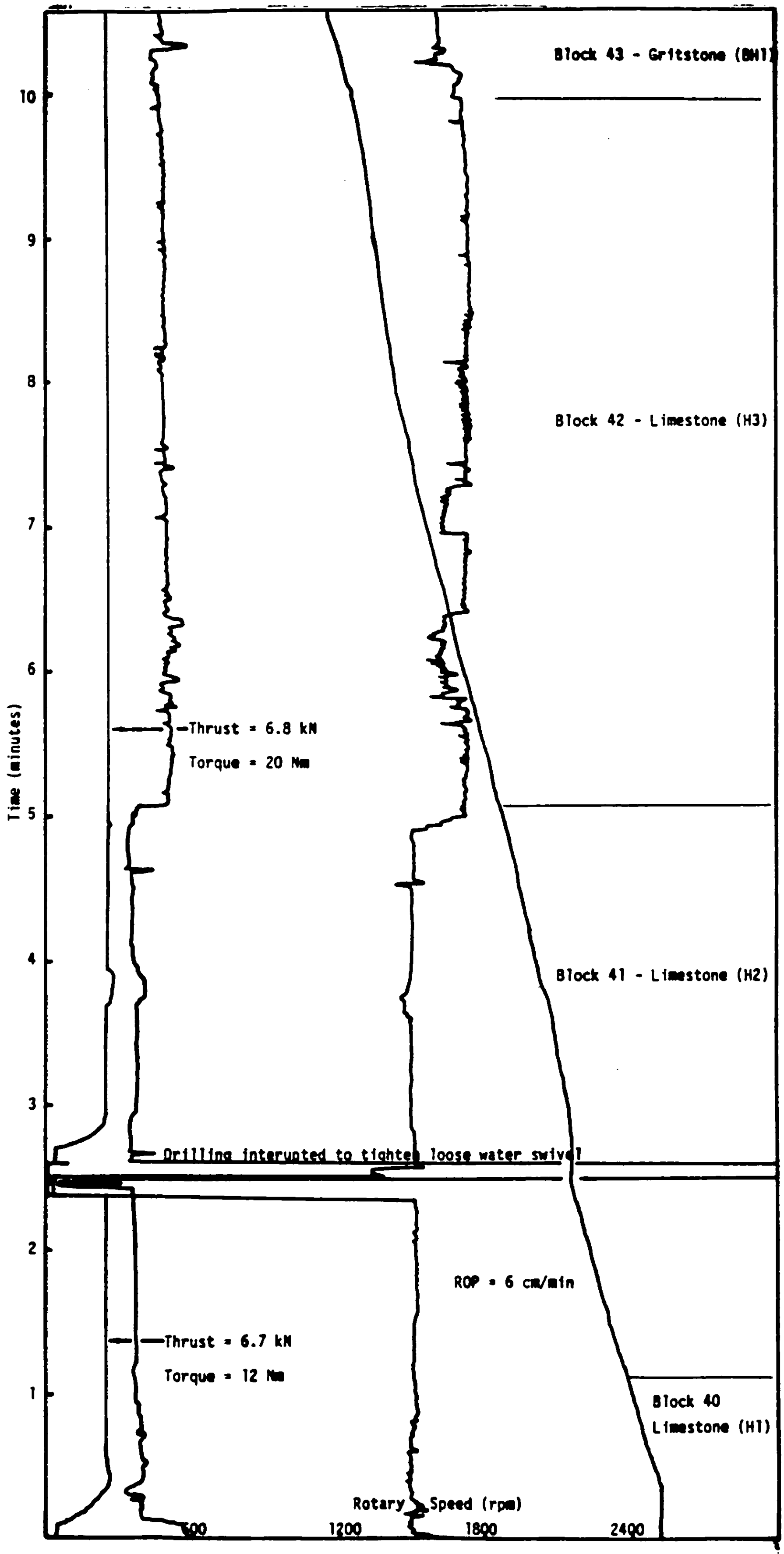
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE ?
21155422	9.47	0.178	5.06	1717.92	7.73	4.93	65.54	99.99	5.79
21155426	9.47	0.184	10.12	1712.11	7.57	4.22	59.97	99.99	5.91
21155430	9.48	0.188	5.06	1741.17	7.44	7.78	35.84	99.99	5.72
21155434	9.48	0.192	6.74	1758.60	6.92	9.92	20.99	99.99	5.15
21155438	9.49	0.196	5.06	1770.22	6.79	11.35	13.57	30.51	5.03
21155442	9.49	0.199	5.06	1773.13	6.92	11.70	17.28	17.45	4.76
21155446	9.49	0.204	6.74	1776.03	6.79	12.06	35.84	99.99	4.76
21155450	9.50	0.206	3.37	1773.13	6.79	11.70	65.54	99.99	4.90
21155454	9.50	0.209	5.06	1776.03	6.79	12.06	59.97	99.99	4.90
21155458	9.50	0.214	6.74	1773.13	6.79	11.70	63.68	99.99	4.90
21155502	9.51	0.217	5.06	1773.13	6.79	11.70	50.69	99.99	4.90
21155506	9.51	0.220	5.06	1770.22	6.79	11.35	24.73	99.99	4.90
21155510	9.51	0.224	5.06	1776.03	6.79	12.06	15.42	11.50	4.78
21155514	9.52	0.226	3.37	1778.94	6.79	12.42	11.71	99.99	4.76
21155518	9.52	0.229	5.06	1781.84	6.79	12.77	19.13	99.99	4.52
21155522	9.52	0.233	5.06	1773.13	6.79	11.70	26.56	99.99	4.78
21155526	9.53	0.236	5.06	1776.03	6.79	12.06	45.12	99.99	4.71
21155530	9.53	0.239	5.06	1781.84	6.79	12.77	59.97	99.99	4.78
21155534	9.53	0.243	5.06	1764.41	7.31	10.63	67.39	99.99	4.76
21155538	9.54	0.246	5.06	1770.22	6.79	11.35	63.68	99.99	4.90
21155542	9.54	0.250	5.06	1921.32	6.79	25.12	50.69	99.99	6.04
21155546	9.54	0.253	5.06	2011.39	6.80	18.44	22.74	99.99	7.31
21155550	9.55	0.257	6.74	2002.67	6.93	19.08	15.31	24.84	7.43
21155554	9.55	0.261	5.06	2014.30	6.80	18.22	15.31	99.99	7.12
21155558	9.56	0.265	6.74	2014.30	6.80	18.22	32.03	99.99	7.18
21155602	9.56	0.269	5.06	2014.30	6.80	18.22	58.04	99.99	7.18
21155606	9.56	0.274	8.43	2005.58	6.93	18.87	65.47	99.99	7.12
21155610	9.57	0.280	8.43	2011.39	6.67	18.44	61.75	99.99	7.06
21155614	9.57	0.284	6.74	2011.39	6.67	18.44	58.04	8.45	7.25
21155618	9.58	0.289	6.74	2011.39	6.67	18.44	35.74	99.99	7.12
21155622	9.58	0.293	6.74	1941.66	6.79	23.61	20.99	99.99	7.74
21155626	9.59	0.297	5.06	2020.11	6.67	17.79	15.31	21.31	7.06
21155630	9.59	0.301	6.74	1979.43	6.67	20.81	13.45	99.99	7.88
21155634	9.59	0.305	5.06	1857.39	6.79	29.87	13.57	99.99	8.18
21155638	9.60	0.308	5.06	1918.41	6.80	25.34	24.60	99.99	8.57
21155642	9.60	0.311	5.06	1950.37	6.67	22.97	45.03	99.99	8.76
21155646	9.61	0.316	6.74	1886.45	6.53	27.71	63.68	99.99	8.75
21155650	9.61	0.319	5.06	1880.64	6.79	28.14	63.68	15.97	9.07
21155654	9.61	0.323	5.06	1900.98	6.79	26.63	67.39	99.99	8.75
21155658	9.62	0.327	6.74	1822.52	6.92	32.46	58.11	99.99	8.75
21155702	9.62	0.331	5.06	1921.32	6.92	25.12	37.69	99.99	8.50
21155706	9.62	0.334	5.06	1915.50	6.79	25.55	19.13	99.99	8.50
21155710	9.63	0.337	5.06	2002.67	6.67	19.08	17.16	99.99	6.87
21155714	9.63	0.342	6.74	2008.49	6.67	18.65	13.45	99.99	6.99
21155718	9.64	0.345	5.06	2014.30	6.67	18.22	17.16	99.99	6.99
21155722	9.64	0.349	5.06	2011.39	6.67	18.44	26.45	99.99	6.93
21155726	9.64	0.352	5.06	2011.39	6.67	18.44	30.17	99.99	6.93
21155730	9.65	0.355	5.06	2014.30	6.67	18.22	50.61	99.99	6.87
21155734	9.65	0.360	6.74	2020.11	6.67	17.79	58.04	99.99	6.87
21155738	9.65	0.362	3.37	2020.11	6.67	17.79	63.61	99.99	6.87
21155742	9.66	0.367	6.74	1892.26	6.79	27.28	65.54	99.99	6.79
21155746	9.66	0.369	3.37	1900.98	6.92	26.63	50.69	99.99	8.56
21155750	9.66	0.373	6.74	1903.88	6.92	26.42	37.69	99.99	8.50
21155754	9.67	0.378	6.74	1909.69	6.66	25.99	17.28	7.70	6.18
21155758	9.67	0.381	5.06	1930.03	6.53	24.48	13.57	99.99	8.31
21155802	9.67	0.383	3.37	2014.30	6.54	18.22	13.45	99.99	7.43
21155806	5. 8	0.386	3.37	2014.30	6.67	18.22	24.60	99.99	6.93
21155810		0.390	6.74	1924.22	6.66	24.91	46.97	99.99	6.79

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
21155814	9.68	0.394	5.06	2011.39	6.80	18.44	63.61	99.99	6.47
21155818	9.69	0.396	3.37	2017.20	6.80	18.00	63.61	24.07	6.74
21155822	9.69	0.399	5.06	2017.20	6.93	18.00	65.47	99.99	6.68
21155826	9.69	0.403	5.06	2020.11	6.67	17.79	63.61	99.99	6.68
21155830	9.69	0.405	3.37	2008.49	6.67	18.65	43.17	21.02	6.66
21155834	9.70	0.408	5.06	2017.20	6.67	18.00	26.45	26.07	6.58
21155838	9.70	0.411	5.06	2002.67	6.67	19.08	13.45	99.99	6.60
21155842	9.70	0.414	3.37	2002.67	6.67	19.08	11.59	99.99	6.60
21155850	9.71	0.418	3.37	1996.86	6.41	19.51	13.45	99.99	7.25
21155854	9.71	0.422	5.06	2025.92	6.80	17.36	19.02	99.99	7.06
21155858	9.71	0.424	3.37	2017.20	6.67	18.00	33.88	99.99	6.55
21155902	9.72	0.426	3.37	2017.20	6.54	18.00	50.61	99.99	6.49
21155906	9.72	0.428	3.37	2023.01	6.93	17.57	63.61	99.99	6.68
21155910	9.72	0.431	3.37	2020.11	6.80	17.79	67.33	99.99	6.55
21155914	9.72	0.432	1.69	2031.73	6.80	16.93	63.61	99.99	6.42
21155918	9.72	0.434	3.37	2034.64	6.93	16.71	48.75	99.99	6.33
21155922	9.73	0.436	3.37	2037.54	6.93	16.49	50.61	99.99	6.36
21155926	9.73	0.438	3.37	2037.54	6.67	16.49	26.45	99.99	6.36
21155930	9.73	0.440	1.69	2031.73	6.67	16.93	20.88	99.99	6.30
21155934	9.73	0.441	1.69	2031.73	6.54	16.93	7.87	99.99	6.36
21155938	9.73	0.443	3.37	2037.54	6.67	16.49	13.45	99.99	6.87
21155942	9.73	0.444	1.69	2031.73	6.67	16.93	13.45	99.99	6.42
21155946	9.74	0.446	3.37	2031.73	6.93	16.93	20.88	99.99	6.30
21155950	9.74	0.449	3.37	2031.73	6.54	16.93	28.31	99.99	6.30
21155954	9.74	0.450	1.69	2031.73	6.67	16.93	46.89	99.99	6.80
21155958	9.74	0.452	3.37	2031.73	6.67	16.93	63.61	99.99	6.23
21160002	9.74	0.454	0.00	2028.83	6.80	17.14	61.75	99.99	6.23
21160006	9.75	0.456	3.37	2028.83	6.80	17.14	61.75	99.99	6.36
21160010	9.75	0.458	1.69	2023.01	6.67	17.57	65.47	99.99	6.36
21160014	9.75	0.460	3.37	2020.11	6.80	17.79	46.89	13.92	6.36
21160018	9.75	0.463	5.06	2014.30	6.80	18.22	39.46	99.99	6.55
21160022	9.76	0.467	5.06	2011.39	6.80	18.44	26.45	99.99	6.68
21160026	9.76	0.469	3.37	2002.67	6.93	19.08	17.16	26.31	6.55
21160030	9.76	0.473	6.74	1996.86	6.80	19.51	9.73	99.99	6.61
21160034	9.77	0.476	3.37	2002.67	6.54	19.08	11.59	99.99	6.61
21160038	9.77	0.481	8.43	1999.77	6.67	19.30	24.60	27.02	6.49
21160042	9.78	0.486	6.74	1962.00	6.93	22.10	37.60	15.59	6.61
21160046	9.78	0.489	5.06	1964.90	6.93	21.89	52.46	29.68	7.06
21160050	9.78	0.492	5.06	1999.77	6.54	19.30	65.47	99.99	6.93
21160054	9.79	0.497	6.74	1959.09	6.93	22.32	63.61	99.99	7.06
21160058	9.79	0.500	5.06	1790.56	6.66	34.83	67.39	20.10	8.81
21160102	9.79	0.504	5.06	1915.50	6.92	25.55	56.25	99.99	7.99
21160106	9.80	0.508	6.74	1889.35	6.66	27.50	39.55	99.99	8.06
21160110	9.80	0.510	3.37	1892.26	6.92	27.28	20.99	99.99	8.18
21160114	9.80	0.515	6.74	1889.35	7.05	27.50	17.28	99.99	7.99
21160118	9.81	0.518	5.06	1883.54	7.05	27.93	15.42	22.44	8.12
21160122	9.81	0.522	5.06	1851.58	6.92	30.30	11.71	3.40	8.25
21160126	9.82	0.526	6.74	1839.96	6.40	31.16	13.57	99.99	8.81
21160130	9.82	0.530	5.06	1837.05	6.92	31.38	13.57	99.99	9.13
21160134	9.82	0.533	5.06	1837.05	6.66	31.38	26.56	99.99	8.94
21160138	9.83	0.536	5.06	1877.73	7.05	28.36	32.13	99.99	8.44
21160142	9.83	0.540	5.06	1889.35	6.40	27.50	46.97	99.99	8.18
21160146	9.83	0.543	5.06	1886.45	7.05	27.71	58.11	99.99	8.12
21160150	9.84	0.546	5.06	1883.54	6.92	27.93	67.39	99.99	8.25
21160154	9.84	0.550	5.06	1845.77	7.05	30.73	65.54	99.99	8.06
21160158	9.84	0.554	6.74	1883.54	6.40	27.93	63.68	99.99	7.93
21160202	9.85	0.557	3.37	1898.07	6.79	26.85	50.69	99.99	7.80
21160206	9.85	0.560	5.06	1889.35	6.40	27.50	30.27	99.99	7.93

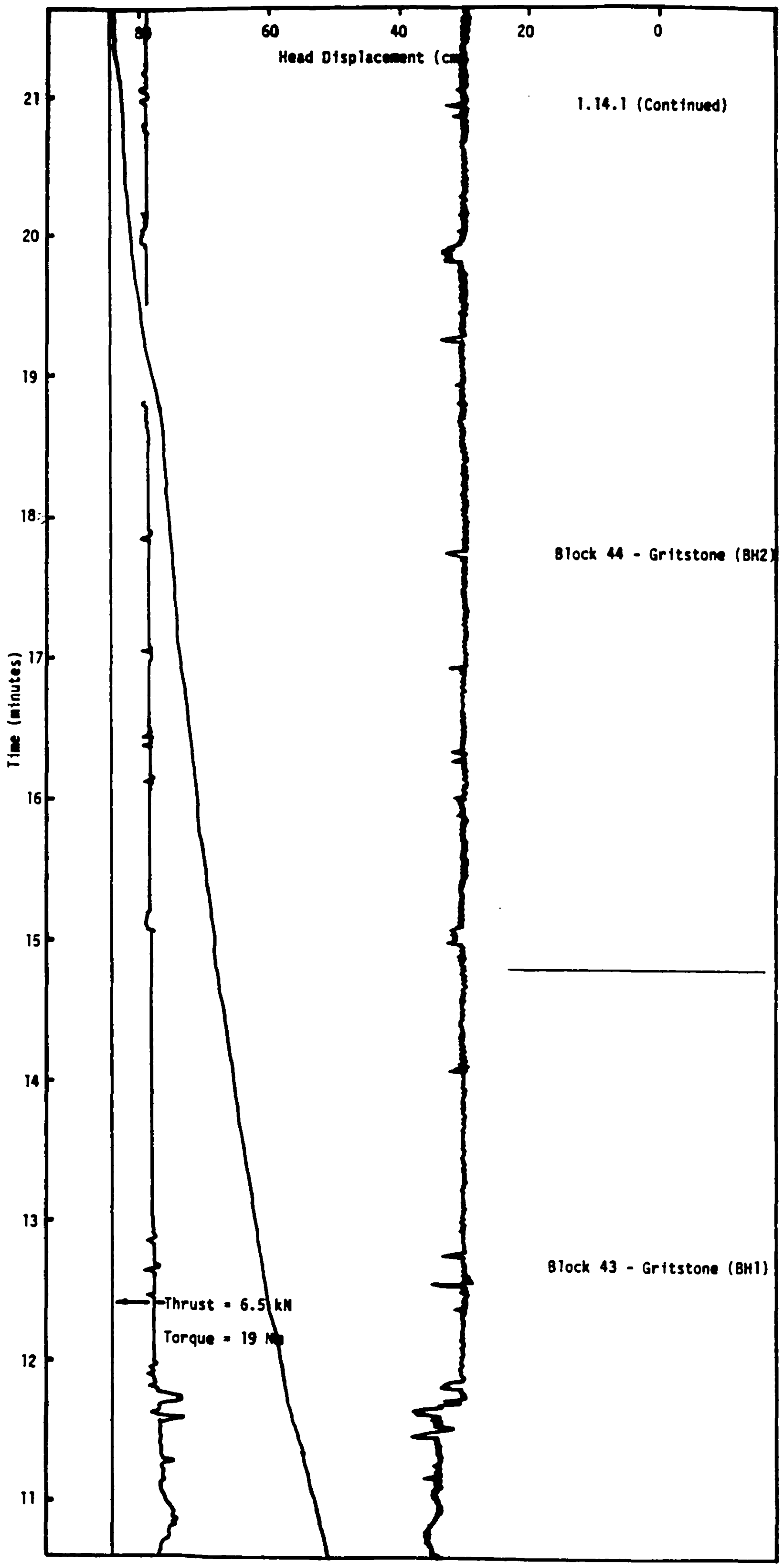
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. FLO	PAGE 4
21160210	9.85	0.563	5.06	1874.83	7.31	28.57	20.99	99.99	6.16
21160214	9.86	0.567	5.06	1976.52	6.54	21.02	13.45	99.99	9.39
21160218	9.86	0.570	5.06	1877.73	7.18	26.36	8.[illegible]	99.99	6.12
21160222	9.86	0.573	5.06	1790.56	7.05	34.83	13.57	99.99	9.13
21160226	9.87	0.578	6.74	1947.47	7.18	23.18	22.85	10.73	6.54
21160230	9.87	0.581	5.06	2005.58	7.19	18.87	33.88	99.99	6.36
21160234	9.87	0.585	5.06	2014.30	6.67	18.22	54.32	99.99	7.37
21160238	9.88	0.588	5.06	2005.58	6.54	18.87	37.60	99.99	6.17
21160242	9.88	0.590	3.37	1999.77	6.80	19.30	46.89	99.99	6.49
21160246	9.88	0.594	5.06	2002.67	6.54	19.08	61.75	99.99	6.17
21160250	9.89	0.597	5.06	2008.49	7.19	18.65	67.33	99.99	6.11
21160254	9.89	0.599	3.37	2011.39	7.19	18.44	65.47	99.99	6.17
21160258	9.89	0.602	3.37	2014.30	7.19	18.22	50.61	99.99	6.17
21160302	9.89	0.605	5.06	2014.30	7.06	18.22	48.75	99.99	6.17
21160306	9.90	0.607	3.37	2017.20	6.41	18.00	35.74	99.99	6.17
21160310	9.90	0.609	3.37	2014.30	6.80	18.22	17.16	99.99	6.11
21160314	9.90	0.612	3.37	2011.39	7.06	18.44	11.59	99.99	6.05
21160318	9.90	0.615	5.06	2017.20	6.67	18.00	9.73	99.99	6.05
21160322	9.91	0.617	3.37	2002.67	7.19	19.08	17.16	99.99	6.17
21160326	9.91	0.619	3.37	1996.86	6.54	19.51	33.88	31.34	6.17
21160330	9.91	0.622	3.37	2011.39	7.19	18.44	50.61	99.99	6.05
21160334	9.91	0.625	5.06	2014.30	6.80	18.22	67.33	99.99	6.17
21160338	9.92	0.627	3.37	1996.86	6.41	19.51	59.90	99.99	6.11
21160342	9.92	0.631	5.06	2008.49	6.54	18.65	65.47	99.99	6.23
21160346	9.92	0.633	3.37	2011.39	6.41	18.44	59.90	99.99	6.05
21160350	9.93	0.635	3.37	2005.58	6.54	18.87	45.03	99.99	5.98
21160354	9.93	0.637	3.37	2014.30	7.19	18.22	32.03	99.99	5.98
21160358	9.93	0.640	3.37	2011.39	7.19	18.44	19.02	10.39	5.98
21160402	9.93	0.643	5.06	2014.30	6.54	18.22	13.45	99.99	6.05
21160406	9.94	0.645	3.37	2014.30	6.41	18.22	9.73	99.99	5.98
21160410	9.94	0.648	3.37	2011.39	6.80	18.44	13.45	7.70	6.05
21160414	9.94	0.649	1.69	2005.58	7.06	18.87	19.02	99.99	6.17
21160418	9.94	0.652	5.06	2002.67	7.32	19.08	26.45	99.99	6.11
21160422	9.94	0.653	1.69	2002.67	6.80	19.08	39.46	99.99	6.05
21160426	9.95	0.657	5.06	1999.77	7.19	19.30	54.32	99.99	6.17
21160430	9.95	0.658	1.69	2005.58	6.93	18.87	67.33	99.99	6.11
21160434	9.95	0.660	3.37	2002.67	6.54	19.08	67.33	99.99	6.23
21160438	9.95	0.663	5.06	1996.86	7.19	19.51	67.33	99.99	6.17
21160442	9.95	0.664	1.69	2002.67	6.67	19.08	58.04	99.99	6.11
21160446	9.96	0.667	3.37	1976.52	6.41	21.02	43.17	99.99	6.55
21160450	9.96	0.669	3.37	1999.77	7.06	19.30	22.74	99.99	6.17
21160454	9.96	0.672	5.06	1988.15	6.67	20.16	15.31	99.99	6.17
21160458	9.96	0.673	1.69	1988.15	6.28	20.16	13.45	99.99	6.17
21160502	9.96	0.675	1.69	1993.96	7.19	19.73	17.16	4.84	6.23
21160506	9.97	0.678	5.06	1996.86	6.80	19.51	26.45	99.99	6.17
21160510	9.97	0.681	5.06	1993.96	6.41	19.73	48.75	99.99	6.11
21160514	9.97	0.682	1.69	1999.77	6.93	19.30	67.33	99.99	6.11
21160518	9.98	0.686	5.06	2005.58	6.28	18.87	63.61	99.99	6.05
21160522	9.98	0.688	3.37	2002.67	6.80	19.08	63.61	99.99	5.98
21160526	9.98	0.689	1.69	1996.86	6.80	19.51	61.75	99.99	6.05
21160530	9.98	0.691	3.37	1999.77	7.06	19.30	45.03	99.99	5.98
21160534	9.98	0.694	3.37	1996.86	6.28	19.51	26.45	99.99	5.98
21160538	9.98	0.695	1.69	1962.00	6.28	22.10	28.31	99.99	5.98
21160542	9.99	0.697	3.37	1956.18	6.53	22.53	11.71	99.99	6.61
21160546	9.99	0.699	3.37	1988.15	6.93	20.16	7.87	99.99	6.11
21160550	9.99	0.700	1.69	1996.86	6.54	19.51	7.87	99.99	6.11
21160554	9.99	0.702	1.69	1988.15	6.79	20.16	17.28	99.99	6.16
21160558	9.99	0.704	3.37	1991.05	7.31	19.95	26.56	99.99	6.10

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
21160602	9.99	0.705	1.69	2002.67	6.27	19.08	46.97	99.99	5.97
21160610	10.00	0.709	3.37	1999.77	7.05	19.30	65.54	99.99	5.91
21160614	10.00	0.711	1.69	1996.86	6.79	19.51	67.39	99.99	5.97
21160618	10.00	0.713	3.37	2002.67	6.92	19.08	46.97	3.40	5.91
21160622	10.00	0.713	0.00	1999.77	6.79	19.30	37.69	17.45	5.85
21160626	10.00	0.715	3.37	1991.05	6.27	19.95	24.70	7.75	5.97
21160630	10.01	0.716	1.69	1999.77	7.18	19.30	17.28	99.99	5.91
21160634	10.01	0.717	1.69	1988.15	6.40	20.16	6.14	6.88	5.97
21160638	10.01	0.718	1.69	1991.05	7.18	19.95	4.28	37.51	5.91
21160642	10.01	0.721	3.37	2011.39	6.27	18.44	8.00	99.99	5.65
21160646	10.01	0.722	1.69	2008.49	6.40	18.65	24.71	99.99	5.72
21160650	10.01	0.724	3.37	2005.58	6.27	18.87	39.55	99.99	5.65
21160654	10.01	0.725	1.69	1953.28	7.05	22.75	50.69	99.99	5.79
21160658	10.02	0.726	1.69	1988.15	6.40	20.16	61.82	99.99	5.79
21160702	10.02	0.729	3.37	2002.67	7.05	19.08	58.11	99.99	5.97
21160706	10.02	0.731	3.37	2005.58	6.66	18.87	56.25	99.99	5.72
21160710	10.02	0.732	1.69	2005.58	6.66	18.87	39.55	99.99	5.79
21160714	10.02	0.734	3.37	1993.96	7.31	19.73	22.85	99.99	5.72
21160718	10.03	0.735	1.69	2002.67	7.05	19.08	17.28	99.99	5.85
21160722	10.03	0.738	3.37	2005.58	6.53	18.87	9.85	99.99	5.72
21160726	10.03	0.739	1.69	2014.30	7.18	18.22	11.71	26.30	5.79
21160730	10.03	0.740	1.69	2011.39	6.66	18.44	26.56	99.99	5.79
21160734	10.03	0.742	3.37	2011.39	6.27	18.44	46.97	99.99	5.66
21160738	10.03	0.743	1.69	2011.39	6.79	18.44	67.39	10.38	5.66
21160742	10.03	0.744	1.69	2011.39	6.53	18.44	59.97	17.45	5.66
21160746	10.04	0.747	3.37	2008.49	6.40	18.65	61.82	99.99	5.79
21160750	10.04	0.748	1.69	1999.77	7.31	19.30	50.69	99.99	5.66
21160754	10.04	0.750	3.37	2005.58	7.31	18.87	30.27	99.99	5.72
21160758	10.04	0.750	0.00	1999.77	6.27	19.30	19.13	99.99	5.72
21160802	10.04	0.752	3.37	2008.49	6.40	18.65	9.85	3.40	5.66
21160806	10.04	0.753	1.69	1999.77	7.57	19.30	9.85	99.99	5.79
21160810	10.05	0.756	3.37	2005.58	6.79	18.87	13.57	99.99	5.66
21160814	10.05	0.757	1.69	2011.39	7.44	18.44	22.85	99.99	5.66
21160818	10.05	0.758	1.69	2008.49	6.92	18.65	37.69	99.99	5.66
21160822	10.05	0.759	1.69	2014.30	6.66	18.22	54.40	99.99	6.67
21160826	10.05	0.761	3.37	2002.67	6.27	19.08	63.68	99.99	5.66
21160830	10.05	0.761	0.00	2005.58	6.66	18.87	67.39	99.99	5.66
21160834	10.05	0.761	0.00	2002.67	6.27	19.08	56.25	6.88	5.72
21160838	10.05	0.763	3.37	2005.58	6.66	18.87	35.84	99.99	5.66
21160842	10.05	0.765	1.69	1999.77	6.27	19.30	19.13	24.82	5.66
21160846	10.06	0.766	1.69	2002.67	6.27	19.08	8.00	18.49	5.66
21160850	10.06	0.767	1.69	2008.49	7.31	18.65	9.85	99.99	5.72
21160854	10.06	0.768	1.69	2005.58	6.92	18.87	17.28	99.99	5.66
21160858	10.06	0.769	1.69	2008.49	7.18	18.65	24.70	99.99	5.66
21160902	10.06	0.770	1.69	2008.49	6.92	18.65	39.55	99.99	5.79
21160906	10.06	0.772	3.37	1999.77	7.83	19.30	59.97	99.99	5.66
21160910	10.06	0.775	3.37	1988.15	7.44	20.16	65.54	99.99	5.79
21160914	10.07	0.778	5.06	1996.86	8.10	19.51	58.11	99.99	5.79
21160918	10.07	0.783	6.74	1993.96	8.36	19.73	50.69	99.99	5.79
21160922	10.07	0.785	3.37	1996.86	7.70	19.51	32.13	99.99	5.72
21160926	10.08	0.788	5.06	1999.77	7.44	19.30	17.28	99.99	5.72
21160930	10.08	0.790	3.37	1996.86	8.10	19.51	6.14	99.99	5.60
21160934	10.08	0.793	3.37	1996.86	7.83	19.51	11.71	99.99	5.66
21160938	10.08	0.795	3.37	1988.15	8.23	20.16	19.13	99.99	5.72
21160942	10.09	0.798	5.06	1991.05	8.23	19.95	43.26	99.99	5.72
21160946	10.09	0.799	1.69	1988.15	8.23	20.16	67.39	99.99	5.60
21160950	10.09	0.802	3.37	1912.60	8.23	25.77	61.82	99.99	5.66
21160954	[illegible]	0.804	3.37	1996.86	8.23	19.51	61.82	99.99	5.72

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H..	PAGE 6
21160958	10.10	0.806	3.37	1991.05	7.70	19.95	52.54	99.99	5.60
21161002	10.10	0.807	1.69	1979.43	7.31	20.81	37.69	25.81	5.60
21161006	10.10	0.810	3.37	2002.67	7.70	19.08	20.99	21.59	5.66
21161010	10.10	0.812	3.37	1993.96	8.23	19.73	9.85	99.99	5.66
21161014	10.10	0.814	3.37	1996.86	7.57	19.51	4.28	99.99	5.66
21161018	10.10	0.815	1.69	1988.15	7.31	20.16	11.71	99.99	5.60
21161022	10.11	0.816	1.69	1991.05	8.10	19.95	20.99	99.99	5.72
21161026	10.11	0.817	1.69	1927.13	7.18	24.69	39.55	99.99	6.54
21161030	10.11	0.818	1.69	1991.05	7.18	19.95	56.25	99.99	6.23
21161034	10.11	0.820	1.69	2002.67	7.83	19.08	63.68	99.99	5.66
21161038	10.11	0.821	1.69	1999.77	7.57	19.30	61.82	17.80	5.53
21161042	10.11	0.823	3.37	1996.86	7.70	19.51	46.97	99.99	5.60
21161046	10.11	0.824	1.69	1999.77	7.18	19.30	24.70	99.99	5.60
21161050	10.11	0.825	1.69	1999.77	7.83	19.30	15.42	99.99	5.53
21161054	10.12	0.826	1.69	2002.67	7.31	19.08	8.00	99.99	5.53
21161058	10.12	0.829	3.37	2005.58	7.83	18.87	11.71	99.99	5.53
21161102	10.12	0.830	1.69	2005.58	7.97	18.87	28.41	99.99	5.47
21161106	10.12	0.831	1.69	2005.58	8.23	18.87	54.40	99.99	5.53
21161110	10.12	0.832	1.69	1982.34	7.18	20.59	63.68	99.99	5.72
21161114	10.12	0.834	3.37	2002.67	8.36	19.08	56.25	5.94	5.85
21161118	10.12	0.835	1.69	2002.67	8.10	19.08	65.54	99.99	5.53
21161122	10.13	0.836	1.69	1982.34	7.44	20.59	46.97	15.97	5.47
21161126	10.13	0.838	1.69	2005.58	7.18	18.87	33.98	18.15	5.47
21161130	10.13	0.839	1.69	2002.67	7.05	19.08	17.28	27.92	5.60
21161134	10.13	0.840	1.69	1976.52	8.36	21.02	11.71	99.99	5.53
21161138	10.13	0.841	1.69	2002.67	8.23	19.08	8.00	99.99	5.41
21161142	10.13	0.842	1.69	2002.67	7.44	19.08	11.71	99.99	5.53
21161146	10.13	0.843	1.69	1999.77	7.57	19.30	26.56	99.99	5.53
21161150	10.13	0.843	0.00	1999.77	7.83	19.30	43.26	99.99	5.53
21161154	10.13	0.844	1.69	2008.49	8.49	18.65	58.11	99.99	5.60
21161158	10.13	0.844	0.00	2005.58	7.18	18.87	65.54	99.99	5.34
21161202	10.13	0.844	0.00	2011.39	8.36	18.44	58.11	99.99	5.34
21161206	10.14	0.845	1.69	2008.49	7.44	18.65	35.84	26.77	5.34
21161210	10.13	0.844	1.69	2011.39	8.62	18.44	20.99	12.52	5.60
21161214	10.13	0.844	0.00	1793.47	-2.76	34.61	9.85	30.39	5.22
21161218	10.13	0.844	0.00	35.54	-2.76	165.12	6.14	99.99	-1.60



RECORD OF TRRL DRILL RUN 1.14.1 (9.29 to 10.13 metres)



80
60
40
20
0
Head Displacement (cm)
1.14.1 (Continued)
21
20
19
18
17
16
15
14
13
12
11
Time (minutes)
Block 44 - Gritstone (BH2)
Block 43 - Gritstone (BH1)
Thrust = 6.5 kN
Torque = 19 Nm

USER: EX9069 -AT SYSTEM

NR_T1.14.2

EX9069

NR_T1.14.2

LABEL: PRT030 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:34, ON: PR0 BY: PR0

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
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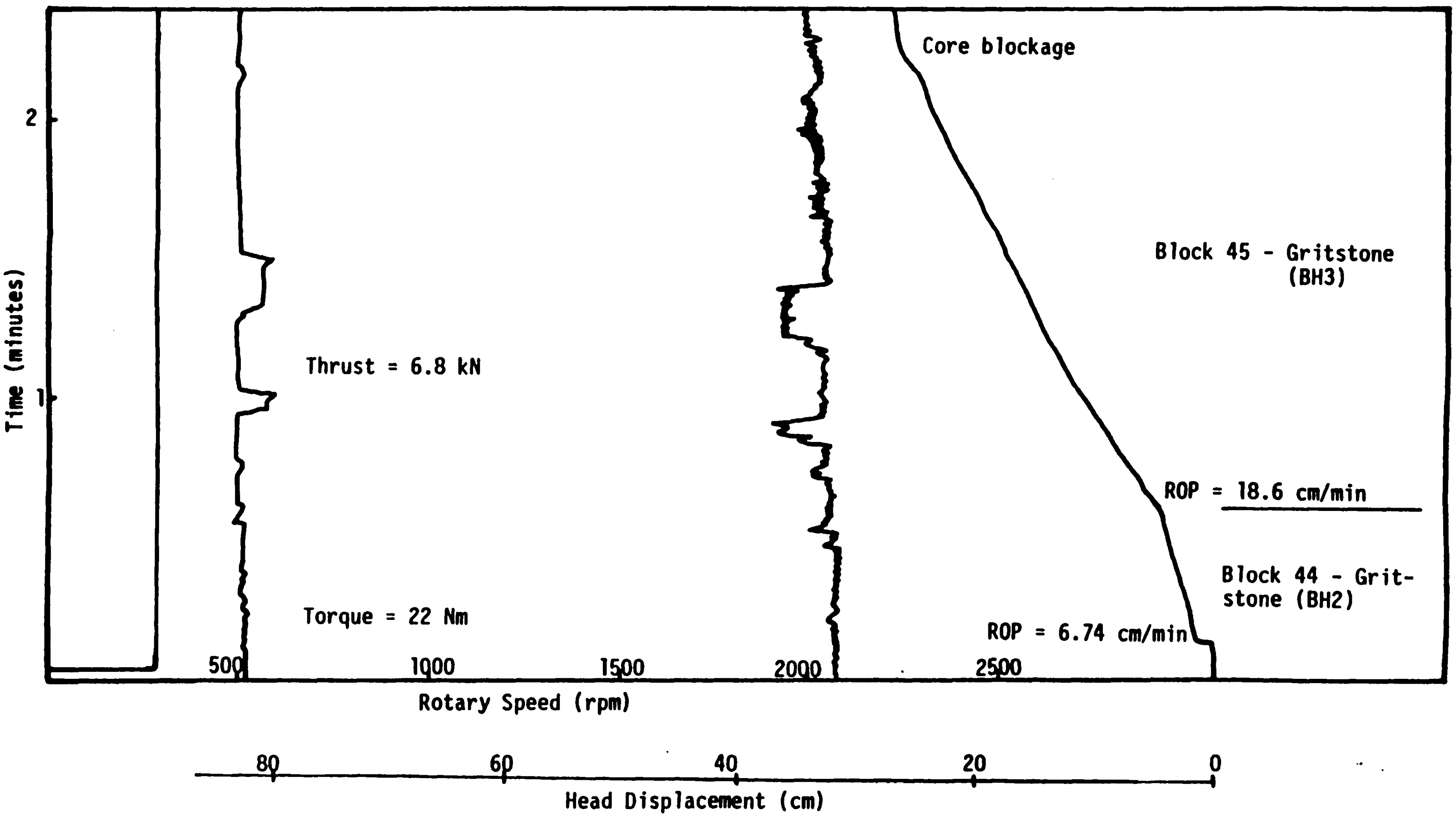
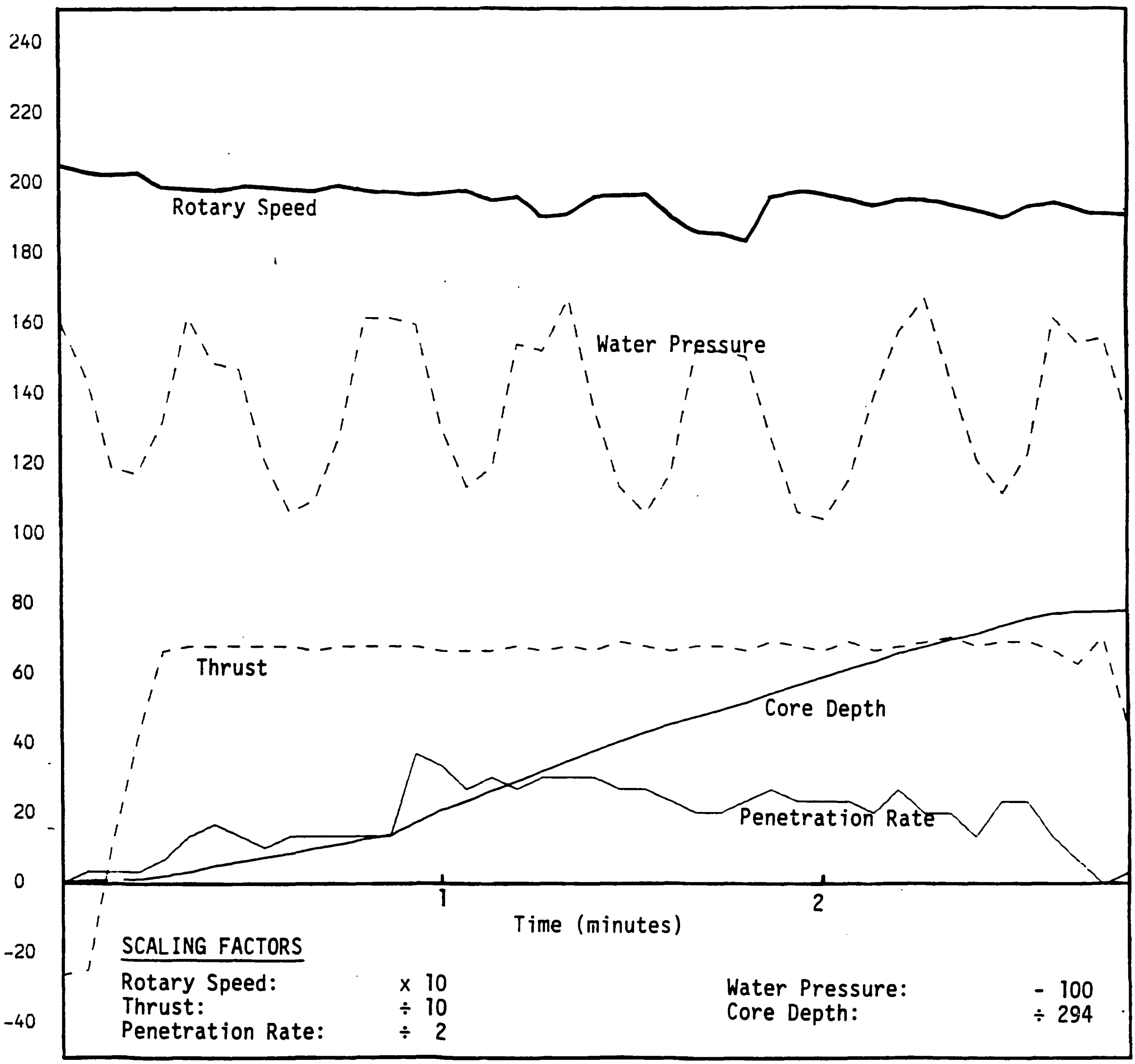
21162454	10.13	0.000	0.00	2051.19	-2.62	17.49	59.97	99.99	6.98
21162458	10.13	0.001	1.69	2036.55	-2.49	18.55	45.12	99.99	5.72
21162502	10.13	0.002	1.69	2027.93	1.17	19.18	19.13	99.99	5.79
21162506	10.13	0.003	1.69	2033.74	4.17	18.76	17.28	29.02	5.66
21162510	10.14	0.006	3.37	1990.11	6.66	21.93	32.13	27.92	6.10
21162514	10.14	0.010	6.74	1987.21	6.79	22.14	61.82	29.45	6.16
21162518	10.15	0.016	8.43	1984.30	6.79	22.35	48.83	28.14	6.35
21162522	10.15	0.020	6.74	1993.11	6.79	21.93	46.97	23.26	6.23
21162526	10.15	0.024	5.06	1990.11	6.79	21.93	20.99	29.24	6.16
21162530	10.16	0.028	6.74	1987.21	6.79	22.14	6.14	20.10	6.35
21162534	10.16	0.033	6.74	1981.39	6.66	22.56	9.85	99.99	6.23
21162538	10.17	0.037	6.74	1993.02	6.79	21.72	28.41	99.99	6.23
21162542	10.17	0.042	6.74	1981.39	6.79	22.56	61.82	99.99	6.14
21162546	10.18	0.046	6.74	1978.48	6.79	22.78	61.82	95.99	6.10
21162550	10.19	0.058	18.55	1972.66	6.79	23.20	59.97	99.99	6.10
21162554	10.20	0.070	16.86	1978.48	6.66	22.78	30.27	99.99	6.29
21162558	10.21	0.079	13.49	1981.39	6.66	22.56	13.57	99.99	6.23
21162602	10.22	0.089	15.18	1955.21	6.66	24.47	19.13	99.99	6.35
21162606	10.23	0.098	13.49	1963.94	6.79	23.83	54.40	99.99	6.35
21162610	10.24	0.108	15.18	1905.77	6.66	28.06	52.54	33.66	6.67
21162614	10.25	0.118	15.18	1917.40	6.79	27.21	67.39	20.40	7.99
21162618	10.26	0.128	15.18	1966.85	6.66	23.62	35.84	22.99	6.42
21162622	10.27	0.137	13.49	1963.94	6.92	23.83	13.57	30.92	6.35
21162626	10.28	0.146	13.49	1972.66	6.79	23.20	6.14	20.10	6.48
21162630	10.28	0.154	11.80	1908.67	6.66	27.85	17.28	99.99	6.48
21162634	10.29	0.161	10.12	1862.14	6.79	31.23	52.54	25.08	7.93
21162638	10.30	0.168	10.12	1856.32	6.79	31.65	52.54	95.99	7.87
21162642	10.31	0.175	11.80	1838.87	6.66	32.92	50.69	27.69	7.55
21162646	10.31	0.184	13.49	1963.94	6.92	23.83	26.56	20.10	6.35
21162650	10.32	0.192	11.80	1978.48	6.79	22.78	6.14	27.69	6.29
21162654	10.33	0.200	11.80	1966.85	6.66	23.62	4.28	22.99	6.42
21162658	10.34	0.208	11.80	1955.21	6.92	24.47	15.42	99.99	6.35
21162702	10.34	0.215	10.12	1937.76	6.66	25.73	39.55	99.99	6.54
21162706	10.35	0.224	13.49	1952.30	6.79	24.68	58.11	99.99	6.54
21162710	10.36	0.230	10.12	1952.30	6.92	24.68	67.39	99.99	6.61
21162714	10.37	0.237	10.12	1931.94	7.05	26.16	43.26	99.99	6.54
21162718	10.37	0.242	6.74	1920.31	6.79	27.00	20.99	95.99	7.05
21162722	10.38	0.250	11.80	1897.04	6.92	28.69	11.71	4.83	6.79
21162726	10.39	0.257	11.80	1934.85	6.92	25.95	22.85	95.99	6.79
21162730	10.39	0.262	6.74	1943.58	6.66	25.31	61.82	20.40	6.61
21162734	10.39	0.264	3.37	1923.22	6.27	26.79	54.40	99.99	6.98
21162738	10.39	0.264	0.00	1911.58	7.05	27.64	56.25	22.72	7.17
21162742	10.40	0.265	1.69	1911.58	4.44	27.64	32.13	21.59	7.24



RECORD OF TRRL DRILL RUN 1.14.2 (10.13 to 10.40 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.14.2 (10.13 to 10.40 metres)



USER: EX9269 -AT SYSTEM

NR_T1.15.1

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EX9269

NR_T1.15.1

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LABEL: PRT031 -FORM

SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:34, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
21171724	10.40	0.000	0.00	2016.29	-2.23	20.03	28.41	93.99	7.62
21171728	10.40	0.001	1.69	2027.93	0.77	19.16	45.12	99.99	7.43
21171732	10.40	0.002	1.70	2027.93	4.70	19.18	63.64	99.99	7.62
21171736	10.41	0.006	5.10	1987.21	6.53	22.14	56.25	99.59	7.62
21171740	10.42	0.016	15.30	1955.21	6.79	24.47	65.54	95.99	8.37
21171744	10.42	0.022	8.50	1946.49	6.79	25.10	50.69	95.99	9.00
21171748	10.43	0.027	8.50	1940.67	6.79	25.52	19.13	95.99	8.62
21171752	10.43	0.029	3.40	1955.21	6.79	24.47	9.85	99.99	8.69
21171756	10.43	0.032	3.40	1943.58	6.79	25.31	20.99	99.99	8.56
21171800	10.43	0.034	3.40	1952.30	6.79	24.68	43.26	99.99	8.50
21171804	10.44	0.037	5.10	1955.21	6.79	24.47	56.25	99.99	8.44
21171808	10.44	0.040	3.40	1958.12	6.79	24.25	41.41	99.99	8.37
21171812	10.44	0.041	1.70	1952.30	6.79	24.68	67.39	99.99	8.50
21171816	10.44	0.043	3.40	1955.21	6.79	24.47	35.84	99.99	8.50
21171820	10.45	0.045	3.40	1958.12	6.79	24.25	19.13	99.99	8.18
21171824	10.45	0.048	3.40	1934.85	7.05	25.95	6.14	95.95	8.31
21171828	10.45	0.051	5.10	1908.67	7.83	27.85	13.57	99.99	8.88
21171832	10.45	0.054	5.10	1929.03	7.70	26.37	22.85	93.93	8.75
21171836	10.46	0.059	6.80	1934.85	7.70	25.95	48.83	95.99	8.62
21171840	10.46	0.065	8.50	1911.58	7.70	27.64	50.69	99.99	8.75
21171844	10.47	0.068	5.10	1911.58	7.70	27.64	41.41	99.99	8.88
21171848	10.47	0.073	6.80	1873.77	7.70	30.38	56.25	99.99	9.51
21171852	10.48	0.077	6.80	1873.77	7.70	30.38	30.27	99.99	9.13
21171856	10.48	0.082	6.80	1897.04	7.70	28.69	6.14	99.99	9.07
21171900	10.49	0.086	6.80	1902.86	7.83	28.27	9.85	99.99	9.07
21171904	10.49	0.091	6.80	1949.39	7.70	24.89	15.42	99.99	8.16
21171908	10.50	0.095	6.80	1958.12	7.70	24.25	35.84	95.99	8.12
21171912	10.50	0.101	8.50	1949.39	7.83	24.89	63.68	95.99	8.18
21171916	10.51	0.107	8.50	1943.58	7.70	25.31	50.69	95.99	8.31
21171920	10.51	0.111	6.80	1937.76	7.70	25.73	50.69	95.99	8.44
21171924	10.51	0.114	5.10	1934.85	7.70	25.95	46.97	95.99	8.37
21171928	10.52	0.120	8.50	1946.49	7.57	25.10	11.71	99.99	8.31
21171932	10.53	0.126	8.50	1946.49	7.70	25.10	13.57	99.99	8.06
21171936	10.53	0.130	6.80	1937.76	7.83	25.73	30.27	99.99	8.06
21171940	10.53	0.135	6.80	1905.77	7.70	28.06	67.39	99.99	8.62
21171944	10.54	0.141	8.50	1926.13	7.70	26.58	37.69	99.99	8.18
21171948	10.55	0.145	6.80	1908.67	7.83	27.85	50.69	99.99	8.56
21171952	10.55	0.150	6.80	1926.13	7.83	26.58	32.13	99.99	8.31
21171956	10.56	0.155	8.50	1937.76	7.70	25.73	11.71	99.99	8.25
21172000	10.56	0.161	8.50	1931.94	7.70	26.16	9.85	95.99	8.31
21172004	10.57	0.167	8.50	1923.22	7.83	26.79	17.28	95.49	8.31
21172008	10.57	0.172	8.50	1937.76	7.70	25.73	30.27	99.99	8.31
21172012	10.58	0.179	10.20	1940.67	7.83	25.52	59.97	99.99	8.31
21172016	10.58	0.184	6.80	1943.58	7.83	25.31	52.54	99.95	8.12
21172020	10.59	0.189	8.50	1931.94	7.83	26.16	48.83	99.99	7.99
21172024	10.59	0.194	6.80	1923.22	7.83	26.79	46.97	99.99	8.31
21172028	10.60	0.197	5.10	1920.31	7.70	27.00	17.28	99.99	8.25
21172032	10.60	0.202	6.80	1940.67	7.70	25.52	13.57	99.99	8.31
21172036	10.61	0.206	6.80	1937.76	7.70	25.73	33.98	99.99	7.93
21172040	10.61	0.211	6.80	1952.30	7.83	24.68	58.11	99.99	7.87
21172044	10.61	0.214	5.10	1955.21	7.83	24.47	35.84	95.99	7.87
21172050	10.62	0.219	4.53	1981.39	7.70	22.56	6.14	99.99	7.49
21172054	10.6[illegible]	0.221	3.40	1943.58	7.70	25.31	9.85	95.99	7.55
21172058	10.[illegible]	0.224	5.10	1958.12	7.83	24.25	19.13	99.99	7.55

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
21172102	10.63	0.231	10.20	1966.85	7.97	23.62	50.67	99.99	7.43
21172106	10.64	0.236	6.80	1978.48	7.83	22.79	63.68	99.99	7.93
21172110	10.64	0.240	6.80	1972.66	7.97	23.20	67.39	99.99	7.43
21172114	10.64	0.244	5.10	1972.66	7.83	23.20	24.70	99.99	7.36
21172118	10.65	0.248	6.80	1955.21	7.70	24.47	8.00	99.99	7.49
21172122	10.65	0.253	6.80	1955.21	7.63	24.47	11.71	99.99	7.87
21172126	10.66	0.257	6.80	1961.03	7.63	24.04	33.98	99.99	7.68
21172130	10.66	0.262	6.80	1963.94	7.97	23.83	63.68	99.99	7.49
21172134	10.67	0.266	6.80	1963.94	7.83	23.83	50.69	99.99	7.43
21172138	10.67	0.271	6.80	1955.21	7.83	24.47	56.25	99.99	7.62
21172142	10.67	0.274	5.10	1937.76	7.63	25.73	24.70	99.99	7.80
21172146	10.68	0.279	6.80	1946.49	7.97	25.10	2.43	99.99	7.74
21172150	10.68	0.283	6.80	1963.94	7.63	23.83	0.57	99.99	7.82
21172154	10.69	0.287	5.10	1937.76	7.83	25.73	11.71	99.99	7.74
21172158	10.69	0.291	6.80	1943.58	7.83	25.31	33.98	99.99	7.80
21172202	10.70	0.296	6.80	1934.85	7.70	25.95	59.97	99.99	7.67
21172206	10.70	0.299	5.10	1946.49	7.97	25.10	59.97	99.99	7.87
21172210	10.70	0.304	6.80	1946.49	7.83	25.10	61.82	99.99	7.62
21172214	10.71	0.308	6.80	1958.12	7.83	24.25	26.41	99.99	7.49
21172218	10.71	0.312	5.10	1952.30	7.70	24.68	8.00	99.99	7.49
21172222	10.71	0.315	5.10	1958.12	7.97	24.25	9.85	99.99	7.43
21172226	10.72	0.320	6.80	1963.94	7.83	23.83	32.13	99.99	7.43
21172230	10.72	0.324	6.80	1961.03	7.83	24.04	59.97	99.99	7.68
21172234	10.73	0.328	5.10	1966.85	7.83	23.62	63.68	99.99	7.43
21172238	10.73	0.332	6.80	1966.85	7.70	23.62	63.68	99.99	7.24
21172242	10.74	0.335	5.10	1961.03	7.97	24.04	48.83	99.99	7.36
21172246	10.74	0.340	6.80	1958.12	7.97	24.25	30.27	99.99	7.43
21172250	10.74	0.343	5.10	1966.85	7.83	23.62	4.28	9.14	7.24
21172254	10.75	0.347	5.10	1961.03	7.70	24.04	13.57	21.88	7.30
21172258	10.75	0.351	6.80	1955.21	7.70	24.47	45.12	99.99	7.36
21172302	10.75	0.355	5.10	1946.49	8.10	25.10	50.69	99.99	7.49
21172306	10.76	0.359	6.80	1952.30	8.10	24.68	46.97	99.99	7.43
21172310	10.76	0.363	5.10	1946.49	7.97	25.10	48.83	99.99	7.49
21172314	10.77	0.367	6.80	1940.67	7.97	25.52	13.57	99.99	7.36
21172318	10.77	0.369	3.40	1952.30	7.70	24.68	8.00	99.99	7.36
21172322	10.77	0.373	5.10	1958.12	8.10	24.25	8.00	99.99	7.36
21172326	10.78	0.376	5.10	1955.21	7.97	24.47	24.70	99.99	7.43
21172330	10.78	0.381	6.80	1972.66	7.97	23.20	63.68	99.99	7.24
21172334	10.78	0.384	5.10	1966.85	8.10	23.62	61.82	99.99	7.05
21172338	10.79	0.386	3.40	1963.94	7.70	23.83	54.40	99.99	7.11
21172342	10.79	0.389	3.40	1966.85	8.10	23.62	46.97	99.99	7.11
21172346	10.79	0.393	6.80	1961.03	8.10	24.04	15.42	99.99	7.11
21172350	10.80	0.397	5.10	1966.85	7.97	23.62	11.71	25.32	7.17
21172354	10.80	0.399	3.40	1955.21	7.83	24.47	28.41	99.99	7.24
21172358	10.80	0.402	5.10	1961.03	7.70	24.04	65.54	99.99	7.17
21172402	10.81	0.406	5.10	1966.85	7.97	23.62	41.41	99.99	7.11
21172406	10.81	0.409	5.10	1961.03	7.97	24.04	63.68	99.99	7.17
21172410	10.81	0.413	5.10	1963.94	8.10	23.83	19.13	99.99	6.98
21172414	10.81	0.415	3.40	1963.94	8.10	23.83	6.14	99.99	7.05
21172418	10.82	0.418	5.10	1949.39	8.75	24.89	4.28	99.99	7.17
21172422	10.82	0.423	6.80	1926.13	8.62	26.58	13.57	99.99	7.30
21172426	10.83	0.427	6.80	1926.13	8.62	26.58	37.69	99.99	7.74
21172430	10.83	0.431	5.10	1929.03	8.88	26.37	61.82	99.99	7.68
21172434	10.83	0.433	3.40	1923.22	9.14	26.79	56.25	99.99	7.74
21172438	10.84	0.435	3.40	1923.22	8.49	26.79	65.54	99.99	7.74
21172442	10.84	0.439	5.10	1943.58	8.62	25.31	35.84	99.99	7.74
21172446	10.84	0.441	3.40	1940.67	8.49	25.52	8.00	99.99	7.30
21172450	10.84	0.443	3.40	1902.86	9.01	28.27	9.85	16.73	7.62

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 3
21172454	10.84	0.444	1.70	1902.86	9.27	28.27	28.41	99.99	8.31
21172458	10.85	0.447	3.40	1888.31	8.49	29.33	67.39	99.99	7.68
21172502	10.85	0.449	3.40	1879.59	9.01	29.96	45.12	99.99	8.18
21172506	10.85	0.450	1.70	1865.05	9.01	31.02	58.11	99.99	8.37
21172510	10.85	0.451	1.70	1885.41	8.49	29.54	30.27	99.99	8.37
21172514	10.85	0.453	3.40	1906.67	7.97	27.85	15.42	14.77	7.74
21172518	10.86	0.456	3.40	1969.75	7.57	23.41	0.57	99.99	6.92
21172522	10.86	0.460	6.80	1961.03	7.57	24.04	4.28	99.99	7.30
21172526	10.86	0.462	3.40	1937.76	7.97	25.73	13.57	99.99	7.24
21172530	10.86	0.465	3.40	1911.58	8.10	27.64	48.83	99.99	7.68
21172534	10.87	0.466	1.70	1920.31	7.97	27.00	67.39	99.99	7.49
21172538	10.87	0.467	1.70	1911.58	8.10	27.64	52.54	99.99	7.55
21172542	10.87	0.469	3.40	1917.40	7.97	27.21	67.39	99.99	7.36
21172546	10.87	0.470	1.70	1934.85	8.10	25.95	20.99	99.99	7.24
21172550	10.87	0.473	3.40	1926.13	7.97	26.58	6.14	99.99	7.30
21172554	10.87	0.475	3.40	1926.13	8.10	26.58	0.57	99.99	7.55
21172558	10.88	0.476	1.70	1929.03	8.23	26.37	15.42	99.99	7.36
21172602	10.88	0.476	0.00	1920.31	7.83	27.00	32.13	99.99	7.43
21172606	10.88	0.477	1.70	1908.67	7.70	27.85	58.11	99.99	7.49
21172610	10.88	0.479	3.40	1917.40	8.23	27.21	59.97	99.99	7.62
21172614	10.88	0.479	0.00	1911.58	8.23	27.64	61.82	99.99	7.49
21172618	10.88	0.481	1.70	1908.67	8.23	27.85	35.64	99.99	7.49
21172622	10.88	0.481	0.00	1914.49	7.83	27.42	17.28	99.99	7.62
21172626	10.88	0.483	3.40	1899.95	7.83	28.48	0.57	99.99	7.62
21172630	10.88	0.484	1.70	1914.49	8.10	27.42	2.43	99.99	7.80
21172634	10.88	0.484	0.00	1902.86	7.83	28.27	17.28	99.99	7.43
21172638	10.88	0.485	1.70	1821.42	8.10	23.39	50.69	99.99	7.24
21172642	10.88	0.485	0.00	1722.53	7.97	31.61	56.25	99.99	4.78
21172646	10.89	0.486	1.70	1713.80	8.10	32.33	33.98	99.99	4.90
21172650	10.89	0.486	0.00	1716.71	7.83	32.09	54.40	99.99	5.03
21172654	10.89	0.487	1.70	1719.62	7.97	31.85	54.40	18.15	4.84
21172658	10.89	0.487	0.00	1725.43	7.83	31.37	20.99	35.84	4.78
21172702	10.89	0.488	1.70	1719.62	7.97	31.85	2.43	25.88	4.84
21172706	10.89	0.490	1.70	1702.17	7.83	33.30	1.28	30.09	4.96
21172710	10.89	0.490	0.00	1702.17	7.70	33.30	4.28	99.99	5.03
21172714	10.89	0.491	1.70	1687.62	8.10	34.51	24.70	99.99	5.22
21172718	10.89	0.492	1.70	1681.81	7.70	34.99	43.26	10.95	5.09
21172722	10.89	0.492	0.00	1696.35	7.70	33.78	63.66	99.99	4.90
21172726	10.89	0.493	1.70	1675.99	7.70	35.48	59.97	99.99	5.03
21172730	10.89	0.493	0.00	1667.26	7.97	36.20	67.39	99.99	5.22
21172734	10.89	0.494	1.70	1687.62	8.23	34.51	46.97	99.99	5.09
21172738	10.89	0.494	0.00	1678.90	8.10	35.23	11.71	99.99	5.34
21172742	10.90	0.495	1.70	1702.17	8.10	33.30	3.14	99.99	5.34
21172746	10.90	0.495	0.00	1699.26	7.83	33.54	4.28	99.99	5.22
21172750	10.90	0.496	1.70	1702.17	8.10	33.30	19.13	21.30	5.09
21172754	10.90	0.498	1.70	1705.07	7.57	33.06	52.54	25.08	5.09
21172758	10.90	0.498	0.00	1734.16	7.70	30.64	48.83	99.99	4.52
21172802	10.90	0.499	1.70	1731.25	7.83	30.88	43.26	99.99	4.78
21172806	10.90	0.500	1.70	1734.16	7.70	30.64	67.39	99.99	4.71
21172810	10.90	0.501	1.70	1725.43	7.70	31.37	37.69	99.99	4.78
21172814	10.90	0.501	0.00	1734.16	7.57	30.64	9.85	27.92	4.59
21172818	10.90	0.502	1.70	1725.43	7.70	31.37	0.57	31.12	4.65
21172822	10.90	0.503	1.70	1707.98	7.70	32.82	0.57	13.00	4.96
21172826	10.90	0.503	0.00	1710.89	7.97	32.58	11.71	99.99	4.96
21172830	10.90	0.504	1.70	1725.43	7.97	31.37	28.41	99.99	4.71
21172834	10.91	0.505	1.70	1731.25	8.10	30.88	48.83	99.99	4.71
21172838	10.91	0.505	0.00	1734.16	7.70	30.64	65.54	99.99	4.59
21172842	10.91	0.507	1.70	1728.34	8.10	31.13	63.68	99.99	4.59

	TOTAL	CORE	PENETRATN	ROTARY			INLET H_2O	I. H_2O	
21172846	10.91	0.508	1.70	1658.54	8.10	30.93	67.39	99.99	4.65
21172854	10.91	0.510	1.70	1737.07	7.70	30.40	6.14	99.99	4.52
21172858	10.91	0.511	1.70	1737.07	7.70	30.40	1.28	13.46	4.78
21172902	10.91	0.512	1.70	1734.16	7.97	30.64	0.57	30.09	4.52
21172906	10.91	0.513	1.70	1737.07	7.83	30.40	11.71	99.99	4.40
21172910	10.92	0.516	3.40	1725.43	8.10	31.37	24.70	99.99	4.59
21172914	10.92	0.517	1.70	1719.62	7.97	31.85	43.26	99.99	4.65
21172918	10.92	0.518	1.70	1661.45	7.70	36.68	58.11	99.99	5.60
21172922	10.92	0.519	1.70	1745.79	7.70	29.68	67.39	99.99	4.33
21172926	10.92	0.520	1.70	1739.98	7.97	30.16	61.62	99.99	4.40
21172930	10.92	0.521	1.70	1754.52	7.97	28.95	46.97	99.99	4.08
21172934	10.92	0.522	1.70	1742.89	7.83	29.92	22.85	99.99	4.27
21172938	10.92	0.525	3.40	1731.25	7.97	30.88	6.14	99.99	4.46
21172942	10.93	0.527	3.40	1751.61	7.83	29.19	1.28	99.99	4.33
21172946	10.93	0.528	1.70	1739.98	7.97	30.16	6.14	99.99	4.33
21172950	10.93	0.529	1.70	1739.98	7.83	30.16	15.42	99.99	4.40
21172954	10.93	0.530	1.70	1719.62	7.97	31.85	32.13	99.99	4.27
21172958	10.93	0.533	3.40	1760.34	7.97	28.47	58.11	99.99	4.21
21173002	10.93	0.534	1.70	1763.25	7.83	28.23	52.54	99.99	4.08
21173006	10.93	0.535	1.70	1766.15	7.97	27.98	41.41	99.99	4.02
21173010	10.94	0.537	3.40	1760.34	7.97	28.47	46.97	99.99	4.21
21173014	10.94	0.538	1.70	1763.25	7.83	28.23	61.62	99.99	4.02
21173018	10.94	0.539	1.70	1763.25	7.97	28.23	39.55	13.46	4.08
21173022	10.94	0.541	1.70	1757.43	7.83	28.71	19.13	99.99	4.08
21173026	10.94	0.542	1.70	1757.43	7.83	28.71	4.28	27.00	4.08
21173030	10.94	0.543	1.70	1763.25	7.83	28.23	3.14	35.13	4.02
21173034	10.94	0.544	1.70	1757.43	7.97	28.71	1.28	99.99	4.08
21173038	10.94	0.545	1.70	1751.61	7.97	29.19	13.57	99.99	4.08
21173042	10.95	0.546	1.70	1760.34	7.83	28.47	24.70	99.99	4.14
21173046	10.95	0.549	3.40	1751.61	7.83	29.19	35.84	99.99	4.14
21173050	10.95	0.550	1.70	1748.70	7.70	29.43	52.54	99.99	4.52
21173054	10.95	0.551	1.70	1754.52	7.83	28.95	61.82	99.99	4.14
21173058	10.95	0.552	1.70	1757.43	8.10	28.71	67.39	99.99	4.21
21173102	10.95	0.553	1.70	1751.61	8.10	29.19	52.54	99.99	4.14
21173106	10.95	0.554	1.70	1751.61	7.83	29.19	58.11	99.99	4.21
21173110	10.96	0.555	1.70	1745.79	7.70	29.68	33.98	99.99	4.21
21173114	10.96	0.556	1.70	1751.61	7.70	29.19	6.14	99.99	4.27
21173118	10.96	0.558	1.70	1748.70	7.97	29.43	1.28	99.99	4.21
21173122	10.96	0.560	3.40	1748.70	8.10	29.43	3.14	99.99	4.14
21173126	10.96	0.561	1.70	1748.70	8.10	29.43	0.57	99.99	4.08
21173130	10.96	0.563	3.40	1751.61	7.83	29.19	6.14	99.99	4.14
21173134	10.96	0.564	1.70	1745.79	7.83	29.68	24.70	99.99	4.14
21173138	10.97	0.567	3.40	1751.61	7.83	29.19	45.12	99.99	4.14
21173142	10.97	0.568	1.70	1754.52	8.10	28.95	63.68	99.99	4.21
21173146	10.97	0.569	1.70	1745.79	8.10	29.68	58.11	99.99	4.14
21173150	10.97	0.570	1.70	1754.52	7.83	28.95	33.98	99.99	4.08
21173154	10.97	0.572	3.40	1713.80	7.97	32.33	35.84	99.99	4.14
21173158	10.97	0.575	3.40	1751.61	8.10	29.19	45.12	99.99	4.14
21173202	10.98	0.576	1.70	1757.43	7.97	28.71	58.11	99.99	3.96
21173206	10.98	0.578	3.40	1751.61	7.83	29.19	45.12	99.99	4.21
21173210	10.98	0.579	1.70	1757.43	7.97	28.71	22.85	99.99	4.02
21173214	10.98	0.580	1.70	1754.52	7.97	28.95	11.71	99.99	4.08
21173218	10.98	0.583	3.40	1754.52	7.83	28.95	2.43	99.99	4.06
21173222	10.98	0.584	1.70	1745.79	7.97	29.68	1.28	99.99	4.02
21173226	10.98	0.585	1.70	1754.52	7.83	28.95	1.28	99.99	4.21
21173230	10.99	0.586	1.70	1757.43	8.10	28.71	0.57	99.99	4.08
21173234	10.99	0.588	3.40	1754.52	7.97	28.95	13.57	99.99	4.02
21173238	[illegible].99	0.589	1.70	1763.25	7.83	28.23	30.27	99.99	4.02

	TOTAL	CORE	PENETRAIN	ROTARY			INLET H2O	I. H2O	PAGE 5
21173242	10.99	0.590	1.70	1760.34	7.97	28.47	45.12	99.99	3.36
21173246	10.99	0.593	3.40	1763.25	8.10	28.23	59.97	99.99	4.02
21173252	10.99	0.595	2.27	1754.52	7.83	28.95	58.11	99.99	4.02
21173256	11.00	0.596	1.70	1763.25	8.10	28.23	45.12	99.99	3.69
21173300	11.00	0.598	3.40	1757.43	7.83	28.71	32.13	95.99	3.96
21173304	11.00	0.600	1.70	1760.34	7.97	28.47	11.71	18.15	4.08
21173308	11.00	0.601	1.70	1760.34	7.83	28.47	2.43	20.10	3.89
21173312	11.00	0.603	3.40	1757.43	7.97	28.71	3.14	32.12	3.96
21173316	11.00	0.604	1.70	1757.43	7.97	28.71	1.28	99.99	3.96
21173320	11.00	0.605	1.70	1757.43	7.97	28.71	0.57	27.92	3.96
21173324	11.01	0.606	1.70	1760.34	7.97	28.47	3.57	99.99	3.96
21173328	11.01	0.607	1.70	1760.34	7.97	28.47	8.00	99.99	3.96
21173332	11.01	0.610	3.40	1760.34	7.97	28.47	11.71	4.83	3.96
21173336	11.01	0.611	1.70	1763.25	7.97	28.23	17.28	99.99	3.89
21173340	11.01	0.612	1.70	1754.52	8.10	28.95	24.70	99.99	3.96
21173344	11.01	0.614	3.40	1757.43	7.97	28.71	35.84	99.99	4.06
21173348	11.02	0.615	1.70	1754.52	7.97	28.95	43.25	99.99	4.02
21173352	11.02	0.617	1.70	1745.79	7.83	29.68	52.54	99.99	4.27
21173356	11.02	0.618	1.70	1745.79	7.97	29.68	52.54	99.99	4.27
21173400	11.02	0.620	3.40	1748.70	7.97	29.43	65.54	99.99	4.14
21173404	11.02	0.621	1.70	1751.61	7.97	29.19	59.97	99.99	4.21
21173408	11.02	0.622	1.70	1754.52	7.83	28.95	61.82	99.99	4.14
21173412	11.02	0.623	1.70	1754.52	7.83	28.95	61.82	99.59	4.21
21173416	11.02	0.624	1.70	1754.52	7.97	28.95	58.11	99.99	4.14
21173420	11.03	0.627	3.40	1754.52	8.10	28.95	58.11	95.99	4.02
21173424	11.03	0.627	0.00	1763.25	7.83	28.23	61.82	99.99	3.96
21173428	11.03	0.628	1.70	1763.25	7.63	28.23	50.69	99.99	3.89
21173432	11.03	0.628	0.00	1766.15	8.10	27.98	43.26	99.99	3.83
21173436	11.03	0.628	0.00	1766.15	7.83	27.98	32.13	99.99	3.83
21173440	11.03	0.628	0.00	1769.06	7.97	27.74	20.99	99.99	3.69
21173444	11.03	0.628	0.00	1763.25	7.97	28.23	11.71	99.99	3.77
21173448	11.03	0.628	0.00	1771.97	8.10	27.50	6.14	99.99	3.83
21173452	11.03	0.628	0.00	1769.06	7.97	27.74	4.28	99.99	3.83
21173456	11.33	0.629	1.70	1559.65	-3.02	45.14	1.28	99.99	2.69

USER: EX9069 -AT SYSTEM

NR_T1.15.2

EX9069

NR_T1.15.2

LABEL: PRT032 -FORM

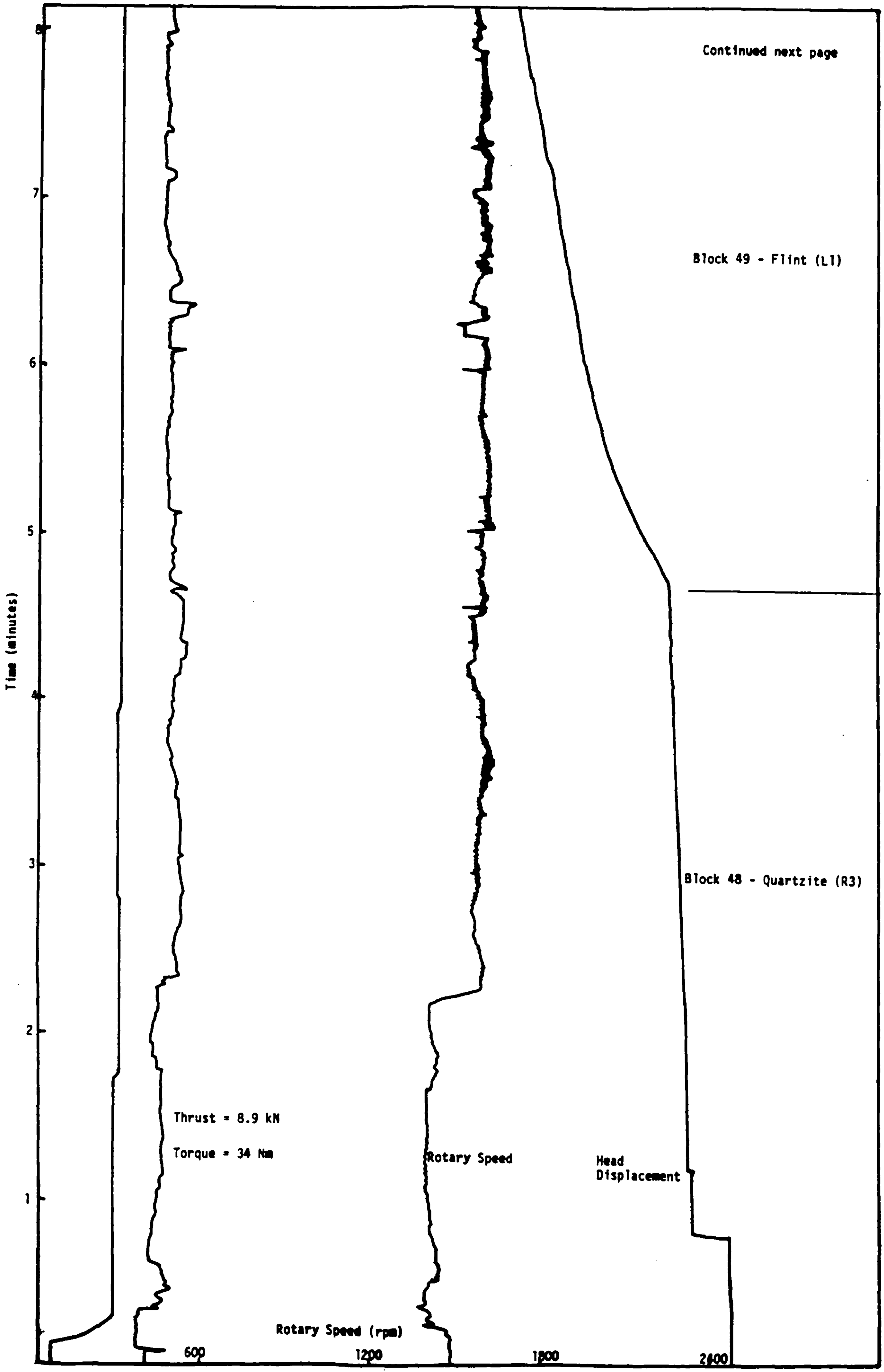
SPOOLED: 82-01-21.19:08
STARTED: 82-01-21.19:34, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

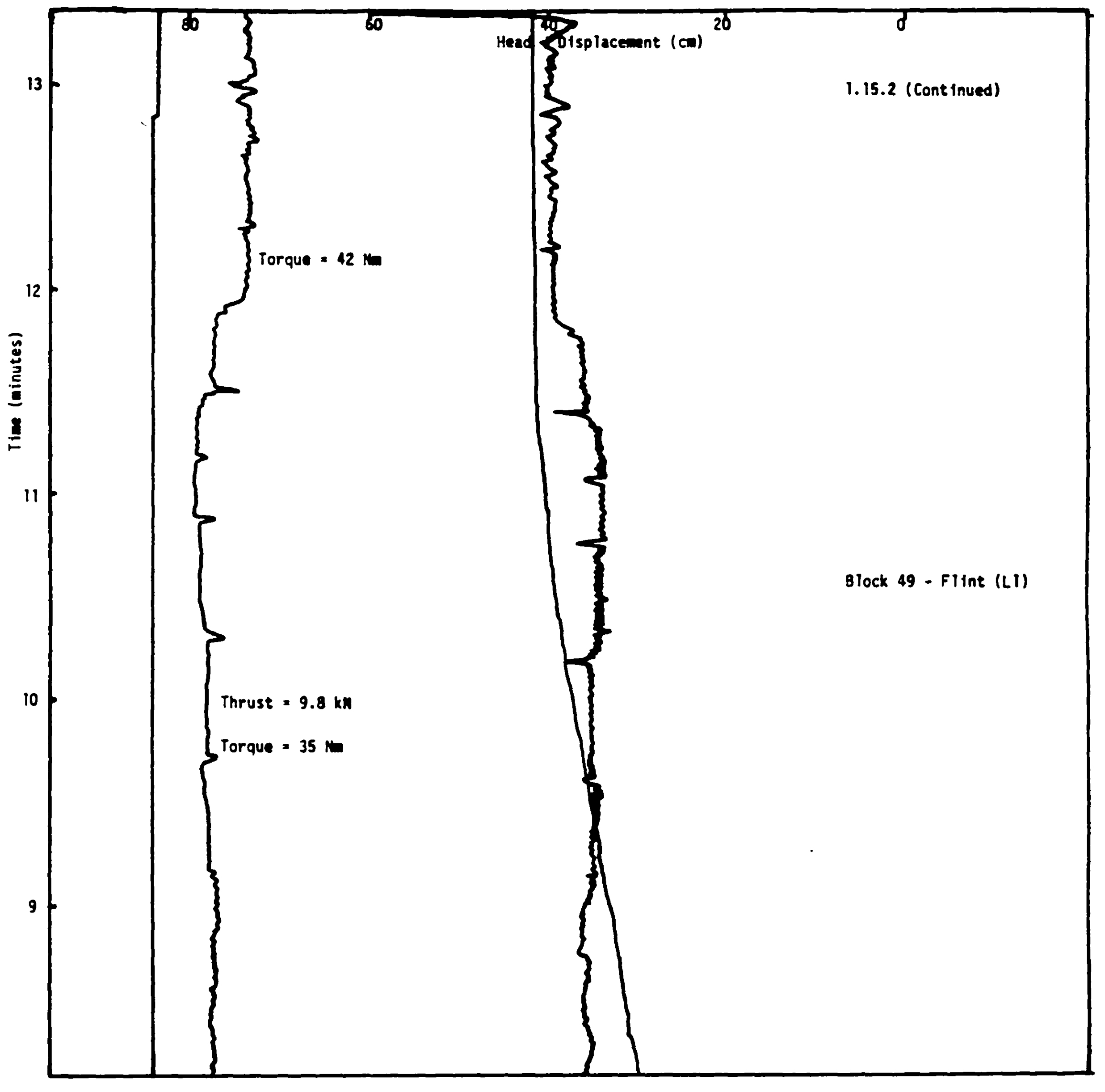
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
21174250	11.03	0.000	0.00	1655.63	9.01	38.52	39.55	99.99	5.22
21174254	11.03	0.000	0.00	1673.08	9.01	37.26	59.97	99.99	5.22
21174258	11.03	0.001	1.70	1678.90	8.88	36.72	61.82	99.99	5.03
21174302	11.03	0.002	1.70	1649.81	8.88	39.09	19.13	99.99	5.15
21174306	11.03	0.003	1.70	1641.09	9.14	39.80	4.28	99.99	5.34
21174310	11.03	0.005	1.70	1626.54	8.75	40.99	22.85	99.99	5.53
21174314	11.03	0.005	0.00	1635.27	8.88	40.28	50.69	99.99	5.47
21174318	11.04	0.006	1.70	1623.63	8.88	41.22	56.23	99.99	5.53
21174322	11.04	0.006	0.00	1786.51	9.01	27.96	65.54	99.99	6.79
21174326	11.04	0.007	1.70	1841.78	8.88	32.71	13.57	10.38	8.06
21174330	11.04	0.008	1.70	1838.87	9.01	32.92	2.43	35.67	7.99
21174334	11.04	0.009	1.70	1859.23	8.88	31.44	8.00	99.99	7.74
21174338	11.04	0.010	1.70	1838.87	9.01	32.92	39.55	99.99	8.12
21174342	11.04	0.010	0.00	1812.69	9.01	34.82	33.98	33.28	8.44
21174346	11.04	0.011	1.70	1821.42	9.14	34.19	67.39	99.99	8.31
21174350	11.04	0.012	1.70	1818.51	9.01	34.49	6.14	99.99	8.37
21174354	11.04	0.012	0.00	1803.97	8.75	35.45	4.28	99.99	8.50
21174358	11.04	0.014	1.70	1812.69	8.36	34.82	11.71	99.99	8.25
21174402	11.04	0.014	0.00	1830.14	7.97	33.55	26.56	99.99	8.12
21174406	11.04	0.014	0.00	1824.33	8.10	33.97	61.82	99.99	8.12
21174410	11.04	0.015	1.70	1818.51	7.97	34.40	52.54	99.99	8.18
21174414	11.04	0.015	0.00	1824.33	8.49	33.97	0.57	99.99	8.25
21174418	11.05	0.016	1.70	1835.96	8.23	33.13	2.43	99.99	8.06
21174422	11.05	0.016	0.00	1827.23	8.10	33.76	39.55	34.95	7.93
21174426	11.05	0.017	1.70	1833.05	8.10	33.34	35.84	99.99	7.99
21174430	11.05	0.017	0.00	1838.87	7.97	32.92	61.82	5.94	7.93
21174434	11.05	0.017	0.00	1850.50	8.36	32.07	11.71	30.71	7.99
21174438	11.05	0.019	3.40	1862.14	8.10	31.23	8.00	33.47	7.74
21174446	11.05	0.020	0.85	1885.41	7.97	29.54	35.84	99.99	7.49
21174450	11.05	0.020	0.00	1870.86	7.97	30.59	67.39	99.99	7.36
21174454	11.05	0.020	0.00	1862.14	8.36	31.23	48.83	99.99	7.68
21174458	11.05	0.020	0.00	1838.87	8.23	32.92	2.43	99.99	7.93
21174502	11.05	0.022	1.70	1827.23	9.14	33.76	1.28	99.99	7.74
21174506	11.05	0.023	1.70	1847.59	9.14	32.28	24.70	99.99	7.80
21174510	11.05	0.023	0.00	1827.23	9.53	33.76	54.49	99.99	8.12
21174514	11.05	0.024	1.70	1818.51	9.14	34.40	50.69	99.99	8.31
21174518	11.05	0.024	0.00	1795.24	9.14	36.09	28.41	33.09	8.56
21174522	11.05	0.024	0.00	1798.15	9.14	35.88	2.43	33.00	8.56
21174526	11.05	0.025	1.70	1830.14	9.27	33.55	13.57	29.67	8.12
21174530	11.06	0.026	1.70	1809.78	9.27	35.03	30.27	29.02	8.56
21174534	11.06	0.026	0.00	1815.60	9.14	34.61	45.12	99.99	8.06
21174538	11.06	0.026	0.00	1789.42	9.40	36.51	65.54	99.99	8.18
21174542	11.06	0.028	3.40	1771.97	9.14	37.79	39.55	99.99	7.49
21174546	11.06	0.034	8.50	1865.05	9.01	31.02	4.28	99.99	7.43
21174550	11.07	0.042	11.90	1830.14	9.14	33.55	6.14	22.99	7.66
21174554	11.08	0.051	13.60	1850.50	9.14	32.07	52.74	99.99	7.68
21174558	11.09	0.059	11.90	1859.23	9.14	31.44	61.82	99.99	7.93
21174602	11.10	0.067	11.90	1844.69	9.14	32.50	45.12	99.99	7.49
21174606	11.10	0.073	8.50	1847.59	9.27	32.28	24.70	99.99	7.68
21174610	11.11	0.080	11.90	1835.96	9.27	33.13	4.28	99.99	7.68
21174614	11.12	0.087	10.20	1859.23	9.27	31.44	8.00	99.99	7.56
21174618	11.12	0.093	8.50	1870.86	9.40	30.59	20.99	99.99	7.36
21174622	11.13	0.101	11.90	1844.69	9.14	32.50	48.83	99.99	7.43
21174626	11.14	0.107	8.50	1870.59	9.27	29.96	35.84	99.99	7.24

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
21174630	11.14	0.111	6.80	1882.50	9.14	29.75	32.13	99.99	7.17
21174634	11.15	0.116	6.80	1873.77	9.14	30.38	2.43	99.99	7.24
21174638	11.15	0.119	5.10	1870.86	9.14	30.59	0.57	99.99	7.43
21174642	11.15	0.124	6.80	1865.05	9.14	31.02	13.57	99.99	7.62
21174646	11.16	0.128	6.80	1841.78	9.27	32.71	41.41	99.99	7.80
21174650	11.16	0.131	5.10	1827.23	9.14	33.76	52.54	99.99	7.80
21174654	11.16	0.135	5.10	1841.78	9.14	32.71	54.40	99.99	7.74
21174658	11.17	0.138	5.10	1850.50	9.40	32.07	6.14	99.99	7.62
21174702	11.17	0.142	5.10	1833.05	9.14	33.34	4.28	99.99	7.55
21174706	11.17	0.145	5.10	1841.78	9.01	32.71	22.85	99.99	7.49
21174710	11.18	0.147	3.40	1853.41	9.27	31.86	65.54	99.99	7.36
21174714	11.18	0.151	5.10	1870.86	9.27	30.59	20.99	99.99	7.43
21174718	11.18	0.153	3.40	1865.05	9.40	31.02	59.97	8.45	7.49
21174722	11.19	0.156	5.10	1774.88	9.14	37.57	20.99	9.14	8.56
21174726	11.19	0.159	3.40	1870.86	9.27	30.59	4.28	99.99	8.56
21174730	11.19	0.162	5.10	1867.95	9.14	30.81	9.85	24.57	7.36
21174734	11.19	0.164	3.40	1812.69	9.27	34.82	41.41	99.99	8.18
21174738	11.20	0.168	5.10	1833.05	9.14	33.34	67.39	99.99	7.87
21174742	11.20	0.170	3.40	1865.05	9.01	31.02	56.25	99.99	7.55
21174746	11.20	0.173	5.10	1850.50	9.01	32.07	52.54	99.99	7.43
21174750	11.21	0.176	3.40	1873.77	9.14	30.38	8.00	99.99	7.30
21174754	11.21	0.179	5.10	1870.86	9.14	30.59	9.85	19.47	7.11
21174758	11.21	0.180	1.70	1870.86	9.01	30.59	41.41	23.53	7.30
21174802	11.21	0.184	5.10	1862.14	9.40	31.23	39.55	99.99	7.30
21174806	11.21	0.185	1.70	1862.14	9.27	31.23	43.25	99.99	7.43
21174810	11.22	0.187	3.40	1812.69	9.14	34.82	37.69	99.99	7.49
21174814	11.22	0.192	6.80	1876.68	9.27	30.17	8.00	99.99	7.80
21174818	11.23	0.196	6.80	1870.86	9.27	30.59	8.00	19.47	7.30
21174822	11.23	0.199	5.10	1888.31	9.80	29.33	20.99	99.99	7.17
21174826	11.23	0.202	3.40	1865.05	9.67	31.02	48.83	99.99	7.17
21174830	11.24	0.205	5.10	1859.23	9.27	31.44	67.39	99.99	7.43
21174834	11.24	0.207	3.40	1841.78	9.40	32.71	59.97	99.99	7.55
21174838	11.24	0.210	3.40	1867.95	9.67	30.31	13.57	99.99	7.43
21174842	11.24	0.212	3.40	1870.86	9.27	30.59	4.28	99.99	7.11
21174846	11.25	0.215	5.10	1867.95	9.14	30.81	15.42	99.99	7.11
21174850	11.25	0.218	3.40	1859.23	9.14	31.44	63.68	99.99	7.11
21174854	11.25	0.221	5.10	1853.41	9.14	31.86	46.97	99.99	7.36
21174858	11.25	0.224	5.10	1859.23	9.14	31.44	65.54	99.99	7.30
21174902	11.26	0.227	3.40	1856.32	9.67	31.65	20.99	99.99	7.30
21174906	11.26	0.228	1.70	1815.60	9.14	34.61	2.43	19.79	7.93
21174910	11.26	0.230	3.40	1841.78	9.40	32.71	17.28	99.99	7.55
21174914	11.26	0.233	5.10	1830.14	9.53	33.55	33.98	99.99	7.49
21174918	11.27	0.237	5.10	1821.42	9.27	34.19	45.12	99.99	7.68
21174922	11.27	0.240	5.10	1809.78	9.27	35.03	63.68	99.99	7.99
21174926	11.27	0.243	3.40	1827.23	9.40	33.76	45.12	99.99	7.68
21174934	11.28	0.247	3.40	1844.69	9.80	32.50	4.28	99.99	7.43
21174938	11.28	0.249	3.40	1824.33	9.53	33.97	32.13	99.99	7.74
21174942	11.28	0.253	5.10	1806.87	9.93	35.24	48.83	99.99	7.68
21174946	11.28	0.255	3.40	1801.06	9.27	35.67	63.68	99.99	7.93
21174954	11.29	0.260	3.40	1827.23	9.27	33.76	9.85	99.99	7.55
21174958	11.29	0.262	3.40	1827.23	9.93	33.76	2.43	99.99	7.68
21175002	11.30	0.265	5.10	1803.97	9.53	35.45	20.99	99.99	7.93
21175006	11.30	0.269	5.10	1795.24	9.27	36.09	61.82	99.99	7.87
21175010	11.30	0.271	3.40	1815.60	9.14	34.61	41.41	99.99	7.87
21175014	11.30	0.273	3.40	1835.96	9.53	33.13	67.39	99.99	7.68
21175018	11.31	0.275	3.40	1844.69	9.80	32.50	19.13	99.99	7.36
21175022	11.31	0.279	5.10	1844.69	9.27	32.50	6.14	99.99	7.30
21175026	11.31	0.281	3.40	1847.59	9.01	32.28	13.57	21.33	7.30

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 3
21175030	11.31	0.283	3.40	1833.05	9.14	33.34	41.41	99.99	7.43
21175034	11.32	0.286	3.40	1841.78	9.27	32.71	54.4[illegible]	99.99	7.30
21175038	11.32	0.289	5.10	1862.14	9.67	31.23	63.68	99.99	7.17
21175042	11.32	0.292	5.10	1859.23	9.27	31.44	19.13	99.99	7.05
21175046	11.32	0.295	3.40	1865.05	9.40	31.02	6.14	99.99	6.58
21175050	11.33	0.297	3.40	1853.41	9.01	31.86	11.71	99.99	7.80
21175054	11.33	0.299	3.40	1821.42	9.80	34.19	50.69	99.99	7.43
21175058	11.33	0.303	5.10	1847.59	9.53	32.28	32.13	99.99	7.43
21175102	11.34	0.306	5.10	1835.96	9.40	33.13	58.11	99.99	7.24
21175106	11.34	0.308	3.40	1838.87	9.40	32.92	20.99	12.52	7.36
21175110	11.34	0.311	3.40	1824.33	9.40	33.97	6.14	99.99	7.49
21175114	11.34	0.314	5.10	1830.14	9.53	33.55	15.42	99.99	7.36
21175118	11.35	0.316	3.40	1835.96	9.93	33.13	37.69	99.99	7.43
21175122	11.35	0.318	3.40	1830.14	9.27	33.55	63.68	99.99	7.24
21175126	11.35	0.321	3.40	1847.59	9.14	32.28	67.39	99.99	7.99
21175130	11.35	0.323	3.40	1856.32	9.14	31.65	22.85	99.99	6.96
21175134	11.36	0.325	3.40	1865.05	9.01	31.02	4.28	99.99	6.92
21175138	11.36	0.328	3.40	1870.86	9.53	30.59	13.57	99.99	6.92
21175142	11.36	0.330	3.40	1865.05	9.01	31.02	58.11	99.99	6.98
21175146	11.36	0.331	1.70	1870.86	9.53	30.59	33.98	99.99	6.92
21175150	11.36	0.332	1.70	1865.05	9.40	31.02	61.82	99.99	6.92
21175154	11.36	0.333	1.70	1862.14	9.27	31.23	19.13	18.15	6.86
21175158	11.36	0.334	1.70	1873.77	9.67	30.38	6.14	99.99	6.86
21175202	11.37	0.335	1.70	1879.59	9.93	29.96	11.71	99.99	6.79
21175206	11.37	0.337	1.70	1879.59	9.01	29.96	35.84	99.99	6.86
21175210	11.37	0.339	3.40	1876.68	9.27	30.17	65.54	99.99	6.79
21175214	11.37	0.340	1.70	1879.59	9.40	29.96	67.39	99.99	6.73
21175218	11.37	0.341	1.70	1885.41	9.93	29.54	24.70	99.99	7.24
21175222	11.37	0.342	1.70	1885.41	9.93	29.54	6.14	99.99	6.79
21175226	11.37	0.343	1.70	1865.05	9.27	31.02	8.00	99.99	6.86
21175230	11.38	0.346	3.40	1853.41	9.14	31.86	41.41	99.99	6.98
21175234	11.38	0.347	1.70	1833.05	9.80	33.34	39.55	99.99	7.30
21175238	11.38	0.347	0.00	1803.97	9.40	35.45	37.69	99.99	7.93
21175242	11.38	0.348	1.70	1809.78	9.01	35.03	33.98	99.99	7.36
21175246	11.38	0.348	0.00	1801.06	9.80	35.67	8.00	99.99	7.55
21175250	11.38	0.348	0.00	1815.60	8.88	34.61	6.14	99.99	7.43
21175254	11.38	0.348	0.00	1806.87	9.67	35.24	22.85	99.99	7.74
21175258	11.38	0.348	0.00	1795.24	9.53	36.09	63.68	99.99	7.62
21175302	11.38	0.348	0.00	1725.43	9.80	41.16	26.56	99.99	8.06
21175306	11.38	0.348	0.00	1707.98	10.06	42.43	59.97	99.99	8.81
21175310	11.38	0.349	1.70	1702.17	9.14	42.85	9.85	99.99	8.75
21175314	11.38	0.349	0.00	1693.44	9.27	43.48	6.14	99.99	8.81
21175318	11.38	0.349	0.00	1710.89	9.27	42.22	20.99	99.99	8.88
21175322	11.38	0.349	0.00	1713.80	9.01	42.00	39.55	99.99	8.50
21175326	11.38	0.349	0.00	1725.43	8.62	41.16	65.54	99.99	9.07
21175330	11.38	0.349	0.00	1693.44	9.01	43.48	65.54	99.99	8.81
21175334	11.38	0.349	0.00	1696.35	8.62	43.27	11.71	99.99	8.69
21175338	11.38	0.349	0.00	1731.25	9.01	40.74	2.43	99.99	8.56
21175342	211.38	0.350	0.00	1702.17	9.40	42.85	17.28	99.99	8.88
21175346	11.38	0.350	0.00	1684.71	9.27	44.12	56.25	99.99	8.81
21175350	11.38	0.350	0.00	1664.35	9.80	45.50	48.83	99.99	8.69
21175354	11.38	0.350	0.00	1713.80	9.53	42.00	52.54	99.99	9.00
21175358	11.38	0.350	0.00	1693.44	8.75	43.48	30.27	99.99	8.94
21175402	11.38	0.350	0.00	1734.16	10.06	40.53	6.14	99.99	8.37
21175406	11.38	0.350	0.00	1771.97	10.32	37.78	8.00	99.99	8.69
21175410	11.38	0.351	1.70	1690.53	9.80	43.69	32.13	99.99	9.13
21175414	11.38	0.351	0.00	1713.80	10.32	42.00	45.12	99.99	9.00
21175418	11.38	0.351	0.00	1702.17	10.19	42.85	63.68	99.99	8.94



RECORD OF TRRL DRILL RUN 1.15.2 (11.03 to 11.38 metres)


80
60
40
20
0
Head Displacement (cm)
1.15.2 (Continued)
13
12
11
10
9
Time (minutes)
Torque = 42 Nm
Thrust = 9.8 kN
Torque = 35 Nm
Block 49 - Flint (L1)

USER: EX9069 -AT SYSTEM

NF_T1.16.1

EX9069

NF_T1.16.1

LABEL: FRT033 -FORM

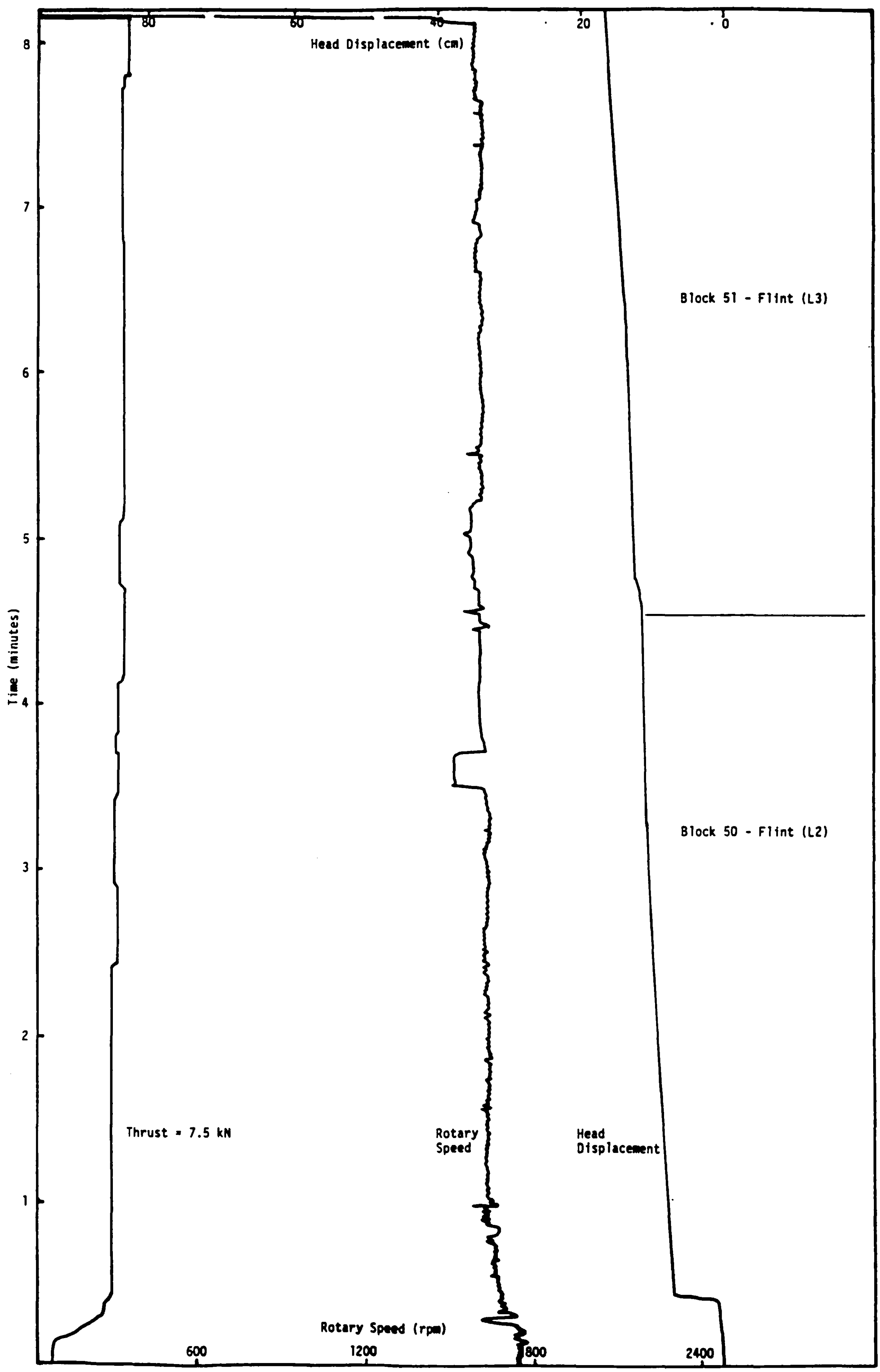
SPOOLED: 82-01-21.19:09
STARTED: 82-01-21.19:35, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
21182702	11.38	0.000	0.00	2015.36	-2.23	20.99	9.73	15.98	6.61
21182706	11.38	0.002	3.37	2021.20	1.17	19.67	30.17	99.99	6.68
21182710	11.38	0.003	1.70	2021.20	4.18	19.67	45.03	99.99	6.68
21182714	11.39	0.010	10.20	1852.34	6.27	31.94	63.68	99.99	6.48
21182718	11.45	0.067	65.00	1957.15	6.60	24.33	58.04	99.99	7.69
21182722	11.45	0.068	1.70	1942.59	7.32	25.38	56.04	99.99	7.68
21182726	11.45	0.070	3.40	1925.12	7.45	26.65	13.45	99.99	7.88
21182730	11.45	0.070	0.00	1898.92	7.44	28.56	4.28	99.99	7.99
21182734	11.45	0.071	1.70	1905.77	7.31	27.21	15.42	99.99	7.99
21182738	11.45	0.073	1.70	1916.39	7.98	27.29	37.63	99.99	8.00
21182742	11.45	0.074	1.70	1890.18	7.44	29.19	59.97	99.99	8.06
21182746	11.45	0.075	1.70	1922.21	7.59	26.86	24.69	99.99	8.45
21182750	11.46	0.076	1.70	1879.59	7.97	29.13	41.41	99.99	8.31
21182754	11.46	0.077	1.70	1867.95	7.83	29.99	24.70	99.99	8.50
21182758	11.46	0.078	1.70	1879.59	7.97	29.13	4.28	99.99	8.18
21182802	11.46	0.079	1.70	1879.59	7.31	29.13	1.28	99.99	8.50
21182806	11.46	0.079	0.00	1882.50	7.70	28.92	2.43	6.68	8.37
21182810	11.46	0.080	1.70	1876.68	7.31	29.35	17.28	99.99	8.50
21182814	11.46	0.082	1.70	1867.95	7.70	29.99	50.69	99.99	8.44
21182818	11.46	0.083	1.70	1876.68	7.97	29.35	65.54	99.99	8.31
21182822	11.46	0.084	1.70	1882.50	7.44	28.92	63.68	99.99	8.37
21182826	11.46	0.085	1.70	1882.50	8.10	28.92	37.69	99.99	8.31
21182830	11.47	0.086	1.70	1865.05	7.31	30.20	6.14	99.99	8.25
21182834	11.47	0.086	0.00	1881.45	7.97	29.82	1.28	99.99	8.37
21182838	11.47	0.087	1.70	1891.22	7.57	28.28	8.00	99.99	8.18
21182842	11.47	0.088	1.70	1891.22	7.57	28.28	33.98	99.99	8.12
21182846	11.47	0.090	1.70	1896.01	7.44	28.77	61.82	99.99	8.06
21182850	11.47	0.090	0.00	1891.22	7.44	28.28	26.56	99.99	8.12
21182854	11.47	0.091	1.70	1888.31	7.31	28.49	48.83	99.99	8.12
21182858	11.47	0.092	1.70	1887.27	8.10	29.40	35.84	99.99	8.12
21182902	11.47	0.092	0.00	1891.22	7.97	28.28	8.00	99.99	8.12
21182906	11.47	0.093	1.70	1882.50	7.97	28.92	1.28	99.99	8.31
21182910	11.47	0.093	0.00	1882.50	8.10	28.92	6.14	99.99	7.99
21182914	11.47	0.094	1.70	1879.59	8.10	29.13	24.70	99.99	8.31
21182918	11.48	0.095	1.70	1893.10	7.70	26.98	45.12	99.99	8.06
21182922	11.48	0.095	0.00	1888.31	8.75	28.49	67.39	99.99	8.31
21182926	11.48	0.096	1.70	1872.72	8.88	30.46	54.40	99.99	8.31
21182930	11.48	0.097	1.70	1872.72	8.23	30.46	41.41	99.99	8.18
21182934	11.48	0.097	0.00	1870.86	8.36	29.77	9.85	99.99	8.18
21182938	11.48	0.099	1.70	1879.59	8.49	29.13	2.43	13.46	8.18
21182942	11.48	0.099	0.00	1879.59	8.62	29.13	19.13	3.40	8.06
21182946	11.48	0.100	1.70	1885.41	8.23	28.71	30.27	99.99	8.12
21182950	11.48	0.100	0.00	1888.31	7.97	28.49	43.26	99.99	8.06
21182954	11.48	0.101	1.70	1888.31	7.97	28.49	65.54	99.99	7.99
21182958	11.48	0.101	0.00	1888.31	7.44	28.49	61.82	99.99	7.87
21183002	11.48	0.102	1.70	1867.95	7.57	29.99	26.56	99.99	8.18
21183006	11.48	0.102	0.00	1885.41	8.10	28.71	1.28	99.99	8.12
21183010	11.48	0.102	0.00	1902.86	7.83	27.42	1.28	99.99	7.80
21183014	11.48	0.103	1.70	1905.77	8.23	27.21	13.57	99.99	7.74
21183018	11.48	0.103	0.00	1885.41	7.44	28.71	48.83	99.99	7.87
21183022	11.48	0.103	0.00	1888.31	8.23	28.49	48.83	99.99	7.99
21183026	11.48	0.104	1.70	1878.54	8.62	30.04	33.98	99.99	7.99
21183030	11.48	0.104	0.00	1756.26	8.49	38.92	59.97	99.99	9.57
21183034	11.49	0.105	1.70	1753.34	9.14	39.13	15.42	99.99	9.57

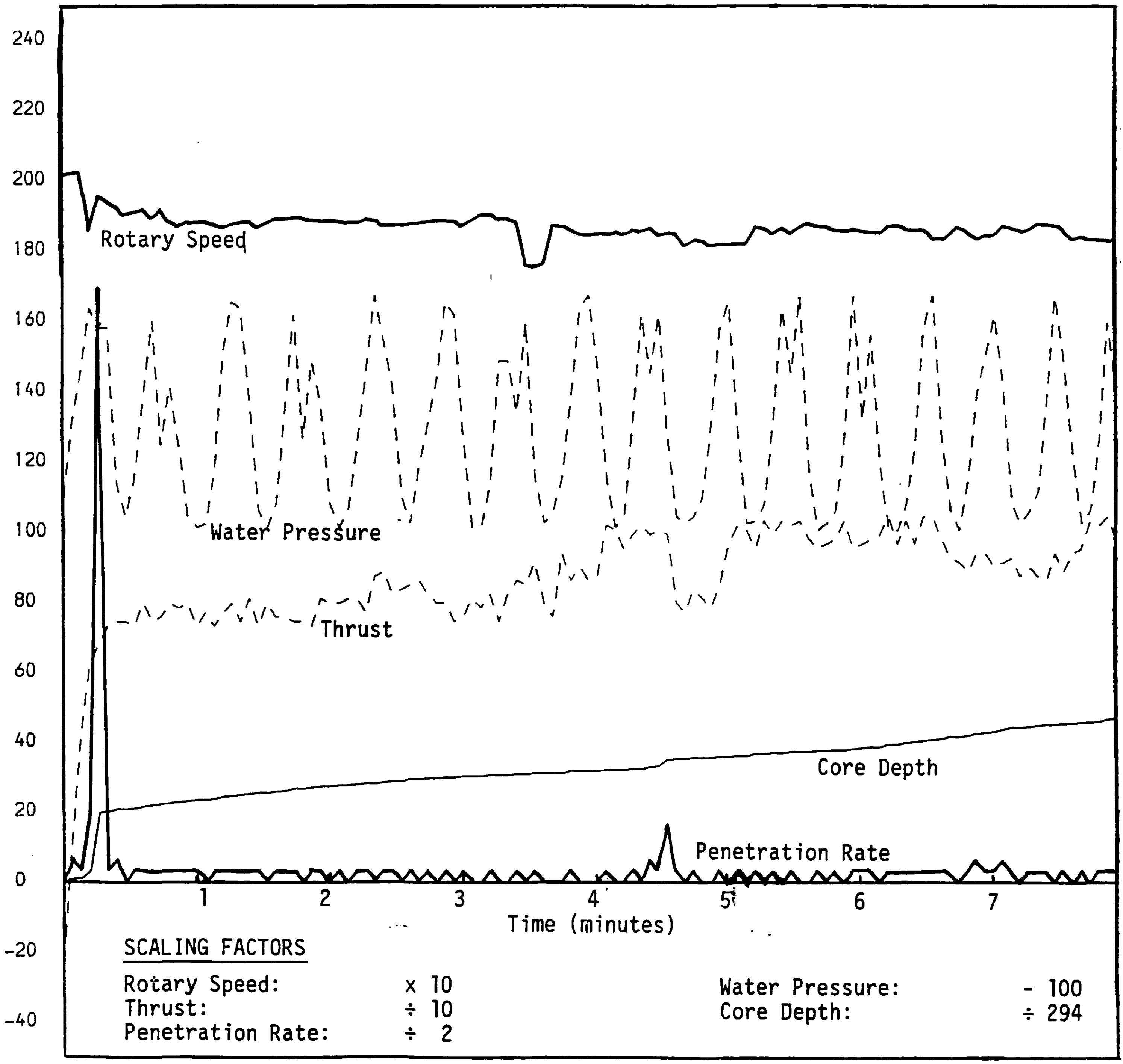
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
21183038	11.49	0.105	0.00	1764.99	7.97	38.29	2.43	99.99	9.63
21183042	11.49	0.105	0.00	1875.63	7.97	30.25	6.14	99.99	7.99
21183046	11.49	0.105	0.00	1872.72	9.40	30.46	15.42	99.99	8.15
21183050	11.49	0.107	1.70	1861.07	8.62	31.31	37.69	99.99	8.31
21183054	11.49	0.107	0.00	1846.51	9.01	32.36	63.68	99.99	8.37
21183058	11.49	0.107	0.00	1846.51	8.62	32.36	67.39	99.99	8.31
21183102	11.49	0.107	0.00	1849.42	8.75	32.15	46.97	99.99	8.31
21183106	11.49	0.108	1.70	1849.42	10.19	32.15	15.42	99.99	8.31
21183110	11.49	0.108	0.00	1855.25	10.06	31.73	1.28	99.99	8.25
21183114	11.49	0.108	0.00	1843.60	9.53	32.57	4.28	99.99	8.25
21183118	11.49	0.109	1.70	1861.07	9.93	31.31	30.27	99.99	8.12
21183122	11.49	0.109	0.00	1855.25	10.19	31.73	61.82	99.99	8.00
21183126	11.49	0.111	3.40	1863.98	9.93	31.09	45.12	26.32	7.68
21183130	11.49	0.112	1.70	1843.60	10.06	32.57	61.82	14.35	8.12
21183134	11.50	0.118	8.50	1853.41	9.93	31.05	26.56	99.99	8.12
21183138	11.50	0.119	1.70	1849.42	7.97	32.15	4.28	33.28	8.12
21183142	11.50	0.119	0.00	1815.60	7.70	33.83	2.43	30.51	8.44
21183146	11.50	0.120	1.70	1831.95	8.36	33.42	4.28	29.86	8.44
21183150	11.50	0.120	0.00	1829.04	8.10	33.63	9.85	33.47	8.37
21183154	11.50	0.120	0.00	1818.51	7.83	33.62	30.27	99.99	8.56
21183158	11.50	0.121	1.70	1820.31	8.49	34.27	58.11	99.99	8.62
21183202	11.50	0.121	0.00	1818.51	9.67	33.62	65.54	99.99	8.69
21183206	11.50	0.122	1.70	1818.51	10.19	33.62	28.41	99.99	8.37
21183210	11.50	0.122	0.00	1827.23	10.06	32.98	2.43	99.99	8.50
21183214	11.50	0.124	1.70	1870.86	9.53	29.77	3.14	99.99	7.93
21183218	11.50	0.124	0.00	1865.05	10.32	30.20	8.00	99.99	7.80
21183222	11.50	0.125	1.70	1847.59	9.93	31.48	32.13	99.99	7.80
21183226	11.50	0.125	0.00	1867.95	10.32	29.99	63.68	16.35	7.87
21183230	11.51	0.126	1.70	1847.59	10.19	31.48	45.12	99.99	8.12
21183234	11.51	0.126	0.00	1867.95	10.32	29.99	67.39	20.10	7.87
21183238	11.51	0.126	0.00	1881.45	9.80	29.82	17.28	27.46	7.68
21183242	11.51	0.127	1.70	1872.72	9.53	30.46	0.57	31.92	7.68
21183246	11.51	0.127	0.00	1869.80	9.67	30.67	2.43	27.92	7.68
21183250	11.51	0.128	1.70	1858.16	9.80	31.52	6.14	24.31	7.80
21183254	11.51	0.128	0.00	1858.16	10.32	31.52	26.56	14.35	7.93
21183258	11.51	0.129	1.70	1866.89	9.53	30.88	67.39	32.51	7.74
21183302	11.51	0.130	1.70	1858.16	9.67	31.52	32.13	99.99	7.87
21183306	11.51	0.131	1.70	1855.25	9.80	31.73	56.25	99.99	7.87
21183310	11.51	0.131	0.00	1852.34	9.93	31.94	19.13	27.23	7.99
21183314	11.51	0.133	1.70	1872.72	10.45	30.46	0.57	38.08	7.80
21183318	11.51	0.134	1.70	1875.63	9.67	30.25	0.57	30.71	7.62
21183322	11.51	0.135	1.70	1861.07	10.32	31.31	8.00	12.52	7.68
21183326	11.52	0.136	1.70	1863.98	9.67	31.09	24.70	99.99	7.80
21183330	11.52	0.137	1.70	1866.89	10.45	30.88	58.11	99.99	7.68
21183334	11.52	0.138	1.70	1831.95	10.45	33.42	67.39	99.99	7.74
21183338	11.52	0.139	1.70	1834.87	9.80	33.21	26.56	99.99	7.99
21183342	11.52	0.141	1.70	1849.42	9.27	32.15	6.14	99.99	8.18
21183346	11.52	0.141	0.00	1869.80	9.14	30.67	0.57	15.58	7.80
21183350	11.52	0.142	1.70	1852.34	6.88	31.94	15.42	30.30	7.74
21183354	11.52	0.144	3.40	1837.78	9.40	33.00	39.55	30.92	8.12
21183358	11.52	0.145	1.70	1849.42	9.40	32.15	50.69	27.69	7.99
21183402	11.53	0.146	1.70	1849.42	9.01	32.15	61.82	21.88	7.62
21183406	11.53	0.148	3.40	1875.63	9.14	30.25	41.41	99.99	7.55
21183410	11.53	0.150	1.70	1866.89	9.27	30.88	8.00	31.52	7.62
21183414	11.53	0.150	0.00	1855.25	8.75	31.73	2.43	34.22	7.74
21183418	11.53	0.151	1.70	1866.89	9.01	30.88	6.14	31.92	7.80
21183422	11.53	0.152	1.70	1878.54	8.75	30.04	11.71	30.09	7.36
21183426	11.53	0.153	1.70	1878.54	8.62	30.04	37.69	15.97	7.43

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
21183430	11.53	0.153	0.00	1872.72	9.40	30.46	67.34	95.94	7.49
21183434	11.53	0.154	1.70	1861.07	8.88	31.31	48.83	99.99	7.43
21183438	11.53	0.154	0.00	1834.87	9.45	33.21	20.99	99.99	7.99
21183442	11.54	0.155	1.70	1840.69	9.53	32.79	2.43	99.99	7.80
21183446	11.54	0.155	0.00	1837.78	10.32	33.00	6.14	25.81	7.80
21183450	11.54	0.156	1.70	1834.87	10.19	33.21	26.56	27.22	7.95
21183454	11.54	0.158	1.70	1829.04	10.45	33.63	59.97	99.99	7.87
21183458	11.54	0.159	1.70	1837.78	9.80	[illegible]	41.41	36.37	7.99



RECORD OF TRRL DRILL RUN 1.16.1 (11.38 to 11.54 metres)

COMPUTER RECORD OF TRRL DRILL RUN 1.16.1 (11.38 to 11.54 metres)



USER: EX9069 -AT SYSTEM

NR_T1.16.2

EX9069

NR_T1.16.2

LABEL: PRT034 -FORM

SPOOLED: 82-01-21.19:09
STARTED: 82-01-21.19:35, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
21183832	11.54	0.000	0.00	1854.17	-2.75	31.81	0.44	3.41	8.07
21183836	11.54	0.001	1.69	1912.46	-2.23	27.57	3.27	21.89	7.25
21183840	11.54	0.001	0.00	1915.37	-1.05	27.36	13.45	31.14	7.25
21183844	11.54	0.001	0.00	1900.80	3.01	28.42	54.32	30.11	7.18
21183848	11.54	0.002	1.70	1892.06	4.58	29.05	50.61	29.89	7.31
21183852	11.54	0.002	0.00	1886.23	6.41	29.48	30.17	29.47	7.43
21183856	11.54	0.003	1.70	1886.23	7.45	29.48	2.30	34.97	7.31
21183900	11.54	0.002	1.70	1887.27	7.57	28.58	0.57	31.32	7.55
21183904	11.54	0.003	1.70	1877.49	9.03	30.11	4.16	23.54	7.56
21183908	11.54	0.003	0.00	1869.80	8.88	29.86	30.27	30.51	7.55
21183912	11.54	0.003	0.00	1826.13	8.75	33.07	59.97	99.99	8.25
21183916	11.54	0.005	1.70	1898.92	8.62	27.72	45.12	99.99	7.62
21183920	11.54	0.005	0.00	1901.83	8.62	27.51	6.14	99.99	7.30
21183924	11.55	0.006	1.70	1907.65	9.14	27.08	6.14	28.71	7.43
21183928	11.55	0.006	0.00	1913.48	8.36	26.65	17.28	32.12	6.98
21183932	11.55	0.007	1.70	1913.48	8.49	26.65	26.56	28.14	7.17
21183936	11.55	0.007	0.00	1887.27	9.67	28.58	61.82	99.99	7.30
21183940	11.55	0.008	1.70	1855.25	9.80	30.93	46.97	99.99	7.62
21183944	11.55	0.009	1.70	1866.89	9.53	30.07	9.85	99.99	7.68
21183948	11.55	0.010	1.70	1878.54	10.06	29.22	0.57	99.99	7.55
21183952	11.55	0.011	1.70	1884.36	9.53	28.79	15.42	32.51	7.43
21183956	11.55	0.012	1.70	1896.01	9.53	27.94	54.40	33.28	7.36
21184000	11.55	0.014	1.70	1881.45	10.06	29.01	30.27	31.12	7.30
21184004	11.55	0.014	0.00	1878.54	9.80	29.22	46.97	30.51	7.43
21184008	11.55	0.015	1.70	1869.80	9.55	29.86	7.87	34.97	7.50
21184012	11.55	0.015	0.00	1866.89	9.68	30.07	1.42	41.61	7.56
21184016	11.55	0.015	0.00	1875.63	10.20	29.43	7.87	39.57	7.43
21184020	11.56	0.016	1.70	1861.07	10.07	30.50	45.03	31.54	7.62
21184024	11.56	0.016	0.00	1858.16	9.42	30.71	65.47	99.99	7.69
21184028	11.56	0.017	1.70	1858.16	10.33	30.71	33.88	99.99	7.69
21184032	11.56	0.017	0.00	1863.98	10.20	30.29	2.30	99.99	7.62
21184036	11.56	0.018	1.70	1866.89	10.20	30.07	4.16	23.27	7.56
21184040	11.56	0.018	0.00	1866.89	9.55	30.07	43.17	31.74	7.56
21184044	11.56	0.019	1.70	1861.07	5.55	30.50	43.17	30.31	7.56
21184048	11.56	0.019	0.00	1834.87	9.94	32.42	65.47	33.86	7.62
21184052	11.56	0.019	0.00	1852.34	10.20	31.14	11.59	34.05	7.62
21184056	11.56	0.019	0.00	1852.34	9.81	31.14	3.27	31.14	7.62
21184100	11.56	0.020	1.70	1846.51	10.33	31.57	7.87	99.99	7.69
21184104	11.56	0.020	0.00	1808.66	10.33	34.35	52.46	28.60	7.56
21184108	11.56	0.020	0.00	1764.99	10.33	37.55	63.61	99.99	8.32
21184112	11.56	0.020	0.00	1811.57	8.50	34.13	24.60	99.99	8.13
21184116	11.56	0.020	0.00	1858.16	9.29	30.71	6.02	9.14	7.56
21184120	11.56	0.022	1.70	1852.34	8.89	31.14	4.16	27.25	7.69
21184124	11.56	0.022	0.00	1843.60	8.89	31.78	30.17	25.83	7.69
21184128	11.56	0.022	0.00	1831.95	9.55	32.64	41.32	23.54	7.88
21184132	11.56	0.022	0.00	1823.22	10.33	33.28	52.46	36.22	7.81
21184136	11.56	0.023	1.70	1797.02	10.33	35.20	11.59	31.54	8.00
21184140	11.56	0.023	0.00	1820.31	10.33	33.49	0.44	37.42	8.13
21184144	11.56	0.023	0.00	1817.40	9.81	33.71	6.02	38.10	8.07
21184148	11.56	0.024	1.70	1823.22	9.42	33.28	37.60	30.31	8.07
21184152	11.56	0.024	0.00	1823.22	9.29	33.28	61.75	99.99	7.88
21184156	11.56	0.024	0.00	1829.04	10.60	32.85	33.88	99.99	8.00
21184200	11.56	0.024	0.00	1840.69	11.38	32.00	1.42	24.33	8.26
21184204	11.56	0.025	1.70	1834.87	10.99	32.42	7.87	99.99	7.75

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE
21184208	11.57	0.026	1.70	1817.40	10.73	33.71	35.74	99.99	8.[illegible]
21184212	11.57	0.027	1.70	1884.36	10.33	28.79	50.61	35.15	7.18
21184216	11.57	0.028	1.70	1814.49	10.46	33.92	59.90	35.66	7.12
21184220	11.57	0.029	1.70	1823.22	10.33	33.28	13.45	34.05	7.81
21184224	11.57	0.029	0.00	1814.49	10.86	33.92	1.42	37.59	7.88
21184228	11.57	0.031	1.70	1814.49	11.25	33.92	7.87	30.73	7.94
21184232	11.57	0.031	0.00	1808.66	10.99	34.35	67.33	35.66	8.07
21184236	11.57	0.031	0.00	1797.02	10.46	35.20	43.17	29.47	8.13
21184240	11.57	0.032	1.70	1764.99	10.46	37.55	30.17	37.42	8.45
21184244	11.57	0.032	0.00	1767.90	10.86	37.34	6.02	40.21	8.45
21184248	11.57	0.033	1.70	1831.95	10.99	32.64	2.30	28.38	8.00
21184252	11.57	0.034	1.70	1855.25	10.33	30.93	19.02	99.99	7.56
21184256	11.57	0.034	0.00	1834.87	11.25	32.42	67.33	99.99	7.69
21184300	11.57	0.034	0.00	1863.98	10.46	30.29	63.61	99.99	7.37
21184304	11.58	0.035	1.70	1869.80	11.12	29.86	11.59	99.99	7.37
21184308	11.58	0.035	0.00	1869.80	11.25	29.86	11.59	32.53	7.25
21184312	11.58	0.035	0.00	1869.80	10.33	29.86	26.45	37.59	7.25
21184316	11.58	0.035	0.00	1872.72	10.73	29.65	48.75	31.74	7.12
21184320	11.58	0.036	1.70	1846.51	11.25	31.37	67.33	30.11	7.50
21184324	11.58	0.036	0.00	1852.34	10.73	31.14	15.31	35.33	7.37
21184328	11.58	0.036	0.00	1802.84	10.60	34.78	0.44	36.04	8.00
21184332	11.58	0.036	0.00	1814.49	10.46	33.92	11.59	29.26	7.75
21184336	11.58	0.037	1.70	1814.49	11.25	33.92	26.45	22.73	7.75
21184340	11.58	0.037	0.00	1817.40	11.25	33.71	58.04	99.99	7.81
21184344	11.58	0.037	0.00	1811.57	11.38	34.13	32.03	99.99	7.88
21184348	11.58	0.039	1.70	1805.75	11.51	34.56	0.44	99.99	7.94
21184352	11.58	0.039	0.00	1808.66	12.04	34.35	9.73	99.99	7.68
21184356	11.58	0.039	0.00	1805.75	12.17	34.56	46.89	23.81	7.94
21184400	11.58	0.040	1.70	1802.84	11.90	34.78	26.45	35.33	7.94
21184404	11.58	0.041	1.70	1808.66	12.17	34.35	56.18	32.53	7.94
21184408	11.58	0.041	0.00	1820.31	11.51	33.49	11.59	34.97	7.81
21184412	11.58	0.043	3.40	1834.87	12.04	32.42	4.16	36.91	7.75
21184416	11.58	0.044	1.70	1829.04	11.51	32.85	20.88	27.93	7.68
21184420	11.59	0.045	1.70	1826.13	12.17	33.07	45.03	99.99	7.75
21184424	11.59	0.046	1.70	1829.04	12.04	32.85	56.18	99.99	7.88
21184428	11.59	0.046	0.00	1820.31	11.51	33.49	28.31	99.99	8.00
21184432	11.59	0.048	1.70	1805.75	11.38	34.56	9.73	22.45	8.07
21184436	11.59	0.049	1.70	1791.19	11.51	35.63	26.45	33.67	8.19
21184440	11.59	0.050	1.70	1791.19	11.90	35.63	58.04	20.42	8.26
21184444	11.59	0.051	1.70	1791.19	11.38	35.63	59.90	34.79	8.13
21184448	11.59	0.052	1.70	1770.81	12.17	37.13	13.45	30.73	8.63
21184452	11.59	0.054	3.40	1814.49	12.17	33.92	6.02	29.68	8.00
21184456	11.60	0.056	1.70	1829.04	12.17	32.85	15.31	21.02	7.75
21184500	11.60	0.057	1.70	1829.04	11.51	32.85	50.61	99.99	7.69
21184504	11.60	0.058	1.70	1820.31	11.64	33.49	65.47	99.99	7.81
21184508	11.60	0.058	0.00	1820.31	11.77	33.49	17.16	99.99	7.81
21184512	11.60	0.059	1.70	1811.57	11.51	34.13	7.87	99.99	7.94
21184516	11.60	0.061	3.40	1814.49	11.77	33.92	19.02	99.99	7.68
21184520	11.60	0.061	0.00	1820.31	11.38	33.49	63.61	99.99	7.94
21184524	11.60	0.062	1.70	1814.49	11.64	33.92	39.46	99.99	7.88
21184528	11.60	0.063	1.70	1814.49	11.77	33.92	22.74	34.05	7.81
21184532	11.60	0.065	1.70	1811.57	11.77	34.13	6.02	40.05	7.94
21184536	11.60	0.065	0.00	1805.75	12.17	34.56	17.16	99.99	7.68
21184540	11.61	0.066	1.70	1814.49	11.77	33.92	48.75	22.45	7.88
21184544	11.61	0.067	1.70	1814.49	12.43	33.92	26.45	19.48	7.81
21184548	11.61	0.068	1.70	1820.31	11.77	33.49	32.03	27.02	7.75
21184552	11.61	0.070	3.40	1831.95	11.38	32.64	2.30	37.08	7.62
21184556	11.61	0.070	0.00	1826.13	12.04	33.07	13.45	36.22	7.62

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
21184600	11.61	0.071	1.70	1823.22	12.30	33.28	37.60	29.68	7.69
21184604	11.61	0.073	1.70	1823.22	11.51	33.28	61.75	99.99	7.02
21184608	11.61	0.073	0.00	1826.13	12.30	33.07	32.03	99.99	7.62
21184612	11.61	0.073	0.00	1797.02	11.51	35.20	4.16	99.99	7.56
21184616	11.61	0.074	1.70	1677.65	12.30	43.96	20.88	99.99	9.56
21184620	11.61	0.074	0.00	1683.47	12.17	43.54	63.61	21.83	9.58
21184624	11.61	0.074	0.00	1692.29	12.43	42.93	33.83	31.54	9.46
21184628	11.61	0.075	1.70	1703.85	10.20	42.04	24.61	21.60	9.27
21184632	11.61	0.075	0.00	1709.67	10.33	41.61	2.30	33.49	9.08
21184636	11.61	0.075	0.00	1686.38	9.68	43.32	19.02	34.60	10.15
21184640	11.61	0.075	0.00	1715.49	10.60	41.19	45.[illegible]	15.19	9.52
21184644	11.61	0.075	0.00	1727.14	10.20	40.33	67.33	95.99	8.95
21184648	11.62	0.076	1.70	1703.85	12.30	42.04	17.16	99.99	9.46

USER: EX9069 -AT SYSTEM

NR_T1.17

LABEL: PRT035 -FORM

SPOOLED: 82-01-21.19:09
STARTED: 82-01-21.19:35, ON: PR0 BY: PR0

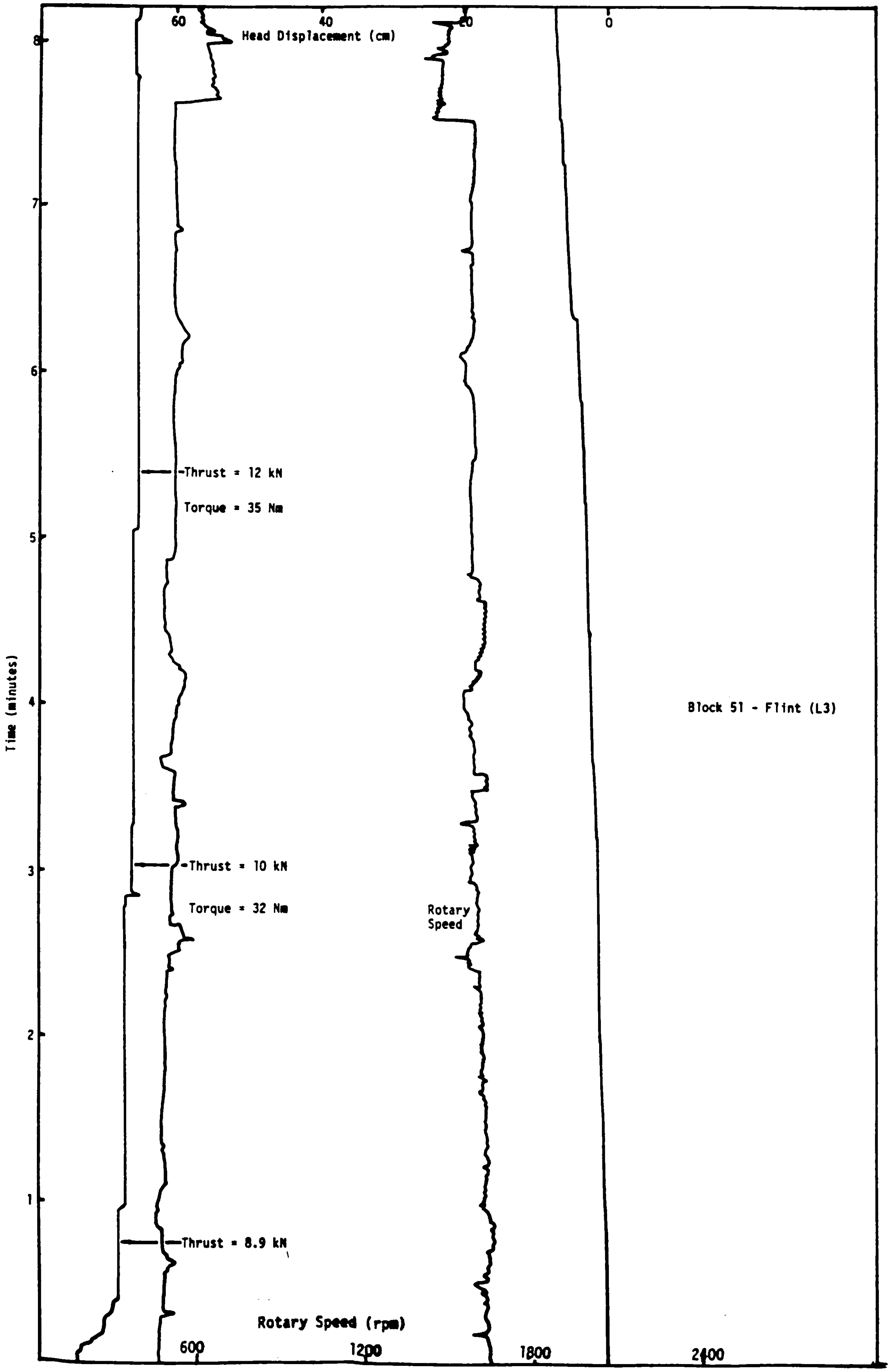
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

-584-

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
22145052	11.62	0.000	3.37	2056.14	7.57	17.11	8.00	99.99	9.51
22145056	11.62	0.002	3.37	2064.87	7.57	16.48	8.00	99.99	9.51
22145100	11.62	0.002	0.00	2064.87	7.57	16.48	8.00	99.99	9.63
22145104	11.62	0.003	1.70	2064.87	7.57	16.48	8.00	99.99	9.45
22145108	11.63	0.006	3.40	2059.05	7.57	16.90	8.00	99.99	9.32
22145112	11.63	0.006	0.00	2056.14	7.57	17.11	9.85	99.99	9.32
22145116	11.63	0.008	3.40	2053.23	7.57	17.32	8.00	99.99	9.38
22145120	11.63	0.008	0.00	2053.23	7.57	17.32	8.00	99.99	9.38
22145124	11.63	0.009	1.70	2050.32	7.57	17.54	9.85	99.99	9.26
22145128	11.63	0.010	1.70	2056.14	7.44	17.11	9.85	99.99	9.13
22145132	11.63	0.012	3.40	2064.01	7.45	16.56	7.87	3.40	9.14
22145136	11.63	0.012	0.00	2061.96	7.57	15.72	9.85	99.99	9.13
22145140	11.63	0.014	1.70	2056.14	7.57	16.15	11.71	99.99	9.13
22145144	11.63	0.015	1.70	2056.14	7.57	16.15	11.71	99.99	9.13
22145148	11.63	0.015	0.00	2053.23	7.57	16.36	11.71	99.99	9.13
22145152	11.64	0.016	1.70	2050.32	7.57	16.58	9.85	99.99	9.13
22145156	11.64	0.016	0.00	2047.41	7.57	16.79	9.85	99.99	9.13
22145200	11.64	0.016	0.00	2044.49	7.44	17.00	9.85	99.99	9.13
22145204	11.64	0.018	3.40	2046.52	7.45	17.83	2.30	3.40	9.08
22145208	11.64	0.017	1.70	2044.49	7.57	17.00	8.00	99.99	9.67
22145212	11.64	0.019	3.40	2043.61	7.45	18.04	7.87	3.40	9.08
22145216	11.64	0.019	0.00	2038.67	7.45	17.43	6.02	3.40	9.01
22145220	11.64	0.019	0.00	2034.86	7.32	18.68	4.16	3.40	9.14
22145224	11.64	0.018	1.70	2033.74	7.57	16.81	6.14	99.99	9.19
22145228	11.64	0.020	3.40	2034.86	7.45	18.68	4.16	3.40	9.08
22145232	11.64	0.019	1.70	2029.94	8.49	18.07	6.14	99.99	9.26
22145236	11.64	0.019	0.00	2024.11	8.49	18.50	6.14	99.99	9.26
22145240	11.64	0.022	3.40	2020.29	8.37	19.74	4.16	3.40	9.14
22145244	11.64	0.022	0.00	2023.21	8.37	19.53	4.16	3.40	9.14
22145248	11.64	0.022	0.00	2015.38	8.37	19.14	6.02	3.40	9.20
22145252	11.64	0.022	0.00	2015.38	8.37	19.14	6.02	3.40	9.14
22145256	11.64	0.023	1.70	2012.47	8.37	19.36	7.87	3.40	9.20
22145300	11.64	0.023	0.00	2017.38	8.37	19.95	7.87	3.40	9.14
22145304	11.64	0.023	0.00	2020.29	8.37	19.74	4.16	3.40	9.01
22145308	11.64	0.024	1.70	2012.47	8.37	19.36	6.02	3.40	9.01
22145312	11.64	0.024	0.00	2020.29	8.37	19.74	7.87	3.40	9.20
22145316	11.64	0.024	0.00	2023.21	8.37	19.53	4.16	3.40	9.20
22145320	11.64	0.024	0.00	2027.02	8.62	18.29	9.85	99.99	9.00
22145324	11.65	0.026	3.40	2026.12	8.37	19.31	7.87	3.40	8.89
22145328	11.65	0.026	0.00	2026.12	8.37	19.31	6.02	3.40	8.82
22145332	11.65	0.027	1.70	2034.86	8.37	18.58	6.02	3.40	8.82
22145336	11.65	0.027	0.00	2034.86	8.50	18.68	7.87	3.40	8.76
22145340	11.65	0.027	0.00	2035.76	8.62	17.55	8.00	99.99	8.75
22145344	11.65	0.029	3.40	1967.83	8.37	23.55	6.02	3.40	8.70
22145348	11.65	0.028	1.70	2022.11	8.49	17.67	8.00	99.99	8.69
22145352	11.65	0.031	3.40	2032.85	8.49	17.86	4.28	99.99	8.62
22145356	11.65	0.032	1.70	2026.12	8.37	19.31	6.02	3.40	8.70
22145400	11.65	0.032	0.00	2029.94	8.49	18.07	6.14	99.99	8.75
22145404	11.65	0.033	1.70	2027.02	8.37	18.29	6.02	3.40	8.63
22145408	11.65	0.034	1.70	2026.12	8.37	19.31	4.16	3.40	8.63
22145412	11.65	0.034	0.00	2017.38	8.37	19.95	4.16	3.40	8.70
22145416	11.66	0.035	1.70	2020.29	8.37	19.74	2.30	3.40	8.70
22145420	11.65	0.034	1.70	2019.20	8.49	17.89	6.14	99.99	8.75
22145424	11.66	0.035	1.70	2012.47	8.50	19.36	2.30	3.40	8.76

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
22145428	11.66	0.035	0.00	2009.56	8.50	19.57	2.30	3.40	8.82
22145432	11.66	0.035	0.00	1995.93	8.62	19.62	2.43	99.99	8.88
22145436	11.66	0.036	1.70	2006.64	8.37	19.78	0.44	3.40	8.82
22145440	11.66	0.036	0.00	2005.72	8.37	20.80	4.16	3.40	8.82
22145444	11.66	0.036	0.00	2003.73	8.37	20.00	2.30	3.40	8.82
22145448	11.66	0.037	1.70	2002.81	8.37	21.01	0.44	3.40	8.69
22145452	11.66	0.037	0.00	2003.73	8.37	20.00	0.44	3.40	8.82
22145456	11.66	0.037	0.00	2003.73	8.37	20.00	0.44	3.40	8.69
22145500	11.66	0.039	1.70	2005.72	8.37	20.80	0.44	3.40	8.82
22145504	11.66	0.039	0.00	2005.72	8.37	20.80	0.44	3.40	8.76
22145508	11.66	0.039	0.00	2005.72	8.37	20.80	1.42	3.40	8.76
22145512	11.66	0.039	0.00	2009.56	8.37	19.57	2.30	3.40	8.70
22145516	11.66	0.040	1.70	2003.73	8.37	20.00	0.44	3.40	8.63
22145520	11.66	0.039	1.70	2009.56	8.62	19.57	2.43	99.99	8.69
22145524	11.66	0.041	3.40	2008.64	8.37	20.56	0.44	3.40	8.57
22145528	11.66	0.041	0.00	2014.46	8.37	20.16	2.30	3.40	8.57
22145532	11.66	0.041	0.00	2014.46	8.37	20.16	2.30	3.40	8.57
22145536	11.66	0.041	0.00	2011.55	8.37	20.37	6.02	3.40	8.63
22145540	11.66	0.042	1.70	1991.15	8.50	21.86	4.16	3.40	8.57
22145544	11.66	0.041	1.70	2015.38	8.62	19.14	6.14	99.99	8.50
22145548	11.66	0.042	1.70	2005.72	8.50	20.80	4.16	3.40	8.51
22145552	11.66	0.043	1.70	2009.56	8.50	19.57	4.16	3.40	8.45
22145556	11.66	0.043	0.00	2003.73	8.37	20.00	4.16	3.40	8.51
22145600	11.66	0.043	0.00	2000.82	8.50	20.21	4.16	3.40	8.51
22145604	11.66	0.043	0.00	1999.89	8.37	21.22	6.02	3.40	8.57
22145608	11.66	0.043	0.00	2004.66	8.36	18.97	8.00	99.99	8.56
22145612	11.66	0.044	1.70	2003.73	8.50	20.00	4.16	3.40	8.51
22145616	11.67	0.045	1.70	2000.82	8.37	20.21	2.30	3.40	8.82
22145620	11.66	0.044	1.70	1984.30	8.62	20.48	6.14	99.99	8.56
22145624	11.67	0.046	3.40	2000.82	8.50	20.21	2.30	3.40	8.51
22145628	11.67	0.046	0.00	1999.89	8.37	21.22	4.16	3.40	8.45
22145632	11.67	0.046	0.00	1995.93	8.62	19.62	4.28	99.99	8.69
22145636	11.67	0.048	1.70	1986.26	8.37	21.28	0.44	3.40	8.57
22145640	11.67	0.049	1.70	1996.98	8.50	21.43	0.44	3.40	8.51
22145644	11.67	0.049	0.00	1997.91	8.37	20.43	0.44	3.40	8.51
22145648	11.67	0.050	1.70	1992.09	8.63	20.85	4.16	3.40	8.45
22145652	11.67	0.050	0.00	1982.41	8.37	22.49	2.30	3.40	8.51
22145656	11.67	0.049	1.70	1990.11	8.49	20.05	4.28	99.99	8.56
22145700	11.67	0.051	3.40	1989.18	8.24	21.07	0.44	3.40	8.57
22145704	11.67	0.050	1.70	1987.21	8.49	20.26	8.00	99.99	8.62
22145708	11.67	0.051	1.70	1987.21	8.49	20.26	4.28	99.99	8.56
22145712	11.67	0.052	1.70	1983.35	8.24	21.49	2.30	3.40	8.57
22145716	11.67	0.051	1.70	1981.39	8.49	20.69	6.14	99.99	8.62
22145720	11.67	0.053	3.40	1982.41	8.49	22.49	4.28	3.40	8.56
22145724	11.67	0.052	1.70	1978.48	8.34	20.91	4.41	99.99	8.61
22145728	11.67	0.052	0.00	1984.30	8.47	20.48	6.27	99.99	8.55
22145732	11.67	0.053	1.70	1990.11	8.47	20.05	4.41	99.99	8.49
22145736	11.67	0.053	0.00	1987.21	8.61	20.26	6.27	99.99	8.43
22145740	11.67	0.054	1.70	1977.53	8.49	21.92	2.43	3.40	8.50
22145744	11.67	0.054	0.00	1978.48	8.47	20.91	6.27	99.99	8.61
22145748	11.68	0.056	1.70	1974.62	8.62	22.14	2.43	3.40	8.50
22145752	11.68	0.056	0.00	1977.53	8.36	21.92	4.28	3.40	8.50
22145756	11.68	0.056	0.00	1974.62	8.36	22.14	4.28	3.40	8.50
22145800	11.68	0.057	1.70	1980.44	8.36	21.71	4.28	3.40	8.56
22145804	11.68	0.056	1.70	1981.39	8.61	20.69	6.27	99.99	8.55
22145808	11.68	0.057	1.70	1980.44	8.36	21.71	4.28	3.40	8.44
22145812	11.68	0.057	0.00	1983.35	8.23	21.49	4.28	3.40	8.31
22145816	11.68	0.058	1.70	1986.26	8.49	21.28	6.14	3.40	8.31

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
22145820	11.68	0.058	0.00	1986.26	8.62	21.28	4.28	3.40	8.18
22145824	11.68	0.058	0.00	1986.26	8.49	21.28	2.43	3.40	8.25
22145828	11.68	0.058	0.00	1977.53	8.62	21.92	4.28	3.40	8.18
22145832	11.68	0.058	0.00	1990.11	8.74	20.05	6.27	99.99	8.30
22145836	11.68	0.058	0.00	1990.11	8.47	20.05	6.27	99.99	8.30
22145840	11.68	0.060	3.40	1965.88	8.49	22.78	2.43	3.40	8.25
22145844	11.68	0.060	0.00	1968.79	8.36	22.56	4.28	3.40	8.37
22145848	11.68	0.062	3.40	1986.26	8.23	21.28	4.28	3.40	8.06
22145852	11.69	0.063	1.70	1989.18	8.36	21.07	2.43	3.40	8.18
22145856	11.68	0.065	1.70	1992.09	8.62	20.85	2.43	3.40	8.12
22145900	11.69	0.066	1.70	1995.00	8.36	20.64	4.28	3.40	7.99
22145904	11.69	0.066	0.00	1989.18	8.23	21.07	4.28	3.40	8.12
22145908	11.68	0.065	1.70	1990.11	8.47	20.05	6.27	99.99	8.11
22145912	11.69	0.067	3.40	1980.44	8.36	21.71	6.14	3.40	8.12
22145916	11.69	0.067	0.00	1986.26	8.49	21.28	2.43	3.40	8.12
22145920	11.69	0.068	1.70	1989.18	8.36	21.07	6.14	3.40	8.25
22145924	11.69	0.069	1.70	1983.35	8.49	21.49	2.43	3.40	8.12
22145928	11.69	0.070	1.70	1986.26	8.36	21.28	4.28	3.40	8.37
22145932	11.69	0.070	0.00	1971.71	8.49	22.35	4.26	3.40	8.25
22145936	11.69	0.071	1.70	1977.53	8.62	21.92	2.43	3.40	8.25
22145940	11.69	0.071	0.00	1968.79	8.36	22.56	2.43	3.40	8.12
22145944	11.69	0.073	1.70	1974.62	8.62	22.14	4.28	3.40	8.06
22145948	11.69	0.073	0.00	1968.79	8.49	22.56	4.28	3.40	8.18
22145952	11.69	0.074	1.70	1957.15	8.62	23.42	4.28	3.40	8.06
22145956	11.69	0.075	1.70	1974.62	8.62	22.14	8.00	3.40	8.12
22150000	11.69	0.075	0.00	1972.66	8.36	21.34	4.28	3.40	8.18
22150004	11.69	0.075	0.00	1965.88	8.62	22.78	4.28	3.40	8.18
22150008	11.70	0.076	1.70	1974.62	8.36	22.14	4.28	3.40	8.12
22150012	11.70	0.077	1.70	1971.71	8.36	22.35	4.28	3.40	8.18
22150016	11.70	0.077	0.00	1939.68	8.49	24.70	4.28	3.40	8.18
22150020	11.70	0.076	1.70	1972.66	8.74	21.34	6.27	99.99	8.11
22150024	11.70	0.078	3.40	1969.75	8.36	21.56	2.43	3.40	8.06
22150028	11.70	0.078	0.00	1972.66	8.47	21.34	6.27	99.99	8.11
22150032	11.70	0.079	1.70	1974.62	8.36	22.14	4.28	3.40	8.12
22150036	11.70	0.080	1.70	759.79	7.97	111.35	4.28	3.40	8.12



RECORD OF TRRL DRILL RUN 1.17 (11.62 to 11.70 metres)

USER: EX9869 -AT SYSTEM

NR_T2.2.1

EX9869

NR_T2.2.1

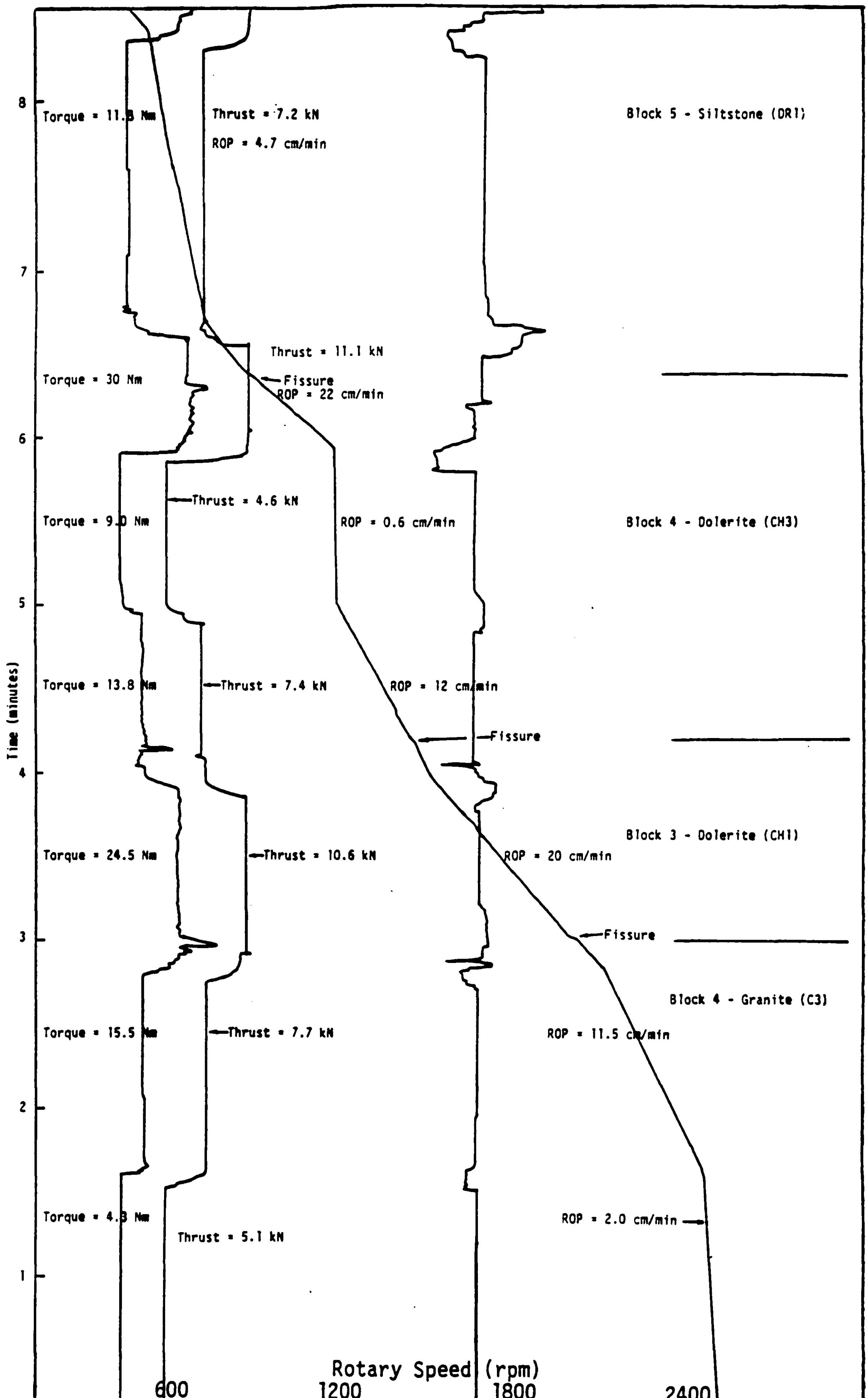
LABEL: PRT003 -FORM

SPOOLED: 82-01-25.17:40
STARTED: 82-01-25.17:43, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
19143340	0.21	0.000	0.00	1601.44	-3.02	5.01	93.38	41.28	2.57
19143345	0.21	0.001	1.35	1598.54	-1.97	5.38	74.82	41.90	2.57
19143350	0.21	0.001	0.00	1601.44	0.91	5.01	87.81	40.35	2.57
19143355	0.21	0.003	2.70	1592.74	5.22	6.13	71.10	38.90	2.63
19143400	0.21	0.004	1.35	1598.54	5.09	5.38	72.96	27.00	2.69
19143405	0.22	0.007	2.70	1595.64	5.09	5.76	84.10	3.40	2.69
19143410	0.22	0.009	2.70	1598.54	5.09	5.38	80.38	19.79	2.69
19143415	0.22	0.010	1.35	1601.44	5.09	5.01	84.10	3.40	2.69
19143420	0.22	0.011	1.35	1604.34	4.96	4.64	87.81	28.81	2.69
19143425	0.22	0.013	2.70	1607.24	4.96	4.27	91.52	17.80	2.69
19143430	0.22	0.015	1.35	1607.24	5.22	4.27	76.67	13.91	2.63
19143435	0.23	0.016	1.35	1607.24	5.22	4.27	67.39	18.49	2.69
19143440	0.23	0.017	1.35	1607.24	5.22	4.27	76.67	7.70	2.63
19143445	0.23	0.018	1.35	1607.24	5.22	4.27	95.23	3.40	2.63
19143450	0.23	0.019	1.35	1598.54	5.22	5.38	76.67	3.40	2.63
19143455	0.23	0.020	1.35	1604.34	5.09	4.64	85.95	22.16	2.63
19143500	0.23	0.021	1.35	1607.24	5.09	4.27	71.10	32.70	2.63
19143505	0.23	0.022	1.35	1607.24	5.09	4.27	67.39	24.57	2.63
19143510	0.23	0.024	1.35	1604.34	5.09	10.26	78.53	9.14	2.57
19143515	0.23	0.025	1.35	1610.14	5.09	9.55	91.52	3.40	2.63
19143520	0.24	0.029	5.40	1557.94	7.83	15.88	84.10	3.40	3.89
19143525	0.25	0.039	12.14	1560.84	7.83	15.53	69.25	3.40	4.02
19143530	0.26	0.048	10.79	1598.54	7.82	15.97	74.87	3.40	4.14
19143535	0.27	0.057	10.79	1598.54	7.82	15.97	89.71	3.40	4.27
19143540	0.28	0.067	12.14	1604.34	7.82	15.30	87.85	3.40	4.33
19143545	0.29	0.078	12.14	1607.24	7.69	14.97	89.71	3.40	4.33
19143550	0.30	0.087	10.79	1607.24	7.69	14.97	71.16	3.40	4.20
19143555	0.31	0.097	12.14	1603.02	7.70	12.73	65.54	4.83	4.14
19143600	0.32	0.106	10.79	1605.92	7.70	12.38	80.38	4.83	4.08
19143605	0.32	0.115	10.79	1605.92	7.70	12.38	87.81	4.83	4.14
19143610	0.33	0.125	12.14	1601.44	7.70	10.61	74.82	4.83	4.21
19143615	0.34	0.134	10.79	1604.34	7.57	10.26	74.82	4.83	4.14
19143620	0.35	0.144	12.14	1598.54	7.57	10.96	89.66	4.83	4.08
19143625	0.36	0.154	12.14	1610.14	7.70	9.55	87.81	4.83	4.02
19143630	0.37	0.162	9.44	1604.34	7.70	10.26	69.25	4.83	4.08
19143635	0.39	0.177	17.54	1523.14	10.45	20.09	67.39	4.83	5.72
19143640	0.40	0.195	21.59	1630.44	10.84	28.72	80.38	4.83	6.73
19143645	0.43	0.220	31.03	1633.34	10.45	24.87	80.38	4.83	7.05
19143650	0.45	0.236	18.89	1633.34	10.58	24.87	91.52	4.83	6.61
19143655	0.46	0.252	18.89	1639.14	10.71	24.29	69.25	4.83	6.79
19143700	0.48	0.269	20.24	1601.44	10.71	28.05	58.11	4.83	6.54
19143705	0.50	0.286	20.24	1584.04	10.71	26.11	63.68	4.83	6.48
19143710	0.51	0.301	18.89	1581.14	10.58	26.41	89.66	4.83	6.35
19143715	0.53	0.318	20.24	1586.94	10.71	25.81	85.95	4.83	6.42
19143720	0.54	0.334	18.89	1598.54	10.58	24.60	78.53	4.83	6.48
19143725	0.56	0.350	18.89	1578.24	10.58	26.72	78.53	4.83	6.42
19143730	0.58	0.367	20.24	1572.44	10.58	27.32	89.66	4.83	6.54
19143735	0.59	0.383	20.24	1586.94	10.71	25.81	89.66	4.83	6.54
19143740	0.61	0.400	20.24	1595.64	10.19	24.90	82.24	4.83	6.73
19143745	0.62	0.412	13.49	1673.94	7.44	16.73	85.95	4.83	4.46
19143750	0.63	0.415	9.44	1584.04	7.44	12.72	80.38	4.83	3.83
19143755	0.64	0.433	16.19	1557.94	7.44	15.88	80.38	4.83	4.90
19143800	0.65	0.444	13.49	1581.14	7.44	13.07	87.81	4.83	4.02
19143805	0.66	0.453	10.79	1584.04	7.44	12.72	84.10	4.83	3.89

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
19143810	0.67	0.462	10.79	1584.04	7.44	12.72	65.54	4.83	3.83
19143815	0.68	0.472	12.14	1575.34	7.31	13.77	59.97	4.83	3.96
19143820	0.69	0.483	13.49	1575.34	7.44	13.77	76.67	13.00	4.02
19143825	0.70	0.494	12.14	1572.44	7.44	14.12	74.82	13.00	4.02
19143830	0.71	0.505	13.49	1581.14	7.31	13.07	80.38	4.83	4.02
19143835	0.73	0.516	13.49	1575.34	7.44	13.77	74.82	4.83	3.83
19143840	0.74	0.526	12.14	1575.34	7.31	13.77	91.52	4.83	3.89
19143845	0.74	0.534	9.44	1618.84	5.74	8.50	78.53	4.83	2.76
19143850	0.75	0.535	1.35	1630.44	4.57	7.09	69.25	4.83	2.57
19143855	0.75	0.535	0.00	1592.74	4.57	6.13	80.36	4.83	2.31
19143900	0.75	0.536	1.35	1563.74	4.57	9.84	93.38	4.83	2.19
19143905	0.75	0.536	0.00	1566.64	4.57	9.47	76.67	4.83	2.13
19143910	0.75	0.537	1.35	1566.64	4.57	9.47	72.96	4.83	2.13
19143915	0.75	0.537	0.00	1563.74	4.57	9.84	85.95	4.83	2.13
19143920	0.75	0.537	0.00	1572.44	4.57	8.73	82.24	4.83	2.13
19143925	0.75	0.539	1.35	1575.34	4.57	8.35	71.10	4.83	2.19
19143930	0.75	0.539	0.00	1578.24	4.57	7.98	63.68	4.83	2.19
19143935	0.75	0.539	0.00	1578.24	4.57	7.98	74.82	4.83	2.19
19143940	0.75	0.540	1.35	1581.14	4.44	7.61	72.96	5.78	2.19
19143945	0.76	0.552	14.84	1441.95	11.23	25.43	82.24	4.83	5.85
19143950	0.78	0.572	24.29	1497.05	11.10	31.60	93.38	4.83	6.42
19143955	0.81	0.596	28.33	1566.64	11.23	31.52	85.95	4.83	7.17
19144000	0.83	0.621	29.68	1584.04	11.23	29.79	76.67	4.83	7.17
19144005	0.85	0.644	28.33	1555.04	11.10	32.68	63.68	4.83	8.06
19144010	0.87	0.664	24.29	1595.64	11.10	28.63	67.39	4.83	7.11
19144015	0.85	0.681	20.24	1595.64	11.10	28.63	84.10	4.83	7.24
19144020	0.91	0.699	21.59	1592.74	11.10	28.92	84.10	4.83	7.11
19144025	0.92	0.714	17.54	1723.23	8.10	15.90	82.24	4.83	5.03
19144030	0.93	0.720	6.75	1763.83	7.31	11.85	87.81	4.83	3.96
19144035	0.93	0.723	4.05	1650.74	7.18	9.97	59.97	4.83	3.20
19144040	0.94	0.727	5.40	1607.24	7.18	9.91	69.25	4.83	3.01
19144045	0.94	0.731	4.05	1592.74	7.18	11.66	74.82	4.83	2.95
19144050	0.95	0.735	5.40	1589.84	7.18	12.01	84.10	4.83	3.01
19144055	0.95	0.740	5.40	1586.94	7.18	12.36	72.96	4.83	3.14
19144100	0.95	0.744	5.40	1589.84	7.18	12.01	80.38	4.83	3.07
19144105	0.96	0.749	5.40	1586.94	7.18	12.36	89.66	4.83	3.14
19144110	0.96	0.752	4.05	1592.74	7.18	11.66	82.24	4.83	3.07
19144115	0.97	0.757	5.40	1589.84	7.18	12.01	72.96	4.83	3.01
19144120	0.97	0.761	5.40	1589.84	7.18	12.01	63.68	4.83	2.95
19144125	0.97	0.765	4.05	1595.64	7.18	11.31	72.96	4.83	2.82
19144130	0.98	0.768	4.05	1595.64	7.18	11.31	76.67	4.83	2.76
19144135	0.98	0.771	4.05	1595.64	7.18	11.31	85.95	4.83	2.76
19144140	0.98	0.775	4.05	1595.64	7.18	11.31	87.81	4.83	2.69
19144145	0.99	0.778	4.05	1589.84	7.18	12.01	67.39	4.83	2.82
19144150	0.99	0.783	5.40	1589.84	7.18	12.01	58.11	4.83	2.88
19144155	1.00	0.786	4.05	1589.84	7.18	12.01	67.39	4.83	2.82
19144200	1.00	0.790	5.40	1586.94	7.18	12.36	91.52	4.83	2.88
19144205	1.00	0.794	4.05	1586.94	7.18	12.36	84.10	4.83	2.95
19144210	1.01	0.798	5.40	1508.65	9.93	21.85	76.67	4.83	4.14
19144215	1.03	0.815	20.24	1470.95	11.10	26.42	76.67	4.83	5.72
19144220	1.04	0.832	20.24	1537.64	11.10	34.42	89.66	4.83	6.67
19144225	1.06	0.851	22.94	1613.04	11.10	30.38	85.95	4.83	7.68


Torque = 11.8 Nm
Thrust = 7.2 kN
ROP = 4.7 cm/min
Block 5 - Siltstone (DR1)
Thrust = 11.1 kN
Torque = 30 Nm
Fissure
ROP = 22 cm/min
Thrust = 4.6 kN
Torque = 9.0 Nm
ROP = 0.6 cm/min
Block 4 - Dolerite (CH3)
Torque = 13.8 Nm
Thrust = 7.4 kN
ROP = 12 cm/min
Fissure
Block 3 - Dolerite (CH1)
Torque = 24.5 Nm
Thrust = 10.6 kN
ROP = 20 cm/min
Fissure
Block 4 - Granite (C3)
Torque = 15.5 Nm
Thrust = 7.7 kN
ROP = 11.5 cm/min
Torque = 4.8 Nm
Thrust = 5.1 kN
ROP = 2.0 cm/min
Time (minutes)
1
2
3
4
5
6
7
8
Rotary Speed (rpm)
600
1200
1800
2400

USER: EX9869 -AT SYSTEM

NR_T2.2.2

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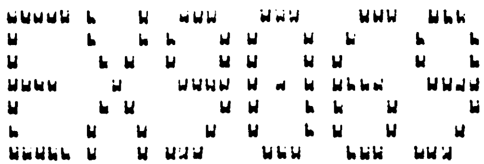

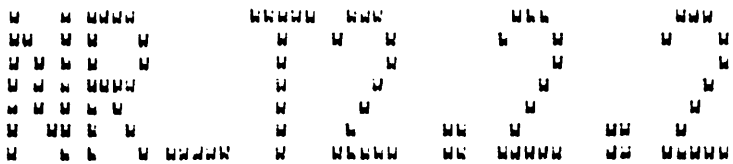

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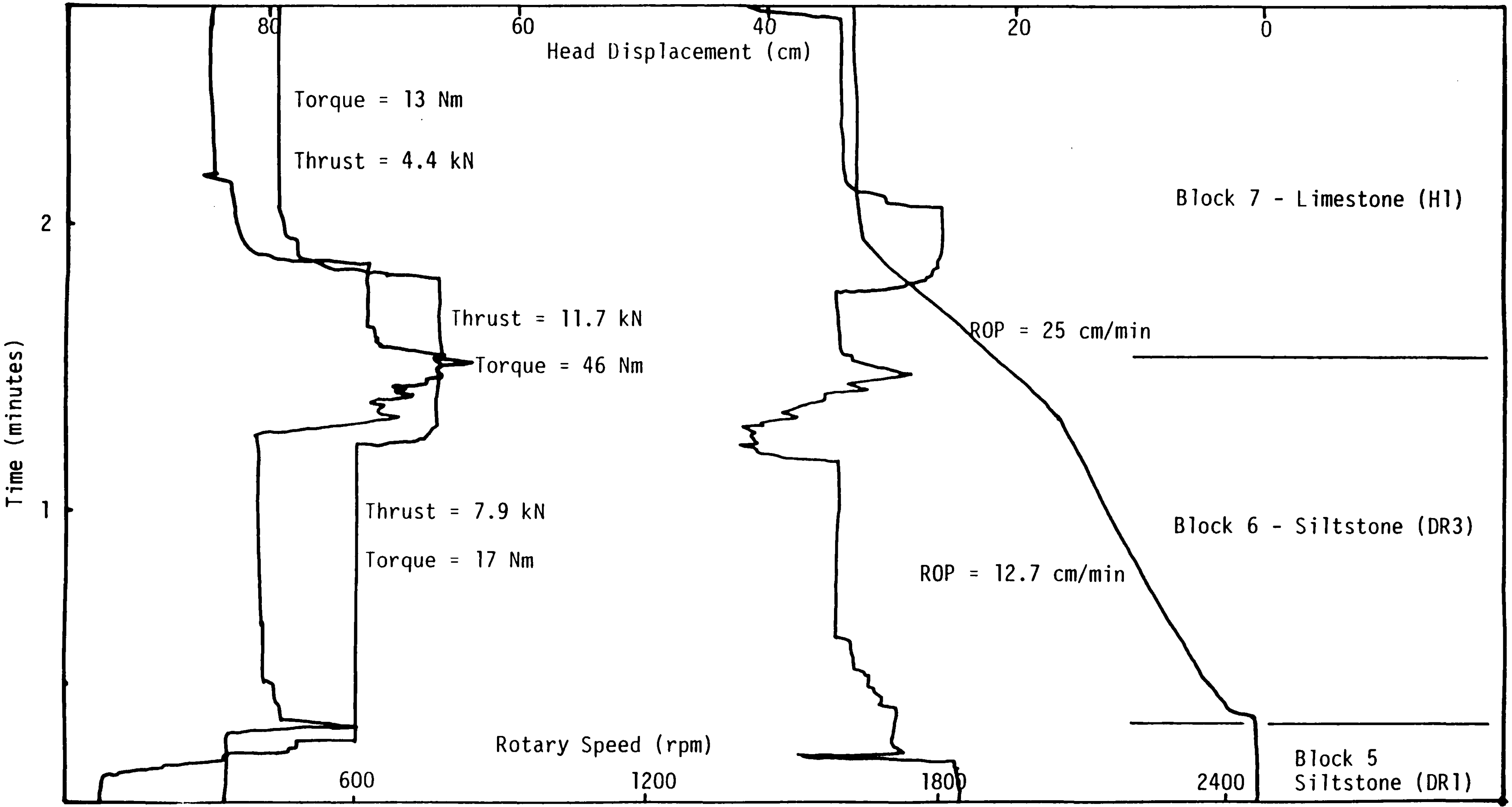
LABEL: FRT004 -FORM

SPOOLED: 82-01-25.17:40
STARTED: 82-01-25.17:44, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
19144305	1.05	0.000	0.00	1836.33	-2.76	9.05	59.97	4.83	3.77
19144310	1.05	0.001	1.34	1827.63	0.25	9.88	61.82	4.83	3.83
19144315	1.05	0.004	4.02	1514.45	8.62	39.80	84.10	4.83	4.65
19144320	1.09	0.040	42.83	1723.23	7.97	19.85	72.96	4.83	5.47
19144325	1.10	0.054	16.06	1679.74	7.97	20.24	78.53	4.83	5.41
19144330	1.12	0.066	14.72	1644.94	7.97	19.75	95.23	4.83	4.90
19144335	1.13	0.078	14.72	1601.44	7.83	20.17	89.66	4.83	4.46
19144340	1.14	0.089	13.39	1589.84	7.83	16.97	74.82	4.83	4.27
19144345	1.15	0.100	13.39	1598.54	7.97	15.97	67.39	4.83	4.27
19144350	1.16	0.110	12.05	1592.74	7.97	16.64	74.82	4.83	4.02
19144355	1.17	0.120	12.05	1589.84	7.83	16.97	84.10	4.83	4.33
19144400	1.18	0.131	12.05	1589.84	7.57	16.97	76.67	4.83	4.27
19144405	1.19	0.141	12.05	1589.84	7.83	16.97	78.53	4.83	4.21
19144410	1.20	0.151	12.05	1598.54	7.83	15.97	74.82	4.83	4.21
19144415	1.21	0.160	10.71	1598.54	7.83	15.97	67.39	4.83	4.14
19144420	1.23	0.175	18.74	1427.45	11.76	35.64	63.68	4.83	7.80
19144425	1.25	0.195	24.09	1494.15	11.89	41.74	84.10	4.83	8.69
19144430	1.27	0.215	24.09	1592.74	11.63	45.77	89.66	4.83	11.53
19144435	1.29	0.240	29.45	1702.94	11.76	31.65	74.82	4.83	10.20
19144440	1.31	0.263	28.11	1578.24	11.63	36.78	74.82	4.83	8.31
19144445	1.33	0.284	25.43	1572.44	11.76	37.31	76.67	4.83	8.56
19144450	1.36	0.306	25.43	1566.64	11.76	37.84	89.66	4.83	8.31
19144455	1.37	0.320	17.40	1795.73	5.87	16.84	85.95	4.83	4.90
19144500	1.37	0.321	1.34	1816.03	5.09	14.98	71.10	4.83	4.21
19144505	1.37	0.322	1.34	1821.83	4.57	14.45	95.23	4.83	4.08
19144510	1.37	0.323	1.34	1795.73	4.57	4.02	76.67	4.83	4.02
19144515	1.37	0.323	0.00	1584.04	4.44	12.72	82.24	4.83	2.38
19144520	1.37	0.325	1.34	1581.14	4.44	13.07	91.52	4.83	2.38
19144525	1.37	0.325	0.00	1584.04	4.44	12.72	85.95	4.83	2.38
19144530	1.38	0.326	1.34	1581.14	4.44	13.07	61.82	4.83	2.38
19144535	1.38	0.326	0.00	1584.04	4.44	12.72	58.11	4.83	2.38
19144540	1.38	0.326	0.00	1584.04	4.44	12.72	76.67	4.83	2.38
19144545	1.38	0.327	1.34	1584.04	4.44	12.72	95.23	4.83	2.31



RECORD OF TRRL DRILL RUN 2.2.2 (1.05 to 1.38 metres)

USER: EX9069 -AT SYSTEM

NR_T2.3.1

EX9069

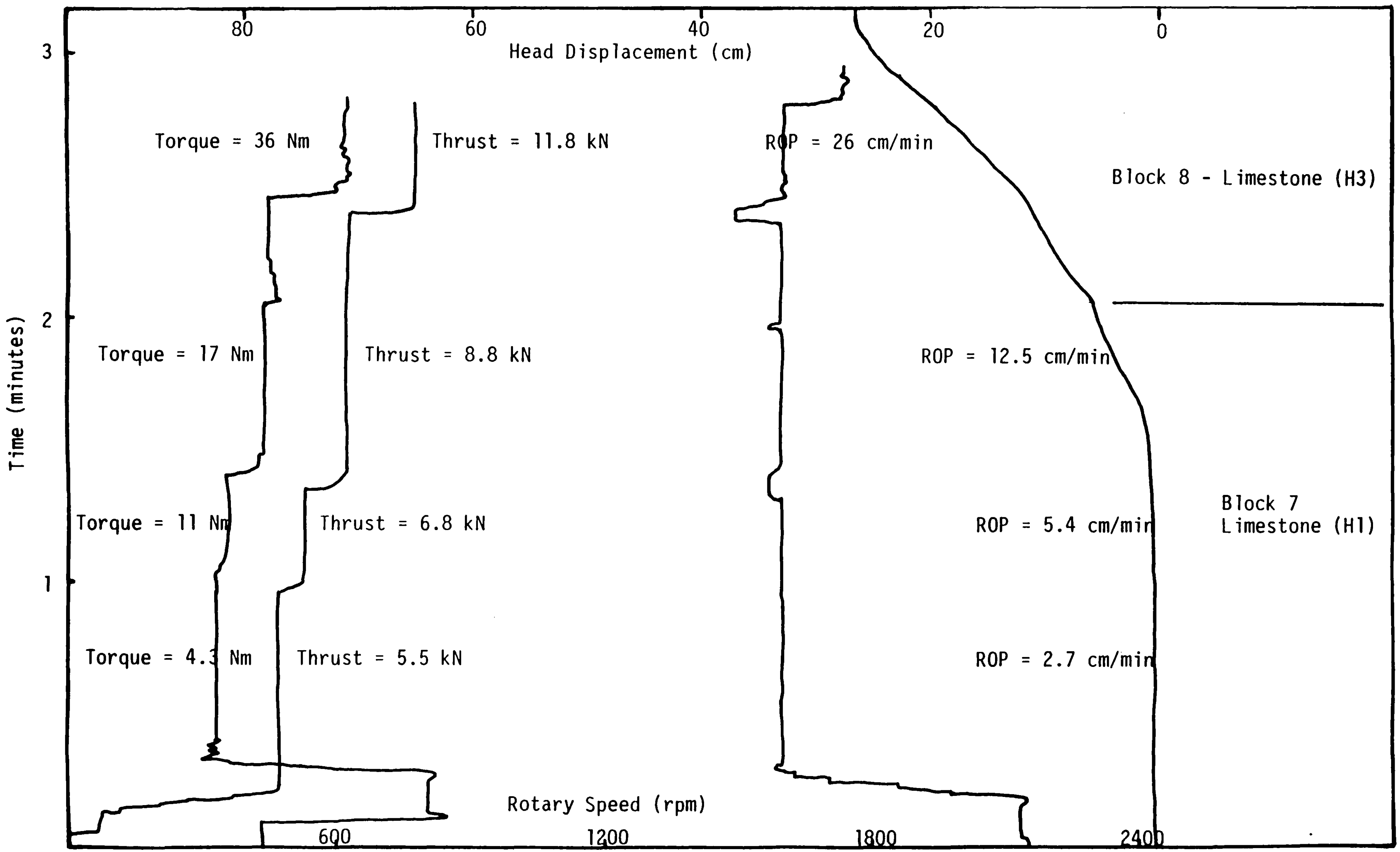
NR_T2.3.1

LABEL: PRT005 -FORM

SPOOLED: 82-01-25.17:40
STARTED: 82-01-25.17:44, ON: PRG BY: PRG

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
20145635	1.37	-0.000	0.00	2124.71	-2.88	10.42	78.42	23.02	7.82
20145640	1.37	0.002	2.69	2130.52	3.14	9.99	80.28	4.84	7.51
20145645	1.38	0.005	2.69	1909.69	5.63	5.98	57.97	26.32	6.05
20145650	1.38	0.007	2.69	1581.35	5.50	12.47	95.16	32.93	2.89
20145655	1.38	0.008	1.35	1592.98	5.50	5.44	65.47	21.90	3.21
20145700	1.38	0.010	2.69	1598.79	5.50	4.69	67.26	3.40	3.27
20145705	1.38	0.011	1.35	1598.79	5.50	4.69	43.09	3.40	3.27
20145710	1.38	0.014	2.69	1601.69	5.50	4.32	44.95	3.40	3.21
20145715	1.39	0.015	1.35	1601.69	5.50	4.32	76.56	3.40	3.21
20145720	1.39	0.017	2.69	1604.60	5.50	3.94	72.84	32.93	3.14
20145725	1.39	0.018	1.35	1604.60	5.50	3.94	85.86	3.40	3.27
20145730	1.39	0.020	2.69	1590.07	6.80	11.41	74.76	3.40	3.64
20145735	1.40	0.026	6.73	1587.16	6.80	11.77	54.32	3.40	3.77
20145740	1.40	0.030	5.38	1590.07	6.80	11.41	89.62	7.70	3.83
20145745	1.41	0.035	5.38	1592.98	6.80	11.06	65.47	3.40	3.83
20145750	1.41	0.039	5.38	1592.98	6.80	11.06	84.05	3.40	3.83
20145755	1.42	0.046	8.07	1543.58	8.76	17.08	65.47	3.40	5.10
20145800	1.43	0.056	12.11	1607.50	8.76	19.05	65.47	3.40	5.54
20145805	1.44	0.067	13.46	1607.50	8.76	19.05	80.33	26.07	5.60
20145810	1.45	0.077	12.11	1605.92	8.76	17.22	80.33	3.40	5.54
20145815	1.46	0.089	13.46	1605.92	8.76	17.22	72.90	3.40	5.54
20145820	1.47	0.099	12.11	1614.63	8.76	16.24	45.03	3.40	5.41
20145825	1.48	0.109	12.11	1608.82	8.76	16.89	93.34	12.02	5.48
20145830	1.49	0.119	12.11	1542.06	8.76	24.40	71.04	3.40	5.67
20145835	1.51	0.135	24.22	1597.21	8.76	18.19	82.19	3.40	5.67
20145840	1.52	0.152	14.80	1611.73	8.76	16.56	63.61	3.40	5.41
20145845	1.53	0.162	12.11	1603.02	8.76	17.54	30.17	3.40	5.48
20145850	1.54	0.173	13.46	1603.02	8.76	17.54	85.91	3.40	5.48
20145855	1.56	0.185	14.80	1478.20	12.04	31.58	69.19	3.40	7.75
20145900	1.58	0.205	24.22	1600.12	11.90	36.12	71.04	3.40	9.27
20145905	1.60	0.227	25.57	1611.73	11.77	35.07	91.48	3.40	8.89
20145910	1.62	0.248	25.57	1597.21	11.90	36.38	85.91	3.40	9.01
20145915	1.64	0.269	25.57	1597.21	11.77	36.38	71.04	3.40	9.08
20145920	1.66	0.291	25.57	1603.02	11.64	35.85	84.05	3.40	8.82
20145925	1.68	0.304	16.15	1751.06	-4.45	22.53	48.75	3.40	6.42



RECORD OF TRRL DRILL RUN 2.3.1 (1.37 to 1.68 metres)

USER: EX9069 -AT SYSTEM

NR_T2.3.2

EX9069

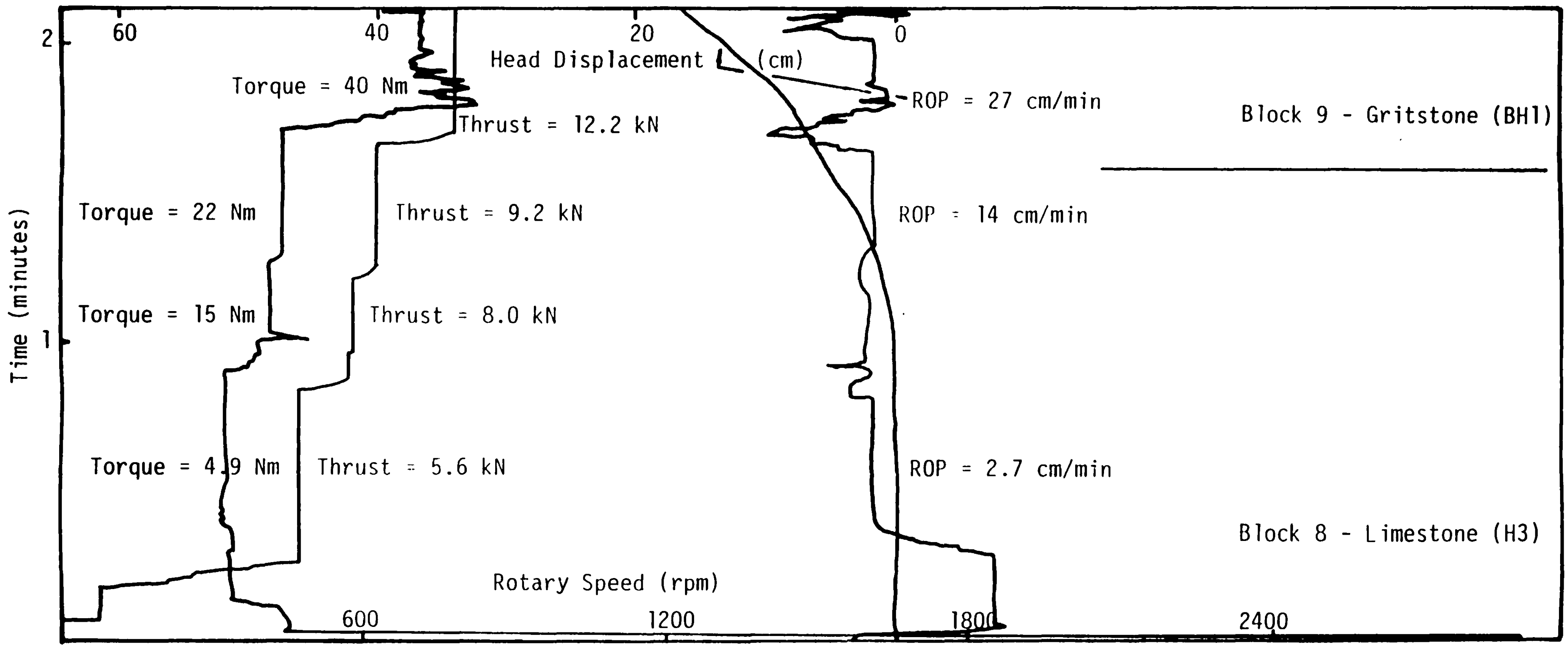
NR_T2.3.2

LABEL: PRT006 -FORM

SPOOLED: 82-01-25.17:40
STARTED: 82-01-25.17:44, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
20150055	1.69	0.000	0.00	1561.01	-3.54	38.08	30.17	99.99	4.97
20150100	1.69	0.001	1.35	1828.33	-2.62	13.47	82.14	99.99	4.79
20150105	1.69	0.001	0.00	1834.15	0.39	12.94	65.43	13.01	4.22
20150110	1.69	0.004	4.04	1828.33	5.76	13.47	67.26	99.99	4.66
20150115	1.70	0.008	4.04	1720.83	5.75	6.59	95.20	99.99	4.02
20150120	1.70	0.010	2.65	1578.45	5.62	7.31	87.77	99.99	3.01
20150125	1.70	0.012	2.69	1578.45	5.62	7.31	76.62	99.99	3.08
20150130	1.70	0.015	2.69	1579.80	5.75	4.48	71.04	99.99	3.01
20150135	1.71	0.017	2.69	1576.89	5.75	4.86	72.93	99.99	2.95
20150140	1.71	0.020	4.04	1579.80	5.75	4.48	71.04	99.99	2.95
20150145	1.71	0.022	2.69	1536.25	7.59	15.72	33.86	99.99	2.95
20150150	1.72	0.030	9.42	1591.41	7.98	14.10	59.93	99.99	4.66
20150155	1.74	0.046	18.84	1585.60	7.98	14.79	78.48	99.99	4.72
20150200	1.75	0.056	12.11	1585.60	7.98	14.79	76.62	95.99	4.53
20150205	1.76	0.065	10.76	1588.50	7.98	14.45	48.75	99.99	4.59
20150210	1.77	0.076	13.46	1556.57	9.03	18.22	87.77	99.99	5.35
20150215	1.78	0.089	14.80	1608.82	9.03	21.28	67.33	99.99	5.60
20150220	1.79	0.101	14.80	1603.02	9.16	21.90	35.74	99.99	5.67
20150225	1.80	0.112	13.46	1608.82	9.16	21.28	39.46	99.99	5.67
20150230	1.81	0.123	13.46	1608.82	9.03	21.28	67.33	99.99	5.60
20150235	1.82	0.135	13.46	1475.30	11.90	35.58	82.19	99.99	7.56
20150240	1.84	0.155	24.22	1547.87	12.17	40.82	95.20	99.99	10.09
20150245	1.87	0.176	25.57	1623.34	12.17	39.59	46.89	99.99	11.35
20150250	1.89	0.198	26.91	1594.31	12.30	39.43	67.33	99.99	10.40
20150255	1.91	0.221	26.91	1605.92	12.17	38.42	72.93	99.99	10.40
20150300	1.93	0.244	28.26	1489.81	5.75	50.73	84.05	95.99	12.99



RECORD OF TRRL DRILL RUN 2.3.2 (1.69 to 1.93 metres)

USER: EX9069 -AT SYSTEM

NR_T2.4.1

****

EX9069

NR_T2.4.1

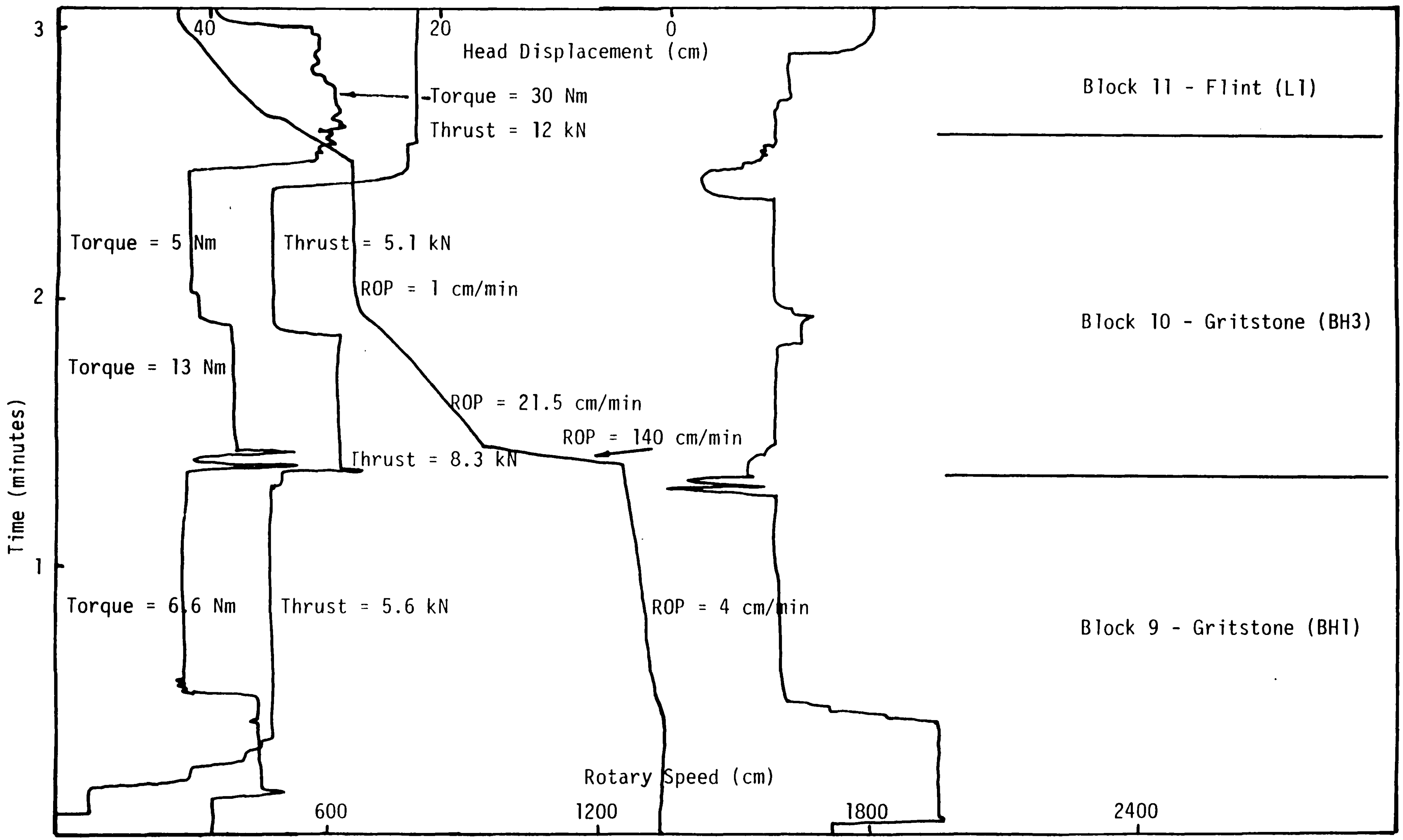
****

LABEL: PRT007 -FORM

SPOOLED: 82-01-25.17:40
STARTED: 82-01-25.17:44, ON: PRO BY: PRO

O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
21161246	1.81	0.000	0.00	1728.34	-3.67	27.53	43.00	46.31	4.22
21161250	1.81	0.001	1.35	1952.30	-2.88	8.07	83.96	45.76	5.05
21161255	1.81	0.002	1.35	1952.30	1.97	8.07	48.58	49.14	4.98
21161300	1.81	0.002	0.00	1958.12	4.33	7.56	44.86	47.95	4.92
21161305	1.82	0.007	5.38	1949.39	5.64	8.32	50.45	44.48	5.05
21161310	1.82	0.013	8.07	1859.23	5.64	8.36	74.65	46.45	4.67
21161315	1.83	0.017	4.04	1591.64	5.63	8.19	46.81	45.24	2.70
21161320	1.83	0.020	4.04	1588.73	5.63	8.55	50.53	49.37	2.64
21161325	1.83	0.022	2.69	1585.82	5.63	8.92	48.67	50.53	2.70
21161330	1.84	0.026	4.04	1585.82	5.63	8.92	80.28	48.85	2.64
21161335	1.84	0.028	2.69	1584.26	5.63	6.56	85.86	47.11	2.70
21161340	1.84	0.030	2.69	1584.26	5.63	6.56	85.86	49.50	2.70
21161345	1.84	0.034	4.04	1581.35	5.63	6.94	54.25	49.76	2.64
21161350	1.85	0.036	2.69	1584.26	5.63	6.56	50.53	45.87	2.64
21161355	1.85	0.039	4.04	1581.35	5.63	6.94	76.56	46.01	2.64
21161400	1.85	0.043	4.04	1581.35	5.76	6.94	69.12	49.24	2.70
21161405	1.97	0.159	139.95	1508.71	8.38	16.30	56.11	41.33	4.66
21161410	1.99	0.177	21.53	1580.01	8.27	14.92	46.72	30.55	4.41
21161415	2.00	0.193	18.84	1606.18	8.27	11.80	80.23	27.51	4.48
21161420	2.02	0.210	20.18	1597.46	8.27	12.84	29.97	36.08	4.79
21161425	2.04	0.228	21.53	1600.37	8.27	12.49	72.79	45.62	4.67
21161430	2.06	0.246	21.53	1591.64	8.27	13.53	41.14	38.80	4.73
21161435	2.08	0.267	25.57	1655.63	6.17	5.92	59.75	21.91	4.60
21161440	2.08	0.269	2.69	1652.72	5.12	11.44	69.06	29.07	3.28
21161445	2.08	0.270	1.35	1568.37	5.12	5.31	35.55	40.57	2.77
21161450	2.08	0.271	1.35	1568.37	5.12	5.31	54.17	15.20	2.71
21161455	2.08	0.271	0.00	1568.37	5.12	5.31	59.75	10.97	2.71
21161500	2.08	0.272	1.35	1571.28	5.12	4.92	67.20	29.07	2.64
21161505	2.08	0.274	1.35	1568.37	5.12	5.31	50.45	4.84	2.71
21161510	2.09	0.280	8.07	1405.49	11.68	26.98	50.45	4.84	5.81
21161515	2.12	0.312	37.68	1524.74	11.81	36.82	89.54	4.84	8.40
21161520	2.16	0.349	44.41	1594.55	11.81	33.28	56.03	4.84	9.16
21161525	2.18	0.371	26.91	1585.82	11.81	34.11	44.86	35.00	8.78
21161530	2.20	0.389	21.53	1623.63	11.81	30.55	37.41	23.03	8.28
21161535	2.21	0.405	18.84	1623.63	11.81	30.55	82.09	4.84	8.65
21161540	2.23	0.419	17.49	1690.53	11.81	24.25	76.51	33.33	8.15
21161545	2.23	0.422	2.69	1812.69	11.68	12.75	43.00	14.37	4.67



RECORD OF TRRL DRILL RUN 2.4.1 (1.81 to 2.23 metres)

USER: EX9069 -AT SYSTEM

NR_T2.4.2

LABEL: PRT008 -FORM

SPOOLED: 82-01-25.17:40
STARTED: 82-01-25.17:45, ON: PR0 BY: PR0

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
21162700	2.23	0.000	0.00	1853.41	-2.75	8.91	63.54	3.40	4.35
21162705	2.23	0.001	1.35	1856.32	2.23	8.64	41.23	25.35	4.22
21162710	2.23	0.002	1.35	1830.14	5.76	11.10	15.19	3.40	4.66
21162715	2.24	0.006	4.04	1613.32	5.76	8.58	72.84	26.08	3.65
21162720	2.24	0.008	2.69	1581.35	5.76	6.94	52.39	3.40	3.46
21162725	2.24	0.010	2.69	1584.26	5.76	6.56	37.51	3.40	3.46
21162730	2.24	0.011	1.35	1581.35	5.76	6.94	52.39	3.40	3.46
21162735	2.24	0.012	1.35	1584.26	5.76	6.56	50.53	33.31	3.40
21162740	2.24	0.015	2.69	1587.16	5.76	6.19	74.70	32.93	3.33
21162745	2.25	0.016	1.35	1584.26	5.76	6.56	37.51	3.40	3.33
21162750	2.25	0.018	2.69	1587.16	5.76	6.19	31.93	3.40	3.33
21162755	2.25	0.018	0.00	1587.16	5.90	6.19	43.09	3.40	3.33
21162800	2.25	0.022	5.38	1561.01	9.04	9.56	78.42	3.40	4.03
21162805	2.26	0.027	5.38	1622.03	9.04	12.74	48.67	3.40	4.22
21162810	2.26	0.031	5.38	1619.13	9.04	13.08	18.91	3.40	4.22
21162815	2.27	0.036	5.38	1622.03	9.04	12.74	74.70	3.40	4.03
21162820	2.27	0.038	2.69	1622.03	9.04	12.74	50.53	3.40	4.09
21162825	2.27	0.041	4.04	1622.03	9.04	12.74	63.54	3.40	4.03
21162830	2.28	0.047	6.73	1612.00	8.92	11.11	82.09	4.84	4.10
21162835	2.28	0.052	5.38	1614.91	8.92	10.76	57.89	4.84	3.97
21162840	2.28	0.055	4.04	1620.73	8.92	10.07	89.54	4.84	4.03
21162845	2.29	0.058	4.04	1600.37	9.97	12.49	44.86	4.84	3.97
21162850	2.30	0.067	10.76	1620.73	12.07	15.05	33.69	4.84	5.74
21162855	2.31	0.076	10.76	1614.91	12.07	20.18	41.14	4.84	6.19
21162900	2.32	0.089	14.80	1614.91	12.07	20.18	69.06	4.84	6.00
21162905	2.33	0.099	12.11	1609.09	12.07	20.81	57.89	4.84	6.12
21162910	2.34	0.108	10.76	1614.91	12.07	20.18	78.37	4.84	5.68
21162515	2.34	0.113	6.73	1609.09	12.07	20.81	54.17	4.84	5.55
21162920	2.35	0.122	10.76	1623.63	12.07	19.25	61.62	4.84	5.93
21162925	2.36	0.131	10.76	1585.82	5.64	23.32	70.92	4.84	5.74
21162930	2.40	0.170	47.10	1577.10	12.07	24.25	85.82	4.84	6.38
21162935	2.41	0.183	14.80	1588.73	12.07	23.00	59.75	4.84	6.31
21162940	2.43	0.195	14.80	1603.27	12.07	21.44	76.51	4.84	6.50
21162945	2.44	0.206	13.46	1606.18	12.07	21.12	50.45	4.84	5.93
21162950	2.45	0.215	10.76	1617.82	12.07	19.87	35.55	4.84	5.81
21162955	2.45	0.222	8.07	1684.71	8.40	2.45	83.96	4.84	4.16
21163000	2.45	0.224	2.69	1594.55	8.40	7.82	61.62	4.84	3.59
21163005	2.46	0.227	2.69	1588.73	8.40	8.55	70.92	4.84	3.53
21163010	2.46	0.229	2.69	1588.73	8.40	8.55	26.24	4.84	3.47
21163015	2.46	0.231	2.69	1588.73	8.40	8.55	24.38	4.84	3.53
21163020	2.46	0.234	4.04	1585.82	8.40	8.92	41.14	4.84	3.53
21163025	2.47	0.237	2.69	1588.73	8.40	8.55	46.72	4.84	3.72
21163030	2.47	0.239	2.69	1588.73	8.40	8.55	70.92	4.84	3.47
21163035	2.47	0.241	2.69	1588.73	8.40	8.55	78.37	4.84	3.47
21163040	2.47	0.242	1.35	1582.91	9.18	9.28	50.45	4.84	3.34
21163045	2.48	0.246	4.04	1565.46	10.76	11.47	35.55	4.84	4.10
21163050	2.48	0.251	6.73	1591.64	10.76	13.53	35.55	4.84	4.22
21163055	2.48	0.255	4.04	1606.18	10.76	11.80	56.03	4.84	4.29
21163100	2.49	0.258	4.04	1614.91	10.76	10.76	76.51	4.84	4.35
21163105	2.49	0.262	5.38	1614.91	10.76	10.76	65.34	4.84	4.35
21163110	2.50	0.267	5.38	1614.91	10.76	10.76	65.34	4.84	4.35
21163115	2.50	0.271	5.38	1600.37	10.76	12.49	87.68	4.84	4.60
21163120	2.51	0.277	6.73	1614.91	10.76	10.76	46.72	4.84	4.41
21163125	2.51	0.280	4.04	1612.00	10.76	11.11	39.28	4.84	4.35

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
21163130	2.52	0.286	6.73	1591.64	12.07	13.53	50.45	4.84	4.60
21163135	2.52	0.293	8.07	1603.27	11.94	12.15	78.37	4.84	4.67
21163140	2.53	0.298	6.73	1603.27	11.94	12.15	61.62	4.84	4.67
21163145	2.53	0.304	6.73	1603.27	11.94	12.15	57.89	4.84	4.67
21163150	2.54	0.308	5.38	1603.27	11.94	12.15	65.34	4.84	4.73
21163155	2.54	0.314	6.73	1606.18	11.94	11.80	33.69	4.84	4.67
21163200	2.55	0.318	5.38	1597.46	11.94	12.84	37.41	4.84	4.73
21163205	2.55	0.324	6.73	1591.64	11.94	13.53	61.62	4.84	4.86
21163210	2.56	0.329	5.38	1588.73	11.94	13.88	18.80	4.84	5.05
21163215	2.56	0.333	5.38	1588.73	11.94	13.88	89.54	4.84	5.05
21163220	2.57	0.336	4.04	1585.82	11.94	14.22	46.72	4.84	5.17
21163225	2.57	0.340	4.04	1582.91	11.94	14.57	41.14	4.84	5.05
21163230	2.57	0.343	4.04	1585.82	11.94	14.22	52.31	4.84	5.11
21163235	2.58	0.347	4.04	1585.82	11.94	14.22	76.51	4.84	5.11
21163240	2.58	0.350	4.04	1562.55	11.94	16.99	82.09	4.84	5.05
21163245	2.58	0.353	4.04	1580.01	11.94	14.92	46.72	4.84	5.24
21163250	2.59	0.358	5.38	1588.73	11.81	13.88	74.65	4.84	5.11
21163255	2.59	0.361	4.04	1620.73	11.94	15.05	39.28	4.84	5.30
21163300	2.60	0.368	8.07	1620.73	11.81	15.05	35.55	4.84	5.49
21163305	2.60	0.375	8.07	1609.09	11.94	16.37	48.58	4.84	5.30
21163310	2.61	0.376	1.35	23.92	-3.14	200.10	13.21	4.84	-1.35

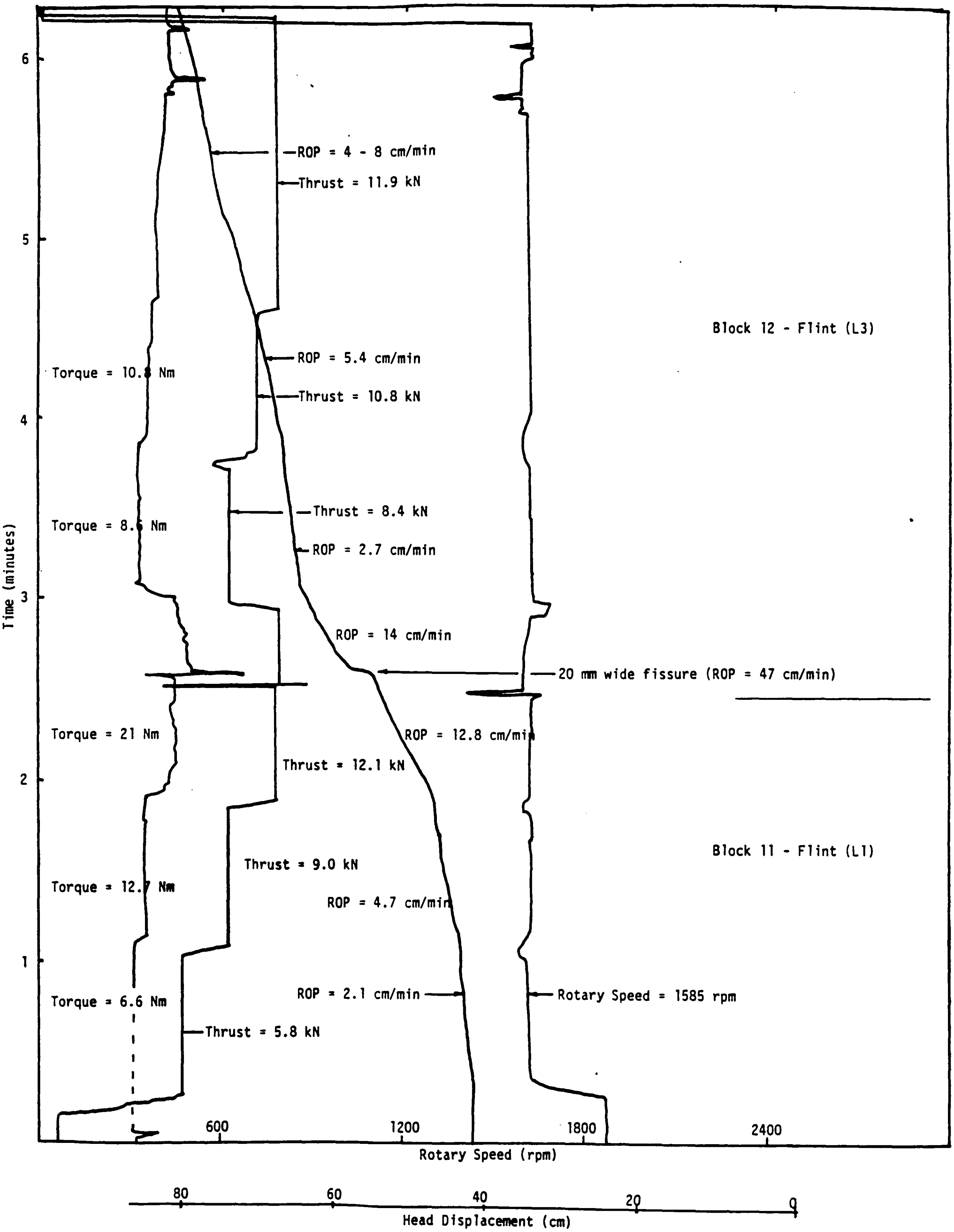


FIGURE 5.25 RECORD OF TRRL DRILL RUN 2.4.2 (2.23 to 2.61 metres)

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USER: EX9069 -AT SYSTEM

NR_T2.5.1

EX9069

NR_T2.5.1

LABEL: PRT009 -FORM

SPOOLED:  82-01-25.17:41
STARTED:  82-01-25.17:45, ON:    PRO   BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E
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-609-

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27154230	2.61	0.000	0.00	1584.48	3.91	5.88	39.55	3.40	3.39
27154235	2.61	0.001	1.35	1587.61	4.57	4.80	41.41	3.40	3.39
27154240	2.61	0.001	0.00	1584.70	5.09	5.18	71.10	3.40	3.39
27154245	2.61	0.002	1.35	1587.84	4.97	4.09	56.18	4.84	3.33
27154250	2.61	0.001	1.35	1586.27	4.96	7.60	85.95	3.40	3.32
27154255	2.61	0.002	1.35	1584.70	4.96	5.18	37.69	3.40	3.32
27154300	2.61	0.002	0.00	1573.03	6.79	6.70	58.11	3.40	3.45
27154305	2.62	0.007	5.38	1599.28	6.92	3.27	56.25	3.40	3.83
27154310	2.62	0.008	1.35	1612.55	6.92	4.26	0.57	3.40	3.89
27154315	2.62	0.011	4.04	1604.86	6.92	3.25	69.25	3.40	3.89
27154320	2.62	0.012	1.35	1611.23	6.92	7.01	39.55	3.40	3.89
27154325	2.62	0.015	2.69	1609.90	6.79	3.94	45.12	3.40	3.89
27154330	2.63	0.019	5.38	1597.70	6.92	0.68	50.69	3.40	3.83
27154335	2.63	0.017	2.69	1605.38	6.79	1.78	78.53	3.40	3.77
27154340	2.63	0.018	1.35	1597.95	6.79	6.12	35.84	3.40	3.77
27154345	2.63	0.019	1.35	1593.45	6.79	4.04	50.69	3.40	3.70
27154350	2.63	0.022	4.04	1597.95	6.79	6.12	30.27	3.40	3.64
27154355	2.63	0.024	1.35	1594.79	6.79	1.07	82.24	3.40	3.64
27154400	2.63	0.024	0.00	1574.39	7.44	3.80	4.28	3.40	3.70
27154405	2.64	0.028	5.38	1564.10	8.23	8.52	82.24	3.40	4.27
27154410	2.64	0.031	4.04	1603.27	8.23	6.72	43.26	3.40	4.46
27154415	2.65	0.036	5.38	1600.62	8.23	6.42	41.41	3.40	4.46
27154420	2.65	0.041	6.73	1610.95	8.23	7.66	56.25	3.40	4.33
27154425	2.65	0.045	4.04	1603.53	8.23	6.06	85.95	3.40	4.33
27154430	2.65	0.049	5.38	1599.28	8.23	9.10	56.25	3.40	4.46
27154435	2.66	0.054	5.38	1606.45	8.23	11.21	50.69	3.40	4.33
27154440	2.67	0.056	2.69	1594.55	8.23	7.82	30.27	3.40	4.33
27154445	2.67	0.061	5.38	1553.83	10.06	12.94	39.55	3.40	5.15
27154450	2.68	0.068	9.42	1604.60	10.06	14.76	2.43	3.40	5.91
27154455	2.69	0.077	10.76	1610.41	10.06	14.08	69.25	3.40	5.97
27154500	2.70	0.085	9.42	1600.12	10.06	13.07	45.12	3.40	6.10
27154505	2.71	0.095	12.11	1608.82	10.06	12.04	41.41	3.40	5.79
27154510	2.71	0.104	10.76	1550.77	11.89	23.42	54.40	3.40	6.23
27154515	2.73	0.118	16.15	1565.28	12.41	25.94	85.95	3.40	7.68
27154520	2.74	0.131	16.15	1585.60	12.41	27.64	46.97	3.40	7.93
27154525	2.75	0.145	16.15	1585.60	12.41	23.77	32.13	3.40	7.80
27154530	2.77	0.160	18.84	1591.41	12.41	23.14	32.13	3.40	8.06
27154535	2.79	0.176	18.84	1595.88	12.41	24.47	35.84	3.40	8.12
27154540	2.81	0.202	30.95	1556.57	12.28	26.87	20.99	3.40	10.64
27154545	2.83	0.224	26.91	1581.35	12.28	25.99	54.40	3.40	8.31
27154550	2.85	0.244	24.22	1633.66	10.19	20.51	52.54	3.40	8.06
27154555	2.87	0.259	17.49	1601.69	9.01	15.09	52.54	3.40	5.15
27154600	2.88	0.272	16.15	1577.10	9.14	19.98	48.83	3.40	5.53
27154605	2.90	0.287	17.49	1584.26	9.14	17.11	69.25	3.40	5.66
27154610	2.91	0.301	16.15	1594.31	9.01	13.76	54.40	3.40	5.22
27154615	2.92	0.313	14.80	1590.07	9.01	11.41	84.10	3.40	5.22
27154620	2.94	0.326	16.15	1596.12	9.01	15.22	39.55	4.83	5.15
27154625	2.95	0.341	17.49	1594.79	9.14	12.60	32.13	3.40	5.15
27154630	2.96	0.349	9.42	1660.55	6.00	12.22	69.25	4.83	3.64
27154635	2.96	0.350	1.35	1586.27	6.00	7.60	8.00	4.83	2.88
27154640	2.95	0.352	2.69	1593.45	6.00	4.04	76.67	3.40	2.95
27154645	2.96	0.352	0.00	1588.96	6.00	1.85	41.41	3.40	3.01
27154650	2.96	0.354	2.69	1591.87	6.00	1.46	41.41	3.40	2.95
27154655	2.97	0.355	1.35	1591.87	6.00	1.46	58.11	3.40	2.95

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
27154700	2.97	0.357	1.35	1593.21	6.00	4.75	71.10	3.40	2.95
27154705	2.97	0.358	1.35	1588.73	6.00	2.60	80.38	4.83	2.95
27154710	2.98	0.369	13.46	1475.30	13.06	31.49	41.41	4.83	7.93
27154715	3.00	0.394	29.60	1577.10	12.93	34.93	32.13	4.83	9.26
27154720	3.03	0.422	33.64	1623.63	12.93	30.55	46.97	3.40	8.75
27154725	3.05	0.440	21.53	1636.56	12.93	27.79	28.41	3.40	8.50
27154730	3.07	0.456	21.53	1630.75	12.93	28.35	58.11	3.40	8.18
27154735	3.09	0.477	22.88	1613.32	12.93	30.02	41.41	3.40	8.56
27154740	3.10	0.492	18.84	1758.60	8.88	16.08	50.69	4.83	6.61
27154745	3.11	0.502	12.11	1608.82	9.01	12.04	71.10	4.83	5.34
27154750	3.12	0.510	9.42	1610.41	9.01	14.08	56.25	4.83	4.78
27154755	3.13	0.518	9.42	1603.02	9.01	12.73	56.25	4.83	4.90
27154800	3.14	0.527	10.76	1607.50	9.01	14.42	32.13	4.83	4.84
27154805	3.14	0.535	9.42	1603.02	9.01	12.73	46.97	4.83	4.78
27154810	3.15	0.544	10.76	1600.12	9.01	13.07	4.28	4.83	4.84
27154815	3.16	0.551	8.07	1634.95	7.05	8.95	74.82	4.83	3.89
27154820	3.16	0.554	4.04	1608.82	7.05	6.66	39.55	3.40	3.64
27154825	3.17	0.556	2.69	1608.82	7.05	6.66	43.26	4.83	3.64
27154830	3.17	0.560	4.04	1608.82	7.18	6.66	65.54	4.83	3.70
27154835	3.17	0.563	4.04	1610.41	7.05	8.93	50.69	4.83	3.64
27154840	3.18	0.565	2.69	1605.92	7.18	7.02	85.95	4.63	3.64
27154845	3.18	0.567	2.69	1611.73	7.05	6.29	33.98	3.40	3.64
27154850	3.18	0.571	4.04	1608.82	7.05	6.66	35.84	4.83	3.64
27154855	3.18	0.573	2.69	1579.80	7.05	4.48	56.25	4.83	3.32
27154900	3.19	0.575	2.69	1579.80	7.05	4.48	30.27	4.83	3.32
27154905	3.19	0.579	4.04	1576.89	7.05	10.64	56.25	4.83	3.32
27154910	3.19	0.581	2.69	1576.89	7.05	10.64	39.55	3.40	3.39
27154915	3.19	0.583	2.69	1579.80	7.05	10.28	50.69	4.83	3.39
27154920	3.20	0.585	2.69	1579.80	7.05	10.28	84.10	4.83	3.26
27154925	3.20	0.588	2.69	1579.80	7.05	10.28	39.55	4.83	3.39
27154930	3.20	0.590	2.69	1573.99	7.05	11.01	33.98	4.83	3.39
27154935	3.20	0.593	4.04	1576.89	7.05	10.54	32.13	4.83	3.39
27154940	3.21	0.595	2.69	1576.89	7.05	10.64	43.26	3.40	3.39
27154945	3.21	0.598	2.69	1579.80	7.05	10.28	82.24	4.83	3.39
27154950	3.21	0.600	2.69	1576.89	7.05	10.64	82.24	4.83	3.39
27154955	3.21	0.602	2.69	1579.80	6.92	4.48	41.41	4.83	3.32
27155000	3.21	0.603	1.35	1579.80	6.92	10.28	89.66	4.83	3.32
27155005	3.22	0.606	2.69	1579.80	6.92	10.28	76.67	4.83	3.39
27155010	3.22	0.608	2.69	1576.89	7.05	10.64	43.26	4.83	3.26
27155015	3.22	0.610	2.69	1579.80	7.05	10.28	63.68	4.83	3.26
27155020	3.22	0.612	2.69	1582.70	7.05	9.92	33.98	4.83	3.26
27155025	3.24	0.629	20.18	1539.16	9.93	15.36	45.12	4.83	5.41
27155030	3.25	0.644	17.49	1617.53	9.80	20.35	89.66	4.83	6.67
27155035	3.27	0.660	20.18	1594.31	9.93	22.83	6.14	4.83	6.35
27155040	3.29	0.675	17.49	1591.41	9.93	23.14	39.55	4.83	6.04
27155045	3.30	0.690	17.49	1582.70	9.93	19.83	45.12	4.83	6.29
27155050	3.31	0.703	16.15	1587.39	9.80	16.23	48.83	4.83	6.16
27155055	3.33	0.724	25.57	1581.57	12.67	38.79	35.84	4.83	10.33
27155100	3.36	0.747	26.91	1603.79	12.80	40.52	67.39	4.83	9.63
27155105	3.37	0.761	17.49	1862.62	5.09	16.81	33.98	4.83	5.22
27155110	3.37	0.765	4.04	1736.40	7.44	8.76	45.12	4.83	5.47
27155115	3.38	0.771	8.07	1561.36	7.44	18.76	1.28	4.83	4.08
27155120	3.39	0.776	5.38	1581.78	7.44	16.37	0.57	4.83	4.27
27155125	3.39	0.782	6.73	1587.84	7.44	19.83	84.10	4.83	4.14
27155130	3.40	0.787	6.73	1584.70	7.57	16.03	37.69	4.83	4.02
27155135	3.40	0.792	5.38	1591.87	7.44	7.53	74.82	4.83	4.02
27155140	3.41	0.795	4.04	1588.96	7.44	13.30	45.12	4.83	4.02
27155145	3.41	0.800	5.38	1591.87	7.44	1.46	33.98	4.83	3.83

	TOTAL	CORE	PENETRAIN	POTARY			INLET H2O	I. H2O	
27155150	3.41	0.804	5.38	1590.53	7.44	4.42	35.84	4.83	3.89
27155155	3.42	0.807	4.04	1587.61	7.44	15.69	43.26	4.83	3.96
27155200	3.42	0.811	4.04	1588.96	7.44	13.33	76.67	4.83	3.89
27155205	3.43	0.816	6.73	32.65	-2.89	213.06	24.70	4.83	18.22

USER: EX9069 -AT SYSTEM

NR_T2.5.2

EX9069

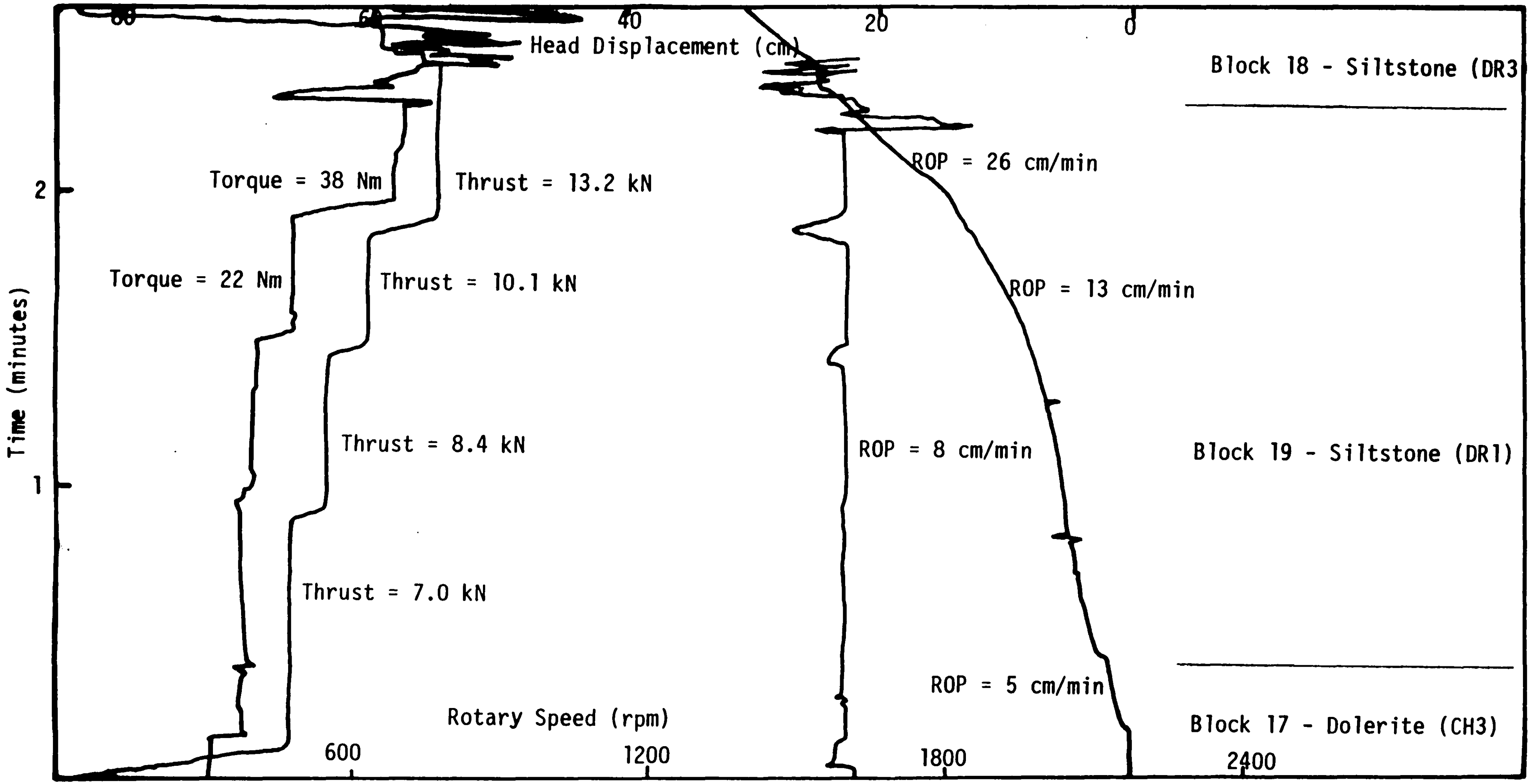
NR_T2.5.2

LABEL: PRT01C -FORM

SPOOLED: 82-01-25.17:41
STARTED: 82-01-25.17:45, ON: PRO BY: PRO

O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27160400	3.43	0.000	0.00	1619.13	-0.41	2.07	45.29	37.04	3.26
27160405	3.44	0.011	13.46	1581.57	6.91	16.91	84.14	3.40	4.71
27160410	3.45	0.017	6.73	1605.92	6.91	7.02	47.06	3.40	4.45
27160415	3.45	0.021	5.38	1594.31	6.91	13.76	45.29	3.40	4.45
27160420	3.46	0.031	12.11	1591.64	7.04	18.34	34.08	27.22	4.58
27160425	3.47	0.036	5.38	1598.79	7.04	10.35	63.04	26.28	4.52
27160430	3.47	0.040	5.38	1606.18	7.04	6.36	63.75	35.11	4.45
27160435	3.47	0.045	5.38	1607.77	7.04	13.86	45.29	40.48	4.39
27160440	3.48	0.050	6.73	1598.79	6.92	1.65	41.41	34.95	4.33
27160445	3.48	0.050	0.00	1609.36	7.04	15.84	63.75	3.40	4.39
27160450	3.48	0.054	4.04	1601.69	7.04	10.00	47.06	3.40	4.33
27160455	3.49	0.063	10.76	1582.91	8.36	9.28	67.39	4.83	4.52
27160500	3.49	0.061	2.69	1601.69	8.36	10.00	30.27	4.83	4.90
27160505	3.50	0.065	5.38	1598.79	8.36	10.35	41.41	3.40	5.03
27160510	3.50	0.070	5.38	1597.21	8.36	8.11	82.24	4.83	4.96
27160515	3.51	0.076	8.07	1591.41	8.36	8.83	8.71	5.94	5.15
27160520	3.51	0.083	8.07	1588.50	8.36	14.45	39.55	38.08	5.22
27160525	3.52	0.087	5.38	1588.50	8.36	14.45	46.97	31.32	5.15
27160530	3.53	0.098	12.11	1614.63	10.06	20.66	89.66	4.83	6.73
27160535	3.54	0.109	13.46	1594.31	10.06	18.52	48.83	4.83	6.48
27160540	3.55	0.119	12.11	1587.39	10.06	24.96	46.97	4.83	6.67
27160545	3.56	0.130	13.46	1590.07	10.06	20.97	30.27	4.83	6.54
27160550	3.57	0.141	13.46	1594.31	10.06	18.52	54.40	4.83	6.42
27160555	3.59	0.157	18.84	1563.92	13.06	37.81	63.68	4.83	9.82
27160600	3.61	0.176	22.88	1594.31	13.06	36.64	1.28	4.83	10.39
27160605	3.63	0.198	26.91	1579.80	13.20	37.95	59.97	27.00	10.90
27160610	3.65	0.220	25.57	1585.60	13.20	37.42	43.26	12.02	10.90
27160615	3.67	0.242	26.91	1843.60	13.06	19.09	61.82	4.83	11.40
27160620	3.68	0.251	10.76	1597.46	13.06	38.90	37.69	4.83	10.71
27160625	3.70	0.275	28.26	1523.24	13.20	44.21	37.69	4.83	11.46
27160630	3.73	0.297	26.91	1629.45	9.93	33.18	50.69	4.83	10.08
27160635	3.74	0.314	20.18	1594.55	-2.36	39.15	41.41	4.83	7.30



RECORD OF TRRL DRILL RUN 2.5.2 (3.43 to 3.74 metres)

USER: EX9069 -AT SYSTEM

NR_T2.6

EX9069

NR_T2.6

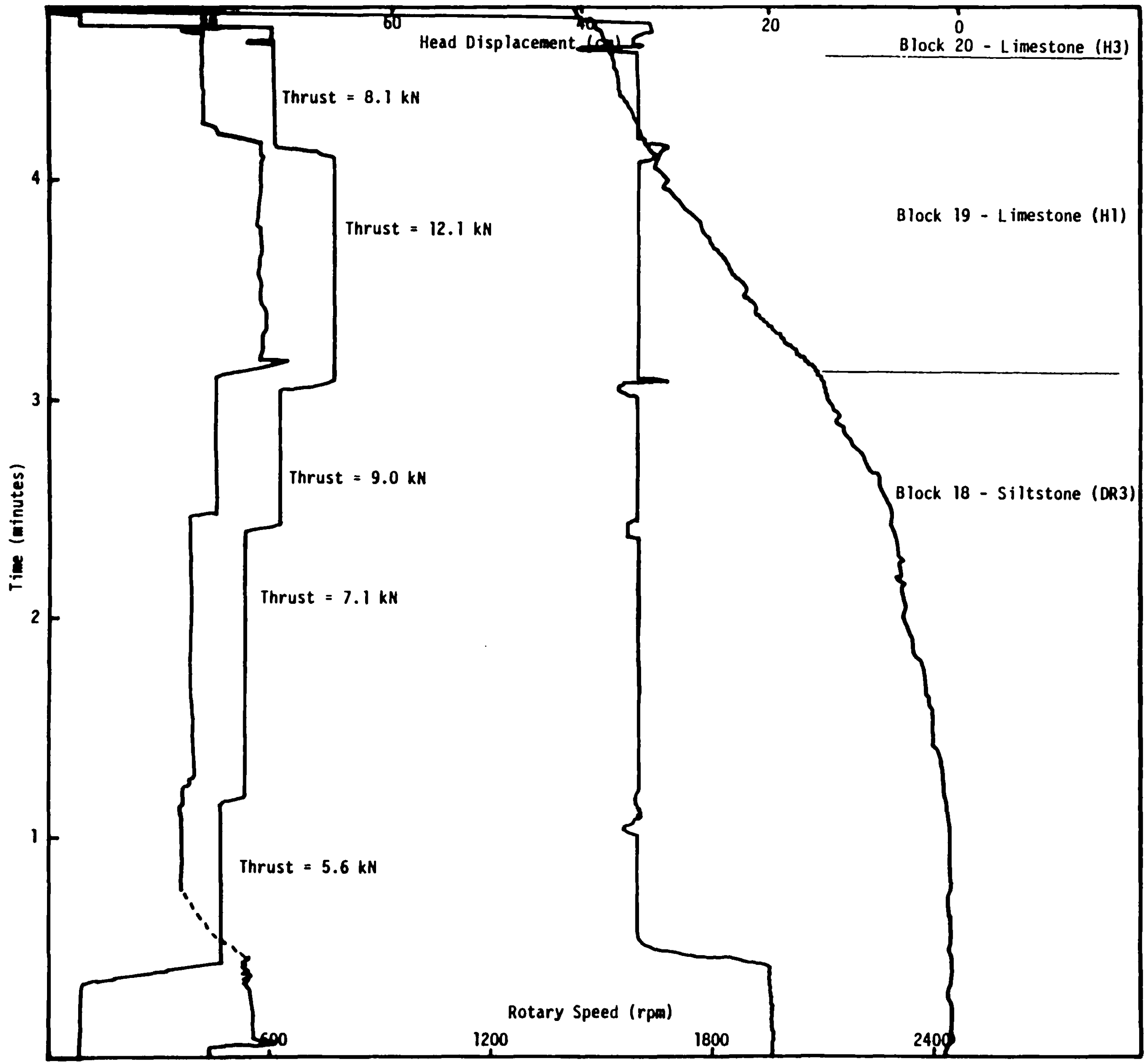
LABEL: FRT011 -FORM

SPOOLED: 82-01-25.17:41
STARTED: 82-01-25.17:46, ON: PR0 BY: PRO

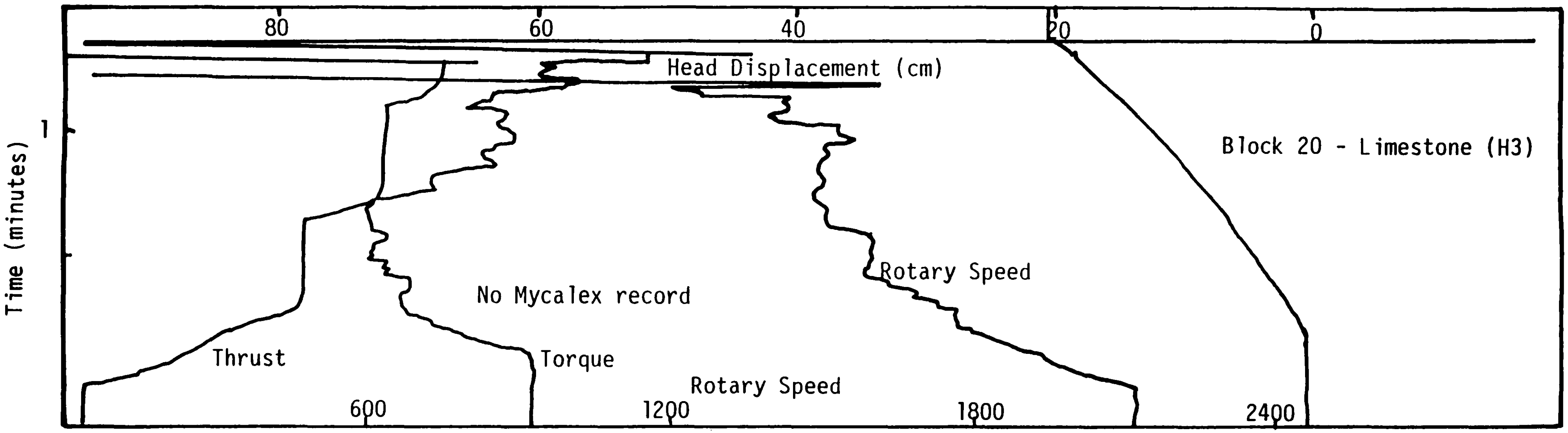
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
31625	3.74	0.000	0.00	2005.49	-2.74	4.08	54.02	6.89	6.84
31630	3.74	0.001	1.35	2006.58	-2.74	7.59	39.09	6.89	6.71
31635	3.74	0.001	0.00	2010.64	-2.74	6.90	20.44	11.53	6.65
31640	3.74	0.001	0.00	1985.72	-2.74	3.92	40.96	19.52	6.65
31645	3.74	0.002	1.35	1983.72	2.38	7.25	68.94	32.20	6.46
31650	3.74	0.004	2.69	1989.63	5.40	2.89	27.90	37.16	6.71
31655	3.75	0.007	2.69	1630.33	5.40	5.29	33.50	40.77	4.11
31700	3.75	0.007	0.00	1617.18	5.27	24.47	29.76	39.33	3.79
31705	3.75	0.009	2.69	1625.03	5.27	6.64	65.21	8.47	3.73
31710	3.74	0.004	5.38	1614.71	5.63	5.31	52.39	3.40	3.90
31715	3.74	0.002	2.69	1617.93	5.63	9.90	28.21	3.40	3.90
31720	3.74	0.004	2.69	1616.61	5.63	7.01	52.39	34.99	3.90
31725	3.75	0.009	5.38	1612.05	5.76	1.28	46.81	35.53	3.90
31730	3.75	0.013	5.38	1648.04	5.63	5.07	63.54	37.10	3.90
31735	3.75	0.010	4.04	1613.94	7.07	0.64	37.51	42.69	4.66
31740	3.75	0.013	4.04	1644.40	7.07	6.73	39.37	38.12	4.85
31745	3.76	0.018	5.38	1653.95	7.07	4.36	74.79	13.01	4.66
31750	3.76	0.021	4.04	1652.65	7.07	7.01	52.39	3.40	4.41
31755	3.77	0.027	6.73	1650.64	7.07	7.24	39.37	3.40	4.41
31800	3.77	0.027	0.00	1649.34	7.07	13.07	61.69	31.56	4.54
31805	3.77	0.033	6.73	1651.00	7.07	4.72	31.93	15.81	4.47
31810	3.77	0.035	2.69	1659.69	7.07	8.51	74.79	35.70	4.47
31815	3.78	0.043	9.42	1662.67	7.07	3.99	37.51	40.07	4.47
31820	3.79	0.046	4.04	1662.67	7.07	3.99	39.37	29.05	4.47
31825	3.79	0.053	8.07	1664.35	7.07	0.49	82.14	3.40	4.41
31830	3.79	0.052	1.35	1655.98	7.07	6.02	52.39	3.40	4.35
31835	3.79	0.049	2.69	1671.11	7.07	26.70	39.37	3.40	4.28
31840	3.79	0.053	4.04	1660.23	7.07	13.51	30.07	3.40	4.28
31845	3.80	0.058	6.73	1657.27	7.07	8.85	56.11	3.40	4.28
31850	3.81	0.065	8.07	1619.10	5.04	7.36	63.54	36.41	5.74
31855	3.82	0.077	14.80	1653.75	9.04	23.76	39.37	39.59	5.99
31900	3.83	0.089	13.46	1657.09	9.04	18.96	39.37	39.43	5.99
31905	3.84	0.101	14.80	1662.52	9.04	4.70	74.79	3.40	6.05
31910	3.85	0.108	8.07	1656.72	9.04	8.11	50.53	3.40	6.05
31915	3.86	0.117	10.76	1653.38	9.04	0.21	46.81	3.40	5.93
31920	3.87	0.130	16.15	1650.41	9.04	6.46	30.07	3.40	5.86
31925	3.88	0.141	13.46	1665.13	9.04	33.71	57.97	3.40	5.93
31930	3.89	0.155	16.15	1613.45	11.92	36.10	48.67	3.40	8.46
31935	3.92	0.178	28.26	1626.05	11.92	15.17	17.05	26.32	8.39
31940	3.93	0.192	16.15	1652.80	11.92	28.74	39.37	31.35	8.46
31945	3.94	0.198	8.07	1646.49	11.92	2.71	69.12	3.40	8.20
31950	3.96	0.215	20.18	1631.64	12.05	4.51	54.25	3.40	8.08
31955	3.97	0.228	14.80	1656.72	12.05	15.01	61.69	3.40	7.76
32000	3.98	0.242	17.49	1642.53	11.92	27.80	30.07	3.40	8.27
32005	3.99	0.250	9.42	1642.19	12.05	34.63	41.23	3.40	8.14
32010	4.01	0.269	22.88	1659.15	11.92	15.85	85.86	18.84	7.95
32015	4.03	0.292	26.91	1676.58	11.92	20.07	22.01	3.40	8.01
32020	4.03	0.293	1.34	1651.13	11.92	1.33	76.56	15.20	8.08
32025	4.04	0.297	5.38	1644.13	11.92	12.62	39.37	26.56	8.20
32030	4.06	0.317	24.22	1632.28	12.05	18.59	48.67	19.17	8.20
32035	4.06	0.322	5.38	1759.59	8.12	2.19	67.26	3.40	6.12
32040	4.08	0.339	20.18	1657.84	8.12	3.65	37.51	3.40	4.98
32045	4.08	0.341	2.69	1664.61	8.12	11.61	70.98	3.40	4.98
32050	4.08	0.342	1.34	1643.16	8.12	9.51	63.54	3.40	4.98

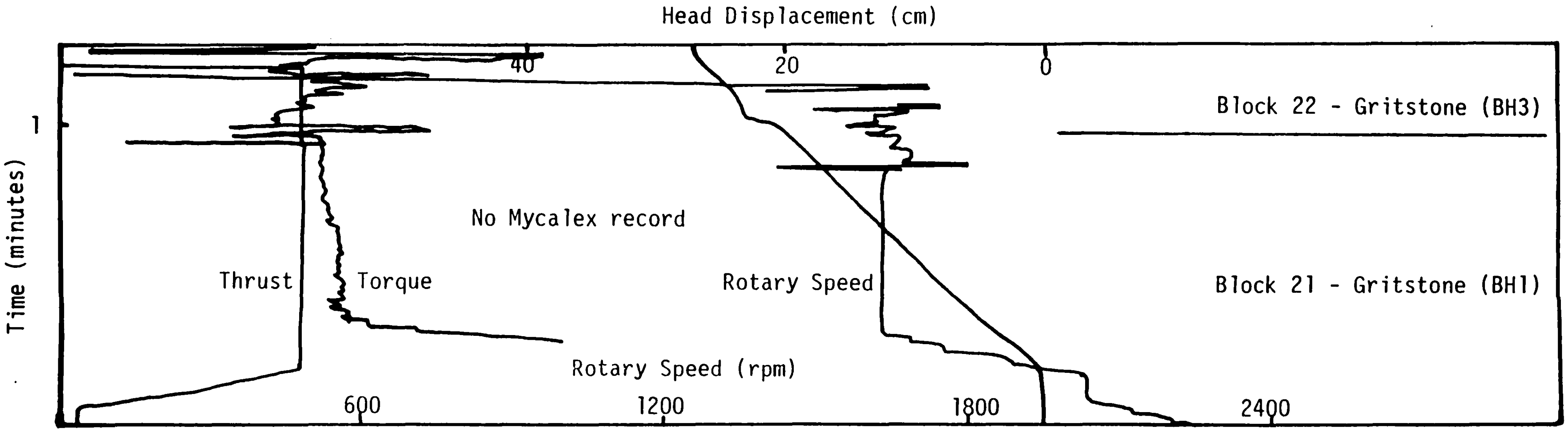
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
32055	4.09	0.349	8.07	1661.99	8.12	28.10	41.23	3.40	5.04
32100	4.10	0.364	18.84	1694.00	8.12	34.15	17.05	3.4[illegible]	5.04
32105	4.12	0.385	24.22	1652.37	8.12	10.96	37.51	39.75	5.42
32110	4.13	0.390	6.73	1506.95	-3.80	21.72	33.79	41.79	2.07



RECORD OF TRRL DRILL RUN 2.6 (3.74 to 4.13 metres)



RECORD OF TRRL DRILL RUN 2.7.1 (4.13 to 4.32 metres)



RECORD OF TRRL DRILL RUN 2.7.2 (4.32 to 4.54 metres)

USER: EX9069 -AT SYSTEM

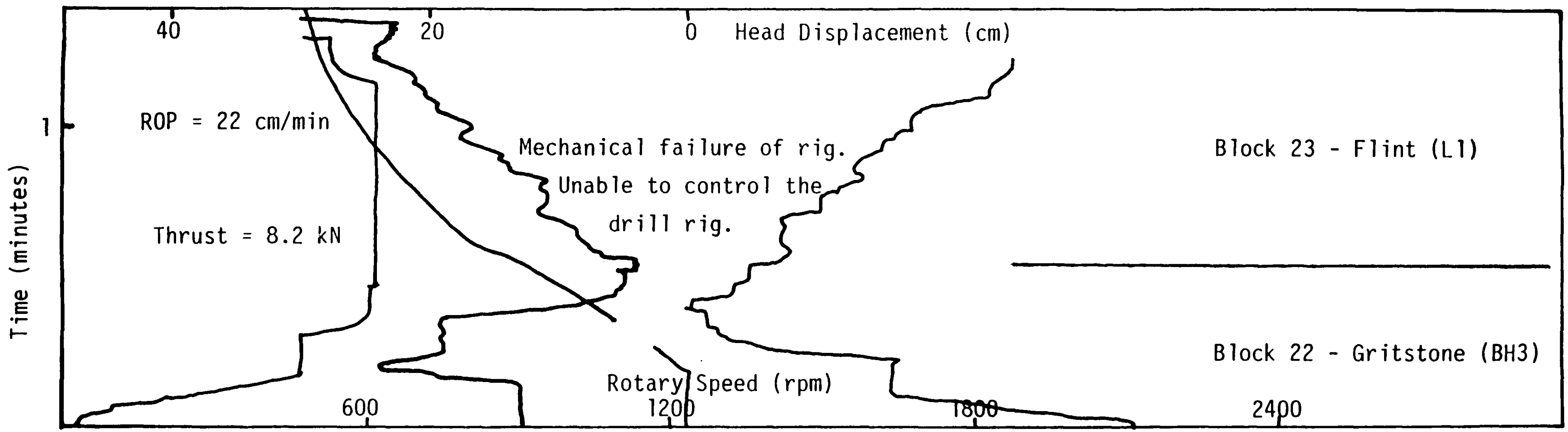
NR_T2.8

LABEL: PRT012 -FORM

SPOOLED: 82-01-25.17:41
STARTED: 82-01-25.17:46, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
9145620	4.54	0.000	0.00	2129.95	-2.89	8.91	60.18	48.86	8.53
9145625	4.54	0.003	2.69	2024.51	0.37	16.79	65.73	47.26	9.10
9145630	4.55	0.013	12.11	1904.41	1.67	25.77	43.52	45.34	11.05
9145635	4.57	0.027	16.15	1766.74	4.79	36.07	56.55	39.79	12.48
9145640	4.58	0.041	17.49	1696.45	5.05	33.74	56.55	10.36	11.22
9145645	4.60	0.057	18.84	1583.78	4.93	29.62	63.88	42.44	9.98
9145650	4.61	0.071	16.15	1601.38	4.93	31.35	78.68	35.08	9.54
9145655	4.62	0.084	16.15	1525.14	7.14	38.65	50.93	26.96	9.85
9145700	4.64	0.102	21.53	1487.03	8.19	47.59	73.13	35.79	11.61
9145705	4.66	0.120	21.53	1507.55	8.19	52.51	15.69	37.35	13.44
9145710	4.68	0.138	21.53	1519.28	8.19	51.59	84.24	34.16	13.63
9145715	4.70	0.156	21.53	1528.07	8.19	50.90	56.48	28.54	13.69
9145720	4.71	0.175	22.88	1437.18	10.53	58.06	87.94	35.97	14.19
9145725	4.74	0.201	30.95	903.54	-2.24	100.14	45.37	12.98	15.77
9145730	4.74	0.158	2.69	56.17	-2.76	166.96	58.33	37.01	-1.22
9145846	4.74	0.158	0.00	53.21	-2.89	166.10	71.34	16.32	-1.28
9145850	4.74	0.158	0.00	53.21	-2.89	166.10	21.09	32.64	-1.28
9145855	4.74	0.197	1.35	1974.71	-2.76	20.52	60.18	31.07	8.47
9145900	4.74	0.197	0.00	1974.71	-2.76	20.52	60.18	36.66	7.02
9145905	4.74	0.197	0.00	2291.06	-3.54	3.14	63.88	49.25	8.59
9145910	4.74	0.198	1.34	2293.35	-3.41	5.40	76.78	35.45	8.35
9145915	4.74	0.201	2.69	2187.79	0.37	6.16	52.70	34.37	8.23
9145920	4.76	0.215	17.49	2000.14	4.94	19.98	74.93	35.98	14.71
9145925	4.78	0.240	29.60	1956.16	5.07	13.77	10.28	38.20	14.02
9145930	4.80	0.261	25.57	1721.59	4.93	15.83	86.09	24.02	9.92
9145935	4.82	0.281	24.22	1610.17	4.93	14.20	58.33	3.39	8.78
9145940	4.84	0.302	24.22	1618.97	4.80	13.18	84.24	31.87	8.72
9145945	4.86	0.322	24.22	1616.04	4.80	13.52	63.88	3.39	8.66
9145950	4.88	0.341	22.88	1621.90	4.80	12.84	58.33	33.98	8.34
9145955	4.90	0.359	21.53	1624.83	4.80	12.51	60.18	35.26	8.22
9150000	4.92	0.378	22.88	1639.49	4.93	10.81	2.74	13.44	7.90
9150005	4.94	0.397	22.88	1642.43	4.93	10.47	52.78	3.39	8.03
9150010	4.97	0.429	39.02	1668.81	4.93	7.43	69.43	34.16	6.71
9150015	4.98	0.444	17.49	1586.72	5.06	16.91	30.57	41.68	7.40
9150020	5.00	0.464	24.22	1665.88	5.06	7.76	87.94	3.39	7.27



RECORD OF TRRL DRILL RUN 2.8 (4.54 to 5.00 metres)

APPENDIX 6
THE CORSHAM DRILLING RECORDS

USER: EX9069 -AT SYSTEM

R_C2.1.1

EX9069

R_C2.1.1

LABEL: PRT001 -FORM

SPOOLED: 82-01-25.18:24
STARTED: 82-01-25.18:27, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4742	0.00	0.000	0.00	2184.92	3.93	2.68	104.51	99.99	8.94
4746	0.00	0.002	3.35	2141.12	0.53	0.83	113.79	99.99	8.50
4750	0.05	0.048	68.69	2176.16	0.66	1.98	97.09	99.99	8.56
4754	0.06	0.063	21.78	1895.82	4.98	20.48	58.82	99.99	5.85
4758	0.06	0.063	0.00	23.92	25.59	170.47	24.81	99.99	-1.35

-626-

USER: EX9369 -AT SYSTEM

R_C2.1.2

EX9369

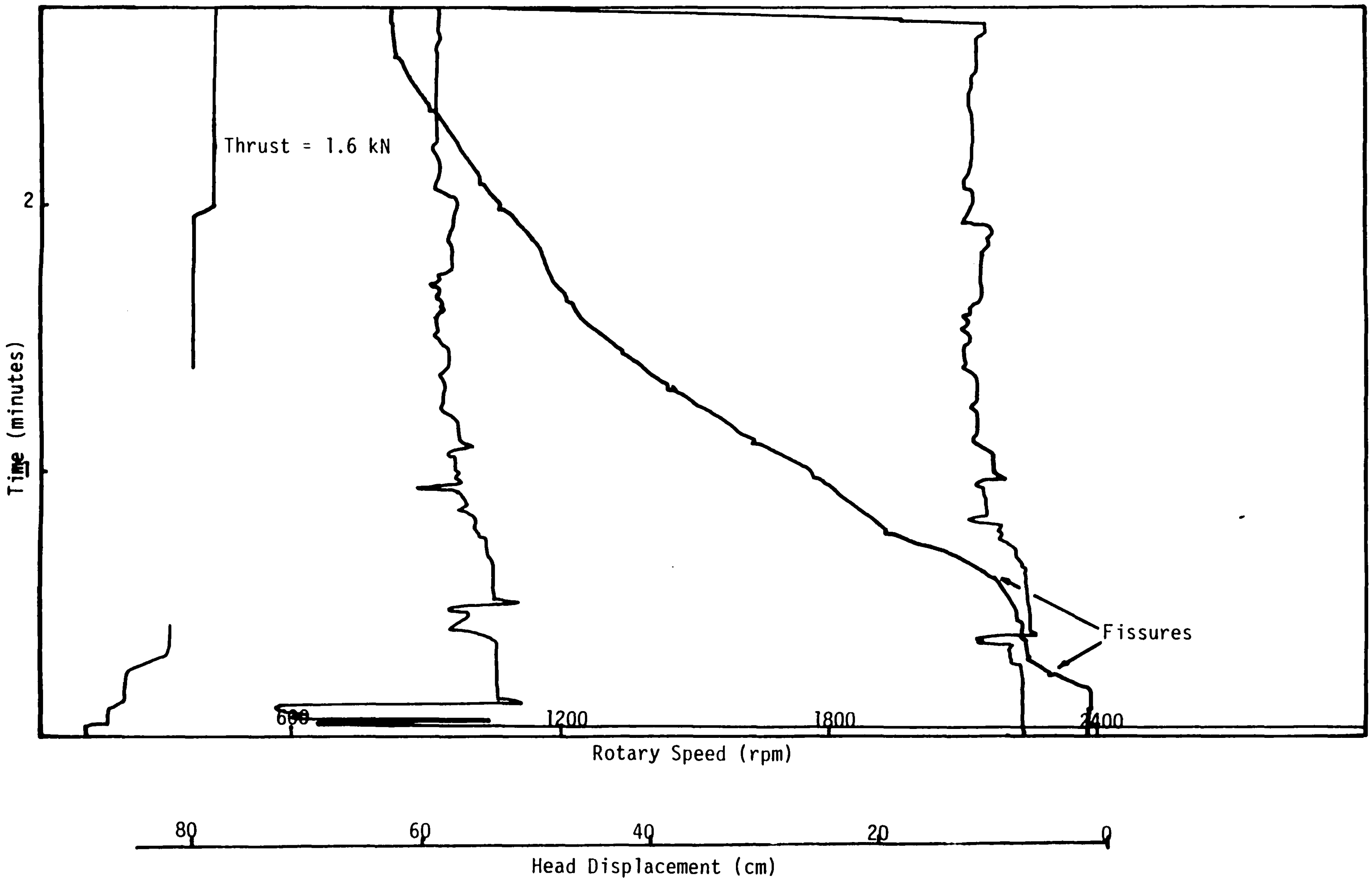
R_C2.1.2

LABEL: PRT002 -FORM

SPOOLED: 82-01-25.18:24
STARTED: 82-01-25.18:27, ON: PRO BY: PRO

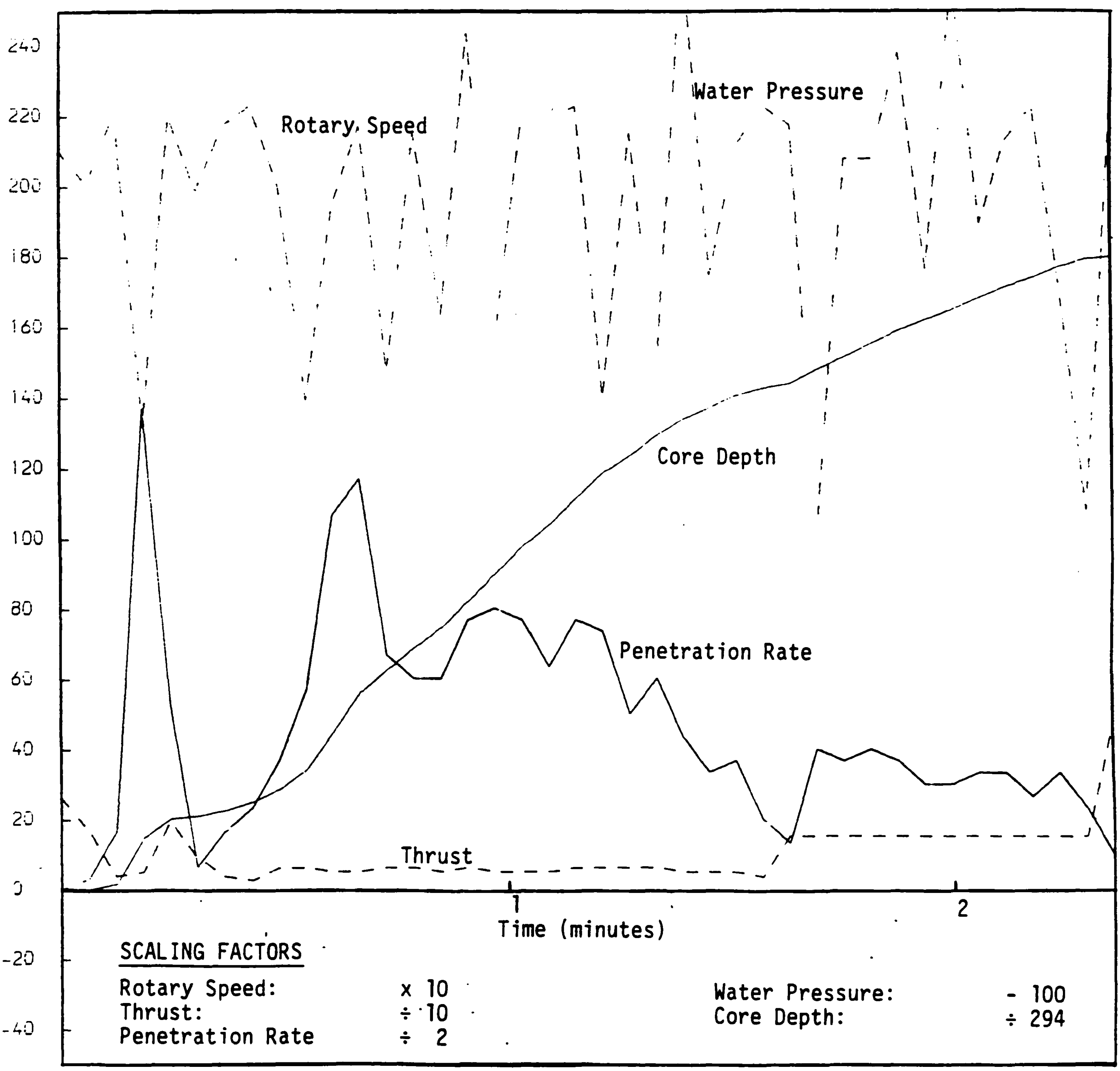
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4818	0.06	0.000	0.00	2193.69	2.62	3.39	110.08	99.99	8.18
4822	0.06	0.001	1.67	2196.61	1.71	3.62	100.87	99.99	8.06
4826	0.07	0.007	8.38	2129.44	0.40	1.76	121.22	99.99	7.74
4830	0.11	0.052	68.69	2164.48	0.53	1.05	32.13	95.99	7.74
4834	0.13	0.070	26.81	2202.45	1.97	4.09	120.07	99.99	7.87
4838	0.13	0.073	3.35	2193.69	0.93	3.39	98.94	95.99	7.87
4842	0.14	0.078	8.38	2182.00	0.40	2.45	117.51	95.99	7.93
4846	0.15	0.086	11.73	2185.67	0.28	0.18	123.08	99.99	8.05
4850	0.16	0.098	18.43	2164.48	0.64	1.05	100.83	99.99	8.25
4854	0.18	0.117	28.48	2144.83	0.64	3.37	39.55	99.99	8.69
4858	0.21	0.153	53.61	2036.89	0.51	11.79	95.27	99.99	7.42
4902	0.25	0.192	58.64	2121.49	0.51	5.19	117.52	99.99	8.61
4906	0.27	0.214	33.51	2086.48	0.64	7.92	47.51	99.99	8.99
4910	0.29	0.235	30.16	2109.82	0.64	6.10	115.66	99.99	8.93
4914	0.31	0.255	30.16	2092.31	0.51	7.46	63.75	99.99	8.80
4918	0.34	0.280	38.53	2089.40	0.64	7.69	143.93	99.99	9.18
4922	0.37	0.307	40.21	2086.48	0.51	7.92	56.33	95.99	8.87
4926	0.39	0.333	38.53	2095.23	0.51	7.24	119.37	99.99	8.87
4930	0.41	0.354	31.83	2103.98	0.51	6.55	119.37	95.99	8.80
4934	0.44	0.380	38.53	2063.14	0.64	9.74	123.08	99.99	9.37
4938	0.46	0.404	36.86	2092.31	0.64	7.46	40.09	99.99	9.62
4942	0.48	0.421	25.13	2083.56	0.64	8.15	115.66	99.99	9.69
4946	0.50	0.441	30.16	2092.31	0.64	7.46	48.91	99.99	9.06
4950	0.52	0.456	21.78	2130.24	0.51	4.50	168.03	99.99	8.36
4954	0.53	0.467	16.75	2106.90	0.51	6.33	74.87	99.99	8.49
4958	0.54	0.479	18.43	2130.24	0.51	4.53	111.96	99.99	8.49
5002	0.55	0.486	10.05	2141.91	0.38	3.59	123.08	99.99	8.17
5006	0.55	0.490	6.70	2060.22	1.55	9.97	117.52	99.99	8.49
5010	0.56	0.504	20.10	2092.31	1.55	7.46	3.01	99.99	8.93
5014	0.58	0.516	18.43	2060.22	1.55	9.97	108.25	99.99	8.99
5018	0.59	0.525	20.10	2083.56	1.55	8.15	108.25	99.99	9.43
5022	0.60	0.542	18.43	2089.40	1.55	7.69	138.36	99.99	8.93
5026	0.61	0.552	15.08	2086.48	1.55	7.92	76.73	99.99	9.06
5030	0.62	0.562	15.08	2083.56	1.55	8.15	158.76	99.99	8.74
5034	0.63	0.573	16.75	2060.22	1.55	9.97	89.71	99.99	9.18
5038	0.64	0.584	16.75	2083.56	1.55	8.15	113.81	99.99	9.06
5042	0.65	0.593	13.40	2098.15	1.55	7.01	123.08	99.99	8.55
5046	0.66	0.604	16.75	2103.98	1.55	6.55	71.16	99.99	8.55
5050	0.67	0.612	11.73	2133.16	1.55	4.28	8.12	99.99	7.92
5054	0.68	0.615	5.03	58.93	4.72	166.15	128.64	99.99	-1.41



RECORD OF CORSHAM DRILL RUN 2.1.2 (0.06 to 0.68 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.1.2 (0.06 to 0.68 metres)



USER: EX9069 -AT SYSTEM

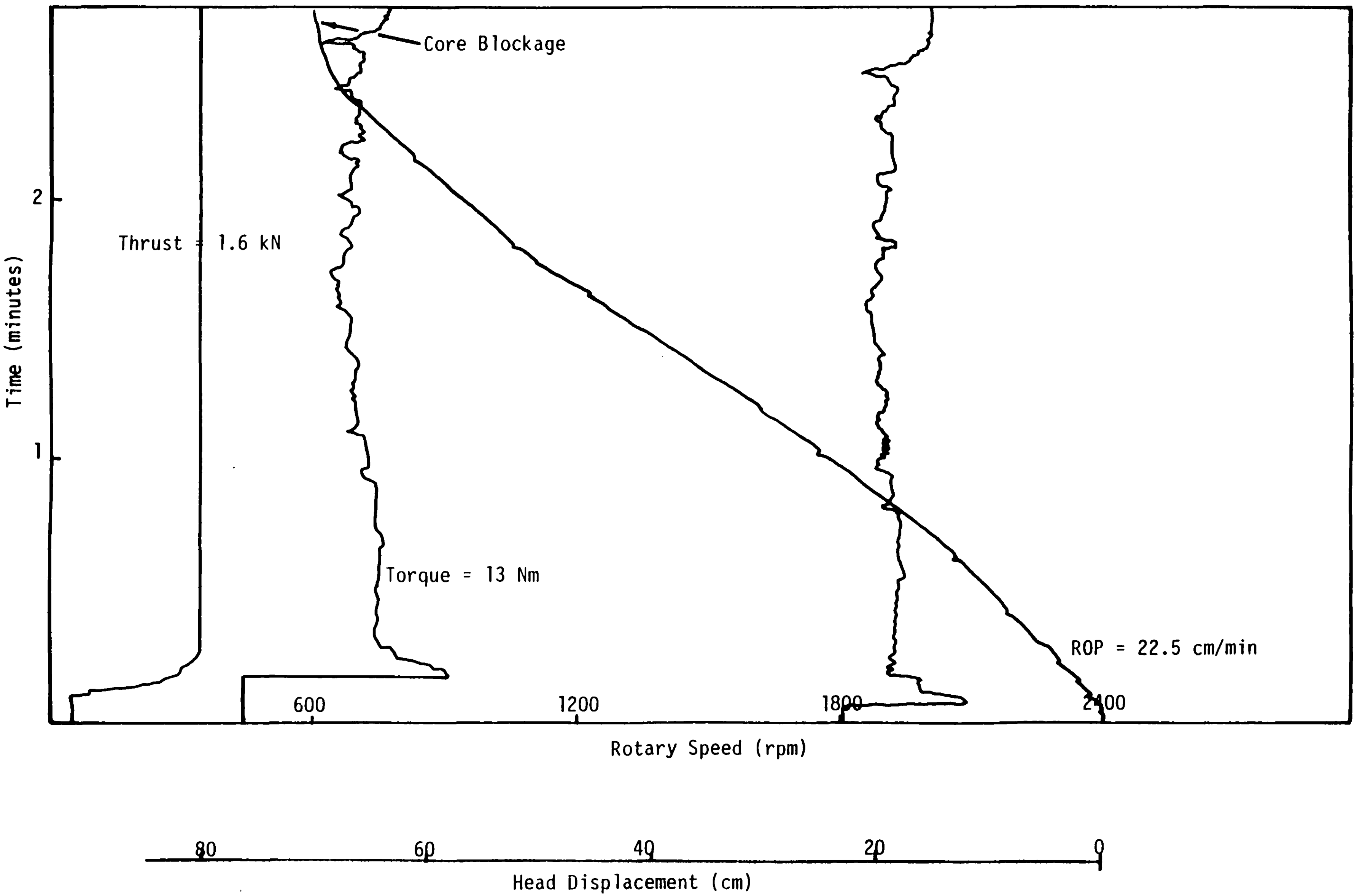
R_C2.2

LABEL: FRT003 -FORM

SPOOLED: 82-01-25.18:24
STARTED: 82-01-25.18:27, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 1
TIME ----	TOTAL DEPTH (M) -----	CORE DEPTH (M) -----	PENETRATN RATE (CM/MIN) ---------	ROTARY SPEED (RPM) ------	THRUST (KN) ------	TORQUE (NM) ------	INLET H2O PRESSURE (KN/M**2) ---------	I. H2O FLOW (L/MIN) -------	INLET OIL PRESSURE (MN/M**2) ---------
22101120	0.68	0.000	0.00	1854.17	4.72	28.16	113.83	3.39	6.21
22101124	0.68	0.001	1.67	2125.21	3.93	7.55	52.89	3.39	9.11
22101128	0.69	0.006	6.69	1996.98	0.76	12.03	158.47	3.39	9.11
22101132	0.70	0.020	21.75	1947.43	1.42	16.01	111.97	99.99	10.05
22101136	0.72	0.037	25.10	1959.09	1.68	15.08	99.01	99.99	9.80
22101140	0.73	0.051	21.75	1973.66	1.55	13.91	100.86	99.99	9.61
22101144	0.75	0.067	21.75	1947.43	1.68	16.01	21.40	99.99	9.93
22101148	0.76	0.083	21.75	1976.58	1.55	13.67	91.60	3.39	9.55
22101152	0.78	0.096	20.08	1988.23	1.55	12.73	110.12	3.39	9.49
22101156	0.79	0.109	20.08	1973.66	1.55	13.91	164.03	3.39	9.23
22101200	0.80	0.125	23.42	1967.83	1.55	14.37	74.93	3.39	9.61
22101204	0.82	0.141	23.42	1973.66	1.55	13.91	102.71	3.39	9.55
22101208	0.84	0.158	23.42	1959.09	1.68	15.08	110.12	3.39	9.30
22101212	0.86	0.178	30.12	1956.18	1.55	15.31	41.58	99.99	9.68
22101216	0.88	0.199	30.12	1953.26	1.55	15.55	62.15	99.99	9.61
22101220	0.90	0.219	30.12	1909.54	1.68	19.06	113.83	3.39	10.12
22101224	0.92	0.240	31.79	1941.60	1.55	16.48	91.60	3.39	9.68
22101228	0.94	0.260	30.12	1915.37	1.55	18.59	113.83	3.39	9.80
22101232	0.96	0.281	31.79	1941.60	1.68	16.48	99.19	99.99	9.80
22101236	0.98	0.302	31.79	1950.35	1.68	15.78	69.37	3.39	9.61
22101240	1.00	0.325	33.46	1918.29	1.68	18.36	95.30	3.39	10.12
22101244	1.03	0.347	33.46	1935.77	1.68	16.95	95.30	3.39	9.74
22101248	1.05	0.369	33.46	1880.40	1.68	21.41	69.56	3.39	10.12
22101252	1.07	0.395	38.48	1894.97	1.68	20.23	108.27	3.39	10.18
22101256	1.10	0.419	36.81	1874.57	1.68	21.87	89.75	3.39	10.43
22101300	1.12	0.444	36.81	1915.37	1.68	18.59	43.44	3.39	10.05
22101304	1.15	0.466	36.81	1894.97	1.68	20.23	227.01	3.39	9.61
22101308	1.17	0.491	33.46	1941.60	1.68	16.48	110.12	3.39	9.49
22101312	1.19	0.513	33.46	1915.37	1.68	18.59	102.71	3.39	9.49
22101316	1.21	0.533	30.12	1932.86	1.68	17.19	102.71	3.39	9.74
22101320	1.23	0.550	25.10	1956.18	1.55	15.31	4.54	3.39	9.42
22101324	1.25	0.567	25.10	1894.97	1.68	20.23	99.01	3.39	9.55
22101328	1.26	0.585	26.77	1962.00	1.68	14.84	215.89	3.39	8.86
22101332	1.28	0.602	26.77	1959.09	1.68	15.08	111.97	3.39	9.30
22101336	1.30	0.617	21.75	1944.52	1.55	16.25	102.71	3.39	9.05
22101340	1.31	0.634	25.10	1941.60	1.68	16.48	99.01	3.39	10.05
22101344	1.33	0.651	26.77	1968.79	1.55	16.78	8.24	3.39	8.92
22101348	1.35	0.666	21.75	1944.52	1.55	16.25	100.86	3.39	8.73
22101352	1.36	0.683	25.10	2008.64	1.68	11.09	100.86	3.39	9.05
22101356	1.37	0.693	16.75	2055.27	1.55	7.34	56.59	3.39	8.04
22101400	1.38	0.698	8.37	2055.27	1.55	7.34	15.65	3.39	7.72
22101404	1.38	0.704	8.37	2064.01	1.42	6.64	99.01	3.39	7.60
22101408	1.39	0.706	3.35	23.92	4.72	169.09	113.84	3.39	-1.35



RECORD OF CORSHAM DRILL RUN 2.2 (0.68 to 1.39 metres)

USER: EX9069 -AT SYSTEM

R_C2.3

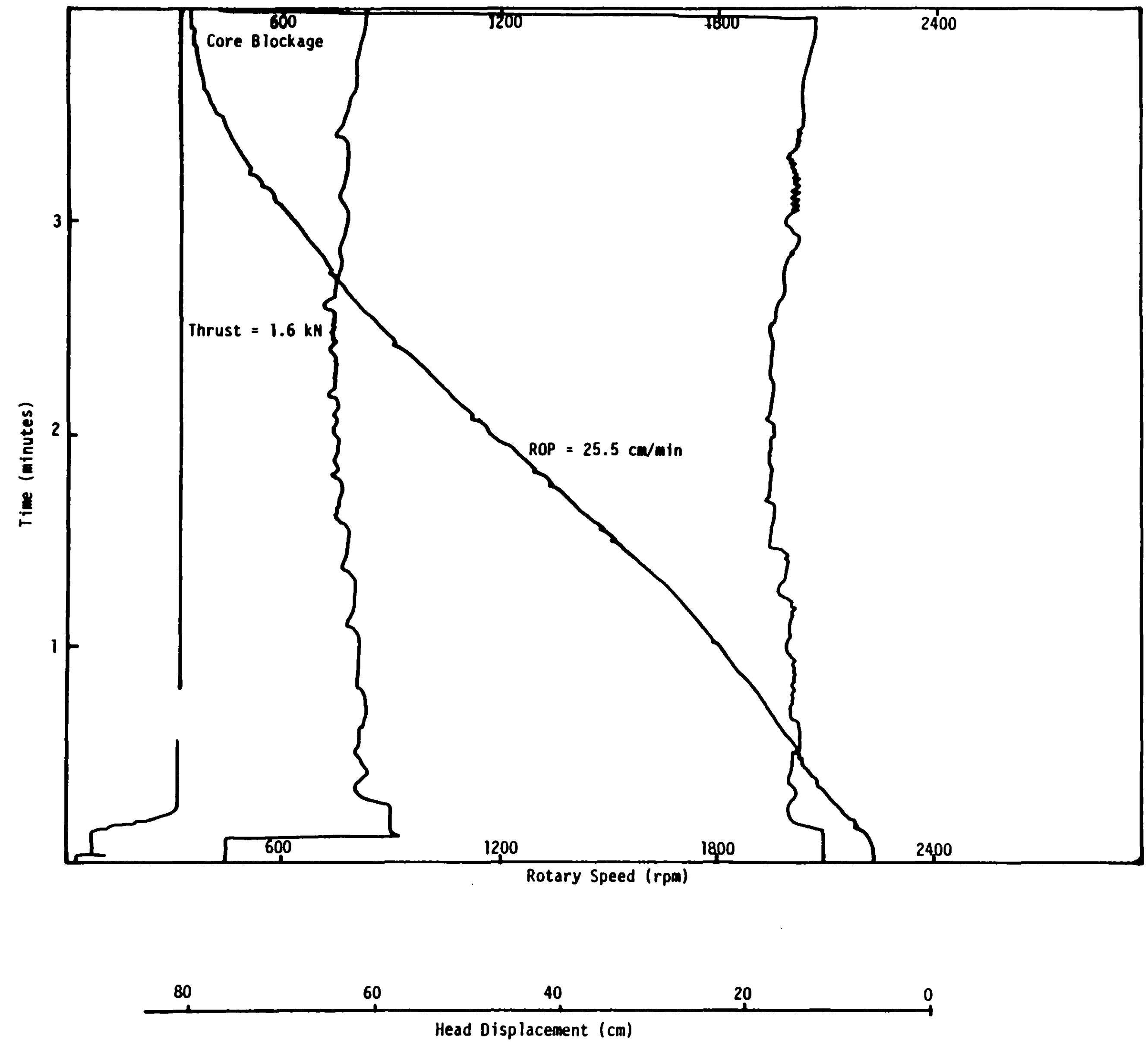
LABEL: PRT004 -FORM

SPOOLED: 82-01-25.18:24
STARTED: 82-01-25.18:27, ON: PR0 BY: PR0

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
22102808	1.39	0.000	0.00	2145.61	3.93	5.99	73.26	99.99	8.60
22102812	1.39	0.001	1.67	2125.21	4.06	1.72	110.12	3.39	7.66
22102816	1.39	0.001	0.00	2116.47	1.06	8.21	100.86	99.99	7.72
22102820	1.40	0.010	13.39	2011.55	1.42	16.19	99.01	99.99	9.11
22102824	1.42	0.026	23.42	2037.78	1.42	14.20	86.23	3.39	9.05
22102828	1.43	0.039	20.08	2046.52	1.42	13.53	108.27	99.99	8.48
22102832	1.44	0.054	21.75	2017.38	1.42	15.75	95.30	3.39	9.05
22102836	1.45	0.068	21.75	2043.61	1.42	13.75	117.53	3.39	8.73
22102840	1.47	0.080	18.40	2066.92	1.42	11.98	134.39	99.99	8.42
22102844	1.48	0.089	13.39	2078.58	1.29	11.09	76.78	3.39	7.98
22102848	1.49	0.098	13.39	2034.86	1.42	8.98	102.71	99.99	8.23
22102852	1.50	0.112	20.08	2043.61	1.42	8.28	82.34	99.99	8.67
22102856	1.51	0.123	16.73	2046.52	1.42	8.05	17.53	99.99	8.42
22102900	1.52	0.134	16.73	2052.35	1.42	7.56	97.16	99.99	8.35
22102904	1.53	0.144	15.06	2037.78	1.42	8.75	232.57	3.39	8.29
22102908	1.55	0.157	20.08	2023.21	1.42	9.92	108.27	99.99	9.05
22102912	1.56	0.170	18.41	2034.86	1.42	8.98	104.56	99.99	8.35
22102916	1.57	0.182	18.41	2046.52	1.42	8.05	84.19	95.99	8.35
22102920	1.58	0.194	18.41	2026.12	1.42	9.69	65.85	95.99	8.23
22102924	1.60	0.209	21.75	2008.64	1.42	11.09	117.53	95.99	9.05
22102928	1.61	0.223	21.75	2014.46	1.42	10.62	89.75	99.99	8.48
22102932	1.63	0.236	21.75	2037.78	1.42	8.75	113.83	99.99	8.48
22102936	1.64	0.252	21.75	1970.75	1.55	14.14	130.69	99.99	8.92
22102940	1.66	0.270	26.77	1996.98	1.42	12.03	34.18	99.99	8.86
22102944	1.68	0.287	25.10	2011.55	1.42	10.86	106.42	99.99	8.67
22102948	1.69	0.302	23.42	1959.09	1.55	15.08	110.12	99.99	8.92
22102952	1.71	0.320	26.77	1988.23	1.55	12.73	89.93	99.99	8.86
22102956	1.73	0.337	25.10	1994.06	1.42	12.27	111.97	99.99	8.86
22103000	1.74	0.354	25.10	1964.92	1.55	14.61	87.89	99.99	9.05
22103004	1.76	0.370	25.10	1988.23	1.55	12.73	71.22	99.99	6.92
22103008	1.78	0.387	25.10	2008.64	1.42	11.09	254.79	99.99	8.73
22103012	1.79	0.403	23.42	1959.09	1.55	15.08	113.83	99.99	8.79
22103016	1.81	0.419	25.10	1996.98	1.55	12.03	110.12	99.99	8.73
22103020	1.83	0.436	25.10	2000.82	1.55	14.27	12.13	99.99	8.67
22103024	1.84	0.451	21.75	1976.58	1.55	13.67	76.78	99.99	8.54
22103028	1.86	0.470	26.77	1989.18	1.55	15.18	100.86	99.99	8.67
22103032	1.88	0.486	23.42	1985.32	1.55	12.97	56.59	99.99	8.73
22103036	1.89	0.502	23.42	1965.88	1.55	17.01	108.27	99.99	8.60
22103040	1.91	0.520	26.77	2000.82	1.55	14.27	102.71	99.99	8.54
22103044	1.93	0.535	23.42	2014.46	1.55	10.62	41.77	99.99	8.35
22103048	1.94	0.548	18.41	2029.94	1.55	11.99	117.53	99.99	7.91
22103052	1.95	0.562	21.75	2015.38	1.55	13.13	201.07	99.99	8.29
22103056	1.97	0.577	21.75	2035.76	1.55	11.53	76.78	99.99	7.85
22103100	1.98	0.589	18.41	2056.14	1.54	9.94	243.31	99.99	7.71
22103104	1.99	0.595	15.06	2053.23	1.42	10.17	115.68	95.99	7.47
22103108	2.00	0.612	20.08	2021.20	1.55	12.67	113.83	99.99	8.29
22103112	2.02	0.626	20.08	2053.23	1.55	10.17	52.89	99.99	7.60
22103116	2.03	0.637	16.73	2053.23	1.55	10.17	100.86	99.99	7.66
22103120	2.04	0.648	16.73	2059.05	1.55	9.71	132.54	99.99	7.47
22103124	2.05	0.660	18.40	2003.73	1.55	14.04	91.60	99.99	7.79
22103128	2.06	0.675	21.75	2059.05	1.55	9.71	260.35	99.99	7.72
22103132	2.08	0.686	16.73	2070.70	1.42	8.80	110.12	99.99	7.41
22103136	2.08	0.695	13.39	2091.08	1.42	7.20	113.83	99.99	7.03
22103140	2.09	0.703	11.71	2088.17	1.42	7.43	102.71	99.99	6.97

	TOTAL	CORE	PENETRAIN	ROTARY			INLET H2O	I. H2O	
22103144	2.10	0.712	13.39	2067.79	1.42	9.03	69.37	99.99	7.16
22103148	2.11	0.721	13.39	2093.99	1.42	6.97	99.01	99.99	6.97
22103152	2.12	0.727	10.04	2105.63	1.42	6.06	110.12	99.99	6.65
22103156	2.12	0.732	6.69	2117.28	1.55	5.15	99.19	99.99	6.59
22103200	2.12	0.734	3.35	2123.10	1.55	4.69	17.53	99.99	6.46
22103204	2.13	0.736	3.35	2123.10	1.55	4.69	108.27	99.99	6.40



RECORD OF CORSHAM DRILL RUN 2.3 (1.39 to 2.13 metres)

USER: EX9069 -AT SYSTEM

R_C2.4.1

****
****

EX9069

R_C2.4.1

****
****

LABEL: FRT005 -FORM

SPOOLED: 82-01-25.18:24
STARTED: 82-01-25.18:27, ON: PRO BY: PRO

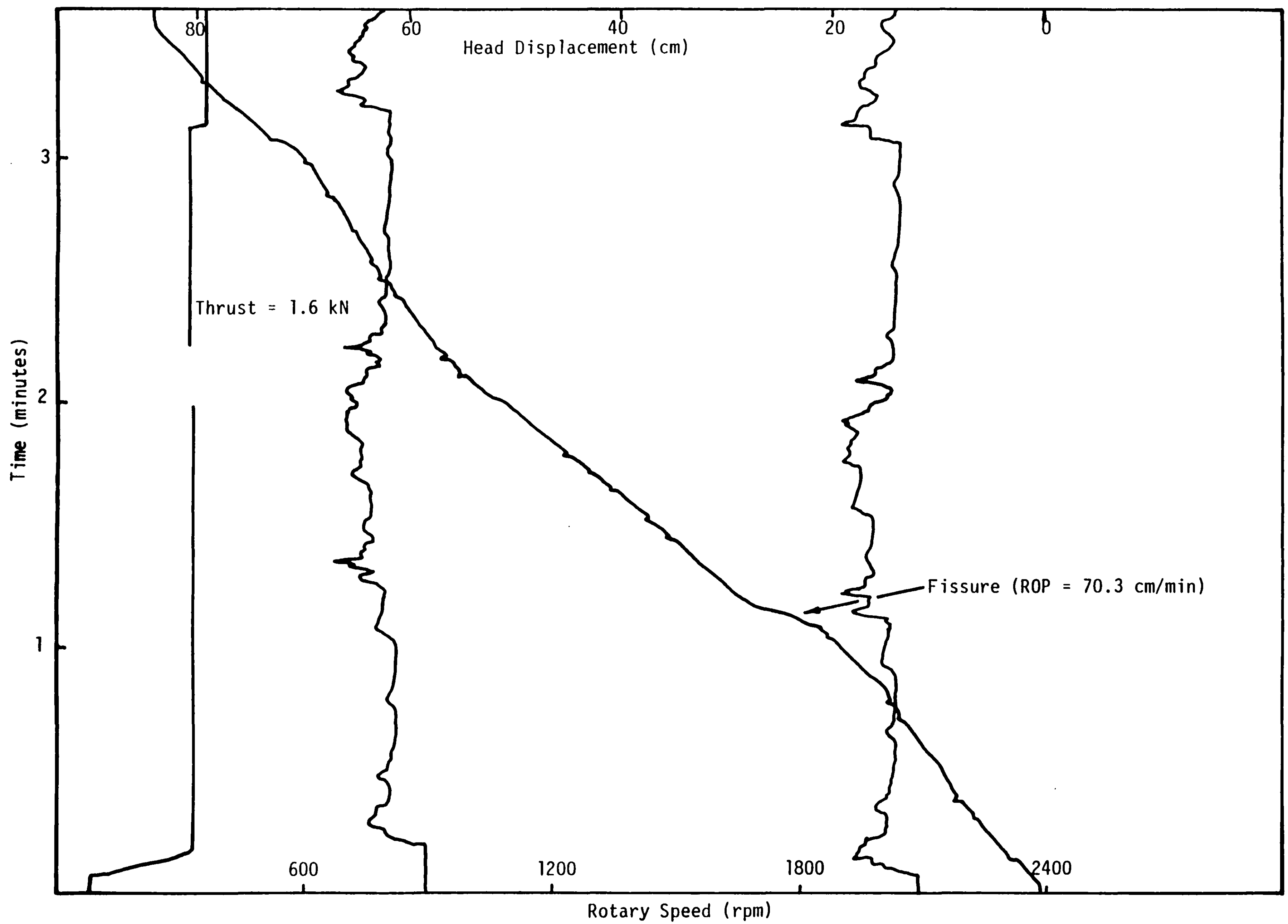
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
22104900	2.13	0.000	0.00	2125.21	3.54	1.72	84.19	99.99	7.60
22104904	2.13	0.001	1.67	2066.92	0.02	6.41	106.42	99.99	7.53
22104908	2.14	0.013	18.40	1962.00	1.55	14.84	69.37	99.99	9.49
22104912	2.16	0.031	26.77	2008.64	1.42	11.09	99.01	99.99	9.17
22104916	2.18	0.047	23.42	2052.35	1.55	7.58	69.37	99.99	8.60
22104920	2.19	0.061	21.75	2002.81	1.55	11.56	93.45	99.99	8.60
22104924	2.21	0.078	25.10	2055.27	1.42	7.34	111.97	99.99	8.48
22104928	2.22	0.090	18.40	2064.01	1.42	6.64	104.56	99.99	8.23
22104932	2.23	0.102	16.73	2081.50	1.42	5.23	95.30	99.99	7.91
22104936	2.24	0.110	13.39	2066.92	1.55	6.41	1.02	99.99	7.98
22104940	2.25	0.123	18.40	2061.09	1.42	6.87	36.03	99.99	8.54
22104944	2.26	0.135	18.40	2072.75	1.55	5.94	104.56	99.99	7.91
22104948	2.28	0.146	16.73	2075.67	1.55	5.70	97.16	99.99	7.79
22104952	2.29	0.155	13.39	2075.67	1.55	5.70	24.91	99.99	7.66
22104956	2.30	0.166	16.73	2008.64	1.55	11.09	152.91	99.99	8.42
22105000	2.31	0.184	26.77	2046.52	1.42	8.05	110.12	99.99	8.23
22105004	2.33	0.200	23.42	2055.27	1.42	7.34	106.42	99.99	8.23
22105008	2.35	0.215	23.42	1970.75	1.55	14.14	6.39	99.99	8.73
22105012	2.38	0.248	48.52	1947.43	1.42	16.01	100.86	99.99	7.98
22105016	2.42	0.294	70.28	2002.81	1.55	11.56	89.75	99.99	8.79
22105020	2.44	0.313	28.44	1985.32	1.55	12.97	113.83	99.99	8.60
22105024	2.46	0.330	25.10	2018.29	1.55	12.90	204.78	99.99	8.67
22105028	2.48	0.347	25.10	2014.46	1.55	10.62	58.26	99.99	8.48
22105032	2.49	0.361	21.75	1982.41	1.55	13.20	102.71	99.99	8.54
22105036	2.51	0.380	28.44	1982.41	1.55	13.20	69.37	99.99	9.05
22105040	2.53	0.399	28.44	1985.32	1.55	12.97	21.42	99.99	8.86
22105044	2.55	0.418	28.44	1942.59	1.55	18.83	104.56	99.99	8.86
22105048	2.57	0.439	31.79	1947.43	1.55	16.01	89.75	99.99	9.23
22105052	2.59	0.458	28.44	1967.83	1.55	14.37	65.67	99.99	8.73
22105056	2.61	0.479	30.12	1986.26	1.55	15.41	225.16	99.99	9.23
22105100	2.63	0.496	26.77	2035.76	1.54	11.53	21.32	99.99	8.22
22105104	2.64	0.514	26.77	1997.91	1.55	14.50	15.65	99.99	7.53
22105108	2.67	0.540	26.77	2024.11	1.55	12.45	108.27	99.99	8.10
22105112	2.69	0.558	26.77	2076.52	1.55	8.34	106.42	99.99	7.53
22105116	2.70	0.571	21.75	2035.76	1.55	11.53	108.46	99.99	7.47
22105120	2.72	0.587	23.42	2076.52	1.41	8.34	25.02	99.99	7.21
22105124	2.73	0.598	16.73	2082.34	1.42	7.89	100.86	99.99	7.22
22105128	2.74	0.608	15.06	2091.08	1.42	7.20	63.81	99.99	7.09
22105132	2.75	0.618	15.06	2076.52	1.42	8.34	6.58	99.99	7.03
22105136	2.76	0.631	20.08	2073.61	1.42	8.57	106.42	99.99	7.41
22105140	2.77	0.643	16.73	2088.17	1.41	7.43	93.49	99.99	6.96
22105144	2.78	0.653	15.06	2093.99	1.41	6.97	115.69	99.99	6.90
22105148	2.79	0.661	13.39	2096.90	1.41	6.75	43.45	99.99	6.83
22105152	2.80	0.670	13.39	2067.79	1.41	9.03	106.44	99.99	6.90
22105156	2.81	0.684	20.08	2091.08	1.41	7.20	80.53	99.99	7.15
22105200	2.82	0.694	15.06	2091.08	1.41	7.20	21.24	99.99	6.90
22105204	2.83	0.703	13.39	2029.94	2.19	11.99	106.44	99.99	7.02
22105208	2.85	0.719	25.10	1948.41	2.45	18.37	89.79	99.99	8.41
22105212	2.87	0.743	35.14	1968.79	2.45	16.78	111.99	99.99	8.59
22105216	2.89	0.763	30.12	1997.91	2.46	14.50	193.67	99.99	7.85
22105220	2.91	0.784	31.79	1995.00	2.45	14.73	47.23	99.99	8.53
22105224	2.93	0.802	26.77	2015.38	2.32	13.13	102.74	99.99	7.90
22105228	2.95	0.815	20.08	2076.52	2.32	8.34	91.64	99.99	7.08
22105232	2.96	0.828	20.08	2015.38	2.46	13.13	95.30	99.99	7.66

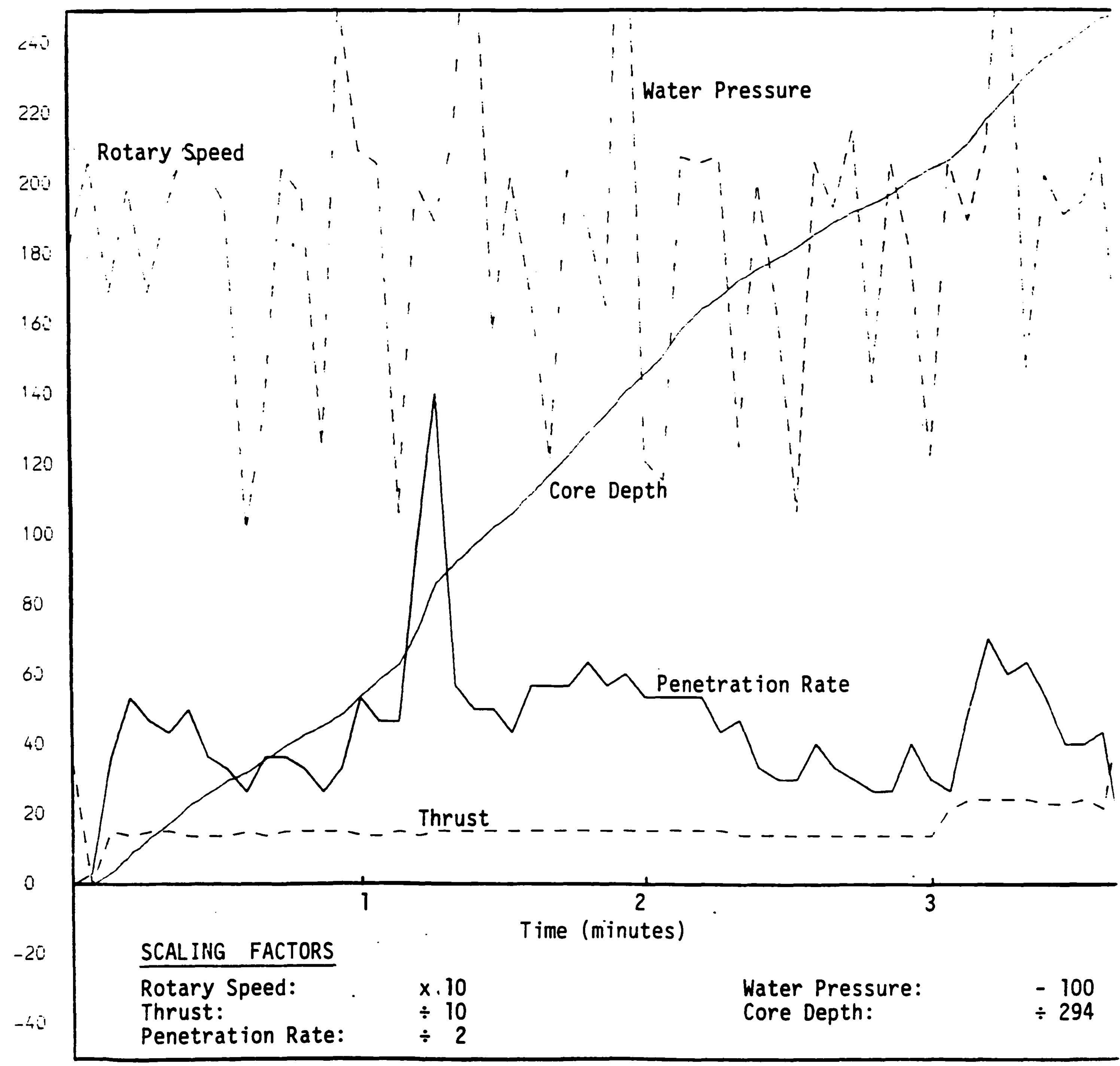
	TOTAL	CORE	PENETRATN	ROTARY			INLET H20	I. H20	
22165236	2.97	0.843	21.75	2114.37	2.19	5.36	108.29	99.99	7.02
22165240	2.98	0.847	5.02	1183.86	4.98	77.42	43.45	99.99	5.26

-640-

RECORD OF CORSHAM DRILL RUN 2.4.1 (2.13 to 2.98 metres)



COMPUTER RECORD OF CORSHAM DRILL RUN 2.4.1 (2.13 to 2.98 metres)



USER: EX9069 -AT SYSTEM

R_C2.4.2

EX9069

R_C2.4.2

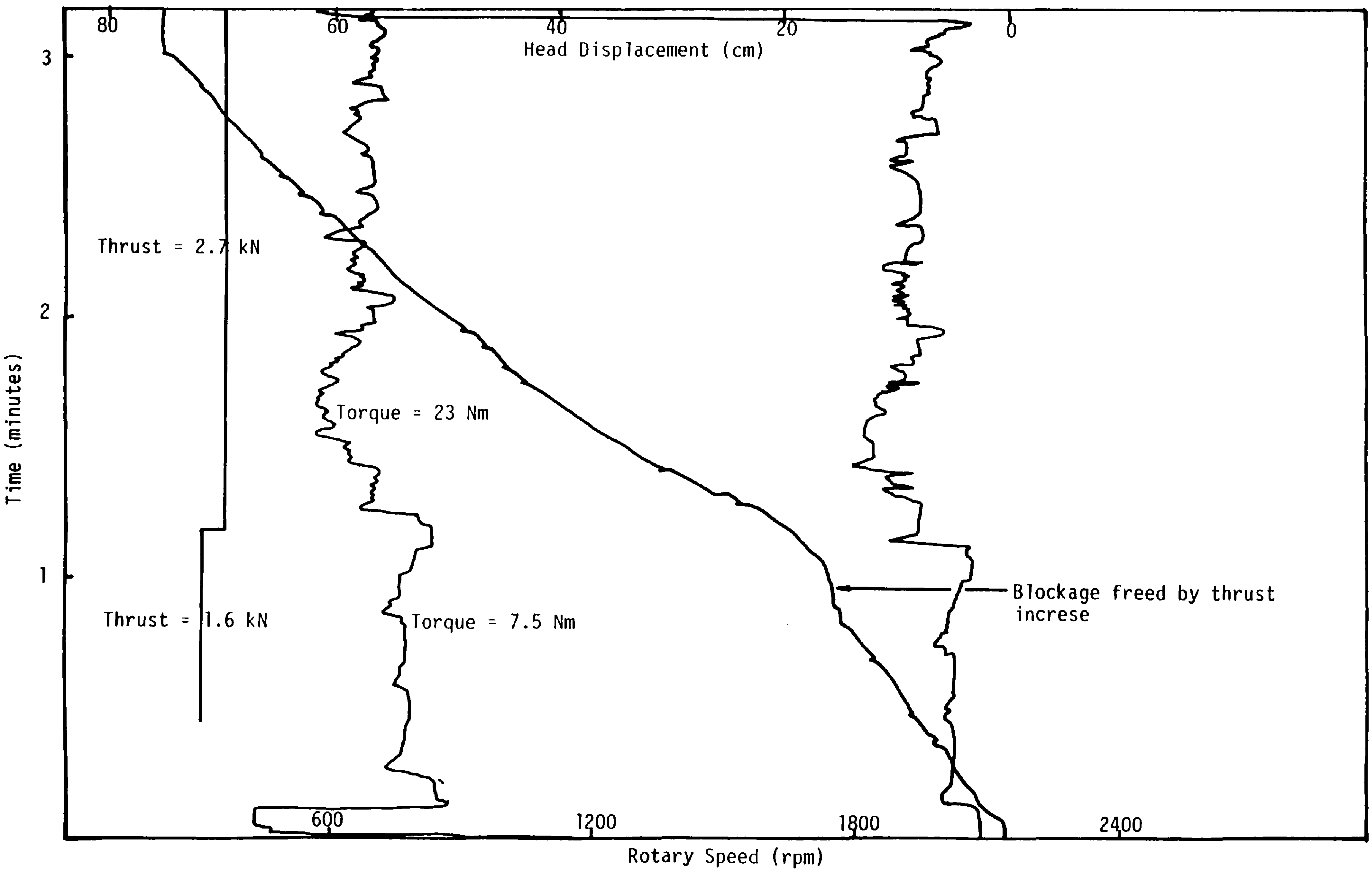
LABEL: FRT006 -FORM

SPOOLED: 82-01-25.18:24
STARTED: 82-01-25.18:28, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

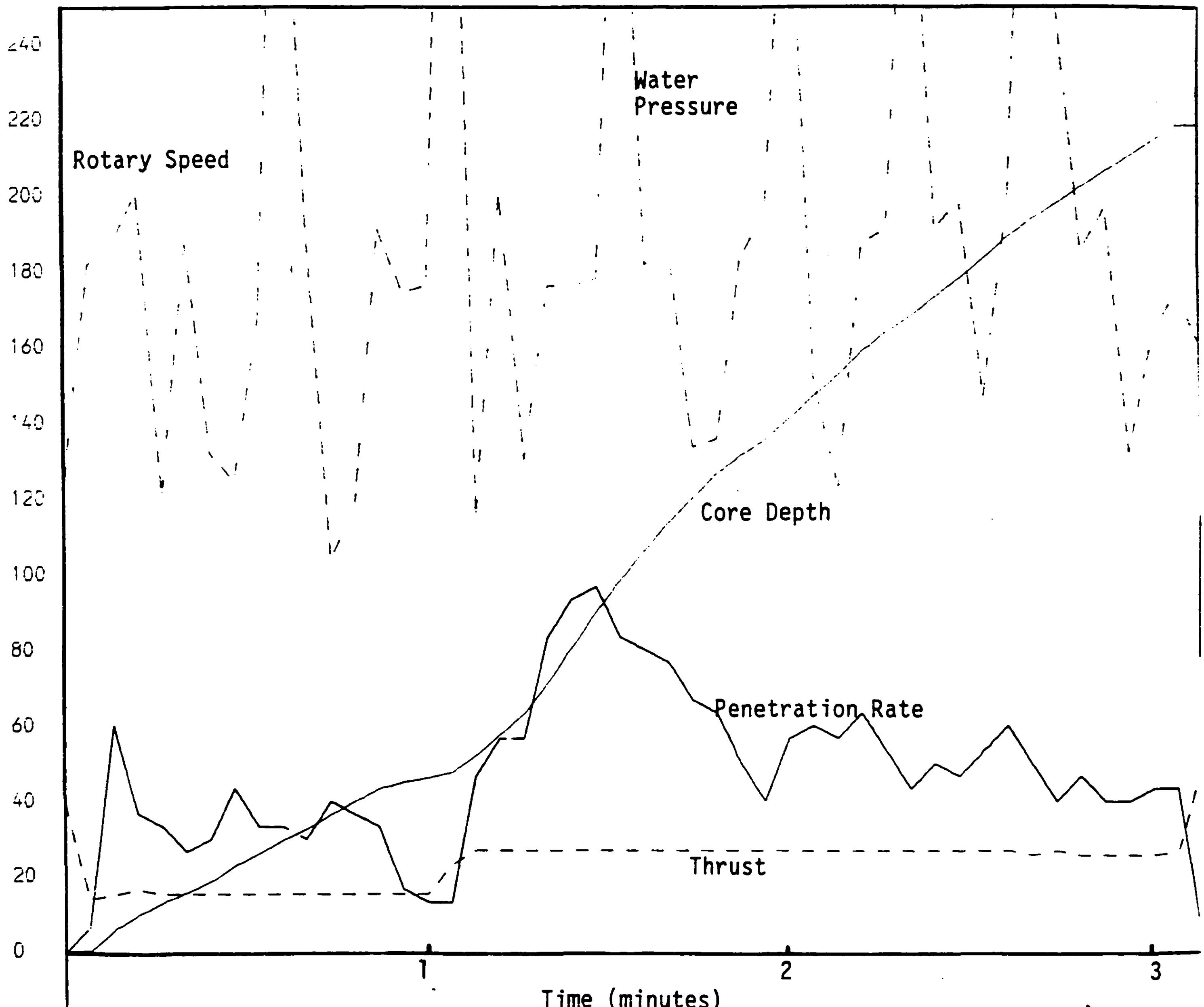
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
22105328	2.98	0.000	0.00	2128.13	3.93	1.48	26.77	99.99	6.46
22105332	2.98	0.002	3.35	2037.78	1.42	8.75	82.34	99.99	6.46
22105336	3.00	0.022	30.12	2055.27	1.55	7.34	87.89	99.99	7.66
22105340	3.01	0.035	18.40	2064.01	1.66	6.64	101.05	99.99	7.16
22105344	3.03	0.046	16.73	2084.41	1.55	5.00	21.21	99.99	7.03
22105348	3.03	0.055	13.39	2087.32	1.55	4.77	87.89	99.99	6.78
22105352	3.04	0.065	15.06	2017.38	1.55	10.39	32.32	99.99	7.16
22105356	3.06	0.075	21.75	2037.78	1.55	8.75	25.10	95.99	7.22
22105400	3.07	0.090	16.73	2064.01	1.55	6.64	67.52	99.99	6.90
22105404	3.08	0.102	16.73	2069.84	1.55	6.17	247.38	99.99	7.09
22105408	3.09	0.112	15.06	2055.27	1.55	7.34	95.33	99.99	7.09
22105412	3.10	0.125	20.08	2055.27	1.55	7.34	4.54	99.99	7.66
22105416	3.12	0.137	18.40	2049.44	1.55	7.81	17.69	99.99	7.28
22105420	3.13	0.148	16.73	2090.24	1.55	4.53	91.63	99.99	6.72
22105424	3.13	0.154	8.37	2122.30	1.55	1.95	74.93	99.99	6.53
22105428	3.14	0.158	6.69	2119.38	1.55	2.19	76.76	99.99	6.72
22105432	3.14	0.163	6.69	2011.55	2.33	10.86	289.99	99.99	6.65
22105436	3.16	0.178	23.42	1996.98	2.72	12.03	15.65	99.99	8.04
22105440	3.18	0.197	28.44	1999.89	2.72	11.80	100.86	99.99	8.04
22105444	3.20	0.216	28.44	1921.20	2.72	18.12	30.66	99.99	8.48
22105448	3.22	0.244	41.83	1924.12	2.72	17.89	76.78	99.99	8.98
22105452	3.26	0.276	46.85	1863.98	2.72	24.99	76.78	99.99	10.18
22105456	3.29	0.308	48.52	1865.83	2.72	22.58	78.63	99.99	9.42
22105500	3.32	0.336	41.83	1845.43	2.72	24.22	234.42	99.99	9.61
22105504	3.34	0.363	40.16	1865.83	2.72	22.58	82.34	99.99	9.05
22105508	3.37	0.388	38.48	1913.48	2.72	21.11	86.04	99.99	9.11
22105512	3.39	0.410	33.46	1938.69	2.72	16.72	34.18	99.99	8.35
22105516	3.41	0.432	31.79	2002.81	2.72	11.56	36.21	99.99	8.04
22105520	3.43	0.448	25.10	2029.04	2.72	9.45	84.19	99.99	8.04
22105524	3.44	0.462	20.08	1947.43	2.72	16.01	95.30	99.99	7.72
22105528	3.46	0.481	28.44	1944.52	2.72	16.25	206.63	99.99	8.23
22105532	3.48	0.501	30.12	1947.43	2.72	16.01	52.75	99.99	8.42
22105536	3.50	0.520	28.44	1877.49	2.71	21.64	23.09	99.99	8.09
22105540	3.52	0.541	31.79	1964.92	2.72	14.61	87.89	95.99	8.29
22105544	3.54	0.559	26.77	2020.29	2.72	10.16	91.60	99.99	7.47
22105548	3.55	0.573	21.75	1959.09	2.72	15.08	217.75	99.99	8.23
22105552	3.57	0.590	25.10	1996.98	2.72	12.03	91.60	99.99	7.53
22105556	3.59	0.606	23.42	1976.58	2.72	13.67	99.01	99.99	7.79
22105600	3.60	0.624	26.77	1918.29	2.72	18.36	47.33	99.99	8.23
22105604	3.62	0.644	30.12	1956.18	2.72	15.31	99.01	99.99	8.04
22105608	3.64	0.660	25.10	2043.61	2.59	8.28	258.50	99.99	7.47
22105612	3.65	0.674	20.08	1964.92	2.72	14.61	151.06	99.99	7.35
22105616	3.67	0.689	23.42	2014.46	2.59	10.52	86.04	99.99	7.53
22105620	3.68	0.703	20.08	2002.81	2.59	11.56	97.16	99.99	7.28
22105624	3.70	0.716	20.08	2037.78	2.59	8.75	32.51	99.99	6.90
22105628	3.71	0.731	21.75	1991.15	2.59	12.50	63.81	99.99	7.66
22105632	3.73	0.745	21.75	2128.13	2.71	1.48	74.98	99.99	6.71
22105636	3.73	0.746	1.67	23.92	4.85	169.09	60.18	99.99	-1.35

-644-



RECORD OF CORSHAM DRILL RUN 2.4.2 (2.98 to 3.73 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.4.2 (2.98 to 3.73 metres)



SCALING FACTORS

Rotary Speed:	x 10	Water Pressure:	- 100
Thrust:	÷ 10	Core Depth:	÷ 294
Penetration Rate:	÷ 2		

USER: EX9069 -AT SYSTEM

R_C2.5

EX9069

R_C2.5

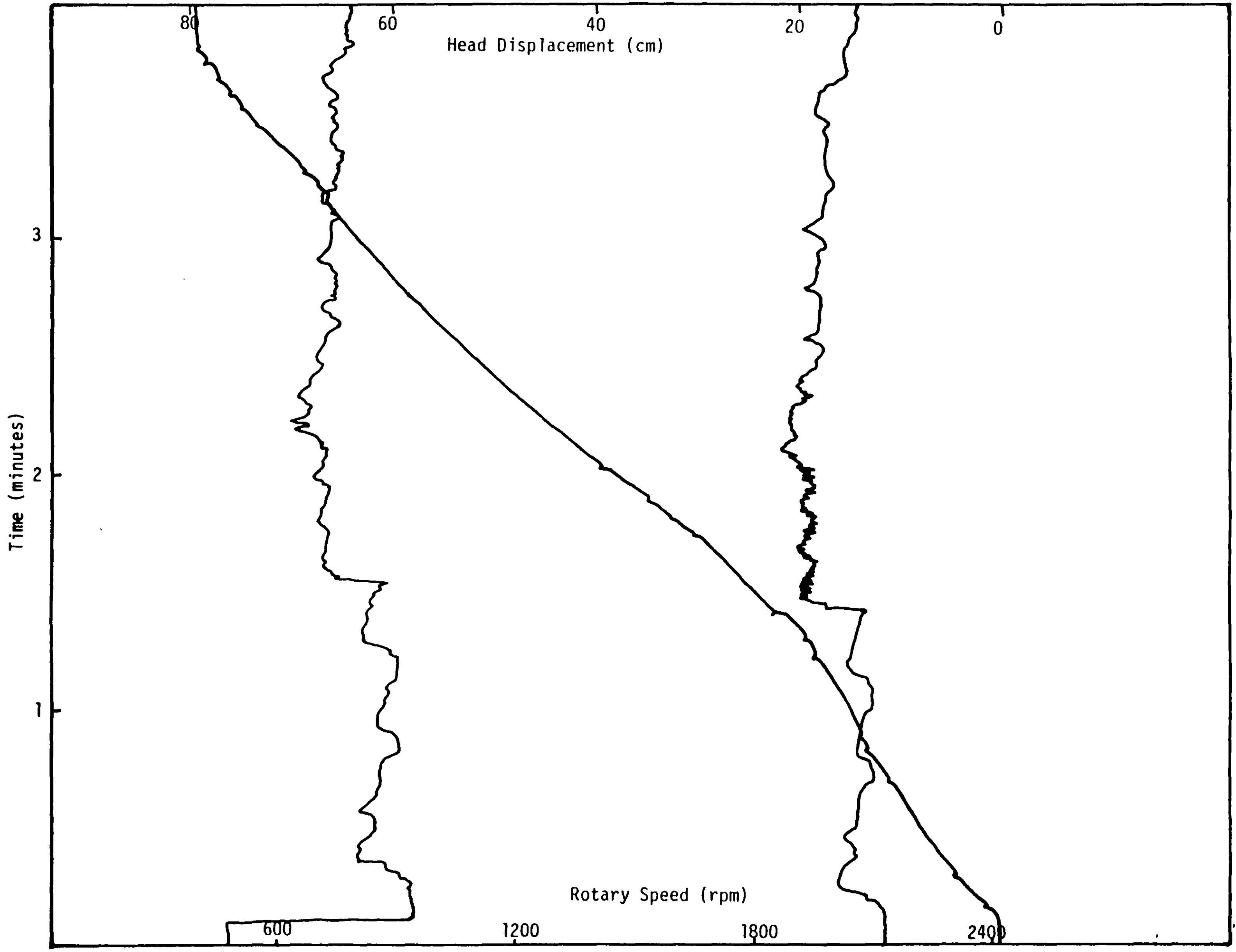
LABEL: FRT007 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:28, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
22111634	3.73	0.000	0.00	2154.36	3.93	5.33	45.29	99.99	6.09
22111638	3.73	0.001	1.67	2139.78	3.93	6.44	84.19	99.99	7.28
22111642	3.73	0.001	0.00	2139.78	0.72	6.44	67.52	99.99	7.16
22111646	3.74	0.006	6.69	2072.75	1.55	11.54	64.00	99.99	7.53
22111650	3.75	0.021	23.42	2017.38	1.68	15.75	86.04	99.99	8.86
22111654	3.77	0.040	28.44	2040.69	1.68	13.97	74.93	99.99	8.54
22111658	3.78	0.055	21.75	2058.18	1.55	12.64	26.95	99.99	7.98
22111702	3.80	0.069	21.75	2040.69	1.55	13.97	195.52	99.99	8.73
22111706	3.81	0.083	20.08	2075.67	1.68	5.70	93.45	99.99	7.98
22111710	3.82	0.093	15.06	2087.32	1.55	10.43	65.67	99.99	7.79
22111714	3.83	0.102	15.06	2110.64	1.68	2.89	64.00	99.99	7.41
22111718	3.84	0.108	10.04	2110.64	1.55	2.89	69.37	99.99	7.47
22111722	3.85	0.117	13.39	2049.44	1.55	13.31	93.45	99.99	7.66
22111726	3.86	0.129	18.40	2081.50	1.68	10.87	125.13	99.99	7.72
22111730	3.87	0.139	15.06	2093.15	1.68	4.30	91.60	99.99	7.72
22111734	3.88	0.148	13.39	2119.38	1.68	2.19	86.04	99.99	7.60
22111738	3.89	0.155	10.04	2119.38	1.55	2.19	74.93	99.99	7.22
22111742	3.89	0.163	11.71	2061.09	1.55	6.87	84.19	99.99	7.66
22111746	3.90	0.174	16.73	2029.04	1.68	9.45	74.93	99.99	8.29
22111750	3.91	0.184	15.06	2052.35	1.68	7.58	15.65	99.99	8.04
22111754	3.92	0.193	13.39	2064.01	1.68	6.64	239.97	99.99	7.79
22111758	3.93	0.201	11.71	2098.98	1.68	3.83	97.16	99.99	7.60
22111802	3.94	0.211	15.06	1927.03	2.72	17.66	87.89	99.99	9.05
22111806	3.96	0.229	26.77	1935.77	2.72	16.95	43.44	99.99	9.36
22111810	3.98	0.245	25.10	1944.52	2.72	16.25	4.54	99.99	9.30
22111814	3.99	0.262	25.10	1924.12	2.72	17.89	86.04	99.99	9.05
22111818	4.01	0.280	26.77	1935.77	2.72	16.95	99.01	99.99	9.42
22111822	4.03	0.297	25.10	1953.26	2.72	15.55	234.42	99.99	9.11
22111826	4.04	0.315	26.77	1900.80	2.85	19.76	91.60	99.99	9.17
22111830	4.06	0.335	30.12	1947.43	2.72	16.01	99.01	99.99	9.17
22111834	4.08	0.352	26.77	1927.03	2.72	17.66	67.70	99.99	8.92
22111838	4.10	0.370	26.77	1862.91	2.85	22.81	100.86	99.99	9.55
22111842	4.13	0.396	38.48	1897.89	2.85	20.00	236.27	99.99	10.24
22111846	4.15	0.416	30.12	1877.49	2.85	21.64	0.83	99.99	9.61
22111850	4.17	0.435	28.44	1903.72	2.72	19.53	180.73	99.99	9.49
22111854	4.18	0.454	28.44	1941.60	2.72	16.48	2.68	99.99	9.23
22111858	4.20	0.473	28.44	1918.29	2.72	18.36	11.95	99.99	9.42
22111902	4.22	0.492	28.44	1962.00	2.72	14.84	78.63	99.99	8.79
22111906	4.24	0.509	25.10	1994.06	2.72	12.27	95.30	99.99	8.29
22111910	4.25	0.524	23.42	1947.43	2.72	16.01	241.83	99.99	8.92
22111914	4.27	0.541	25.10	1985.32	2.72	12.97	87.89	99.99	8.35
22111918	4.29	0.557	23.42	1991.15	2.72	12.50	89.75	99.99	8.29
22111922	4.30	0.571	21.75	1929.95	2.85	17.42	1.02	99.99	8.79
22111926	4.32	0.588	25.10	1970.75	2.85	14.14	52.70	99.99	8.42
22111930	4.33	0.602	21.75	1970.75	2.85	14.14	76.78	99.99	8.54
22111934	4.34	0.615	18.40	1976.58	2.72	13.67	80.48	99.99	8.29
22111938	4.36	0.630	23.42	1953.26	2.85	15.55	275.17	99.99	8.92
22111942	4.37	0.644	20.08	1985.32	2.85	12.97	97.16	99.99	8.16
22111946	4.39	0.656	18.40	2002.81	2.72	11.56	93.45	99.99	8.10
22111950	4.40	0.667	16.73	1985.32	2.85	12.97	62.15	99.99	7.91
22111954	4.41	0.680	20.08	1973.66	2.85	13.91	100.86	99.99	8.42
22111958	4.42	0.694	20.08	1982.41	2.85	13.20	74.93	99.99	8.04
22112002	4.44	0.707	20.08	1976.58	2.85	13.67	30.47	99.99	8.16
22112006	4.45	0.723	23.42	1956.18	2.85	15.31	232.57	99.99	8.23

	TOTAL	CORE	PENETRAIN	ROTARY			INLET H20	I. H20	
22112010	4.47	0.740	25.10	1979.49	2.85	13.44	95.30	99.99	8.35
22112014	4.48	0.754	21.75	2017.38	2.72	10.39	100.80	99.99	7.98
22112016	4.50	0.765	16.73	2023.21	2.72	9.92	41.77	99.99	7.22
22112022	4.51	0.776	16.73	2029.04	2.72	9.45	58.26	99.99	7.60
22112026	4.52	0.786	15.06	2049.44	2.72	7.81	126.98	99.99	7.35
22112030	4.52	0.792	8.37	2084.41	2.46	5.00	78.63	93.99	7.03
22112034	4.53	0.795	5.02	2093.15	2.59	4.30	93.45	99.99	7.03
22112038	4.53	0.798	3.35	143.29	4.59	159.74	56.40	99.99	-1.28



RECORD OF CORSHAM DRILL RUN 2.5 (3.73 to 4.53 metres)

USER: EX9769 -AT SYSTEM

R_C2.6.1

LABEL: PRT006 -FORM

SPOOLED: 82-11-25.18:25
STARTED: 82-11-25.18:28, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27102304	4.53	0.000	0.00	23.92	4.85	169.09	97.19	3.39	-1.35
27102347	4.53	0.001	1.67	2108.55	3.93	5.83	82.38	3.39	6.96
27102352	4.54	0.008	8.03	2061.96	0.24	9.48	100.89	99.99	6.96
27102356	4.55	0.020	18.40	1992.09	1.54	14.95	17.54	3.39	9.10
27102400	4.55	0.022	3.35	2006.64	1.41	13.81	74.98	3.39	8.41
27102404	4.55	0.023	1.67	2009.56	1.28	13.59	87.94	3.39	8.15
27102408	4.55	0.025	1.67	2015.38	1.28	13.13	76.83	3.39	8.15
27102412	4.56	0.026	1.67	2027.02	1.41	12.22	180.39	99.99	8.15

USER: EX9069 -AT SYSTEM

R_C2.6.2

EX9069

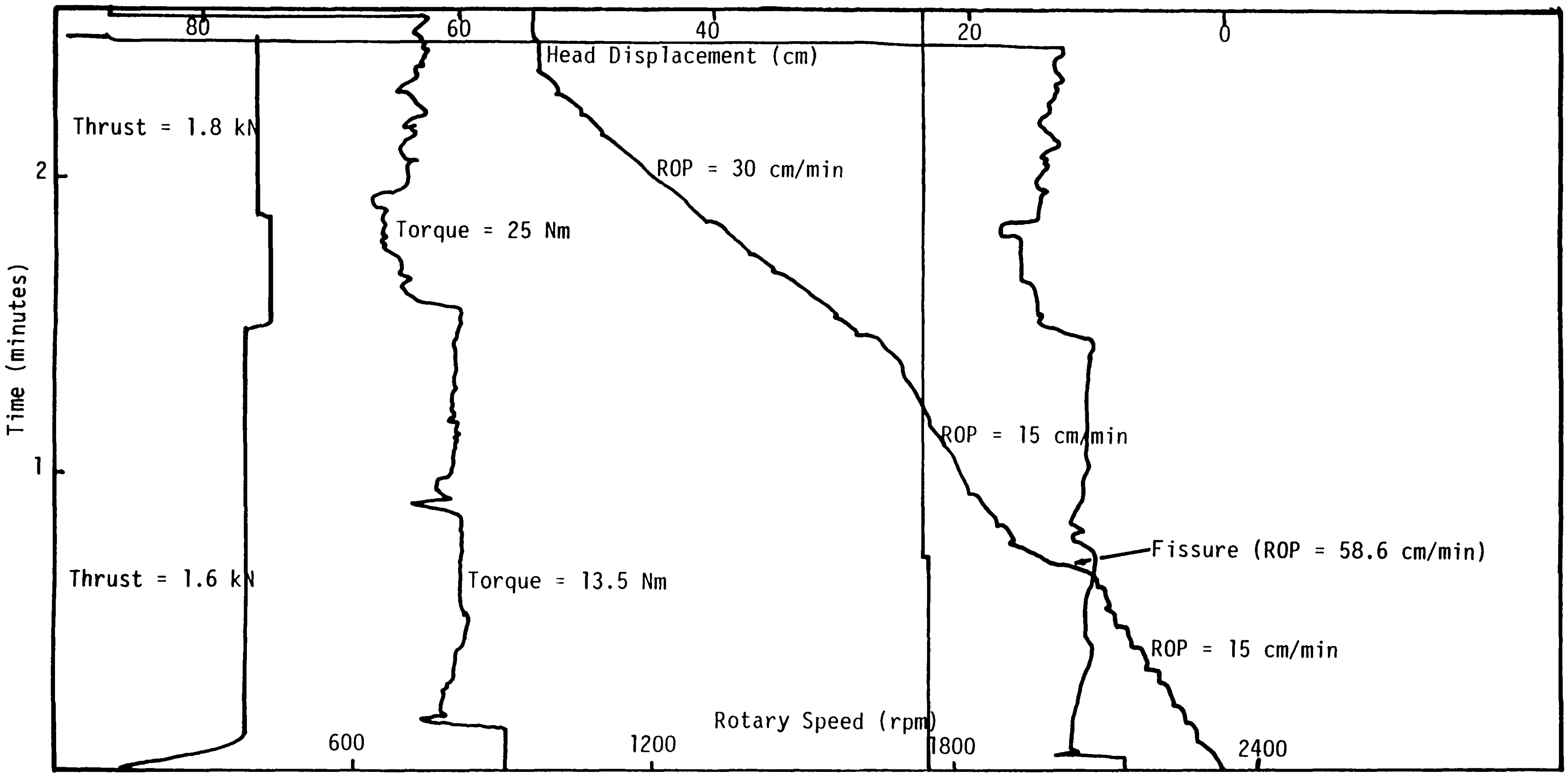
R_C2.6.2

LABEL: PRT009 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:28, ON: PR0 BY: PR0

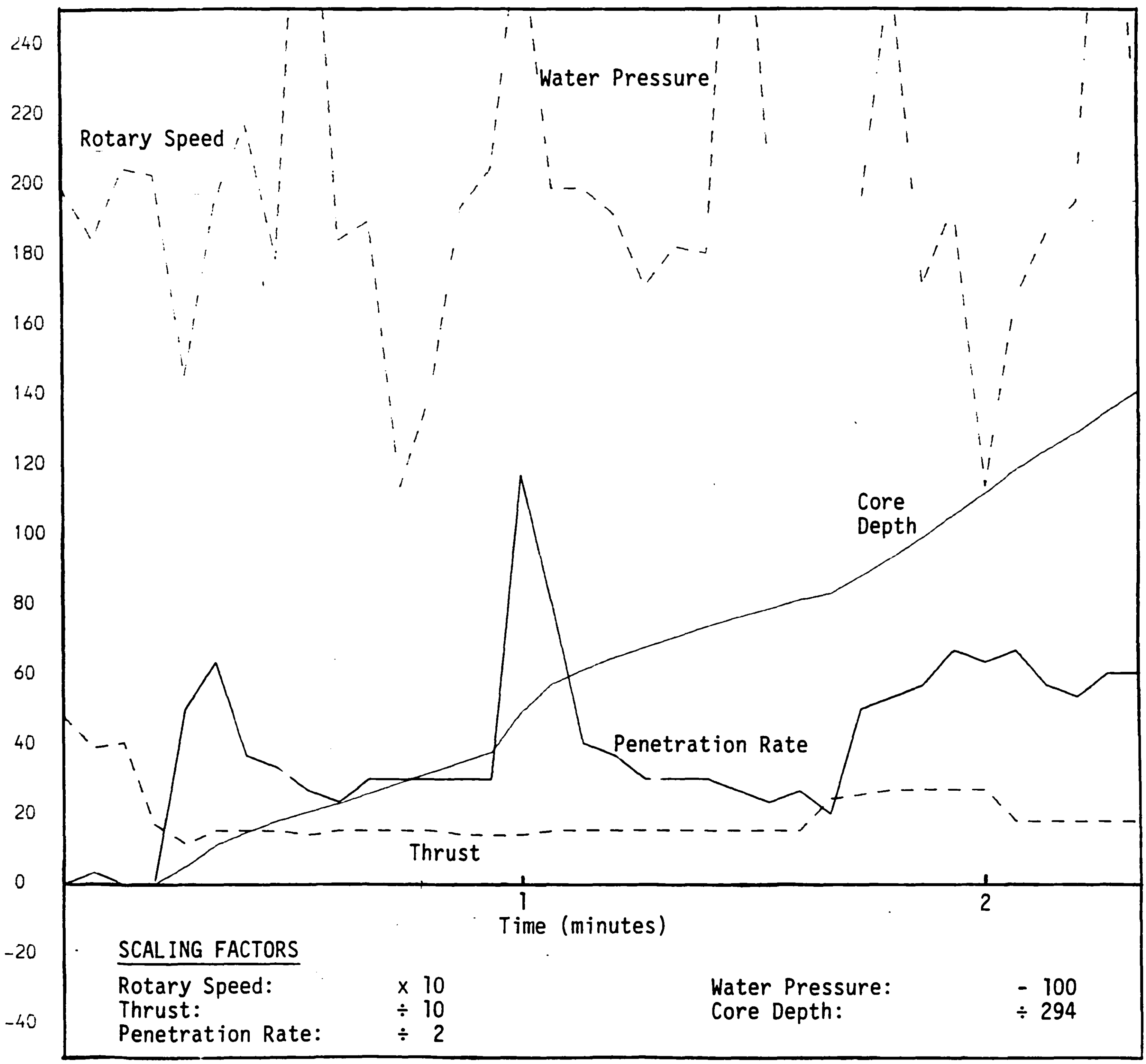
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27103520	4.56	0.000	0.00	1840.69	4.85	26.81	99.04	4.83	6.14
27103524	4.56	0.001	1.67	2093.99	3.93	6.97	84.24	4.83	7.34
27103528	4.56	0.001	0.00	2099.81	4.07	6.52	104.59	4.83	7.34
27103532	4.56	0.001	0.00	2099.81	1.72	6.52	102.74	4.83	7.34
27103536	4.58	0.018	25.10	1971.71	1.15	16.55	45.33	4.83	8.66
27103540	4.60	0.039	31.79	1971.71	1.54	16.55	95.34	4.83	8.97
27103544	4.61	0.051	18.40	2009.56	1.54	13.59	117.47	4.83	8.53
27103548	4.62	0.062	16.73	2015.38	1.54	13.13	78.68	4.83	8.41
27103552	4.63	0.071	13.39	2041.58	1.41	11.08	234.05	4.83	8.03
27103556	4.64	0.079	11.71	2024.11	1.54	12.45	84.24	4.83	7.84
27103600	4.65	0.089	15.06	1986.26	1.54	15.41	89.79	4.83	8.34
27103604	4.66	0.099	15.06	2015.38	1.54	13.13	13.92	4.83	8.41
27103608	4.67	0.109	15.06	2024.11	1.54	12.45	39.82	4.83	8.09
27103612	4.68	0.119	15.06	2047.41	1.41	10.62	93.49	4.83	7.78
27103616	4.69	0.129	15.06	2029.94	1.41	11.99	104.59	4.83	7.78
27103620	4.73	0.168	58.56	2024.11	1.41	12.45	174.84	4.83	7.59
27103624	4.76	0.195	40.16	1997.91	1.54	14.50	99.04	4.83	8.72
27103628	4.77	0.205	20.08	2015.38	1.54	13.13	99.04	4.83	7.90
27103632	4.78	0.221	18.40	2029.94	1.54	11.99	91.64	4.83	7.84
27103636	4.79	0.231	15.06	2006.64	1.54	13.81	71.28	4.83	8.03
27103640	4.80	0.241	15.06	2000.82	1.54	14.27	82.38	4.83	8.28
27103644	4.81	0.251	15.06	2027.02	1.54	12.22	80.53	4.83	7.90
27103648	4.82	0.260	13.39	2018.29	1.54	12.90	226.65	4.83	7.90
27103652	4.83	0.268	11.71	2027.02	1.54	12.22	106.44	4.83	7.84
27103656	4.84	0.277	13.39	2044.49	1.54	10.85	106.44	4.83	7.59
27103700	4.84	0.283	10.04	1936.77	2.45	19.29	86.09	4.83	7.71
27103704	4.86	0.300	25.10	1896.01	2.58	22.48	93.49	4.83	9.54
27103708	4.88	0.318	26.77	1898.92	2.71	22.25	161.88	4.83	9.48
27103712	4.90	0.337	28.44	1852.34	2.71	25.90	71.28	4.83	9.60
27103716	4.92	0.359	33.46	1858.16	2.71	25.44	93.49	4.83	9.85
27103720	4.94	0.380	31.79	1852.34	2.71	25.90	13.84	4.83	9.60
27103724	4.96	0.403	33.46	1922.21	1.80	20.43	67.58	4.83	9.54
27103728	4.98	0.422	28.44	1936.77	1.80	19.29	86.09	4.83	8.97
27103732	5.00	0.439	26.77	1896.01	1.80	22.48	95.34	4.83	9.10
27103736	5.02	0.460	30.12	1942.59	1.80	18.83	235.93	4.83	8.47
27103740	5.04	0.480	30.12	1954.24	1.80	17.92	106.44	4.83	8.34



RECORD OF CORSHAM DRILL RUN 2.6.2 (4.56 to 5.04 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.6.2 (4.56 to 5.04 metres)



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USER: EX9069 -AT SYSTEM

R_C2.7.1

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W      W W  W   W W  WW W     W   W
WWWW    W    WWWW W W W WWWW   WWWW
W      W W      W WW  W W   W     W
W     W   W    W  W   W W   W    W
WWWWW W   W WWW    WWW   WWW  WWW


WWWW          WWW   WWW         WWWWW       W
W   W        W   W W   W            W      WW
W   W        W         W           W        W
WWWW         W        W           W         W
W W          W       W           W          W
W  W         W   W  W       WW  W       WW  W
W   W WWWWW   WWW  WWWWW    WW  W       WW WWW

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LABEL: PRTC1C -FORM

SPOOLED:  82-01-25.18:25
STARTED:  82-01-25.18:28, ON:   PRO   BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E
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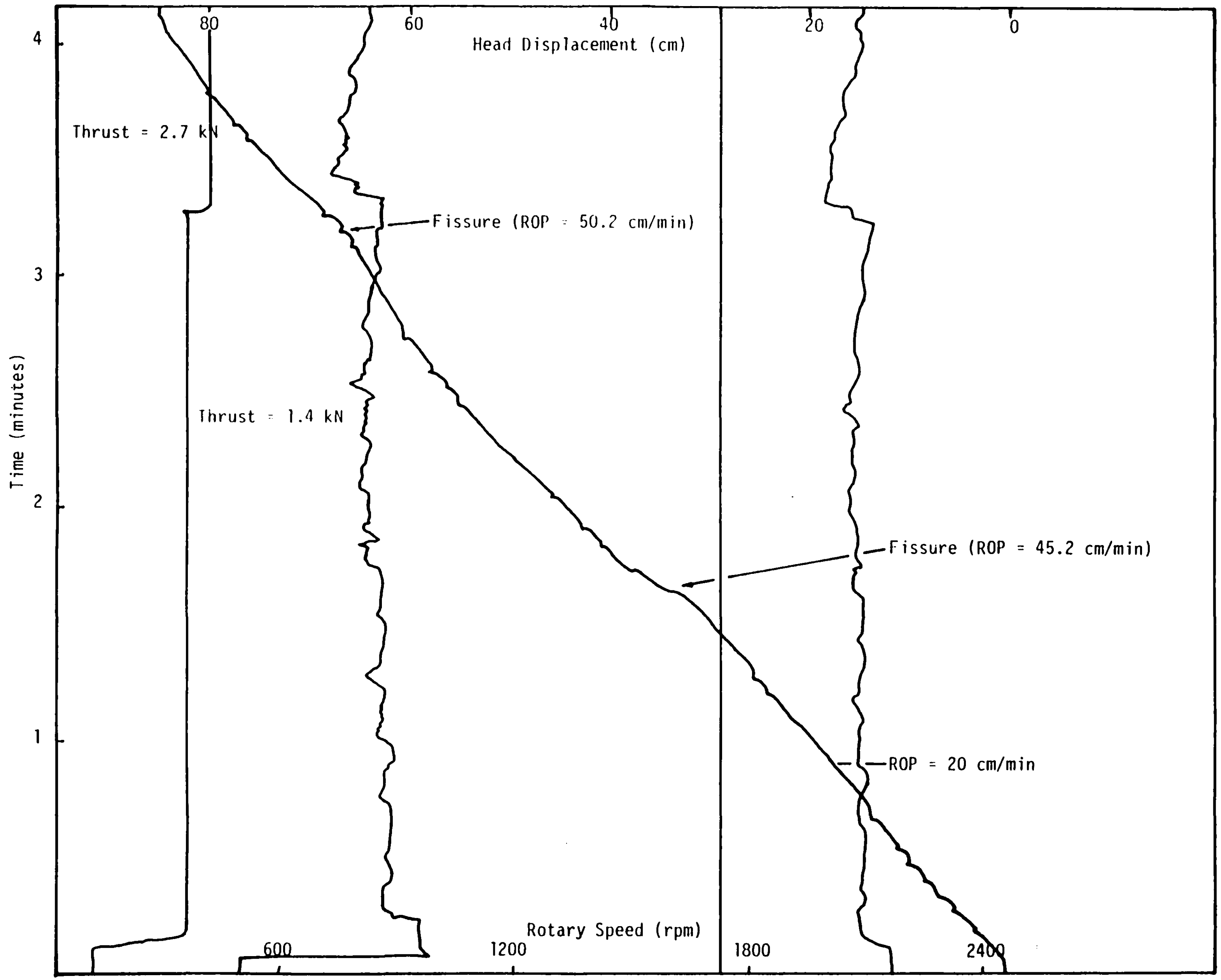
-657-

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27110844	5.04	0.000	0.00	2117.28	0.37	5.15	93.49	99.99	7.90
27110848	5.05	0.012	18.40	2009.56	1.54	13.59	10.21	99.99	9.22
27110852	5.07	0.031	28.44	2035.76	1.41	11.53	182.24	99.99	9.29
27110856	5.09	0.048	25.10	2076.52	1.41	8.34	39.82	99.99	8.66
27110900	5.10	0.062	21.75	2029.94	1.41	11.99	110.14	95.99	8.91
27110904	5.12	0.079	25.10	2064.87	1.41	9.25	95.34	99.99	8.66
27110908	5.13	0.093	20.08	2070.70	1.41	8.89	87.94	99.99	8.66
27110912	5.14	0.105	18.40	2079.43	1.41	8.11	43.52	99.99	8.34
27110916	5.16	0.116	16.73	2018.29	1.41	12.90	160.03	99.99	8.91
27110920	5.17	0.131	21.75	2047.41	1.41	10.62	111.99	99.99	8.85
27110924	5.18	0.144	20.08	2061.96	1.41	9.48	84.24	99.99	8.72
27110928	5.19	0.154	15.06	2076.52	1.41	8.34	26.86	99.99	8.15
27110932	5.21	0.165	16.73	1989.18	1.41	15.18	89.79	99.99	8.91
27110936	5.22	0.180	21.75	2038.67	1.41	11.31	87.94	99.99	8.78
27110940	5.23	0.192	18.40	2044.49	1.41	10.85	110.14	99.99	8.72
27110944	5.25	0.205	20.08	2044.49	1.41	10.85	167.43	99.99	8.53
27110948	5.26	0.220	21.75	2009.56	1.41	13.59	63.88	99.99	9.16
27110952	5.27	0.234	21.75	2050.32	1.41	10.39	104.59	99.99	8.47
27110956	5.29	0.248	20.08	2061.96	1.41	9.48	21.32	99.99	8.41
27111000	5.30	0.259	16.73	2067.79	1.41	9.03	43.52	99.99	8.09
27111004	5.31	0.272	20.08	2038.67	1.41	11.31	97.19	99.99	8.72
27111008	5.33	0.286	20.08	2047.41	1.41	10.62	89.79	99.99	8.28
27111012	5.34	0.299	20.08	2067.79	1.41	9.03	10.21	99.99	8.22
27111016	5.35	0.311	18.40	2027.02	1.41	12.22	119.32	99.99	8.22
27111020	5.37	0.329	26.77	2024.11	1.54	12.45	100.89	99.99	8.91
27111024	5.40	0.359	45.18	2035.76	1.41	11.53	104.59	99.99	8.39
27111028	5.42	0.380	31.79	2021.20	1.54	12.67	37.97	99.95	8.72
27111032	5.44	0.358	26.77	2024.11	1.54	12.45	97.19	99.99	8.66
27111036	5.45	0.413	21.75	2012.47	1.41	13.36	132.27	99.99	8.59
27111040	5.47	0.429	25.10	2015.38	1.41	13.13	106.44	99.99	8.97
27111044	5.49	0.445	23.42	2027.02	1.41	12.22	87.94	99.99	8.66
27111048	5.50	0.460	21.75	2038.67	1.41	11.31	8.29	99.99	8.22
27111052	5.51	0.474	21.75	2015.38	1.54	13.13	102.74	99.99	8.91
27111056	5.53	0.491	25.10	2032.85	1.41	11.76	87.94	99.99	8.53
27111100	5.55	0.506	23.42	2053.23	1.41	10.17	60.18	99.99	8.34
27111104	5.56	0.522	23.42	1986.26	1.54	15.41	241.45	99.99	8.78
27111108	5.58	0.539	25.10	2032.85	1.41	11.76	99.04	99.99	8.53
27111112	5.59	0.552	20.08	2050.32	1.41	10.39	2.81	99.99	8.09
27111116	5.60	0.564	18.40	2047.41	1.41	10.62	15.77	99.99	7.90
27111120	5.62	0.578	20.08	2032.85	1.41	11.76	84.24	99.99	8.53
27111124	5.63	0.591	20.08	2053.23	1.41	10.17	86.09	99.99	7.97
27111128	5.64	0.602	16.73	2061.96	1.41	9.48	87.94	99.99	7.97
27111132	5.65	0.611	13.39	2079.43	1.41	8.11	245.16	99.99	7.65
27111136	5.66	0.620	13.39	2056.14	1.41	9.94	108.29	99.99	7.71
27111140	5.67	0.631	16.73	2064.87	1.41	9.25	111.99	99.99	7.84
27111144	5.68	0.640	13.39	2099.81	1.41	6.52	49.00	99.99	7.53
27111148	5.69	0.648	11.71	2088.17	1.41	7.43	111.99	99.99	7.21
27111152	5.69	0.655	10.04	2061.96	1.92	9.48	84.28	99.99	7.14
27111156	5.71	0.667	18.40	1977.53	2.71	16.09	65.73	99.99	8.53
27111202	5.72	0.684	16.73	1971.71	2.71	16.55	213.70	99.99	9.16
27111204	5.74	0.701	50.20	1986.26	2.71	15.41	99.04	99.99	8.72
27111208	5.76	0.716	23.42	1989.18	2.71	15.18	97.19	99.99	8.59
27111212	5.77	0.733	25.10	1971.71	2.71	16.55	74.98	99.99	9.04
27111216	5.79	0.748	23.42	1997.91	2.71	14.50	93.49	99.99	8.53

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
27111220	5.81	0.762	20.08	2024.11	2.71	12.45	137.83	99.99	8.15
27111224	5.82	0.775	20.08	1986.26	2.71	15.41	76.83	99.99	8.34
27111228	5.83	0.790	21.75	2032.85	2.71	11.76	99.04	99.99	8.15
27111232	5.84	0.801	16.73	2050.32	2.71	10.39	32.42	99.99	7.65
27111236	5.65	0.812	16.73	2076.52	2.58	8.34	63.88	99.99	7.46
27111240	5.86	0.821	13.39	2047.41	2.71	10.62	95.34	99.99	7.27
27111244	5.87	0.832	16.73	2047.41	2.71	10.62	108.29	99.99	7.97
27111248	5.88	0.843	16.73	2070.70	2.58	8.80	180.39	99.99	7.34
27111252	5.89	0.847	5.02	1610.68	4.85	44.82	80.58	99.99	4.00



RECORD OF CORSHAM DRILL RUN 2.7.1 (5.04 to 5.89 metres)

USER: EX9069 -AT SYSTEM

R_C2.7.2

EX9069

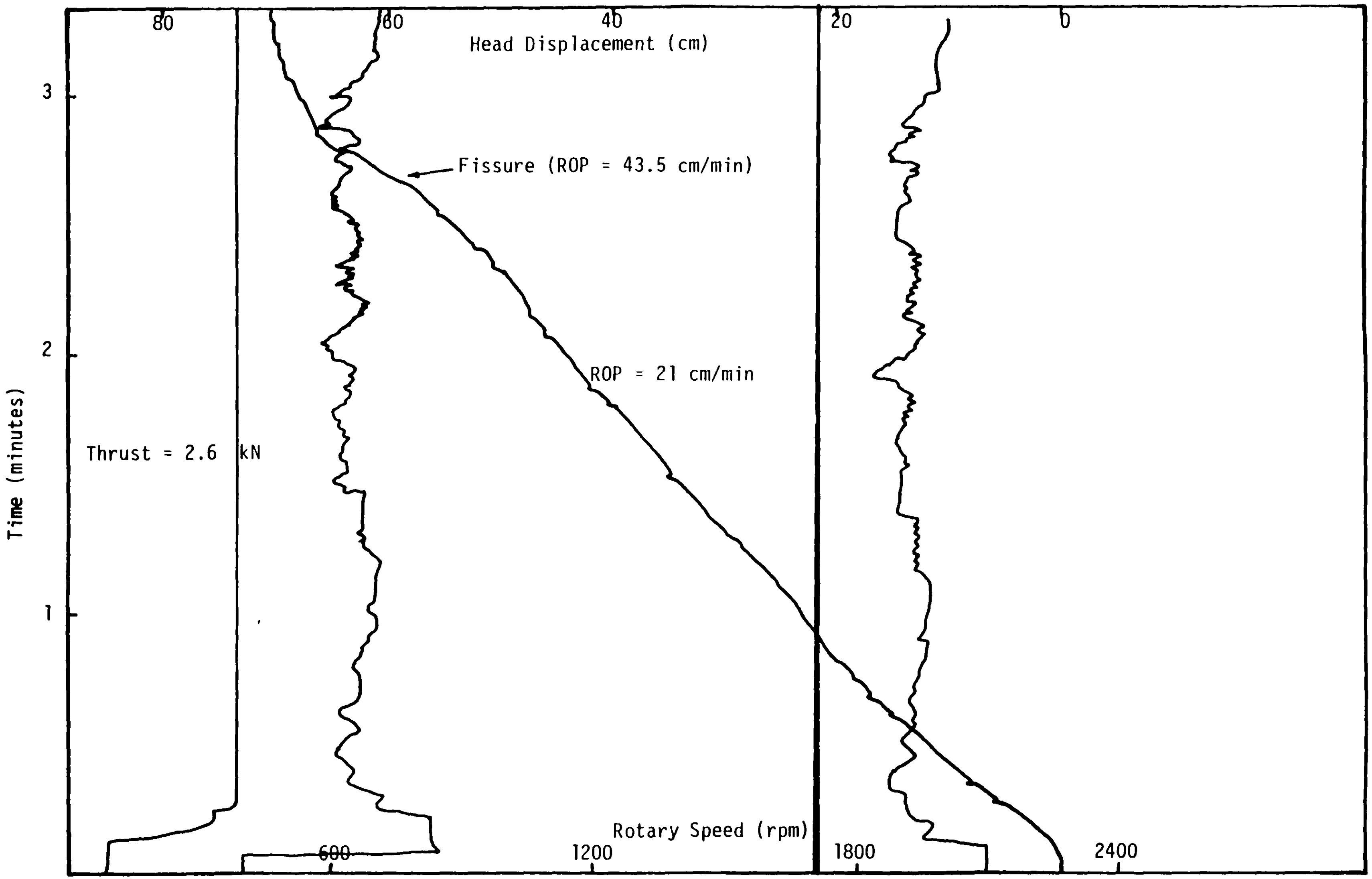
R_C2.7.2

LABEL: PRT011 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:28, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27111350	5.89	0.000	0.00	2085.25	0.68	7.66	104.59	99.99	7.02
27111354	5.91	0.013	20.08	1974.62	1.41	16.32	17.54	99.99	8.91
27111358	5.92	0.029	23.42	1884.36	2.58	23.39	67.58	99.99	9.60
27111402	5.94	0.049	30.12	1863.98	2.58	24.99	86.09	99.99	9.66
27111406	5.96	0.070	31.79	1866.89	2.58	24.76	89.79	3.39	10.10
27111410	5.98	0.090	30.12	1925.12	2.45	20.20	239.60	99.99	9.35
27111414	6.00	0.112	31.79	1884.36	2.58	23.39	99.04	3.39	9.98
27111418	6.02	0.131	28.44	1922.21	2.45	20.43	87.86	99.99	9.16
27111422	6.04	0.147	25.10	1913.48	2.45	21.11	74.98	99.99	9.16
27111426	6.06	0.165	26.77	1933.95	2.45	19.74	87.86	99.99	9.35
27111430	6.07	0.182	25.10	1948.41	2.45	18.37	104.59	99.99	8.91
27111434	6.09	0.195	20.08	1965.88	2.58	17.01	86.09	99.99	8.59
27111438	6.10	0.209	20.08	1936.77	2.58	19.29	84.24	99.99	8.85
27111442	6.11	0.223	21.75	1962.97	2.58	17.23	256.26	99.99	8.72
27111446	6.13	0.235	18.40	1968.79	2.58	16.78	99.04	99.99	8.66
27111450	6.14	0.247	16.73	1968.79	2.58	16.78	95.34	99.99	8.41
27111454	6.15	0.259	18.40	1925.12	2.58	20.20	36.12	99.99	8.97
27111458	6.16	0.271	18.40	1930.95	2.58	19.74	37.90	99.99	9.10
27111502	6.17	0.284	20.08	1928.03	2.45	19.97	108.29	99.99	9.10
27111506	6.19	0.298	20.08	1925.12	2.45	20.20	86.09	99.99	8.97
27111510	6.20	0.313	23.42	1872.72	2.58	24.30	39.82	99.99	9.92
27111514	6.22	0.329	23.42	1875.63	2.58	24.08	187.79	99.99	9.54
27111518	6.23	0.344	21.75	1893.10	2.58	22.71	62.03	99.99	9.41
27111522	6.25	0.357	20.08	1866.89	2.58	24.76	86.09	99.99	9.54
27111526	6.26	0.371	21.75	1890.18	2.58	22.94	102.74	99.99	9.66
27111530	6.27	0.385	20.08	1896.01	2.58	22.48	87.94	99.99	9.29
27111534	6.29	0.397	18.40	1916.39	2.58	20.88	78.68	99.99	8.97
27111538	6.30	0.413	23.42	1808.66	2.58	29.32	226.65	99.99	9.85
27111542	6.32	0.431	26.77	1887.27	2.58	23.16	71.28	99.99	9.66
27111546	6.33	0.444	20.08	1936.77	2.58	19.29	93.49	99.99	8.85
27111550	6.35	0.455	16.73	1933.86	2.58	19.51	108.29	99.99	8.72
27111554	6.36	0.465	20.08	1922.21	2.58	20.43	50.85	99.99	9.41
27111558	6.37	0.480	16.73	1930.95	2.58	19.74	78.68	99.99	9.35
27111602	6.38	0.491	16.73	1948.41	2.58	18.37	86.09	99.99	8.72
27111606	6.39	0.503	18.40	1922.21	2.58	20.43	74.98	99.99	8.78
27111610	6.41	0.516	20.08	1855.25	2.58	25.67	248.86	99.99	9.35
27111614	6.42	0.532	23.42	1866.89	2.58	24.76	110.14	99.99	9.60
27111618	6.44	0.548	23.42	1907.65	2.58	21.57	95.34	99.99	9.29
27111622	6.45	0.563	23.42	1881.45	2.58	23.62	39.82	99.99	9.29
27111626	6.47	0.579	23.42	1939.68	2.58	19.06	30.50	99.99	8.66
27111630	6.50	0.608	43.50	1834.87	2.58	27.27	104.59	99.99	9.48
27111634	6.52	0.632	36.81	1925.12	2.58	20.20	86.09	99.99	8.97
27111638	6.55	0.657	36.81	1890.18	2.58	22.94	73.13	99.99	9.41
27111642	6.56	0.672	21.75	1962.97	2.45	17.23	222.95	99.99	8.59
27111646	6.57	0.679	11.71	1995.00	2.19	14.73	80.53	99.99	7.90
27111650	6.58	0.687	11.71	1992.09	2.19	14.95	71.21	99.99	7.97
27111654	6.58	0.695	11.71	2003.73	2.58	14.04	69.43	99.99	7.65
27111658	6.59	0.702	10.04	2018.29	2.32	12.90	95.34	99.99	7.53
27111702	6.60	0.708	10.04	1089.52	4.98	85.64	102.77	99.99	6.51



RECORD OF CORSHAM DRILL RUN 2.7.2 (5.89 to 6.60 metres)

USER: EX9969 -AT SYSTEM

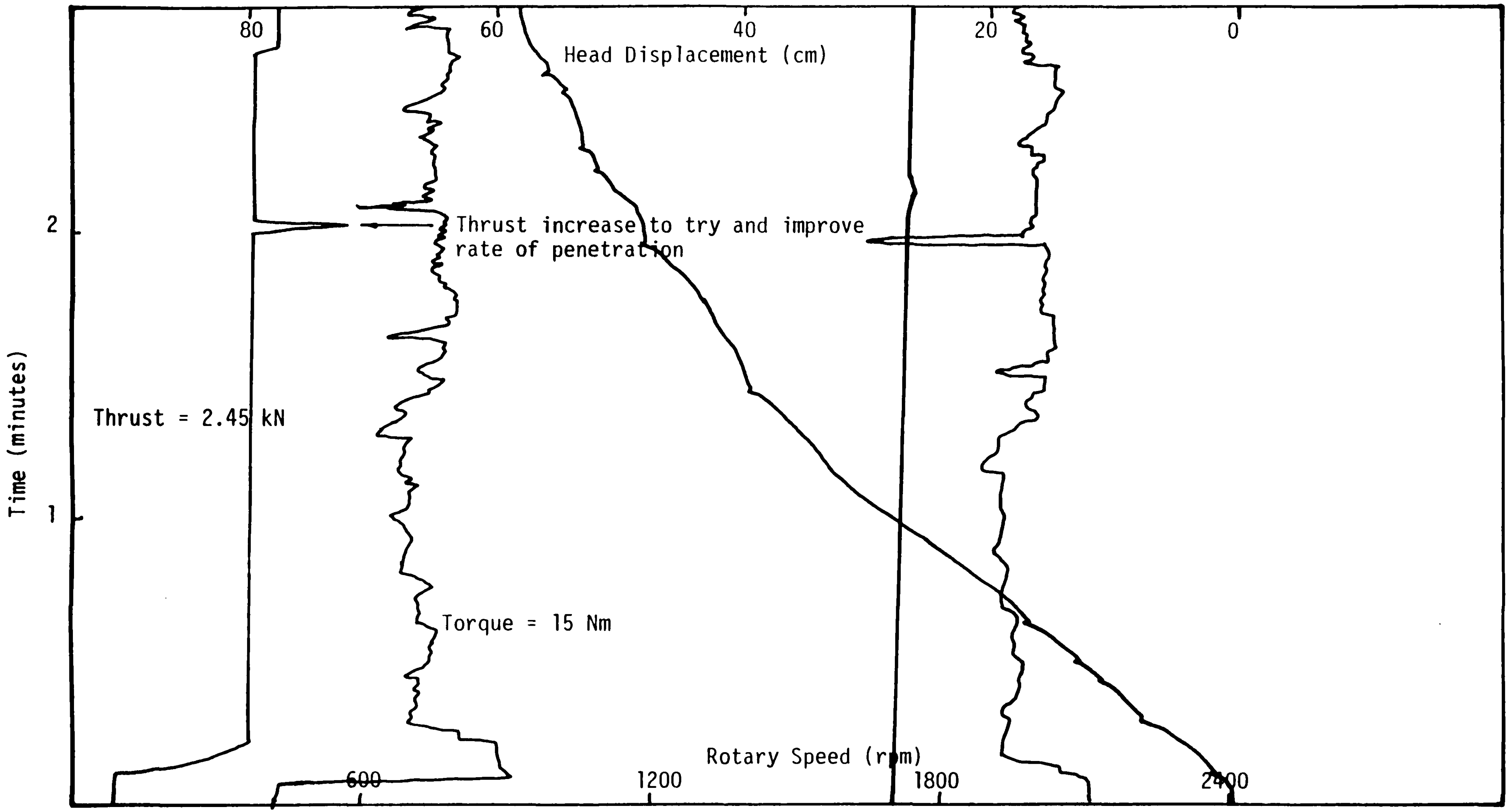
R_C2.8

LABEL: PRT012 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:28, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27113626	6.60	0.000	0.00	2105.63	0.94	0.03	102.74	99.99	7.84
27113630	6.61	0.006	8.37	1568.79	1.80	11.32	110.14	99.99	8.97
27113634	6.63	0.026	30.12	1916.39	2.45	15.67	12.07	99.99	10.10
27113638	6.65	0.046	30.12	1945.50	2.58	13.25	73.13	99.99	9.98
27113642	6.66	0.365	28.44	1916.39	2.58	15.67	82.38	99.99	10.36
27113646	6.68	0.085	30.12	1965.88	2.45	11.56	106.44	99.99	9.48
27113650	6.70	0.103	26.77	1983.35	2.45	10.11	161.88	99.99	9.29
27113654	6.72	0.120	26.77	1936.77	2.45	13.98	43.45	99.99	9.85
27113658	6.74	0.139	28.44	1939.68	2.45	13.73	87.94	99.99	9.79
27113702	6.76	0.157	26.77	1916.39	2.45	15.67	110.14	99.99	9.60
27113706	6.78	0.178	31.79	1910.56	2.58	16.15	8.29	99.99	10.17
27113710	6.80	0.197	28.44	1945.50	2.58	13.25	2.74	99.99	9.85
27113714	6.82	0.216	28.44	1878.54	2.45	18.80	32.42	99.99	10.10
27113718	6.84	0.236	30.12	1930.95	2.58	14.46	156.33	99.99	9.85
27113722	6.86	0.257	30.12	1925.12	2.58	14.94	91.64	99.99	9.60
27113726	6.88	0.278	31.79	1910.56	2.58	16.15	104.59	99.99	10.10
27113730	6.90	0.300	33.46	1939.68	2.45	13.73	19.39	99.99	9.85
27113734	6.92	0.321	31.79	1904.74	2.58	16.63	47.23	99.99	10.48
27113738	6.94	0.338	25.10	1922.21	2.58	15.18	80.53	99.99	10.17
27113742	6.95	0.351	20.08	2009.56	2.58	7.94	84.28	99.99	8.96
27113746	6.97	0.366	21.75	1968.79	2.58	11.32	267.36	99.99	9.16
27113750	6.98	0.379	20.08	2021.20	2.45	6.97	108.29	99.99	8.28
27113754	7.00	0.397	26.77	2009.56	2.45	7.94	97.19	99.99	9.22
27113758	7.01	0.407	15.06	2044.49	2.32	5.04	49.00	99.99	8.03
27113802	7.01	0.413	8.37	2021.20	2.45	6.97	15.77	99.99	8.09
27113806	7.02	0.425	18.40	1986.26	2.45	9.87	86.09	99.99	8.59
27113810	7.04	0.436	16.73	2009.56	2.45	7.94	23.09	99.99	8.66
27113814	7.04	0.444	11.71	2024.11	2.58	6.73	259.96	99.99	8.59
27113818	7.05	0.454	15.06	2018.29	2.58	7.22	87.98	99.99	8.14
27113822	7.07	0.472	26.77	1971.71	2.45	11.08	93.49	99.99	9.66
27113826	7.08	0.482	15.06	2003.73	2.45	8.42	100.89	99.99	8.53
27113830	7.09	0.490	11.71	2006.64	2.45	8.18	2.74	99.99	8.41
27113834	7.10	0.498	11.71	1971.71	2.45	11.08	89.79	99.99	8.41
27113838	7.11	0.514	25.10	2018.29	2.45	7.22	106.44	99.99	8.47
27113842	7.12	0.523	13.39	1986.26	2.44	9.87	165.29	99.99	9.21
27113846	7.13	0.531	11.71	2035.76	2.44	5.77	97.22	99.99	8.02
27113850	7.14	0.537	8.37	2056.14	2.44	4.08	82.10	99.99	7.77
27113854	7.14	0.542	8.37	2035.76	2.44	5.77	73.19	99.99	8.02
27113858	7.15	0.549	10.04	1960.06	3.49	12.04	84.28	99.99	8.14
27113902	7.16	0.560	16.73	1971.71	3.50	11.08	99.04	99.99	8.97
27113906	7.17	0.571	16.73	1933.86	3.50	14.22	300.67	99.99	8.78
27113910	7.18	0.582	16.73	1593.21	4.59	46.19	108.31	99.99	9.09
27113914	7.18	0.583	1.67	23.92	4.72	169.09	93.52	99.99	-1.35



RECORD OF CORSHAM DRILL RUN 2.8 (6.60 to 7.18 metres)

USER: EX9269 -AT SYSTEM

R_C2.9

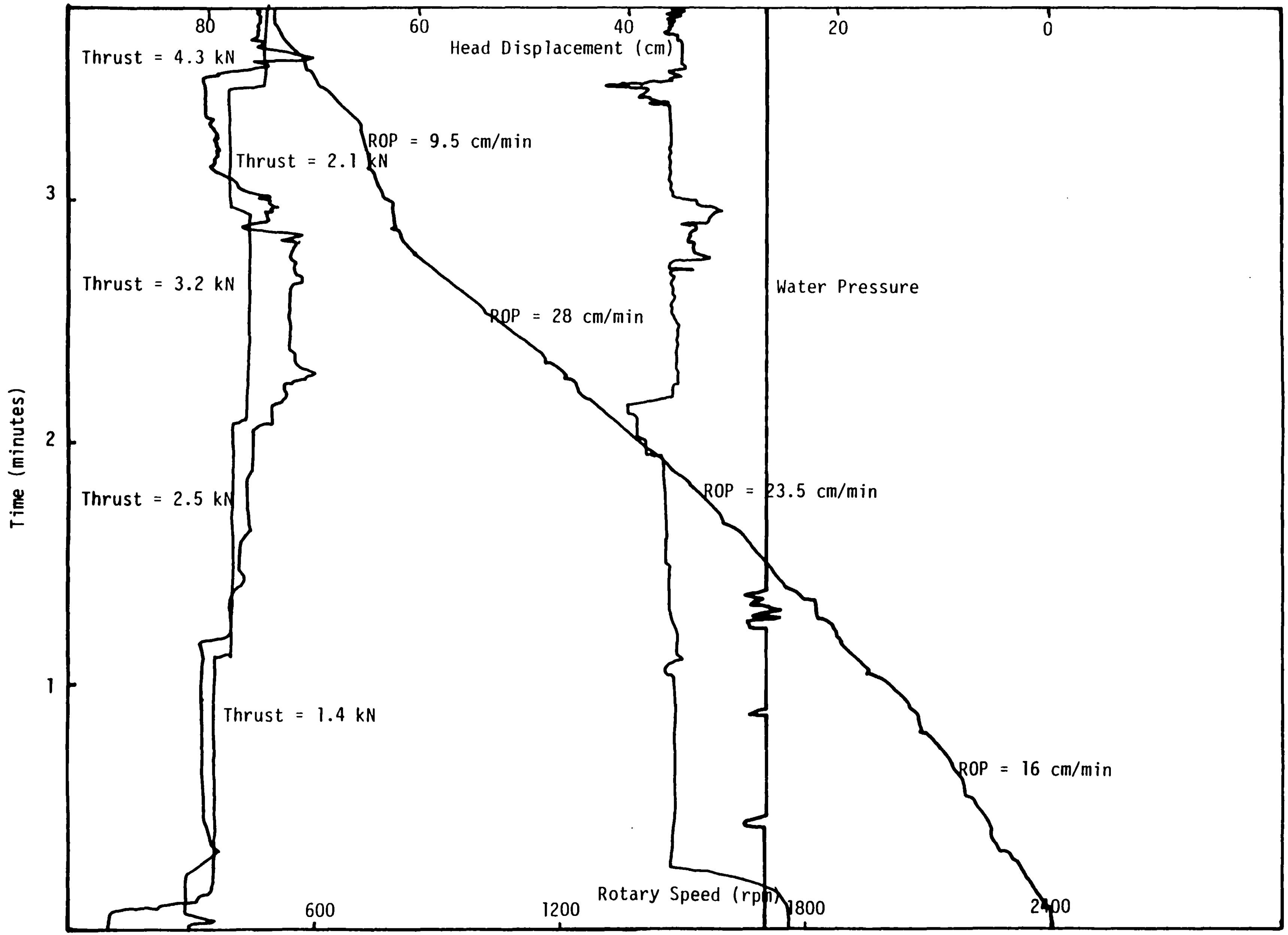
LABEL: PRT013 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:28, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

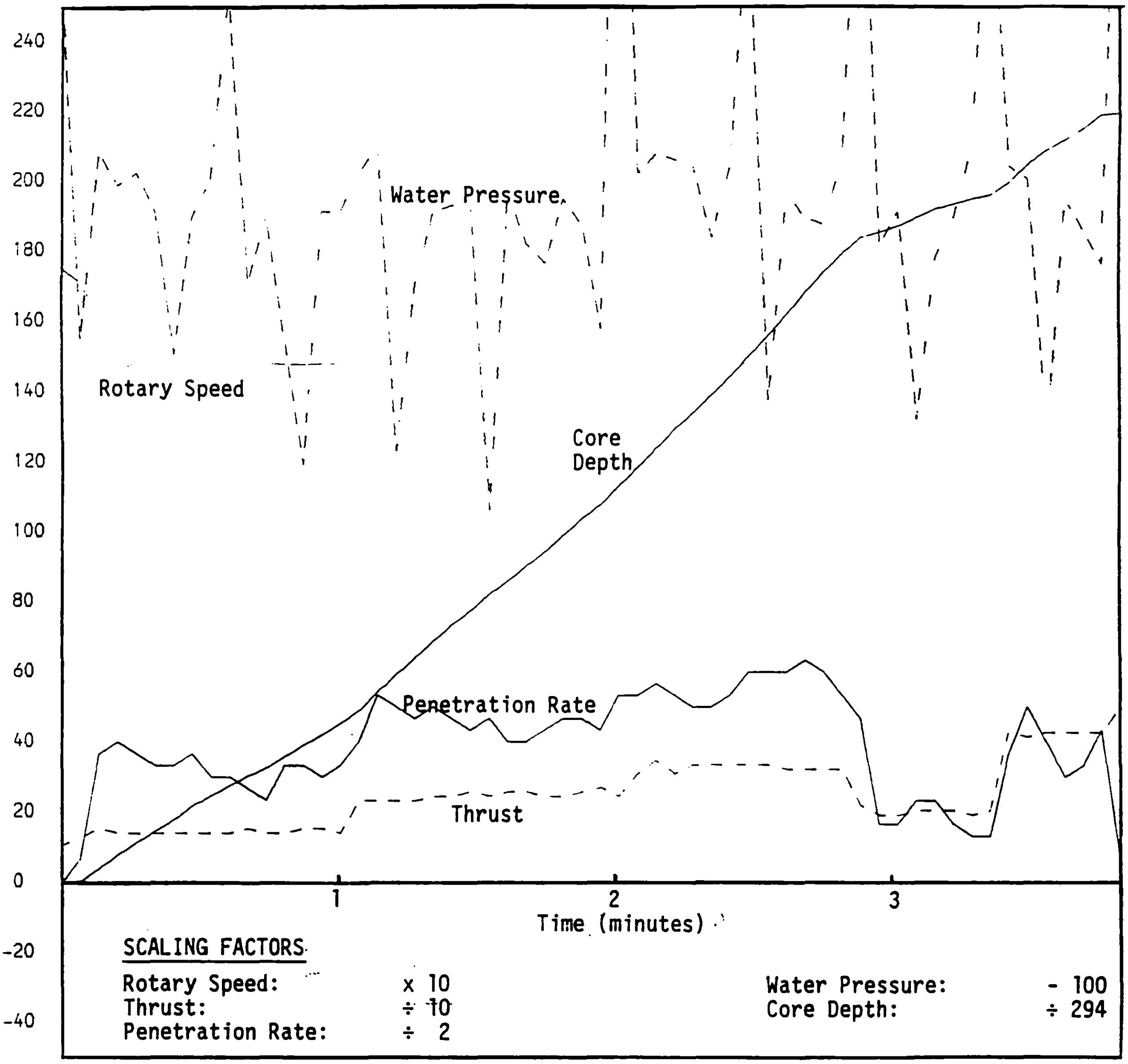
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27151820	7.18	0.000	0.00	1750.43	1.06	33.88	158.47	99.99	4.26
27151824	7.18	0.002	3.35	1712.58	1.29	36.84	54.74	99.99	4.39
27151828	7.19	0.015	18.40	1613.59	1.55	40.78	108.46	99.99	5.52
27151832	7.21	0.028	20.08	1459.28	1.42	30.25	99.01	99.99	3.57
27151836	7.22	0.040	18.40	1485.49	1.42	27.17	102.71	99.99	3.94
27151840	7.23	0.051	16.73	1488.40	1.42	26.82	91.60	99.99	3.50
27151844	7.24	0.062	16.73	1473.84	1.42	28.53	50.85	99.99	3.88
27151848	7.25	0.075	18.40	1491.31	1.42	26.48	89.75	99.99	3.69
27151852	7.26	0.085	15.06	1488.40	1.42	26.82	100.86	99.99	3.50
27151856	7.27	0.095	15.06	1491.31	1.42	26.48	154.77	99.99	3.57
27151900	7.28	0.104	13.39	1494.22	1.55	26.14	71.22	99.99	3.44
27151904	7.29	0.112	11.71	1482.58	1.42	27.51	89.75	99.99	3.69
27151908	7.30	0.123	16.73	1479.66	1.42	27.85	54.55	99.99	4.07
27151912	7.31	0.134	16.73	1479.66	1.55	27.85	19.36	99.99	3.88
27151916	7.32	0.144	15.06	1482.58	1.55	27.51	91.63	99.99	3.82
27151920	7.34	0.155	16.73	1482.58	1.42	27.51	91.60	99.99	3.57
27151924	7.35	0.168	20.08	1465.11	2.33	29.56	102.71	99.99	5.27
27151928	7.37	0.186	26.77	1462.20	2.33	29.90	110.12	99.99	5.14
27151932	7.38	0.203	25.10	1465.11	2.33	29.56	23.25	99.99	4.95
27151936	7.40	0.219	23.42	1444.73	2.33	31.96	71.22	99.99	5.65
27151940	7.42	0.235	25.10	1453.46	2.46	30.93	91.60	99.99	5.27
27151944	7.43	0.251	23.42	1453.46	2.46	30.93	93.45	99.99	5.39
27151948	7.45	0.265	21.75	1430.17	2.59	33.67	93.64	99.99	5.77
27151952	7.46	0.281	23.42	1444.73	2.46	31.96	6.39	99.99	5.83
27151956	7.47	0.294	20.08	1441.81	2.59	32.30	97.16	99.99	5.71
27152000	7.49	0.308	20.08	1438.90	2.59	32.64	82.34	99.99	5.52
27152004	7.50	0.322	21.75	1430.17	2.46	33.67	76.97	99.99	6.09
27152008	7.52	0.338	23.42	1433.08	2.46	33.33	95.30	99.99	5.90
27152012	7.53	0.354	23.42	1438.90	2.59	32.64	87.89	99.99	5.83
27152016	7.55	0.368	21.75	1392.32	2.72	38.12	58.26	99.99	6.34
27152020	7.57	0.386	26.77	1395.23	2.46	37.78	284.43	99.99	6.34
27152024	7.58	0.404	26.77	1395.23	3.11	37.78	102.71	99.99	6.84
27152028	7.60	0.423	28.44	1427.26	3.50	34.01	108.27	99.99	7.91
27152032	7.62	0.441	26.77	1500.04	3.11	25.45	106.60	99.99	7.85
27152036	7.64	0.457	25.10	1488.40	3.37	26.82	104.56	99.99	7.66
27152040	7.65	0.474	25.10	1491.31	3.37	26.48	84.19	99.99	7.72
27152044	7.67	0.492	26.77	1494.22	3.37	26.14	104.56	99.99	7.98
27152048	7.69	0.512	30.12	1479.66	3.37	27.85	180.70	99.99	7.47
27152052	7.71	0.532	30.12	1476.75	3.37	28.19	37.88	99.99	8.16
27152056	7.73	0.552	30.12	1479.66	3.24	27.85	97.16	99.99	7.47
27152100	7.75	0.573	31.79	1441.81	3.24	32.30	89.75	99.99	8.29
27152104	7.77	0.593	30.12	1520.42	3.24	23.06	87.89	99.99	6.34
27152108	7.79	0.611	26.77	1517.51	3.24	23.40	106.42	99.99	7.47
27152112	7.81	0.627	23.42	1575.74	2.20	16.55	221.45	99.99	5.90
27152116	7.81	0.632	8.37	1529.16	1.94	22.03	82.34	99.99	4.76
27152120	7.82	0.638	8.37	1433.08	1.94	33.33	91.60	99.99	4.13
27152124	7.83	0.646	11.71	1473.84	2.07	28.53	32.32	99.99	4.07
27152128	7.83	0.654	11.71	1462.20	2.07	29.90	78.63	99.99	3.82
27152132	7.84	0.659	8.37	1485.49	2.07	27.17	89.75	99.99	3.63
27152136	7.84	0.664	6.69	1473.84	1.94	28.53	110.12	99.99	3.57
27152140	7.85	0.668	6.69	1470.93	2.07	28.88	197.37	99.99	3.76
27152144	7.86	0.680	18.40	1418.52	4.29	35.04	104.56	99.99	5.90
27152148	7.88	0.697	25.10	1470.93	4.16	28.88	100.86	99.99	6.78
27152152	7.89	0.711	20.08	1508.78	4.29	24.43	28.81	99.99	6.53

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	PAGE 2
27152156	7.99	0.721	15.06	1485.49	4.29	27.17	95.30	99.99	6.46
27152200	7.91	0.732	16.73	1468.02	4.29	29.22	86.04	99.99	6.78
27152204	7.93	0.746	21.75	1494.22	4.29	26.14	76.78	99.99	6.97
27152208	7.93	0.748	3.35	23.92	4.98	199.01	262.20	99.99	-1.35



RECORD OF CORSHAM DRILL RUN 2.9 (7.18 to 7.93 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.9 (7.18 to 7.93 metres)



USER: EX9069 -AT SYSTEM

R_C2.10.1

EX9069

R_C2.10.1

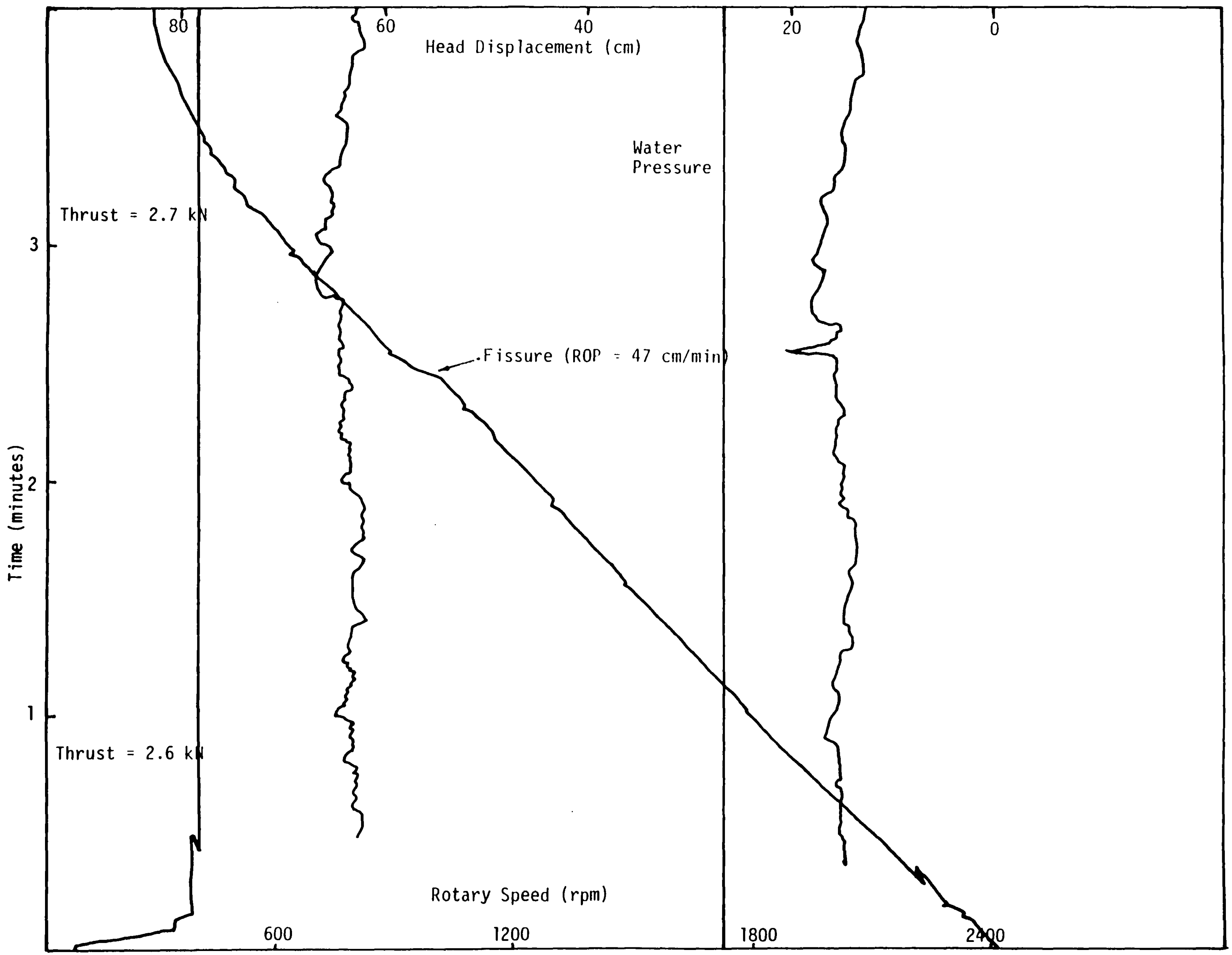
LABEL: PRT014 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:29, ON: PRG BY: PRG

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

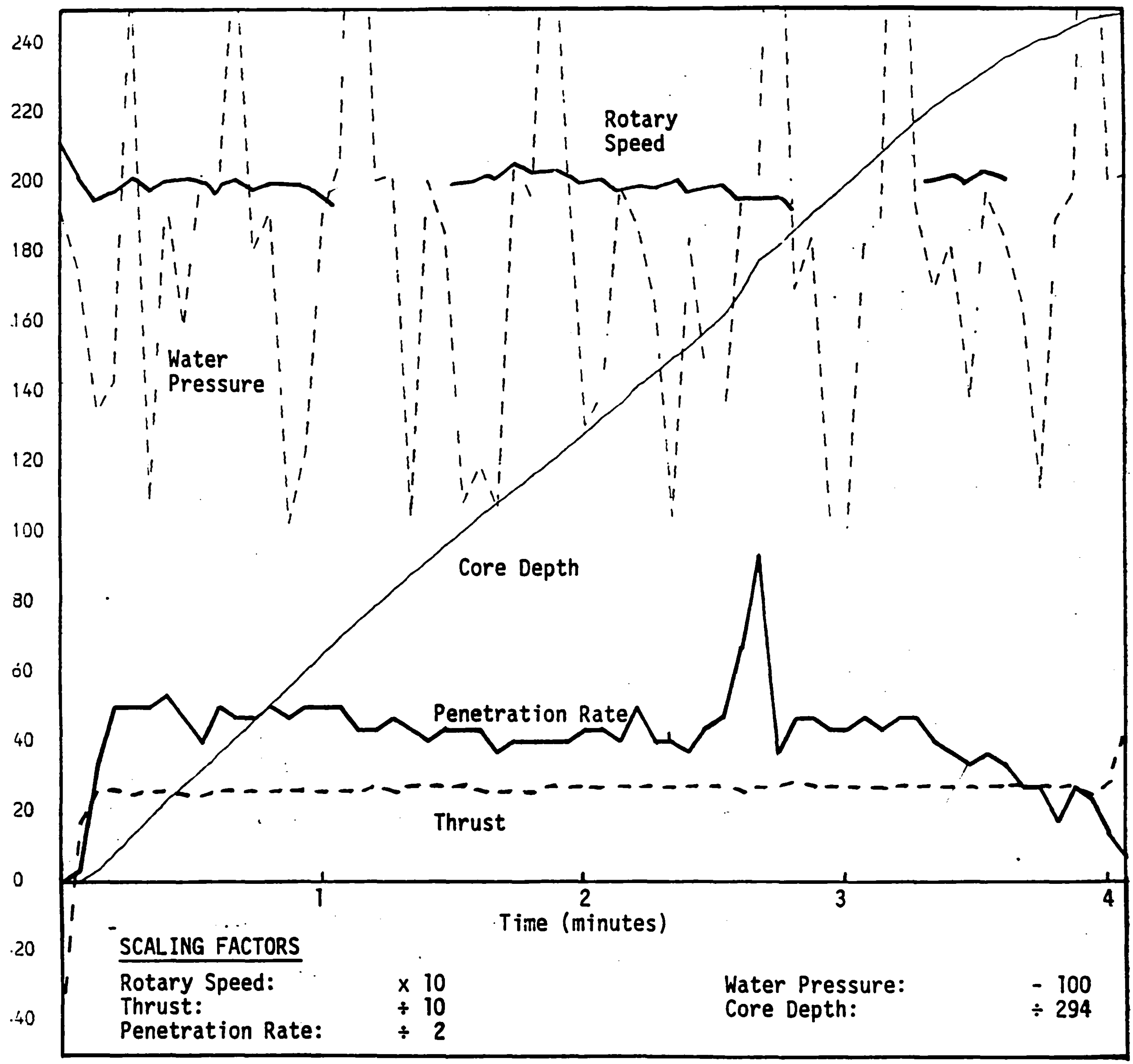
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27153840	7.93	0.000	0.00	2111.46	4.06	0.51	91.56	4.83	7.67
27153844	7.93	0.001	1.67	2018.29	1.55	7.22	74.87	4.83	7.67
27153848	7.94	0.012	16.78	1945.50	2.60	13.25	34.53	4.83	8.55
27153852	7.96	0.029	25.16	1971.71	2.60	11.08	43.35	4.83	9.62
27153856	7.98	0.046	25.16	2015.38	2.47	7.46	160.61	4.83	9.12
27153900	7.99	0.063	25.16	1974.62	2.60	10.84	8.57	4.83	9.37
27153904	8.01	0.081	26.84	2003.73	2.60	8.42	97.12	4.83	9.12
27153908	8.03	0.096	23.49	2015.38	2.47	7.46	58.63	4.83	9.12
27153912	8.04	0.110	20.13	2003.73	2.47	8.42	102.68	4.83	8.80
27153916	8.06	0.126	25.16	1992.09	2.60	9.39	95.27	4.83	9.25
27153920	8.07	0.142	23.49	2006.64	2.60	8.18	168.03	3.40	9.25
27153924	8.09	0.158	23.49	1980.44	2.60	10.35	80.43	3.40	8.80
27153928	8.10	0.174	25.16	1992.09	2.60	9.39	91.56	3.40	9.43
27153932	8.12	0.190	23.49	1995.00	2.60	9.15	2.56	3.40	9.31
27153936	8.14	0.207	25.16	1989.18	2.60	9.63	23.40	3.40	9.12
27153940	8.15	0.224	25.16	1562.97	2.60	11.80	91.56	4.83	9.81
27153944	8.17	0.240	25.16	1989.18	2.60	9.63	106.39	3.40	9.25
27153948	8.18	0.255	21.81	2009.56	2.60	7.94	260.74	3.40	8.87
27153952	8.20	0.270	21.81	1971.71	2.73	11.08	100.83	3.40	9.37
27153956	8.22	0.285	23.49	2000.82	2.60	8.66	102.68	3.40	8.87
27154000	8.23	0.300	21.81	2015.38	2.73	7.46	4.41	3.40	8.80
27154004	8.24	0.313	20.13	2012.47	2.73	7.70	100.83	3.40	8.49
27154008	8.26	0.328	21.81	1992.09	2.73	9.39	86.00	3.40	9.06
27154012	8.27	0.342	21.81	2000.82	2.73	8.66	8.57	3.40	8.80
27154016	8.29	0.357	21.81	2041.58	2.60	5.28	19.24	3.40	8.30
27154020	8.30	0.369	18.45	2006.64	2.59	8.18	6.58	3.39	8.54
27154024	8.31	0.382	20.13	2056.14	2.59	4.08	106.42	3.39	8.04
27154028	8.33	0.396	20.13	2032.85	2.59	6.01	95.30	3.39	8.10
27154032	8.34	0.409	20.13	2027.02	2.72	6.49	208.48	3.39	7.85
27154036	8.35	0.423	20.13	1986.26	2.72	9.87	106.42	3.39	8.67
27154040	8.37	0.437	21.81	2003.73	2.72	8.42	30.66	3.39	8.54
27154044	8.38	0.452	21.81	2012.47	2.72	7.70	39.92	3.39	8.48
27154048	8.40	0.465	20.13	1971.71	2.72	11.08	99.01	3.39	8.73
27154052	8.41	0.482	25.16	1986.26	2.72	9.87	87.89	3.39	9.17
27154056	8.43	0.495	20.13	1986.26	2.72	9.87	65.85	3.39	8.67
27154100	8.44	0.509	20.13	2027.02	2.72	6.49	4.54	3.39	8.54
27154104	8.45	0.521	18.45	1968.79	2.72	11.32	84.19	3.39	8.86
27154108	8.47	0.536	21.81	1983.35	2.72	10.11	43.44	3.39	8.67
27154112	8.48	0.551	23.49	1995.00	2.72	9.15	32.51	3.39	8.42
27154116	8.50	0.574	33.55	1936.77	2.59	13.98	95.30	3.39	8.54
27154120	8.54	0.605	46.97	2009.56	2.72	7.94	100.86	3.39	8.35
27154124	8.55	0.617	18.45	1965.88	2.72	11.56	252.94	3.39	8.35
27154128	8.56	0.633	23.49	1913.48	2.85	15.91	69.37	3.39	9.55
27154132	8.58	0.649	23.49	1945.50	2.72	13.25	84.19	3.39	9.42
27154136	8.59	0.663	21.81	1974.62	2.72	10.84	4.72	3.39	8.92
27154140	8.61	0.678	21.81	1925.12	2.72	14.94	1.02	3.39	9.68
27154144	8.62	0.693	23.49	1971.71	2.72	11.08	84.19	3.39	9.11
27154148	8.64	0.708	21.81	1968.79	2.72	11.32	89.75	3.39	8.67
27154152	8.65	0.724	23.49	1954.24	2.72	12.53	258.50	3.39	8.79
27154156	8.67	0.739	23.49	1997.91	2.72	8.91	93.45	3.39	8.92
27154200	8.68	0.753	20.13	2003.73	2.72	8.42	69.37	3.39	8.54
27154204	8.69	0.765	18.45	2027.02	2.72	6.49	82.34	3.39	7.85
27154208	8.71	0.776	16.77	1995.00	2.72	9.15	37.88	3.39	7.91
27154212	8.72	0.788	18.45	2021.20	2.72	6.97	97.16	3.39	8.29

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
27154216	8.73	0.800	16.77	2047.41	2.72	4.80	86.04	3.39	7.79
2715422[illegible]	8.74	0.809	13.42	2041.58	2.72	5.28	65.67	3.39	7.53
27154224	8.75	0.818	13.42	2085.25	2.72	1.66	12.13	3.39	7.41
27154228	8.75	0.823	8.39	2067.79	2.72	3.11	89.75	3.39	7.09
27154232	8.76	0.832	13.42	2041.58	2.72	5.28	97.16	3.39	7.66
27154236	8.77	0.840	11.74	2076.52	2.46	2.39	262.20	3.39	7.28
27154240	8.77	0.844	6.71	2085.25	2.85	1.66	100.86	3.39	6.97
27154244	8.78	0.847	3.35	699.38	4.59	116.59	102.71	3.39	-1.09



RECORD OF CORSHAM DRILL RUN 2.10.1 (7.93 to 8.78 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.10.1 (7.93 to 8.78 metres)



USER: EX9069 -AT SYSTEM

R_C2.10.2

EX9069

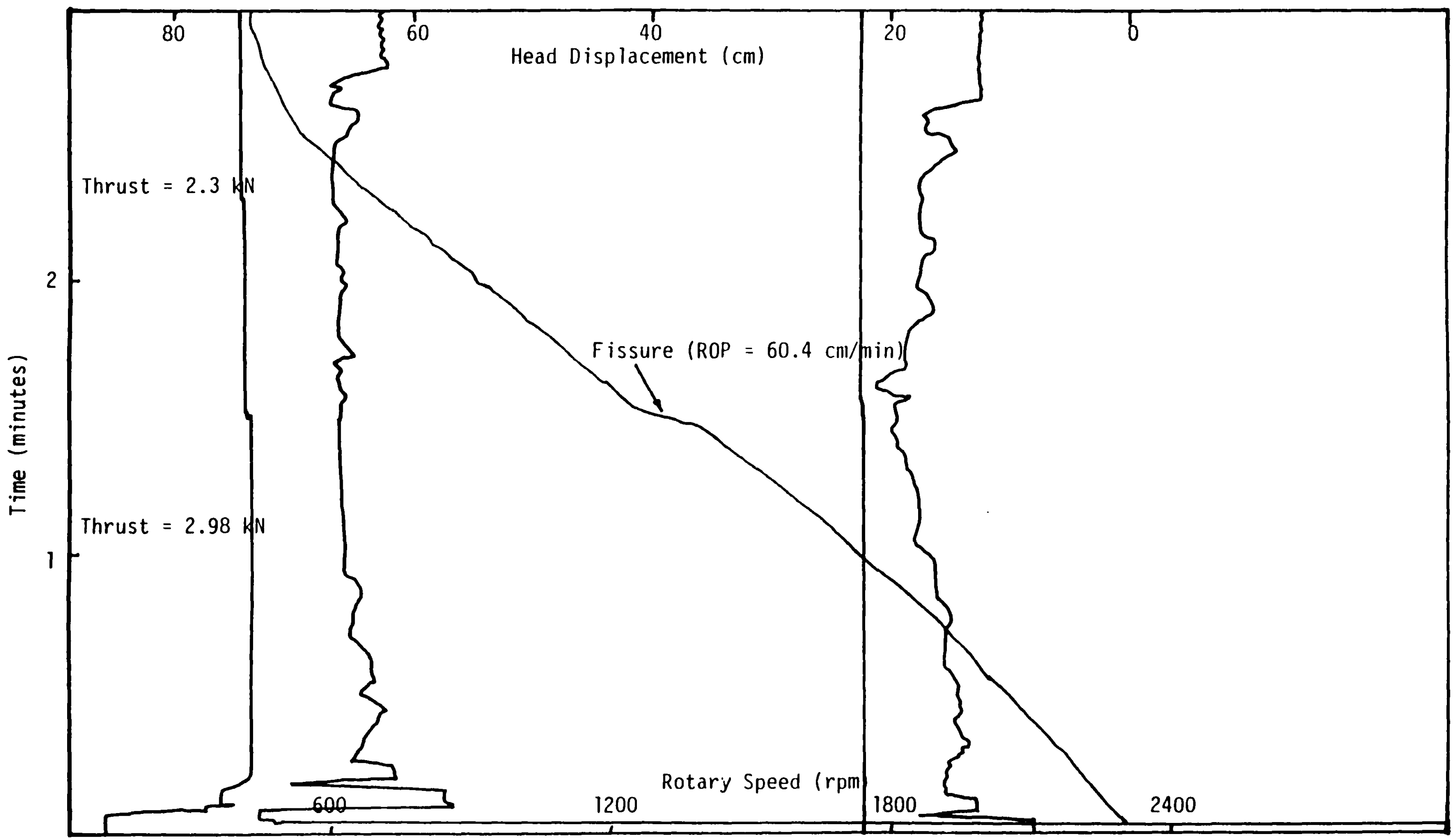
R_C2.10.2

LABEL: PRT015 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:29, ON: PRO BY: PRO

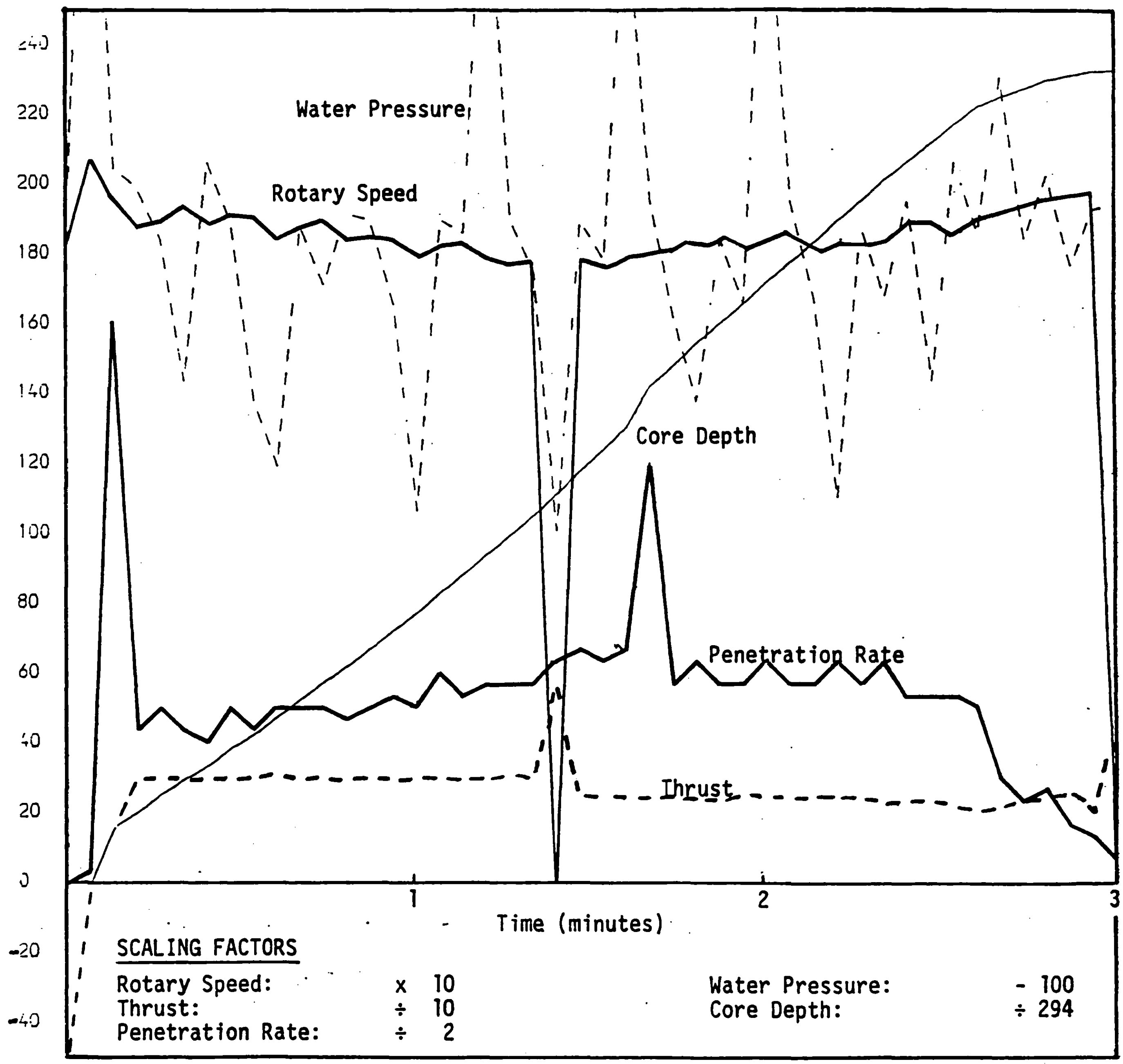
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27154256	8.78	0.000	0.00	1834.87	4.85	27.27	95.30	3.39	5.83
27154300	8.78	0.001	1.67	2373.61	3.93	8.57	254.79	3.39	7.16
27154304	8.83	0.055	80.52	1965.36	1.55	12.04	104.56	3.39	8.86
27154308	8.85	0.069	21.81	1878.54	2.98	23.85	99.01	3.39	9.99
27154312	8.87	0.086	25.16	1893.10	2.98	22.71	84.19	3.39	9.61
27154316	8.88	0.101	21.81	1939.68	2.98	19.06	43.44	3.39	9.17
27154320	8.89	0.114	20.13	1884.36	2.98	23.39	106.69	3.39	9.42
27154324	8.91	0.131	25.16	1913.48	2.98	21.11	89.75	3.39	9.17
27154328	8.93	0.145	21.81	1907.65	2.98	21.57	37.88	3.39	9.36
27154332	8.94	0.162	25.16	1842.69	3.11	21.94	19.34	3.39	9.68
27154336	8.96	0.179	25.16	1875.63	2.98	19.05	87.89	3.39	9.80
27154340	8.98	0.196	25.16	1898.92	2.98	17.11	71.22	3.39	9.55
27154344	8.99	0.211	23.49	1843.69	2.98	26.81	91.63	3.39	9.49
27154348	9.01	0.228	25.16	1846.51	2.98	21.46	89.75	3.39	10.12
27154352	9.03	0.246	26.84	1840.69	2.98	26.81	65.67	3.39	10.05
27154356	9.04	0.263	25.16	1785.37	2.98	26.53	6.58	3.39	10.24
27154400	9.06	0.283	30.20	1823.22	2.98	23.39	89.75	3.39	10.31
27154404	9.08	0.301	26.84	1831.95	2.98	22.67	86.04	3.39	9.99
27154408	9.10	0.320	28.52	1788.28	2.98	26.29	206.63	3.39	10.49
27154412	9.12	0.339	28.52	1767.90	3.11	27.98	89.75	3.39	10.49
27154416	9.14	0.358	28.52	1776.64	2.98	27.26	74.93	3.39	10.49
27154420	9.16	0.379	31.87	23.92	5.63	352.36	0.96	3.39	10.66
27154424	9.18	0.402	33.55	1794.11	2.46	35.92	89.75	3.39	10.62
27154428	9.20	0.423	31.87	1767.90	2.46	37.83	78.63	3.39	10.93
27154432	9.23	0.445	33.55	1706.76	2.46	42.28	182.55	3.39	10.37
27154436	9.27	0.485	60.39	1820.31	2.46	34.01	95.30	3.39	10.62
27154440	9.28	0.504	28.52	1805.75	2.46	35.07	61.96	3.39	10.31
27154444	9.31	0.526	31.87	1811.57	2.46	34.54	37.84	3.39	10.62
27154448	9.32	0.545	28.52	1858.16	2.33	31.22	84.19	3.39	9.55
27154452	9.34	0.564	28.52	1811.57	2.59	34.64	65.67	3.39	9.74
27154456	9.36	0.585	31.87	1837.78	2.46	32.73	202.93	3.39	9.80
27154500	9.38	0.604	28.52	1866.89	2.46	33.61	95.30	3.39	9.61
27154504	9.40	0.623	28.52	1794.11	2.46	35.92	67.52	3.39	9.80
27154508	9.42	0.644	31.87	1823.22	2.46	33.79	10.09	3.39	9.99
27154512	9.44	0.663	28.52	1817.40	2.46	34.22	88.08	3.39	9.68
27154516	9.46	0.684	31.87	1834.87	2.33	32.94	67.52	3.39	9.99
27154520	9.48	0.702	26.84	1887.27	2.33	29.12	95.30	3.39	9.36
27154524	9.50	0.720	26.84	1893.10	2.33	28.70	43.62	3.39	9.05
27154528	9.52	0.738	26.84	1846.51	2.20	32.09	106.42	3.39	9.93
27154532	9.53	0.755	25.16	1896.01	2.07	28.49	86.04	3.39	9.49
27154536	9.54	0.765	15.10	1962.97	2.20	23.60	130.69	3.39	8.10
27154540	9.55	0.773	11.74	1965.06	2.33	23.82	84.19	3.39	8.16
27154544	9.56	0.782	13.42	1954.24	2.46	24.24	102.71	3.39	8.16
27154548	9.57	0.787	8.39	1971.71	2.59	22.97	76.97	3.39	8.04
27154552	9.57	0.792	6.71	1983.35	2.07	22.12	93.45	3.39	7.91
27154556	9.57	0.794	3.35	29.74	4.85	164.46	95.30	3.39	-1.28



RECORD OF CORSHAM DRILL RUN 2.10.2 (8.78 to 9.57 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.10.2 (8.78 to 9.57 metres)



USER: EX9069 -AT SYSTEM

R_C2.11.1

EX9069

R_C2.11.1

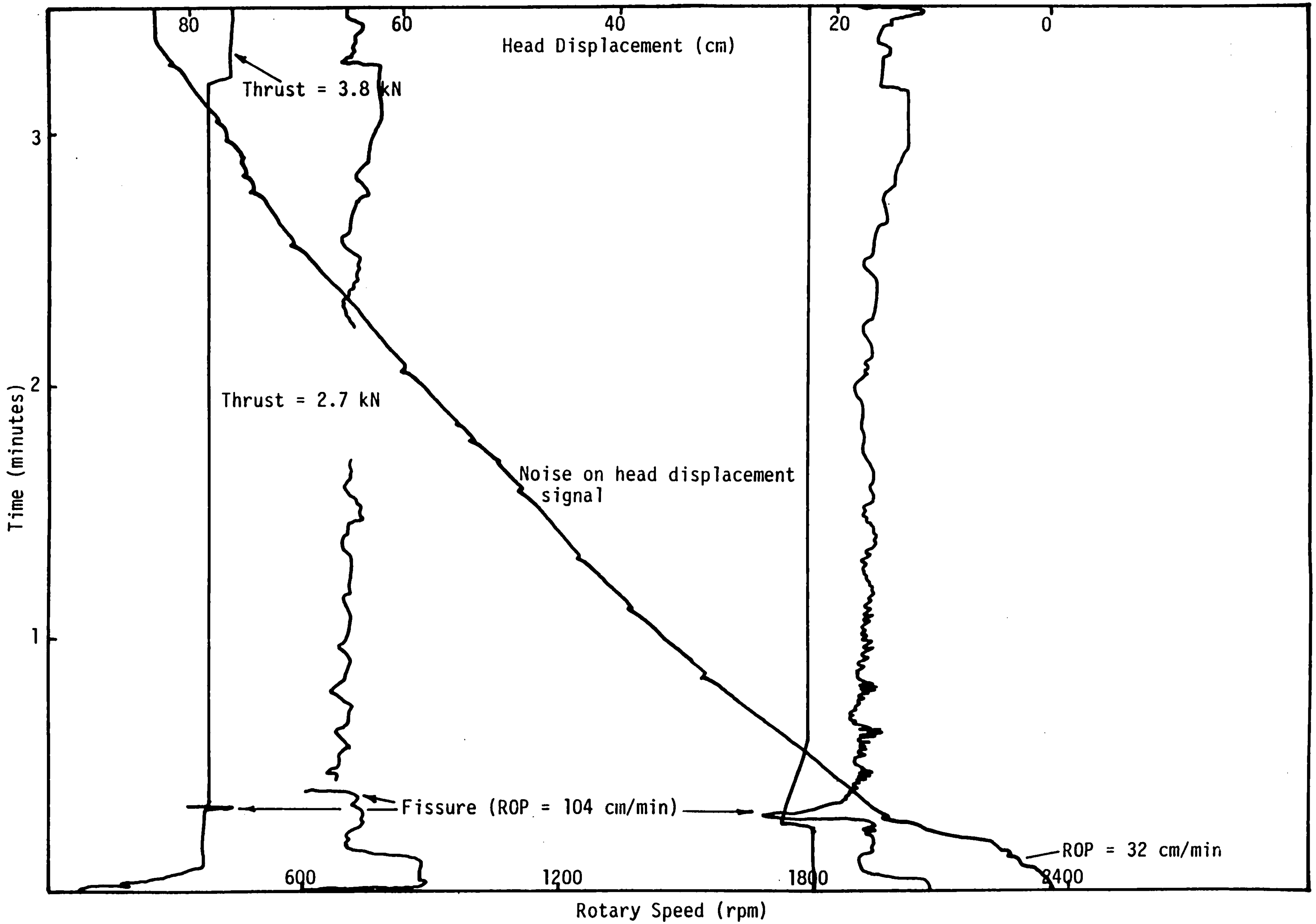
LABEL: PRT016 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:29, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

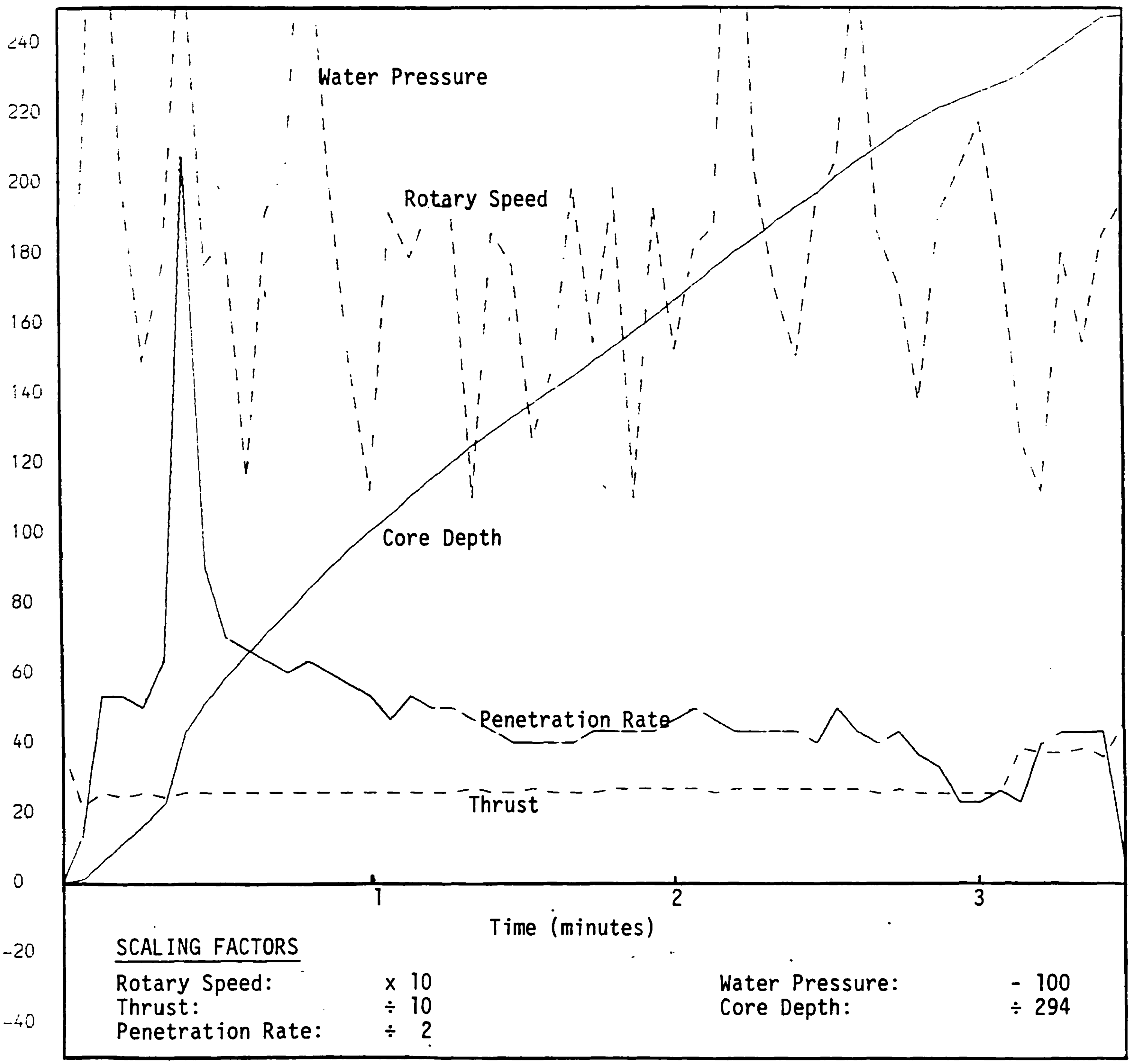
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27162240	9.57	0.000	0.00	2082.34	3.93	7.89	100.86	4.83	7.66
27162244	9.57	0.004	6.67	1907.65	2.20	21.57	97.16	3.39	8.23
27162248	9.59	0.022	26.77	1907.65	2.59	21.57	223.30	3.39	9.93
27162252	9.61	0.040	26.77	1957.15	2.46	17.69	102.71	3.39	9.36
27162256	9.63	0.057	25.10	1919.30	2.59	20.66	48.99	3.39	9.36
27162300	9.65	0.078	31.79	1913.48	2.46	21.11	76.78	3.39	9.30
27162304	9.72	0.147	103.74	1884.36	2.59	23.39	175.14	3.39	10.18
27162308	9.75	0.177	45.18	1898.92	2.59	22.25	76.78	3.39	10.12
27162312	9.77	0.201	35.14	1904.74	2.59	21.80	84.19	3.39	9.68
27162316	9.79	0.223	33.46	1910.56	2.59	21.34	15.65	3.39	10.05
27162320	9.81	0.244	31.79	1928.03	2.59	19.97	91.60	3.39	9.68
27162324	9.83	0.264	30.12	1852.34	2.59	25.90	104.56	3.39	10.12
27162328	9.86	0.286	31.79	1901.83	2.59	22.02	193.67	3.39	9.80
27162332	9.88	0.306	30.12	1910.56	2.59	21.34	104.56	3.39	9.36
27162336	9.89	0.325	28.44	1913.48	2.59	21.11	48.99	3.39	9.80
27162340	9.91	0.342	26.77	1922.21	2.59	20.43	12.13	3.39	9.49
27162344	9.93	0.358	23.42	1904.74	2.59	21.80	91.63	3.39	9.30
27162348	9.95	0.376	26.77	1925.12	2.59	20.20	78.63	3.39	9.55
27162352	9.96	0.393	25.10	1933.86	2.59	19.51	93.64	3.39	9.42
27162356	9.98	0.409	25.10	1928.03	2.59	19.97	93.45	3.39	9.11
27162400	9.99	0.425	23.42	1901.83	2.72	22.02	10.09	3.39	9.68
27162404	10.01	0.439	21.75	1928.03	2.59	19.97	86.04	3.39	9.23
27162408	10.02	0.453	20.08	1942.59	2.59	18.83	76.78	3.39	9.05
27162412	10.04	0.466	20.08	1896.01	2.72	22.48	26.95	3.39	9.23
27162416	10.05	0.480	20.08	1936.77	2.59	19.29	47.14	3.39	9.05
27162420	10.06	0.493	20.08	1933.86	2.59	19.51	99.01	3.39	9.11
27162424	10.08	0.508	21.75	1936.77	2.59	19.29	54.55	3.39	9.05
27162428	10.09	0.522	21.75	1913.48	2.72	21.11	99.01	3.39	9.49
27162432	10.11	0.537	21.75	1907.65	2.72	21.57	10.09	3.39	9.23
27162436	10.12	0.551	21.75	1913.48	2.72	21.11	93.45	3.39	9.23
27162440	10.14	0.567	23.42	1869.80	2.72	24.53	52.70	3.39	9.49
27162444	10.15	0.583	25.10	1919.30	2.72	20.66	82.34	3.39	9.42
27162448	10.17	0.599	23.42	1939.68	2.59	19.06	87.89	3.39	9.11
27162452	10.18	0.614	21.75	1930.95	2.72	19.74	249.24	3.39	8.73
27162456	10.20	0.628	21.75	1928.03	2.72	19.97	102.71	3.39	9.23
27162500	10.21	0.643	21.75	1960.06	2.72	17.46	69.37	3.39	8.73
27162504	10.23	0.657	21.75	1971.71	2.72	16.55	50.85	3.39	8.48
27162508	10.24	0.670	20.08	1910.56	2.72	21.34	95.30	3.39	8.92
27162512	10.26	0.687	25.10	1945.50	2.72	18.60	106.42	3.39	8.67
27162516	10.27	0.702	21.75	1962.97	2.72	17.23	167.73	3.39	8.54
27162520	10.28	0.715	20.08	1989.18	2.59	15.18	86.04	3.39	8.04
27162524	10.30	0.730	21.75	1977.53	2.72	16.09	71.22	3.39	8.42
27162528	10.31	0.742	18.40	2003.73	2.59	14.04	37.88	3.39	7.85
27162532	10.32	0.753	16.73	2032.85	2.59	11.76	91.60	3.39	7.60
27162536	10.33	0.761	11.71	2047.41	2.59	10.62	104.56	3.39	7.28
27162540	10.34	0.769	11.71	2038.67	2.59	5.53	117.72	3.39	7.22
27162544	10.35	0.777	13.38	2032.85	2.59	11.76	84.19	3.39	7.35
27162548	10.36	0.785	11.71	1942.59	3.89	18.83	26.95	3.39	7.09
27162552	10.37	0.799	20.08	1965.88	3.76	17.01	12.13	3.39	8.16
27162556	10.38	0.813	21.75	1992.09	3.76	14.95	80.46	3.39	7.91
27162600	10.40	0.828	21.75	1951.33	3.89	18.15	54.74	3.39	8.54
27162604	10.41	0.842	21.75	2067.79	3.63	9.03	86.04	3.39	7.85
27162608	10.41	0.844	3.34	1831.95	4.59	27.50	95.30	3.39	5.58

-682-



RECORD OF CORSHAM DRILL RUN 2.11.1 (9.57 to 10.41 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.11.1 (9.57 to 10.41 metres)



USER: EX9069 -AT SYSTEM

R_C2.11.2

EX9069

R_C2.11.2

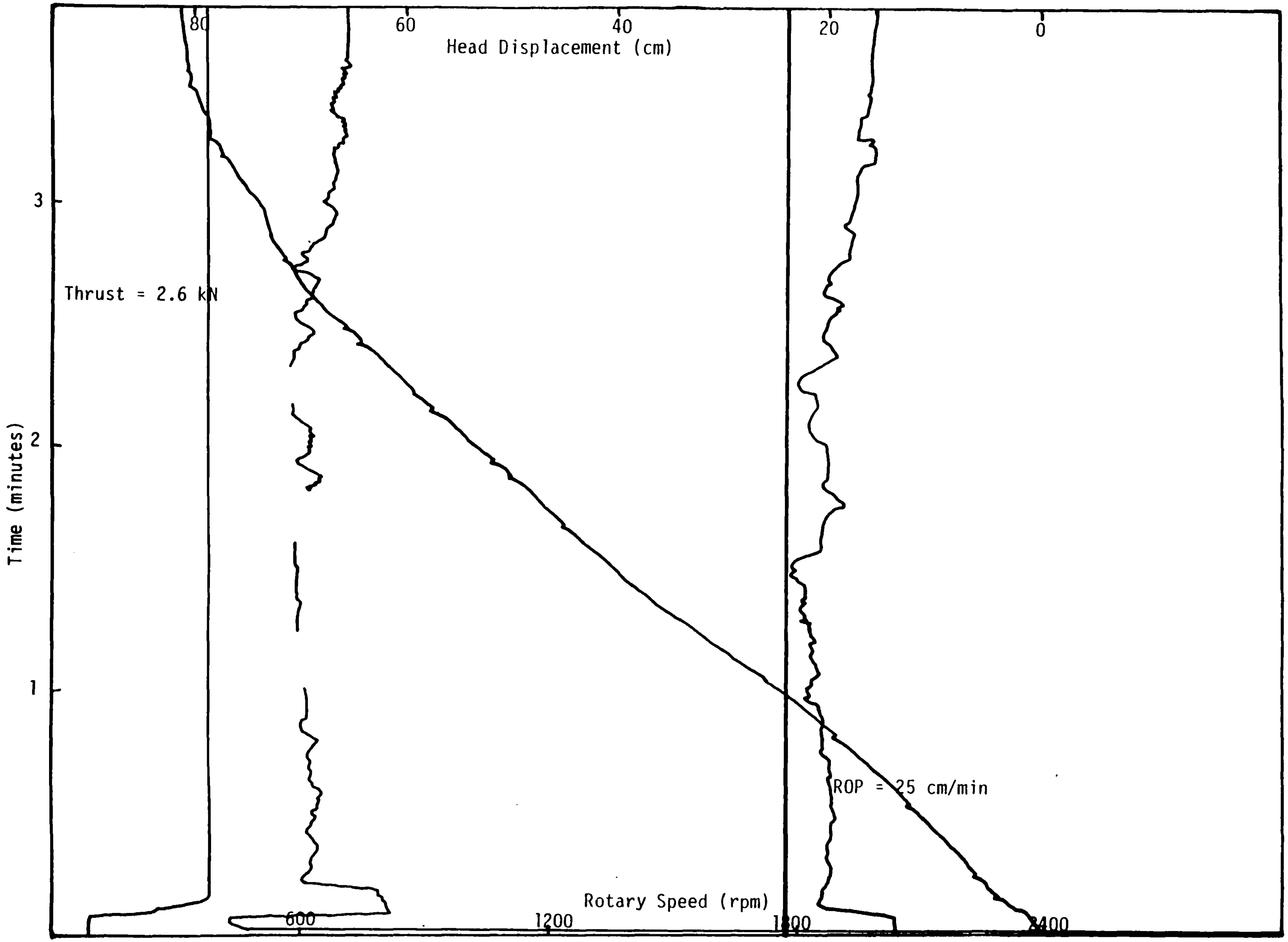
LABEL: PRT017 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:29, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

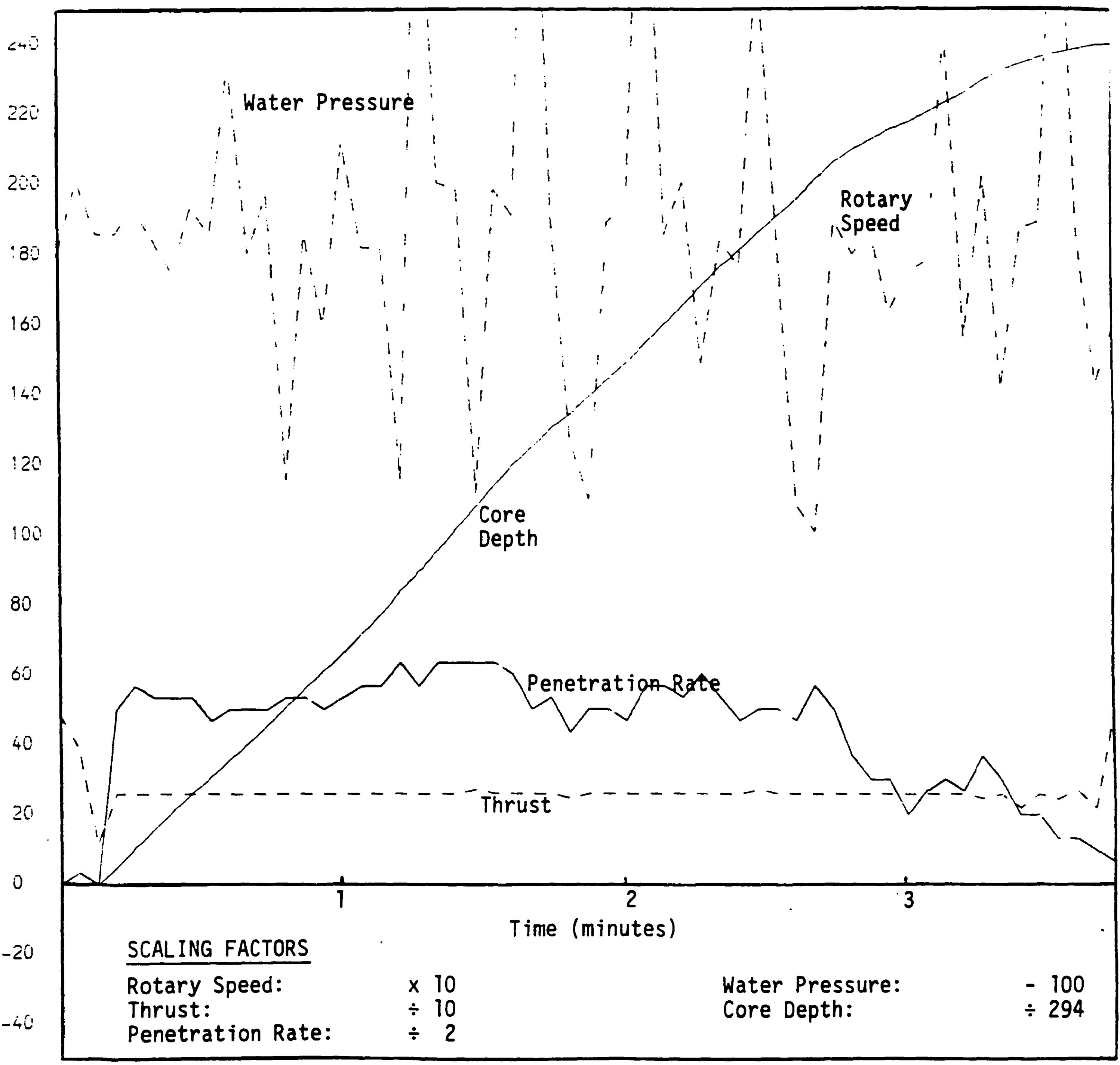
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27163630	10.41	0.000	0.00	1797.02	4.85	30.23	82.34	99.99	8.92
27163634	10.41	0.001	1.67	2044.49	3.93	10.85	100.86	99.99	7.16
27163638	10.41	0.001	0.00	1997.91	1.15	14.59	86.04	95.99	7.28
27163642	10.43	0.018	25.10	1861.07	2.59	25.22	86.04	99.99	9.86
27163646	10.45	0.037	28.44	1861.07	2.59	25.22	93.45	99.99	9.30
27163650	10.46	0.055	26.77	1869.80	2.59	24.53	84.19	99.99	9.11
27163654	10.48	0.073	26.77	1866.89	2.59	24.76	74.93	99.99	9.55
27163658	10.50	0.090	26.77	1884.36	2.59	23.39	93.45	99.99	9.23
27163702	10.52	0.106	23.42	1884.36	2.59	23.39	86.04	99.99	8.92
27163706	10.53	0.123	25.10	1863.98	2.59	24.99	134.39	99.99	9.30
27163710	10.55	0.139	25.10	1863.98	2.59	24.99	80.48	99.99	9.42
27163714	10.57	0.156	25.10	1863.98	2.59	24.99	97.16	99.99	9.11
27163718	10.58	0.174	26.77	1866.89	2.59	24.76	15.84	99.99	9.61
27163722	10.60	0.192	26.77	1861.07	2.59	25.22	86.04	99.99	9.30
27163726	10.62	0.205	25.10	1834.87	2.59	27.27	60.11	95.99	9.17
27163730	10.64	0.226	26.77	1834.87	2.59	27.27	112.16	99.99	9.80
27163734	10.66	0.245	28.44	1846.51	2.59	26.36	82.34	99.99	9.61
27163738	10.67	0.264	28.44	1808.66	2.59	29.32	82.34	99.99	9.49
27163742	10.70	0.286	31.79	1826.13	2.59	27.95	15.84	99.99	9.49
27163746	10.71	0.305	28.44	1840.69	2.59	26.81	212.19	99.99	9.42
27163750	10.74	0.326	31.79	1820.31	2.59	28.41	100.86	99.99	9.86
27163754	10.76	0.347	31.79	1837.78	2.59	27.04	99.01	99.99	9.55
27163758	10.78	0.368	31.79	1764.99	2.72	32.74	11.95	99.99	9.68
27163802	10.80	0.389	31.79	1814.49	2.59	28.86	99.01	99.99	9.61
27163806	10.82	0.409	30.12	1872.72	2.59	24.30	91.60	99.99	9.17
27163810	10.84	0.426	25.10	1840.69	2.59	26.81	269.61	99.99	9.36
27163814	10.85	0.444	26.77	1878.54	2.59	23.85	91.60	99.99	8.86
27163818	10.87	0.458	21.75	1907.65	2.46	21.57	26.77	99.99	8.35
27163822	10.89	0.475	25.10	1861.07	2.59	25.22	10.28	99.99	9.17
27163826	10.90	0.492	25.10	1890.18	2.59	22.94	89.75	99.99	8.73
27163830	10.92	0.508	23.42	1881.45	2.59	23.62	95.30	99.99	8.67
27163834	10.94	0.527	28.44	1814.49	2.59	28.86	232.57	99.99	9.55
27163838	10.96	0.545	28.44	1855.25	2.59	25.67	86.04	99.99	9.05
27163842	10.97	0.563	26.77	1831.95	2.59	27.50	100.86	99.99	8.98
27163846	10.99	0.583	30.12	1823.22	2.59	28.18	49.18	99.99	9.36
27163850	11.01	0.601	26.77	1878.54	2.59	23.85	84.19	99.99	8.92
27163854	11.03	0.617	23.42	1866.89	2.59	24.76	76.78	99.99	8.48
27163858	11.04	0.634	25.10	1881.45	2.72	23.52	165.88	99.99	9.23
27163902	11.06	0.650	25.10	1904.74	2.59	21.80	82.34	99.99	8.67
27163906	11.08	0.666	23.42	1881.45	2.59	23.62	8.24	99.99	8.29
27163910	11.09	0.685	28.44	1884.36	2.59	23.39	0.83	99.99	8.73
27163914	11.11	0.702	25.10	1910.56	2.59	21.34	89.75	99.99	8.54
27163918	11.12	0.714	18.40	1954.24	2.59	17.92	80.48	99.99	7.85
27163922	11.13	0.724	15.06	1936.77	2.59	19.29	86.04	99.99	7.60
27163926	11.14	0.734	15.06	1951.33	2.59	18.15	64.00	99.99	7.85
27163930	11.15	0.741	10.04	1968.79	2.59	16.78	74.93	99.99	7.60
27163934	11.16	0.750	13.38	1962.97	2.59	17.23	78.63	99.99	7.72
27163938	11.17	0.760	15.06	1986.26	2.59	15.41	143.65	99.99	7.22
27163942	11.18	0.769	13.38	1977.53	2.59	16.09	56.40	99.99	7.22
27163946	11.19	0.781	18.40	1971.71	2.46	16.55	102.71	99.99	7.66
27163950	11.20	0.791	15.06	2000.82	2.59	14.27	41.77	99.99	7.16
27163954	11.21	0.798	10.04	2009.56	2.20	13.59	87.89	99.99	7.03
27163958	11.21	0.804	10.04	1997.91	2.59	14.50	89.75	99.99	7.03
2716[illegible]02	11.22	0.809	6.69	2009.56	2.46	13.59	214.04	99.99	6.90

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
27161006	11.22	0.813	6.69	2315.38	2.72	13.13	87.85	99.99	6.84
27161010	11.23	0.817	5.02	2012.47	2.20	13.34	43.44	99.99	6.90
27161014	11.23	0.819	3.34	175.32	4.85	157.23	60.11	99.99	-1.22



RECORD OF CORSHAM DRILL RUN 2.11.2 (10.41 to 11.23 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.11.2 (10.41 to 11.23)



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USER: EX9069 -AT SYSTEM

R_C2.12.1

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EX9069

R_C2.12.1

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LABEL: PRT018 -FORM

SPOOLED:  82-01-25.18:25
STARTED:  82-01-25.18:29, ON:    PR0   BY: PR0

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E
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-069-

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
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27162120	11.23	0.000	0.00	2021.20	1.98	12.67	76.78	99.99	7.66
27162124	11.23	0.004	6.67	1878.54	2.72	23.85	84.19	99.99	8.54
27162128	11.25	0.023	28.44	1843.60	2.85	26.58	49.18	99.99	9.93
27162132	11.27	0.041	26.77	1866.89	2.72	24.76	65.67	99.99	9.61
27162136	11.29	0.059	26.77	1834.87	2.85	27.27	82.34	99.99	9.55
27162140	11.31	0.077	26.77	1866.89	2.85	24.76	121.42	99.99	9.61
27162144	11.32	0.094	25.10	1890.18	2.85	22.94	78.63	99.99	9.36
27162148	11.34	0.110	25.10	1849.42	2.85	26.13	78.63	99.99	9.30
27162152	11.36	0.128	26.77	1834.87	2.85	27.27	73.26	99.99	9.74
27162156	11.38	0.147	28.44	1869.80	2.85	24.53	58.26	99.99	9.61
27162200	11.40	0.166	28.44	1805.75	2.85	29.55	82.34	99.99	10.05
27162204	11.42	0.185	28.44	1826.13	2.85	27.95	108.46	99.99	9.93
27162208	11.43	0.204	28.44	1811.57	2.85	29.09	56.40	99.99	9.93
27162212	11.45	0.224	30.12	1794.11	2.85	30.46	78.63	99.99	10.43
27162216	11.47	0.243	28.44	1820.31	2.85	28.41	45.48	99.99	10.05
27162220	11.49	0.262	28.44	1799.93	2.85	30.00	73.07	99.99	9.99
27162224	11.51	0.281	28.44	1834.87	2.85	27.27	86.04	99.99	9.93
27162228	11.53	0.299	26.77	1831.95	2.85	27.50	130.69	99.99	9.80
27162232	11.55	0.316	25.10	1788.28	2.72	30.92	87.89	99.99	10.05
27162236	11.56	0.335	28.44	1826.13	2.85	27.95	78.63	99.99	9.74
27162240	11.58	0.352	26.77	1834.87	2.85	27.27	87.89	99.99	9.74
27162244	11.60	0.371	28.44	1823.22	2.98	28.18	87.89	99.99	10.05

USER: EX9069 -AT SYSTEM

R_C2.12.2

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EX9069

R_C2.12.2

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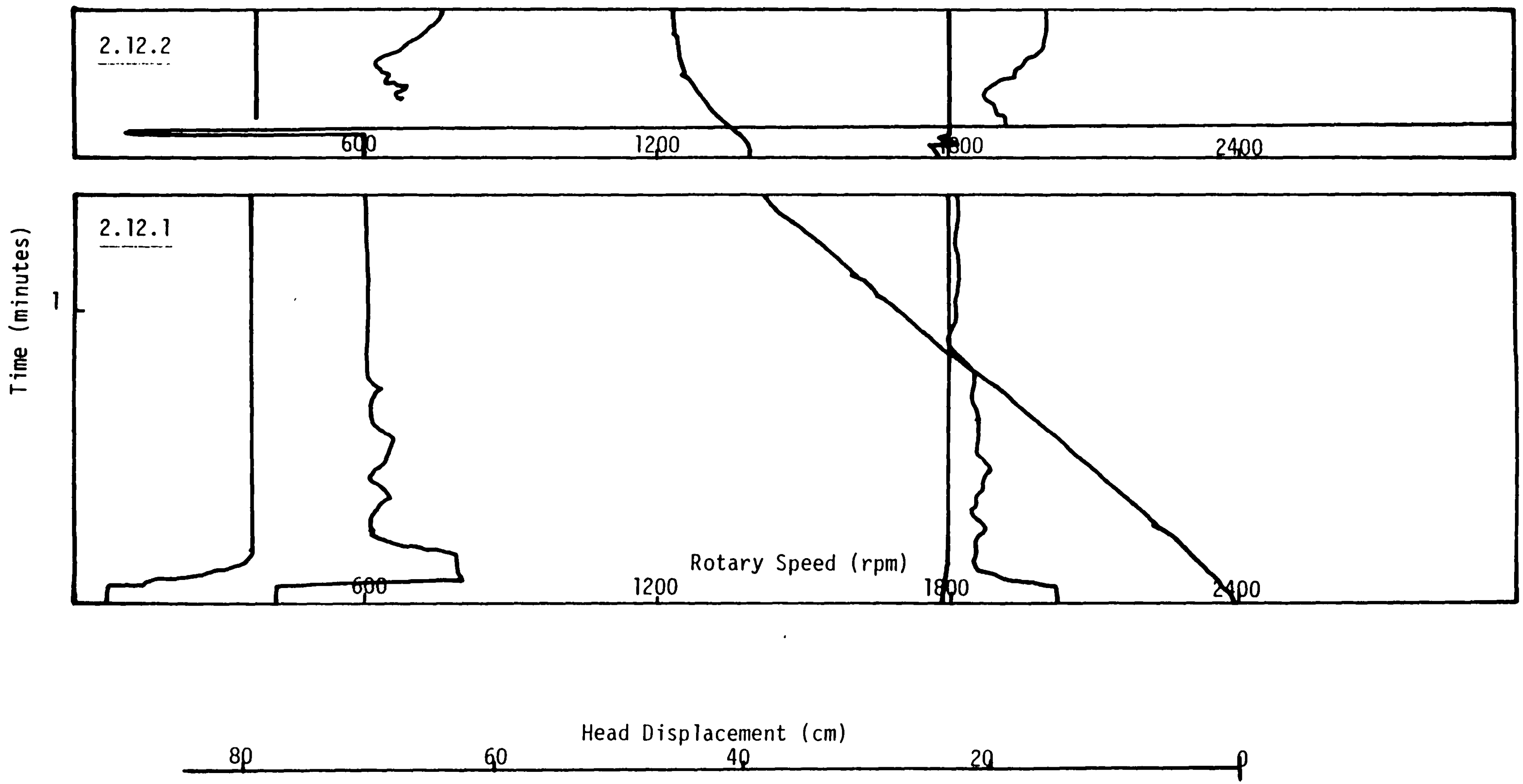
LABEL: PRT019 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:29, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
27162820	11.60	0.000	0.00	2024.11	3.80	12.45	17.69	99.99	6.46
27162824	11.60	0.000	0.00	2024.11	3.93	12.45	69.37	99.99	7.72
27162828	11.60	0.002	3.34	1896.01	2.59	22.48	104.56	99.99	8.29
27162832	11.62	0.018	23.42	1872.72	2.46	24.30	86.04	99.99	9.55
27162836	11.63	0.033	23.42	1893.10	2.46	22.71	24.91	99.99	9.68
27162840	11.65	0.048	21.75	1971.71	2.46	16.55	32.32	99.99	8.60
27162844	11.66	0.057	13.38	2009.56	2.59	13.59	80.48	99.99	7.98
27162848	11.66	0.061	6.69	2015.38	2.33	13.13	28.62	99.99	7.79
27162852	11.66	0.064	3.34	1788.28	4.85	30.92	58.44	99.99	7.66



RECORD OF CORSHAM DRILL RUNS 2.12.1 (11.23 to 11.60 metres) AND 2.12.2 (11.60 to 11.66 metres)

USER: EX9069 -AT SYSTEM

R_C2.13.1

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EX9069

R_C2.13.1

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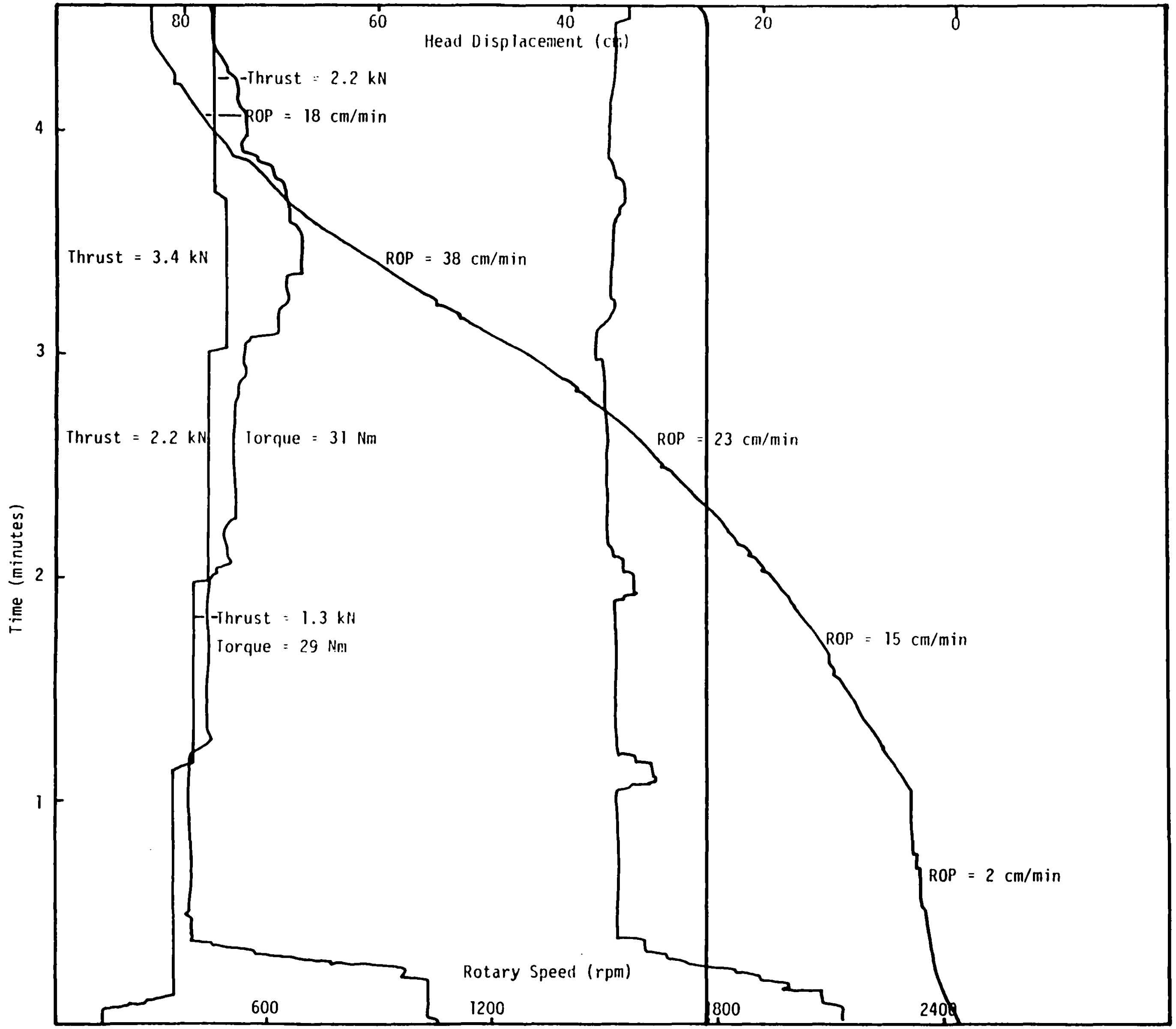
LABEL: FRTC20 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:29, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

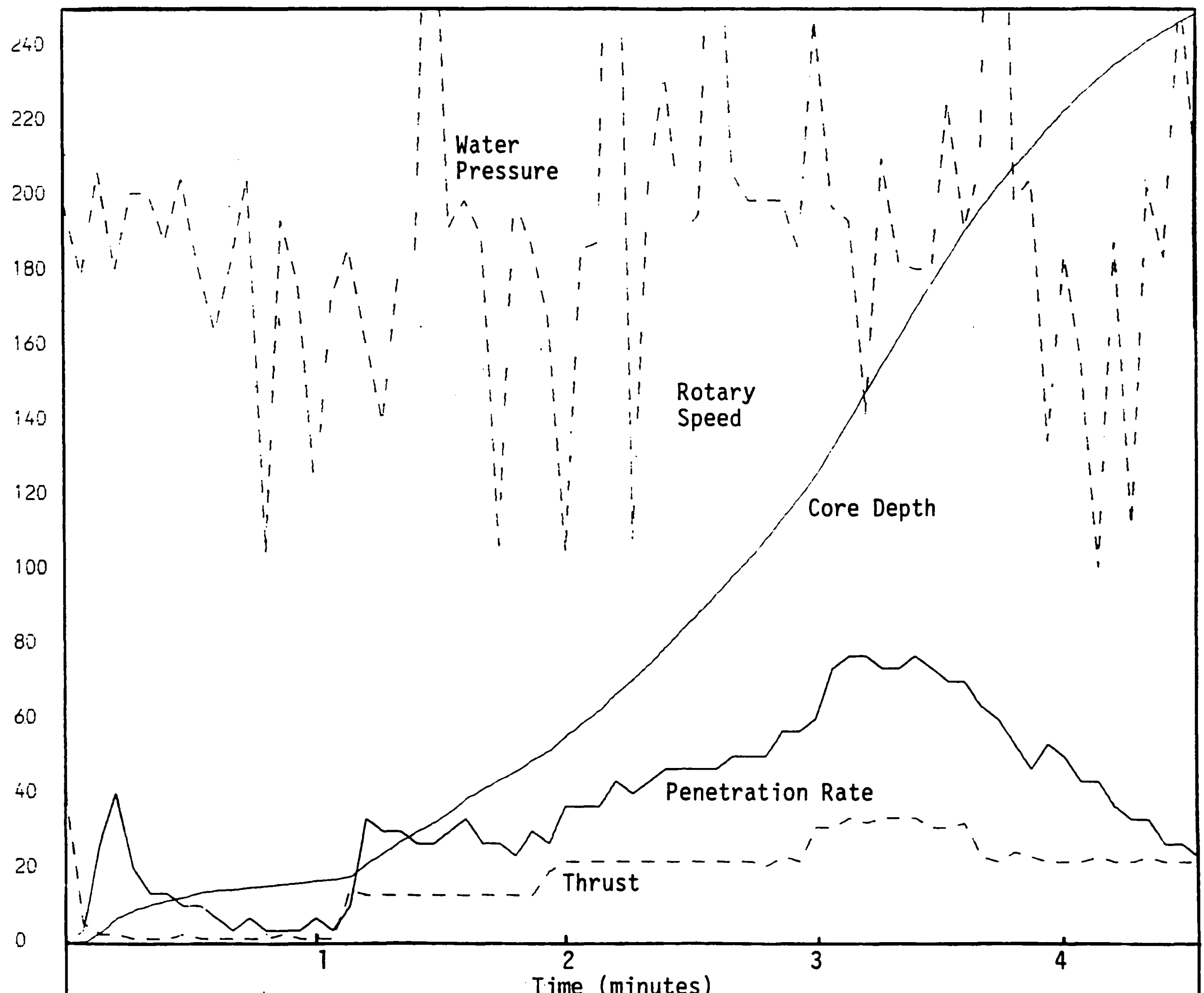
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M* 2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
2[redacted]2834	11.66	0.000	0.00	2111.46	4.06	0.51	97.16	3.39	9.55
2[redacted]2838	11.66	0.001	1.67	2105.63	0.54	0.03	78.82	3.39	9.42
2[redacted]2842	11.67	0.010	13.38	2027.02	0.24	6.49	106.42	99.99	10.49
2[redacted]2846	11.68	0.023	20.08	1863.98	0.24	20.01	80.48	99.99	7.28
2[redacted]2850	11.69	0.030	10.04	1671.82	0.11	35.95	100.86	3.39	5.71
2[redacted]2854	11.69	0.035	6.69	1555.36	0.11	31.90	100.86	99.99	4.20
2[redacted]2858	11.70	0.039	6.69	1491.31	0.11	26.48	87.89	99.99	3.32
2[redacted]2902	11.70	0.042	5.02	1491.31	0.24	26.48	104.56	99.99	3.69
2[redacted]2906	11.71	0.046	5.02	1491.31	0.11	26.48	80.48	99.99	3.63
2[redacted]2910	11.71	0.048	3.34	1491.31	0.11	26.48	64.00	99.99	3.63
2[redacted]2914	11.71	0.049	1.67	1491.31	0.11	26.48	82.34	99.99	3.63
2[redacted]2918	11.71	0.051	3.34	1488.40	0.11	26.82	104.75	99.99	3.63
2[redacted]2922	11.71	0.052	1.67	1491.31	0.11	26.48	4.54	99.99	3.57
2[redacted]2926	11.71	0.054	1.67	1491.31	0.24	26.48	93.45	99.99	3.63
2[redacted]2930	11.71	0.055	1.67	1491.31	0.11	26.48	76.78	99.99	3.57
2[redacted]2934	11.72	0.057	3.34	1494.22	0.11	26.14	19.36	99.99	3.57
2[redacted]2938	11.72	0.058	1.67	1564.10	0.11	17.92	73.26	99.99	3.63
2[redacted]2942	11.72	0.061	5.02	1575.74	1.42	16.55	86.04	99.99	5.27
2[redacted]2946	11.73	0.073	16.73	1485.49	1.29	27.17	61.96	99.99	5.27
2[redacted]2950	11.74	0.083	15.06	1470.93	1.29	28.88	39.73	99.99	4.57
2[redacted]2954	11.75	0.093	15.06	1473.84	1.29	28.53	80.48	99.99	4.51
2[redacted]2958	11.76	0.102	13.38	1479.66	1.29	27.85	84.19	99.99	4.26
2[redacted]3002	11.77	0.110	13.38	1473.84	1.29	28.53	225.16	99.99	4.45
2[redacted]3006	11.78	0.120	15.06	1465.11	1.29	29.56	91.60	99.99	4.70
2[redacted]3010	11.79	0.132	16.73	1468.02	1.29	29.22	99.01	99.99	4.76
2[redacted]3014	11.80	0.141	13.38	1473.84	1.29	28.53	89.93	99.99	4.70
2[redacted]3018	11.81	0.149	13.38	1473.84	1.29	28.53	6.39	99.99	4.57
2[redacted]3022	11.82	0.157	11.71	1468.02	1.29	29.22	99.01	99.99	4.51
2[redacted]3026	11.83	0.167	15.06	1465.11	1.29	29.56	87.89	99.99	4.83
2[redacted]3030	11.84	0.176	13.38	1543.72	1.94	20.32	67.52	99.99	5.46
2[redacted]3034	11.85	0.189	18.40	1523.34	2.20	22.72	4.72	99.99	5.96
2[redacted]3038	11.86	0.201	18.40	1497.13	2.20	25.80	86.04	99.99	5.52
2[redacted]3042	11.87	0.213	18.40	1453.46	2.20	30.93	87.89	99.99	5.71
2[redacted]3046	11.89	0.228	21.75	1456.37	2.20	30.59	273.32	99.99	5.90
2[redacted]3050	11.90	0.241	20.08	1459.28	2.20	30.25	8.24	99.99	5.96
2[redacted]3054	11.92	0.255	21.75	1459.28	2.20	30.25	102.71	99.99	5.65
2[redacted]3058	11.93	0.271	23.42	1450.55	2.20	31.27	132.54	99.99	6.02
2[redacted]3102	11.95	0.287	23.42	1459.28	2.20	30.25	89.75	99.99	5.71
2[redacted]3106	11.96	0.302	23.42	1462.20	2.20	29.90	95.30	99.99	5.58
2[redacted]3110	11.98	0.318	23.42	1444.73	2.20	31.96	215.89	99.99	5.96
2[redacted]3114	11.99	0.335	25.10	1444.73	2.20	31.96	106.42	99.99	6.09
2[redacted]3118	12.01	0.351	25.10	1441.81	2.20	32.30	99.01	99.99	6.15
2[redacted]3122	12.03	0.368	25.10	1438.90	2.07	32.64	99.19	99.99	6.46
2[redacted]3126	12.05	0.387	28.44	1441.81	2.33	32.30	99.01	99.99	6.15
2[redacted]3130	12.07	0.406	28.44	1435.99	2.20	32.98	86.04	99.99	6.21
2[redacted]3134	12.09	0.426	30.12	1427.26	3.11	34.01	147.36	99.99	8.04
2[redacted]3138	12.11	0.451	36.81	1427.26	3.11	34.01	97.16	99.99	7.79
2[redacted]3142	12.14	0.476	38.48	1491.31	3.37	26.48	93.45	99.99	8.73
2[redacted]3146	12.16	0.502	38.48	1505.87	3.24	24.77	41.77	99.99	8.67
2[redacted]3150	12.19	0.527	36.81	1500.04	3.37	25.45	110.12	99.99	9.68
2[redacted]3154	12.21	0.551	36.81	1500.04	3.37	25.45	82.34	99.99	9.36
2[redacted]3158	12.24	0.577	38.48	1494.22	3.37	26.14	80.67	99.99	9.55
2[redacted]3202	12.26	0.601	36.81	1517.51	3.11	23.40	80.48	99.99	9.05
2[redacted]3206	12.28	0.625	35.14	1511.69	3.11	24.08	125.13	99.99	9.05

	TOTAL	CORE	PENETRAIN	ROTARY			INLET H2O	I. H2O	
28103210	12.31	0.648	35.14	1523.34	3.24	22.72	91.60	99.99	8.60
28103214	12.33	0.669	31.79	1543.72	2.33	20.32	108.27	99.99	8.42
28103218	12.35	0.689	30.12	1546.63	2.20	19.98	301.10	99.99	7.91
28103222	12.37	0.707	26.77	1476.75	2.46	28.19	99.01	99.99	6.46
28103226	12.38	0.723	23.42	1456.37	2.33	30.59	104.56	99.99	6.21
28103230	12.40	0.741	26.77	1456.37	2.20	30.59	34.36	99.99	6.34
28103234	12.42	0.757	25.10	1476.75	2.20	28.19	84.19	99.99	6.15
28103238	12.43	0.772	21.75	1476.75	2.20	28.19	56.40	99.99	5.71
28103242	12.45	0.786	21.75	1488.40	2.33	26.82	0.83	99.99	5.65
28103246	12.46	0.799	18.40	1494.22	2.20	26.14	87.89	99.99	5.20
28103250	12.47	0.810	16.73	1508.78	2.20	24.43	11.95	99.99	4.83
28103254	12.48	0.821	16.73	1505.87	2.33	24.77	102.71	99.99	4.51
28103258	12.49	0.830	13.38	1505.87	2.20	24.77	84.19	99.99	4.89
28103302	12.50	0.839	13.38	1514.60	2.20	23.74	154.77	99.99	4.26
28103306	12.51	0.847	11.71	1540.81	2.20	20.66	108.27	99.99	3.38



RECORD OF CORSHAM DRILL RUN 2.13.1 (11.66 to 12.51 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.13.1 (11.66 to 12.51 metres)



SCALING FACTORS

Rotary Speed:	x 10	Water Pressure:	- 100
Thrust:	÷ 10	Core Depth:	÷ 294
Penetration Rate:	÷ 2		

USER: EX9069 -AT SYSTEM

R_C2.13.2

EX9069

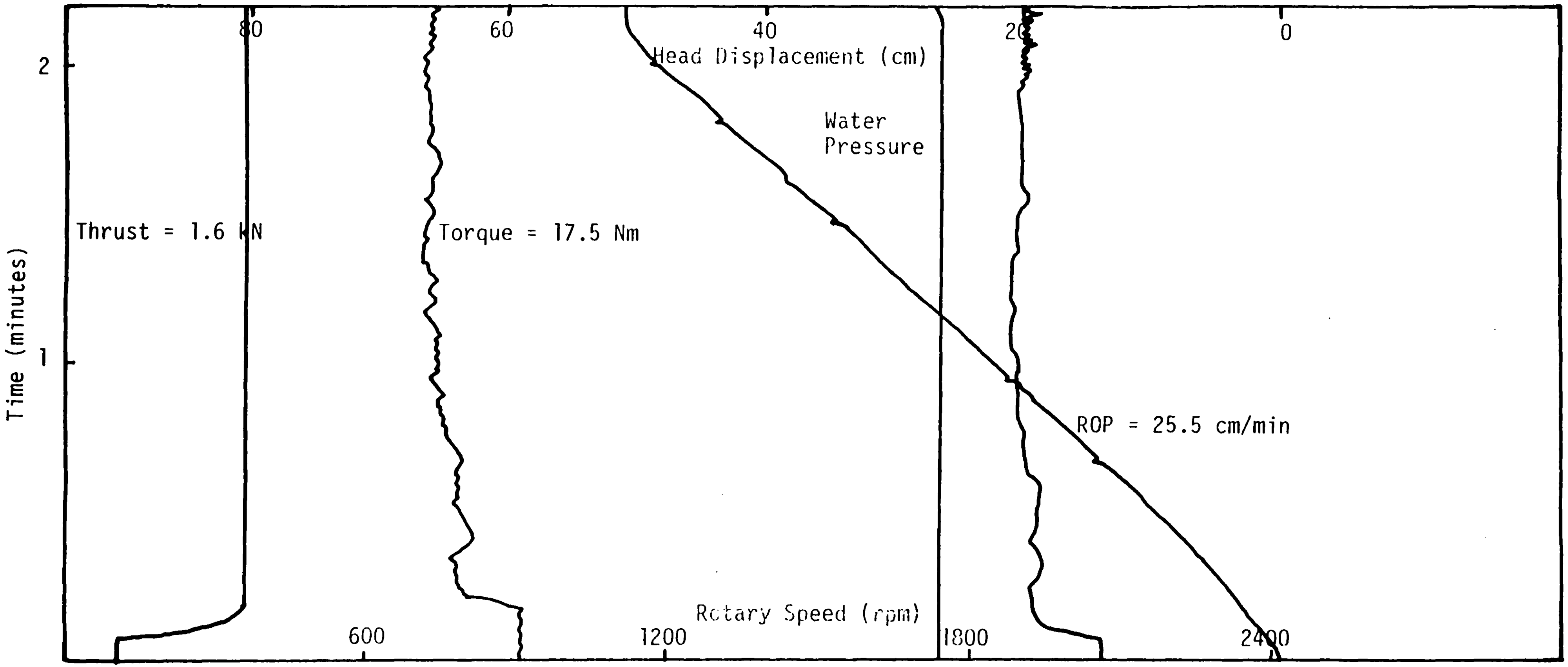
R_C2.13.2

LABEL: PRT021 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:30, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28103636	12.51	0.000	0.00	2064.87	0.67	3.35	93.45	99.99	8.73
28103640	12.52	0.007	11.72	1930.95	1.42	14.46	239.97	99.99	10.37
28103644	12.53	0.022	23.42	1916.39	1.55	15.67	93.45	99.99	11.00
28103648	12.55	0.038	23.42	1933.86	1.55	14.22	37.88	99.99	11.12
28103652	12.56	0.050	18.40	1962.97	1.42	11.80	47.14	99.99	10.37
28103656	12.57	0.061	16.73	1922.21	1.55	15.18	87.89	99.99	10.56
28103700	12.59	0.076	21.75	1930.95	1.55	14.46	73.26	99.99	10.68
28103704	12.60	0.089	20.08	1930.95	1.55	14.46	91.60	99.99	10.62
28103708	12.61	0.103	20.08	1936.77	1.55	13.98	97.16	99.99	10.43
28103712	12.63	0.117	21.75	1901.83	1.55	16.87	56.59	99.99	11.00
28103716	12.64	0.134	25.10	1896.01	1.42	17.36	95.30	99.99	11.06
28103720	12.66	0.151	25.10	1896.01	1.68	17.36	91.60	99.99	11.06
28103724	12.68	0.168	26.77	1887.27	1.55	18.08	123.28	99.99	11.31
28103728	12.70	0.185	25.10	1896.01	1.55	17.36	89.75	99.99	11.12
28103732	12.71	0.202	25.10	1896.01	1.55	17.36	93.45	99.99	11.06
28103736	12.73	0.219	25.10	1861.07	1.42	20.25	56.59	99.99	11.38
28103740	12.75	0.236	26.77	1878.54	1.42	18.80	71.22	99.99	11.12
28103744	12.76	0.253	25.10	1881.45	1.68	18.56	89.75	99.99	11.00
28103748	12.78	0.271	26.77	1849.42	1.55	21.22	23.25	99.99	11.44
28103752	12.80	0.289	26.77	1863.98	1.55	20.01	30.47	99.99	11.06
28103756	12.82	0.306	25.10	1884.36	1.55	18.32	87.89	99.99	10.87
28103800	12.83	0.322	25.10	1890.18	1.55	17.84	47.14	99.99	11.12
28103804	12.85	0.339	25.10	1901.83	1.68	16.87	8.24	99.99	10.68
28103808	12.86	0.355	25.10	1910.56	1.68	16.15	91.60	99.99	10.56
28103812	12.88	0.373	26.77	1893.10	1.55	17.60	108.27	99.99	10.81
28103816	12.90	0.390	26.77	1890.18	1.42	17.84	97.16	99.99	10.75
28103820	12.92	0.408	26.77	1898.92	1.42	17.11	93.64	99.99	10.62
28103824	12.94	0.426	26.77	1887.27	1.42	18.08	110.12	99.99	10.81
28103828	12.95	0.443	25.10	1887.27	1.42	18.08	104.56	99.99	10.62
28103832	12.97	0.460	25.10	1907.65	1.68	16.39	277.02	99.99	10.31
28103836	12.99	0.476	25.10	1907.65	1.55	16.39	102.71	99.99	10.62
28103840	13.00	0.493	25.10	1898.92	1.55	17.11	102.71	99.99	10.49
28103844	13.02	0.510	25.10	1925.12	1.42	14.94	28.81	99.99	10.24
28103848	13.03	0.515	8.37	23.92	4.72	172.61	99.01	99.99	-1.35



RECORD OF CORSHAM DRILL RUN 2.13.2 (12.51 to 13.03 metres)

USER: EX9069 -AT SYSTEM

R_C2.13.3

EX9069

R_C2.13.3

LABEL: PRT022 -FORM

SPOOLED: 82-01-25.18:25
STARTED: 82-01-25.18:30, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
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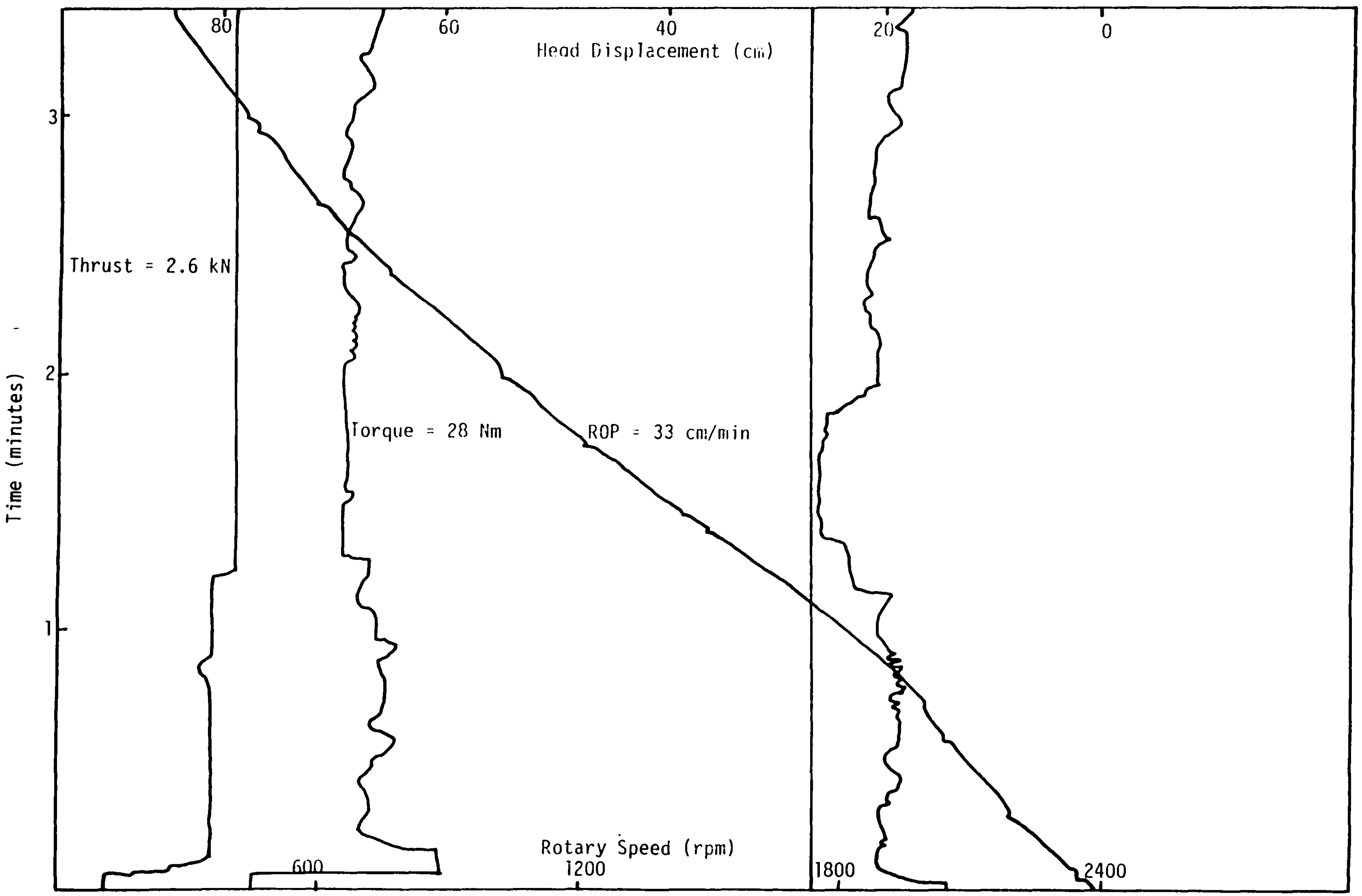
28103916	13.03	0.000	0.00	2061.96	3.93	3.59	74.93	99.99	8.60
28103920	13.03	0.001	1.67	2059.05	3.54	3.83	158.47	99.99	8.23
28103924	13.04	0.012	16.71	1869.80	1.55	19.53	91.79	99.99	10.37
28103928	13.06	0.030	26.74	1890.18	1.29	17.84	28.62	99.99	10.56
28103932	13.08	0.046	23.39	1904.74	1.29	16.63	24.91	99.99	10.24
28103936	13.09	0.062	25.07	1866.89	1.68	19.77	73.07	99.99	10.56
28103940	13.11	0.080	26.74	1907.65	1.55	16.39	32.51	99.99	10.43
28103944	13.12	0.095	21.72	1942.59	1.55	13.49	95.30	99.99	10.12
28103948	13.14	0.109	21.72	1910.56	1.55	16.15	45.48	99.99	9.74
28103952	13.15	0.125	23.39	1933.86	1.42	14.22	82.34	99.99	10.12
28103956	13.17	0.139	21.72	1942.59	1.42	13.49	84.19	99.99	9.49
28104000	13.18	0.153	20.05	1951.33	1.55	12.77	234.42	99.99	9.36
28104004	13.20	0.166	20.05	1928.03	1.02	14.70	76.78	99.99	9.74
28104008	13.21	0.178	18.38	1925.12	1.42	14.94	48.99	99.99	8.86
28104012	13.22	0.194	23.39	1922.21	1.42	15.18	13.80	99.99	9.80
28104016	13.24	0.208	21.72	1881.45	1.42	18.56	71.22	99.99	9.93
28104020	13.26	0.227	28.41	1881.45	1.29	18.56	99.19	99.99	10.62
28104024	13.27	0.244	25.07	1904.74	1.42	16.63	86.04	99.99	10.24
28104028	13.29	0.261	25.06	1834.87	2.20	22.43	82.34	99.99	9.86
28104032	13.31	0.281	30.08	1805.75	2.59	24.84	76.97	99.99	11.38
28104036	13.33	0.302	31.75	1788.28	2.59	26.29	84.19	99.99	11.44
28104040	13.35	0.323	31.75	1724.23	2.59	31.50	67.52	99.99	11.69
28104044	13.38	0.345	33.42	1762.08	2.59	28.46	93.64	99.99	11.75
28104048	13.40	0.368	33.42	1735.88	2.59	30.64	74.93	99.99	11.82
28104052	13.42	0.391	35.09	1762.08	2.59	28.46	67.70	99.99	11.63
28104056	13.44	0.413	33.42	1767.90	2.59	27.98	74.93	99.99	11.44
28104100	13.46	0.434	31.75	1764.99	2.59	28.22	82.34	99.99	11.63
28104104	13.49	0.456	31.75	1799.33	2.59	25.32	275.17	99.99	11.19
28104108	13.51	0.478	33.42	1773.72	2.46	27.50	84.19	99.99	11.50
28104112	13.53	0.500	33.42	1840.69	2.59	21.94	95.30	99.99	10.75
28104116	13.55	0.519	28.41	1893.18	2.59	17.84	34.36	99.99	10.18
28104120	13.56	0.535	23.39	1890.18	2.59	17.84	110.31	99.99	10.05
28104124	13.58	0.550	23.39	1895.01	2.46	17.36	69.37	99.99	10.12
28104128	13.60	0.566	23.39	1875.63	2.59	19.05	76.78	99.99	9.86
28104132	13.61	0.584	26.74	1846.51	2.59	21.46	115.87	99.99	10.62
28104136	13.63	0.600	25.07	1846.51	2.33	21.46	89.75	99.99	10.81
28104140	13.65	0.618	26.74	1834.87	2.59	22.43	87.89	99.99	10.37
28104144	13.67	0.637	28.41	1861.07	2.59	20.25	317.77	99.99	10.43
28104148	13.68	0.654	25.07	1893.10	2.46	17.60	82.34	99.99	9.99
28104152	13.70	0.668	21.72	1869.80	2.46	19.53	97.16	99.99	9.74
28104156	13.71	0.684	23.39	1852.34	2.46	20.98	78.82	99.99	10.18
28104200	13.73	0.702	26.74	1866.89	2.46	19.77	86.04	99.99	10.24
28104204	13.75	0.716	21.72	1887.27	2.59	18.08	60.11	99.99	9.93
28104208	13.76	0.731	21.72	1866.80	2.46	19.77	149.21	99.99	10.24
28104212	13.77	0.744	20.05	1875.63	2.20	17.05	73.07	99.99	9.80
28104216	13.79	0.756	18.38	1936.77	2.46	13.98	36.03	99.99	9.49
28104220	13.80	0.768	16.71	1913.48	2.46	15.91	34.18	99.99	9.17
28104224	13.81	0.782	21.72	1898.92	2.59	17.11	76.78	99.99	9.74
28104228	13.82	0.794	18.38	1939.68	2.46	13.73	126.98	99.99	9.05
28104232	13.84	0.805	16.71	1954.24	2.20	12.53	84.19	99.99	8.98
28104236	13.85	0.817	16.71	1962.07	2.46	11.80	84.19	99.99	8.60
28104240	13.86	0.830	20.05	1928.03	2.59	14.70	101.05	99.99	9.30
28104244	13.87	0.842	18.38	1936.77	2.46	13.98	93.45	99.99	8.48
28104248	13.88	0.847	6.68	326.71	4.98	147.50	97.16	99.99	-1.16



RECORD OF CORSHAM DRILL RUN 2.13.3 (13.03 to 13.88 metres)

USER: EX9069 -AT SYSTEM

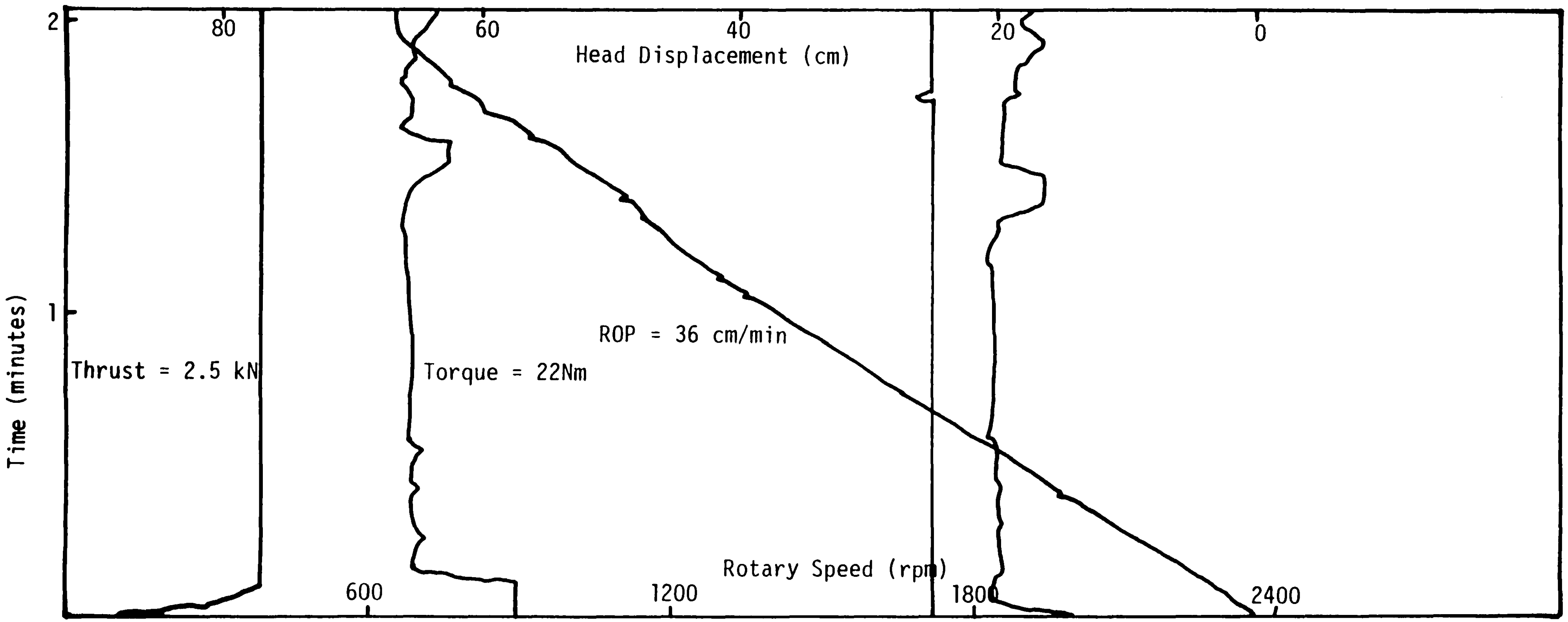
R_C2.14.1

LABEL: PRT023 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:30, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28110904	13.88	0.000	0.00	2056.14	0.93	4.08	87.89	99.99	8.73
28110908	13.89	0.009	15.03	1823.22	2.59	23.39	95.37	99.99	10.49
28110912	13.91	0.030	31.83	1837.78	2.59	22.19	256.65	99.99	11.69
28110916	13.93	0.050	30.16	1863.98	2.46	20.01	36.33	99.99	11.06
28110920	13.95	0.074	35.18	1846.51	2.59	21.46	21.21	99.99	11.38
28110924	13.98	0.101	39.58	1866.89	2.59	19.77	89.75	99.99	11.19
28110928	14.01	0.126	35.18	1837.78	2.46	22.19	91.63	99.99	11.25
28110932	14.03	0.153	40.21	1846.51	2.46	21.46	156.62	99.99	11.00
28110936	14.06	0.180	40.21	1843.60	2.46	21.70	89.75	99.99	11.19
28110940	14.08	0.204	36.86	1820.31	2.46	23.63	87.89	99.99	11.25
28110944	14.11	0.229	36.86	1840.69	2.46	21.94	15.84	99.99	11.44
28110948	14.13	0.252	35.18	1843.60	2.46	21.70	54.55	99.99	11.25
28110952	14.16	0.277	36.86	1840.69	2.59	21.94	126.98	99.99	11.44
28110956	14.18	0.300	35.18	1849.42	2.59	21.22	54.74	99.99	11.25
28111000	14.21	0.325	36.86	1826.13	2.46	23.15	39.92	99.99	11.50
28111004	14.23	0.348	35.18	1834.87	2.46	22.43	76.78	99.99	11.25
28111008	14.25	0.373	36.86	1826.13	2.59	23.15	23.25	99.99	11.56
28111012	14.28	0.398	36.86	1831.95	2.59	22.67	28.81	99.99	11.25
28111016	14.30	0.420	33.51	1799.93	2.46	25.32	87.89	99.99	11.12
28111020	14.32	0.443	35.18	1829.04	2.46	22.91	34.36	99.99	11.25
28111024	14.35	0.466	33.51	1858.16	2.46	20.49	206.63	99.99	10.62
28111028	14.36	0.485	28.48	1930.95	2.33	14.46	89.75	99.99	10.12
28111032	14.38	0.500	23.45	1951.33	2.46	12.77	78.63	99.99	9.49
28111036	14.39	0.515	21.78	1837.78	2.46	22.19	56.40	99.99	9.86
28111040	14.42	0.539	36.86	1866.89	2.46	19.77	2.87	99.99	10.62
28111044	14.44	0.562	33.51	1852.34	2.46	20.98	84.19	99.99	10.62
28111048	14.47	0.586	36.86	1855.25	2.46	20.74	82.34	99.99	10.75
28111052	14.49	0.609	33.51	1898.92	2.46	17.11	74.93	99.99	10.24
28111056	14.51	0.631	33.51	1890.18	2.46	17.84	102.71	99.99	10.43
28111100	14.53	0.651	30.16	1930.95	2.46	14.46	32.32	99.99	9.80
28111104	14.55	0.669	26.80	1881.45	2.46	18.56	100.86	99.99	9.68
28111108	14.57	0.689	30.16	1459.28	5.50	53.57	65.85	99.99	9.99
28111112	14.57	0.690	1.67	23.92	4.72	172.61	69.56	99.99	-1.35



RECORD OF CORSHAM DRILL RUN 2.14.1 (13.88 to 14.57 metres)

USER: EX5069 -AT SYSTEM

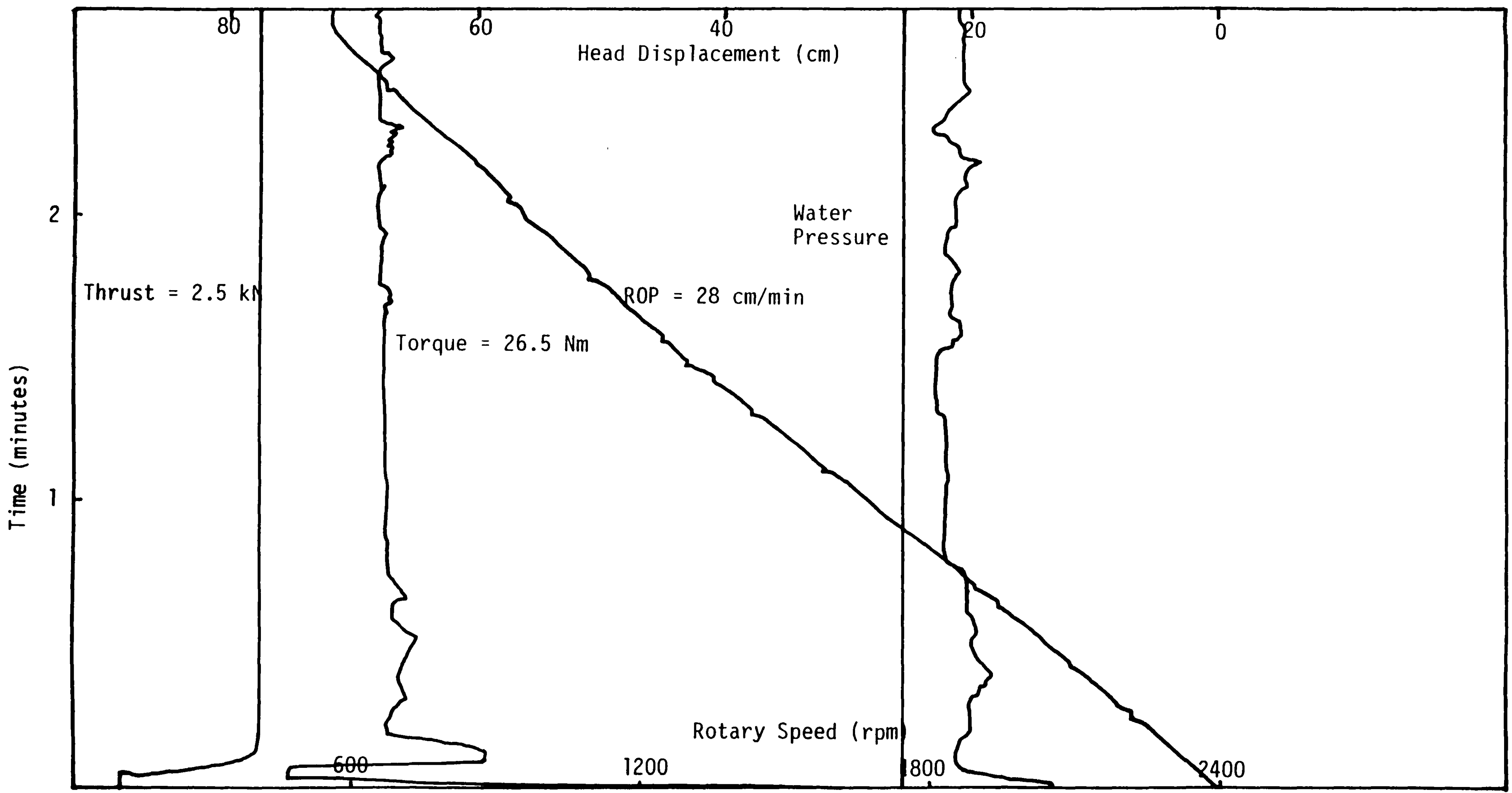
R_C2.14.2

LABEL: PRT024 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:30, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28111140	14.57	0.000	0.00	1992.09	0.50	9.39	26.77	99.99	8.23
28111144	14.59	0.016	23.45	1811.57	2.59	24.36	91.79	99.99	11.12
28111148	14.61	0.036	30.16	1852.34	2.46	20.98	78.63	99.99	10.81
28111152	14.62	0.054	26.80	1869.80	2.46	19.53	93.45	99.99	10.31
28111156	14.64	0.073	28.48	1872.72	2.46	19.29	4.72	99.99	10.56
28111200	14.66	0.090	26.80	1898.92	2.33	17.11	91.60	99.99	10.05
28111204	14.68	0.106	23.45	1910.56	2.33	16.15	80.48	99.99	9.80
28111208	14.70	0.125	28.48	1843.60	2.33	21.70	56.59	99.99	10.43
28111212	14.71	0.144	28.48	1890.18	2.33	17.84	89.93	99.99	10.49
28111216	14.73	0.162	26.80	1834.87	2.33	22.43	71.22	99.99	10.43
28111220	14.75	0.182	30.16	1840.69	2.33	21.94	21.21	99.99	10.75
28111224	14.77	0.202	30.16	1846.51	2.33	21.46	78.63	99.99	10.75
28111228	14.79	0.221	28.48	1794.11	2.33	25.81	65.67	99.99	11.38
28111232	14.81	0.241	30.16	1802.84	2.46	25.08	221.45	99.99	11.06
28111236	14.83	0.262	31.83	1797.02	2.33	25.57	97.16	99.99	10.87
28111240	14.85	0.283	30.16	1823.22	2.33	23.39	80.48	99.99	11.00
28111244	14.87	0.303	30.16	1831.95	2.33	22.67	125.13	99.99	10.87
28111248	14.89	0.322	28.48	1799.93	2.33	25.32	1.02	99.99	11.06
28111252	14.91	0.342	30.16	1791.19	2.46	26.05	73.07	99.99	11.06
28111256	14.93	0.361	28.48	1785.37	2.33	26.53	34.18	99.99	11.06
28111300	14.95	0.381	30.16	1773.72	2.46	27.50	60.30	99.99	11.38
28111304	14.97	0.402	31.83	1776.64	2.46	27.26	80.48	99.99	11.38
28111308	14.99	0.420	26.80	1782.46	2.46	26.77	89.75	99.99	11.19
28111312	15.01	0.439	28.48	1843.60	2.33	21.70	2.68	99.99	10.68
28111316	15.02	0.455	23.45	1846.51	2.33	21.46	71.22	99.99	10.12
28111320	15.04	0.472	26.80	1799.93	2.46	25.32	74.93	99.99	10.87
28111324	15.06	0.491	28.48	1826.13	2.33	23.15	23.25	99.99	10.75
28111328	15.08	0.510	28.48	1861.07	2.33	20.25	73.26	99.99	10.24
28111332	15.10	0.529	28.48	1799.93	2.33	25.32	74.93	99.99	10.93
28111336	15.12	0.550	30.16	1834.87	2.33	22.43	99.01	99.99	10.49
28111340	15.14	0.566	25.13	1814.49	2.33	24.12	39.73	99.99	10.37
28111344	15.15	0.582	23.45	1869.80	2.33	19.53	93.45	99.99	10.31
28111348	15.17	0.596	21.78	1866.89	2.33	19.77	89.75	99.99	10.05
28111352	15.18	0.609	18.43	1823.22	2.33	23.39	89.75	99.99	10.05
28111356	15.20	0.627	26.80	1764.99	2.33	28.22	67.70	99.99	10.93
28111400	15.21	0.643	25.13	1823.22	2.20	23.39	88.08	99.99	10.56
28111404	15.23	0.660	25.13	1866.89	2.33	19.77	69.37	99.99	10.12
28111408	15.25	0.677	25.13	1826.13	2.46	23.15	76.78	99.99	10.37
28111412	15.26	0.695	26.80	1829.04	2.20	22.91	17.69	99.99	10.18
28111416	15.28	0.710	23.45	1863.98	2.33	20.01	62.15	99.99	10.18
28111420	15.30	0.727	25.13	1811.57	2.33	24.36	82.34	99.99	10.18
28111424	15.31	0.741	20.10	61.77	4.98	169.47	84.19	99.99	-1.22



RECORD OF CORSHAM DRILL RUN 2.14.2 (14.57 to 15.31 metres)

USER: EX5069 -AT SYSTEM

R_C2.14.3

EX5069

R_C2.14.3

LABEL: PRT025 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:31, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

-712-

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28111752	15.31	0.000	0.00	2312.47	0.15	7.70	76.78	99.99	7.98
28111756	15.32	0.010	15.06	1791.19	2.46	26.05	84.19	3.39	10.56
28111800	15.34	0.028	26.77	1805.75	2.46	24.84	189.96	3.39	10.56
28111804	15.35	0.042	21.75	1863.98	2.20	20.01	89.75	3.39	10.12
28111808	15.36	0.052	15.06	1890.18	2.33	17.84	74.93	3.39	9.80
28111812	15.37	0.061	13.38	1861.07	2.46	20.25	139.95	3.39	9.93
28111816	15.38	0.070	13.38	1884.36	2.46	18.32	48.99	99.99	9.80
28111820	15.39	0.077	10.04	1910.56	2.46	16.15	78.63	99.99	9.42
28111824	15.39	0.085	11.71	1925.12	2.33	14.94	76.97	3.39	9.17
28111828	15.40	0.090	8.37	1930.95	2.20	14.46	87.89	99.99	9.23
28111832	15.41	0.097	10.04	1896.01	3.50	17.36	36.21	99.99	9.74
28111836	15.41	0.104	10.04	1907.65	3.24	16.39	89.75	99.99	9.61
28111840	15.42	0.105	8.37	1738.79	4.85	30.39	100.86	99.99	9.36

USER: EX9069 -AT SYSTEM

R_C2.15.1

EX9069

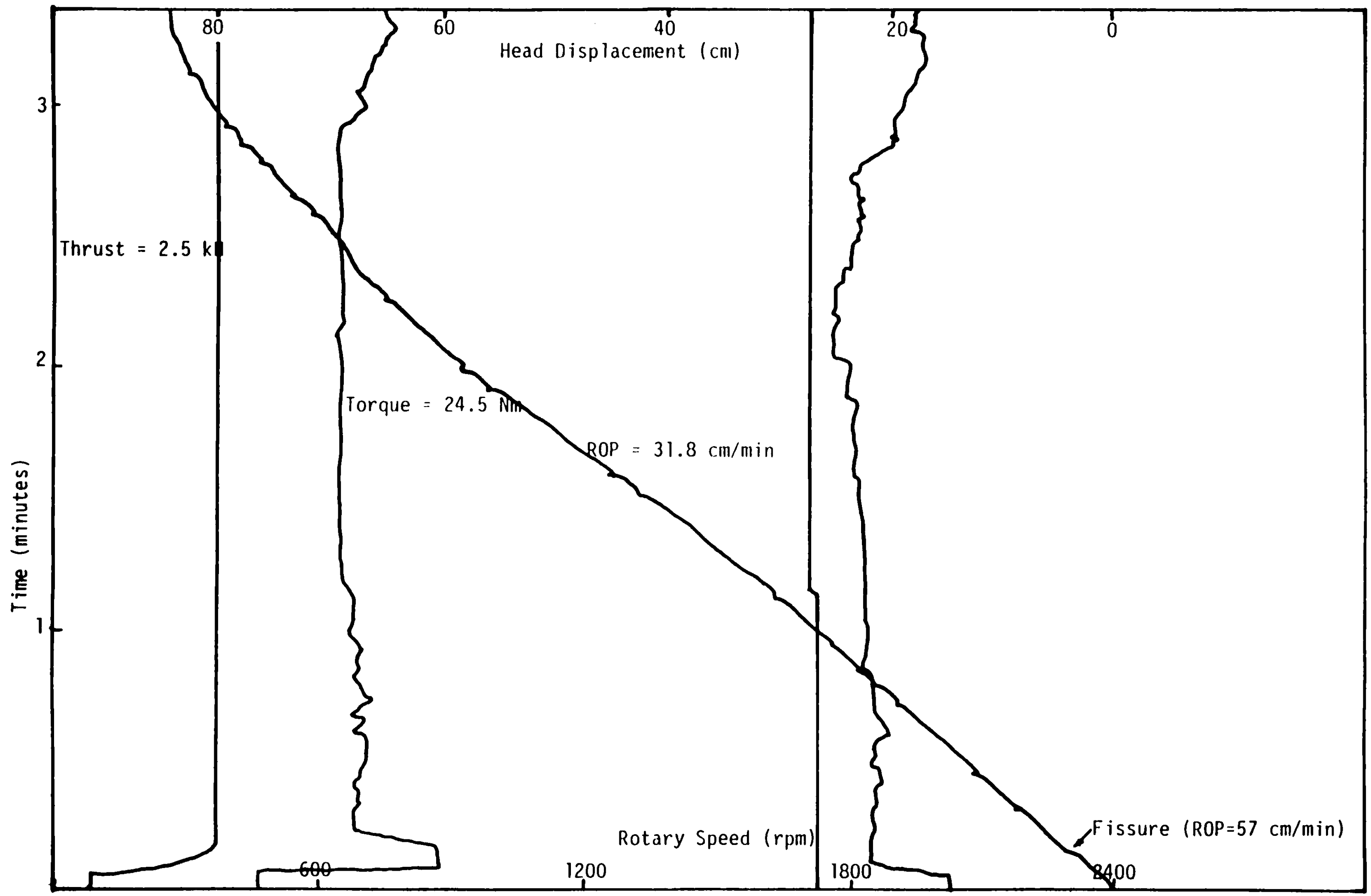
R_C2.15.1

LABEL: PRT026 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:31, ON: PRO BY: PRO

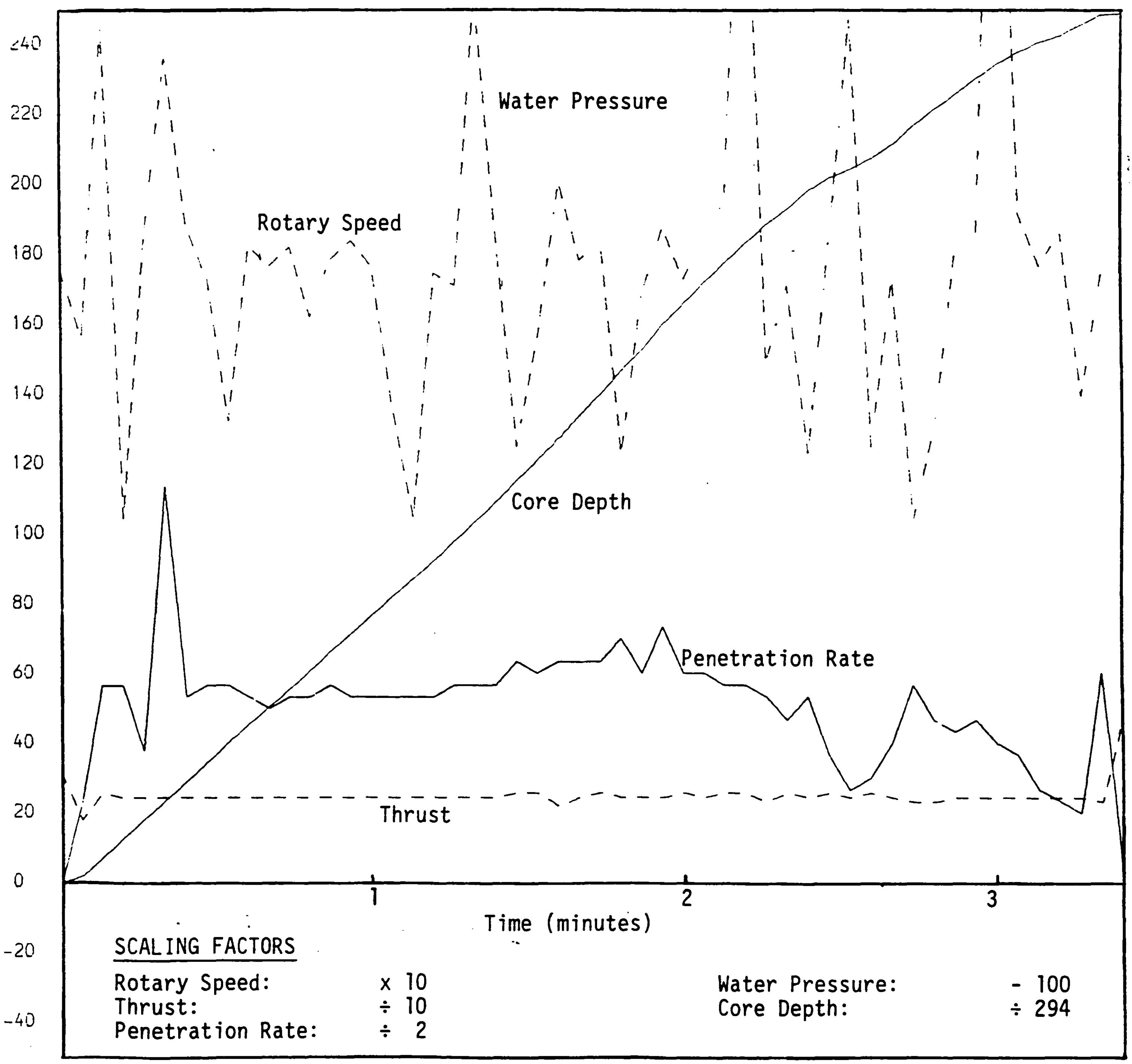
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28114244	15.42	0.000	0.00	2041.58	3.15	11.08	74.93	3.39	8.79
28114248	15.43	0.007	11.69	1884.36	1.81	23.39	56.40	3.39	9.61
28114252	15.45	0.026	28.41	1846.51	2.59	21.46	145.50	3.39	11.31
28114256	15.46	0.045	28.41	1865.89	2.46	19.77	4.54	3.39	11.19
28114302	15.48	0.063	18.94	1846.51	2.46	21.46	84.19	99.99	11.12
28114304	15.50	0.082	56.81	1875.63	2.46	19.05	136.24	99.99	11.00
28114308	15.52	0.100	26.74	1890.18	2.46	17.84	87.89	3.39	10.75
28114312	15.54	0.119	28.41	1829.04	2.46	22.91	73.07	99.99	10.75
28114316	15.56	0.138	28.41	1849.42	2.46	21.22	32.51	3.39	10.93
28114320	15.58	0.156	26.74	1887.27	2.46	18.08	82.52	99.99	10.37
28114324	15.59	0.173	25.06	1849.42	2.46	21.22	76.78	99.99	10.93
28114328	15.61	0.190	26.74	1866.89	2.46	19.77	82.34	99.99	10.75
28114332	15.63	0.208	26.74	1849.42	2.46	21.22	62.15	99.99	10.68
28114336	15.65	0.227	28.41	1840.69	2.46	21.94	78.63	99.99	11.44
28114340	15.66	0.244	26.74	1852.34	2.46	20.98	84.19	99.99	10.93
28114344	15.68	0.262	26.74	1823.22	2.46	23.39	76.78	99.99	10.81
28114348	15.70	0.280	26.74	1843.60	2.46	21.70	36.03	99.99	11.12
28114352	15.72	0.297	26.74	1840.69	2.46	21.94	4.72	99.99	11.12
28114356	15.74	0.315	26.74	1805.75	2.46	24.84	74.93	99.99	11.12
28114400	15.75	0.334	28.41	1820.31	2.46	23.63	71.22	99.99	11.19
28114404	15.77	0.353	28.41	1820.31	2.46	23.63	154.77	99.99	11.00
28114408	15.79	0.372	28.41	1797.02	2.46	25.57	84.19	99.99	11.25
28114412	15.81	0.393	31.75	1802.84	2.59	25.08	25.10	99.99	11.25
28114416	15.83	0.413	30.08	1814.49	2.59	24.12	56.59	99.99	10.93
28114420	15.85	0.434	31.75	1820.31	2.20	23.63	100.86	99.99	11.12
28114424	15.88	0.456	31.75	1823.22	2.46	23.39	78.63	99.99	10.93
28114428	15.90	0.477	31.75	1802.84	2.59	25.08	84.38	99.99	11.38
28114432	15.92	0.500	35.09	1811.57	2.46	24.36	23.25	99.99	11.19
28114436	15.94	0.520	30.08	1773.72	2.46	27.50	69.37	99.99	11.06
28114440	15.96	0.545	36.76	1811.57	2.46	24.36	87.89	99.99	11.06
28114444	15.98	0.565	30.08	1770.81	2.59	27.74	73.07	99.99	10.93
28114448	16.00	0.585	30.08	1779.55	2.46	27.01	84.19	99.99	11.56
28114452	16.02	0.604	28.40	1791.19	2.59	26.05	95.30	99.99	11.31
28114456	16.04	0.623	28.40	1779.55	2.59	27.01	225.16	99.99	11.63
28114500	16.06	0.641	26.73	1773.72	2.33	27.50	48.99	99.99	11.19
28114504	16.08	0.656	23.39	1797.02	2.59	25.57	71.22	99.99	10.93
28114508	16.09	0.674	26.73	1817.49	2.46	23.88	23.25	99.99	10.87
28114512	16.11	0.686	18.38	1855.25	2.59	20.74	84.19	99.99	10.75
28114516	16.12	0.695	13.37	1829.04	2.46	22.91	147.36	99.99	10.56
28114520	16.13	0.705	15.04	1829.04	2.59	22.91	24.91	99.99	10.75
28114524	16.14	0.719	20.05	1814.49	2.46	24.12	73.07	99.99	10.75
28114528	16.16	0.737	28.40	1858.16	2.33	20.49	4.72	99.99	10.75
28114532	16.17	0.753	23.39	1890.18	2.33	17.84	30.66	99.99	9.99
28114536	16.19	0.768	21.72	1907.65	2.46	16.39	82.34	99.99	9.49
28114540	16.20	0.783	23.39	1913.48	2.46	15.91	86.04	99.99	9.55
28114544	16.22	0.797	20.05	1951.33	2.46	12.77	282.58	99.99	9.05
28114548	16.23	0.809	18.38	1974.62	2.46	10.84	91.60	99.99	8.79
28114552	16.24	0.818	13.37	1992.09	2.46	9.39	76.78	99.99	8.35
28114556	16.25	0.825	11.70	1968.79	2.46	11.32	86.23	99.99	8.48
28114602	16.26	0.836	10.03	1954.24	2.46	12.53	39.73	99.99	8.92
28114604	16.27	0.846	30.08	2015.38	2.33	7.46	74.93	99.99	8.73
28114608	16.27	0.847	1.67	23.92	4.72	169.09	82.34	99.99	-1.35



RECORD OF CORSHAM DRILL RUN 2.15.1 (15.42 to 16.27 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.15.1 (15.42 to 16.27 metres)



USER: EX9069 -AT SYSTEM

R_C2.15.2

EX9069

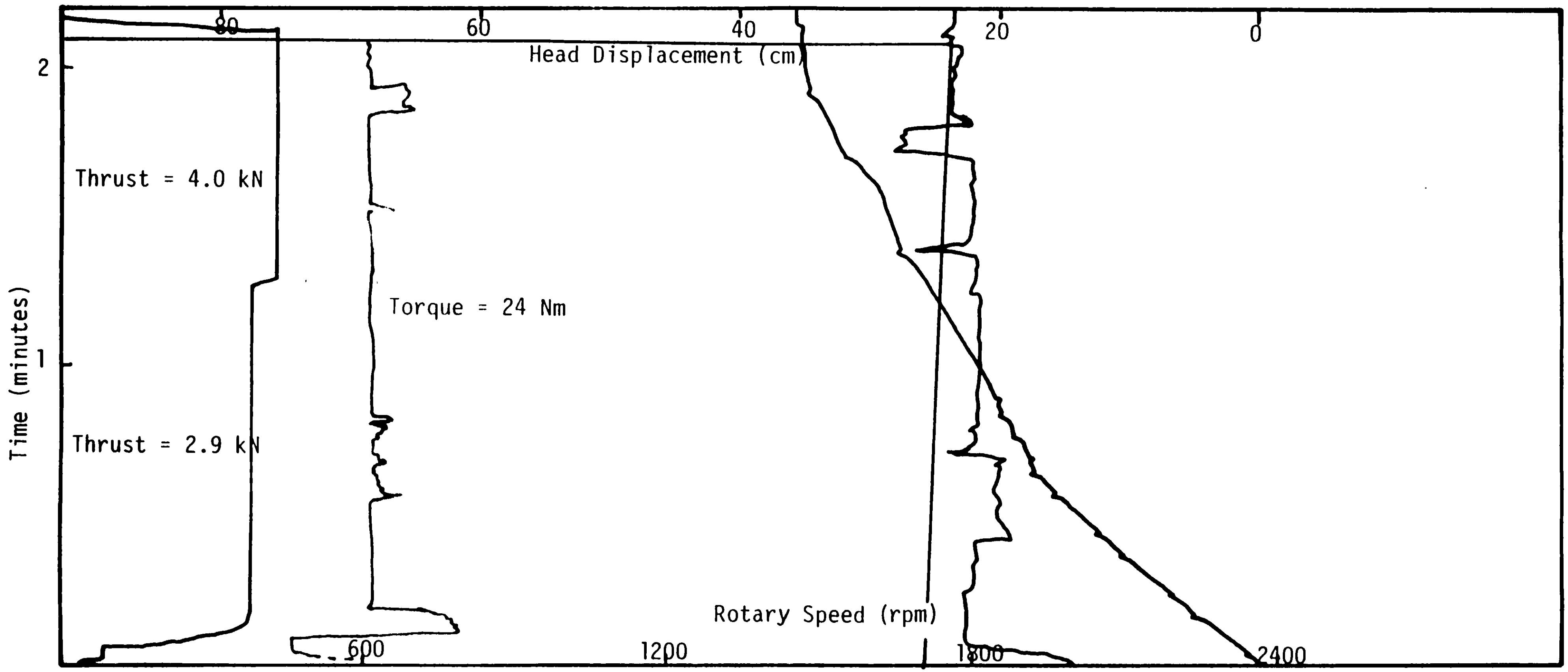
R_C2.15.2

LABEL: PRT027 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:31, ON: PR0 BY: PR0

O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28114620	16.27	0.000	0.00	23.92	3.80	169.09	71.22	95.99	-1.28
28114624	16.27	0.004	6.68	1450.55	4.59	54.30	15.84	99.99	15.41
28114628	16.27	0.004	0.01	1732.96	4.59	35.25	23.25	95.99	6.84
28114632	16.27	0.004	0.01	1997.91	1.85	14.50	76.78	99.99	8.29
28114636	16.28	0.015	15.05	1767.90	2.72	27.98	100.86	99.99	10.49
28114640	16.31	0.036	31.79	1773.72	2.98	27.50	282.58	99.99	10.93
28114644	16.33	0.056	30.12	1785.37	2.85	26.53	99.01	99.99	10.49
28114648	16.35	0.077	31.79	1817.40	2.98	23.88	28.81	99.99	10.49
28114652	16.37	0.097	30.12	1837.78	2.85	22.19	82.34	99.99	10.24
28114656	16.39	0.116	28.44	1802.84	2.85	25.08	82.34	95.99	10.43
28114700	16.40	0.134	26.77	1840.69	2.85	21.94	87.99	99.99	9.86
28114704	16.42	0.152	26.77	1861.07	2.46	20.25	38.07	95.99	9.99
28114708	16.44	0.170	26.77	1840.69	2.98	21.94	73.07	99.99	10.24
28114712	16.46	0.185	23.42	1843.60	2.85	21.70	71.22	99.99	9.55
28114716	16.47	0.200	21.75	1799.93	2.72	25.32	30.66	99.99	10.18
28114720	16.48	0.207	11.71	1811.57	2.72	24.36	80.48	99.99	10.49
28114724	16.49	0.215	11.71	1831.95	2.85	22.67	91.60	99.99	10.18
28114728	16.49	0.224	13.38	1840.69	2.98	21.94	271.46	99.99	10.12
28114732	16.50	0.233	13.38	1837.78	2.72	22.19	95.30	99.99	10.05
28114736	16.51	0.241	11.71	1840.69	2.98	21.94	84.19	99.99	9.86
28114742	16.52	0.251	10.04	1823.22	2.72	23.39	139.95	99.99	9.99
28114744	16.53	0.261	10.04	1820.31	2.85	23.63	91.60	99.99	10.18
28114748	16.54	0.271	10.04	1808.66	4.03	24.60	76.78	99.99	10.24
28114752	16.55	0.281	15.05	1823.22	3.63	23.39	34.36	95.99	10.12
28114756	16.56	0.292	16.73	1814.49	4.03	24.12	97.34	99.99	10.87
28114800	16.57	0.301	13.38	1817.40	4.03	23.88	78.63	99.99	10.12
28114804	16.58	0.308	10.04	1817.40	4.03	23.88	93.45	99.99	9.99
28114808	16.58	0.315	10.04	1820.31	4.03	23.63	69.37	99.99	10.24
28114812	16.59	0.322	11.71	1814.49	3.89	24.12	99.01	99.99	9.93
28114816	16.60	0.334	16.73	1657.27	4.16	37.15	78.63	99.99	11.82
28114820	16.62	0.348	21.75	1802.84	3.89	25.08	95.49	99.99	11.50
28114824	16.63	0.357	13.38	1785.37	4.16	26.53	84.19	99.99	10.93
28114828	16.63	0.364	10.04	1776.64	4.03	27.26	162.18	99.99	10.68
28114832	16.64	0.371	11.71	1785.37	4.16	26.53	84.19	99.99	10.56
28114836	16.65	0.379	11.71	1773.72	3.89	32.06	73.07	99.99	10.24
28114840	16.65	0.380	1.67	23.92	4.46	169.09	10.09	99.99	-1.35



RECORD OF CORSHAM DRILL RUN 2.15.2 (16.27 to 16.65 metres)

USER: EX9969 -AT SYSTEM

NR_C2.16.1

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EX9969

NR_C2.16.1
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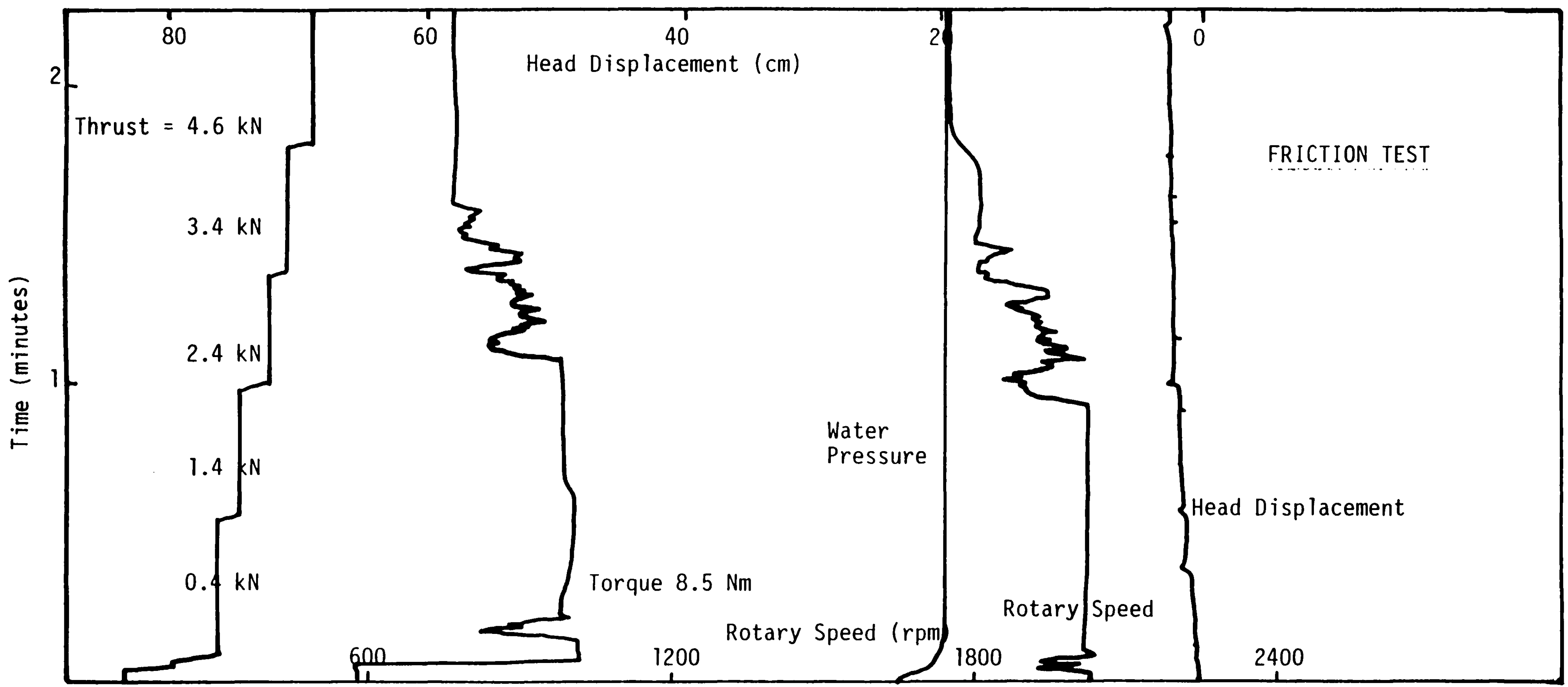
LABEL: PRT028 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:31, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28152236	16.65	-0.000	0.00	2052.35	0.38	7.58	76.73	4.83	11.64
28152240	16.65	0.001	1.67	2061.09	0.38	6.87	78.58	4.83	11.70
28152244	16.65	0.002	1.67	2059.05	0.38	9.71	73.02	4.83	11.70
28152259	16.65	0.004	0.89	2040.69	1.42	8.52	15.99	4.83	11.70
28152304	16.65	0.005	1.34	2043.61	1.42	8.28	255.18	4.83	11.58
28152308	16.65	0.005	0.01	2034.86	1.29	8.98	93.41	4.83	11.64
28152312	16.65	0.007	1.67	2046.52	1.29	8.05	71.16	4.83	11.58
28152324	16.65	0.009	1.11	1894.97	2.34	20.23	78.58	4.83	13.78
28152330	16.66	0.010	1.11	2005.72	2.47	11.33	48.91	4.83	12.21
28152334	16.66	0.011	1.67	1932.86	2.34	17.19	36.38	4.83	12.21
28152349	16.66	0.013	0.89	1854.17	3.38	23.51	23.49	4.83	13.47
28152354	16.66	0.014	1.34	1839.60	3.38	24.69	264.45	4.83	13.78
28152358	16.66	0.015	1.67	1830.86	3.38	25.39	28.96	4.83	13.47
28152402	16.66	0.015	0.01	1810.45	3.38	27.03	78.58	4.83	13.59
28152415	16.66	0.017	0.51	1725.94	4.56	33.83	15.99	4.83	14.16
28152420	16.66	0.017	0.00	1749.25	4.56	31.95	270.01	4.83	14.04
28152428	16.66	0.018	0.84	1755.08	4.56	31.48	71.16	4.83	14.04



RECORD OF CORSHAM DRILL RUN 2.16.1 (16.65 to 16.66 metres)

USER: EX9069 -AT SYSTEM

NR_C2.16.2

EX9069

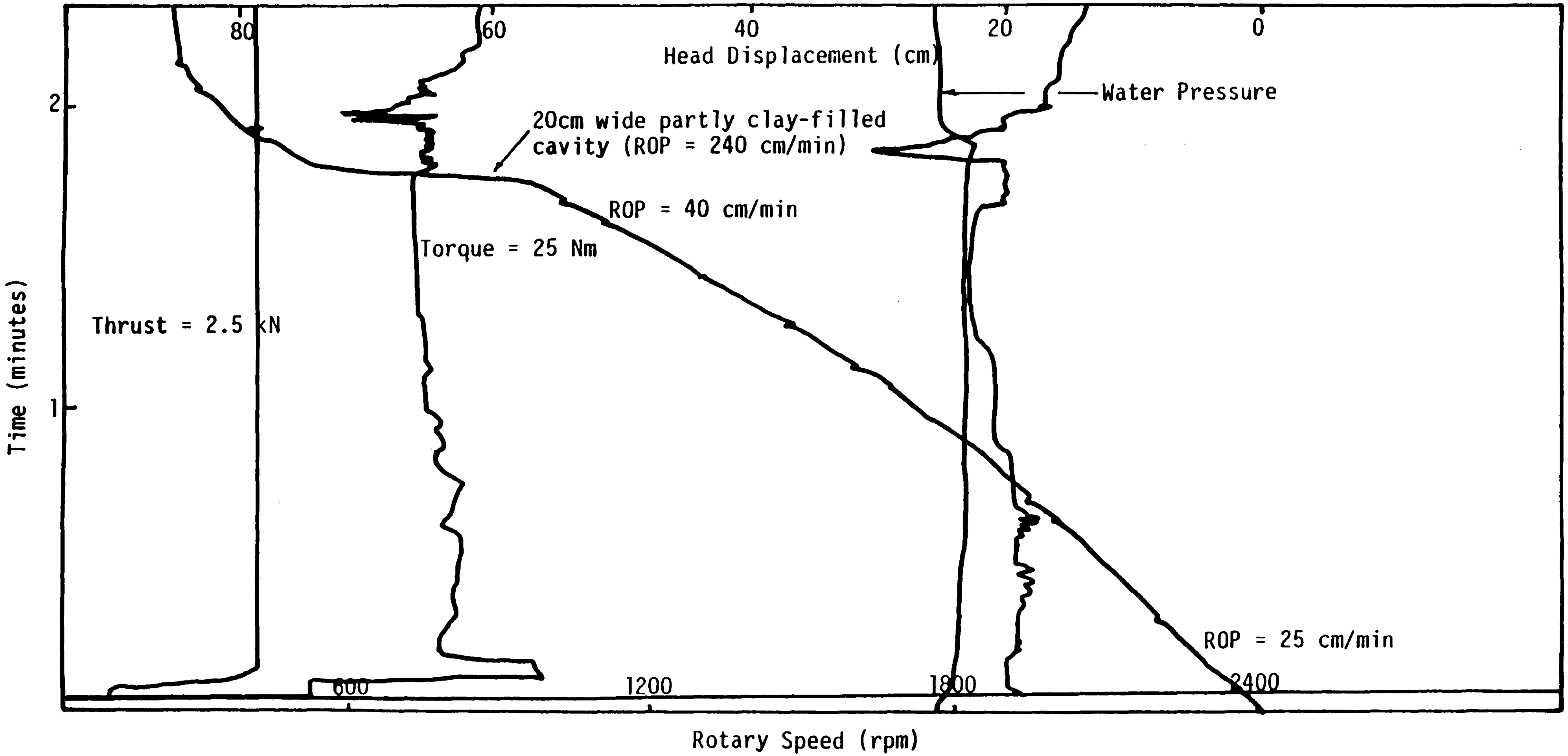
NR_C2.16.2

LABEL: PRT029 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:31, ON: PRO BY: PRO

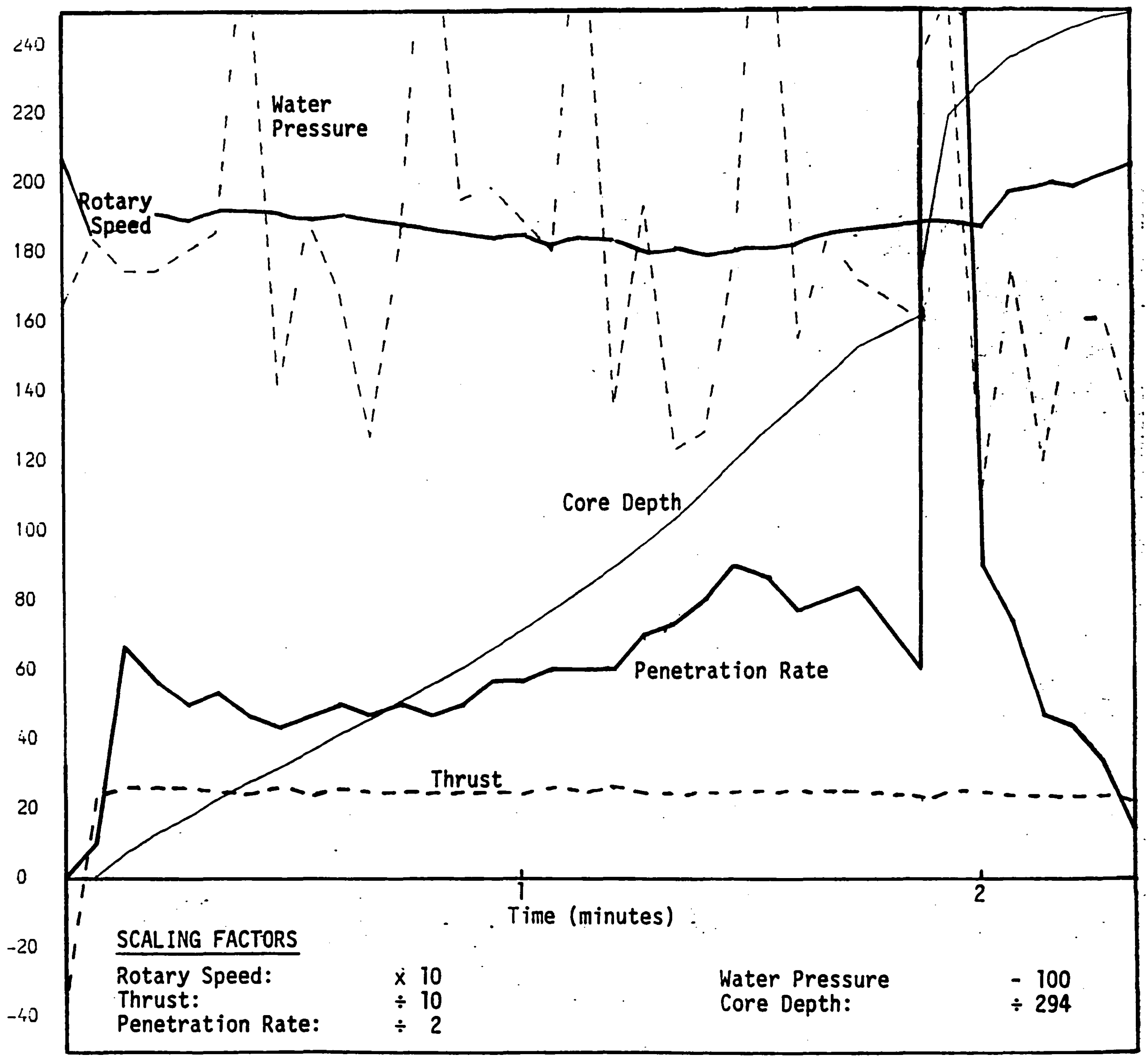
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28154126	16.66	0.000	0.00	2078.58	3.80	5.47	65.60	4.83	11.39
28154130	16.66	0.003	5.01	1851.26	2.34	23.75	84.14	4.83	9.62
28154134	16.69	0.026	33.46	1868.74	2.60	22.34	74.87	4.83	12.46
28154138	16.70	0.045	28.44	1912.46	2.60	18.83	74.87	4.83	12.08
28154142	16.72	0.061	25.10	1892.06	2.60	20.47	80.43	4.83	11.83
28154146	16.74	0.075	26.77	1915.37	2.47	18.59	86.05	4.83	11.77
28154150	16.75	0.095	23.42	1921.20	2.47	18.12	177.30	4.83	11.58
28154154	16.77	0.109	21.75	1912.46	2.60	18.83	39.64	4.83	11.51
28154158	16.78	0.125	23.42	1892.06	2.47	20.47	89.71	4.83	11.96
28154202	16.80	0.142	25.10	1906.63	2.60	19.30	69.31	4.83	11.70
28154206	16.82	0.157	23.42	1897.89	2.47	20.00	27.11	4.83	11.45
28154210	16.83	0.174	25.10	1874.57	2.47	21.87	82.29	4.83	12.02
28154214	16.85	0.190	23.42	1865.83	2.47	22.58	199.55	4.83	11.77
28154218	16.87	0.206	25.10	1854.17	2.47	23.51	95.27	4.83	11.83
28154222	16.89	0.225	28.44	1845.43	2.47	24.22	98.98	4.83	12.33
28154226	16.90	0.244	28.44	1851.26	2.47	23.75	89.71	3.40	12.08
28154230	16.92	0.264	30.12	1822.11	2.60	26.09	80.43	3.40	12.14
28154234	16.94	0.284	30.12	1839.60	2.47	24.69	195.84	4.83	12.21
28154238	16.96	0.305	30.12	1833.77	2.60	25.15	35.93	4.83	12.14
28154242	16.99	0.328	35.13	1792.97	2.47	28.44	93.41	3.40	12.59
28154246	17.01	0.352	36.81	1802.84	2.47	29.78	23.40	3.40	12.40
28154250	17.04	0.379	40.16	1788.28	2.47	30.92	28.52	3.40	12.65
28154254	17.07	0.409	45.18	1802.84	2.47	29.78	80.43	3.40	12.21
28154258	17.10	0.438	43.50	1808.66	2.47	29.32	219.95	3.40	12.14
28154302	17.12	0.464	38.48	1820.31	2.47	28.41	54.92	3.40	11.96
28154306	17.15	0.491	40.16	1846.51	2.47	26.36	84.14	3.40	11.89
28154310	17.18	0.519	41.83	1861.07	2.47	25.22	71.61	3.40	11.26
28154316	17.21	0.549	30.12	1883.31	2.34	21.17	60.49	3.40	11.20
28154318	17.24	0.583	103.73	1575.74	2.21	47.56	134.66	3.40	11.39
28154322	17.41	0.746	244.29	1884.36	2.47	23.39	153.20	3.40	11.58
28154326	17.44	0.776	45.18	1866.89	2.47	24.76	9.97	3.40	11.45
28154330	17.46	0.801	36.81	1971.71	2.34	16.55	74.87	3.40	10.06
28154334	17.48	0.817	23.42	2006.64	2.34	13.81	19.69	3.40	9.50
28154338	17.49	0.831	21.75	1989.18	2.34	15.18	61.89	3.40	9.75
28154342	17.50	0.842	16.73	2027.02	2.34	12.22	60.04	3.40	9.18
28154346	17.51	0.847	6.69	2056.14	2.21	9.94	30.82	3.40	8.87



RECORD OF CORSHAM DRILL RUN 2.16.2 (16.66 to 17.51 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.16.2 (16.66 to 17.51 metres)



USER: EX9069 -AT SYSTEM

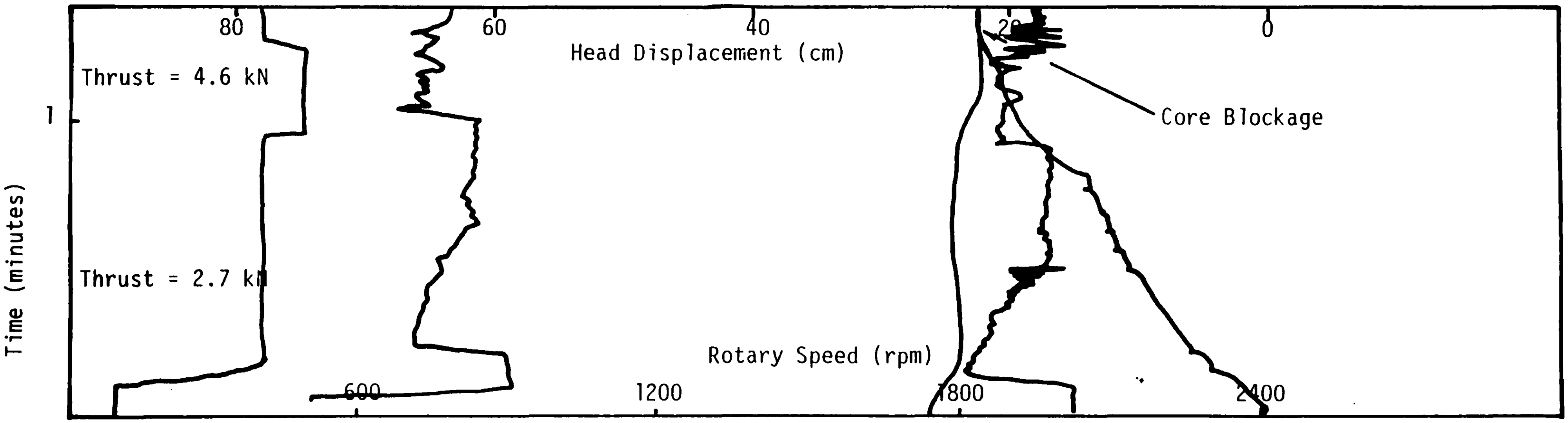
NR_C2.16.3

LABEL: PRT030 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:31, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28155154	17.51	0.000	0.00	1749.25	4.85	31.95	93.41	4.83	7.67
28155204	17.51	0.001	1.67	2031.95	3.93	9.22	93.41	4.83	10.57
28155208	17.51	0.001	0.01	2020.29	3.93	10.16	87.85	4.83	9.43
28155212	17.52	0.009	11.71	1763.82	2.60	30.78	9.97	4.83	11.77
28155216	17.54	0.032	35.13	1833.77	2.73	25.15	89.71	4.83	11.89
28155220	17.56	0.050	26.77	1865.83	2.73	22.58	24.81	4.83	11.58
28155224	17.58	0.067	25.10	1868.74	2.73	22.34	45.20	4.83	11.58
28155228	17.59	0.083	23.42	1894.97	2.73	20.23	76.73	4.83	11.01
28155232	17.61	0.096	20.08	1932.86	2.60	17.19	140.22	4.83	10.76
28155236	17.62	0.107	16.73	1985.32	2.60	12.97	30.37	4.83	10.06
28155240	17.63	0.116	13.38	1932.86	2.60	17.19	104.54	4.83	10.19
28155244	17.64	0.127	16.73	1962.00	2.73	14.84	67.45	4.83	10.13
28155248	17.64	0.135	11.71	1988.23	2.47	12.73	34.53	4.83	9.81
28155252	17.65	0.141	8.37	1979.49	2.47	13.44	6.27	4.83	9.62
28155256	17.66	0.146	8.37	1996.98	2.47	12.03	97.12	4.83	9.69
28155300	17.68	0.171	36.81	1854.17	4.56	23.51	41.94	4.83	10.76
28155306	17.70	0.187	16.73	1845.43	4.43	24.22	49.36	4.83	11.26
28155308	17.71	0.197	30.11	1909.54	4.30	19.06	108.25	4.83	11.33
28155312	17.72	0.206	13.38	1874.57	4.56	21.87	147.63	4.83	11.58
28155316	17.73	0.215	13.38	1854.17	4.56	23.51	26.66	4.83	10.68
28155320	17.73	0.222	10.04	1944.52	2.21	16.25	100.83	4.83	10.25
28155324	17.74	0.226	6.69	1941.60	2.60	16.48	100.83	4.83	10.06
28155328	17.74	0.232	8.37	428.62	4.85	137.40	89.71	4.83	-1.09



RECORD OF CORSHAM DRILL RUN 2.16.3 (17.51 to 17.74 metres)

USER: EX9969 -AT SYSTEM

NR_C2.17.1

EX9969

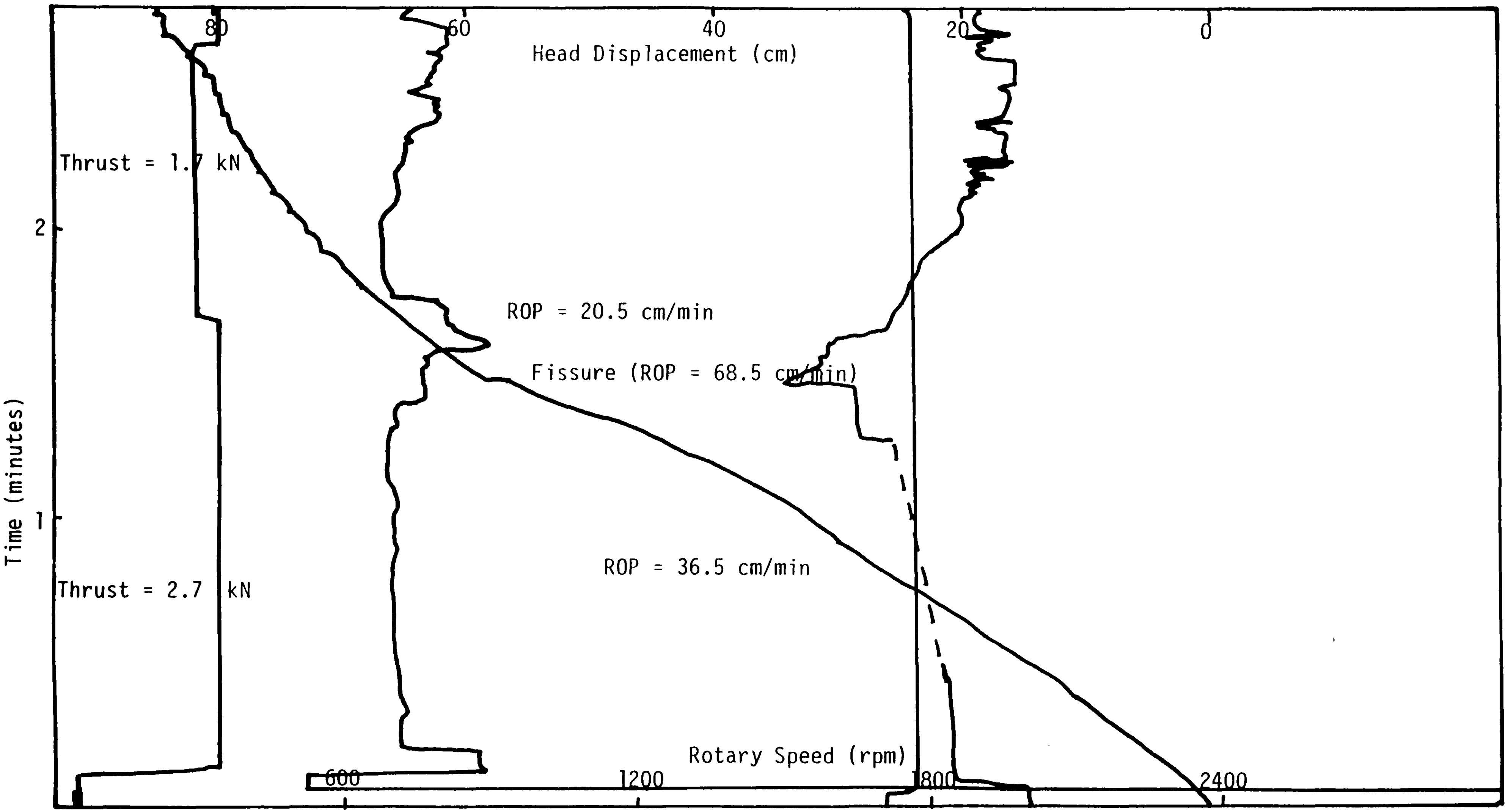
NR_C2.17.1

LABEL: PRT031 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:31, ON: PR? BY: PRD

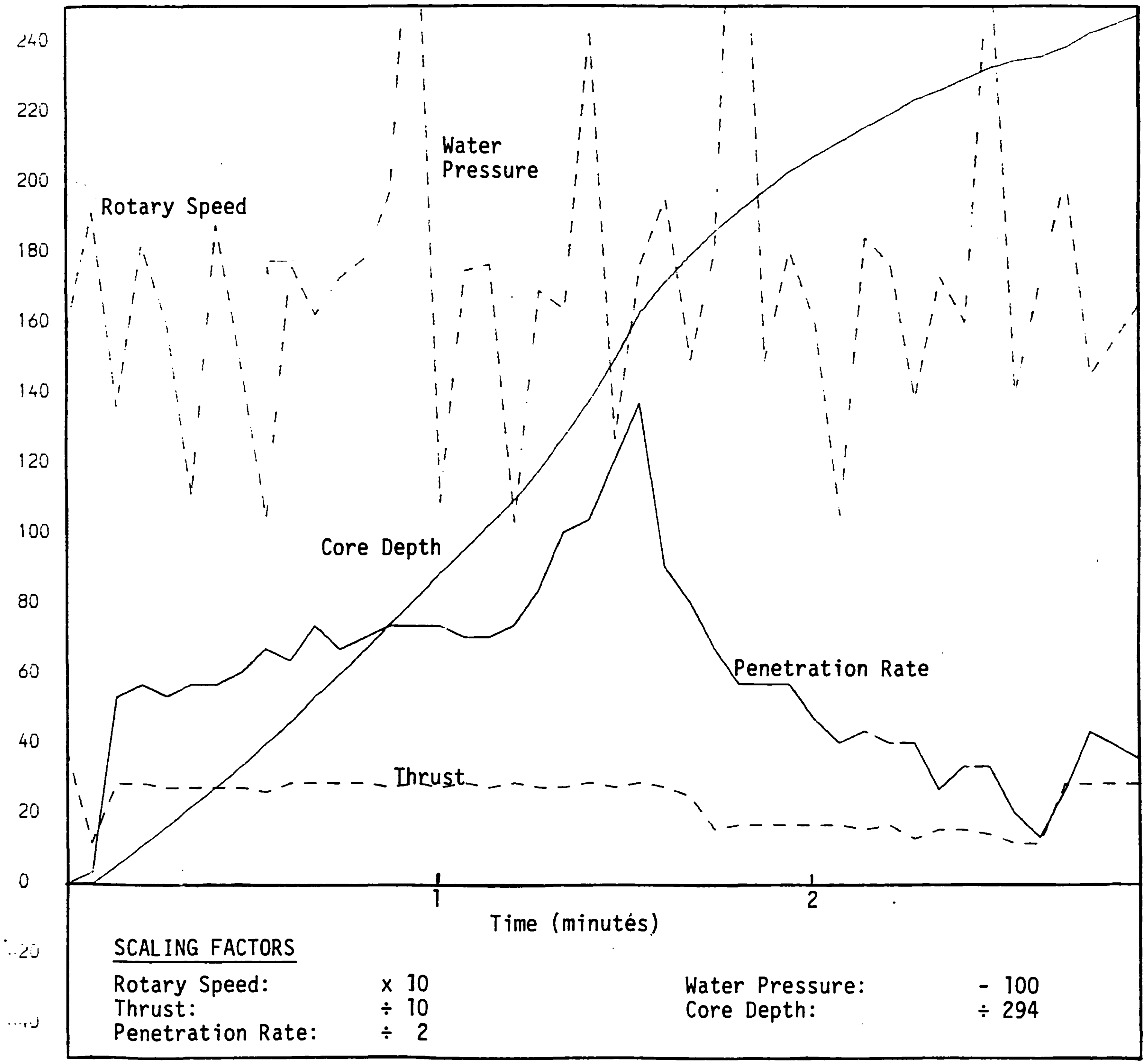
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28161542	17.74	0.000	0.00	2011.55	3.80	10.86	58.18	4.83	9.94
28161546	17.74	0.001	1.67	1988.23	1.16	12.73	91.56	4.83	9.75
28161550	17.76	0.019	26.73	1822.11	2.86	26.09	35.93	4.83	12.14
28161554	17.78	0.038	28.40	1842.51	2.86	24.45	82.29	4.83	11.96
28161558	17.80	0.056	26.73	1842.51	2.73	24.45	60.04	3.40	11.70
28161602	17.81	0.075	28.40	1839.60	2.73	24.69	10.42	4.83	11.96
28161606	17.83	0.094	28.40	1833.77	2.73	25.15	87.85	3.40	11.89
28161610	17.85	0.114	30.08	1798.80	2.73	27.97	47.06	3.40	11.96
28161614	17.88	0.136	33.42	1773.72	2.60	32.06	4.41	3.40	12.46
28161618	17.90	0.157	31.75	1773.72	2.86	32.06	76.73	4.83	12.08
28161622	17.92	0.182	36.76	1773.72	2.86	32.06	62.34	3.40	12.46
28161626	17.94	0.204	33.42	1764.99	2.86	32.74	73.02	3.40	12.27
28161630	17.97	0.227	35.09	1744.61	2.86	34.34	78.58	3.40	12.65
28161634	17.99	0.252	36.76	1764.99	2.73	32.74	97.12	3.40	12.40
28161638	18.02	0.276	36.76	1747.52	2.86	34.11	201.41	3.40	12.71
28161642	18.04	0.301	36.76	1794.11	2.73	30.46	8.57	3.40	12.33
28161646	18.06	0.324	35.09	1753.34	2.86	33.65	74.87	3.40	12.40
28161650	18.09	0.348	35.09	1756.26	2.73	33.42	76.73	3.40	12.52
28161654	18.11	0.372	36.76	1703.85	2.86	37.53	3.01	3.40	12.46
28161658	18.14	0.400	41.77	1700.94	2.73	37.76	69.31	3.40	12.59
28161702	18.17	0.433	50.13	1648.53	2.73	41.86	63.75	3.40	13.15
28161706	18.21	0.468	51.80	1651.44	2.86	41.63	143.93	3.40	13.15
28161710	18.25	0.508	60.16	1491.31	2.73	54.17	26.66	3.40	13.03
28161714	18.29	0.554	68.51	1610.68	2.86	44.82	76.73	3.40	13.78
28161718	18.32	0.584	45.11	1625.24	2.73	43.68	95.72	3.40	13.47
28161722	18.35	0.610	40.10	1680.56	2.47	39.35	49.36	3.40	13.15
28161726	18.37	0.633	33.42	1764.99	1.55	32.74	80.43	3.40	12.08
28161730	18.39	0.652	28.40	1797.02	1.68	30.23	238.49	3.40	11.70
28161734	18.41	0.671	28.40	1799.93	1.68	30.00	48.91	3.40	11.51
28161738	18.43	0.690	28.40	1820.31	1.68	28.41	80.43	3.40	11.45
28161742	18.45	0.705	23.39	1878.54	1.68	23.85	60.04	3.40	10.82
28161746	18.46	0.719	20.05	1884.36	1.68	23.39	4.86	3.40	10.51
28161750	18.47	0.733	21.72	1898.92	1.55	22.25	84.14	3.40	10.63
28161754	18.49	0.746	20.05	1930.95	1.68	19.74	76.73	3.40	10.13
28161758	18.50	0.760	20.05	1971.71	1.29	16.55	38.24	3.40	9.75
28161802	18.51	0.769	13.37	1977.53	1.55	16.09	73.02	3.40	9.12
28161806	18.52	0.780	16.71	1962.97	1.55	17.23	60.04	3.40	9.88
28161810	18.53	0.791	16.71	1992.09	1.42	14.95	168.03	3.40	8.99
28161814	18.54	0.798	10.03	2015.38	1.16	13.13	39.64	3.40	9.25
28161818	18.54	0.802	6.68	2018.29	1.16	12.90	73.02	3.40	8.68
28161822	18.55	0.811	13.37	1919.30	2.86	20.66	101.28	3.40	9.94
28161826	18.57	0.825	21.72	1893.10	2.86	22.71	45.20	3.40	9.81
28161832	18.58	0.843	17.82	1945.50	2.86	18.60	65.60	3.40	9.81
28161834	18.59	0.847	10.03	189.87	4.72	156.09	191.81	3.39	-1.22



RECORD OF CORSHAM DRILL RUN 2.17.1 (17.74 to 18.59 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 2.17.1 (17.74 to 18.59 metres)



USER: EX9069 -AT SYSTEM

NR_C2.17.2

EX9069

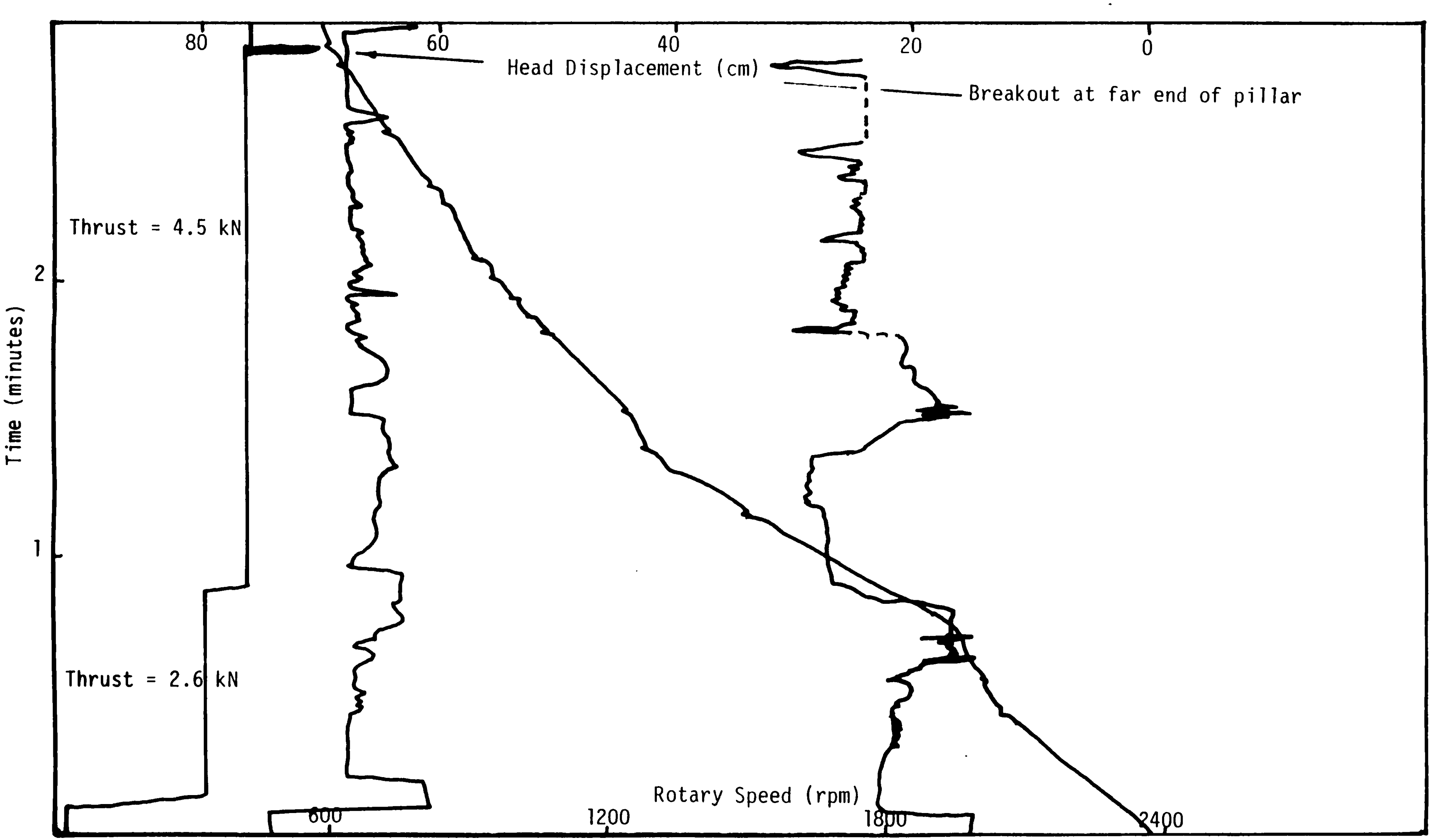
NR_C2.17.2

LABEL: PRT032 -FORM

SPOOLED: 82-01-25.18:26
STARTED: 82-01-25.18:31, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
28162052	18.59	0.000	0.00	1970.75	0.77	14.14	73.47	3.40	8.68
28162056	18.61	0.021	31.79	1785.37	2.60	31.14	63.75	3.40	11.70
28162100	18.63	0.042	31.79	1807.54	2.60	27.26	65.67	99.99	11.33
28162104	18.65	0.064	31.79	1779.55	2.60	31.60	90.15	3.40	11.26
28162108	18.68	0.086	33.46	1839.60	2.60	24.69	61.89	99.99	10.44
28162112	18.69	0.105	28.44	1833.77	2.60	25.15	76.73	99.99	10.51
28162116	18.72	0.126	31.79	1842.51	2.60	24.45	17.39	99.99	10.88
28162120	18.73	0.141	21.75	1857.09	2.47	23.28	89.71	3.40	10.19
28162124	18.74	0.154	20.07	1892.06	2.60	20.47	193.99	99.99	10.13
28162128	18.75	0.160	8.37	1967.83	2.21	14.37	89.71	99.99	9.06
28162132	18.76	0.171	16.73	1953.26	2.47	15.55	11.83	3.40	9.25
28162136	18.77	0.176	8.37	1965.88	2.47	17.01	25.26	99.99	8.99
28162140	18.78	0.187	16.73	1732.96	4.43	35.25	93.41	3.40	11.26
28162144	18.80	0.214	40.15	1674.73	4.56	39.81	43.35	99.99	12.14
28162148	18.83	0.241	40.16	1689.29	4.30	38.67	32.67	99.99	12.14
28162152	18.86	0.269	41.83	1660.18	4.56	40.95	71.16	99.99	12.27
28162156	18.89	0.298	43.50	1683.47	4.43	39.12	262.60	99.99	12.27
28162200	18.92	0.326	41.83	1628.15	4.30	43.46	43.35	99.99	12.40
28162204	18.94	0.354	41.83	1677.65	4.30	39.58	71.16	99.99	12.27
28162208	18.97	0.378	36.81	1680.56	4.43	39.35	132.80	99.99	12.52
28162212	18.99	0.402	35.13	1695.11	4.43	38.21	84.14	99.99	12.21
28162216	19.01	0.421	28.44	1782.46	4.43	31.37	216.24	99.99	10.88
28162220	19.03	0.438	26.77	1910.56	4.43	21.34	23.40	99.99	10.51
28162224	19.04	0.447	13.38	1925.12	4.43	20.20	71.16	99.99	9.12
28162228	19.05	0.458	16.73	1863.98	4.43	24.99	79.03	99.99	9.94
28162232	19.06	0.474	23.42	1834.87	4.43	27.27	39.64	99.99	10.25
28162236	19.08	0.491	25.10	1837.78	4.43	27.04	58.18	99.99	10.06
28162240	19.10	0.508	25.10	1750.43	4.30	33.88	93.86	99.99	12.71
28162244	19.11	0.523	23.42	1727.14	4.16	35.70	71.16	99.99	11.70
28162248	19.13	0.539	23.42	1712.58	4.56	36.84	74.87	99.99	11.83
28162252	19.14	0.553	21.75	1747.52	4.56	34.11	21.10	99.99	11.77
28162256	19.16	0.566	18.40	1756.26	4.56	33.42	82.29	99.99	11.14
28162300	19.17	0.577	16.73	1744.61	4.56	34.34	65.60	99.99	11.39
28162304	19.18	0.588	16.73	1797.02	4.30	30.23	9.97	99.99	10.76
28162308	19.19	0.598	15.05	1764.99	4.56	32.74	54.47	99.99	11.39
28162312	19.20	0.608	15.05	1709.67	4.43	37.07	84.14	99.99	10.63
28162316	19.21	0.620	18.40	1770.81	4.56	32.28	69.31	99.99	10.95
28162320	19.22	0.634	20.08	1753.34	4.56	33.65	97.12	99.99	11.64
28162324	19.23	0.644	15.05	1799.93	4.56	30.00	48.91	99.99	11.01
28162328	19.24	0.654	15.05	1767.90	4.16	32.51	132.54	99.99	10.87
28162336	19.26	0.674	15.06	1794.11	4.30	30.46	3.01	99.99	10.51
28162340	19.28	0.686	18.40	1802.84	4.82	29.78	86.00	99.99	10.63
28162346	19.29	0.705	14.22	1823.22	4.69	28.18	13.68	99.99	10.51
28162352	19.31	0.717	18.40	1715.49	1.42	36.62	76.73	99.99	7.80



RECORD OF CORSHAM DRILL RUN 2.17.2 (18.59 to 19.31 metres)

USER: EX9069 -AT SYSTEM

NR_C3.1

EX9069

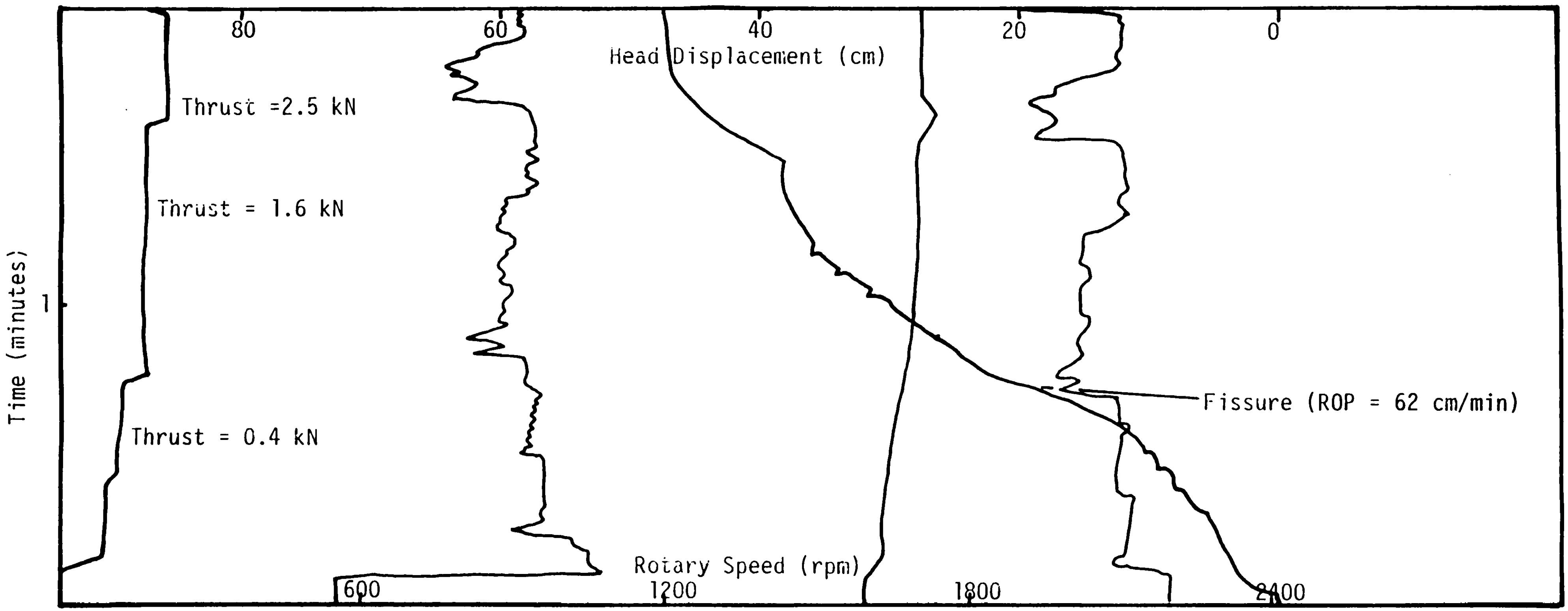
NR_C3.1

LABEL: PRTC11 -FORM

SPOOLED: 82-03-10.15:13
STARTED: 82-03-10.15:19, ON: PRC BY: PRO

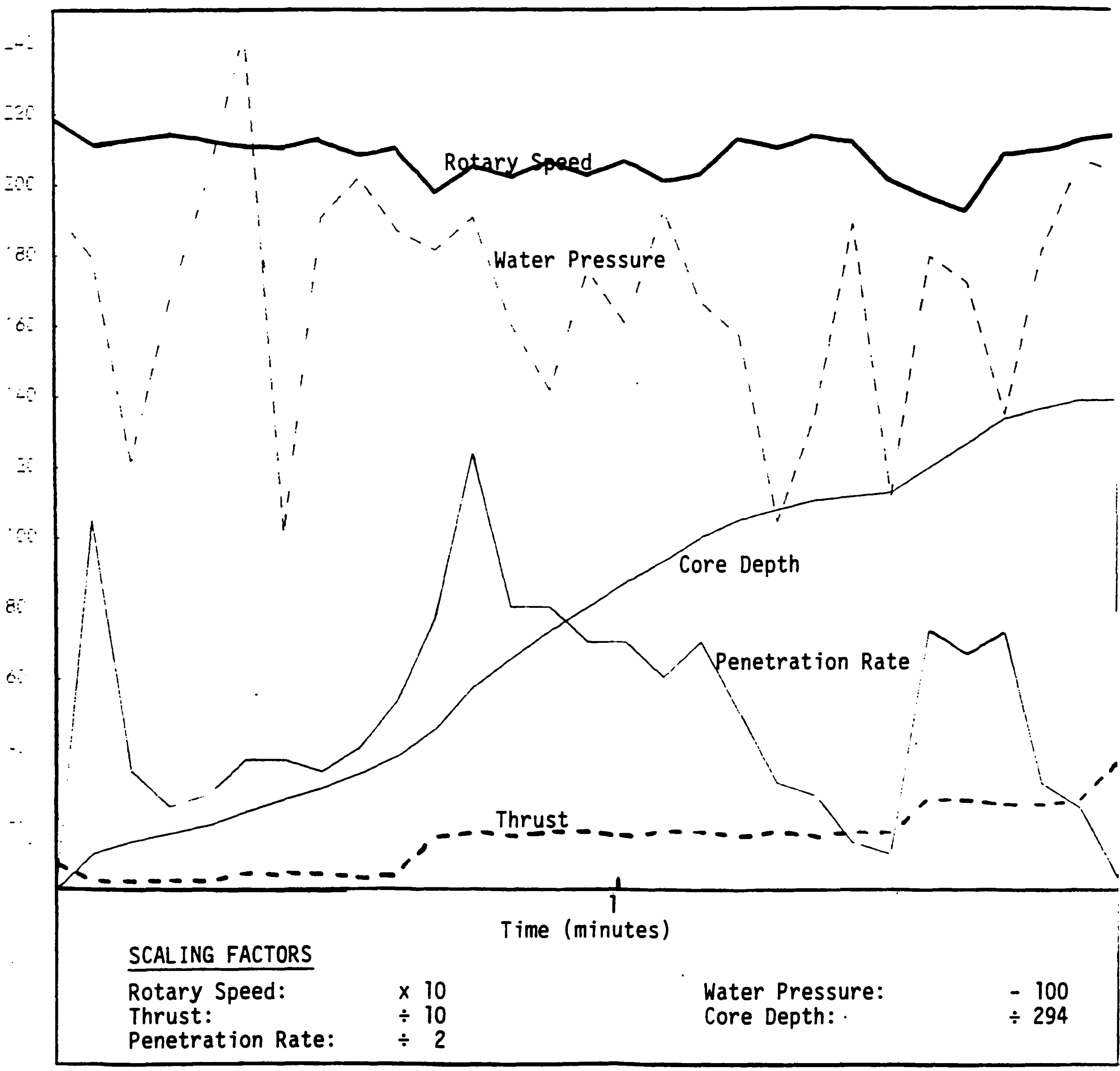
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
3152358	0.00	0.000	0.00	2185.73	0.75	6.03	93.09	3.42	7.20
3152402	0.03	0.035	52.51	2118.90	0.23	9.52	79.88	3.42	8.15
3152406	0.05	0.046	16.73	2130.52	0.23	1.48	21.75	3.42	7.77
3152410	0.05	0.054	11.71	2145.05	0.23	2.68	66.75	3.42	7.58
3152414	0.06	0.062	13.39	2127.62	0.23	1.24	100.50	3.42	7.71
3152418	0.07	0.075	18.41	2107.28	0.44	0.44	143.24	3.42	8.41
3152422	0.09	0.087	18.41	2104.37	0.44	0.68	1.13	3.42	8.15
3152426	0.10	0.098	16.73	2127.62	0.44	1.24	91.13	3.42	7.90
3152430	0.11	0.112	20.08	2084.03	0.30	2.35	102.37	3.42	8.02
3152434	0.13	0.129	26.77	2107.28	0.44	0.44	87.38	3.42	8.28
3152438	0.16	0.155	38.48	1979.43	1.49	10.98	81.75	3.42	9.30
3152442	0.20	0.196	61.91	2054.98	1.62	1.32	91.13	3.42	9.49
3152446	0.22	0.223	40.16	2028.83	1.49	0.96	60.74	3.42	10.13
3152450	0.25	0.250	40.16	2069.50	1.62	2.59	41.99	3.42	9.43
3152454	0.27	0.273	35.14	2028.83	1.62	0.96	76.13	99.99	9.68
3152458	0.30	0.297	35.14	2069.50	1.49	2.59	60.74	99.99	9.24
3152502	0.32	0.317	30.12	2011.35	1.62	2.48	93.00	3.42	9.30
3152506	0.34	0.340	35.14	2031.73	1.62	0.71	66.75	3.42	9.43
3152510	0.36	0.357	25.10	2133.43	1.49	8.17	57.38	99.99	8.15
3152514	0.37	0.367	15.06	2107.28	1.62	5.88	4.49	3.42	8.02
3152518	0.38	0.376	13.39	2139.24	1.49	8.67	34.49	99.99	7.64
3152522	0.38	0.380	6.69	2124.71	1.62	7.41	89.25	3.42	7.51
3152526	0.38	0.384	5.02	2014.30	1.62	2.23	11.99	99.99	8.09
3152530	0.41	0.408	36.81	1962.00	2.55	6.79	79.88	99.99	9.62
3152534	0.43	0.431	33.46	1927.13	2.55	9.84	72.38	99.99	10.89
3152538	0.46	0.455	36.81	2089.84	2.42	4.36	34.88	3.42	9.30
3152542	0.47	0.465	15.06	2098.56	2.42	5.12	81.75	99.99	7.39
3152546	0.47	0.473	11.71	2127.62	2.55	7.66	107.61	99.99	7.39
3152550	0.47	0.474	1.67	2145.05	3.66	9.18	104.25	99.99	7.51



RECORD OF CORSHAM DRILL RUN 3.1 (0.00 to 0.47 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.1 (0.00 to 0.47 metres)



USER: EX9369 -AT SYSTEM

NF_C3.2.1

EX9369

NF_C3.2.1

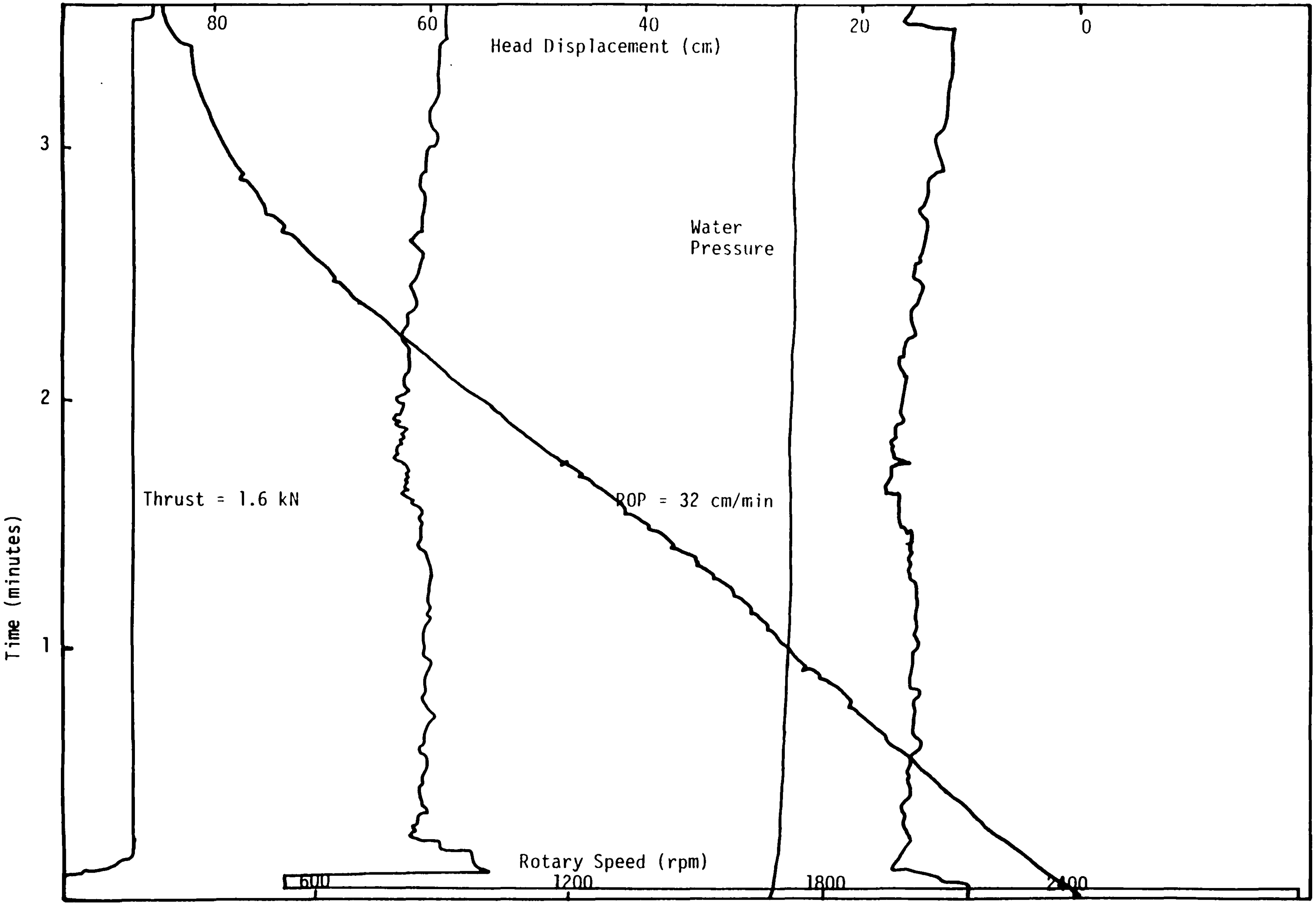
-742

LABEL: FRT012 -FORM

SPOOLED: 82-03-10.15:13
STARTED: 82-03-10.15:19, ON: FRO BY: PRO

O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
3153628	0.47	0.000	0.00	2137.13	1.15	0.76	63.07	3.41	7.57
3153632	0.48	0.012	16.73	1968.77	1.49	8.94	64.94	3.41	9.42
3153636	0.51	0.037	36.81	2006.50	1.49	5.73	91.17	3.41	9.93
3153640	0.53	0.057	30.12	1597.79	1.49	6.47	70.56	3.41	9.67
3153644	0.55	0.077	30.12	1597.79	1.49	6.47	240.35	3.41	9.93
3153648	0.57	0.096	28.44	2023.92	1.49	4.25	21.86	3.41	9.67
3153652	0.58	0.114	26.77	1597.79	1.49	6.47	72.44	3.41	9.48
3153656	[illegible]	0.132	26.77	2021.02	1.49	4.50	62.42	3.41	9.42
3153700	0.62	0.149	26.77	2052.95	1.49	1.78	68.69	3.41	9.16
3153704	0.64	0.166	25.10	2003.60	1.49	5.98	55.58	3.41	9.35
3153708	0.65	0.184	26.77	2023.92	1.49	4.25	9.98	3.41	9.29
3153712	0.67	0.201	25.10	2047.14	1.62	2.28	76.18	99.99	9.16
3153716	0.69	0.216	23.42	2003.60	1.62	5.98	83.67	99.99	9.48
3153720	0.70	0.232	23.42	2023.92	1.49	4.25	25.61	3.41	9.35
3153724	0.72	0.248	23.43	2035.53	1.62	3.26	61.20	3.41	9.10
3153728	0.73	0.263	23.42	2032.63	1.49	3.51	54.93	99.99	9.03
3153732	0.75	0.275	23.43	2026.82	1.62	4.00	83.67	99.99	9.10
3153736	0.76	0.293	21.75	2032.63	1.49	3.51	54.93	3.41	8.97
3153740	0.78	0.305	23.42	2032.63	1.49	3.51	34.98	99.99	8.91
3153744	0.80	0.326	25.10	2012.31	1.62	5.24	55.58	99.99	9.42
3153748	0.81	0.344	26.77	2026.82	1.62	4.00	30.58	99.99	9.16
3153752	0.83	0.360	25.10	2003.60	1.62	5.98	78.05	3.41	8.91
3153756	0.85	0.381	31.79	1986.18	1.62	7.46	285.33	3.41	9.61
3153800	0.87	0.403	31.79	1980.38	1.62	7.95	44.34	99.99	9.48
3153804	0.89	0.423	30.12	1965.86	1.62	9.18	74.31	99.99	9.80
3153808	0.91	0.444	31.79	1980.38	1.62	7.95	69.91	99.99	9.54
3153812	0.94	0.465	31.75	1974.57	1.62	8.44	78.05	99.99	9.35
3153816	0.96	0.486	31.75	1986.18	1.62	7.46	70.56	99.99	9.42
3153820	0.98	0.508	31.79	2009.40	1.62	5.48	78.05	3.41	9.29
3153824	1.00	0.528	30.12	1997.79	1.62	6.47	230.99	99.99	9.48
3153828	1.02	0.548	30.12	2009.40	1.62	5.48	18.12	3.41	9.03
3153832	1.04	0.567	28.44	2000.70	1.62	6.22	72.44	99.99	8.84
3153836	1.06	0.587	30.12	2009.40	1.62	5.48	148.58	99.99	8.97
3153840	1.08	0.607	30.12	2038.43	1.62	3.02	70.56	99.99	8.78
3153844	1.09	0.625	26.77	2009.40	1.62	5.48	55.58	99.99	8.72
3153848	1.11	0.643	26.77	2050.04	1.49	2.03	16.25	99.99	8.27
3153852	1.13	0.659	25.10	2064.56	1.62	0.80	23.74	99.99	8.02
3153856	1.14	0.675	23.42	2009.40	1.62	5.48	5.01	99.99	8.52
3153900	1.16	0.693	26.77	2052.95	1.62	1.78	89.29	99.99	8.08
3153904	1.18	0.708	23.42	2067.46	1.49	0.55	53.71	99.99	7.76
3153908	1.19	0.723	21.75	2055.85	1.49	1.54	42.47	99.99	7.76
3153912	1.21	0.738	23.42	2076.17	1.49	0.19	103.63	99.99	8.08
3153916	1.22	0.752	20.08	2076.17	1.49	0.19	28.71	99.99	7.82
3153920	1.23	0.764	18.41	2113.90	1.49	3.39	74.31	99.99	7.31
3153924	1.25	0.775	16.73	2084.88	1.49	0.93	29.36	99.99	7.31
3153928	1.26	0.786	16.73	2102.29	1.49	2.41	24.96	99.99	7.38
3153932	1.27	0.796	15.06	2122.61	1.49	4.13	57.45	99.99	6.93
3153936	1.27	0.803	10.04	2131.32	1.49	4.87	45.56	99.99	6.74
3153940	1.28	0.810	10.04	2128.42	1.49	4.63	85.55	99.99	6.81
3153944	1.28	0.814	6.69	2137.13	1.49	5.37	85.55	99.99	6.68
3153948	1.29	0.818	5.02	2140.03	1.62	5.61	74.31	99.99	6.61
3153952	1.29	0.820	3.35	2140.03	1.62	5.61	76.18	99.99	6.55
3153956	1.30	0.828	11.71	2003.60	2.54	5.98	62.42	99.99	8.46
3154000	1.32	0.846	26.77	2084.88	2.54	5.98	70.56	99.99	8.21



RECORD OF CORSHAM DRILL RUN 3.2.1 (0.47 to 1.32 metres)

USER: EX9069 -AT SYSTEM

NR_C3.2.2

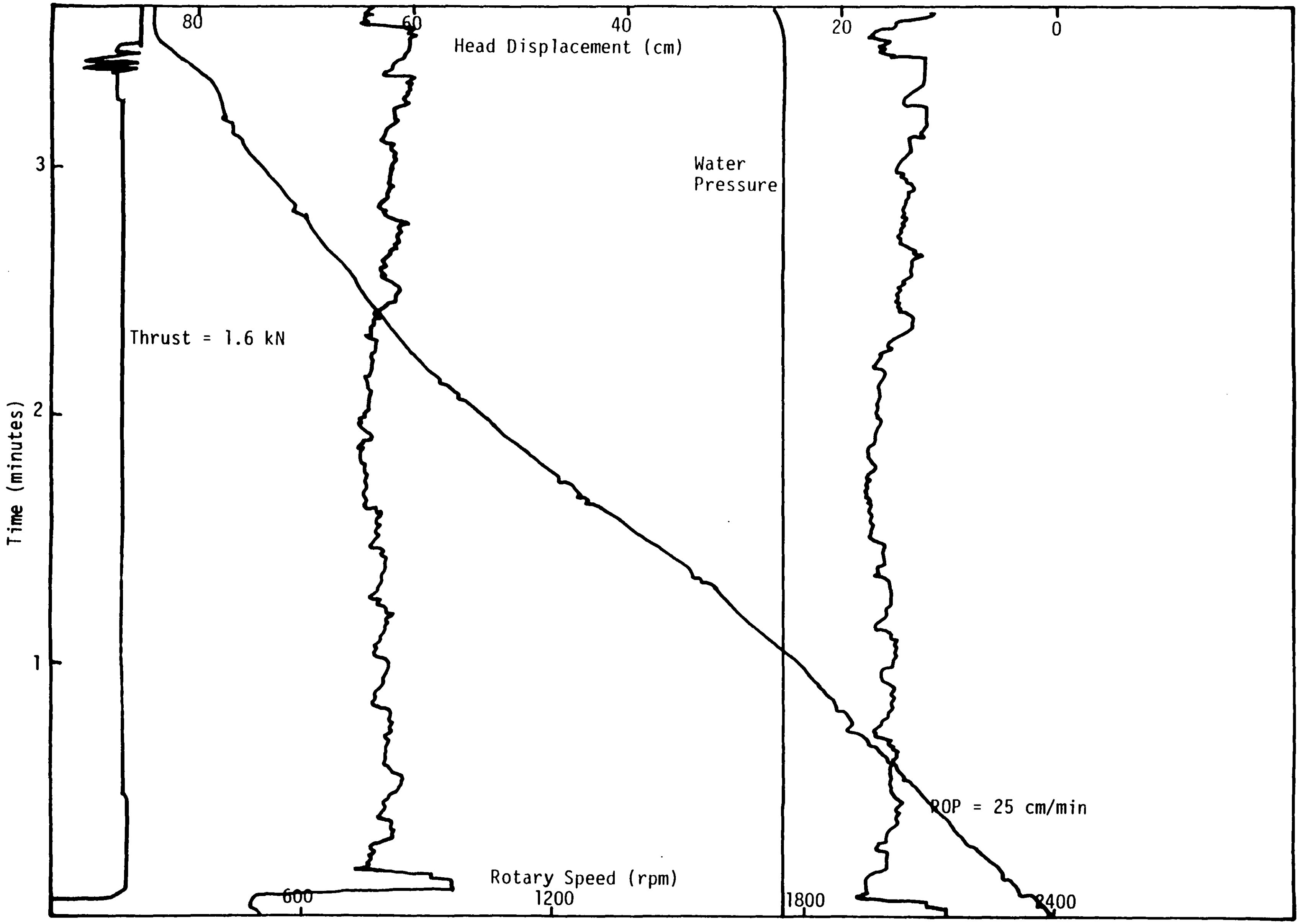
LABEL: PRT013 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:20, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
3154028	1.32	0.000	0.00	2160.35	3.79	7.34	89.29	99.99	7.00
3154032	1.32	0.001	1.67	1931.03	1.75	12.14	16.25	99.99	7.51
3154036	1.34	0.021	30.12	1965.86	1.75	9.18	102.40	99.99	9.29
3154040	1.36	0.040	28.44	2006.50	1.75	5.73	64.29	99.99	9.03
3154044	1.38	0.057	25.10	1986.18	1.62	7.46	48.09	99.99	8.78
3154048	1.39	0.074	25.10	2006.50	1.62	5.73	70.56	99.99	8.72
3154052	1.41	0.090	25.10	2029.72	1.62	3.76	21.86	99.99	8.52
3154056	1.42	0.104	20.08	2023.92	1.62	4.25	81.80	99.99	8.14
3154100	1.44	0.119	23.42	1991.99	1.62	6.96	36.85	99.99	8.78
3154104	1.46	0.136	25.10	2009.40	1.62	5.48	94.91	99.99	8.52
3154108	1.47	0.151	21.75	2021.02	1.62	4.50	6.23	99.99	8.08
3154112	1.49	0.166	23.42	1971.67	1.62	8.69	58.67	99.99	8.78
3154116	1.50	0.182	23.42	2009.40	1.62	5.48	76.18	99.99	8.65
3154120	1.52	0.197	23.42	2026.82	1.62	4.00	75.53	99.99	8.27
3154124	1.53	0.212	21.75	1974.57	1.62	8.44	89.29	99.99	8.52
3154128	1.55	0.229	25.10	2021.02	1.62	4.50	89.29	99.99	8.33
3154132	1.57	0.245	25.10	2023.92	1.62	4.25	91.17	99.99	8.08
3154136	1.58	0.260	21.75	1997.79	1.62	6.47	94.91	99.99	8.14
3154140	1.60	0.278	26.77	2006.50	1.62	5.73	23.09	99.99	8.46
3154144	1.61	0.292	21.75	2021.02	1.62	4.50	100.53	99.99	8.14
3154148	1.63	0.308	23.42	2000.70	1.62	6.22	236.61	99.99	7.82
3154152	1.65	0.326	26.77	1994.89	1.62	6.72	63.07	99.99	8.52
3154156	1.66	0.345	28.44	1991.95	1.62	6.96	91.17	99.99	8.40
3154200	1.68	0.364	28.44	1948.45	1.62	10.66	18.12	99.99	8.72
3154204	1.71	0.387	35.14	1957.15	1.62	9.92	91.17	99.99	8.78
3154208	1.73	0.408	31.79	1962.96	1.62	9.43	53.05	99.99	8.59
3154212	1.75	0.429	31.79	1942.64	1.62	11.15	94.91	99.99	9.03
3154216	1.77	0.451	31.79	1980.38	1.62	7.95	81.80	99.99	8.65
3154220	1.79	0.470	28.44	1945.54	1.62	10.91	102.40	99.99	8.84
3154224	1.81	0.490	30.12	1983.28	1.62	7.70	106.15	99.99	8.52
3154228	1.83	0.509	28.44	1986.18	1.62	7.46	54.93	99.99	8.14
3154232	1.85	0.528	28.44	1989.08	1.62	7.21	79.93	99.99	8.59
3154236	1.87	0.545	26.77	1986.18	1.62	7.46	142.96	99.99	8.21
3154240	1.88	0.562	25.10	1997.79	1.62	6.47	87.42	99.99	7.95
3154244	1.90	0.580	26.77	1997.79	1.62	6.47	102.40	99.99	8.21
3154248	1.92	0.597	25.10	2029.72	1.62	3.76	27.48	99.99	7.95
3154252	1.93	0.609	18.41	2081.97	1.49	0.68	91.17	99.99	6.81
3154256	1.94	0.621	18.41	2023.92	1.62	4.25	39.94	99.99	7.38
3154300	1.96	0.637	23.42	2032.63	1.62	3.51	83.67	99.99	7.70
3154304	1.97	0.651	21.75	2055.85	1.62	1.54	141.08	99.99	7.25
3154308	1.98	0.661	20.08	2087.78	1.49	1.17	87.42	99.99	6.93
3154312	1.99	0.675	20.08	2009.40	1.62	5.48	102.40	99.99	7.57
3154316	2.01	0.690	23.42	2055.85	1.62	1.54	34.98	99.99	7.38
3154320	2.02	0.703	18.40	2058.75	1.62	1.29	85.55	99.99	7.44
3154324	2.03	0.714	16.73	2055.85	1.62	1.54	26.83	99.99	6.87
3154328	2.05	0.727	20.08	2032.63	1.49	3.51	93.04	99.99	7.51
3154332	2.06	0.742	21.75	2084.88	1.49	0.93	195.40	99.99	7.06
3154336	2.08	0.755	20.08	2108.10	1.49	2.90	89.29	99.99	7.00
3154340	2.08	0.763	11.71	2099.39	1.49	2.16	98.66	99.99	6.42
3154344	2.09	0.771	11.71	2029.72	1.62	3.76	87.42	99.99	6.55
3154348	2.10	0.784	20.08	2084.88	0.83	0.93	74.31	99.99	7.00
3154352	2.11	0.791	10.04	2111.00	1.22	3.15	1.26	99.99	6.42
3154356	2.12	0.795	6.69	1989.08	2.54	7.21	87.42	99.99	6.30
3154400	2.13	0.814	28.44	1991.99	2.54	6.96	61.20	99.99	8.08

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
3154404	2.16	0.835	31.79	2018.11	2.54	4.74	93.04	99.99	8.08
3154408	2.17	0.847	16.73	1405.63	4.06	59.58	91.17	99.99	5.02



RECORD OF CORSHAM DRILL RUN 3.2.2 (1.32 to 2.17 metres)

USER: EX5069 -AT SYSTEM

NR_C3.3.1

EX5069

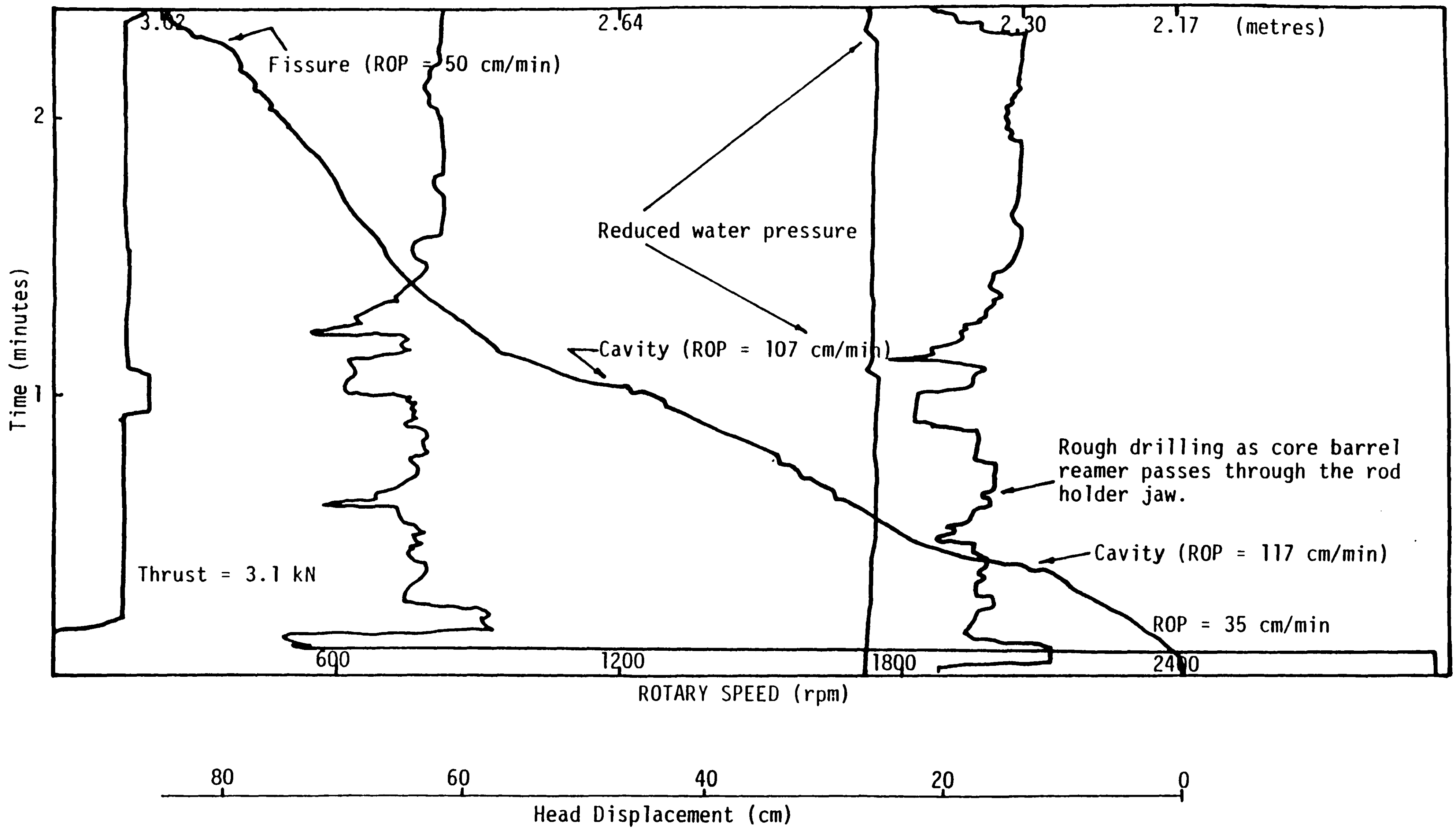
NR_C3.3.1

LABEL: FRT014 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:20, CN: PRO BY: PRO

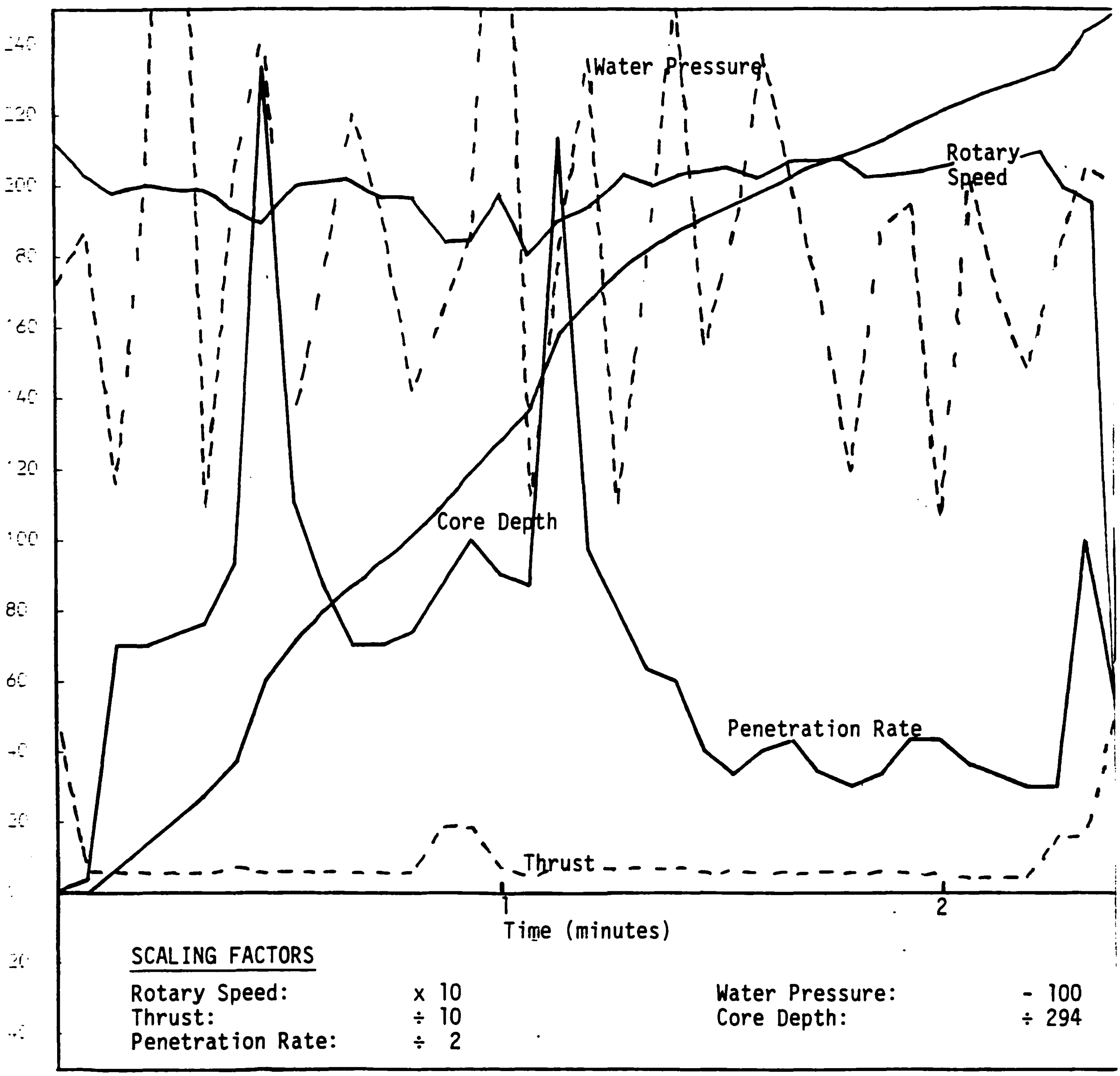
OXFORD POLYTECHNIC COMPUTER CENTRE

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
3155230	2.17	0.000	0.00	2124.71	5.11	1.00	72.38	4.86	6.49
3155234	2.17	0.001	1.67	2028.83	0.62	12.24	87.38	4.86	6.62
3155238	2.19	0.025	35.14	1976.52	0.57	11.22	15.74	4.86	8.92
3155242	2.22	0.048	35.14	1999.77	0.57	9.30	104.25	4.86	8.15
3155246	2.24	0.073	36.81	1988.15	0.57	10.26	302.60	4.86	8.85
3155350	2.27	0.098	38.48	1991.05	0.57	10.02	8.63	4.86	8.34
3155354	2.30	0.129	46.85	1938.75	0.70	14.34	104.25	4.86	8.92
3155358	2.38	0.207	117.13	1900.98	0.57	17.45	143.24	4.86	9.04
3155402	2.41	0.244	55.22	2002.67	0.57	9.06	34.88	4.86	8.47
3155406	2.44	0.273	43.50	2014.30	0.57	8.11	74.25	4.86	8.47
3155410	2.47	0.297	35.14	2020.11	0.57	7.63	120.74	4.86	8.02
3155414	2.49	0.320	35.14	1964.90	0.57	12.18	91.13	4.86	8.73
3155418	2.51	0.345	36.81	1964.90	0.57	12.18	41.99	4.86	8.41
3155422	2.54	0.374	43.50	1839.96	1.89	22.48	62.62	4.86	10.57
3155426	2.58	0.407	50.20	1842.86	1.89	22.25	87.38	4.86	10.60
3155430	2.61	0.437	45.18	1970.71	0.70	11.70	251.98	4.86	8.34
3155434	2.64	0.466	43.50	1796.37	0.44	26.08	12.36	4.86	8.53
3155438	2.71	0.538	107.09	1912.60	0.70	16.49	81.75	4.86	9.49
3155442	2.74	0.570	48.52	1947.47	0.70	13.62	135.74	4.86	8.73
3155446	2.77	0.597	40.16	2017.20	0.70	7.87	10.51	4.86	7.96
3155450	2.79	0.618	31.79	1991.05	0.70	10.02	78.00	3.42	7.71
3155454	2.81	0.638	30.12	2020.11	0.70	7.63	154.48	3.42	7.96
3155458	2.82	0.651	20.08	2078.22	0.57	2.83	55.50	4.86	6.88
3155502	2.83	0.663	16.73	2084.03	0.57	2.35	85.50	4.86	6.81
3155506	2.85	0.676	20.08	2034.64	0.57	6.43	137.61	3.42	7.32
3155510	2.86	0.690	21.75	2075.32	0.57	3.07	100.50	3.42	6.94
3155514	2.87	0.702	16.73	2081.13	0.57	2.59	68.63	3.42	6.88
3155518	2.88	0.712	15.06	2086.94	0.57	2.12	19.49	3.42	6.69
3155522	2.89	0.723	16.73	2034.64	0.57	6.43	87.38	3.42	6.88
3155526	2.91	0.737	21.75	2043.35	0.57	5.71	94.88	3.42	7.39
3155530	2.92	0.752	21.75	2066.60	0.57	3.79	6.37	3.42	7.26
3155534	2.93	0.764	18.40	2072.41	0.44	3.31	102.37	3.42	6.62
3155538	2.95	0.775	16.73	2072.41	0.44	3.31	68.63	4.86	6.69
3155542	2.96	0.785	15.06	2089.84	0.44	1.88	48.00	4.86	6.62
3155546	2.97	0.795	15.06	1970.71	1.62	11.70	79.88	3.42	7.90
3155550	3.00	0.829	50.20	1909.69	1.62	16.73	105.74	3.42	9.62
3155554	3.02	0.847	26.77	994.41	5.11	92.22	100.50	3.42	4.97



RECORD OF CORSHAM DRILL RUN 3.3.1 (2.17 to 3.02 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.3.1 (2.17 to 3.02 metres)



USER: EX5069 -AT SYSTEM

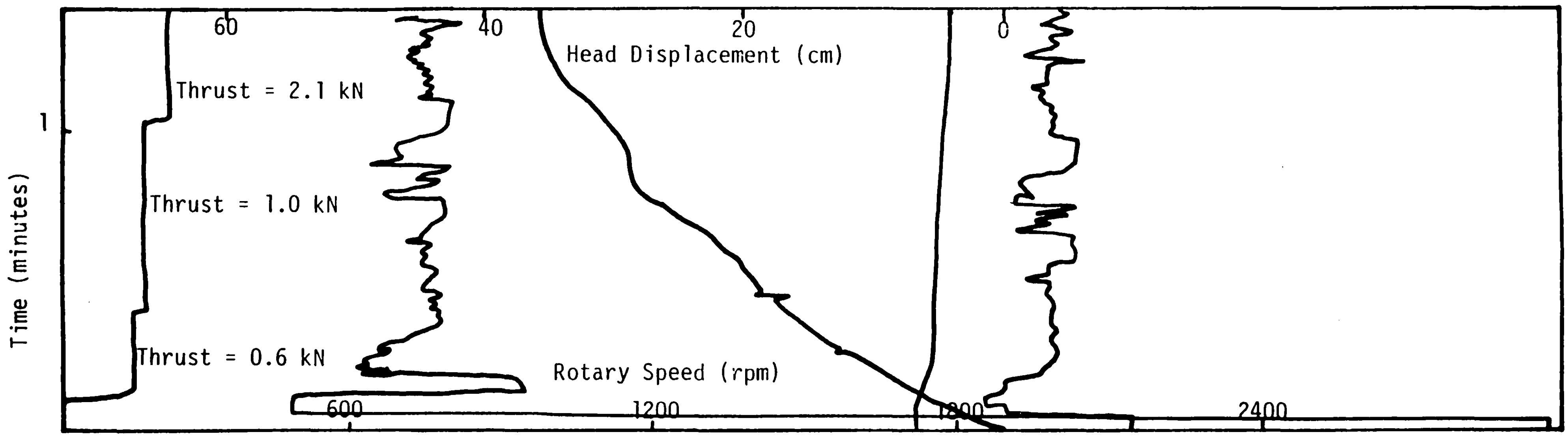
NR_C3.3.2

LABEL: PRT015 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:20, ON: PRO BY: PRO

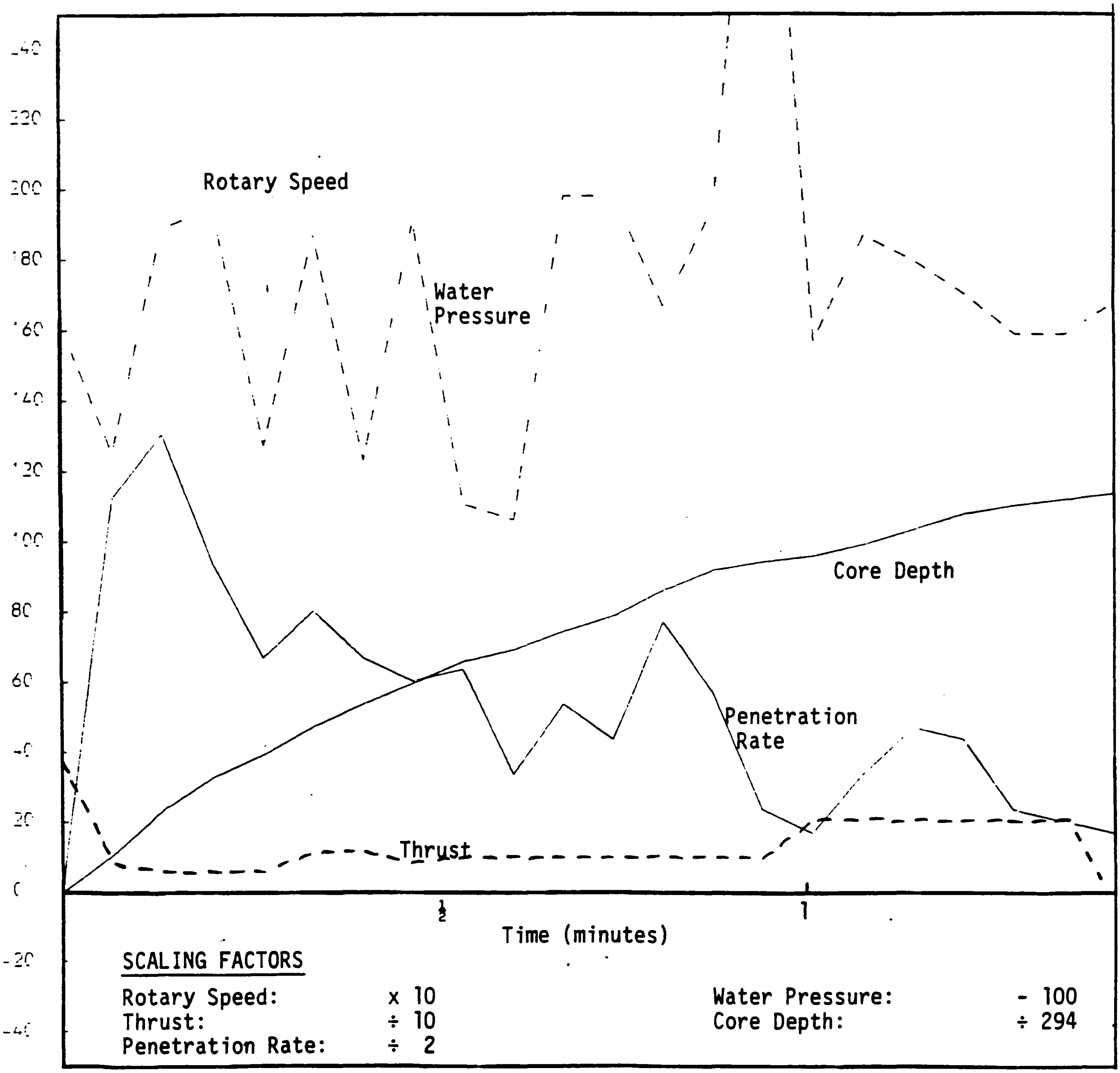
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME-	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (KN/M**2)
3155622	3.02	0.000	0.00	2139.24	3.79	2.20	61.13	99.99	6.37
3155626	3.06	0.037	56.15	1860.30	0.83	20.81	25.57	99.99	9.49
3155630	3.10	0.080	65.26	1895.17	0.57	17.93	89.25	99.99	9.36
3155634	3.13	0.112	46.85	1988.15	0.57	10.26	94.88	99.99	8.34
3155638	3.15	0.134	33.46	1979.43	0.57	10.98	27.38	99.99	6.15
3155642	3.18	0.161	40.16	1981.46	1.12	21.15	87.20	99.99	7.81
3155646	3.20	0.183	33.46	1958.12	1.12	22.87	23.19	99.99	7.68
3155650	3.22	0.203	30.12	1920.19	0.85	25.67	90.97	99.99	7.81
3155654	3.24	0.224	31.79	2019.38	0.99	18.35	10.69	99.99	7.49
3155658	3.26	0.235	16.73	2010.63	0.99	18.99	6.25	99.99	7.17
3155702	3.27	0.253	26.77	2007.71	0.99	19.21	98.50	99.99	7.87
3155706	3.29	0.268	21.75	1926.03	0.99	25.24	98.53	99.99	7.93
3155710	3.31	0.293	38.48	1911.44	0.99	26.32	67.17	99.99	8.64
3155714	3.33	0.312	28.44	2031.05	0.99	17.45	94.73	99.99	7.36
3155718	3.34	0.320	11.71	2040.69	0.98	18.26	253.14	99.99	6.90
3155722	3.35	0.326	8.37	1572.70	2.05	21.22	57.08	99.99	7.74
3155726	3.36	0.337	16.73	1961.03	2.05	22.09	87.20	99.99	7.68
3155730	3.37	0.352	23.42	1575.62	2.05	21.03	79.67	99.99	8.32
3155734	3.39	0.367	21.75	2042.72	2.04	16.02	70.32	99.99	7.61
3155738	3.39	0.375	11.71	1993.13	2.04	19.70	59.04	99.99	7.80
3155742	3.40	0.381	10.04	1998.96	2.04	19.27	59.04	99.99	7.93
3155746	3.41	0.387	8.37	916.63	4.71	99.70	68.44	99.99	5.43



RECORD OF CORSHAM DRILL RUN 3.3.2 (3.02 to 3.41 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.3.2 (3.02 to 3.41 metres)



USER: EXS069 -AT SYSTEM

NR_C3.4.1

EXS069

NR_C3.4.1

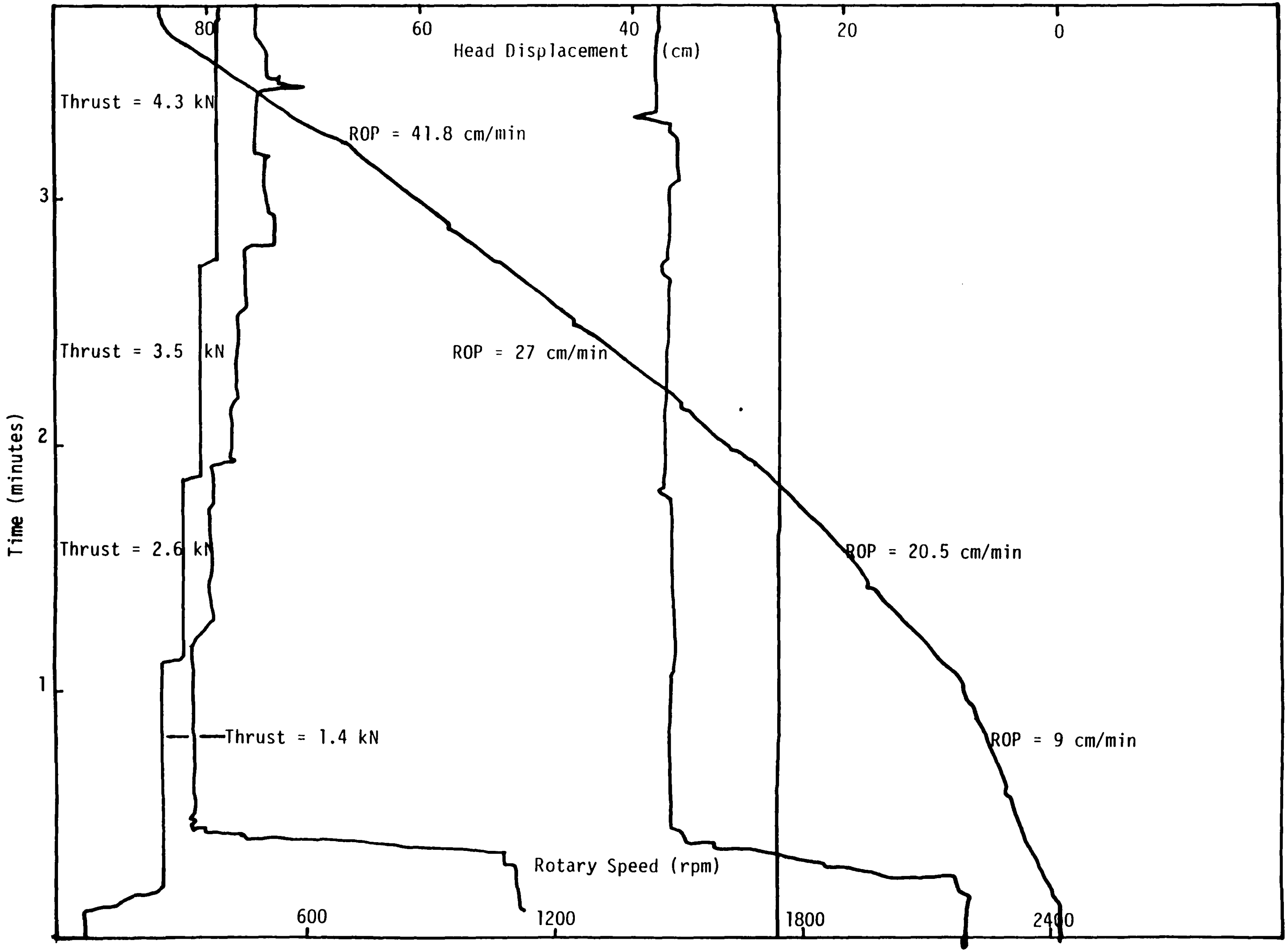
LABEL: FRTC16 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:20, CN: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

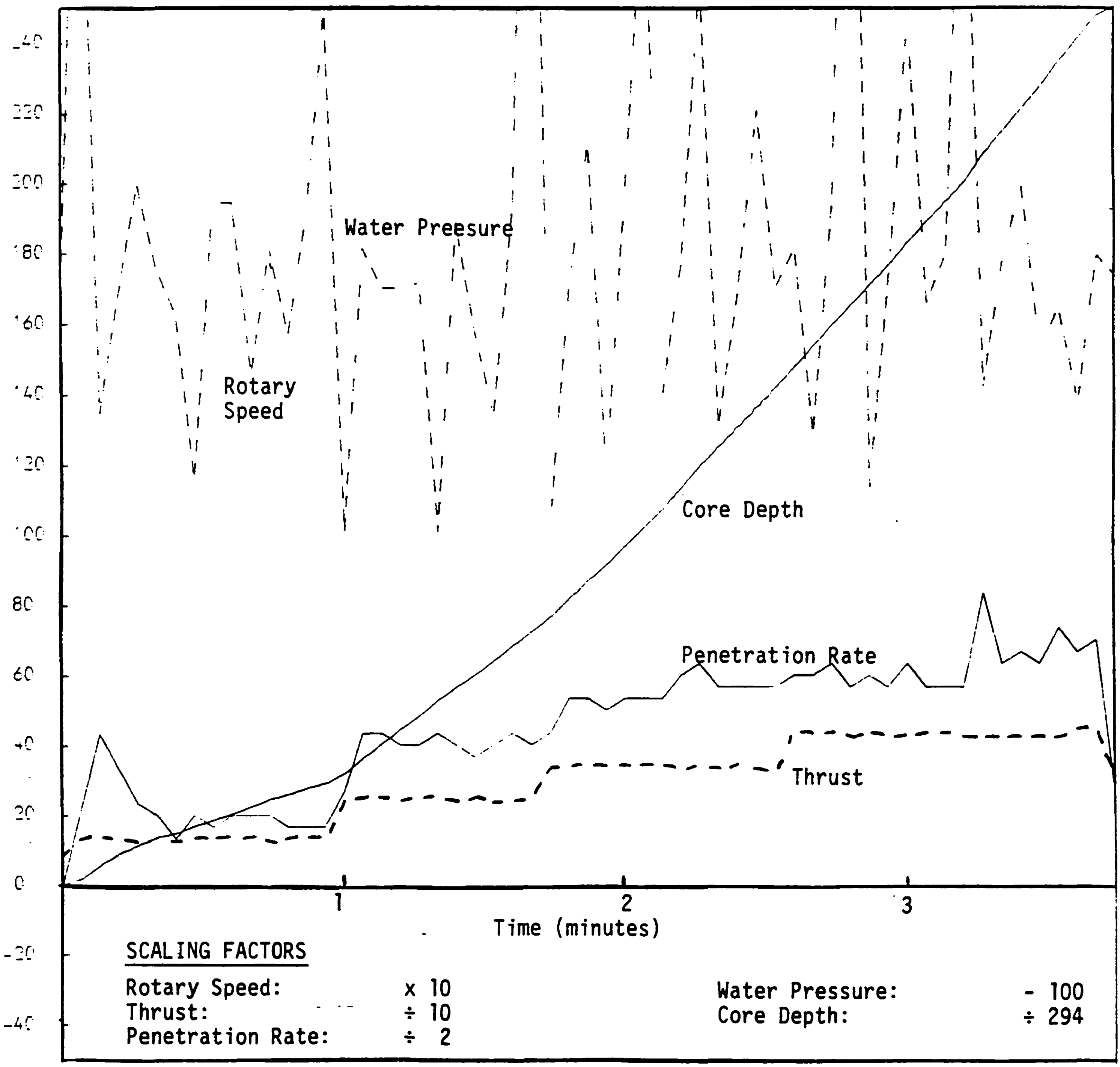
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4102258	3.41	0.000	0.00	2298.26	0.83	10.99	78.00	99.99	7.96
4102302	3.42	0.007	10.81	2155.90	1.36	6.55	246.35	99.99	8.66
4102306	3.43	0.021	21.75	1905.77	1.36	14.62	34.88	99.99	6.62
4102310	3.44	0.032	16.73	1675.99	1.36	24.50	68.63	99.99	4.39
4102314	3.45	0.040	11.71	1507.29	1.23	24.40	100.11	99.99	3.24
4102318	3.46	0.047	10.04	1475.30	1.36	21.26	76.13	99.99	2.99
4102322	3.46	0.051	6.69	1475.30	1.23	21.26	63.00	99.99	2.99
4102326	3.47	0.058	10.04	1469.48	1.36	22.00	16.13	99.99	2.99
4102330	3.47	0.064	8.37	1466.57	1.36	22.38	94.88	99.99	3.05
4102334	3.48	0.070	10.04	1465.13	1.36	25.93	94.88	99.99	3.12
4102338	3.49	0.077	10.04	1468.03	1.36	25.58	46.13	99.99	2.99
4102342	3.49	0.084	10.04	1466.57	1.23	22.38	81.75	99.99	2.99
4102346	3.50	0.089	8.37	1465.13	1.36	25.93	57.38	99.99	2.93
4102350	3.50	0.095	8.37	1468.03	1.36	25.58	91.13	99.99	2.93
4102354	3.51	0.100	8.37	1479.66	1.36	24.15	148.86	99.99	2.86
4102358	3.52	0.109	13.39	1497.09	2.42	22.00	1.13	99.99	4.07
4102402	3.53	0.124	21.75	1497.09	2.55	22.00	81.75	99.99	4.46
4102406	3.55	0.138	21.75	1497.09	2.55	22.00	70.50	99.99	4.33
4102410	3.56	0.152	20.08	1505.81	2.42	20.93	70.50	99.99	4.07
4102414	3.58	0.165	20.08	1488.37	2.55	23.08	71.99	99.99	4.33
4102418	3.59	0.180	21.75	1500.00	2.55	21.65	1.13	99.99	4.26
4102422	3.60	0.193	20.08	1497.09	2.42	22.00	89.25	99.99	4.20
4102426	3.62	0.205	18.40	1500.00	2.55	21.65	57.38	99.99	4.01
4102430	3.63	0.219	20.08	1488.37	2.42	23.08	34.49	99.99	4.58
4102434	3.64	0.233	21.75	1497.09	2.42	22.00	93.00	99.99	4.26
4102438	3.66	0.247	20.08	1502.90	2.55	21.29	298.85	99.99	4.20
4102442	3.67	0.261	21.75	1491.28	3.34	22.72	4.88	99.99	5.16
4102446	3.69	0.279	26.77	1500.00	3.47	21.65	70.50	99.99	5.60
4102450	3.71	0.296	26.77	1517.43	3.47	19.50	111.36	99.99	5.48
4102454	3.72	0.312	25.10	1511.62	3.47	20.22	18.00	99.99	5.41
4102458	3.74	0.330	26.77	1508.71	3.47	20.58	100.11	99.99	5.92
4102502	3.76	0.348	26.77	1511.62	3.47	20.22	186.36	99.99	5.73
4102506	3.78	0.366	26.77	1497.09	3.47	22.00	40.50	99.99	5.86
4102510	3.80	0.386	30.12	1502.90	3.34	21.29	78.00	99.99	5.86
4102514	3.82	0.407	31.79	1505.81	3.47	20.93	158.23	99.99	5.92
4102518	3.84	0.426	28.44	1494.18	3.34	22.36	31.13	99.99	6.37
4102522	3.86	0.445	28.44	1500.00	3.47	21.65	68.63	99.99	5.92
4102526	3.87	0.464	28.44	1494.18	3.34	22.36	120.74	99.99	6.05
4102530	3.89	0.483	28.44	1502.90	3.34	21.29	70.50	99.99	6.11
4102534	3.91	0.503	30.12	1468.03	4.40	25.58	81.75	99.99	7.32
4102538	3.93	0.523	30.12	1514.52	4.40	19.86	28.87	99.99	7.26
4102542	3.95	0.544	31.79	1526.15	4.40	18.43	94.88	99.99	6.94
4102546	3.97	0.563	28.44	1526.15	4.27	18.43	323.22	99.99	6.62
4102550	3.99	0.583	30.12	1523.24	4.40	18.79	13.87	99.99	6.75
4102554	4.01	0.602	28.44	1505.81	4.27	20.93	74.25	99.99	6.94
4102558	4.03	0.624	31.79	1520.33	4.27	19.15	146.98	99.99	6.69
4102602	4.05	0.644	28.44	1505.81	4.40	20.93	66.36	99.99	6.37
4102606	4.07	0.663	28.44	1502.90	4.40	21.29	79.88	99.99	6.24
4102610	4.09	0.682	28.44	1473.84	4.27	24.86	225.73	99.99	6.69
4102614	4.12	0.709	41.83	1476.75	4.27	24.50	42.38	99.99	6.75
4102618	4.14	0.731	31.79	1476.75	4.27	24.50	78.00	99.99	6.81
4102622	4.16	0.753	33.46	1488.37	4.27	23.08	100.11	99.99	6.30
4102626	4.18	0.774	31.79	1479.66	4.27	24.15	53.63	99.99	6.30
4102630	4.21	0.799	36.81	1482.56	4.27	23.79	64.88	99.99	6.18

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
4102634	4.23	0.821	33.46	1491.31	4.53	15.41	38.24	99.99	5.79
4102638	4.25	0.844	35.14	1656.90	4.53	2.36	79.88	99.99	5.86
4102642	4.26	0.853	13.39	32.67	3.12	188.38	74.02	99.99	-1.28



RECORD OF CORSHAM DRILL RUN 3.4.1 (3.41 to 4.26 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.4.1 (3.41 to 4.26 metres)



USER: EX9069 -AT SYSTEM

NF_C3.4.2

LABEL: FRTC17 -FORM

SPOOLED: 82-03-10.15:14
STARTED: 82-03-10.15:20, ON: FRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4102806	4.26	0.000	0.00	1500.09	1.78	28.91	58.96	95.59	3.07
4102810	4.27	0.011	16.94	1511.76	1.65	27.60	1.28	95.99	3.39
4102814	4.28	0.020	13.39	1520.52	1.78	26.61	32.61	95.99	2.94
4102818	4.29	0.027	10.04	1517.60	1.65	26.94	83.44	95.99	2.81
4102822	4.29	0.031	6.69	1517.60	1.65	26.94	19.43	95.99	2.81
4102826	4.30	0.036	6.69	1520.52	1.65	26.61	65.28	99.99	2.69
4102830	4.30	0.045	13.39	1503.01	2.84	28.59	81.55	99.99	3.84
4102834	4.32	0.062	26.77	1535.10	2.84	24.97	291.18	99.99	4.29
4102838	4.34	0.080	26.77	1526.35	2.84	25.95	15.66	99.99	4.29
4102842	4.36	0.096	23.42	1047.91	3.71	81.95	61.34	99.99	4.14

USER: EX9069 -AT SYSTEM

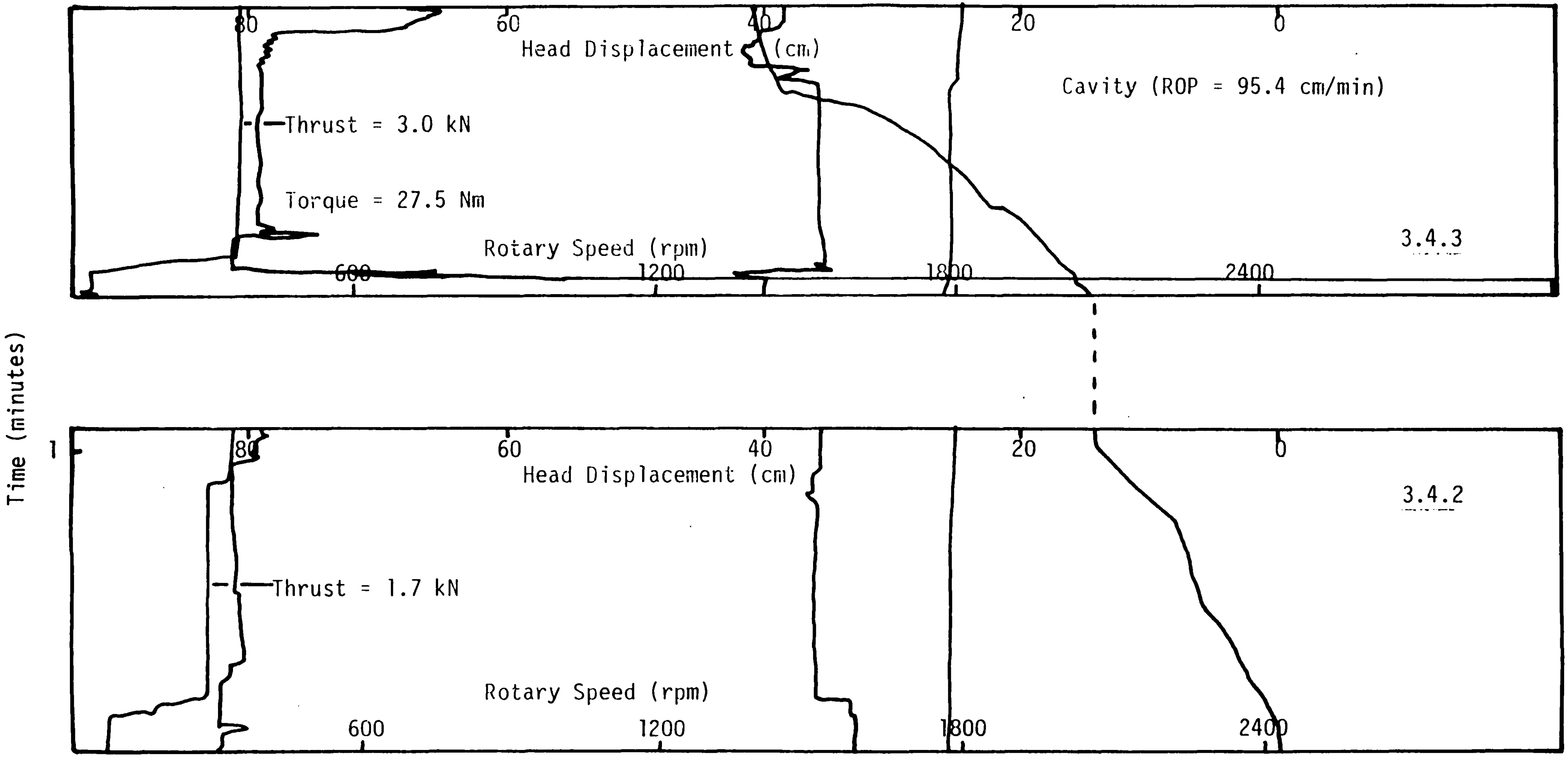
NR_C3.4.3

LABEL: PRT018 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:20, ON: PRO BY: PRO

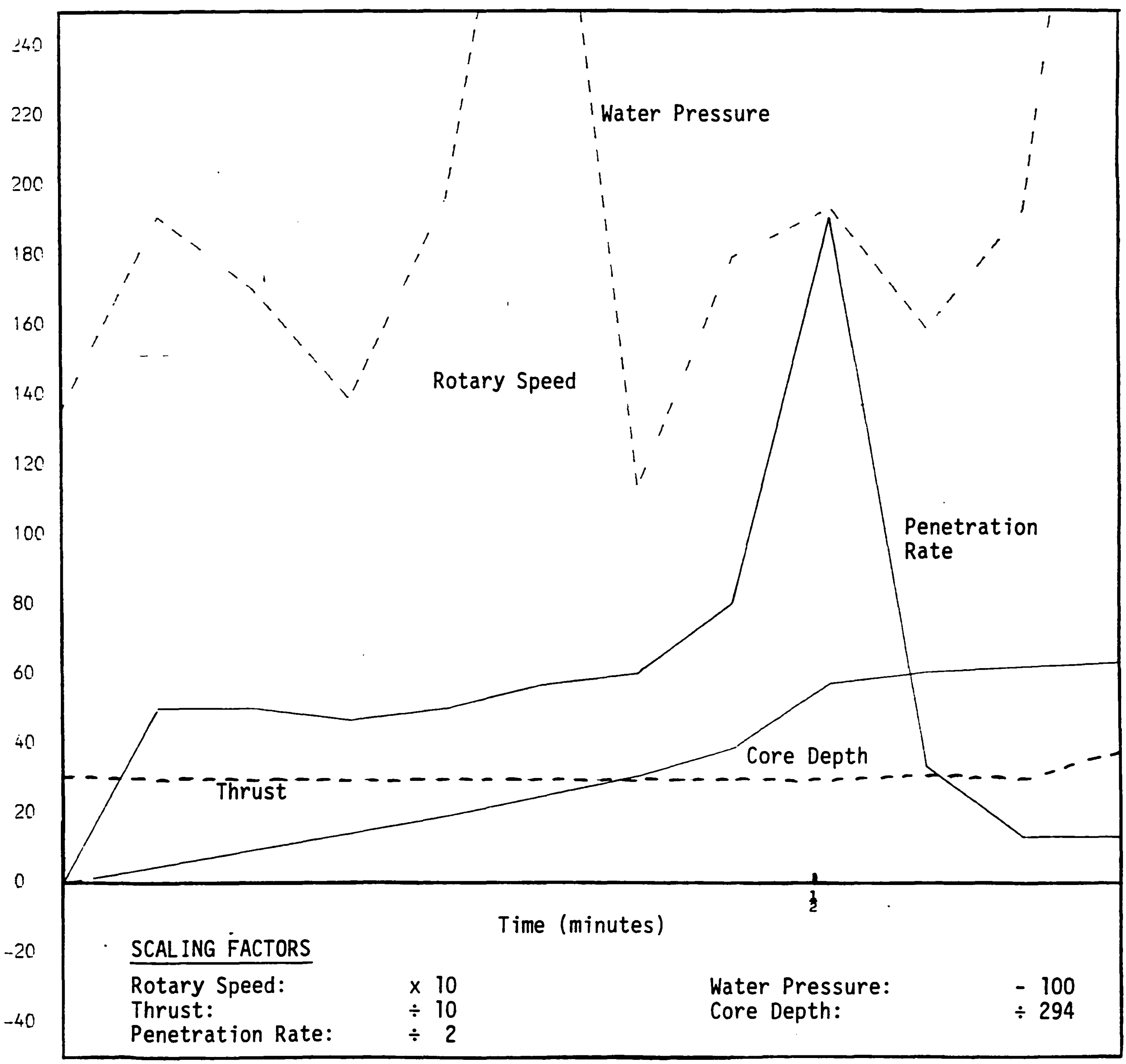
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4102924	4.36	0.000	0.00	1517.60	3.11	26.94	36.37	99.99	4.16
4102928	4.38	0.017	25.10	1514.68	2.98	27.27	90.97	99.99	4.48
4102932	4.39	0.033	25.10	1511.76	2.98	27.60	70.26	99.99	4.22
4102936	4.41	0.049	23.42	1514.68	2.98	27.27	38.93	99.99	4.22
4102940	4.43	0.066	25.10	1505.93	2.98	28.26	96.61	99.99	4.41
4102944	4.44	0.085	26.44	1514.68	2.98	27.27	247.89	99.99	4.16
4102948	4.46	0.105	30.12	1500.09	2.98	28.91	13.78	99.99	3.97
4102952	4.49	0.132	40.16	1456.33	2.98	33.85	79.67	99.99	4.29
4102956	4.56	0.155	95.27	1357.14	2.98	45.03	93.52	99.99	7.68
4103000	4.57	0.206	16.73	1397.99	3.11	40.42	58.96	99.99	9.47
4103004	4.57	0.211	6.69	1462.17	2.98	33.19	92.85	99.99	6.46
4103008	4.58	0.215	6.69	41.42	3.79	193.34	283.65	99.99	-0.77



RECORD OF CORSHAM DRILL RUNS 3.4.2 (4.26 to 4.36 metres) AND 3.4.3 (4.36 to 4.58 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.4.3 (4.36 to 4.58)



USER: EX9069 -AT SYSTEM

NR_C3.5

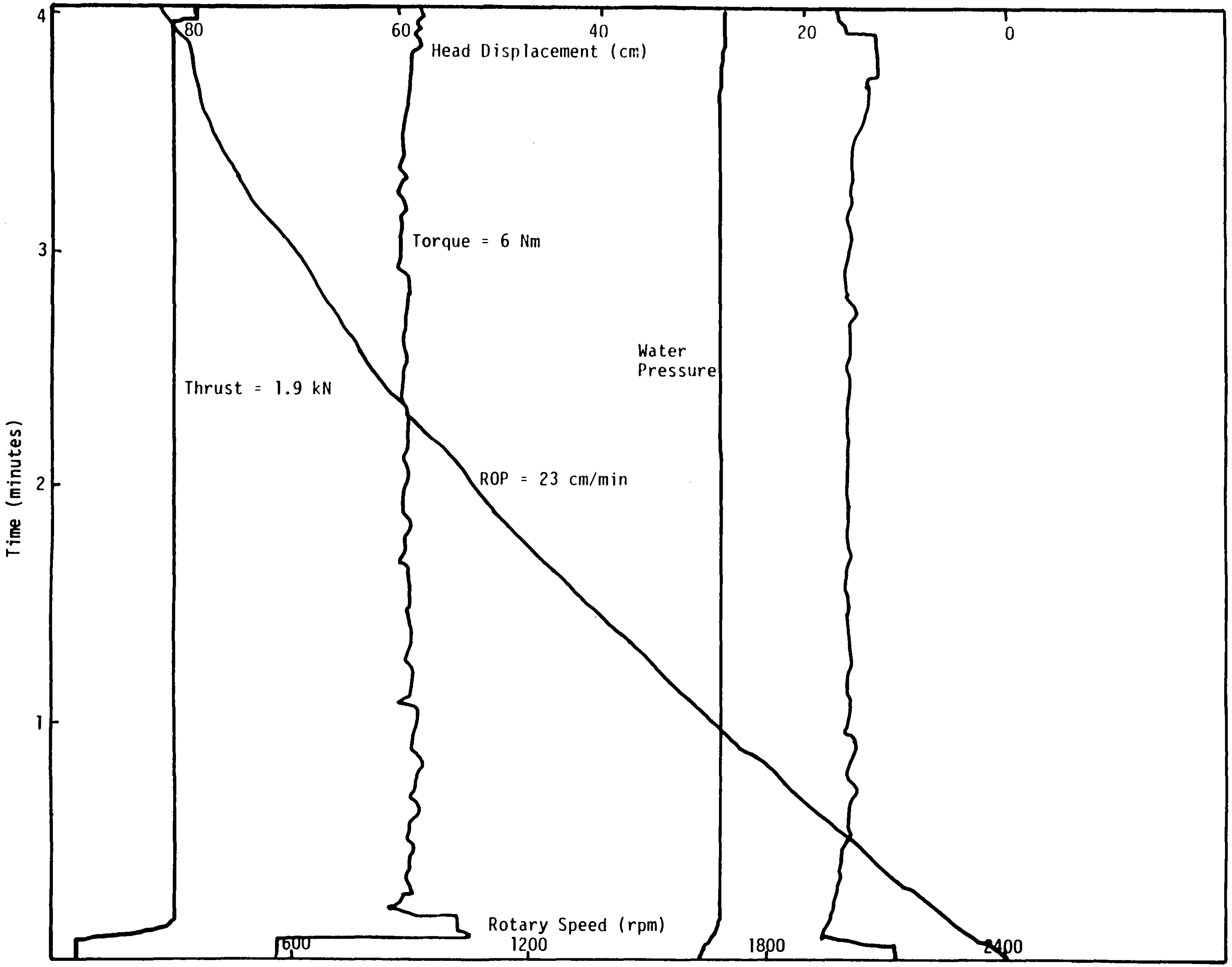
LABEL: PRT019 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:20, ON: PR0 BY: PRC

OXFORD POLYTECHNIC COMPUTER CENTRE

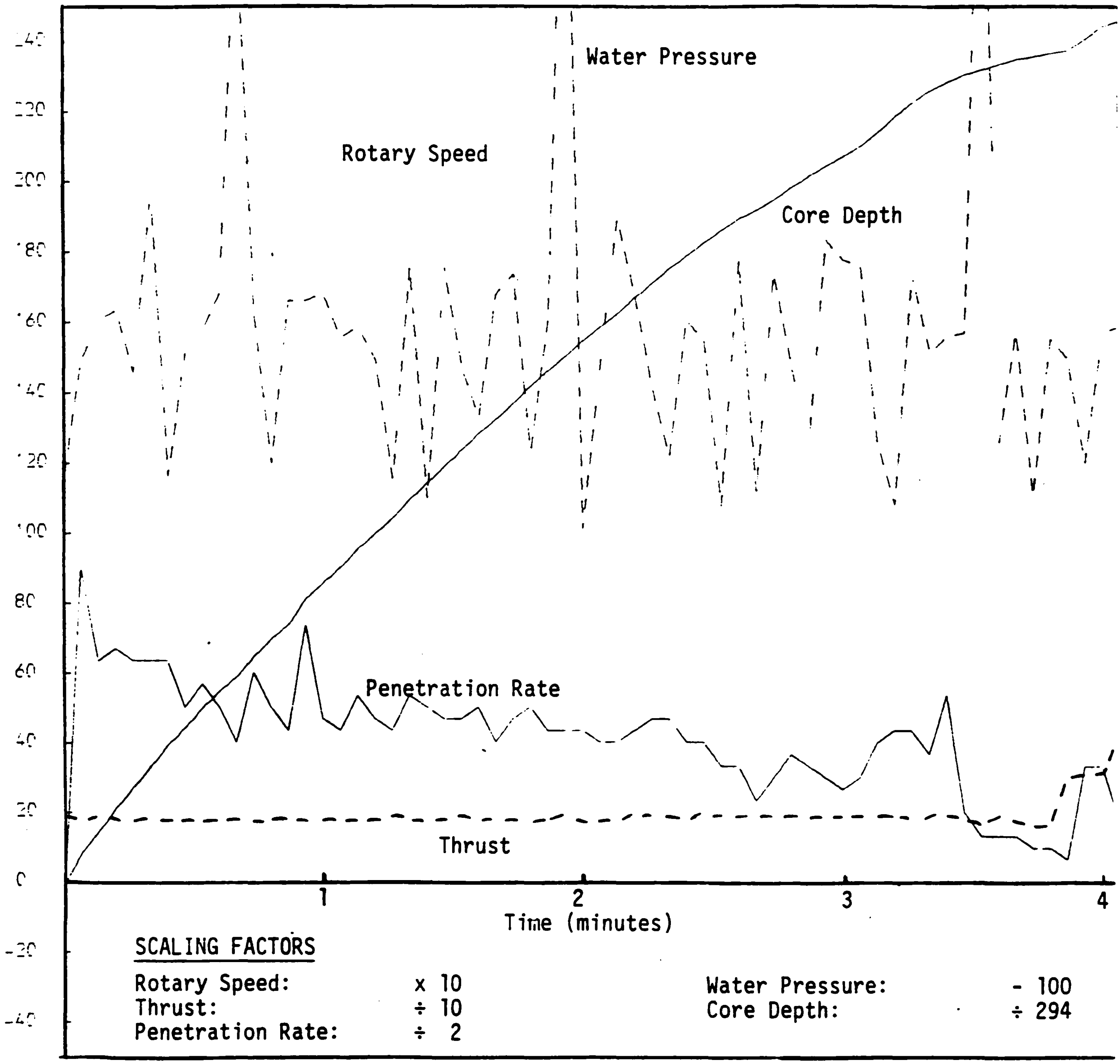
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (KN/M**2)
4105532	4.56	0.000	0.00	1961.03	1.92	13.17	17.55	4.87	10.11
4105536	4.61	0.030	45.10	2031.05	1.78	12.72	49.55	4.87	10.43
4105540	4.63	0.051	31.75	2001.88	1.92	14.98	60.84	4.87	10.17
4105544	4.65	0.074	33.46	2031.05	1.78	12.72	63.40	4.87	9.98
4105548	4.67	0.094	31.79	2042.72	1.78	11.81	45.78	4.87	9.60
4105552	4.69	0.114	31.79	2036.89	1.78	6.95	97.29	3.42	10.05
4105556	4.71	0.135	31.79	2066.06	1.78	4.56	16.34	4.87	9.60
4105600	4.73	0.152	25.10	2036.89	1.78	12.27	51.43	4.87	9.34
4105604	4.75	0.171	28.44	2060.06	1.78	4.56	57.75	4.87	9.28
4105608	4.77	0.187	25.10	2083.56	1.78	3.13	68.38	4.87	9.02
4105612	4.78	0.201	20.08	2045.64	1.78	6.24	180.12	4.87	8.96
4105616	4.80	0.221	30.12	2063.14	1.78	4.80	62.73	4.87	9.21
4105620	4.82	0.238	25.10	2086.48	1.78	2.89	20.1[illegible]	4.87	8.83
4105624	4.83	0.252	21.75	2033.97	1.78	7.19	66.49	4.87	8.77
4105628	4.86	0.277	36.81	2060.22	1.78	5.04	66.49	4.87	9.02
4105632	4.87	0.292	23.42	2071.89	1.78	4.09	68.38	4.87	8.96
4105636	4.89	0.307	21.75	2025.22	1.78	7.91	55.87	4.87	9.34
4105640	4.90	0.325	26.77	2060.22	1.78	5.04	58.96	3.42	9.15
4105644	4.92	0.340	23.42	2060.22	1.78	5.04	49.55	3.42	8.96
4105648	4.93	0.355	21.75	2031.05	1.92	7.43	15.66	3.42	9.21
4105652	4.95	0.373	26.77	2045.64	1.78	6.24	75.91	3.42	9.15
4105656	4.97	0.389	25.10	2051.47	1.78	5.76	10.02	3.42	9.09
4105700	4.98	0.405	23.42	2025.22	1.78	7.91	75.91	3.42	9.09
4105704	5.00	0.421	23.42	2042.72	1.92	6.48	47.67	3.42	9.34
4105708	5.02	0.437	25.10	2051.47	1.78	5.76	33.28	3.42	9.21
4105712	5.03	0.451	20.08	2045.64	1.78	6.24	68.38	3.42	8.70
4105716	5.05	0.466	23.42	2028.13	1.78	7.67	74.02	3.42	9.34
4105720	5.06	0.483	25.10	2045.64	1.78	6.24	23.87	3.42	9.09
4105724	5.08	0.498	21.75	2063.14	1.78	4.80	60.84	3.42	8.77
4105728	5.09	0.512	21.75	2031.05	1.92	7.43	236.59	3.42	9.09
4105732	5.11	0.527	21.75	2068.98	1.78	4.33	1.28	3.42	8.64
4105736	5.12	0.540	20.08	2063.14	1.78	4.80	47.67	3.42	8.64
4105740	5.13	0.553	20.08	2057.31	1.78	5.28	89.76	3.42	8.64
4105744	5.15	0.568	21.75	2033.97	1.92	7.19	68.38	3.42	9.09
4105748	5.16	0.583	23.42	2045.64	1.92	6.24	42.02	3.42	8.77
4105752	5.18	0.597	23.42	2066.06	1.92	4.56	21.99	3.42	8.57
4105756	5.19	0.609	20.08	2045.64	1.78	6.24	60.84	3.42	8.57
4105800	5.20	0.622	20.08	2057.31	1.92	5.28	55.20	3.42	8.83
4105804	5.21	0.634	16.73	2068.98	1.92	4.33	8.13	3.42	8.38
4105808	5.22	0.645	16.73	2077.73	1.92	3.61	77.79	3.42	8.38
4105812	5.23	0.653	11.71	2083.56	1.92	3.13	11.90	3.42	8.06
4105816	5.24	0.663	15.06	2025.22	1.92	7.91	74.02	3.42	8.57
4105820	5.25	0.675	18.40	2048.56	1.92	6.00	47.67	3.42	8.77
4105824	5.27	0.686	16.73	2045.64	1.92	6.24	25.08	3.42	8.51
4105828	5.28	0.696	15.06	2057.31	1.92	5.28	83.44	3.42	8.45
4105832	5.28	0.705	13.39	2068.98	1.92	4.33	77.79	3.42	8.13
4105836	5.30	0.715	15.06	2028.13	1.92	7.67	75.91	3.42	8.57
4105840	5.31	0.728	20.08	2071.89	1.92	4.09	25.75	3.42	8.38
4105844	5.32	0.743	21.75	2057.31	1.92	5.28	8.13	3.42	8.32
4105848	5.34	0.757	21.75	2063.14	1.78	4.80	74.02	3.42	8.06
4105852	5.35	0.769	18.40	2063.14	1.92	4.80	51.43	3.42	8.19
4105856	5.36	0.777	26.77	2089.40	1.92	2.65	55.87	3.42	7.81
4105900	5.36	0.784	10.04	2098.15	1.78	1.94	57.08	3.42	7.61
4105904	5.37	0.785	6.69	2103.98	1.65	1.46	236.59	3.42	7.42

	TOTAL	CORE	PENETRATN	ROTARY			INLET H20	I. H20	
4105908	5.37	0.754	6.69	2118.57	1.92	0.26	25.75	3.42	7.29
4105912	5.38	0.799	6.69	2109.82	1.78	0.98	57.08	3.42	7.36
4105916	5.38	0.802	5.02	2112.74	1.65	0.74	10.69	3.42	7.10
4105920	5.39	0.805	5.02	2138.99	1.65	1.41	55.20	3.42	7.17
4105924	5.39	0.808	3.35	2031.05	2.98	7.43	49.55	3.42	6.91
4105928	5.40	0.819	16.73	1998.96	3.11	10.06	20.10	3.42	9.09
4105932	5.41	0.831	16.73	2007.71	3.11	9.34	57.08	3.42	8.77
4105936	5.42	0.837	8.37	315.65	4.18	145.94	58.96	3.42	-0.90



RECORD OF CORSHAM DRILL RUN 3.5 (4.58 to 5.42 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.5 (4.58 to 5.42 metres)



USER: EX5069 -AT SYSTEM

NP_C3.6.1

EX5069

NP_C3.6.1

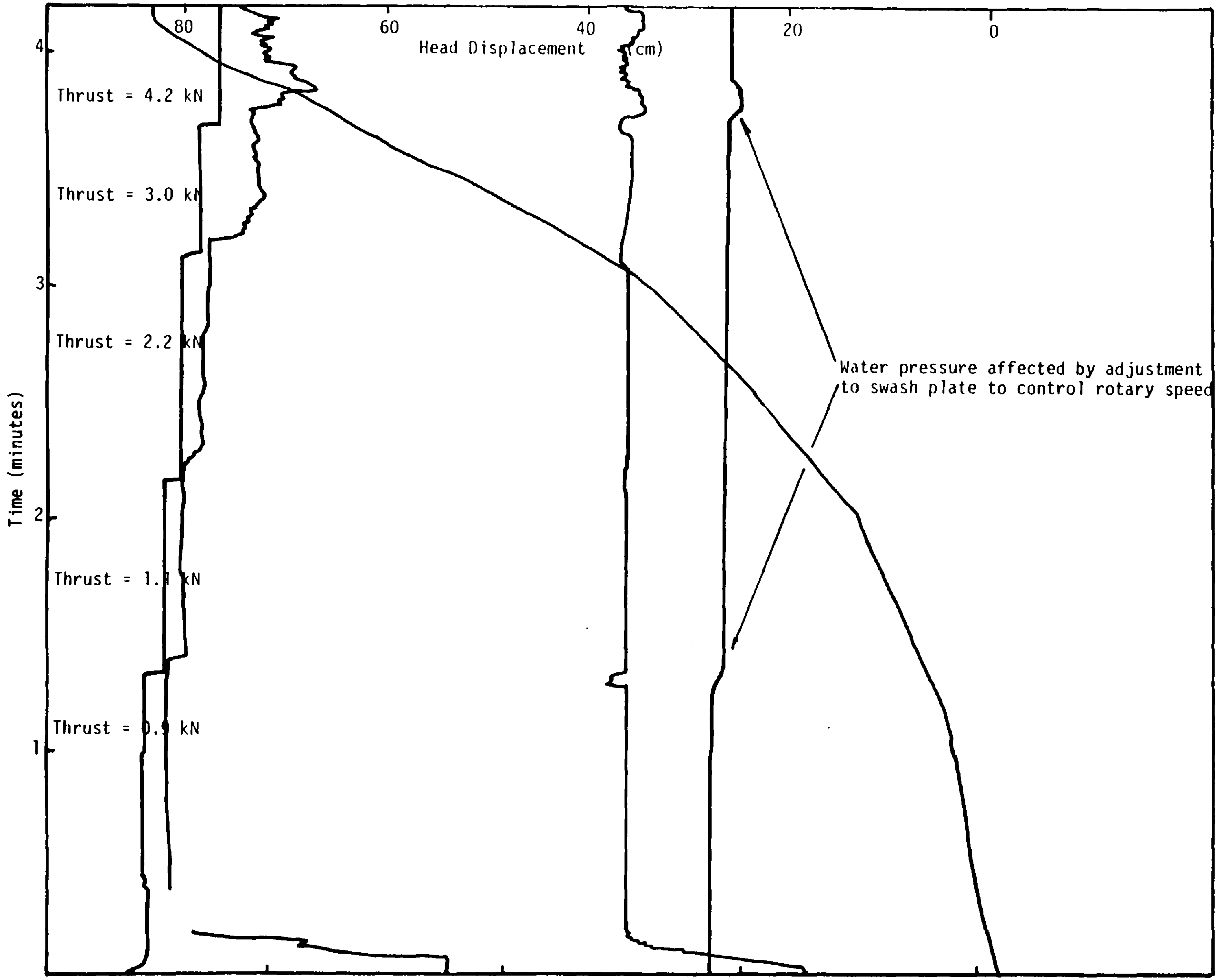
LABEL: PRT020 -FORM

SPOOLED: 82-03-10.15:14
STARTED: 82-03-10.15:21, ON: FRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

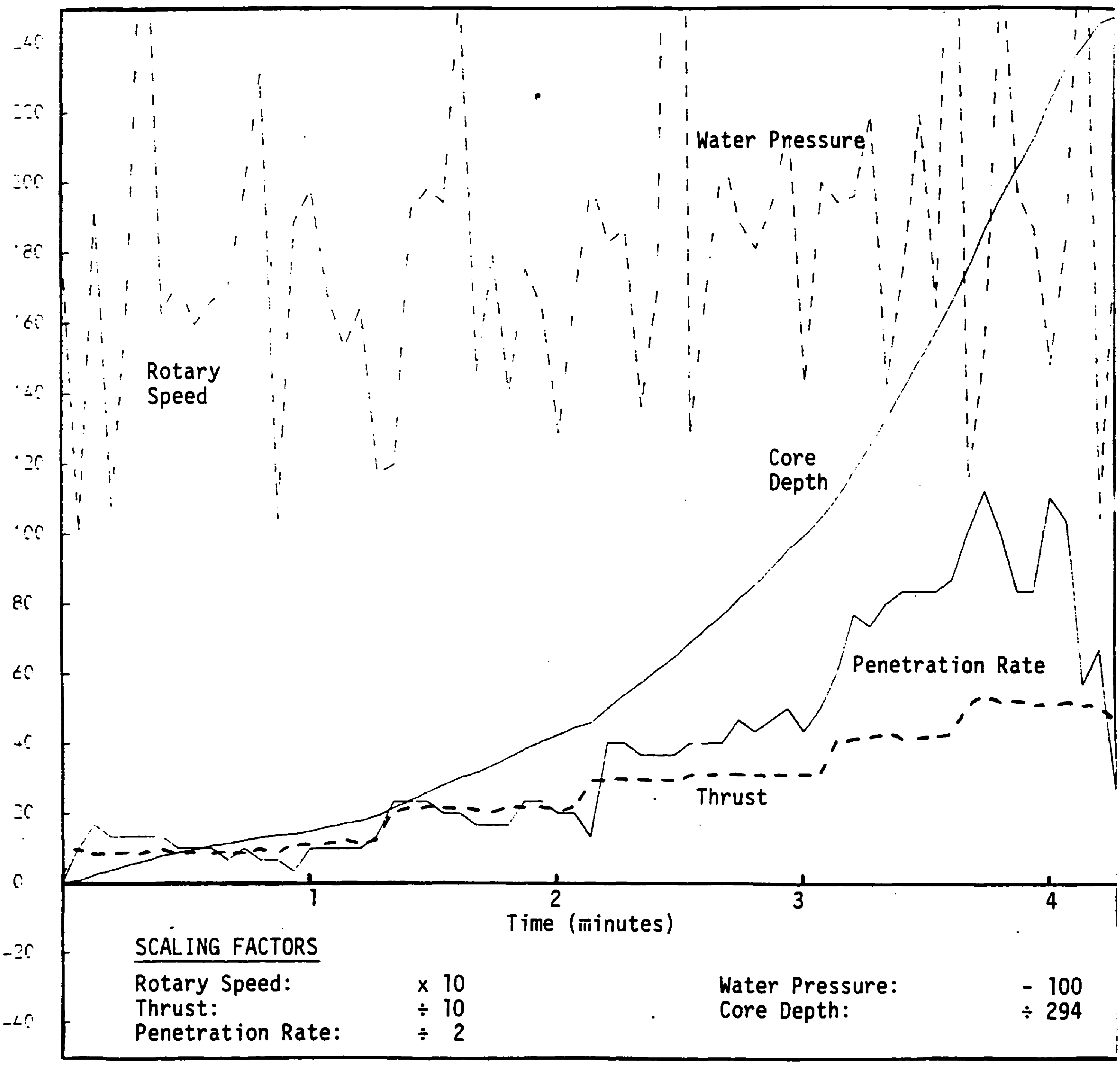
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4111620	5.42	0.000	0.00	2174.00	0.21	1.62	79.67	95.99	7.42
4111624	5.42	0.003	5.02	1927.94	0.99	18.52	0.60	95.99	6.46
4111628	5.43	0.005	8.37	1610.95	0.85	41.84	92.85	95.99	3.97
4111632	5.43	0.013	6.69	1488.43	0.85	35.77	6.93	95.99	3.20
4111636	5.44	0.018	6.69	1488.43	0.85	35.77	72.14	95.99	3.13
4111640	5.44	0.022	6.69	1491.34	0.85	35.46	200.82	95.99	3.13
4111644	5.45	0.027	6.69	1494.26	0.99	35.16	62.73	99.99	3.07
4111648	5.45	0.030	5.02	1497.18	0.85	34.85	72.14	99.99	2.94
4111652	5.45	0.033	5.02	1497.18	0.85	34.85	59.64	99.99	2.81
4111656	5.46	0.037	5.02	1497.18	0.85	34.85	66.49	99.99	2.81
4111700	5.46	0.039	3.35	1497.18	0.85	34.85	70.26	99.99	2.81
4111704	5.46	0.042	5.02	1500.09	0.85	34.55	98.50	99.99	2.75
4111708	5.46	0.045	3.35	1503.01	0.99	34.24	131.17	99.99	2.75
4111712	5.47	0.047	3.35	1503.01	0.85	34.24	4.37	99.99	2.75
4111716	5.47	0.048	1.67	1497.18	1.12	34.85	89.08	95.99	2.75
4111720	5.47	0.051	5.02	1497.18	1.12	34.85	98.50	99.99	2.81
4111724	5.47	0.055	5.02	1494.26	1.12	35.16	68.38	99.99	2.88
4111728	5.48	0.058	5.02	1491.34	1.25	35.46	53.31	95.99	3.01
4111732	5.48	0.061	5.02	1491.34	1.12	35.46	64.61	99.99	3.07
4111736	5.49	0.066	6.69	1485.51	1.25	36.08	17.55	95.99	3.20
4111740	5.49	0.074	11.71	1535.10	2.05	30.88	20.10	95.99	3.84
4111744	5.50	0.081	11.71	1523.43	2.18	32.10	92.85	95.99	3.90
4111748	5.51	0.089	11.71	1520.52	2.18	32.41	98.50	95.99	3.90
4111752	5.52	0.096	10.04	1523.43	2.18	32.10	94.73	95.99	3.77
4111756	5.52	0.103	10.04	1529.27	2.18	31.49	155.64	99.99	3.65
4111800	5.53	0.108	8.37	1526.35	2.05	31.79	46.46	99.99	3.71
4111804	5.53	0.115	8.37	1517.60	2.05	32.71	79.67	99.99	3.84
4111808	5.54	0.123	8.37	1517.60	2.18	32.71	40.81	99.99	3.90
4111812	5.55	0.131	11.71	1523.43	2.18	32.10	75.91	99.99	3.71
4111816	5.56	0.138	11.71	1520.52	2.18	32.41	64.61	99.99	3.65
4111820	5.56	0.145	10.04	1523.43	2.05	32.10	28.84	99.99	3.71
4111824	5.57	0.152	10.04	1532.19	2.18	31.18	68.38	99.99	3.45
4111828	5.58	0.157	6.69	1500.09	2.98	34.55	100.38	95.99	4.03
4111832	5.59	0.171	20.08	1520.52	2.98	32.41	83.44	95.59	5.18
4111836	5.60	0.184	20.08	1535.10	2.98	30.88	87.20	95.99	4.99
4111840	5.62	0.196	18.40	1540.94	2.98	30.27	36.37	95.59	4.93
4111844	5.63	0.209	18.40	1532.19	2.98	31.18	70.26	95.99	4.67
4111848	5.64	0.221	18.40	1526.35	2.98	31.79	447.19	95.99	9.99
4111852	5.66	0.235	20.08	1532.19	3.11	31.18	28.84	95.99	5.12
4111856	5.67	0.249	20.08	1535.10	3.11	30.88	70.26	99.99	4.93
4111900	5.68	0.262	20.08	1520.52	3.11	32.41	108.58	99.99	5.12
4111904	5.70	0.278	23.42	1526.35	3.11	31.79	89.08	99.99	5.37
4111908	5.71	0.292	21.75	1520.52	3.11	32.41	81.55	99.99	5.44
4111912	5.73	0.308	23.42	1517.60	3.11	32.71	94.73	99.99	5.12
4111916	5.74	0.325	25.10	1517.60	3.11	32.71	116.11	99.99	5.50
4111920	5.76	0.339	21.75	1523.43	3.11	32.10	42.69	99.99	5.37
4111924	5.78	0.356	25.10	1514.68	3.11	33.02	100.38	99.99	5.12
4111928	5.80	0.376	30.12	1465.09	4.04	38.22	94.73	99.99	6.85
4111932	5.82	0.402	38.48	1505.93	4.17	33.94	96.61	99.99	7.49
4111936	5.85	0.426	36.81	1532.19	4.17	31.18	119.88	95.99	8.19
4111940	5.87	0.453	40.16	1543.85	4.30	29.96	42.69	99.99	7.61
4111944	5.90	0.481	41.83	1546.77	4.17	29.65	75.91	95.99	7.81
4111948	5.93	0.509	41.83	1540.94	4.17	30.27	119.88	95.99	7.49
4111952	5.96	0.537	41.83	1546.77	4.17	29.65	64.61	95.99	7.55

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
4111956	5.99	0.566	43.50	1532.19	4.30	31.18	238.47	99.99	7.29
4112000	6.02	0.599	50.20	1488.43	5.10	35.77	15.66	99.99	8.83
4112004	6.06	0.626	56.15	1590.53	5.36	25.07	53.31	99.99	10.68
4112008	6.09	0.668	50.20	1529.27	5.23	31.49	165.36	99.99	9.34
4112012	6.12	0.696	41.83	1511.76	5.23	33.32	96.61	99.99	8.00
4112016	6.14	0.724	41.83	1468.00	5.10	37.91	87.20	99.99	7.49
4112020	6.18	0.761	55.22	1485.51	5.10	36.08	48.34	99.99	7.93
4112024	6.22	0.795	51.87	1552.61	5.23	29.04	87.20	99.99	6.97
4112028	6.23	0.814	28.44	1581.78	5.10	25.98	206.47	99.99	6.21
4112032	6.26	0.837	33.46	1561.36	5.10	28.12	4.37	99.99	7.10
4112036	6.26	0.844	11.71	163.39	4.58	180.16	93.00	95.99	-1.09



RECORD OF CORSHAM DRILL RUN 3.6.1 (5.42 to 6.26 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.6.1 (5.42 to 6.26 metres)



USER: EX9069 -AT SYSTEM

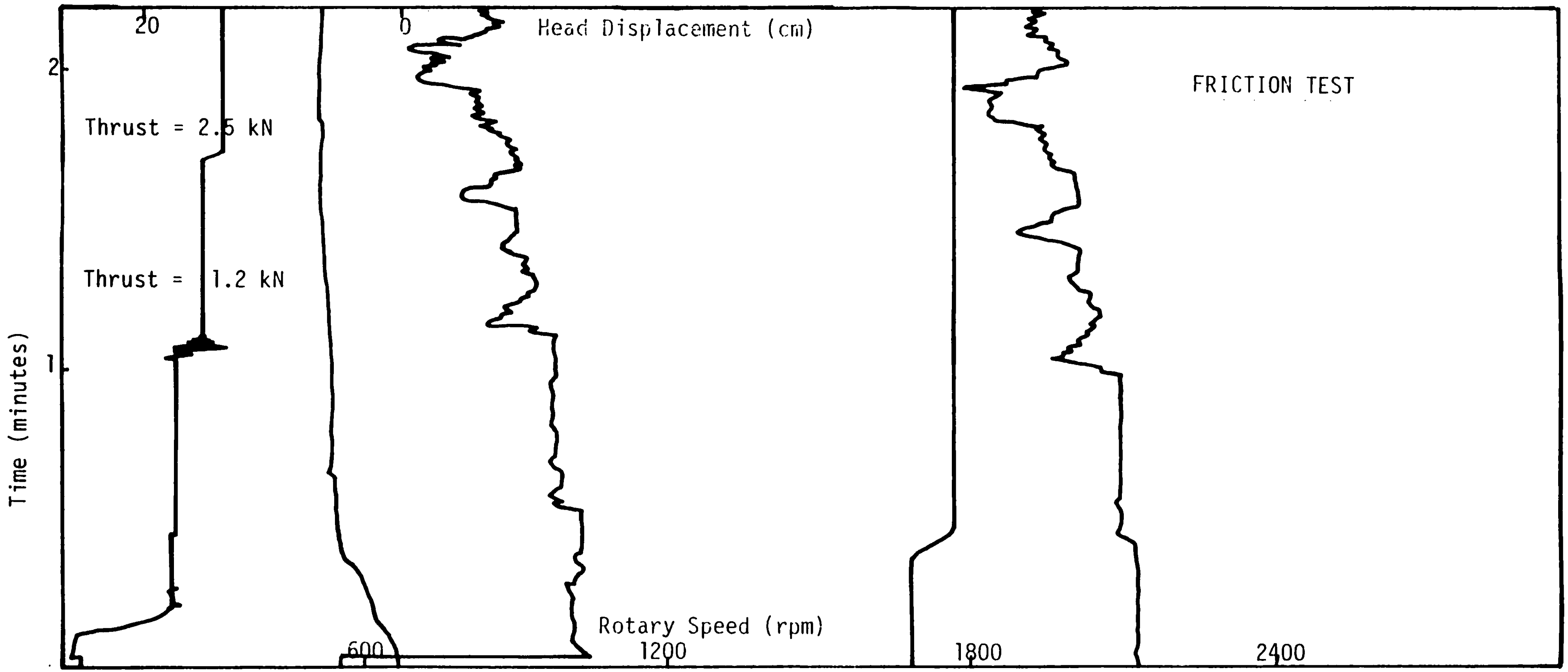
NP_C3.6.2

LABEL: PRT021 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:21, ON: PRO BY: PRO

OXFORD POLYTECHNIC COMPUTER CENTRE

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4114616	6.26	0.000	0.00	2146.40	4.18	16.15	0.69	99.99	7.61
4114620	6.26	0.001	1.67	2150.09	0.48	12.96	85.46	99.99	7.72
4114624	6.27	0.015	20.08	2150.09	0.18	5.63	23.40	99.99	7.52
4114628	6.29	0.027	18.40	2158.81	0.44	13.74	61.06	99.99	7.72
4114632	6.29	0.035	11.71	2167.54	0.31	14.52	64.81	99.99	7.72
4114636	6.30	0.040	8.37	2167.54	0.04	14.52	68.56	3.42	7.65
4114640	6.31	0.047	10.04	2144.83	0.57	23.73	124.74	3.42	7.52
4114644	6.32	0.059	18.40	2123.91	0.18	10.61	59.18	99.99	8.23
4114648	6.32	0.060	1.67	2086.10	0.57	7.22	66.69	3.42	8.03
4114652	6.32	0.061	1.67	2112.27	0.18	9.56	17.77	99.99	8.35
4114656	6.32	0.062	1.67	2089.01	0.18	7.48	64.81	99.99	8.23
4114700	6.32	0.062	0.00	2115.18	0.18	9.83	10.38	99.99	8.03
4114704	6.32	0.064	1.67	2109.37	0.44	9.30	66.69	99.99	8.10
4114708	6.32	0.065	1.67	2109.37	0.57	9.30	134.13	99.99	8.03
4114712	6.32	0.065	0.00	2109.37	0.31	9.30	21.52	99.99	8.03
4114716	6.33	0.066	1.67	2042.47	1.23	3.30	61.06	99.99	8.23
4114720	6.33	0.067	1.67	2030.83	1.23	2.26	235.48	99.99	9.69
4114724	6.33	0.067	1.67	2086.10	1.23	7.22	74.19	99.99	8.74
4114728	6.33	0.068	1.67	2057.01	1.23	4.61	74.19	99.99	8.48
4114732	6.33	0.068	0.00	1998.84	1.37	0.61	79.82	99.99	9.05
4114736	6.33	0.069	1.67	2045.38	1.37	3.56	30.91	99.99	9.12
4114740	6.33	0.069	0.00	1995.93	1.76	0.87	79.82	99.99	8.93
4114744	6.33	0.070	1.67	1937.76	1.50	6.09	27.15	99.99	10.91
4114748	6.33	0.070	0.00	2054.10	1.23	4.35	83.46	99.99	9.57
4114752	6.33	0.071	1.67	2022.11	1.23	1.48	32.91	99.99	8.99
4114756	6.33	0.073	1.67	1966.85	2.42	3.48	77.95	99.99	9.37
4114800	6.33	0.073	0.00	1940.67	2.42	5.83	98.47	99.99	9.82
4114804	6.33	0.074	1.67	1943.58	2.56	5.57	31.03	99.99	10.27
4114808	6.33	0.074	0.00	1847.59	2.42	14.18	87.33	99.99	11.73
4114812	6.33	0.074	0.00	1763.25	2.42	21.75	51.67	99.99	11.03
4114816	6.33	0.075	1.67	1969.75	2.29	3.22	83.58	99.99	10.01
4114820	6.34	0.076	1.67	1966.85	2.29	3.48	179.17	99.99	9.50
4114824	6.34	0.076	0.00	1917.40	2.29	7.92	17.77	99.99	10.39
4114828	6.34	0.076	0.00	1958.12	2.29	4.26	85.46	99.99	9.76



RECORD OF CORSHAM DRILL RUN 3.6.2 (6.26 to 6.34 metres)

USER: EX9169 -AT SYSTEM

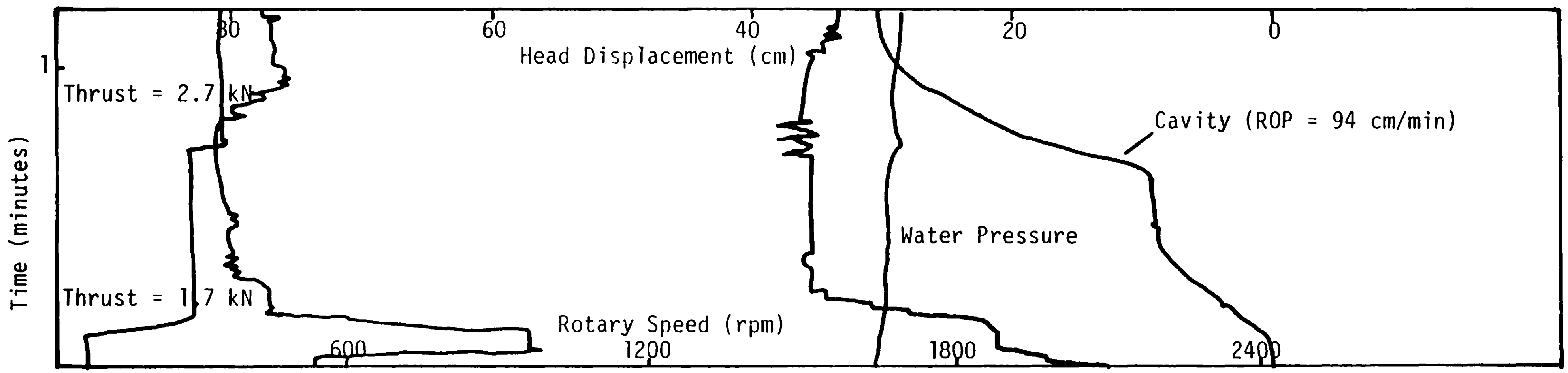
NP_C3.7

LABEL: FRTG22 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:21, ON: PRO BY: PRO

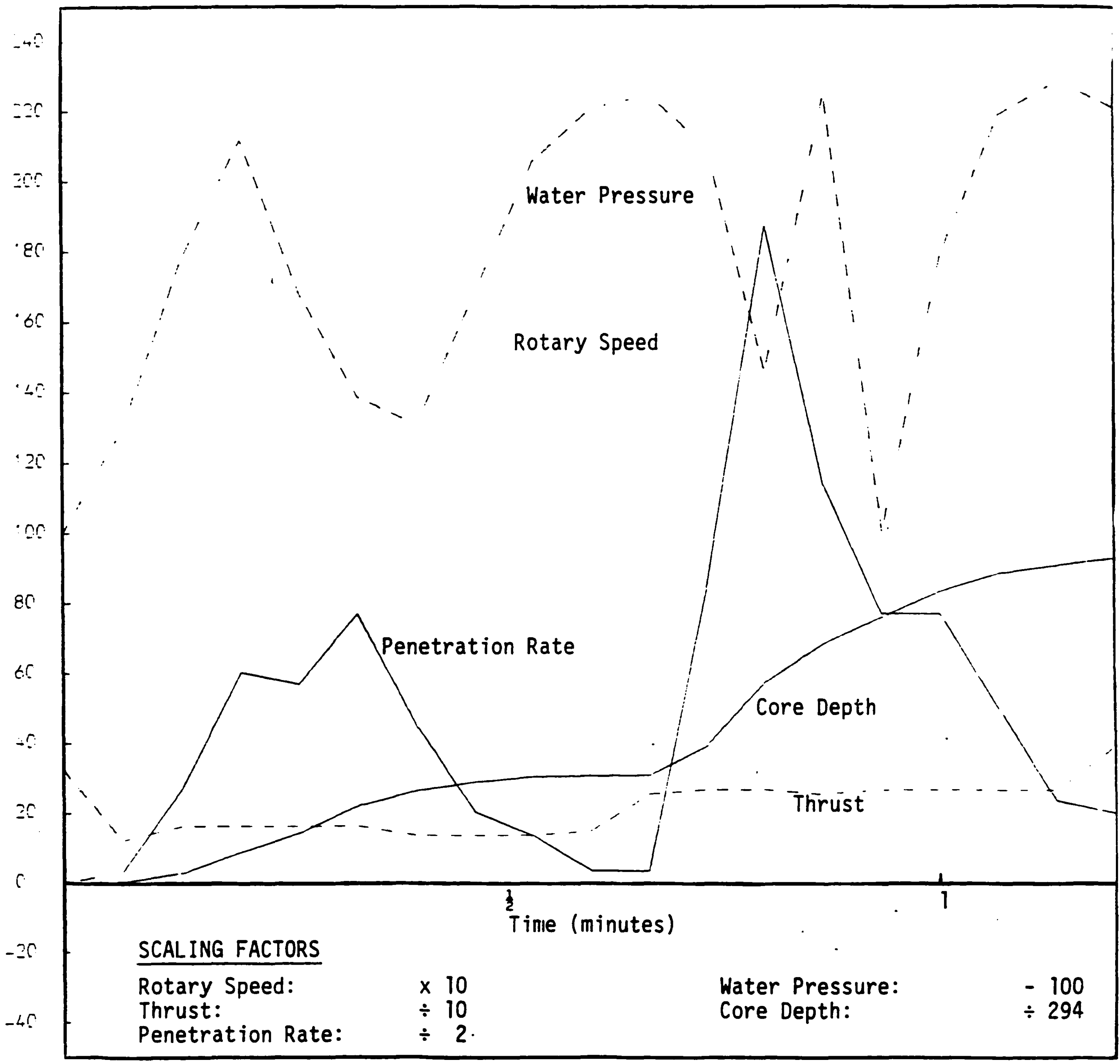
O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4151522	6.34	0.000	0.00	1924.22	3.26	15.54	0.61	4.86	5.15
4151526	6.34	0.001	1.67	1839.96	1.22	22.48	29.36	4.86	4.58
4151530	6.35	0.010	13.35	1668.52	1.62	36.62	78.05	4.86	5.53
4151534	6.37	0.030	30.12	1492.71	1.62	31.88	111.77	4.86	3.81
4151538	6.39	0.049	28.44	1489.81	1.62	32.19	68.69	4.86	3.18
4151542	6.41	0.075	38.48	1513.03	1.62	29.65	38.72	4.86	3.49
4151546	6.43	0.090	22.51	1507.23	1.35	30.28	31.23	4.86	2.92
4151550	6.44	0.098	10.04	1513.03	1.35	29.65	68.69	4.86	2.79
4151554	6.44	0.103	6.69	1515.94	1.35	29.33	106.15	4.86	2.73
4151558	6.44	0.104	1.67	1515.94	1.49	29.33	121.13	4.86	2.67
4151602	6.44	0.105	1.67	1510.13	2.54	29.96	124.88	4.86	2.67
4151606	6.47	0.133	41.83	1504.32	2.67	30.60	109.90	4.86	4.58
4151610	6.54	0.195	93.70	1492.71	2.67	31.88	46.21	4.86	5.66
4151614	6.57	0.233	56.89	1513.03	2.54	29.65	124.88	4.86	5.09
4151618	6.60	0.259	38.48	1495.62	2.67	31.56	0.61	4.86	4.90
4151622	6.62	0.284	38.48	1518.84	2.67	29.01	79.93	4.86	4.90
4151626	6.64	0.301	25.10	1515.94	2.67	29.33	119.26	3.41	4.45
4151630	6.65	0.309	11.71	1544.96	2.67	26.14	128.62	3.41	4.19
4151634	6.66	0.316	10.04	560.93	3.92	134.10	121.13	4.86	2.28



RECORD OF CORSHAM DRILL RUN 3.7 (6.34 to 6.66 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.7 (6.34 to 6.66 metres)



USER: EXS269 -AT SYSTEM

NF_C3.8.1

EXS269

NF_C3.8.1

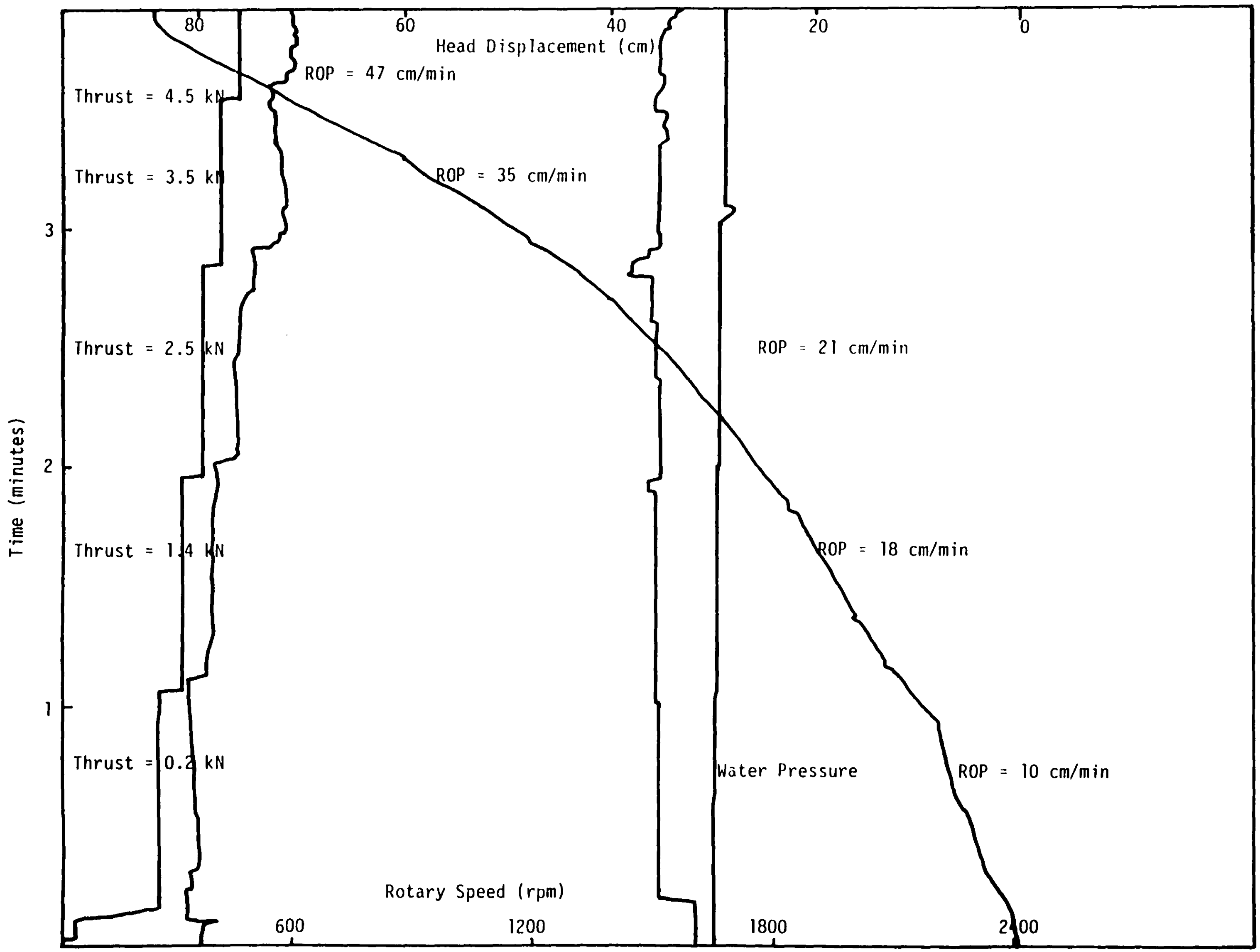
LABEL: FRT023 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:21, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

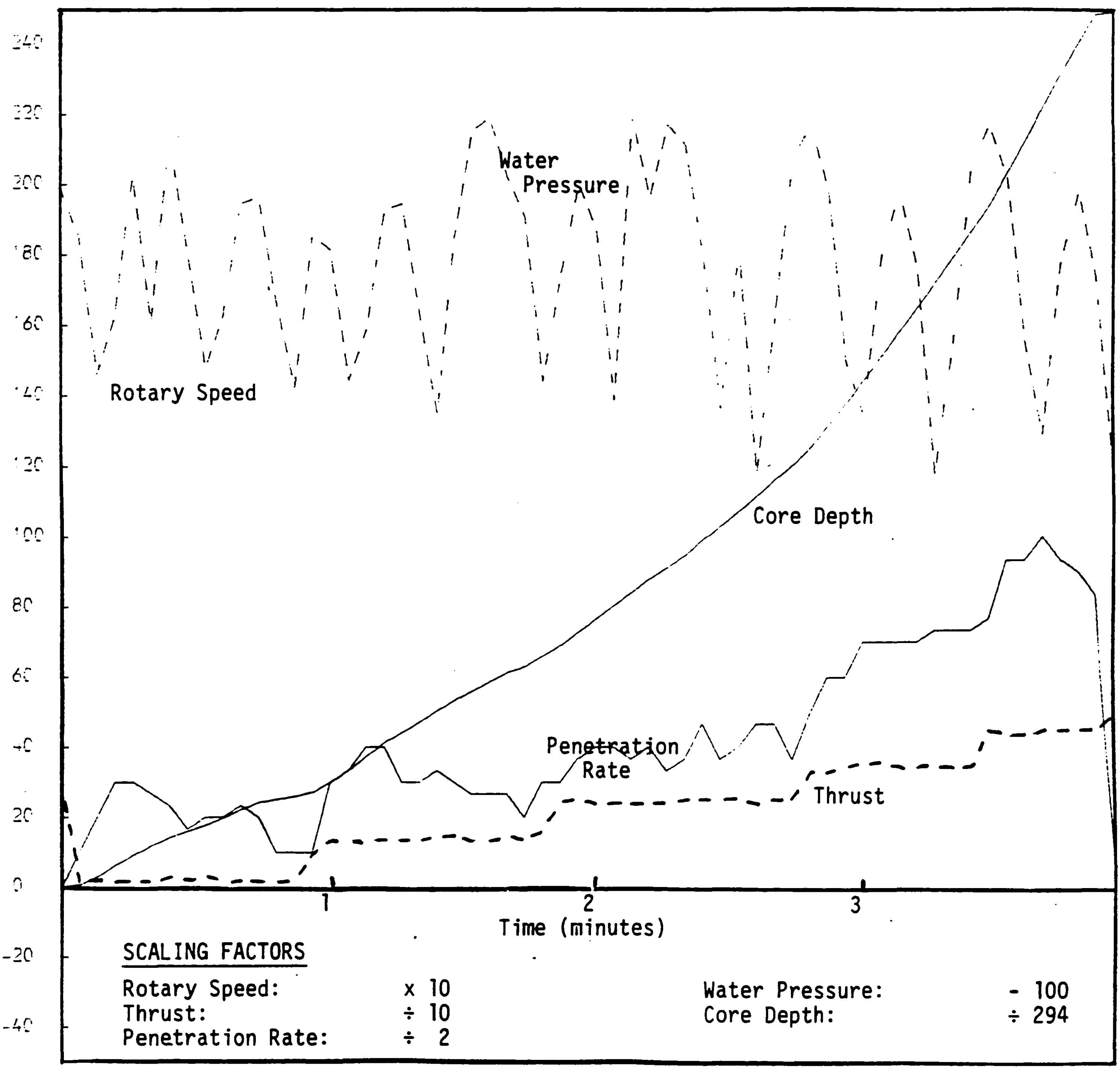
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4152642	6.66	0.000	0.00	1591.41	3.13	102.49	98.66	4.86	3.30
4152646	6.66	0.003	5.02	1571.09	0.17	97.14	85.55	4.86	3.75
4152650	6.67	0.011	10.04	1486.91	0.17	74.99	46.21	4.86	3.18
4152654	6.68	0.022	15.06	1484.01	0.17	74.23	63.07	4.86	3.69
4152658	6.69	0.032	15.06	1489.81	0.17	75.76	102.40	4.86	3.62
4152702	6.70	0.041	13.39	1498.52	0.17	78.05	61.20	4.86	3.49
4152706	6.71	0.049	11.71	1501.42	0.30	78.81	113.64	4.86	3.11
4152710	6.71	0.055	8.37	1504.32	0.17	79.57	81.80	4.86	3.05
4152714	6.72	0.061	10.04	1501.42	0.30	78.81	48.09	4.86	3.11
4152718	6.73	0.068	10.04	1495.62	0.17	77.28	63.07	3.41	3.30
4152722	6.74	0.076	11.71	1504.32	0.17	79.57	94.91	4.86	3.24
4152726	6.74	0.083	10.04	1510.13	0.17	121.45	96.78	4.86	2.92
4152730	6.75	0.086	5.02	1510.13	0.17	121.45	66.82	4.86	2.86
4152734	6.75	0.089	5.02	1510.13	0.17	121.45	42.47	4.86	2.86
4152738	6.75	0.093	5.02	1478.20	0.96	72.70	85.55	4.86	2.86
4152742	6.76	0.103	15.06	1507.23	1.35	120.52	81.80	4.86	3.62
4152746	6.77	0.114	16.73	1486.91	1.35	74.99	44.34	4.86	4.07
4152750	6.79	0.128	20.08	1489.81	1.35	75.76	59.32	4.86	4.07
4152754	6.80	0.141	20.08	1489.81	1.35	75.76	93.04	4.86	4.19
4152758	6.81	0.151	15.06	1501.42	1.35	118.67	94.91	4.86	4.00
4152802	6.82	0.161	15.06	1492.71	1.35	76.52	63.07	4.86	3.94
4152806	6.83	0.172	16.73	1484.01	1.49	74.23	34.98	4.86	4.51
4152810	6.84	0.182	15.06	1492.71	1.49	76.52	85.55	4.86	4.39
4152814	6.85	0.191	13.39	1489.81	1.35	114.97	115.53	4.85	4.13
4152818	6.86	0.200	13.39	1495.62	1.35	116.82	119.26	4.86	4.07
4152822	6.87	0.205	13.39	1498.52	1.48	78.05	102.43	4.85	3.87
4152826	6.88	0.215	10.04	1484.01	1.35	113.12	91.21	3.41	4.19
4152830	6.89	0.225	15.06	1484.01	1.62	74.23	44.34	4.86	4.51
4152834	6.90	0.235	15.06	1460.78	2.40	68.12	74.37	4.85	5.40
4152838	6.91	0.248	18.40	1495.62	2.53	116.82	100.56	4.85	5.40
4152842	6.92	0.261	20.08	1495.62	2.40	77.28	87.46	4.85	5.27
4152846	6.93	0.274	20.08	1486.91	2.40	74.99	38.81	4.85	5.52
4152850	6.95	0.287	18.40	1486.91	2.40	74.99	119.27	4.85	5.40
4152854	6.96	0.300	20.08	1498.52	2.40	117.74	96.82	4.85	5.27
4152858	6.97	0.311	16.73	1495.62	2.40	116.82	117.40	4.85	5.02
4152902	6.98	0.323	18.40	1472.39	2.53	71.17	111.79	4.85	5.84
4152906	7.00	0.338	23.42	1475.30	2.53	110.34	79.98	4.85	5.72
4152910	7.01	0.351	18.40	1475.30	2.54	71.94	36.85	4.86	5.60
4152914	7.02	0.365	20.08	1463.69	2.53	106.64	81.85	4.85	5.72
4152918	7.04	0.380	23.42	1469.49	2.40	70.41	18.23	4.85	5.97
4152922	7.06	0.396	23.42	1469.49	2.53	108.49	63.14	4.85	5.84
4152926	7.07	0.410	18.40	1472.39	2.53	109.42	108.04	4.85	5.97
4152930	7.09	0.427	25.10	1434.66	3.32	97.39	117.40	4.85	7.12
4152934	7.11	0.448	30.12	1518.84	3.32	54.71	98.69	4.85	7.88
4152938	7.13	0.469	30.12	1492.71	3.46	48.86	50.04	4.85	7.69
4152942	7.15	0.492	35.14	1505.75	3.59	41.05	35.07	4.85	7.43
4152946	7.18	0.515	35.14	1517.34	3.59	43.47	79.98	4.85	7.31
4152950	7.20	0.539	35.14	1524.64	3.46	56.01	98.69	4.85	7.43
4152954	7.22	0.562	35.14	1514.45	3.46	42.87	76.24	4.85	7.24
4152958	7.25	0.587	36.81	1527.55	3.46	56.66	18.23	4.85	7.37
4153002	7.27	0.611	36.81	1537.64	3.46	47.72	55.65	4.85	6.99
4153006	7.30	0.636	36.81	1530.45	3.46	57.31	106.17	4.85	7.31
4153010	7.32	0.661	38.48	1494.15	4.51	38.62	117.40	4.85	7.94
4153014	7.35	0.693	46.85	1524.64	4.38	18.08	102.43	4.85	8.32

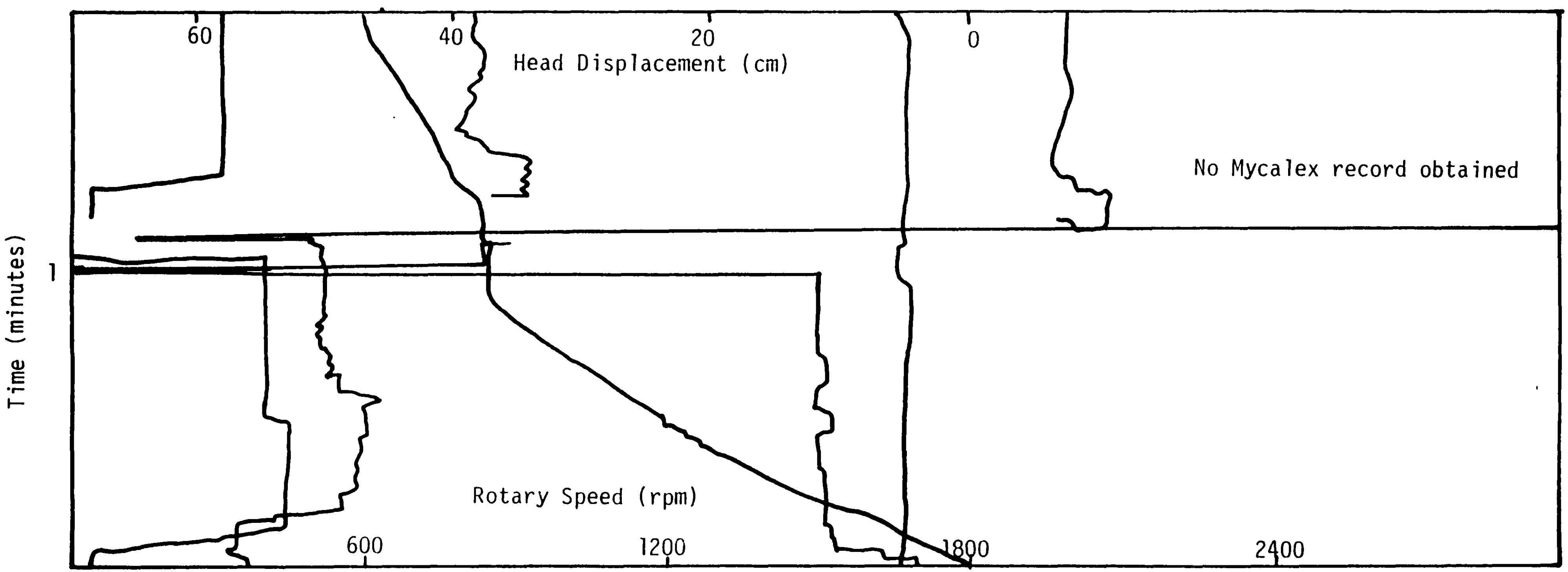
	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
4153018	7.38	0.724	46.85	1478.20	4.38	10.07	55.65	4.85	8.01
4153022	7.42	0.757	50.20	1510.13	4.51	15.58	29.46	4.85	8.20
4153026	7.45	0.789	46.85	1514.45	4.51	24.32	78.11	4.85	7.81
4153030	7.48	0.815	45.18	1549.24	4.51	15.49	98.69	4.85	7.37
4153034	7.51	0.847	41.83	1765.57	4.51	59.67	74.37	4.85	7.12
4153038	7.51	0.850	5.02	23.92	4.98	234.12	20.10	4.85	-1.35



RECORD OF CORSHAM DRILL RUN 3.8.1 (6.66 to 7.51 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.8.1 (6.66 to 7 51 metres)





RECORD OF CORSHAM DRILL RUN 3.8.2 (7.51 to 8.03 metres)

USER: EX5069 -AT SYSTEM

NR_C3.8.3

EX5069

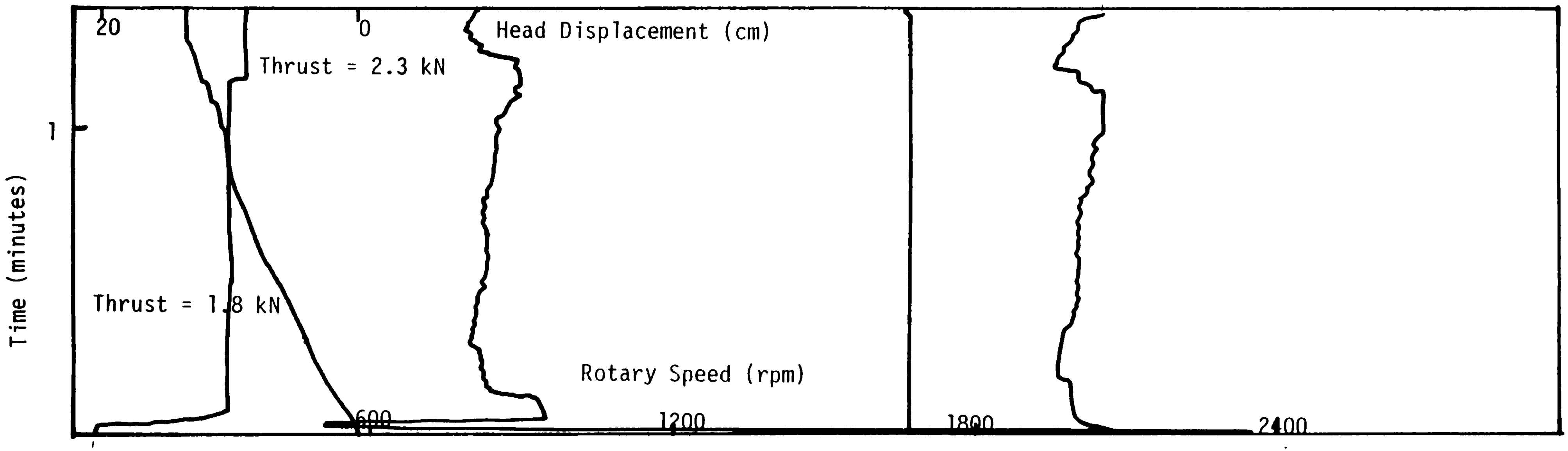
NR_C3.8.3

LABEL: FRT024 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:22, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4153452	8.03	0.000	0.00	2018.11	1.35	4.74	2.48	4.86	7.31
4153456	8.04	0.008	13.38	1991.99	1.88	6.96	29.36	4.86	8.40
4153500	8.05	0.017	13.38	1989.08	1.49	7.21	102.40	4.86	8.46
4153504	8.06	0.026	13.38	1968.77	1.75	8.94	119.26	4.86	8.72
4153508	8.07	0.036	15.06	1991.99	1.88	6.96	113.64	4.86	8.52
4153512	8.07	0.045	13.38	2000.70	1.88	6.22	70.56	4.86	8.40
4153516	8.08	0.052	11.71	2021.02	1.62	4.50	3.13	4.86	8.21
4153520	8.09	0.059	10.04	2021.02	1.68	4.50	59.32	4.86	7.95
4153524	8.10	0.067	11.71	2006.50	1.75	5.73	104.28	4.86	8.02
4153528	8.10	0.074	10.04	2012.31	1.74	5.24	44.43	4.85	8.26
4153532	8.11	0.081	11.71	2026.82	1.74	4.00	108.04	4.85	8.01
4153536	8.12	0.088	11.71	2038.43	1.75	3.02	121.13	4.86	7.89
4153540	8.12	0.094	10.04	2052.95	1.87	1.78	113.66	4.85	7.62
4153544	8.13	0.099	8.37	2055.85	1.49	1.54	74.31	4.86	7.57
4153548	8.13	0.104	6.69	2058.75	1.49	1.29	109.90	3.41	7.44
4153552	8.14	0.108	6.69	2090.68	1.62	1.42	61.20	4.86	7.31
4153556	8.14	0.112	5.02	2093.58	2.01	1.67	104.30	4.85	7.18
4153600	8.14	0.115	5.02	2055.85	2.27	1.54	106.17	4.85	7.18
4153604	8.15	0.120	8.37	1974.57	2.67	8.44	46.30	4.85	8.20
4153608	8.16	0.128	11.71	2003.60	2.28	5.98	26.83	4.86	8.33
4153612	8.17	0.136	11.71	2021.02	2.54	4.50	78.05	4.86	7.95
4153616	8.17	0.141	6.69	2081.97	2.40	0.68	119.27	4.85	7.18



RECORD OF CORSHAM DRILL RUN 3.8.3 (8.03 to 8.17)

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USER: EX9069 -AT SYSTEM

NR_C3.8.4

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LABEL: PRT025 -FORM

SPOOLED:  82-03-10.19:14
STARTED:  82-03-10.19:22, ON:   PPC   BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E
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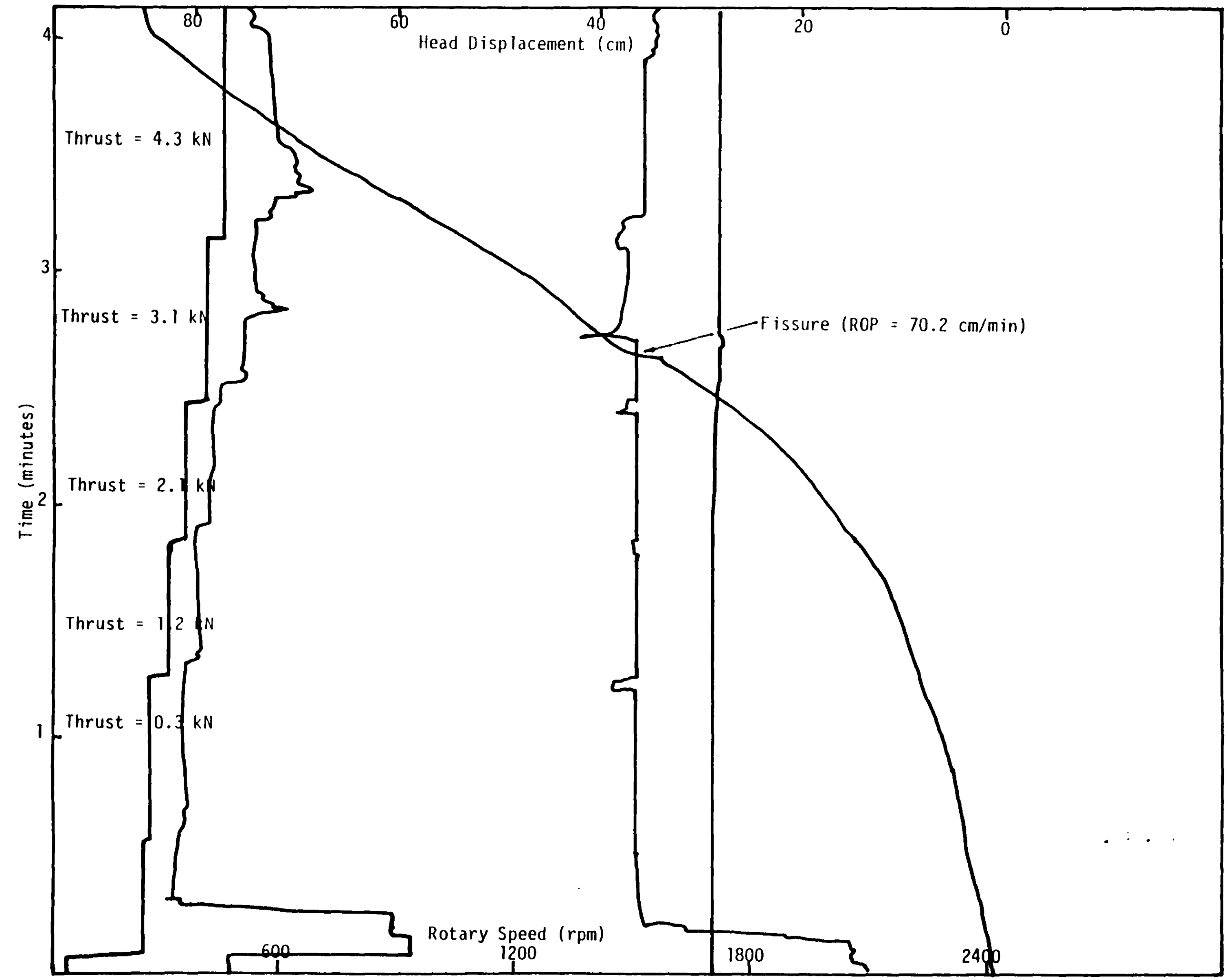
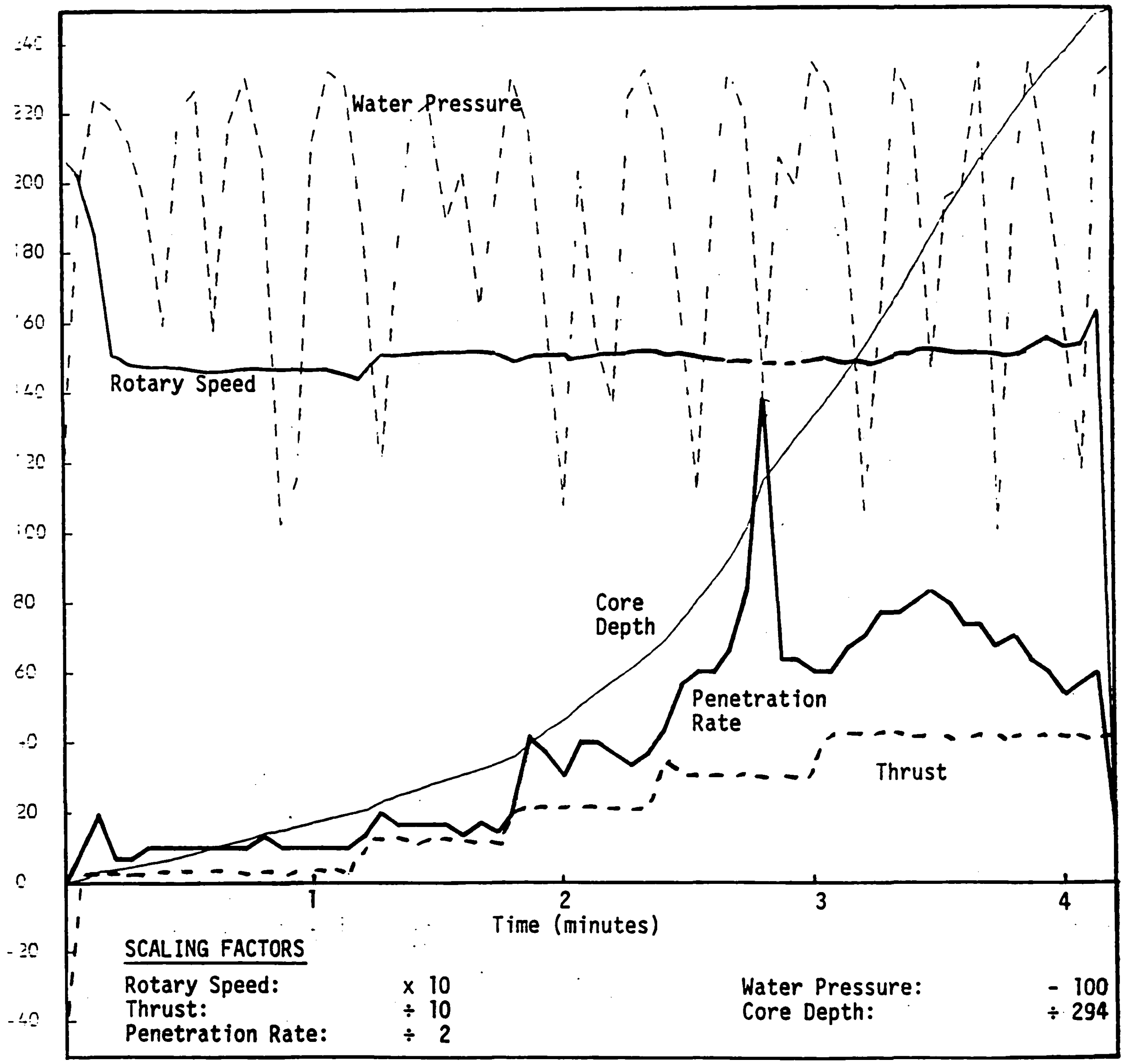
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4154812	8.17	0.000	0.00	2081.97	4.19	0.68	14.49	99.99	7.43
4154816	8.17	0.004	5.01	2026.82	0.23	4.00	98.69	99.99	8.07
4154820	8.18	0.011	10.03	1852.66	0.23	18.80	124.88	99.99	5.97
4154824	8.18	0.013	3.34	1505.75	0.37	33.07	121.14	99.99	2.47
4154828	8.19	0.016	3.34	1482.55	0.23	29.94	111.79	99.99	2.85
4154832	8.19	0.019	5.01	1473.85	0.23	30.93	94.03	99.99	2.98
4154836	8.19	0.022	5.01	1473.85	0.37	30.93	59.40	99.99	3.04
4154840	8.20	0.026	5.01	1470.95	0.37	31.27	121.14	99.99	3.11
4154844	8.20	0.030	5.01	1462.25	0.03	32.26	126.76	99.99	3.30
4154848	8.20	0.035	5.01	1462.25	0.29	32.26	57.53	99.99	3.49
4154852	8.21	0.039	5.01	1465.15	0.16	31.93	117.40	99.99	3.30
4154856	8.21	0.043	5.01	1468.05	0.29	31.60	130.50	99.99	3.23
4154900	8.22	0.048	6.68	1468.05	0.29	31.60	108.04	99.99	3.04
4154904	8.22	0.051	5.01	1470.95	0.16	31.27	2.35	99.99	3.04
4154908	8.22	0.055	5.01	1470.95	0.29	31.27	15.45	99.99	3.11
4154912	8.23	0.059	5.01	1468.05	0.16	31.60	111.79	99.99	3.17
4154916	8.23	0.063	5.01	1465.15	0.42	31.93	132.37	99.99	3.23
4154920	8.24	0.067	5.01	1462.25	0.29	32.26	128.63	99.99	3.30
4154924	8.24	0.071	6.68	1447.75	1.35	33.91	87.46	99.99	3.36
4154928	8.25	0.079	10.03	1505.75	1.22	27.30	15.45	99.99	4.19
4154932	8.25	0.085	8.35	1511.55	1.22	26.63	78.11	99.99	4.00
4154936	8.26	0.090	8.35	1514.45	1.08	26.30	119.27	99.99	4.00
4154940	8.27	0.096	8.35	1517.34	1.22	25.97	123.01	99.99	3.81
4154944	8.27	0.101	8.35	1520.24	1.22	25.64	89.33	99.99	3.81
4154948	8.28	0.106	6.68	1520.24	1.22	25.64	103.39	3.41	3.74
4154952	8.28	0.111	8.35	1520.24	1.08	25.64	65.01	99.99	3.74
4154956	8.29	0.116	6.68	1514.45	1.08	26.30	96.82	99.99	3.81
4155000	8.29	0.123	10.03	1488.35	2.01	29.28	130.50	99.99	4.51
4155004	8.31	0.136	20.05	1508.65	2.14	26.96	115.53	99.99	4.76
4155008	8.32	0.148	18.38	1514.45	2.14	26.30	61.27	99.99	4.83
4155012	8.33	0.158	15.04	1514.45	2.14	26.30	7.96	99.99	4.70
4155016	8.34	0.172	20.05	1497.05	2.14	28.29	104.30	99.99	5.21
4155020	8.35	0.185	20.05	1508.65	2.14	26.96	54.74	99.99	5.02
4155024	8.37	0.197	18.38	1511.55	2.14	26.63	36.94	99.99	4.83
4155028	8.38	0.208	16.71	1514.45	2.14	26.30	124.88	99.99	4.70
4155032	8.39	0.221	18.38	1494.15	2.14	28.62	132.37	99.99	5.27
4155036	8.41	0.235	21.72	1430.35	3.46	35.90	115.53	99.99	5.33
4155040	8.42	0.254	28.41	1511.55	3.06	26.63	66.88	99.99	6.29
4155044	8.44	0.274	30.08	1494.15	3.06	28.62	11.71	99.99	6.54
4155048	8.46	0.294	30.08	1494.15	3.06	28.62	94.95	3.41	6.42
4155052	8.49	0.316	33.42	1485.45	3.06	29.61	132.37	3.41	6.54
4155056	8.51	0.344	41.77	1459.35	3.06	32.59	119.27	99.99	6.54
4155100	8.56	0.391	70.18	1485.45	2.93	29.61	42.56	99.99	6.61
4155104	8.58	0.412	31.75	1491.25	3.06	28.95	107.13	3.41	6.35
4155108	8.60	0.433	31.75	1482.55	3.06	29.94	98.69	99.99	6.61
4155112	8.62	0.453	30.08	1491.25	3.06	28.95	134.24	99.99	6.61
4155116	8.64	0.473	30.08	1485.45	3.19	29.61	126.76	3.41	6.54
4155120	8.67	0.496	33.42	1436.15	4.25	35.24	87.46	99.99	7.05
4155124	8.69	0.519	35.09	1473.85	4.25	30.93	6.09	3.41	8.07
4155128	8.71	0.545	38.43	1505.75	4.38	27.30	63.14	99.99	8.90
4155132	8.74	0.570	38.43	1499.95	4.25	27.96	132.37	99.99	8.64
4155136	8.77	0.597	40.10	1514.45	4.11	26.30	123.01	99.99	8.71
4155140	8.79	0.625	41.77	1505.75	4.25	27.30	46.30	99.99	7.94
4155144	8.82	0.652	40.10	1508.65	4.25	26.96	95.90	99.99	7.56

	TOTAL	CORE	PENETRAIN	ROTARY			INLET H20	I. H20	PAGE 2
4155148	8.85	0.676	36.76	1499.95	4.25	27.96	98.69	99.99	7.43
4155152	8.87	0.701	36.76	1514.45	4.11	26.30	134.24	95.99	7.31
4155156	8.89	0.723	33.42	1505.75	4.25	27.30	0.48	99.99	7.43
4155200	8.92	0.746	35.09	1502.85	4.11	20.93	98.69	95.99	7.37
4155204	8.94	0.768	31.75	1528.94	4.25	24.65	134.24	99.99	7.37
4155208	8.96	0.788	30.08	1555.04	4.11	14.48	104.30	95.99	7.12
4155212	8.98	0.805	26.74	1549.24	4.25	22.33	58.48	95.99	7.05
4155216	8.99	0.824	28.41	1534.74	4.11	23.99	18.23	95.99	6.48
4155220	9.01	0.844	30.08	1633.34	4.25	12.74	130.50	95.99	6.73
4155224	9.02	0.850	8.35	23.92	5.11	196.35	134.24	95.99	-1.35



RECORD OF CORSHAM DRILL RUN 3.8.4 (8.17 to 9.02 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.8.4 (8.17 to 9.02 metres)



USER: EX9069 -AT SYSTEM

NR_C3.9

EX9069

NR_C3.9

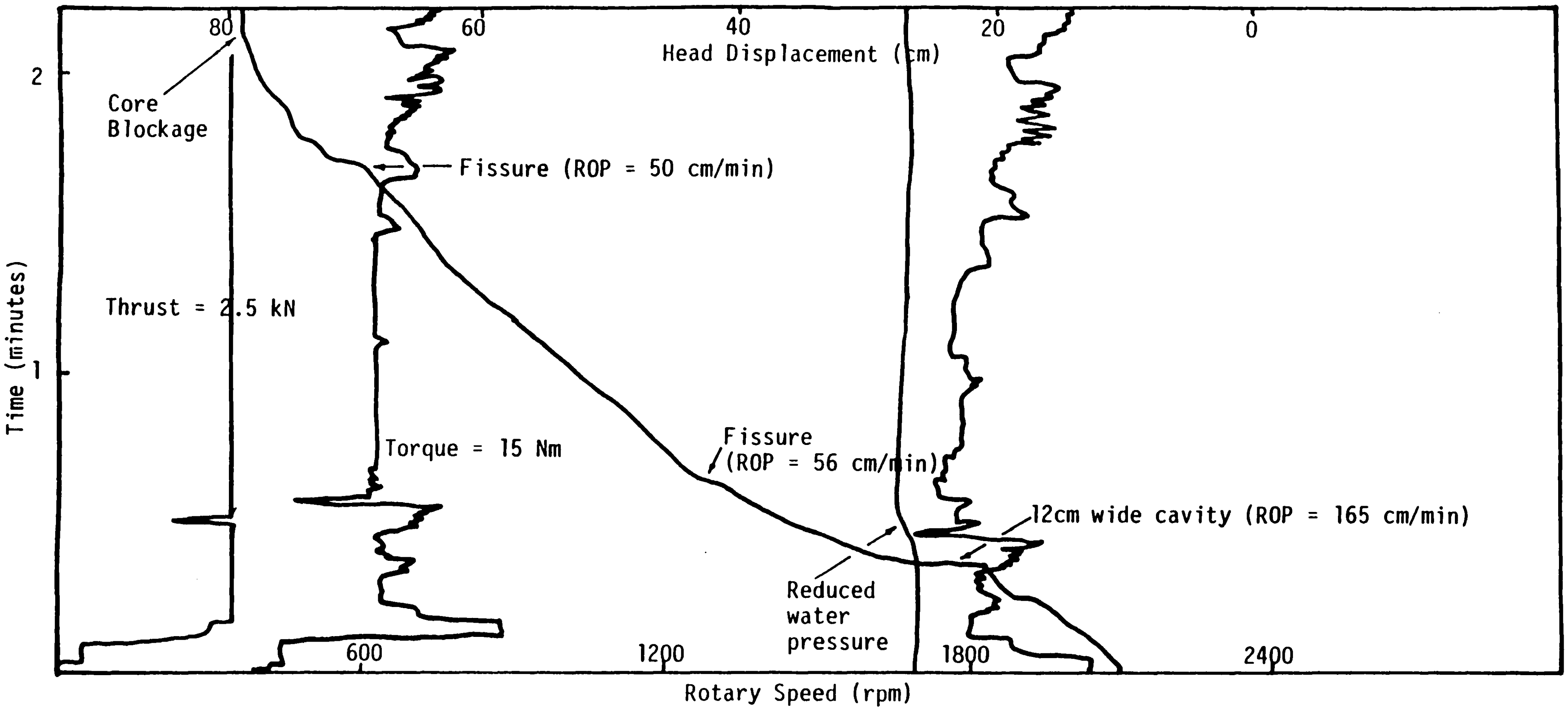
LABEL: FRT026 -FORM

SPOOLED: 82-03-10.19:14
STARTED: 82-03-10.19:22, CN: PR3 BY: FRC

OXFORD POLYTECHNIC COMPUTER CENTRE

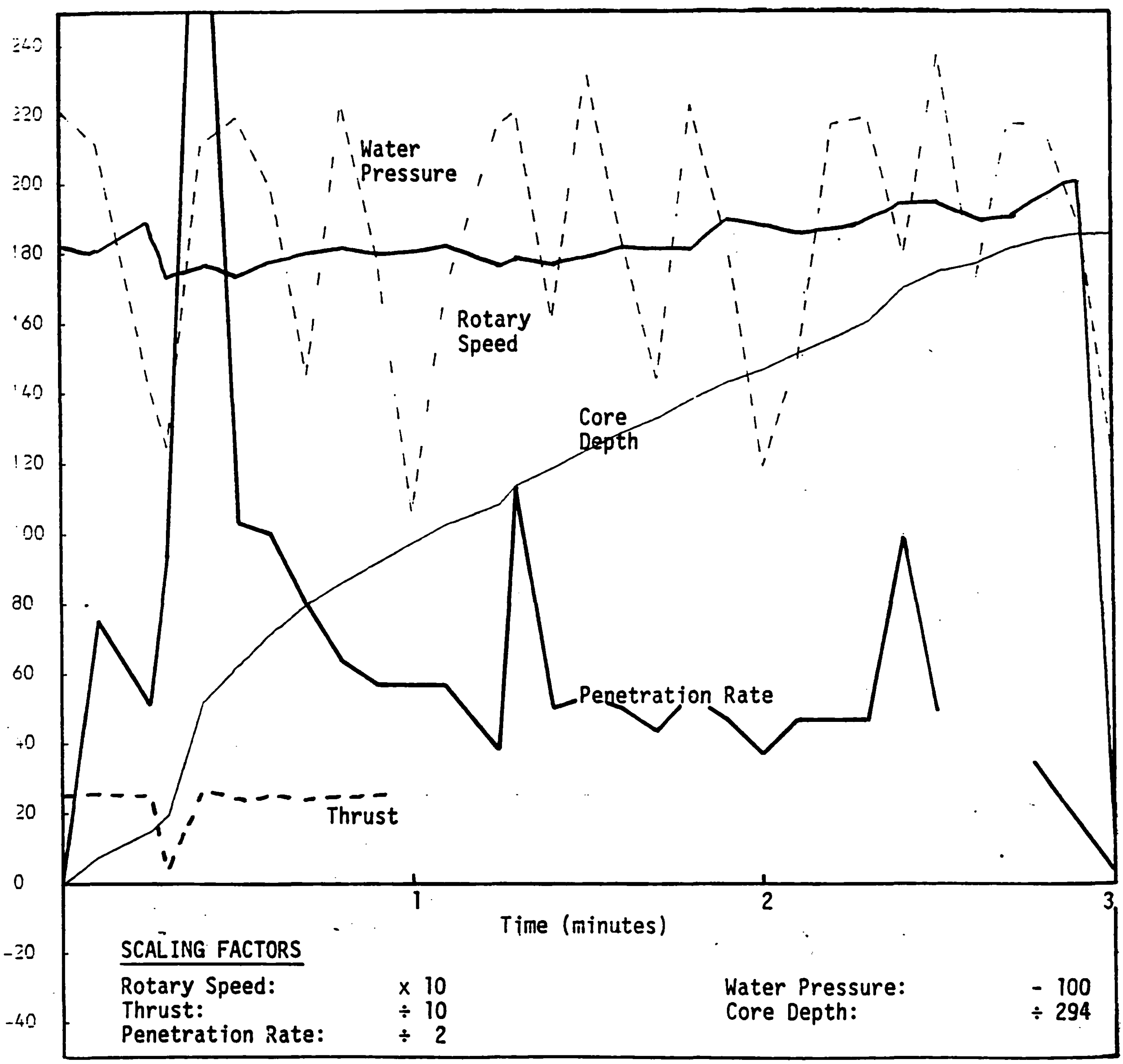
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. F20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4155302	9.02	0.000	0.00	1818.93	2.53	13.38	121.14	95.99	9.66
4155306	9.05	0.026	37.51	1804.43	2.53	14.72	111.79	99.99	10.49
4155310	9.07	0.051	25.62	1894.33	2.53	6.37	42.56	99.99	9.53
4155314	9.09	0.067	46.78	1729.03	0.42	21.73	24.83	99.99	8.71
4155318	9.20	0.177	165.43	1772.53	2.67	17.69	111.79	99.99	9.98
4155322	9.23	0.212	51.80	1731.93	2.40	21.46	119.27	99.99	11.19
4155326	9.27	0.245	50.13	1778.33	2.53	17.15	98.69	99.99	10.80
4155330	9.29	0.272	40.10	1798.63	2.40	15.26	45.38	99.99	10.61
4155334	9.31	0.293	31.75	1816.03	2.53	13.65	123.01	3.41	10.30
4155338	9.33	0.312	28.41	1801.53	2.53	14.99	79.98	95.99	10.42
4155342	9.35	0.331	28.41	1810.23	2.53	14.19	6.09	95.99	10.30
4155346	9.37	0.350	28.41	1827.63	2.53	12.57	70.62	95.99	9.91
4155350	9.39	0.369	18.94	1763.83	2.53	18.50	117.40	95.99	10.74
4155354	9.41	0.388	56.81	1784.13	2.53	16.61	121.14	95.99	10.68
4155358	9.42	0.404	25.07	1772.53	2.53	17.69	61.27	99.99	10.42
4155402	9.44	0.422	26.74	1795.73	2.53	15.53	133.33	3.41	10.61
4155406	9.46	0.439	25.07	1818.93	2.53	13.38	83.72	95.99	10.30
4155410	9.47	0.453	21.72	1818.93	2.53	13.38	44.43	3.41	9.79
4155414	9.49	0.471	26.74	1816.03	2.40	13.65	123.01	99.99	10.23
4155418	9.51	0.487	23.39	1900.13	2.40	5.83	83.72	99.99	9.91
4155422	9.52	0.499	18.38	1874.03	2.40	8.25	19.19	99.99	9.28
4155426	9.53	0.515	23.39	1853.73	2.53	10.14	50.04	99.99	9.85
4155430	9.55	0.530	23.39	1868.23	2.40	8.79	117.40	99.99	9.53
4155434	9.57	0.546	23.39	1897.23	2.27	6.10	119.27	95.99	8.83
4155438	9.60	0.579	50.13	1946.52	2.40	1.51	79.98	95.99	8.20
4155442	9.61	0.595	23.39	1943.62	2.40	1.78	137.07	95.99	8.64
4155446	9.62	0.602	10.03	1888.53	2.40	6.91	70.62	95.99	7.94
4155450	9.64	0.617	23.39	1903.03	2.40	5.56	117.40	95.99	9.53
4155454	9.65	0.627	15.04	1572.62	2.14	0.91	117.40	95.99	8.20
4155458	9.65	0.633	8.35	2013.22	2.01	4.69	89.33	95.99	7.43
4155502	9.65	0.634	1.67	151.51	4.72	164.97	21.06	95.99	-1.22

-800-



RECORD OF CORSHAM DRILL RUN 3.9 (9.02 to 9.65 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.9 (9.02 to 9.65 metres)



USER: EX5069 -AT SYSTEM

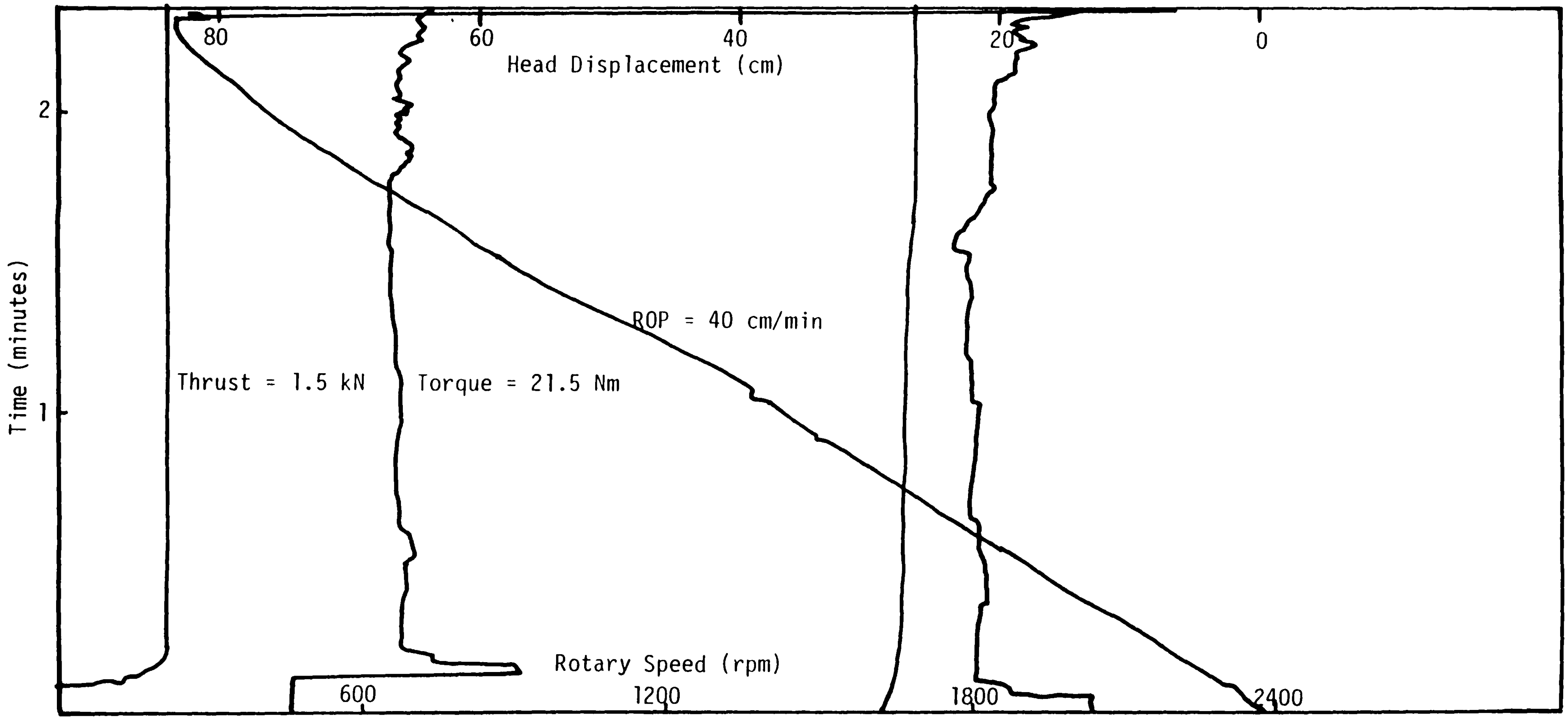
NR_03.10.1

LABEL: FRT027 -FORM

SPOOLED: 82-03-10.19:15
STARTED: 82-03-10.19:22, ON: PRO BY: PRC

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4161730	9.65	0.000	0.00	2053.82	5.37	4.48	104.30	3.41	8.71
4161734	9.66	0.007	10.77	1813.13	0.95	24.40	104.30	3.41	10.42
4161738	9.68	0.031	37.51	1804.43	1.35	20.23	108.04	3.41	11.57
4161742	9.71	0.056	36.81	1807.33	1.48	19.97	157.65	3.41	11.12
4161746	9.73	0.081	38.48	1830.53	1.34	17.94	98.72	3.41	11.05
4161750	9.76	0.107	38.48	1830.53	1.34	17.94	50.81	3.41	10.86
4161754	9.78	0.132	38.48	1842.13	1.48	16.92	121.14	3.41	10.74
4161758	9.81	0.157	36.54	1827.63	1.35	18.19	106.17	3.41	10.80
4161802	9.83	0.184	38.48	1807.33	1.35	19.97	48.17	3.41	11.25
4161806	9.86	0.210	38.48	1792.83	1.35	21.24	112.74	99.99	11.19
4161810	9.88	0.236	40.16	1807.33	1.35	19.97	108.04	99.99	11.31
4161814	9.91	0.262	40.16	1795.73	1.60	20.99	119.28	99.99	11.05
4161818	9.94	0.288	40.16	1821.83	1.47	18.70	16.46	3.41	11.05
4161822	9.96	0.311	35.14	1824.73	1.34	18.45	61.34	99.59	10.73
4161826	9.98	0.335	35.14	1821.83	1.34	18.70	98.72	95.99	10.79
4161830	10.01	0.358	35.14	1816.03	1.34	19.21	117.41	3.41	10.79
4161834	10.03	0.384	38.48	1807.33	1.47	19.97	104.33	95.99	11.11
4161838	10.06	0.410	38.48	1807.33	1.47	19.97	117.41	95.59	10.92
4161842	10.09	0.436	38.48	1784.13	1.47	22.0[illegible]	106.20	95.99	11.30
4161846	10.11	0.464	41.83	1781.23	1.47	22.26	94.98	95.99	11.11
4161850	10.14	0.493	43.50	1817.14	1.47	21.51	93.81	95.99	10.86
4161854	10.17	0.520	40.16	1781.23	1.47	22.26	113.68	95.99	10.79
4161858	10.20	0.549	41.83	1782.38	1.60	24.47	111.81	95.99	10.92
4161902	10.23	0.579	41.83	1759.20	1.60	26.45	30.25	99.99	11.49
4161906	10.26	0.607	41.83	1811.34	1.47	22.00	66.95	99.99	10.92
4161910	10.28	0.634	40.16	1836.33	1.60	17.43	106.20	99.99	10.73
4161914	10.31	0.657	35.14	1869.28	1.47	17.06	113.68	99.99	10.09
4161918	10.33	0.683	38.48	1828.73	1.34	20.52	35.86	99.99	10.54
4161922	[illegible]	[illegible]	35.14	[illegible]	1.47	19.04	106.20	99.99	10.22
4161926	10.38	0.730	35.14	1827.63	1.47	18.19	189.14	99.99	10.35
4161931	10.41	0.755	38.48	1845.03	1.60	16.67	121.15	99.99	10.28
4161934	10.43	0.777	30.12	1853.73	1.60	15.91	106.20	95.99	10.03
4161938	10.45	0.798	30.12	1900.13	1.47	11.85	78.16	99.99	9.52
4161942	10.47	0.817	25.10	1926.22	1.47	9.56	119.98	95.95	9.46
4161946	10.48	0.833	25.10	1888.53	1.47	12.86	111.81	95.99	9.52
4161950	10.50	0.850	25.10	2007.42	1.21	8.32	111.81	95.59	8.63



RECORD OF CORSHAM DRILL RUN 3.10.1 (9.65 to 10.50 metres)

USER: EX5069 -AT SYSTEM

NP_C3.10.2

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EX5069

NR_03.10.2

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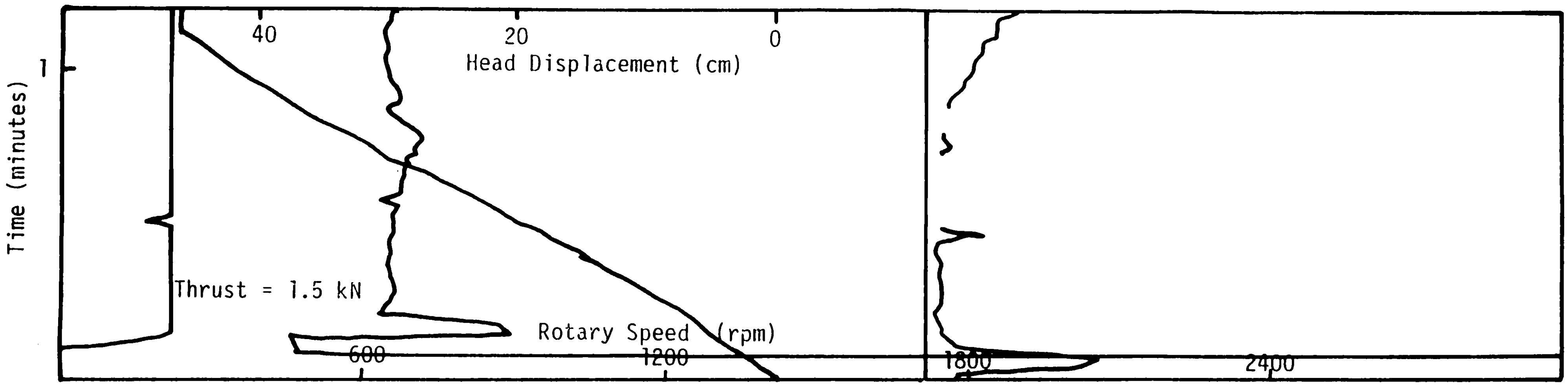
LABEL: PRT028 -FORM

SPOOLED: 82-[illegible]3-10.19:15
STARTED: 82-[illegible]3-10.19:22, ON: PRO BY: PRO

O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4162010	10.50	0.000	0.00	1882.73	0.63	18.64	20.22	99.99	7.42
4162014	10.52	0.021	30.46	1698.36	1.34	31.63	48.25	99.99	11.49
4162018	10.55	0.047	38.48	1736.02	1.34	32.76	98.72	99.99	11.55
4162022	10.57	0.069	33.46	1758.03	1.21	28.96	108.07	99.99	11.05
4162026	10.59	0.093	35.14	1707.05	1.21	30.89	140.54	99.99	11.55
4162030	10.62	0.118	36.81	1709.95	1.21	34.86	115.54	99.99	11.43
4162034	10.65	0.146	43.50	1775.43	0.68	27.52	108.07	99.99	11.11
4162038	10.68	0.175	43.50	1660.70	1.34	34.84	96.85	99.99	11.68
4162042	10.71	0.206	46.85	1660.70	1.08	38.83	125.58	99.99	11.75
4162046	10.74	0.235	43.50	1637.53	1.34	36.82	108.07	99.99	12.06
4162050	10.77	0.265	45.18	1733.13	1.47	32.99	108.07	99.99	11.62
4162054	10.79	0.289	35.14	1701.26	1.21	35.56	113.68	99.99	11.55
4162058	10.82	0.319	45.18	1744.71	1.60	32.05	113.68	99.99	11.24
4162102	10.85	0.348	43.50	1793.96	1.34	28.08	57.60	99.99	10.67
4162106	10.87	0.374	38.48	1816.03	1.34	24.16	20.91	99.99	10.35
4162110	10.91	0.398	36.81	1828.73	1.21	25.28	94.98	99.99	10.28
4162114	10.92	0.422	35.14	1850.83	1.34	21.28	121.15	99.99	9.78
4162118	10.95	0.445	35.14	1879.83	0.95	18.88	88.20	99.99	9.65
4162122	10.96	0.461	23.42	1275.41	4.85	69.92	108.07	99.99	7.36



RECORD OF CORSHAM DRILL RUN 3.10.2 (10.50 to 10.96 metres)

USER: EX9069 -AT SYSTEM

NR_C3.11.1

EX9069

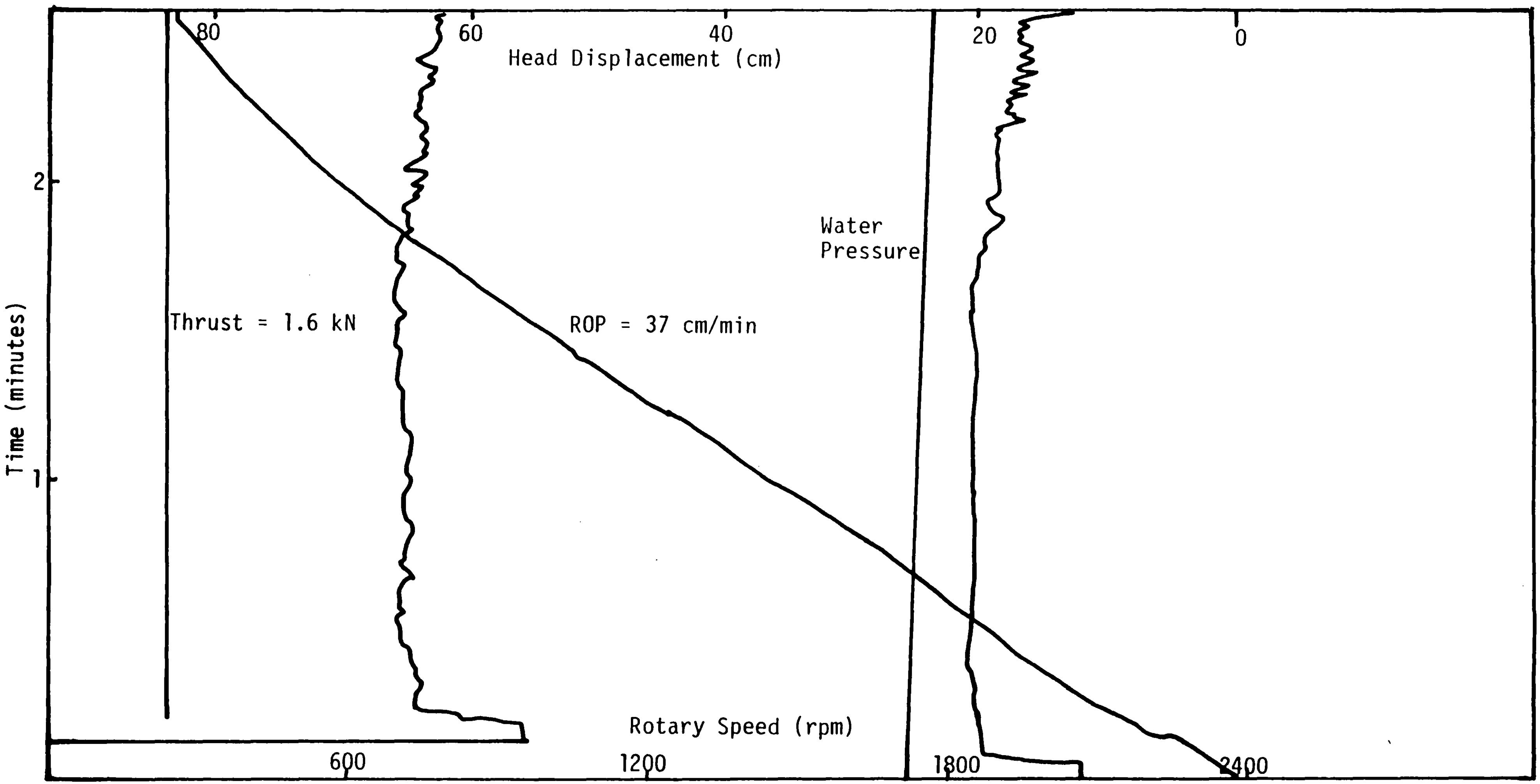
NR_C3.11.1

LABEL: FRT029 -FORM

SPOOLED: 82-03-10.15:15
STARTED: 82-03-10.15:23, ON: FRC BY: PRC

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4164354	10.96	0.000	0.00	1817.82	5.24	21.76	167.01	99.99	6.73
4164358	10.96	0.001	1.67	2099.39	4.85	2.16	116.49	95.59	9.79
4164402	10.96	0.001	0.00	2061.65	1.55	1.04	102.43	95.99	8.20
4164406	10.98	0.015	26.80	1849.75	1.61	19.05	83.72	99.59	11.31
4164410	11.01	0.047	41.89	1875.88	1.61	16.83	85.59	95.59	10.93
4164414	11.03	0.075	41.89	1858.46	1.61	18.31	102.43	95.99	11.12
4164418	11.06	0.101	38.53	1849.75	1.61	19.05	5.13	95.99	11.25
4164422	11.09	0.126	38.53	1826.53	1.61	21.02	107.13	95.99	11.44
4164426	11.11	0.154	41.89	1838.14	1.61	20.03	17.32	95.99	11.25
4164430	11.14	0.181	40.21	1835.24	1.61	20.28	87.46	99.99	11.31
4164434	11.17	0.206	36.86	1849.75	1.61	19.05	76.24	99.99	11.06
4164438	11.19	0.229	35.18	1846.85	1.61	19.29	81.85	99.99	11.19
4164442	11.21	0.251	33.51	1858.46	1.61	18.31	96.82	99.99	11.00
4164446	11.23	0.273	31.83	1829.43	1.74	20.77	32.29	99.99	11.31
4164450	11.25	0.295	33.51	1841.04	1.61	19.79	256.82	99.99	11.31
4164454	11.28	0.317	33.51	1829.43	1.61	20.77	26.67	99.99	10.93
4164458	11.30	0.341	35.18	1858.46	1.61	18.31	76.24	95.99	10.87
4164502	11.33	0.366	38.53	1824.73	1.61	23.44	87.46	95.99	10.93
4164506	11.35	0.392	38.53	1836.33	1.74	22.48	81.85	99.99	11.06
4164510	11.38	0.417	36.86	1816.03	1.61	24.16	68.75	95.59	10.93
4164514	11.40	0.441	36.86	1813.13	1.61	24.40	93.08	95.59	11.06
4164518	11.43	0.466	36.86	1813.13	1.61	24.40	72.49	95.59	10.93
4164522	11.45	0.491	38.53	1824.73	1.61	23.44	74.37	95.99	11.12
4164526	11.48	0.516	36.86	1816.03	1.61	24.16	96.82	95.99	10.80
4164530	11.50	0.539	35.18	1824.73	1.61	23.44	16.36	95.99	11.00
4164534	11.52	0.563	35.18	1836.33	1.61	22.48	196.94	95.99	10.80
4164538	11.55	0.586	35.18	1833.43	1.61	22.72	172.62	99.99	10.93
4164542	11.57	0.610	35.18	1856.63	1.61	20.80	102.43	99.99	10.55
4164546	11.59	0.634	36.86	1842.13	1.61	22.00	79.98	99.99	10.74
4164550	11.62	0.657	33.51	1879.83	1.61	18.88	85.59	99.99	10.36
4164554	11.64	0.678	31.83	1847.93	1.61	21.52	104.30	99.99	10.49
4164558	11.66	0.699	31.83	1885.63	1.61	18.40	83.72	99.99	9.98
4164602	11.68	0.719	30.16	1888.53	1.61	18.16	65.97	99.99	9.98
4164606	11.70	0.739	30.16	1879.83	1.61	18.88	107.13	99.99	10.30
4164610	11.72	0.760	30.16	1903.03	1.61	16.96	93.08	99.99	9.98
4164614	11.74	0.777	26.80	1874.03	1.61	19.36	70.62	95.99	9.72
4164618	11.76	0.795	26.80	1926.22	1.61	15.04	79.98	95.59	9.53
4164622	11.77	0.810	23.45	1932.02	1.61	14.56	104.30	95.99	9.41
4164626	11.78	0.824	21.78	1929.12	1.48	14.80	1.39	95.99	9.15
4164630	11.80	0.840	23.45	1946.52	1.61	13.36	239.98	95.99	9.53
4164634	11.81	0.850	15.08	1027.27	5.51	89.44	21.97	95.99	4.89



RECORD OF CORSHAM DRILL RUN 3.11.1 (10.96 to 11.81 metres)

USER: EX9069 -AT SYSTEM

NF_C0.11.2

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EX9069

NF_C0.11.2

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LABEL: PRT030 -FORM

SPOOLED: 82-03-10.19:15
STARTED: 82-03-10.19:23, ON: PRC BY: PRC

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
4164654	11.81	0.000	0.00	2026.82	0.10	4.00	81.85	99.99	8.01
4164658	11.82	0.013	20.01	1633.34	4.91	39.28	131.45	99.99	10.74
4164702	11.84	0.035	31.83	1856.63	2.14	20.80	81.85	95.99	10.55
4164706	11.86	0.047	18.43	1896.20	2.40	15.10	76.24	95.99	9.98
4164710	11.86	0.054	10.05	1931.03	2.27	12.14	62.22	95.99	9.34
4164714	11.87	0.059	8.37	1926.22	2.14	15.04	281.14	95.99	9.28
4164718	11.67	0.065	8.38	1879.83	2.93	18.88	21.97	95.99	9.60
4164722	11.88	0.070	8.37	1932.02	2.40	14.56	85.59	95.99	9.15
4164726	11.88	0.074	5.02	316.80	4.85	148.24	79.98	95.99	-1.09

USER: EX5069 -AT SYSTEM

NR_C3.12.1

EX5069

NR_C3.12.1

LABEL: FRTC31 -FORM

SPOOLED: 82-03-10.19:15
STARTED: 82-03-10.19:23, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5103328	11.88	0.000	0.00	2125.51	2.87	1.70	44.34	95.99	9.54
5103332	11.88	0.001	1.67	2116.81	0.76	2.40	116.74	95.99	9.48
5103336	11.88	0.003	3.34	2113.90	0.03	2.63	94.91	3.41	9.35
5103340	11.90	0.016	18.40	2099.39	0.17	3.80	66.82	99.99	9.22
5103344	11.92	0.040	36.81	2061.65	0.17	6.83	94.91	3.41	9.22
5103348	11.93	0.046	8.37	1991.99	1.22	12.43	81.80	3.41	10.24
5103352	11.93	0.047	1.67	1989.08	1.35	12.67	83.67	3.41	11.52
5103356	11.93	0.048	1.67	2076.17	1.35	5.67	83.02	99.99	10.18
5103400	11.93	0.052	6.69	2044.24	1.35	8.23	79.93	99.99	9.86
5103404	11.94	0.056	5.02	2076.17	1.35	5.67	45.56	99.99	10.12
5103408	11.94	0.058	3.34	2064.56	1.35	6.60	96.78	99.99	10.56
5103412	11.94	0.060	3.34	2032.63	0.17	9.17	87.42	95.99	10.88
5103416	11.94	0.060	0.00	2122.61	3.00	1.93	74.31	95.99	9.29
5103420	11.94	0.061	1.67	2122.61	3.00	1.93	78.05	3.41	9.29
5103424	11.94	0.061	0.00	2119.71	3.00	2.16	137.34	3.41	9.22
5103428	11.94	0.061	0.00	2113.90	2.87	2.63	68.04	95.99	9.16
5103432	11.94	0.061	0.00	2122.61	2.87	1.93	81.80	95.99	9.10
5103436	11.94	0.061	0.00	2116.81	3.00	2.40	85.55	95.99	9.10
5103440	11.94	0.061	0.00	96.49	3.92	164.85	48.09	3.41	-1.28
5104008	11.95	0.066	7.68	1562.96	1.49	14.77	87.42	3.41	11.52
5104012	11.95	0.068	3.34	2038.43	1.49	8.70	74.31	99.99	11.07
5104016	11.95	0.069	1.67	2006.50	1.35	11.27	204.77	99.99	11.45
5104020	11.95	0.070	1.67	2009.40	1.35	11.03	87.42	99.99	11.14
5104024	11.95	0.071	1.67	1994.89	1.49	12.20	114.86	99.99	11.39
5104028	11.95	0.073	1.67	1974.57	1.45	13.84	1.26	99.99	11.84
5104032	11.95	0.074	1.67	1980.38	1.49	13.37	98.66	99.99	11.26
5104036	11.95	0.075	1.67	1870.07	2.80	22.24	94.91	99.99	11.58
5104040	11.96	0.076	1.67	1832.34	2.80	25.27	51.18	99.99	13.11
5104044	11.96	0.076	0.00	1835.24	2.80	25.04	302.16	99.99	12.98
5104048	11.96	0.076	0.00	1832.34	2.80	20.52	72.44	99.99	13.11
5104052	11.96	0.076	0.00	1826.53	2.80	21.02	70.56	99.59	13.30
5104056	11.96	0.076	0.00	1820.72	2.80	21.51	268.45	95.99	13.11
5104100	11.96	0.076	0.00	1785.89	2.80	24.47	57.45	95.99	13.17
5104104	11.96	0.077	1.67	1780.09	3.73	24.96	167.31	95.99	13.62
5104108	11.96	0.077	0.00	1794.60	3.73	23.73	87.42	99.99	13.36
5104112	11.96	0.077	0.00	1835.24	3.73	20.28	85.55	99.99	13.24
5104116	11.96	0.077	0.00	1881.68	3.73	16.33	94.91	95.99	12.60
5104120	11.96	0.077	0.00	1875.88	3.73	16.83	63.07	99.99	12.47
5104124	11.96	0.077	0.00	1881.68	3.73	16.33	68.69	99.99	12.22
5104128	11.96	0.078	1.67	1878.78	3.73	16.58	94.91	99.99	12.15
5104132	11.96	0.078	0.00	1861.36	3.73	18.06	66.17	99.99	12.28
5104136	11.96	0.078	0.00	1855.56	3.73	18.55	105.50	99.99	12.47
5104140	11.96	0.078	0.00	1841.04	3.73	19.79	68.69	99.99	12.47
5104144	11.96	0.078	0.00	1838.14	3.73	20.03	74.31	99.99	12.47
5104152	11.96	0.079	0.84	1812.02	4.65	22.25	189.78	99.99	12.73
5104156	11.96	0.079	0.00	1832.34	4.65	20.52	18.12	95.99	12.60
5104200	11.96	0.079	0.00	1838.14	4.65	20.03	76.18	99.99	12.35
5104204	11.96	0.079	0.00	1843.95	4.65	19.54	81.80	95.99	12.35
5104208	11.96	0.079	0.00	1887.49	4.65	15.84	68.69	95.99	11.90
5104212	11.96	0.079	0.00	1867.17	4.65	17.57	68.04	95.99	11.96
5104216	11.96	0.079	0.00	1861.36	5.58	18.06	201.02	99.99	12.09
5104220	11.96	0.079	0.00	1846.85	5.71	19.29	79.93	99.99	12.09
5104224	11.96	0.080	1.67	1843.95	5.58	19.54	81.80	99.99	12.03
5104228	11.96	0.080	0.00	1852.66	5.58	18.80	38.72	99.99	12.09

USER: EX9C69 -AT SYSTEM

NR_C3.12.2

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EX9C69

NR_C3.12.2

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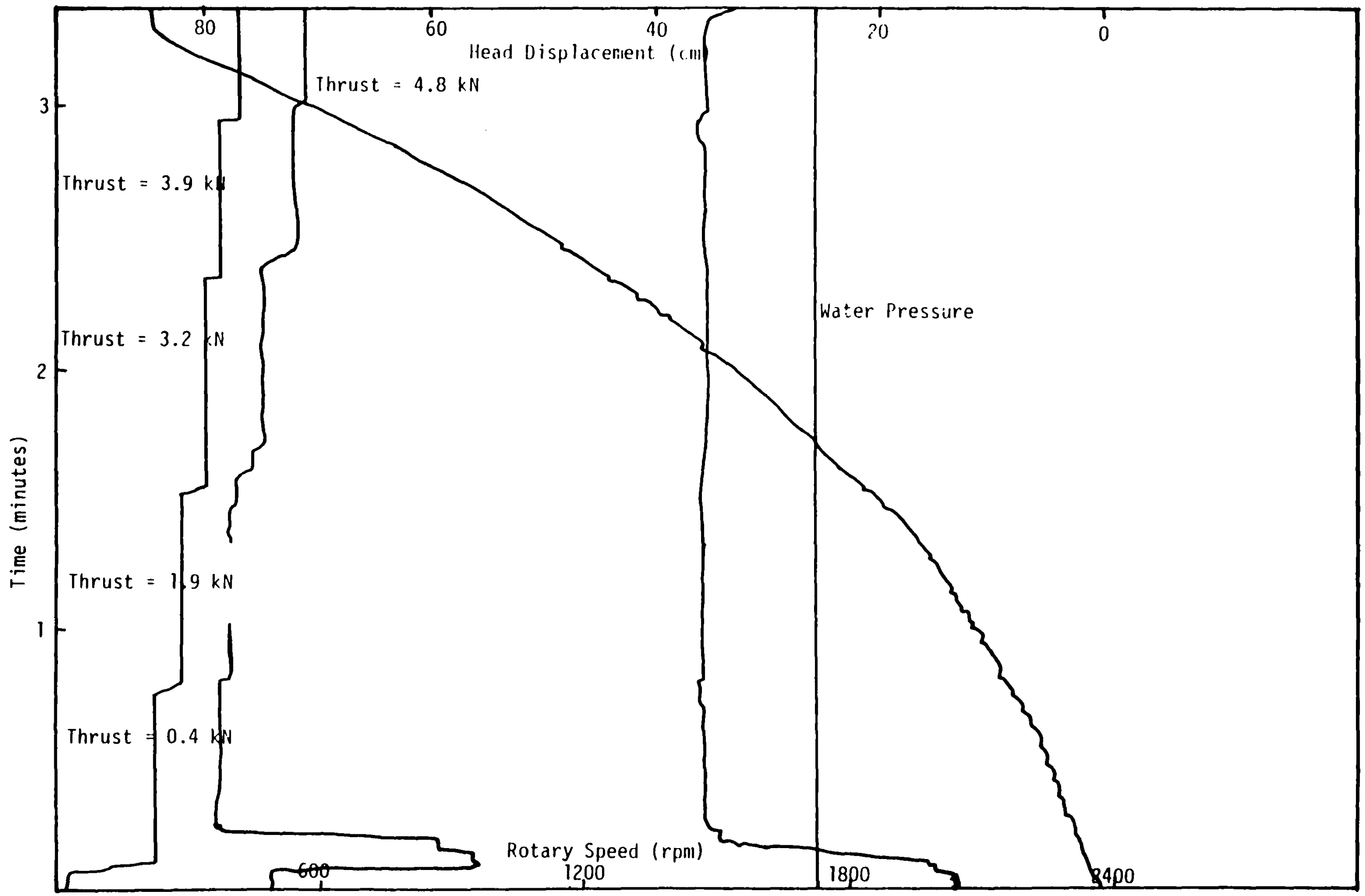
LABEL: PRT032 -FORM

SPOOLED: 82-03-10.19:15
STARTED: 82-03-10.19:23, ON: PRO BY: PRO

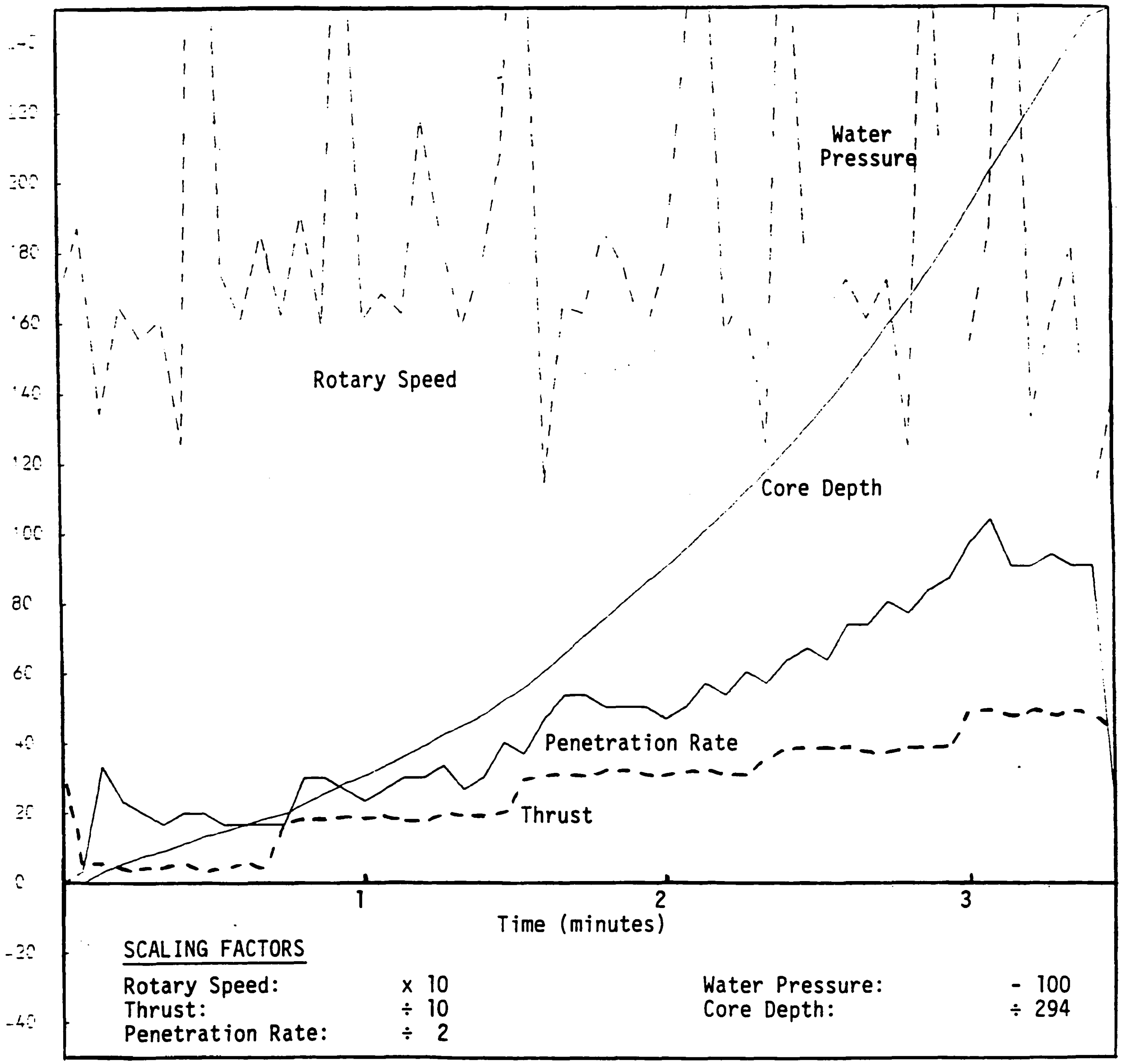
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5185208	11.96	0.000	0.00	2090.68	3.53	4.50	66.82	99.99	8.59
5185212	11.96	0.001	1.67	1986.18	0.56	12.90	87.42	99.99	8.97
5185216	11.97	0.012	16.75	1809.11	0.56	27.14	34.32	3.41	8.59
5185220	11.98	0.020	11.73	1536.25	0.43	27.10	64.94	99.99	4.13
5185224	11.99	0.027	10.05	1472.39	0.43	28.19	55.58	3.41	4.00
5185228	11.99	0.032	8.38	1457.88	0.43	29.90	61.20	3.41	4.39
5185232	12.00	0.035	10.05	1478.20	0.56	27.50	25.61	3.41	4.19
5185236	12.01	0.046	10.05	1460.78	0.30	29.56	319.02	99.99	4.07
5185240	12.01	0.051	8.38	1478.20	0.43	27.50	74.31	99.99	3.88
5185244	12.02	0.057	8.37	1481.10	0.56	27.16	61.20	99.99	4.00
5185248	12.02	0.063	8.38	1460.78	0.43	29.56	85.55	3.41	4.19
5185252	12.03	0.068	8.37	1454.98	1.75	30.25	62.42	99.99	4.13
5185256	12.04	0.078	15.08	1460.78	1.88	29.56	91.17	3.41	4.64
5185300	12.05	0.088	15.08	1492.71	1.88	25.78	59.32	99.99	4.77
5185304	12.06	0.097	13.40	1495.62	1.88	25.44	214.13	99.99	4.64
5185308	12.06	0.105	11.73	1495.62	1.88	25.44	61.20	3.41	4.70
5185312	12.07	0.114	13.40	1489.81	1.88	26.12	68.69	99.99	4.83
5185316	12.08	0.124	15.08	1495.62	1.75	25.44	63.07	99.99	4.90
5185320	12.09	0.134	15.08	1486.91	1.75	26.47	118.61	99.99	4.90
5185324	12.11	0.145	16.75	1495.62	2.01	25.44	83.67	99.99	4.90
5185328	12.11	0.154	13.40	1492.71	1.88	25.78	59.32	99.99	4.77
5185332	12.12	0.164	15.08	1484.01	1.88	26.81	76.18	99.99	5.02
5185336	12.14	0.178	20.10	1489.81	2.01	26.12	109.24	99.99	5.28
5185340	12.15	0.190	18.43	1457.88	2.94	29.90	232.86	3.41	5.66
5185344	12.17	0.206	23.45	1457.88	3.07	29.90	14.37	3.41	5.72
5185348	12.18	0.223	26.80	1510.13	3.07	23.72	64.94	99.99	6.42
5185352	12.20	0.241	26.80	1515.94	3.07	23.03	63.07	3.41	6.42
5185356	12.22	0.258	25.13	1518.84	3.20	22.69	86.77	99.99	6.17
5185400	12.23	0.275	25.13	1510.13	3.20	23.72	76.18	99.99	6.36
5185404	12.25	0.292	25.13	1507.23	3.07	24.06	55.58	99.99	6.23
5185408	12.27	0.307	23.45	1518.84	3.07	22.69	76.18	99.99	5.98
5185412	12.28	0.324	25.13	1507.23	3.20	24.06	133.59	99.99	6.42
5185416	12.30	0.343	28.48	1504.32	3.20	24.41	201.02	3.41	6.49
5185420	12.32	0.361	26.80	1504.32	3.07	24.41	57.45	99.99	6.42
5185424	12.34	0.381	30.16	1513.03	3.07	23.38	68.69	99.99	6.42
5185428	12.36	0.400	28.48	1481.10	3.60	27.16	25.61	3.41	6.42
5185432	12.38	0.421	31.83	1449.17	3.86	30.93	208.51	3.41	7.38
5185436	12.40	0.443	33.51	1481.10	3.86	27.16	70.56	99.99	7.57
5185440	12.42	0.465	31.83	1484.01	3.86	26.81	63.07	99.99	7.31
5185444	12.45	0.489	36.86	1495.62	3.86	25.44	72.44	99.99	7.31
5185448	12.47	0.514	36.86	1469.49	3.72	28.53	61.27	99.99	7.18
5185452	12.50	0.541	40.21	1478.20	3.73	27.50	72.44	99.99	7.38
5185456	12.53	0.566	38.53	1481.10	3.86	27.16	24.96	3.41	7.12
5185500	12.55	0.594	41.89	1478.20	3.85	27.50	206.30	99.99	7.12
5185504	12.58	0.623	43.56	1472.39	3.85	28.19	50.04	99.99	7.24
5185508	12.62	0.656	48.59	1492.71	4.91	25.78	53.78	99.99	7.94
5185512	12.65	0.690	51.94	1498.52	4.91	25.09	87.46	99.99	8.01
5185516	12.68	0.720	45.24	1498.52	4.77	25.09	264.30	99.99	7.94
5185520	12.71	0.751	45.24	1489.81	4.92	26.12	33.10	3.41	8.33
5185524	12.74	0.782	46.91	1489.81	4.78	26.12	61.20	99.99	8.33
5185528	12.77	0.812	45.24	1510.13	4.92	23.72	81.80	99.99	8.21
5185532	12.80	0.842	45.24	1571.09	4.77	16.51	7.96	3.41	7.62
5185536	12.81	0.850	11.73	23.92	4.32	199.59	37.90	3.41	-1.35



RECORD OF CORSHAM DRILL RUN 3.12.2 (11.96 to 12.81 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.12.2 (11.96 to 12.81 metres)



USER: EX5069 -AT SYSTEM

NP_03.12.3

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EX5069

NP_03.12.3

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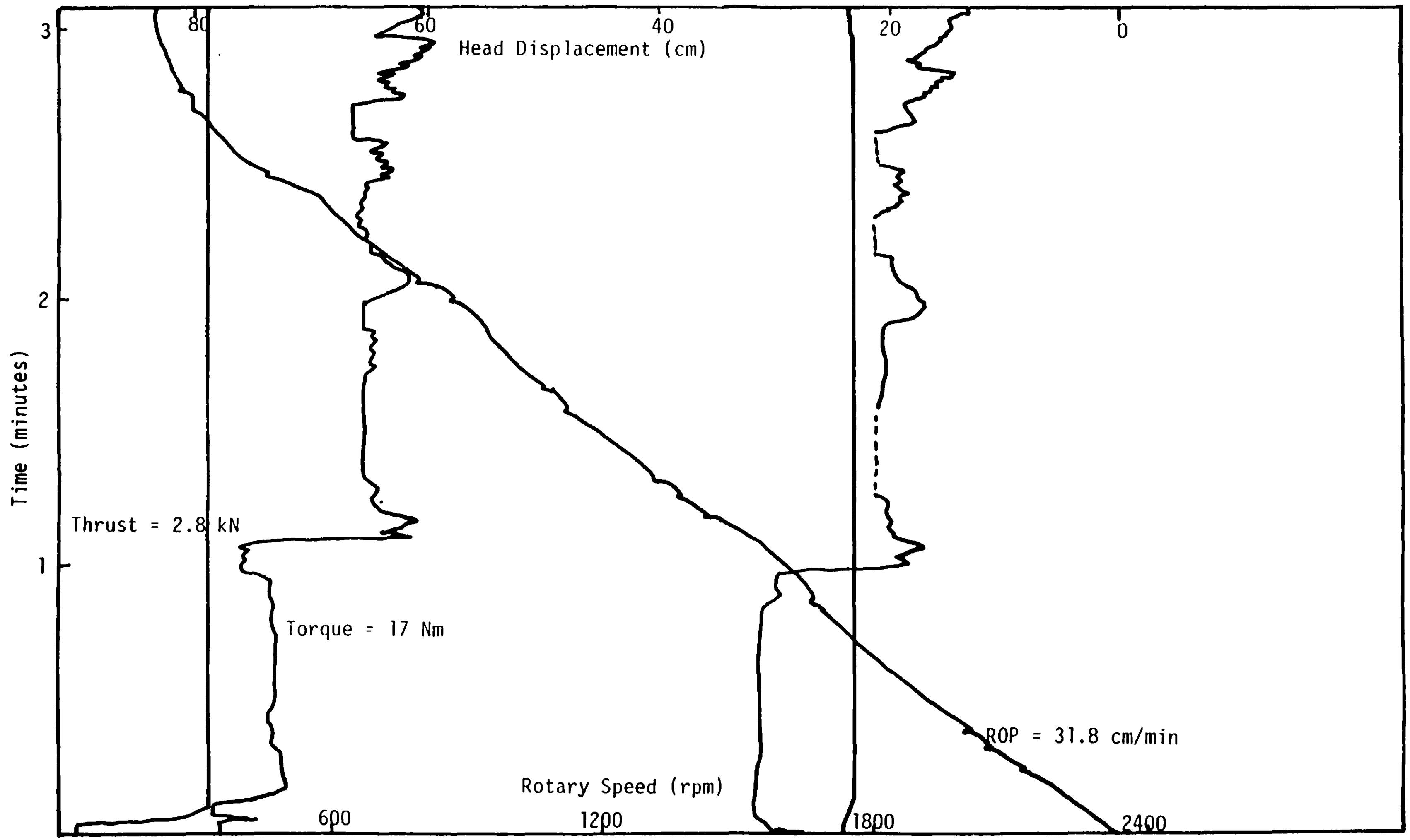
LABEL: FFT033 -FORM

SPOOLED: 82-03-10.15:15
STARTED: 82-03-10.15:23, ON: PRO BY: PRO

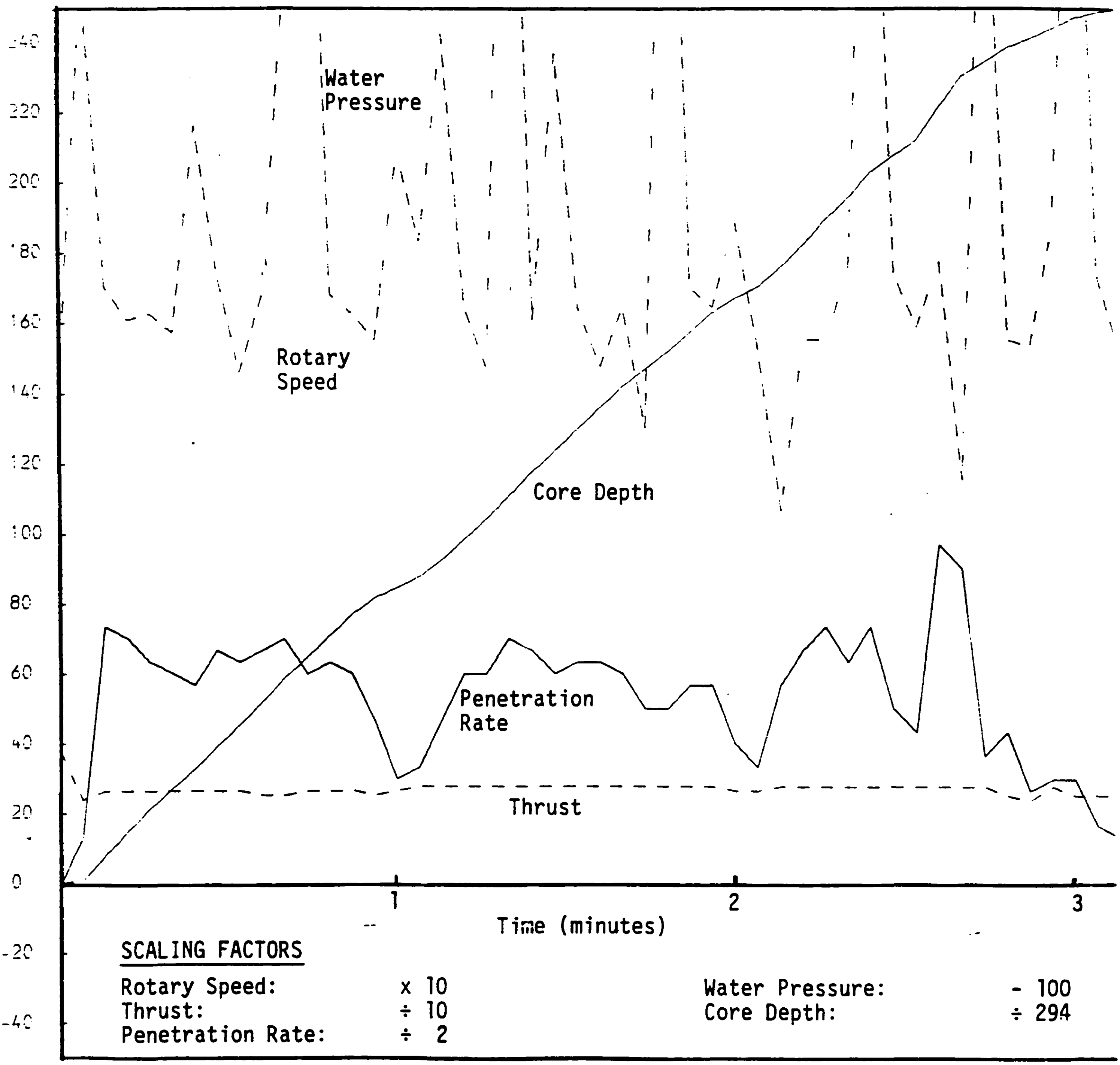
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5105616	12.81	0.000	0.00	1693.00	3.79	2.08	49.96	99.99	3.69
5105620	12.81	0.004	6.69	1544.96	2.41	19.60	157.94	99.99	6.30
5105624	12.84	0.025	36.81	1544.96	2.67	19.60	70.56	99.99	7.31
5105628	12.86	0.052	35.14	1568.19	2.67	16.85	61.20	99.99	6.93
5105632	12.88	0.074	31.79	1582.70	2.67	15.13	63.07	99.99	6.74
5105636	12.90	0.094	30.12	1588.50	2.67	14.45	57.45	99.99	6.55
5105640	12.92	0.113	28.44	1559.48	2.67	17.88	116.74	99.99	6.61
5105644	12.94	0.135	33.46	1565.28	2.67	17.19	74.31	99.99	6.81
5105648	12.97	0.156	31.79	1568.19	2.67	16.85	46.21	99.99	6.42
5105652	12.99	0.178	33.46	1565.28	2.54	17.19	68.69	99.99	6.93
5105656	13.01	0.202	35.14	1576.89	2.54	15.82	156.07	99.99	6.81
5105700	13.03	0.222	30.12	1573.99	2.67	16.16	290.92	99.99	6.74
5105704	13.05	0.243	31.79	1579.80	2.67	15.48	68.69	99.99	6.36
5105708	13.07	0.263	30.12	1571.09	2.67	16.51	63.07	99.99	6.42
5105712	13.09	0.279	23.42	1594.31	2.54	13.76	55.58	99.99	5.28
5105716	13.10	0.289	15.06	1620.43	2.67	10.67	109.24	99.99	5.40
5105720	13.11	0.300	16.73	1861.36	2.80	12.60	83.67	99.99	11.07
5105724	13.13	0.316	23.42	1843.95	2.80	14.16	142.96	99.99	10.69
5105728	13.15	0.336	30.12	1846.85	2.80	13.90	64.94	99.99	11.52
5105732	13.17	0.356	30.12	1800.41	2.80	18.08	47.44	99.99	11.52
5105736	13.19	0.375	35.14	1794.60	2.80	18.61	302.16	99.99	11.71
5105740	13.21	0.402	33.46	1806.21	2.80	17.56	61.20	99.99	11.64
5105744	13.23	0.422	30.12	1797.50	2.80	18.35	137.34	99.99	11.52
5105748	13.25	0.443	31.79	1791.70	2.80	18.87	64.94	99.99	11.71
5105752	13.27	0.464	31.79	1814.92	2.80	16.78	48.09	99.99	11.58
5105756	13.29	0.484	30.12	1838.14	2.80	14.69	64.94	99.99	11.33
5105800	13.31	0.501	25.10	1849.75	2.80	13.64	30.58	99.99	11.07
5105804	13.33	0.518	25.10	1826.53	2.80	15.73	283.43	99.99	11.07
5105808	13.35	0.537	28.44	1832.34	2.80	15.21	70.56	99.99	11.20
5105812	13.37	0.556	28.44	1872.97	2.80	11.55	64.94	99.99	11.20
5105816	13.38	0.569	20.08	1936.84	2.67	5.80	89.29	99.99	9.67
5105820	13.39	0.580	16.73	1867.17	2.67	12.07	53.71	99.99	10.37
5105824	13.41	0.599	28.44	1817.82	2.80	16.52	6.88	99.99	11.07
5105828	13.43	0.621	33.46	1765.57	2.80	21.22	55.58	99.99	11.07
5105832	13.46	0.646	36.81	1826.53	2.80	15.73	55.58	99.99	11.33
5105836	13.48	0.667	31.79	1849.75	2.80	13.64	76.18	99.99	10.94
5105840	13.50	0.692	36.81	1875.88	2.80	11.29	270.32	99.99	10.37
5105844	13.52	0.708	25.10	1843.95	2.80	14.16	74.31	99.99	10.94
5105848	13.53	0.723	21.75	1777.18	2.80	20.17	59.32	99.99	10.50
5105852	13.57	0.755	48.52	1814.92	2.80	16.78	78.05	99.99	11.26
5105856	13.60	0.785	45.18	1878.78	2.80	11.03	15.59	99.99	11.26
5105900	13.61	0.798	18.40	1867.17	2.80	12.07	227.24	99.99	10.24
5105904	13.62	0.812	21.75	1951.35	2.54	4.50	55.58	99.99	10.12
5105908	13.63	0.821	13.38	2006.50	2.41	0.47	53.71	99.99	9.10
5105912	13.64	0.831	15.06	1899.10	2.80	9.20	87.42	99.99	10.18
5105916	13.65	0.841	15.06	1968.77	2.54	2.93	253.46	99.99	9.03
5105920	13.66	0.847	8.37	1994.89	2.54	0.58	74.31	99.99	8.72
5105924	13.66	0.851	6.69	2050.04	2.54	4.39	53.05	99.99	8.08



RECORD OF CORSHAM DRILL RUN 3.12.3 (10.81 to 13.66 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.12.3 (12.81 to 13.66 metres)



USER: EX9069 -AT SYSTEM

NR_C3.12.4

EX9069

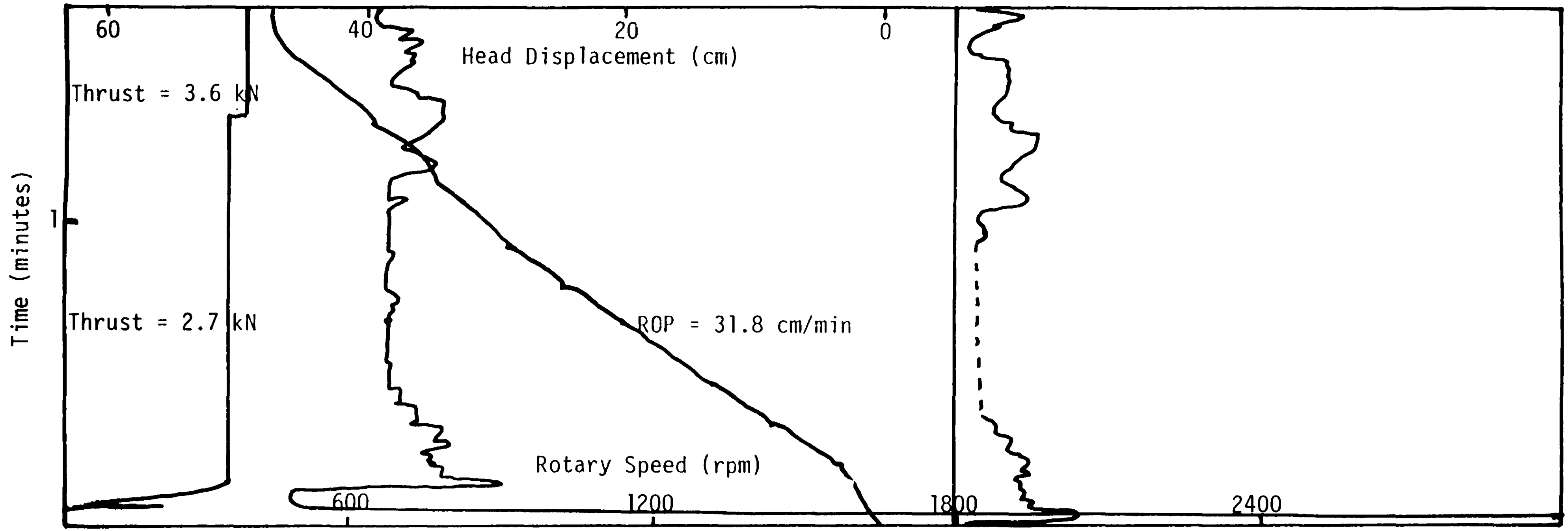
NR_C3.12.4

LABEL: PRT034 -FORM

SPOOLED: 82-03-10.19:15
STARTED: 82-03-10.19:24, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5105552	13.66	0.000	0.00	1928.13	0.83	12.39	57.45	3.41	8.14
5105556	13.67	0.012	16.75	1899.10	2.80	14.85	70.56	3.41	9.93
5110000	13.68	0.022	15.29	1907.81	2.54	14.11	57.45	95.99	9.42
5110004	13.69	0.031	13.28	1870.07	2.67	17.32	193.53	3.41	9.86
5110008	13.70	0.045	20.08	1832.34	2.67	20.52	94.91	3.41	10.56
5110012	13.72	0.065	30.12	1774.28	2.67	25.46	53.71	3.41	11.01
5110016	13.75	0.090	38.48	1745.25	2.67	27.92	74.31	3.41	11.01
5110020	13.78	0.117	40.16	1751.06	2.67	27.43	182.29	3.41	11.45
5110024	13.80	0.143	38.48	1809.11	2.67	22.50	163.56	3.41	10.88
5110028	13.82	0.164	31.79	1817.82	2.54	21.76	59.32	3.41	10.50
5110032	13.85	0.185	31.79	1809.11	2.67	22.50	74.31	3.41	10.88
5110040	13.89	0.229	32.63	1794.60	2.67	23.73	225.37	3.41	11.07
5110044	13.91	0.252	35.14	1794.60	2.67	23.73	74.31	3.41	10.75
5110046	13.94	0.276	35.14	1841.04	2.67	19.79	57.45	3.41	10.43
5110052	13.96	0.297	31.79	1812.02	2.67	22.25	87.42	3.41	10.94
5110056	13.97	0.312	23.42	1884.59	2.54	16.09	64.94	3.41	9.35
5110100	13.99	0.330	26.77	1870.07	2.67	17.32	74.31	3.41	10.24
5110104	14.01	0.347	25.10	1951.35	2.54	10.42	36.20	3.41	9.16
5110108	14.02	0.356	13.38	1945.54	2.54	10.91	124.23	3.41	8.91
5110112	14.03	0.374	26.77	1823.63	3.46	21.26	59.32	3.41	10.37
5110116	14.06	0.396	33.46	1887.49	3.46	15.84	64.94	3.41	9.86
5110124	14.09	0.433	27.61	1800.41	3.60	23.24	328.38	3.41	11.14
5110128	14.12	0.455	33.46	1855.56	3.60	18.55	79.93	3.41	10.56
5110132	14.13	0.465	20.08	1902.00	3.60	14.61	63.07	3.41	9.48
5110136	14.13	0.472	5.02	23.92	4.72	174.15	63.14	95.99	-1.35



RECORD OF CORSHAM DRILL RUN 3.12.4 (13.66 to 14.13 metres)

USER: EX9269 -AT SYSTEM

NR_C3.13.1

EX9269

NR_C3.13.1

LABEL: PRT035 -FORM

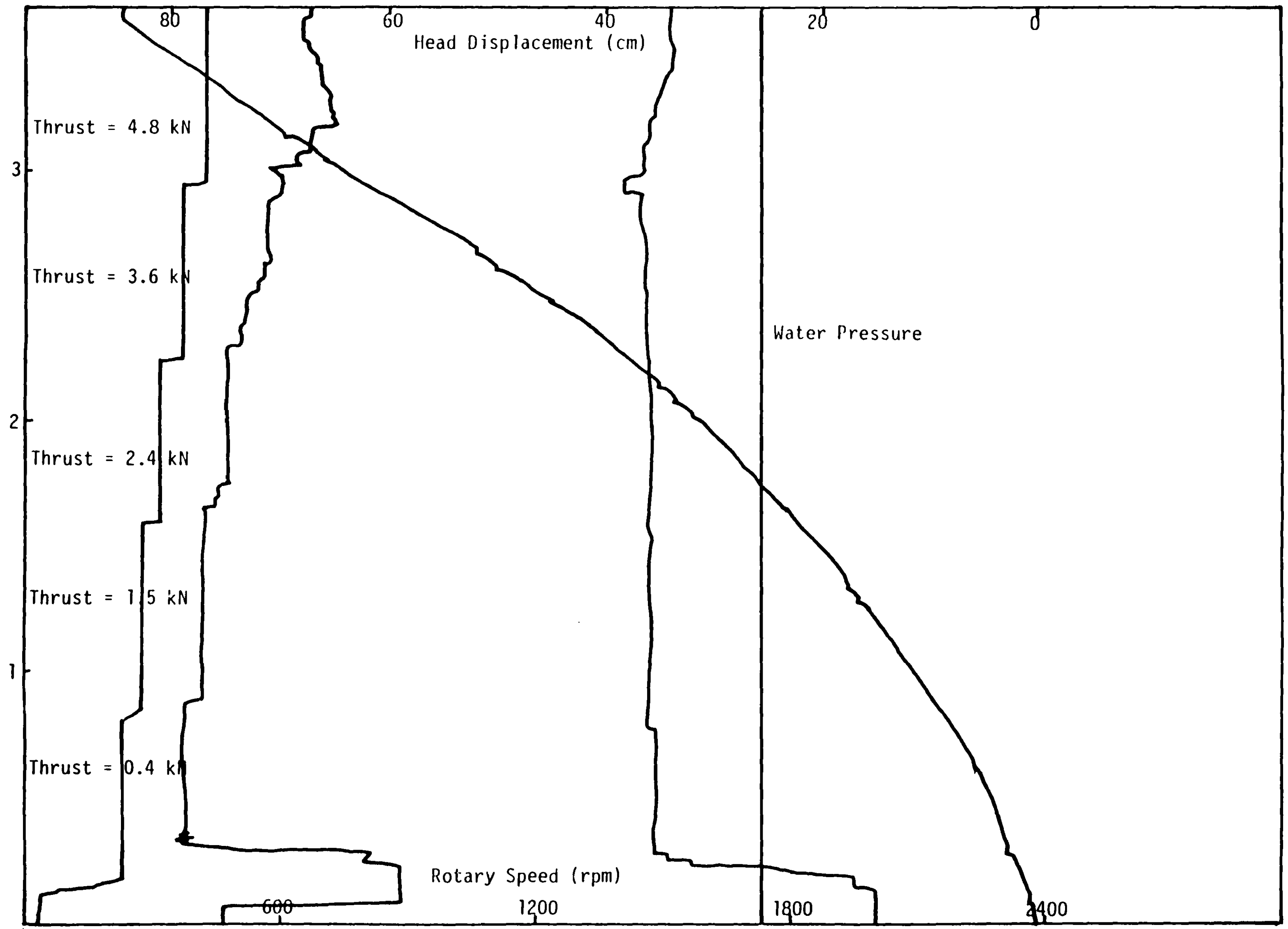
SPOOLED: 82-03-10.19:15
STARTED: 82-03-10.19:24, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

827-

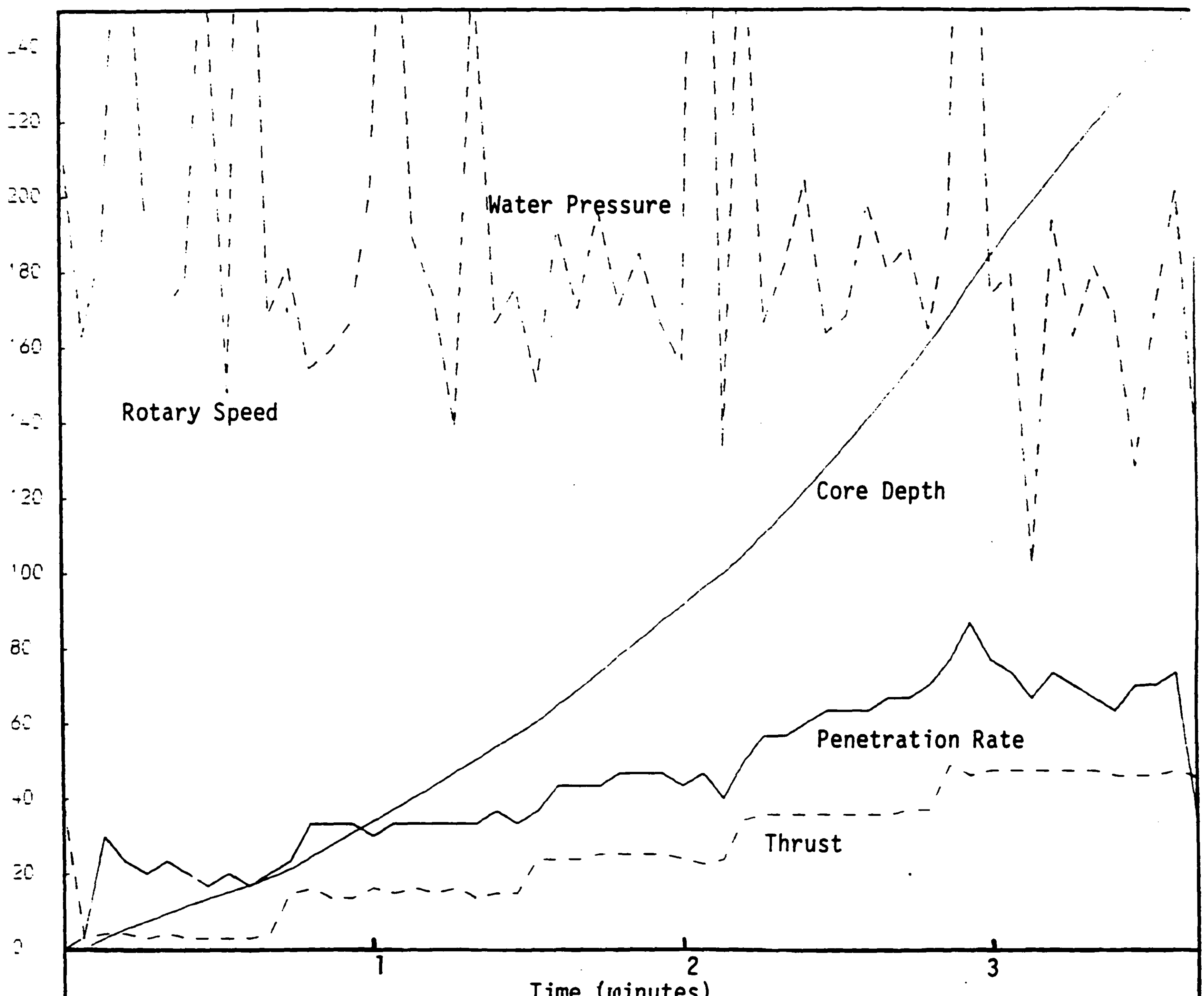
TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5112236	14.13	0.000	0.00	2038.43	3.92	3.02	116.74	3.41	8.97
5112240	14.13	0.001	1.67	1957.15	0.30	9.92	63.07	3.41	8.97
5112244	14.14	0.011	15.06	1771.38	0.43	25.70	87.42	99.99	7.82
5112248	14.15	0.019	11.71	1478.20	0.42	33.47	217.53	99.99	4.70
5112252	14.16	0.026	10.04	1486.91	0.29	32.51	98.69	3.41	4.57
5112256	14.16	0.033	11.71	1489.81	0.42	32.19	70.62	99.99	4.38
5112300	14.17	0.040	10.04	1489.81	0.29	32.19	78.11	99.99	4.32
5112304	14.18	0.046	8.37	1484.01	0.29	32.83	174.49	99.99	4.38
5112308	14.18	0.052	10.04	1486.91	0.29	32.51	48.17	3.41	4.32
5112312	14.19	0.058	8.37	1484.01	0.29	32.83	269.92	99.99	4.32
5112316	14.19	0.065	10.04	1486.91	0.42	32.51	68.75	99.99	4.51
5112320	14.20	0.073	11.71	1469.49	1.48	34.42	81.85	99.99	5.08
5112324	14.21	0.084	16.73	1486.91	1.61	32.51	54.74	99.99	5.21
5112328	14.22	0.095	16.73	1489.81	1.35	32.19	59.40	99.99	5.40
5112332	14.24	0.106	16.73	1501.42	1.35	30.92	66.86	99.99	5.33
5112336	14.25	0.116	15.06	1484.01	1.61	32.83	102.43	99.99	5.33
5112340	14.26	0.127	16.73	1495.62	1.48	31.56	236.24	99.99	5.33
5112344	14.27	0.138	16.73	1501.42	1.61	30.92	89.33	99.99	5.27
5112348	14.28	0.149	16.73	1507.23	1.48	30.28	74.37	99.99	5.08
5112352	14.29	0.161	16.73	1501.42	1.61	24.75	38.81	99.99	5.14
5112356	14.30	0.172	16.73	1498.52	1.35	31.24	163.26	99.99	5.33
5112400	14.31	0.184	18.40	1489.81	1.48	32.19	66.88	99.99	5.27
5112404	14.33	0.195	16.73	1489.81	1.48	32.19	76.24	99.99	5.46
5112408	14.34	0.207	18.40	1472.39	2.40	34.10	51.00	99.99	5.84
5112412	14.35	0.222	21.75	1486.91	2.40	32.51	92.16	99.99	6.54
5112416	14.37	0.236	21.75	1495.62	2.40	31.56	70.62	99.99	6.42
5112420	14.38	0.251	21.75	1504.32	2.53	30.60	96.82	99.99	6.29
5112424	14.40	0.267	23.42	1492.71	2.53	25.78	71.58	99.99	6.35
5112428	14.41	0.282	23.42	1498.52	2.53	31.24	85.59	99.99	6.35
5112432	14.43	0.298	23.42	1504.32	2.53	24.41	66.88	99.99	6.35
5112436	14.44	0.312	21.75	1507.23	2.40	24.06	55.65	99.99	6.16
5112440	14.46	0.328	23.42	1498.52	2.27	25.09	329.79	99.99	6.35
5112444	14.47	0.341	20.08	1498.52	2.40	25.09	33.20	99.99	6.29
5112448	14.49	0.358	25.10	1475.30	3.46	33.79	187.59	99.99	6.92
5112452	14.51	0.377	28.44	1481.10	3.59	33.15	66.88	99.99	7.18
5112456	14.53	0.396	28.44	1481.10	3.59	33.15	81.85	99.99	7.43
5112500	14.55	0.416	30.12	1454.98	3.59	30.25	105.26	99.99	7.81
5112504	14.57	0.437	31.79	1443.37	3.59	31.62	64.10	99.99	8.07
5112508	14.59	0.458	31.79	1449.17	3.59	30.93	68.75	99.99	7.88
5112512	14.61	0.480	31.79	1466.59	3.59	28.87	98.69	99.99	7.94
5112516	14.63	0.502	33.46	1468.05	3.59	31.60	80.94	99.99	7.94
5112520	14.65	0.524	33.46	1436.15	3.72	35.24	87.46	99.99	8.20
5112524	14.68	0.548	35.14	1446.27	3.72	31.28	65.01	99.99	8.51
5112528	14.70	0.573	38.48	1423.05	4.91	34.02	93.08	99.99	8.07
5112532	14.73	0.602	43.50	1486.91	4.64	26.47	294.24	99.99	10.36
5112536	14.76	0.628	38.48	1460.78	4.77	35.38	74.37	99.99	10.36
5112540	14.78	0.653	36.81	1492.71	4.77	31.88	79.98	99.99	11.06
5112544	14.80	0.675	33.46	1507.23	4.77	30.28	2.35	99.99	11.19
5112548	14.83	0.699	36.81	1533.35	4.77	20.97	94.03	99.99	10.61
5112552	14.85	0.723	35.14	1543.44	4.77	22.99	63.14	99.99	10.61
5112556	14.88	0.745	33.46	1553.67	4.77	18.57	81.85	99.99	10.30
5112600	14.90	0.766	31.79	1559.48	4.64	17.88	70.62	99.99	10.23
5112604	14.92	0.790	35.14	1524.64	4.64	28.37	28.54	99.99	10.80
5112608	14.94	0.813	35.14	1544.96	4.64	26.14	70.62	99.99	10.74

	TOTAL	CORE	PENETRATN	ROTARY			INLET H2O	I. H2O	
5112612	14.97	0.838	36.81	1562.38	4.77	17.54	102.43	99.99	10.49
5112616	14.98	0.860	18.40	84.88	4.58	186.33	34.16	99.99	-1.09



RECORD OF CORSHAM DRILL RUN 3.13.1 (14.13 to 14.98 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.13.1 (14.13 to 14.98 metres)



SCALING FACTORS

Rotary Speed:	x 10	Water Pressure:	- 100
Thrust:	÷ 10	Core Depth:	÷ 294
Penetration Rate:	÷ 2		

USER: EM9069 -AT SYSTEM

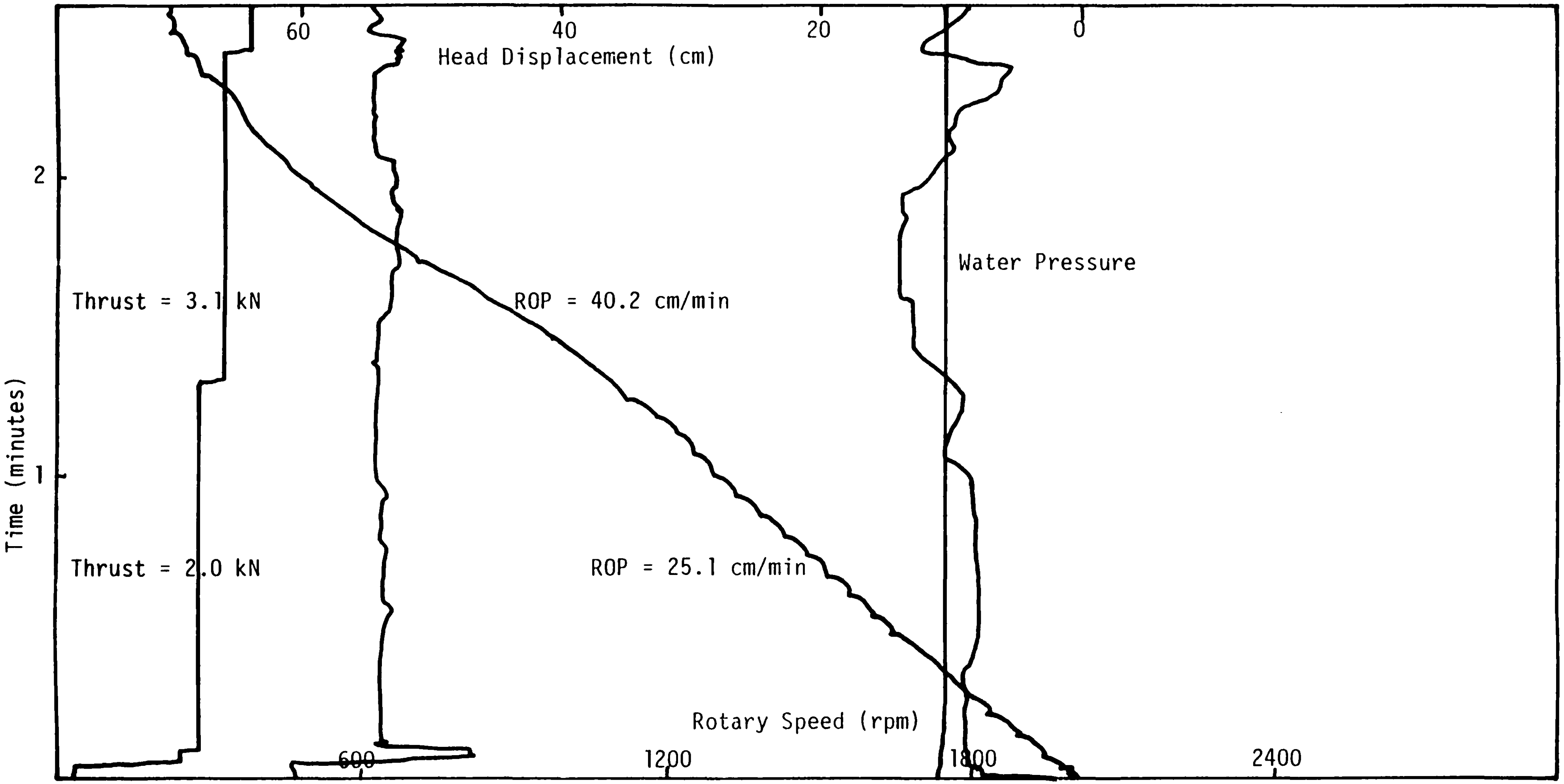
AR_C3.13.2

LABEL: FFTC36 -FORM

SPOOLED: 82-03-10.19:16
STARTED: 82-03-10.19:24, CN: PRO BY: PRO

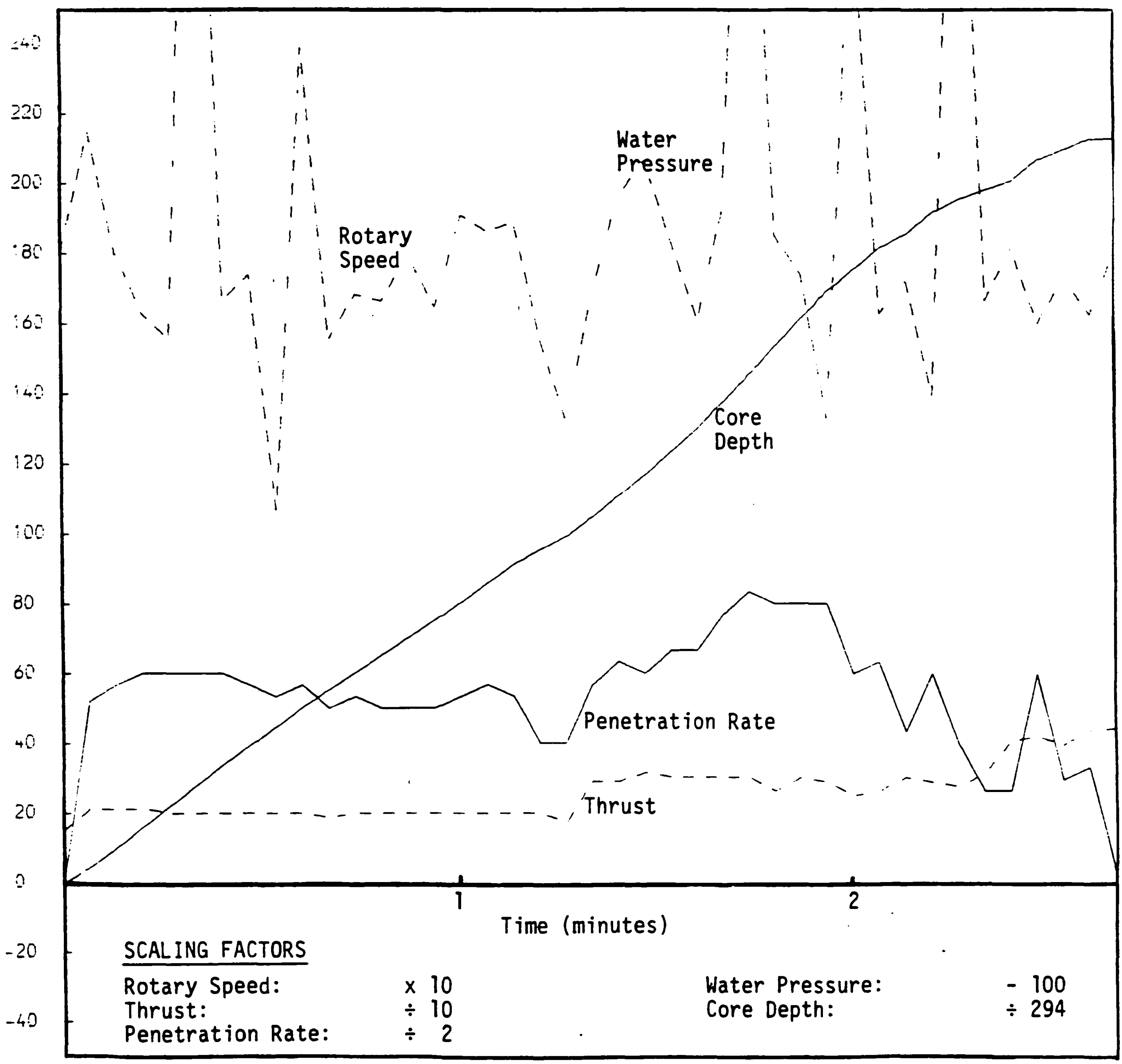
O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
511263[illegible]	14.98	0.000	0.00	1838.14	1.49	14.69	81.80	99.99	8.91
5112640	15.00	0.017	26.16	1788.79	2.15	19.13	114.86	99.99	11.52
5112644	15.02	0.036	28.44	1800.41	2.15	18.08	79.93	99.99	11.20
5112648	15.04	0.056	30.12	1800.41	2.15	18.08	63.07	99.99	11.26
5112652	15.06	0.076	30.12	1806.21	2.01	17.56	55.58	99.99	11.14
5112656	15.08	0.096	30.12	1785.89	2.01	19.39	304.03	99.99	11.20
5112700	15.10	0.116	30.12	1835.24	2.01	14.95	66.82	99.99	10.94
5112704	15.11	0.135	28.44	1843.95	2.01	14.16	74.31	99.99	10.43
5112708	15.13	0.153	26.77	1829.43	2.01	15.47	6.88	99.99	10.75
5112712	15.15	0.172	28.44	1820.72	2.01	16.25	139.21	99.99	10.82
5112716	15.17	0.189	25.10	1841.04	1.88	14.43	55.58	99.99	10.56
5112720	15.19	0.206	26.77	1812.02	2.01	17.04	68.69	99.99	10.82
5112724	15.20	0.223	25.10	1820.72	2.01	16.25	66.82	99.99	10.94
5112728	15.22	0.240	25.10	1832.34	2.01	15.21	79.93	99.99	10.50
5112732	15.24	0.257	25.10	1806.21	2.01	17.56	64.94	99.99	10.82
5112736	15.25	0.274	26.77	1809.11	2.01	17.30	91.17	99.99	10.75
5112740	15.27	0.293	28.44	1742.35	2.01	23.31	86.55	99.99	11.38
5112744	15.29	0.311	26.77	1780.09	2.01	19.91	89.33	99.99	11.31
5112748	15.30	0.325	20.08	1806.21	2.01	17.56	55.58	99.99	10.88
5112752	15.32	0.338	20.08	1814.92	1.75	16.78	32.45	99.99	10.56
5112756	15.34	0.357	28.44	1719.13	2.93	25.40	68.75	99.99	11.63
5112800	15.36	0.378	31.79	1711.64	2.93	28.35	96.82	99.99	11.50
5112804	15.38	0.398	30.12	1675.59	3.19	29.32	107.13	99.99	11.95
5112808	15.40	0.421	33.46	1672.68	3.06	29.58	83.72	99.99	12.08
5112812	15.42	0.443	33.46	1646.56	3.06	31.93	61.27	99.99	12.01
5112816	15.45	0.469	38.48	1663.98	3.06	30.37	93.08	99.99	12.14
5112820	15.48	0.496	41.83	1655.27	3.06	31.15	264.30	99.99	12.08
5112824	15.50	0.523	40.16	1690.10	2.67	28.01	85.59	99.99	12.01
5112828	15.53	0.550	40.16	1666.88	3.06	30.11	74.37	99.99	11.76
5112832	15.56	0.577	40.16	1681.39	2.93	28.80	33.20	99.99	11.82
5112836	15.58	0.597	30.12	1756.86	2.53	22.00	183.85	99.99	11.06
5112840	15.60	0.618	31.79	1794.60	2.67	18.61	63.14	99.99	11.06
5112844	15.61	0.632	21.75	1762.67	3.06	21.48	72.49	99.99	10.87
5112848	15.63	0.653	30.12	1806.21	2.93	17.56	39.77	99.99	10.61
5112852	15.65	0.666	20.08	1872.97	2.80	11.55	266.58	99.99	10.24
5112856	15.65	0.675	13.38	1875.88	3.19	11.29	66.86	99.99	9.66
5112900	15.66	0.684	13.38	1745.25	4.11	23.05	81.85	99.99	10.42
5112904	15.68	0.704	30.12	1782.99	4.25	19.65	60.35	99.99	11.19
5112908	15.69	0.714	15.06	1812.02	3.99	17.04	73.66	99.99	10.50
5112912	15.71	0.725	16.73	1971.67	4.39	2.67	63.07	99.99	10.24
5112916	15.71	0.726	1.67	23.92	4.45	176.14	81.85	99.99	-1.15



RECORD OF CORSHAM DRILL RUN 3.13.2 (14.98 to 15.71 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.13.2 (14.98 to 15.71 metres)



USER: EX5069 -AT SYSTEM

NP_C3.14.1

EX5069

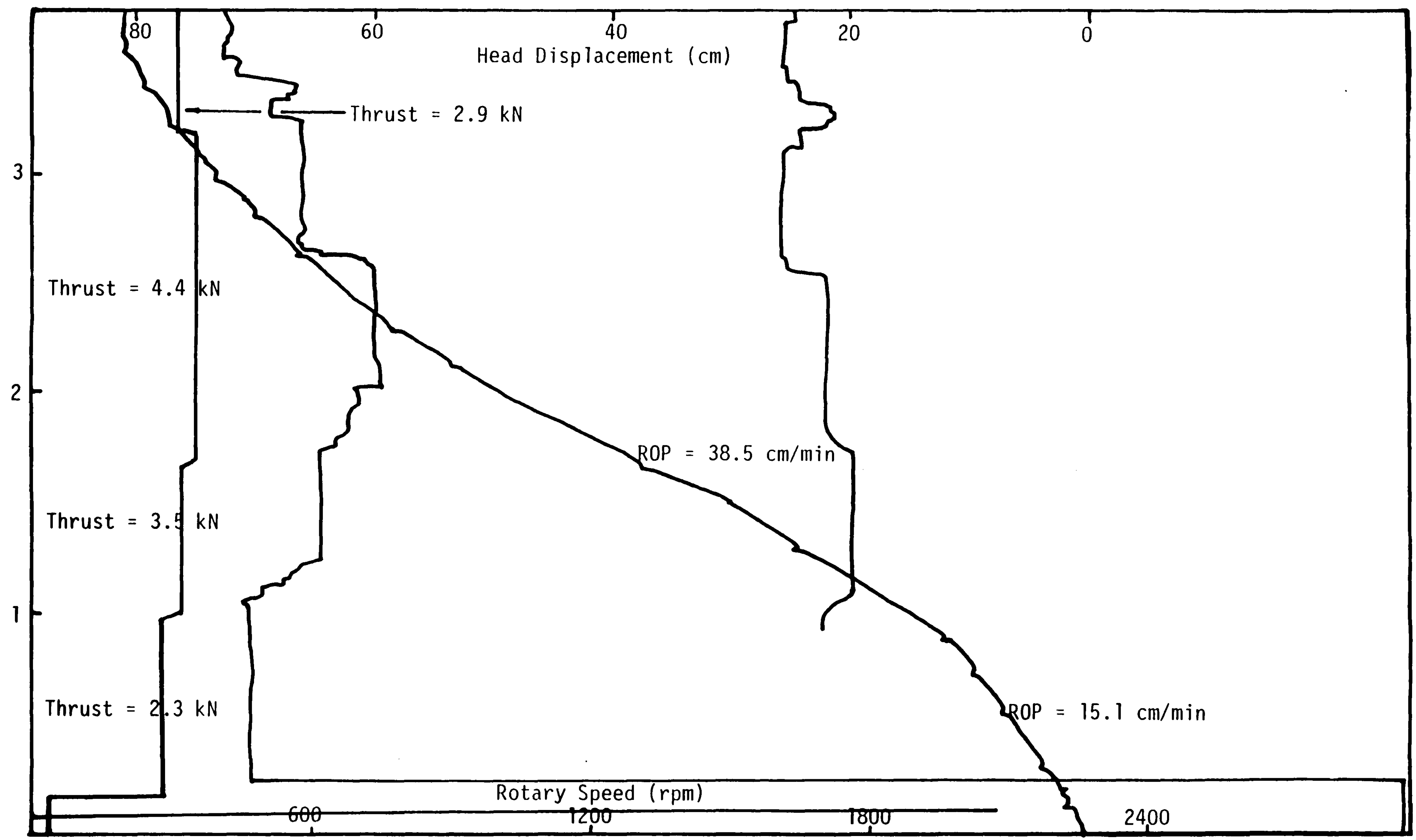
NP_C3.14.1

LABEL: FRTC37 -FORM

SPOOLED: 82-03-10.19:16
STARTED: 82-03-10.19:24, ON: PRO BY: PRO

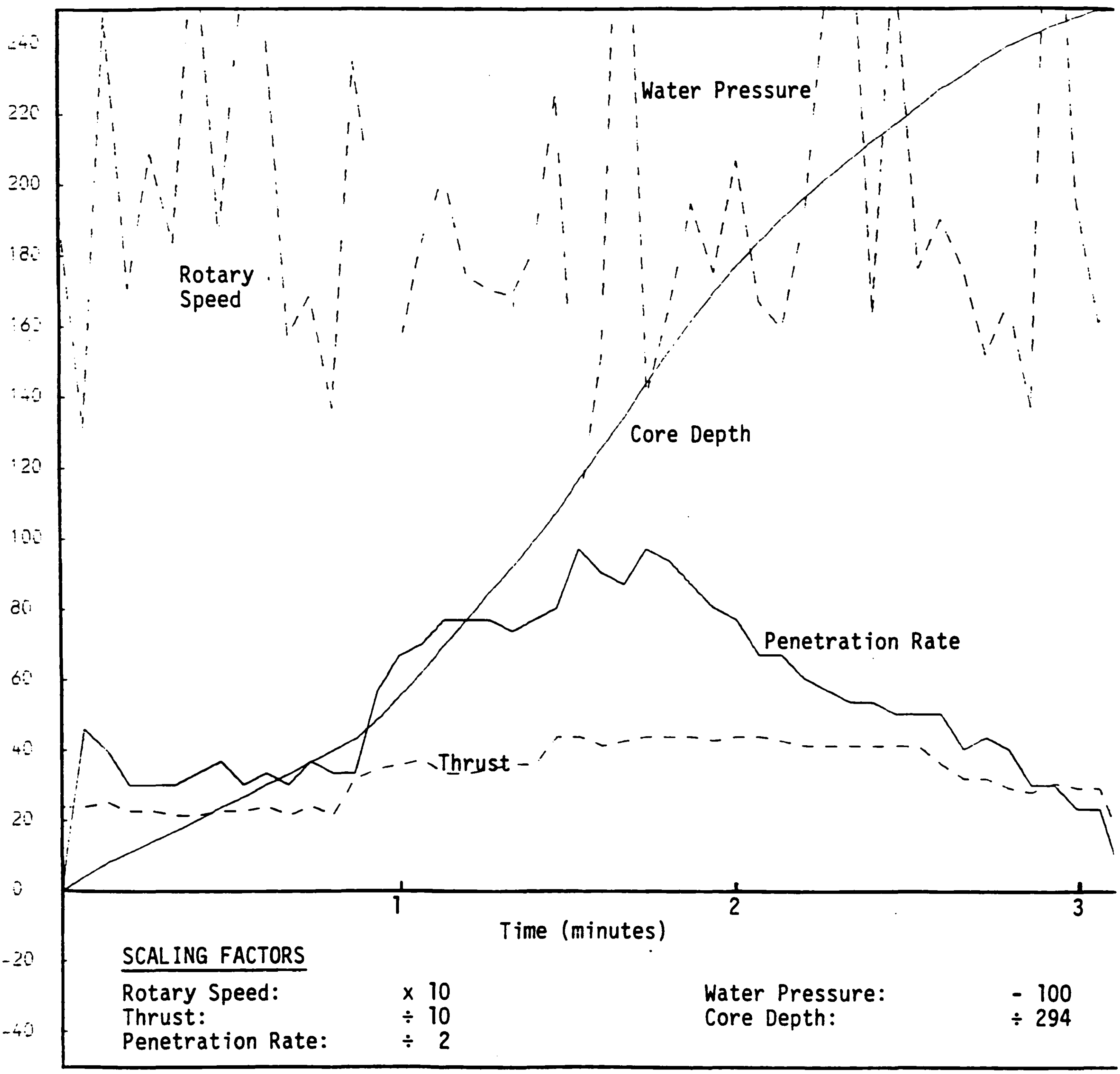
O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

[redacted]	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
[redacted]	15.71	0.000	0.00	2036.42	2.40	5.92	91.21	4.85	9.60
[redacted]	15.72	0.015	23.09	832.34	2.40	20.52	31.45	4.85	9.79
[redacted]	15.74	0.028	20.08	1740.63	2.53	30.40	148.29	4.85	7.43
[redacted]	15.75	0.036	15.06	1729.03	2.27	31.36	70.62	4.85	7.43
[redacted]	15.76	0.048	15.06	1729.03	2.27	31.36	109.00	4.85	7.24
[redacted]	15.77	0.058	15.06	1702.94	2.14	33.52	83.72	4.85	7.50
[redacted]	15.78	0.065	16.73	1711.64	2.14	32.80	174.49	4.85	7.88
[redacted]	15.79	0.081	18.40	1711.64	2.27	32.80	85.59	4.85	7.69
[redacted]	15.80	0.091	15.06	1726.13	2.27	31.60	152.04	4.85	7.62
[redacted]	15.81	0.103	16.73	1723.23	2.40	31.84	153.91	4.85	7.50
[redacted]	15.82	0.113	15.05	1717.44	2.14	32.32	57.53	4.85	7.75
[redacted]	15.83	0.125	18.40	1731.93	2.40	31.12	68.75	4.85	7.31
[redacted]	15.85	0.136	16.73	1731.93	2.14	31.12	36.94	3.41	7.18
[redacted]	15.86	0.147	16.73	1688.44	3.19	34.72	135.20	4.85	7.37
[redacted]	15.88	0.166	28.44	1717.44	3.46	32.32	85.59	3.41	9.53
[redacted]	15.90	0.189	33.46	1787.03	3.59	26.56	53.78	3.41	10.80
[redacted]	15.92	0.212	35.13	1766.73	3.72	28.24	83.72	4.85	11.31
[redacted]	15.95	0.238	38.48	1769.63	3.32	28.00	103.39	3.41	11.50
[redacted]	15.97	0.263	38.48	1763.83	3.32	28.48	74.37	4.85	11.31
[redacted]	16.00	0.285	38.48	1746.43	3.46	29.92	70.62	3.41	11.50
[redacted]	16.02	0.313	36.81	1746.43	3.59	29.92	68.75	4.85	11.50
[redacted]	16.05	0.339	38.48	1758.03	3.59	28.96	81.85	3.41	11.57
[redacted]	16.08	0.366	40.16	1685.54	4.38	30.64	125.84	3.41	12.14
[redacted]	16.11	0.398	48.52	1679.74	4.38	31.15	9.83	3.41	12.39
[redacted]	16.14	0.428	45.18	1659.44	4.11	32.92	51.91	3.41	12.78
[redacted]	16.17	0.457	43.50	1700.04	4.25	29.37	234.36	3.41	13.60
[redacted]	16.20	0.490	48.52	1717.44	4.38	27.84	40.69	3.41	13.60
[redacted]	16.23	0.521	46.85	1702.94	4.38	29.11	65.01	3.41	13.54
[redacted]	16.26	0.550	43.50	1705.84	4.38	28.86	94.95	3.41	13.48
[redacted]	16.29	0.577	40.16	1688.44	4.25	30.38	75.32	3.41	13.73
[redacted]	16.31	0.602	38.48	1717.44	4.38	27.84	107.13	3.41	13.48
[redacted]	16.33	0.625	33.46	1714.54	4.38	28.10	66.88	3.41	13.48
[redacted]	16.36	0.647	33.46	1697.14	4.25	29.62	59.40	3.41	11.82
[redacted]	16.38	0.667	30.12	1572.44	4.11	40.54	89.33	3.41	8.96
[redacted]	16.40	0.686	28.44	1578.24	4.11	40.03	153.91	3.41	9.09
[redacted]	16.41	0.704	26.77	1572.44	4.11	40.54	200.69	3.41	8.96
[redacted]	16.43	0.722	26.77	1586.94	4.11	39.27	63.14	3.41	8.90
[redacted]	16.45	0.738	25.10	1584.04	4.11	39.53	167.01	3.41	9.15
[redacted]	16.47	0.755	25.10	1575.34	4.11	40.29	76.24	3.41	9.15
[redacted]	16.48	0.772	25.10	1642.04	3.59	34.45	90.29	3.41	8.90
[redacted]	16.50	0.785	20.08	1633.34	3.19	35.21	76.24	3.41	7.75
[redacted]	16.51	0.800	21.75	1752.23	3.19	24.80	51.91	3.41	10.04
[redacted]	16.52	0.813	20.08	1615.94	2.93	36.73	66.88	3.41	6.29
[redacted]	16.53	0.823	15.05	1572.44	2.80	40.54	36.94	3.41	5.40
[redacted]	16.54	0.833	15.05	1566.64	3.06	41.05	238.11	3.41	5.97
[redacted]	16.55	0.841	11.71	1604.34	2.93	37.75	96.82	3.41	5.27
[redacted]	16.56	0.849	11.71	1633.34	2.93	35.21	61.27	3.41	5.08
[redacted]	16.56	0.850	1.67	1154.86	1.35	72.86	76.24	3.41	4.32



RECORD OF CORSHAM DRILL RUN 3.14.1 (15.71 to 16.56 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.14.1 (15.71 to 16.56 metres)



USER: EX9969 -AT SYSTEM

NR_C3.14.2

EX9969

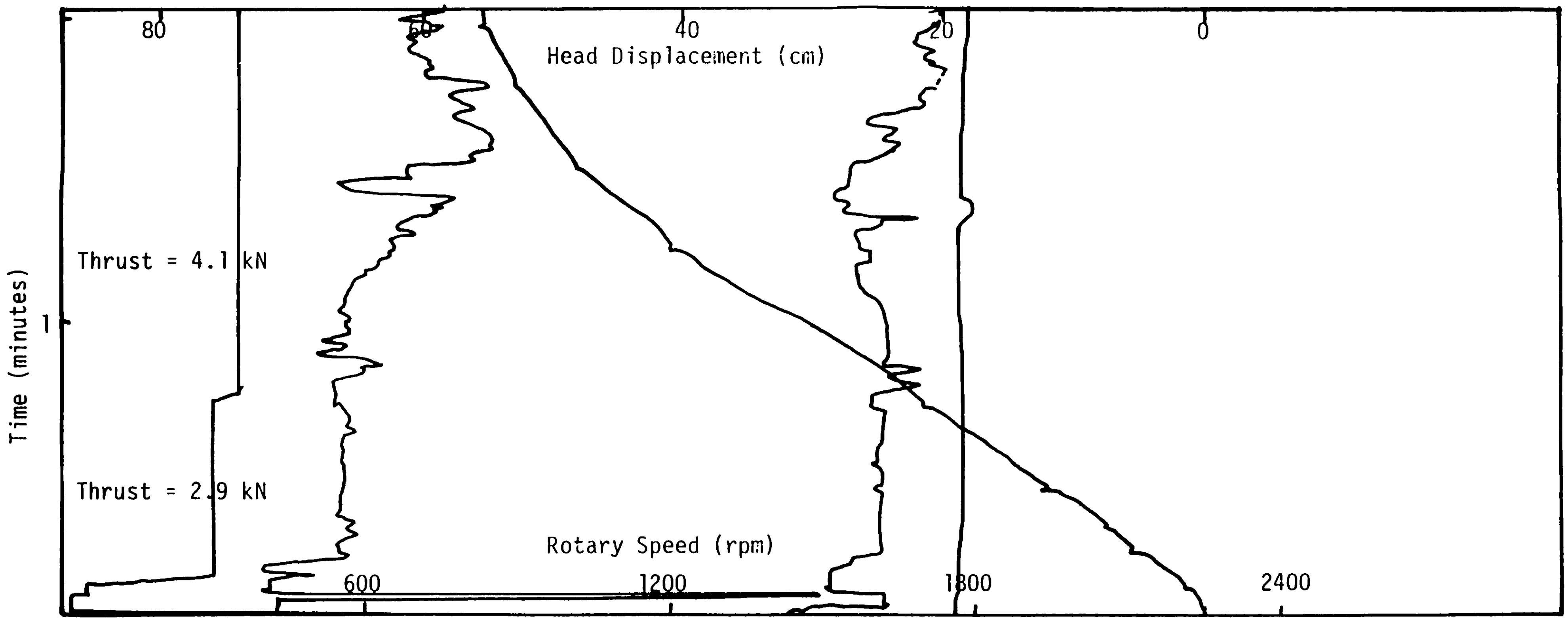
NR_C3.14.2

LABEL: PRT038 -FORM

SPOOLED: 82-03-10.19:16
STARTED: 82-03-10.19:25, ON: PRO BY: PRO

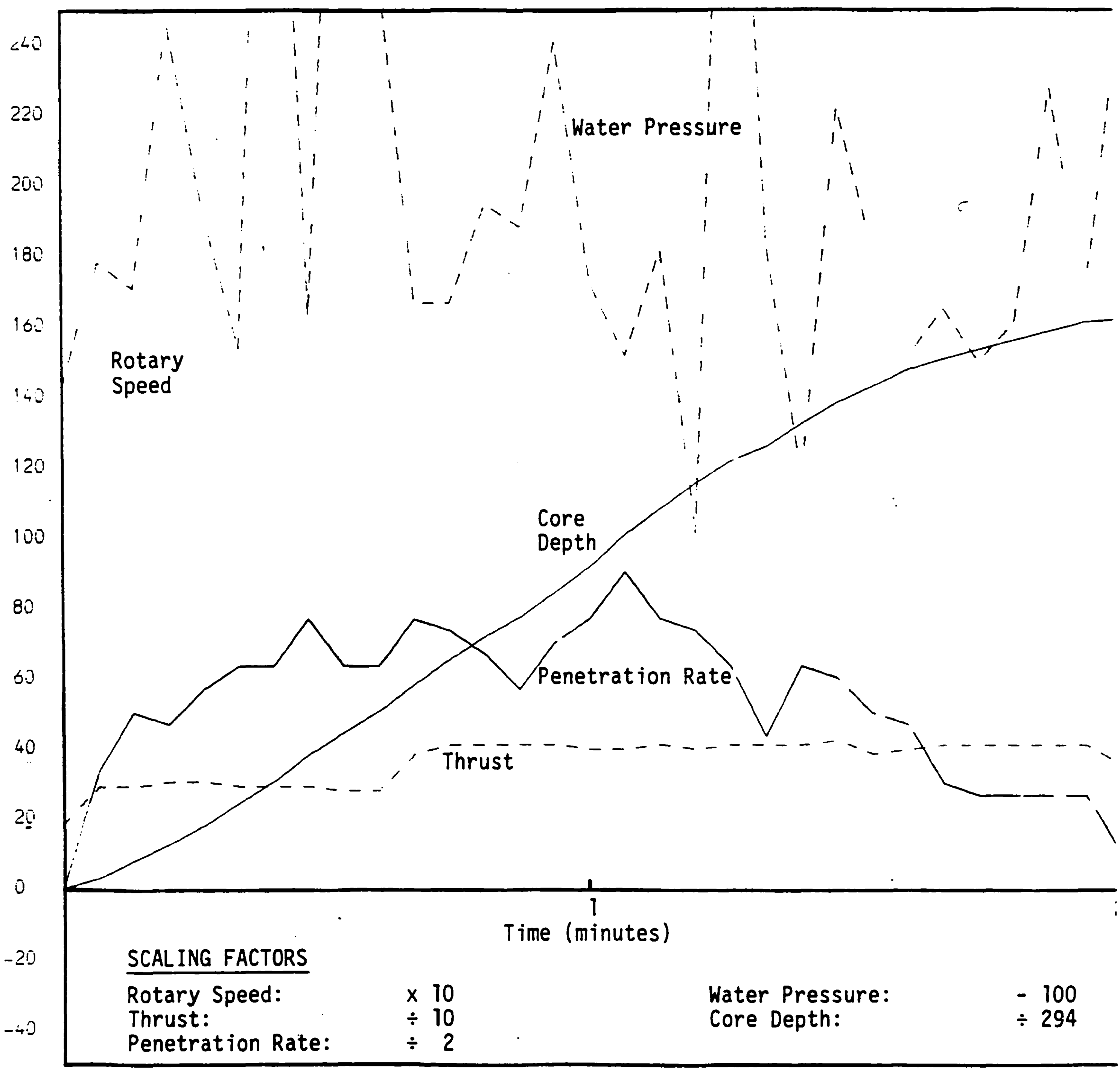
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H20 PRESSURE (KN/M**2)	I. H20 FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5151200	16.56	0.000	0.00	1592.74	1.82	29.47	43.51	95.99	5.40
5151204	16.57	0.011	16.93	1491.25	2.93	39.53	78.11	95.99	7.56
5151208	16.59	0.028	25.10	1618.84	2.93	26.85	70.62	95.99	8.32
5151212	16.60	0.044	23.42	1610.14	3.06	27.75	146.42	95.99	8.83
5151216	16.62	0.062	28.44	1592.74	3.06	29.47	93.08	95.99	8.51
5151220	16.64	0.084	31.79	1595.64	2.93	29.19	53.78	95.99	8.71
5151224	16.66	0.105	31.79	1604.34	2.93	28.32	303.60	99.99	8.39
5151228	16.69	0.131	38.48	1610.14	2.93	27.75	63.14	99.99	8.50
5151232	16.71	0.152	31.79	1624.64	2.80	26.31	268.04	99.99	8.26
5151236	16.73	0.173	31.79	1613.04	2.80	27.46	163.26	99.99	8.32
5151240	16.76	0.199	38.48	1659.44	3.85	22.86	66.88	99.99	9.28
5151244	16.78	0.223	36.81	1581.14	4.11	30.62	66.88	99.99	8.83
5151248	16.81	0.245	33.46	1601.44	4.11	28.61	94.95	99.99	8.58
5151252	16.82	0.264	28.44	1604.34	4.11	28.32	88.42	99.99	8.58
5151256	16.85	0.288	35.13	1575.34	4.11	31.20	140.81	99.99	9.02
5151300	16.87	0.313	38.48	1531.84	3.98	35.51	72.49	95.99	9.72
5151304	16.90	0.344	45.18	1540.54	3.98	34.65	51.91	99.99	10.30
5151308	16.93	0.365	38.48	1578.24	4.11	30.91	81.85	95.99	10.74
5151312	16.95	0.394	36.81	1555.04	3.98	33.21	1.39	95.99	11.89
5151316	16.97	0.415	31.79	1494.15	4.11	39.24	294.24	95.99	9.28
5151320	16.99	0.429	21.75	1514.45	4.11	37.23	83.72	95.99	12.46
5151324	17.01	0.451	31.79	1543.44	4.11	38.99	17.32	95.99	14.30
5151328	17.03	0.471	30.12	1656.54	4.25	28.47	122.10	95.99	13.67
5151332	17.05	0.487	25.10	1630.44	3.85	30.90	81.85	99.99	13.67
5151336	17.06	0.503	23.42	1644.94	3.98	29.55	51.91	99.99	14.18
5151340	17.07	0.513	15.05	1697.14	4.11	24.70	65.01	99.99	13.22
5151344	17.08	0.522	13.38	1752.23	4.11	19.58	50.04	95.99	12.52
5151348	17.09	0.531	13.38	1700.04	4.11	24.43	61.27	99.99	13.16
5151352	17.10	0.540	13.38	1708.74	4.11	23.62	127.71	99.99	13.09
5151356	17.11	0.549	13.38	1787.03	4.11	16.34	68.75	99.99	12.14
5151400	17.11	0.552	5.02	23.92	3.53	176.14	152.04	99.99	-1.35



RECORD OF CORSHAM DRILL RUN 3.14.2 (16.56 to 17.11 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.14.2 (16.56 to 17.11 metres)



USER: EX5069 -AT SYSTEM

NR_C3.15

EX5069

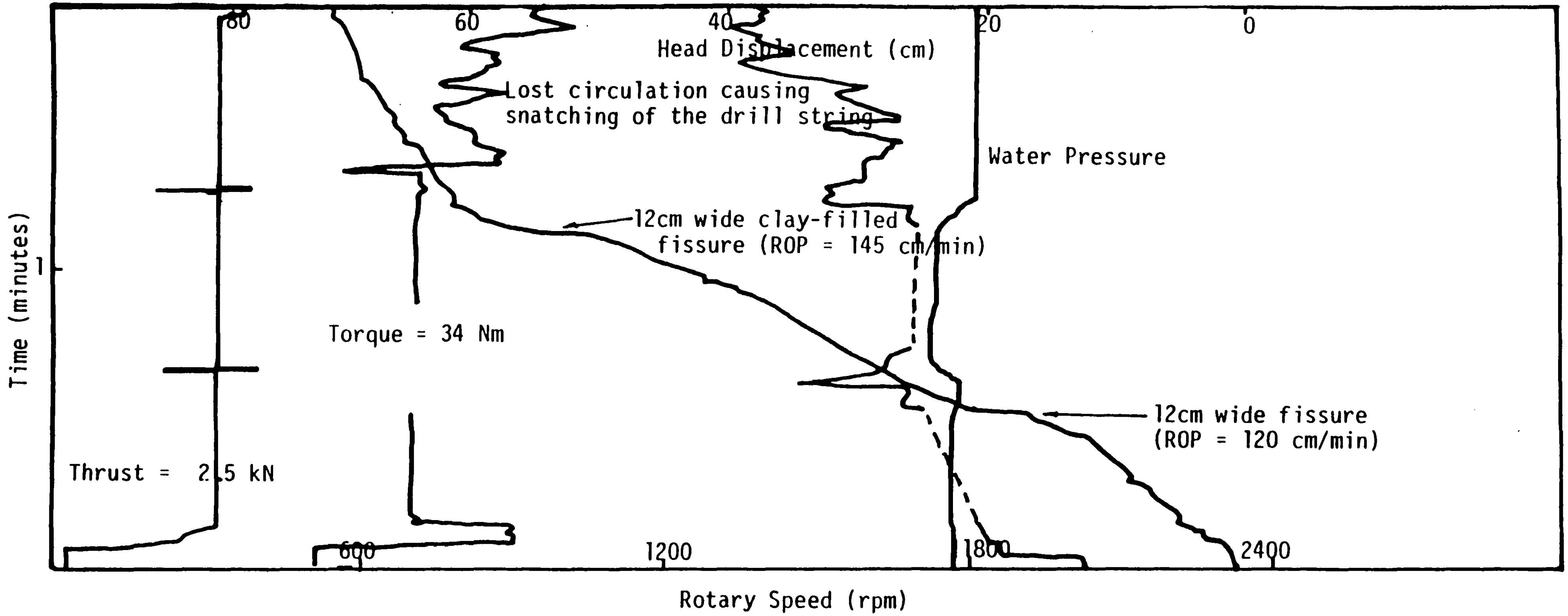
NR_C3.15

LABEL: FRTC39 -FORM

SPOOLED: 82-03-10.19:16
STARTED: 82-03-10.19:25, ON: PRO BY: PRO

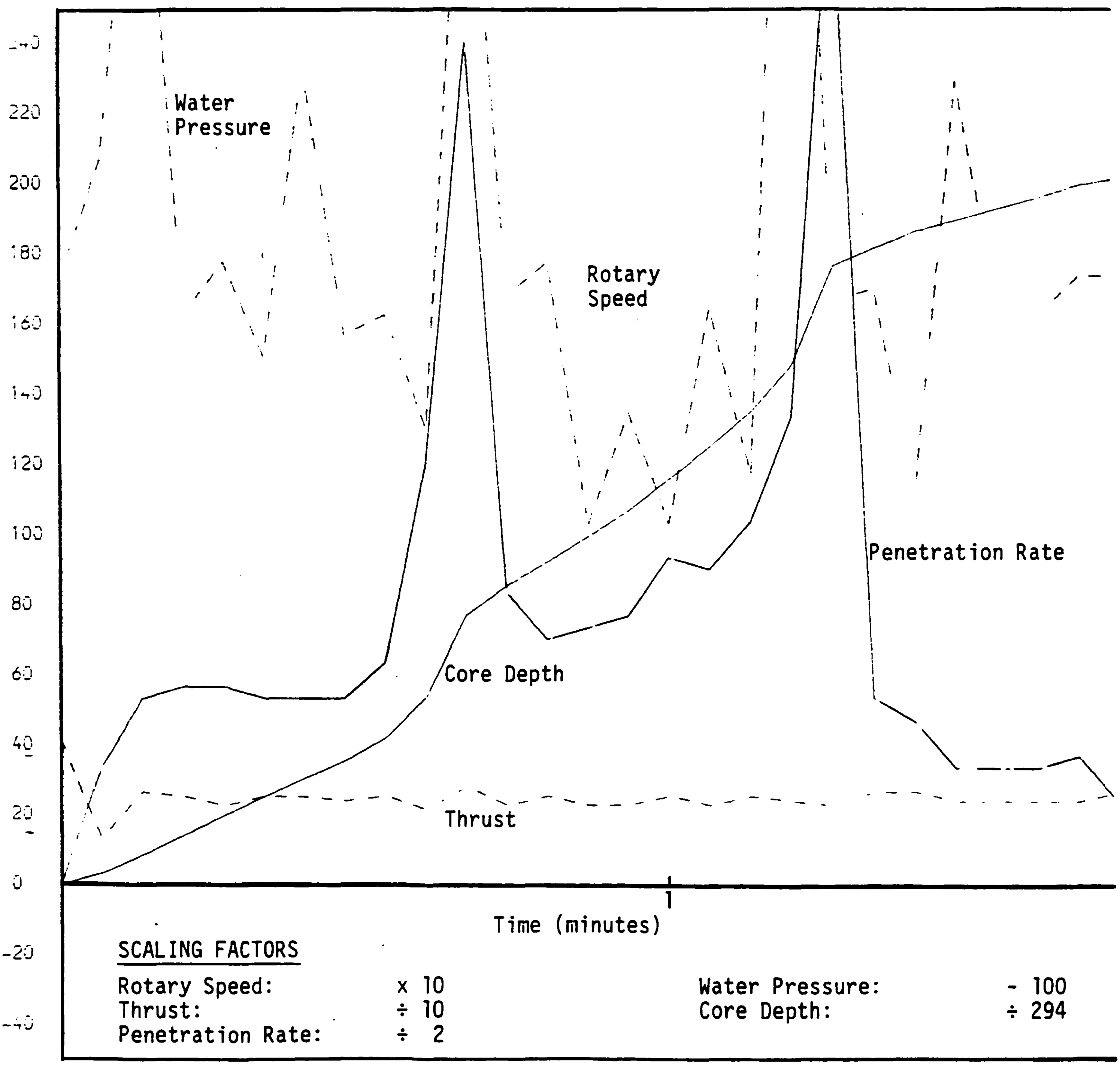
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRAIN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5153244	17.11	0.000	0.00	2023.92	4.19	9.87	72.49	99.99	9.66
5153248	17.12	0.012	16.93	1814.92	1.35	26.67	107.13	95.99	12.01
5153252	17.14	0.030	26.73	1737.73	2.67	34.74	230.62	99.99	12.84
5153256	17.16	0.049	28.40	1746.43	2.53	34.66	63.14	99.99	12.71
5153300	17.18	0.068	28.40	1720.33	2.27	36.11	78.11	99.99	12.84
5153304	17.20	0.086	26.73	1729.33	2.53	35.43	51.00	99.99	12.78
5153308	17.21	0.104	26.73	1758.03	2.53	33.15	133.33	99.99	12.52
5153312	17.23	0.121	26.73	1755.13	2.40	29.20	57.53	99.99	12.65
5153316	17.25	0.143	31.75	1633.34	2.53	39.28	63.14	3.41	12.52
515332	17.29	0.183	60.16	1604.34	2.14	41.68	30.42	99.99	13.16
5153324	17.37	0.263	120.31	1639.14	2.80	38.80	225.01	99.99	13.35
5153328	17.40	0.291	41.77	1688.44	2.27	34.72	68.75	3.41	13.16
5153332	17.42	0.314	35.09	1697.14	2.53	34.00	78.11	3.41	12.78
5153336	17.45	0.335	36.76	1702.94	2.27	33.52	3.26	3.41	12.71
5153340	17.47	0.364	38.43	1671.04	2.27	36.16	35.07	3.41	12.78
5153344	17.51	0.395	46.78	1691.34	2.53	34.48	3.26	3.41	12.97
5153348	17.54	0.426	45.11	1665.24	2.27	36.64	65.01	3.41	12.90
5153352	17.57	0.460	51.80	1650.74	2.53	37.84	17.32	3.41	12.71
5153356	17.61	0.505	66.84	1662.34	2.40	36.88	318.56	3.41	12.65
5153400	17.71	0.602	145.38	1508.65	2.27	49.60	66.88	3.41	14.30
5153404	17.73	0.619	26.73	1584.04	2.67	43.36	70.62	3.41	13.99
5153408	17.74	0.625	23.39	1656.54	2.67	37.36	12.62	3.41	13.22
5153412	17.76	0.646	16.71	1468.05	2.40	52.96	129.58	3.41	14.30
5153416	17.77	0.657	16.71	1537.64	2.40	47.20	63.14	3.41	13.67
5153420	17.78	0.668	16.71	1517.34	2.40	48.88	63.14	3.41	14.30
5153424	17.79	0.681	18.38	1302.76	2.40	66.64	74.37	3.41	14.49
5153428	17.80	0.688	11.70	1421.65	2.67	56.80	74.37	3.41	14.37



RECORD OF CORSHAM DRILL RUN 3.15 (17.11 to 17.80 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.15 (17.11 to 17.80 metres)



USER: EX9069 -AT SYSTEM

NR_C3.16

EX9069

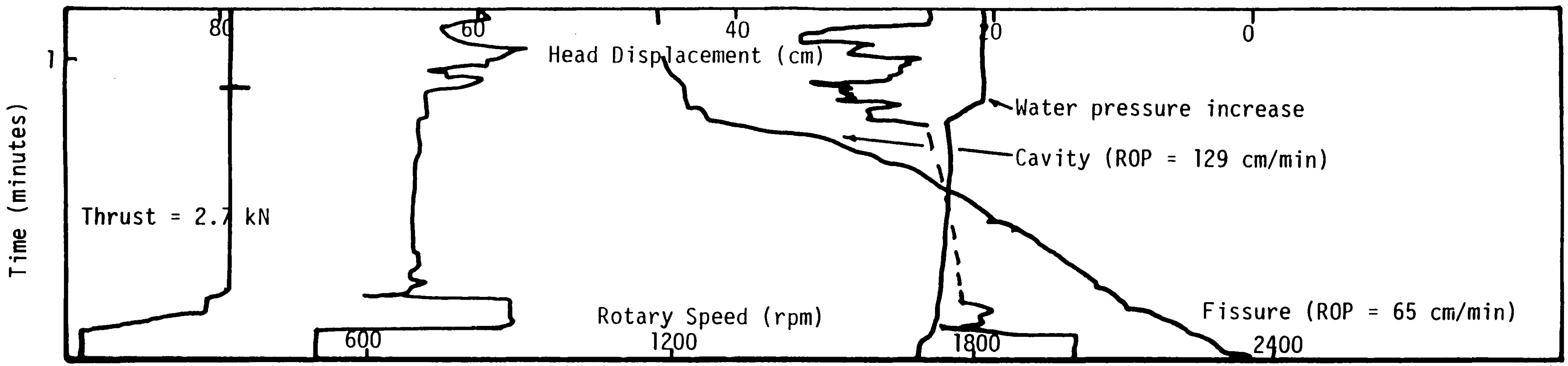
NR_C3.16

LABEL: PRT040 -FORM

SPOOLED: 82-03-10.15:16
STARTED: 82-03-10.15:25, ON: PRC BY: PRO

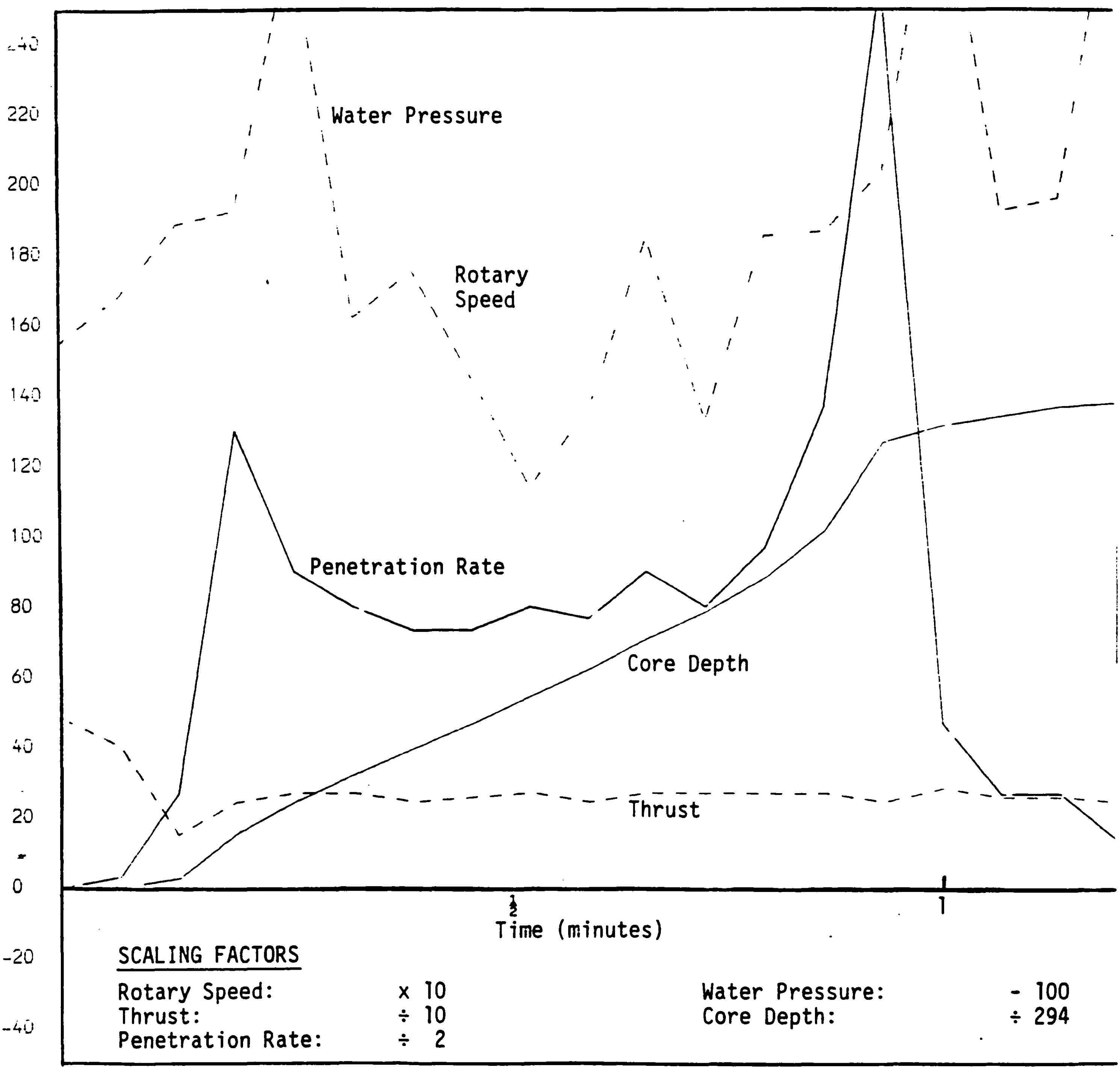
O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5161320	17.80	0.000	0.00	1730.56	4.85	36.05	55.20	3.42	7.93
5161324	17.80	0.001	1.67	2010.63	4.05	14.31	68.38	3.42	9.79
5161328	17.81	0.010	13.37	1780.16	1.52	32.20	89.08	3.42	7.61
5161332	17.85	0.053	65.17	1742.23	2.45	35.15	92.85	3.42	11.58
5161336	17.88	0.084	45.11	1713.06	2.71	37.41	170.70	3.42	12.86
5161340	17.91	0.110	40.10	1736.40	2.71	35.60	62.73	3.42	12.54
5161344	17.93	0.135	36.76	1739.32	2.45	35.38	75.91	3.42	12.54
5161348	17.96	0.159	36.76	1721.81	2.58	36.73	45.78	3.42	12.41
5161352	17.99	0.186	40.10	1704.31	2.71	38.09	14.46	3.42	12.60
5161356	18.01	0.212	38.43	1692.64	2.45	39.00	36.37	3.42	12.73
5161400	18.04	0.242	45.11	1698.47	2.71	38.55	85.32	3.42	12.80
5161404	18.07	0.268	40.10	1660.55	2.71	41.49	33.28	3.42	12.93
5161408	18.10	0.301	48.45	1683.89	2.71	39.68	85.99	3.42	12.99
5161412	18.15	0.346	68.51	1631.37	2.71	43.76	87.20	3.42	14.01
5161416	18.23	0.432	128.67	1476.76	2.45	55.77	104.14	3.42	14.40
5161420	18.25	0.448	23.39	1643.04	2.84	42.85	198.94	3.42	14.21
5161424	18.26	0.457	13.37	1570.11	2.58	48.52	92.85	3.42	14.27
5161428	18.27	0.466	13.37	1508.85	2.58	53.27	96.61	3.42	14.53
5161432	18.27	0.470	6.68	1710.14	2.45	37.64	189.53	3.42	12.67



RECORD OF CORSHAM DRILL RUN 3.16 (17.80 to 18.27 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.16 (17.80 to 18.27 metres)



USER: EX9069 -AT SYSTEM

NR_C3.17.1

EX9069

NR_C3.17.1

LABEL: FRT041 -FORM

SPOOLED: 82-03-10.19:16
STARTED: 82-03-10.19:25, ON: PRO BY: PRO

O X F O R D P O L Y T E C H N I C C O M P U T E R C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	FENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5165118	18.27	0.000	0.00	2004.80	3.92	19.42	90.97	99.99	10.17
5165122	18.27	0.001	1.67	1838.51	2.85	31.70	77.79	99.99	9.53
5165126	18.31	0.037	53.54	1713.06	2.71	37.41	6.93	99.99	12.80
5165130	18.34	0.071	51.86	1695.56	2.58	38.77	123.64	95.59	12.93
5165134	18.37	0.103	46.85	1742.23	2.58	35.15	87.20	95.99	12.48
5165138	18.40	0.129	40.15	1715.98	2.45	37.19	83.44	95.99	12.41
5165142	18.43	0.157	41.83	1698.47	2.58	38.55	74.70	95.99	12.54
5165146	18.46	0.185	41.83	1692.64	2.58	39.00	6.25	95.99	12.80
5165150	18.48	0.214	43.50	1648.88	2.58	42.40	75.91	95.99	12.86
5165154	18.52	0.245	46.85	1675.14	2.58	40.36	106.03	95.99	12.86
5165158	18.55	0.277	46.85	1683.89	2.45	39.68	75.91	99.99	12.86
5165202	18.58	0.306	43.50	1669.30	2.58	40.81	66.49	99.99	12.80
5165206	18.60	0.332	40.16	1680.97	2.71	39.91	69.05	99.99	12.93
5165210	18.63	0.358	38.48	1680.97	2.58	39.91	87.20	99.99	12.67
5165214	18.65	0.385	40.16	1666.38	2.71	41.04	72.14	99.99	12.80
5165218	18.68	0.410	38.48	1686.80	2.58	39.45	89.08	99.99	12.67
5165222	18.71	0.436	38.48	1680.97	2.58	39.91	214.00	99.99	12.67
5165226	18.73	0.462	38.48	1680.97	2.71	39.91	94.73	99.99	12.54
5165230	18.76	0.486	36.81	1704.31	2.45	38.09	75.91	99.99	12.67
5165234	18.78	0.508	31.79	1698.47	2.45	38.55	38.93	99.99	12.48
5165238	18.80	0.531	35.13	1678.05	2.58	40.13	29.52	95.99	12.67
5165242	18.83	0.556	36.81	1660.55	2.98	41.49	85.32	95.99	12.54
5165246	18.85	0.581	38.48	1631.37	3.37	43.76	92.85	95.99	13.12
5165250	18.87	0.605	35.13	1715.98	2.58	37.19	146.23	95.99	12.29
5165254	18.90	0.627	33.46	1704.31	2.45	38.09	42.69	95.99	12.29
5165258	18.92	0.648	31.79	1730.56	2.45	36.05	74.02	95.99	12.22
5165302	18.94	0.668	30.12	1718.90	2.31	36.96	96.61	95.99	11.84
5165306	18.96	0.688	30.12	1750.99	2.18	34.47	78.46	95.99	11.84
5165310	18.98	0.706	26.77	1733.48	2.31	35.83	55.20	95.99	11.71
5165314	19.00	0.725	28.44	1736.40	1.92	35.60	72.14	99.99	11.84
5165318	19.01	0.744	28.44	1745.15	2.05	34.92	60.84	99.99	11.71
5165322	19.03	0.763	28.44	1762.66	2.31	33.56	219.65	99.99	11.52
5165326	19.05	0.781	26.77	1762.66	2.18	33.56	106.03	99.99	11.58
5165330	19.07	0.799	26.77	1800.58	1.92	30.62	81.55	99.99	11.26
5165334	19.08	0.814	23.42	1815.17	2.45	29.48	13.78	99.99	11.20
5165338	19.10	0.830	23.42	1812.25	2.45	29.71	35.16	95.99	11.01
5165342	19.11	0.844	21.75	1975.62	2.18	17.02	27.63	99.99	10.69
5165346	19.12	0.846	1.67	23.92	4.85	165.67	76.46	99.99	-1.41

USER: EX9069 -AT SYSTEM

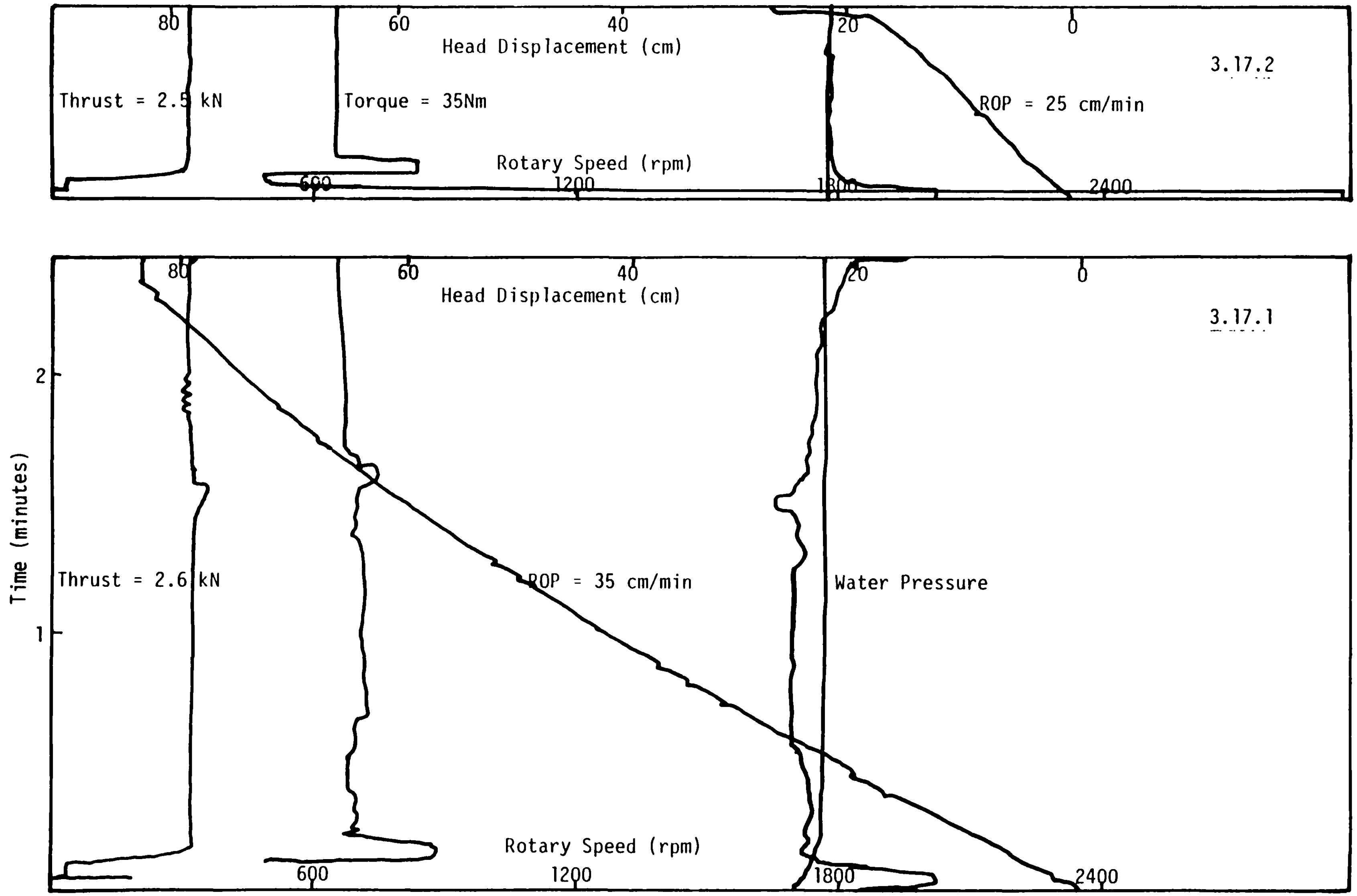
NR_C3.17.2

LABEL: FRT042 -FORM

SPOOLED: 82-03-10.19:16
STARTED: 82-03-10.19:25, ON: PRO BY: PRO

O X F O R D   P O L Y T E C H N I C   C O M P U T E R   C E N T R E

TIME	TOTAL DEPTH (M)	CORE DEPTH (M)	PENETRATN RATE (CM/MIN)	ROTARY SPEED (RPM)	THRUST (KN)	TORQUE (NM)	INLET H2O PRESSURE (KN/M**2)	I. H2O FLOW (L/MIN)	INLET OIL PRESSURE (MN/M**2)
5165354	19.12	0.000	0.00	1759.74	4.85	37.52	87.20	99.99	7.55
5165358	19.12	0.001	1.67	1505.61	0.06	26.75	99.17	99.99	8.83
5165402	19.14	0.017	23.42	1750.99	2.31	34.47	11.90	99.99	11.77
5165406	19.16	0.036	28.44	1756.82	2.45	37.73	72.14	99.99	11.71
5165410	19.17	0.052	25.10	1765.57	2.45	37.09	83.44	99.99	11.39
5165414	19.19	0.068	23.42	1742.23	2.45	35.15	255.42	99.99	11.58
5165418	19.21	0.086	26.77	1745.15	2.18	34.92	106.03	99.99	11.65
5165422	19.22	0.103	25.10	1733.48	2.31	35.83	77.79	99.99	11.58
5165426	19.24	0.119	25.10	1733.48	2.31	35.83	72.14	99.99	11.77
5165430	19.26	0.137	26.77	1718.90	2.45	36.96	53.99	99.99	11.84
5165434	19.27	0.154	25.10	1742.23	2.18	38.81	92.85	99.99	11.58
5165438	19.29	0.172	26.77	1715.98	2.31	37.19	85.32	99.99	11.65
5165442	19.31	0.190	26.77	1713.06	2.31	37.41	63.40	99.99	11.65



RECORD OF CORSHAM DRILL RUNS 3.17.1 (18.27 to 19.12 metres) AND 3.17.2 (19.12 to 19.31 metres)

COMPUTER RECORD OF CORSHAM DRILL RUN 3.17.1 (18.27 to 19.12 metres)