THE APPLICATIONS OF

AUTOMATED MINE SURVEY SYSTEMS

TO MINE SURVEYING PRACTICE

by

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Thesis submitted to the University of Nottingham

for the Degree of Doctor of Philosophy

May 1985

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ABSTRACT

Abstract

Mine surveying is at present undergoing a revolution with the possibility of fully automating survey tasks. This has become possible because of the introduction of automated systems of data measurement, acquisition, processing and plotting.

The field instrumentation required for automation is explained, together with an analysis of the results from numerous evaluation tests. A guide is given to the computer facilities necessary, both hardware and software, to achieve automation within the mine survey office.

Emphasis is given to the experiences and results obtained from the field applications investigated, including underground surveys and surface volumetric surveys. The efforts to automate subsidence monitoring are also covered.

The investigations have highlighted the overall increase in efficiency offered by such systems, and the possible future potential offered to the discipline is discussed.

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INTRODUCTION

INTRODUCTION

University based research into mining engineering problems began at Nottingham almost a century ago. The Department of Mining Engineering has since developed a strong postgraduate research school with an international reputation in the fields of mine environmental engineering, mine surveying, rock mechanics and mineral processing. Mine surveying has always been a major field of study at Nottingham at both undergraduate and, particularly over the past twenty five years, at postgraduate level. During this period mine surveying technology has been revolutonised by the application of electro-optical systems of distance measurement, gyroscopic methods of azimuth control and programmable calculators and computers. The Department has been actively involved in the evaluation of these new instruments and techniques and has played a major role in their implementation and application to mine survey practice.

The most recent advances in field survey equipment include automated systems of data measurement, acquisition, processing and plotting. These systems combine the accuracy of traditional survey instrumentation with the ability to electronically measure angles and distances and automatically record this information, thus eliminating the need for field booking. They have been thoroughly researched and evaluated at Nottingham.

The work reported in this thesis is concerned with the evaluation of automated survey systems with particular reference to their application to mine surveying practice. At the outset of this research the author was convinced that an urgent initiative should be taken in applying automated survey systems to the mining situation, and it is pleasing to note that during the three-year period of this research project several important developments have already taken place. It is believed that work at Nottingham has made a major contribution to their introduction. In addition to seminars and demonstrations to undergraduate and postgraduate students, the author has been actively involved in organising a series of short residential courses at the University. These courses were attended by practicing mine surveyors from all parts of the country in groups of just four per course, allowing three days of close and intensive supervision. The provision of these courses follows directly the research and development on automated survey systems which has been conducted in the Department over the past six years. They were intended to familiarise the surveyors with the field system including automatic data recording and with the computing and plotting. Fully automated surveys were conducted using a known test traverse leading to an automatic plot. Subsequently two systems have been purchased for use in the mining industry and are being used by surveyors who attended these courses, and other installations are imminent.

The interest of the author in automated survey systems began in 1980 whilst working as a mining engineering undergraduate at Nottingham on a final year project titled "The field evaluation of electronic total stations". During the summer vacation following graduation, the author was fortunate in being invited to work with the National Coal Board at their Mining Research and Development Establishment at Bretby, gaining invaluable experience in computer aided design and particularly with the Establishment's approach to automation within the mine surveyor's office. This connection with MRDE and senior NCB personnel has been maintained throughout the duration of the research, and a specific software package for underground junction design has been completed. There has also been close liaison with senior survey staff at the various Areas of the NCB, with the British Gypsum Company, with Hasp Inc. in the USA and with the Survey and General Instrument Company. The author has visited a variety of survey companies and organisations in the United Kingdom and has made two visits to the Kern Company at Aarau in Switzerland. The second of these visits was undertaken specifically to gain a detailed knowledge of the Kern E2/DM503 just prior to delivery of this system to the Department at Nottingham, which replaced the Kern E1/DM502 system. The opportunity to discuss all aspects of automated survey systems with senior research and development personnel at Kern was much appreciated and proved to be particularly useful.

As previously stated one of the primary aims of the research reported in this thesis was to investigate the applicability of automated survey systems to the mining industry, both on the surface and underground. Working closely with other mine surveying postgraduate students at Nottingham, specific practical aims have already been achieved. The award of a Science and Engineering Research Council grant of £84,553 has enabled a new mine surveying research laboratory to be established within the Department's main laboratory, and the grant has been used to fully equip this laboratory with data processing and plotting equipment. Additional computing equipment has also been given to the Department on a "permanent loan" basis by the Survey and General Instrument Company. This equipment, together with a field data measuring and recording system, the Kern E2/DM503, purchased for the Department by the National Coal Board, has provided the necessary facilities for conducting fully automated mine surveys and researching the applications of such systems in mine surveying. A fully automated survey was conducted in February 1983 at British Gypsum's Marblaegis Mine in Nottinghamshire and this is believed to be the first fully automated underground survey to have been conducted in the United Kingdom. A number of coal stocks and other volumetric surveys have been conducted and suitable computer software programs have been developed for all of the above survey tasks. Work is presently being undertaken to determine and record the sudsidence of a coal stock at Calverton Colliery which is being undermined, and the next specific application of automated systems to be examined is that of subsidence monitoring. The NCB has recently awarded the Department a research grant in support of this project. The author has been responsible for selecting suitable sites, establishing monitoring stations and procedures, and commencing the series of observations at these sites. Appendix i at the end of this thesis references the work done by staff and research students on automated survey systems over the past six years.

It is intended that this thesis will provide a practical guide to the mine surveyor to the possible applications of automated survey systems in his branch of the surveying profession and will clearly indicate the advantages that such systems offer. However their application extends far further than the immediately obvious facility to produce mine plans and drawings. Recent research has taken these initial concepts and expanded them to incorporate interactive screen editing, automated digital terrain modelling as well as a wide range of database management functions. These latest developments allow computerised contouring, editing, volumetric calculations, and general functions traditionally associated with utilities mapping. The research has developed to an extent that it is now possible to put all the aspects of a mining operation into a relational database and selectively interrogate any of the information.

This microprocessor based computerised survey development provides an ideal basis for branching into mine planning applications and the most recent research has been directed along these lines. The eventual aim of the research is to allow the total computerised design of a mine to be planned from the initial analysis of borehole information to the final layout and scheduling.

Chapter 1 traces the evolution of the field instrumentation required for the automation of field survey work, namely the electronic total station and the data recorder. Chapter 2 describes the test facilities required for the evaluation of electronic total stations and discusses the results obtained from the instruments which have been tested. An overview of the computing facilities, both hardware and software, required for automated survey is given in Chapter 3, together with descriptions of the systems in use at Nottingham. The applications for use of automated survey systems within mine surveying which have been investigated by the author are detailed in Chapters 4, 5 and 6. Chapter 4 describes the automated surveys which have been conducted underground, whilst Chapter 5 considers surface volumetric surveys. Chapter 6 outlines the work conducted to date in connection with subsidence monitoring, an area of continuing research effort. Chapter 7 outlines the likely or desirable future developments within automated survey, including the necessity for the revision of the present Code of Practice. The overall conclusions are given in Chapter 8.

Published works relating directly to the subject in the text are referenced by the author's name and the year of publication, for example (Author 1985). The complete list of references in alphabetical order is listed starting on page 312. Where more than one paper is referenced by the same author then they appear in chronological order. A bibliography of further works related to the subject matter of this thesis, but not directly referenced in the text, is given on page 321.

CHAPTER ONE

FIELD INSTRUMENTATION
FOR AUTOMATED SURVEY SYSTEMS

Field instrumentation for automated survey systems

1.1 Introduction

During the past twenty-five years mine surveying technology has been revolutionised mainly by the application of advanced survey instrumentation. The introduction of electro-optical systems of distance measurement and gyrotheodolite instruments for correlating underground and surface surveys and for precise azimuth control, have been of particular importance (Hodges 1970). Programmable calculators and computers have enabled survey computations to be completed quickly and mathematically error-free. This has eliminated the use of mathematical tables and manual mathematical manipulation. As a result productivity and efficiency have been dramatically increased.

Mine surveying is now on the verge of a further revolution with the introduction of automated systems of data measurement, acquisition, processing and plotting. This chapter covers the most recent advances in field survey instrumentation for data measurement and acquisition; processing and plotting of the data being dealt with in Chapter 3. Field instrumentation for automating mine surveying has been thoroughly researched and evaluated using the Department's well established field and laboratory test facilities. Considerable effort has been expended in the development of computer software to provide a fully automated survey system which by definition allows the collection and processing of survey data with minimal human intervention. Automated underground and surface surveys have recently been successfully completed. With surveys being carried out in hours rather than days and in many cases with the complete elimination of measurement and booking errors, the implication to productivity is enormous, although it must be emphasised that the main time saving is in the data processing stage and that the full potential of "total station" type instruments cannot be realized unless used in conjunction with automated systems of data acquisition and processing. The introduction of field data recorders into mine surveying is therefore particularly important. This new technology heralds a whole new era for the mining engineer and the mine surveyor.

1.2 The Electronic Total Station

1.2.1 Evolution of electronic total stations

Before considering the new generation of the so-called "electronic total station instruments" and their likely effect on mine surveying practice, it might be helpful to briefly review the developments which have led to their introduction. By reviewing the past developments one can gain a greater appreciation of the equipment, and perhaps better forecast possible future developments.

The introduction of the Geodimeter electro-optical system of distance measurement by Dr E. Bergstrand in 1953 and of the microwave system of distance measurement by Dr T.L. Wadley in 1957, represent possibly the most important developments in field survey instrumentation since the turn of the century. The first instruments were much heavier and larger than conventional survey instruments and this greatly restricted their use in engineering surveying. The first AGA Geodimeter to be introduced weighed 110kg (243lbs) and had a measuring time of about 45 minutes. The AGA 120 introduced in 1978 weighed 2.5kg (5.5lbs) and had a measuring time of less than 1 second, a striking illustration of the tremendous progress which has been made over the past 25 years (Smith 1979). The Model 6 Geodimeter, first exhibited at the 1964 Tenth International Congress of Photogrammetry in Lisbon, represented a major breakthrough in the development of an EDM instrument which would be of practical use to mine surveyors. It had a telescope and standards similar to those of a conventional theodolite and with co-axial optics for the transmitter and receiver, was much easier to operate than previous instruments. The Model 6 still weighed 53kg and took up to 10 minutes to complete a single measurement. The Department of Mining Engineering at Nottingham and the NCB jointly purchased a Model 6 Geodimeter in 1966, and short training courses were organised at the University for mine surveyors (Hodges 1968). The instrument was then used by the surveyors as required, many surveys being successfully completed. It should be noted that this was the first EDM instrument available to NCB underground mine surveyors (Hodges, Skellern and Morley 1967). This instrument has been described as the last of the first generation Geodimeters as it still used visible light. The main problem with using visible light is that high atmospheric absorption of the beam occurs. A major development therefore was the introduction of the Gallium Arsenide Light Emitting Diode as the measuring wave source, producing radiation in the infra-red part of the electromagnetic spectrum. The greatly reduced atmospheric absorbtion produced a relatively stronger signal, thereby allowing increased range from a more compact unit.

The introduction of the Gallium Arsenide LED coupled with rapid improvements in electronics, particularly circuit miniaturisation, enabled the size and weight of instruments to be drastically reduced and their operation simplified. This reduction in size and weight was particularly important for it enabled the distance meter to be mounted onto existing conventional theodolites thereby providing a three-dimensional survey system, and instruments such as the Wild DI-10 were introduced from 1968 onwards. The slope distance was measured with the attached EDM unit and the horizontal and vertical angles observed in the conventional manner with the theodolite. Horizontal and vertical distances still however had to be computed manually. Extensive underground and surface trials were conducted on the Wild DI-10 at Nottingham (Hodges and Greenwood 1969) and this instrument proved to be particularly popular for mine surveying purposes. Many survey organisations, such as the British Gypsum Company, who had not previously used EDM instruments purchased the Wild DI-10. The economies which could be obtained by the use of EDM proved to be outstanding and instruments such as the DI-10 more than paid for themselves in a very short period of time. It is from this time that the use and availability of EDM systems has increased rapidly and they are now regarded, together with the theodolite and level, as an essential item of the mine surveyor's field equipment. The majority of leading survey manufacturers produce a range of electronic distance measurers to satisfy the requirements of a wide variety of survey tasks.

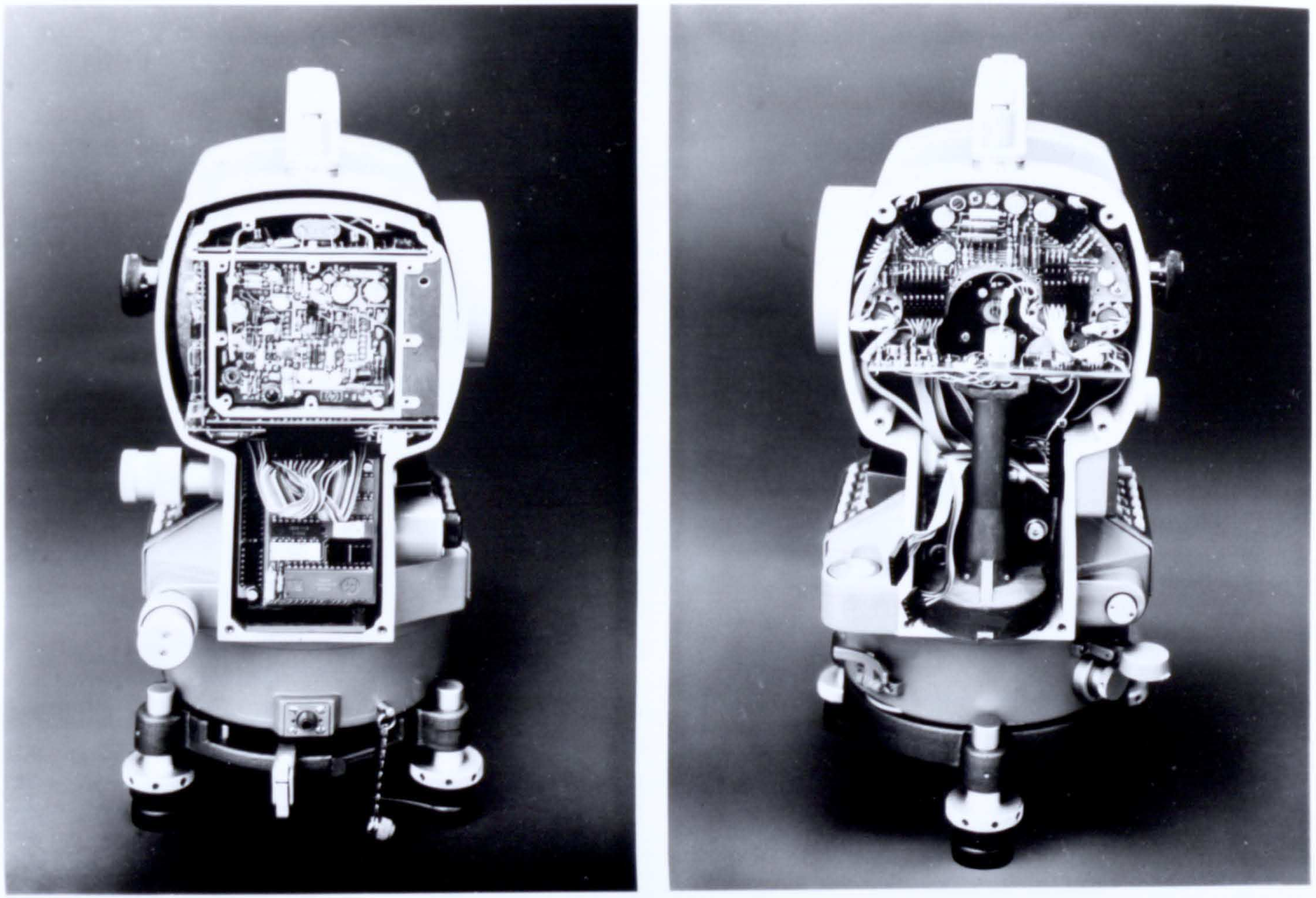
The production of an instrument capable of "self reduction" was the next logical and obvious development. The microprocessor technology, similar to that responsible for the introduction of scientific pocket calculators, together with fully integrated systems combining electronic measurement of both distance and angles enabled such instruments to be produced.

The next technical problem to be overcome was that of automating the registration of field data in order to develop a system that would not only measure all the field data a surveyor needs but would also record this data automatically. In the early 1960's the Fennel code theodolite and the Kern code tacheometer were developed in an attempt to automate the registration of field data. Both instruments incorporated means of recording field measurements on 35mm film which then had to be decoded in the office. These instruments were not successful in the United Kingdom, and evaluation tests were not conducted on their suitability for mine surveying. However Lang (1967) reported that in the West German Federal State of Hessen they had in use more than 25 code theodolites feeding back to a central computation and draughting office. The first instruments which recorded data in a computer compatible format were the Zeiss (Oberkochen) Reg Elta 14 and the AGA Geodimeter 700 series produced in 1971. Both instruments had their own data acquisition system in the form of a punch tape unit which facilitated considerably the transfer of stored field data to the computer. Although these instruments marked a real step forward, and evaluation tests were carried out at Nottingham and elsewhere, they were considered to be unsuitable for mine surveying purposes. There was also a shortage of suitable computers and plotters to complete the automated survey system at that time.

However by 1977 further improvements in electronics enabled more compact computer compatible data collectors to be produced based on magnetic tape or solid state electronics. At the 1977 XV FIG Congress in Stockholm four new total station instruments featuring automatic data recording were introduced; the Hewlett-Packard 3820A, the Wild TC-1, the Kern E1, and the Vectron of Keuffel and Esser. Since 1977 several other systems have appeared on the market and further developments are underway. Incorporating microprocessors to control the instrument, perform the necessary computations and output data for recording and processing, these instruments clearly illustrate present day trends and indicate the type of instruments which may be in general use in mine surveying by the late 1980's. Extensive evaluation tests have been conducted at Nottingham on the Hewlett-Packard 3820A, the Wild TC-1, the AGA 120 and the Kern E1/E2/DM502/DM503 equipment (Hodges 1979a) (Hodges 1979b) (Hodges and Scoble 1980) (Hodges, Scoble and Schofield 1981) (Hodges and Smith 1982) (Hodges, Nicholson and Ketteman 1984). One glance at Plate 1.1 showing the internal circuitry of the Hewlett-Packard 3820A is sufficient to show that this type of instrument is very different to the conventional theodolite and indicates the considerable developments which have taken place over a comparatively short period of time. Following the extensive evaluation tests on the Department's well established field and laboratory test facilities, short courses for surveyors from each of the twelve areas of the NCB were organised in September 1983 on automated survey systems. Since these courses two systems have been purchased for use in the mining industry and several more systems are due to be commisioned shortly. It appears certain that this instrumentation will play an increasing and important role in mine surveying in the immediate future.

Plate 1.1

Internal circuitry of the HP3820A



New Hewlett-Packard 3820 Electronic Total Station for distance and angle measurements

1.2.2 Definition of electronic total stations

Having traced the development process of the instrumentation which is commonly termed as an electronic total station, it is now useful to define exactly what such a term requires.

An electronic total station is a single instrument which is capable of measuring all the field data that a surveyor needs and recording this data automatically. Some of this data, such as slope distance, zenith angle, and horizontal angle are measured directly, and from these quantities the horizontal and vertical distances can be computed and displayed. Other features such as angle averaging, relative direction, and corrections for mislevelment may also be included. Recording of measured data plus station information, such as measurement type, instrument height and the atmospheric parameters, is made with the data recorder.

The need for a clear understanding of what is meant by the term electronic total station was highlighted in the 1981 EDM Supplement of the Civil Engineering Surveyor (Fort 1981), which deliberately omitted to classify any instruments under the heading "Total Station". The reason given was that such a title causes confusion, with the question being asked "How total is total?". The article continues; "The integration of microprocessors with the EDM has brought out such a variety of programmed functions that there appears to be no end to to the possible combinations. In any case, a station in surveying is a point over which the instrument is set-up, not the instrument itself."

It could be argued that the term electronic total station should be replaced by electronic tacheometer, although this tends to detract from the range and precision which are inherent in this class of equipment. The term does however hint at the most obvious application for this type of equipment, namely the rapid assimilation of detail points in the field. The range and accuracy of electronic total stations dictate that the effects of earth curvature and refraction on the measurement of the zenith angle be included in the reduction computation. A value of 6372km for the mean radius of the earth and 0.071 for the coefficient of refraction has been chosen by several manufacturers. These values are sufficiently precise for detail surveys and short range setting out, but care must be taken if high precision work is to be undertaken. It is then necessary for the surveyor to fully understand the basic principles involved in the automatic distance projection if appreciable errors are to be avoided. In all cases it is vitally important that the surveyor understands the capabilities of the instrument being used, and understands the functions available to him.

1.2.3 Review of electronic total stations

Tables 1.1(a) to 1.1(c) give a comparison of 15 currently used electronic total stations, and are intended to give an general view of the types of instrument available. Although the HP3820A has been withdrawn it is included as it is one of the instruments which have been evaluated at Nottingham. The range quoted for each instrument is not its maximum capability, but that which is achievable in average conditions using three prisms. The distance accuracy of each instrument assumes that the normal measurement mode is being used, not the less accurate tracking mode. The angular accuracy is shown as the quoted mean error of a single direction measured in both telescope positions. The smallest display unit is also noted, together with the range of automatic compensation. The first column in Table 1.1(b) describes whether the electronic total station is modular or a single unit, and whether the system includes coaxial optics. Column 3 notes whether the instrument display is by light emitting diode or liquid crystal, whether the display is visible operating in both faces, and whether the battery is housed within the instrument casing. The weight includes the theodolite, EDM and the battery. The supplementary facilities in Table 1.1(c) include the possibility of in the field calculations, such as setting out. The abbreviation D/R refers to the facilities being available in the data recorder, DIF 41 being the Kern unit based on the HP41CV calculator to perform these tasks. Finally the corrections which are automatically applied are atmospheric (A), earth curvature (C) and refraction (R). If the corrections are only applied to the display values and not to the recorded values then this is denoted by "(D)".

INSTRUMENT	Range on three prisms	Accuracy and measure time Norm . Track	Least unit and accuracy Hori . Vert	Angle compensator
K & E Vectron	2000m	±(5mm+6ppm) 6s 6s	3" 3" ±3" ±3"	Vertical
HP 3820A	3000m	±(5mm+5ppm) 5s 1.5s	1" 1" ±2" ±4"	Vertical & Horizontal
Kern E1/502	2000m	±(5mm+5ppm) 8s 2s	2" 2" ±2" ±2"	Vertical
Kern E2/503	3500m	±(3mm+2ppm) 8s 2s	1" 1" ±0".5 ±0".5	Vertical & Horizontal
Wild TC-1	1000m	±(5mm+5ppm) 8s 4s	1" 1" ±2" ±3"	Vertical
Wild T2000	3500m	±(5mm+5ppm) 8s 4s	0".1 0".1 ±0".5 ±0".5	Vertical
AGA Geodimeter 140	3600m	±(5mm+3ppm) 10s 0.4s	2" 2" ±2" ±2"	Vertical & Horizontal
AGA Geodimeter 136	1400m	±(5mm+5ppm) 10s 0.4s	2" 2" ±3" ±3"	Vertical
Zeiss (O) Elta 2	1600m	±(5mm+2ppm) 5s 1s	0".6 0".6 ±0".6 ±0".6	Vertical
Zeiss (O) Elta 3	1600m	±(5mm+2ppm) 5s 1s	0".6 0".6 ±2" ±2"	Vertical
Zeiss (O) Elta 20	2000m	±(5mm+2ppm) 5s 1s	0".6 0".6 ±1" ±1"	Vertical
Zeiss (J) Recota	1500m	±(5mm+5ppm) 5s 5s	1" 1" ±2" ±2"	Vertical
Alpha OMNI 1	3000m	±(5mm+2ppm) 7s 2s	1" 1" ±6" ±6"	Vertical
Topcon ET-1	2000m	±(5mm+5ppm) 5s 0.5s	1" 1" ±2" ±3"	Vertical & Horizontal

Table 1.1(a) Review of electronic total stations

INSTRUMENT	EDM type Optical system	Telescope magnification	Display type Battery type	Approximate total weight (kg)
K & E Vectron	Modular Binocular separate	30 X	LED : One External	11
HP 3820A	Single unit Coaxial	30 X	LED : Both Internal	13
Kern E1/502	Modular Binocular separate	32 X	LCD : Both External	17
Kern E2/503	Modular Binocular separate	32 X	LCD : Both External	17
Wild TC-1	Single unit Coaxial	25 X	LED : Both External	16
Wild T2000	Modular Binocular separate	32 X	LCD : Both Ext + Int	17
AGA Geodimeter 140	Single unit Binocular separate	30 X	LED : Both External	8.5
AGA Geodimeter 136	Single unit Binocular separate	30 X	LED : Both External	8.5
Zeiss (O) Elta 2	Single unit Coaxial	30 X	LED : One Internal	14
Zeiss (O) Elta 3	Single unit Coaxial	30 X	LED : One Internal	14
Zeiss (O) Elta 20	Single unit Coaxial	30 X	LED : One Internal	14
Zeiss (J) Recota	Single unit Coaxial		LCD : Both Internal	12
Alpha OMNI 1	Single unit Binocular separate		LCD : Both Internal	8
Topcon ET-1	Single unit Coaxial	30 X	LCD : Both Ext + Int	8

Table 1.1(b) Review of electronic total stations

INSTRUMENT	Supplementary facilities	Data recorder	Corrections applied	Comments
K & E Vectron	in D/R	Field computer	A	
HP 3820A	No	Total memo	A,C,R	Withdrawn
Kern E1/502	in DIF 41	R48 / AMS	–	
Kern E2/503	in DIF 41	R48 / AMS	A,C,R (D)	Externally similar to E1
Wild TC-1	No	GRE1	A,C,R	
Wild T2000	in D/R	GRE3	A,C,R	
AGA Geodimeter 140	No	Geodat 122/4	A,C,R	
AGA Geodimeter 136	No	Geodat 122/4	A,C,R	Downgraded 140
Zeiss (O) Elta 2	Yes	Mem modules	A,C,R	Most accurate Elta
Zeiss (O) Elta 3	Yes	Mem modules	A,C,R	
Zeiss (O) Elta 20	Yes	Mem modules	A,C,R	
Zeiss (J) Recota	Yes	SSL	A,C,R	
Alpha OMNI 1	Yes	Modules	A,C,R	Low cost ETS
Topcon ET-1	No	FC-1	A,C,R	

Table 1.1(c) Review of electronic total stations

1.3 Automatic data acquisition

1.3.1 Introduction

The electronic data recorder provides the vital link in an automated survey system between the field instrument and the computer, and must be considered as an essential piece of field equipment. It is questionable whether the present capital cost of an electronic total station can be justified without the ability to automatically record and process the data. Obtaining optimum efficiency demands that all of these facilities are available. In the opinion of most surveyors the choice of data recorder from the many which are now on the market is of great importance, and this is understandable when it is considered that the unit of his choice will effectively be his field book. From discussions with equipment manufacturers and potential users, the choice of which field system to buy often hinges upon the suitability of the data recorders supported by the system to a particular application.

The possibility of recording field data in a computer compatible format was so attractive that many early attempts were made to provide this facility using firstly 35mm film and then punched tape. These early, often inconvenient units, have been superseded in recent years by more practically acceptable data recorders based on either solid state memory or magnetic tape.

Experimentation with other systems of data recording such as sound recording or radio transmission will not be considered in this thesis, however details of these and other methods are given by Lundin (1977). The current trend is towards the use of a solid state data recorder for primary field storage, magnetic tapes employed for secondary, or back-up, storage. The merits of each storage medium are discussed in Section 1.3.2. The immediate future trends seem well defined, with a period of enhancement and refinement to features recently developed. Based on solid state electronics, the units are likely to become more powerful, more flexible in their operation, capable of complex calculations in the field, and allow user programmability. Data recorders already exist with a full alphanumeric keyboard, a development bought about mainly by demand from users. The application of this development will be discussed later.

Whatever type of data recorder is chosen, its primary function must be to allow the surveyor to uniquely define his field measurements using an unambiguous coding routine so that the computer can interpret the measured field data. The field coding system developed at Nottingham is detailed in Section 1.3.5.

1.3.2 Survey data recorders

As stated in the previous section, data recorders employing solid state memory components are now almost universally used for the primary storage of field data instead of magnetic tape. The main advantage offered by solid state memory is that the data can be rapidly accessed at random using search functions controlled by the microprocessor, allowing efficient editing and data checking. The main disadvantage of conventional solid state memory is that it is volatile, that is, the data cannot be stored indefinately, as over a period of time corruption and eventually loss will occcur. This problem can be partially overcome by connecting the data recorder to an external power source, extending the data retention time to several months, the exact time varying with each data recorder. Solid state memory is finite, at present most data recorders only being able to store up to a maximum of about 800 fully coded detail points, representing a good days work by an experienced team. When the cost of these units is taken into account (approx. £2000) it becomes obvious that it is not feasible to use them for long, or even medium, data storage, it being desirable to have them constantly available to the field teams. Thus the best solution is to off-load the information stored in the data recorder as soon as possible onto a cheap non-volatile memory medium, thereby freeing the unit for further use. A recent alternative to conventional solid state memory is a non-volatile version known as bubble memory. Although long-term data security is assured, the memory is still of finite length. Bubble memory has been used in Wild's latest data recorder, the GRE3.

One advantage of the use of magnetic tape for primary data capture is that the memory is non-volatile. Also, it offers unlimited, cheap storage capacity, as soon as one tape is filled it being replaced by a new one. The main disadvantage of magnetic tape is that reviewing the data is dependent on the tape speed, automatic random access searching not being possible. This could be considered analogous to searching for a certain word in a particular song on an audio cassette. Also, any corrections have to be coded at the end of the entire data stream as data cannot be overwritten on the tape. This has proved to be inconvenient and by its nature prone to error. Magnetic tape storage was introduced by Wild with their TC-1 Tachymat, where the recording tape unit was housed on top of the instrument. This system has now been discontinued, being replaced by the Wild T2000 using the previously mentioned GRE3 solid state data recorder.

However, the use of a magnetic tape cassette in conjunction with a solid state data recorder provides a very practical solution to the problem of the finite volatile memory of the solid state memories. Magnetic tape is ideally suited to secondary data storage, with a high degree of data security guaranteed. If during a days surveying the data recorder becomes full, then the data can be off-loaded easily onto a cassette so that the remainder of the day is not wasted. Alternatively, a survey team in a remote location can store their information on tape for processing on their return to the office on completion of their assignment, or, more practically in the case of large jobs, post the tapes back to the office. The surveyor could keep his own back-up tape and small battery driven printers are now available so that the surveyor could also keep records on paper if so desired. Several commercial surveying companies are looking to adopt this type of approach to their overseas contracts. Initially it was suggested that conventional audio cassette tapes could be used to back-up the field data recorder, but the author has found that this is unreliable and very slow due to the low baud rates which have to be used for transmission. The baud rate refers to the rate of data transfer between two devices, representing the number of bits/second transmitted. The higher the baud rate the faster and therefore more efficient the transmission. Data recorders such as the Kern R48 and AGA Geodat are limited to a maximum transmission rate of 1200 baud, but this is still far superior to that at which the audio cassette can receive information. Bearing this in mind and considering the problems encountered with data corruption on transmission, even at 300 baud, to an audio cassette, the author would very strongly advise the use of a high quality digital cassette unit. These offer a far superior alternative, comfortably accepting 1200 baud transmissions, as well as proving more reliable and easier to use. The author has used a Cristie Model 210 digital cassette recorder with both Cristie and Phillips digital mini-cassettes to back up work conducted with the Kern R48 data recorder and to transfer data into the computer for processing from external survey companies. On all occasions this system has proved very reliable and efficient. The Ordnance Survey is now also using a Cristie for similar purposes, their field survey teams dumping the field data onto two tapes, one of which is sent to the Ordnance Survey headquarters in Southampton for processing on their VAX computer, the other tape being kept by the field team (OS News 1984). A further important advantage offered by digital cassette recorders is that automatic data transfer to the computer can take place via, for example, a standard RS232 interface, due to the digital nature of the recording. This is not possible using an audio cassette recorder with the data having to be reloaded into a data recorder before transfer to the computer can proceed. Therefore if audio tapes are sent from remote locations this necessitates that a data recorder of the same type is available both in the field and in the office.

In the same way that the sophistication of electronic total stations has increased, not surprisingly, the capabilities of electronic data recorders have increased. Originally most could only support numeric entry and had no "intelligence" of their own. A recent development has been the introduction of units capable of storing a full alphanumeric set, often of both upper and lower case characters. The main hurdle to alphanumerics was designing a unit capable of allowing letters to be entered as well as figures without the instrument becoming too large and awkward to use. Eclipse tried to overcome this problem in their M50 data recorder by extensive use of shift key functions, but overall this tended to make operation slow and complicated due to the number of keystrokes required. Recently AMS Numerics developed the alphanumeric Datasafe II which appears to be becoming very popular within the survey profession. The Datasafe has an extensive yet compact keyboard with a full alphanumeric set of keys. The development of alphanumerics has been rapid over the past couple of years due to the insistence of practicing surveyors that a data recorder requires alpha characters to ease coding in the field. The author's experience has shown that for many applications the advantages of using alphanumeric coding above numeric coding are very slight, if discernible at all, and the attitude should not be one of automatically assuming that alphanumeric coding is the most expedient. This has been borne out from discussions with surveyors now using an alphanumeric data recorder who would prefer to use the "old" numeric unit for the majority of their tasks (Aitchison 1984). It is far more efficient to use a data recorder with a simple to follow and complementary prompting sequence for many tasks. The main application of alphanumerics is probably in the field of land, or utilities surveying, where many different types of feature are to be detailed. In such cases it may be easier to remember that, for example, the code 'HE' represents a hedge, 'MH' a manhole, and so on, rather than a representative numeric code. These features could be extended so that, say, different hedges were represented as 'HE1', 'HE2' etc., where the computer recognises that each set of information is relating to different examples of the same feature. This would have a similar effect to stringing, with the possibility of automatically joining all of the features with the same code even if, for example, the entire length of hedge 'HE1' was not surveyed consecutively. The Ordnance Survey is at present using the Datasafe II for much of its work.

The advent of alphanumerics has necessitated the development of a new form of display on the data recorder. Traditionally two types of display were available, namely LED (Light Emitting Diode) and LCD (Liquid Crystal Display). LCD is preferred due to its lower power consumption and the fact that it is more easily read in daylight. Both of these displays are based on seven segments, the same as those found on pocket calculators. Seven segment displays are suitable for representation of the 10 digits, but cannot represent upper and lower case alpha characters clearly. To combat this some manufacturers have adopted dot matrix displays, where each character is readily defined by a series of dots. The Alpha Electronics Omni System is an example of this type of presentation.

Most data recorders are purchased today as separate units from their associated electronic total stations. This shows a development from early systems such as the Wild TC-1 and Zeiss Elta II, which incorporated integral data recording units. The main advantage of this trend is one of flexibility, allowing the data recorder best suited to be chosen from those available, or upgrading the unit without considering the purchase of a new total station. Such a data recorder can also be used as a hand held device replacing the field book when using conventional instrumentation, still allowing the considerable advantages of automatic data processing. A good example of this is the program written to record gyrotheodolite data on an AGA Geodat data recorder, from which the azimuth could be automatically computed (Smith 1982).

Another recent development has been the introduction of user programmable data recorders. There are various methods necessary to program such devices, but caution is advised as the task is invariably not as easy as it may first appear. Some data recorders such as the Wild GRE3 can be programmed directly through their alphanumeric keyboard in a high level language such as BASIC. This seems to offer the simplest answer to the problems faced by the user intent on writting his own specific programs. However, this process is normally both slow and tedious, even for programmers of some experience. A more expediant answer is to be able to write the software on a computer with text editing facilities and then transfer the program, once complete, to the memory of the data recorder. In other cases programs are written in machine code and then transferred to the RAM (Random Access Memory) of the recording device, although this should only be attempted by extremely competent personnel. A third option uses an assembler and ancilliary equipment allowing transfer of machine code to a ROM (Read Only Memory) within the data recorder.

The extension into user programmable data recorders allows the possibility of an intelligent field system, with calculations carried out in the field, such as resections and setting out information. Such devices could also be used to drive miniature field printers or plotters, enhancing the confidence of the surveyor whilst still on site, and reducing the possibility of errors such as forgetting to survey a certain area. Such capability would obviously be invaluable in remote areas. Until recently microtechnology had not made it feasible to produce a single unit of practical size with enough storage capacity to support intelligence plus data storage capability to a practical level. As such, Kern were amongst the first companies to tackle this problem, and developed two separate units to carry out each task (Munch 1981). Both devices can be used simultaneously off the same electronic total station if desired. The field intelligence is provided using the programmable Hewlett-Packard HP41CV pocket calculator connected to the instrument via a clip-on interface, the DIF 41. The HP41CV permitted field interaction with the results obtained from the instrumènt, allowing error checking, resections, setting out etc. to be performed by running a series of function key initiated programs. It also has sufficient storage capacity to record approximately 200 surveyed data points if desired. If pure field data recording is needed then the more conventional Kern R48 solid state data recorder is used. The most recent data recording devices allow both functions to be efficiently contained within one unit, such as the Wild GRE3, these systems being potentially very powerful.

There appear to be many advantages to a user programmable data recorder, but caution is advised when considering the purchase of one. The programming of such devices is usually a lot more difficult than may first appear, with users often surprised by the level of programming knowledge required, especially as the software must be efficient. Gradually suites of software for survey calculations are being written by professionals, and so it often pays to thoroughly search the market to find which is most applicable. Paying for software of this type is usually more cost effective than trying to be too ambitious and develop the whole suite individually. Even if the programming operation is facile it usually requires a long period of time to satisfactorily complete the task.

An interesting development, and one which is definately worth consideration, is that of a group of data recorders becoming known as semi-user programmable. These allow the user to define the order in which the prompts appear which form the data structure, such as with the AGA Geodat 122. Although the order of the prompts can be chosen, there are only a finite set number of prompts available for use. This type of facility is being expanded so that the user can define a cycle of prompts of his choice, defining exactly the prompt which will appear in each block. It would then be easy to establish a set of prompt routines directly applicable to each type of job. This would prove highly efficient in the field, and seems to represent the best compromise between ease of programming and flexibility.

1.3.3 Review of survey data recorders

Tables 1.2(a) to 1.2(c) show a comparison between 13 survey data recorders. There are other data recording devices which are available but have not been included as they are either considered unsuitable for survey work or their details are not currently available. The majority of the information listed is self explanatory. The data security time quoted assumes that an external power source is not being used. It should be noted that the dimensions are given in millimetres and the weight in grammes. Transmission speeds are quoted as the maximum permissible baud rate. User Programmable (d/s) means that the device is can only be programmed using a development system. CPM means that the any of the languages supported by the CPM operating system may be used to program the data recorder.

DATA RECORDER	Total station input	Memory capacity (bytes)	Display	Data security
K & E Field Computer	K & E Vectron	8k – 24k	LCD	
HP Totalmemo	HP 3820A	12k – 72k	LCD	48 hrs
Kern R48	Kern E1/E2	24k	LCD	1000 hrs
AMS datasafe II	Kern E1/E2 Aga 140/136	128k	LCD	4 weeks +
Wild GRE1	Wild TC1	Unlimited	LED	Permanent
Wild GRE3	Wild T2000	32k / 128k	LCD	Permanent
AGA Geodat 124	Aga 140/136	32k	LCD	2000 hrs
AGA Geodat 122	Aga 140/136	32k	LCD	2000 hrs
Zeiss(O) REC 100	Manual input	16k modules	LED	10 days
Husky Hunter	Aga 140/136	200k	LCD	100 hours
Eclipse M50 K	Kern E1	48k	LED	8 hours
Zeiss(J) EOT2000 SSL	EOT2000	8k modules	LCD	6 months

Table 1.2(a) Review of survey data recorders

DATA RECORDER	Keyboard	Dimensions	Weight (g)	Microprocessor
K & E Field Computer	Alphanumeric	140 250 50	1140	
HP Totalmemo	Numeric	105 230 50	950	iM 6100
Kern R48	Numeric	80 170 40	500	RCA 1802
AMS datasafe II	Alphanumeric	95 216 43	680	Z 80
Wild GRE1	Numeric	170 170 100	2100	
Wild GRE3	Numeric	85 245 57	800	NSC 800
AGA Geodat 124	Alphanumeric	88 172 39	600	RCA 1802
AGA Geodat 122	Numeric	88 172 39	600	RCA 1802
Zeiss(O) REC 100	Numeric	90 191 55	600	
Husky Hunter	Alphanumeric	216 156 32	2000	NSC 800
Eclipse M50 K	Alphanumeric	85 223 40	750	RCA 1802
Zeiss(J) EOT2000 SSL	Alphanumeric	235 185 60	1650	

Table 1.2(b) Review of survey data recorders

DATA RECORDER	Setting out facilities included	User Programmable	Maximum transmission speed	Comments
K & E Field Computer	Yes	Yes (d/s)	300	
HP Totalmemo	No	No	2400	Withdrawn
Kern R48	No	No	1200	
AMS datasafe II	Yes	Yes (CPM)	9600	Kern version available
Wild GRE1	No	No	9600	Magnetic tape storage
Wild GRE3	Yes	Yes (BASIC)	4800	Features bubble memory
AGA Geodat 124	No	Partially	1200	Alphanumeric 122
AGA Geodat 122	No	Partially	1200	
Zeiss(O) REC 100	No	No	9600	
Husky Hunter	No	Yes (CPM)	4800	Low cost but bulky
Eclipse M50 K	No	No	1200	
Zeiss(J) EOT2000 SSL	No	No	300	

Table 1.2(c) Review of survey data recorders

1.3.4 Data transfer

As stated previously, the data recording unit provides the vital link in the chain between field measurement and automatic office computation. It is necessary that there is an efficient method of data flow between the recording device and the computer. This data flow is governed by the interface program, and is covered in great detail by Nicholson (1984). This section does not intend to explain interfacing, but aims to give an overview of the most feasible mechanisms available to allow the transfer of data between the two microprocessors.

Experience in the field of data transfer has shown that it is highly desirable for two way communication to be available between the the host computer and the peripheral, thereby enabling data interrogation and error checking. This is known as 'handshaking', with each block of data being verified as transferred correctly before the transmission of the next block is requested. If full block by block verification is not possible, then it becomes necessary to check the data by some other means. If an error is detected in this way then the entire transfer has to be recommenced. One common technique for such analysis is parity checking.

The three principle methods of data transfer will now be described.

Firstly, consider data transfer via direct interfacing. This method of data transfer is only applicable in situations where the data recorder can be returned to the office with the processing computer. As the name suggests, the transfer is enabled by direct connection of the data recorder to the computer via a suitable interface.

The most common interface is via the standard RS232 port on the backplane of the computer. RS232 is a standard serial interface which was developed by the Electronic Industries Association and comprises of 25 electrical wires, each with a specific 'name' and purpose. Data is transmitted along the wires in a coded stream in single file, hence the term serial interface. The data itself is most commonly defined by the standard ASCII coding system, each character being uniquely defined by seven binary digits, therefore having an allocation of seven bits, plus an eighth bit for error detection purposes, commonly termed the parity bit. An ASCII code chart can be found in Appendix 1, whilst the pin assignments associated with the standard RS232 interface are shown in Appendix 2. Detailed information of ASCII coding and the RS232 interface can be found in Leibson (1980).

A typical representation of a single character is shown in Figure 1.1. From the ASCII code chart it can be seen that the binary digit representation of the digit 5 is 1010110. Note that ASCII code transmits data least significant bit first, and so the digit 5 in Figure 1.1 appears in reverse order. In addition to these seven bits there is also a start bit with a logical state of 0, a parity bit for error detection and, in this example, two stop bits with a logical state of 1. The start and stop bits are necessary so that the computer can distinguish individual characters. By maintaining the logical state of the computer at 1 it recognises that a character is being sent when the logic state is changed by the 0 start bit. On completion of transmission of the character the logical state of the computer is once again set to 1 by the stop bits, allowing the cycle to start again. Parity checking is based on counting the number of binary digits with the value of 1. The parity check is set as being either odd or even, so that if the parity is even and there are an odd number of 1's within the character, the parity bit will be assigned the value of 1 to make the total an even number. As each character is transferred the total number of 1's is checked, and if this value is even then transmission is deemed to have been successful. One problem with parity checking is that it is possible for two mistakes to compensate for each other with the total remaining even. The major cause of errors is noise in the medium and can be caused by electromagnetic interference from electrical devices close to the data wire (Cole 1981).

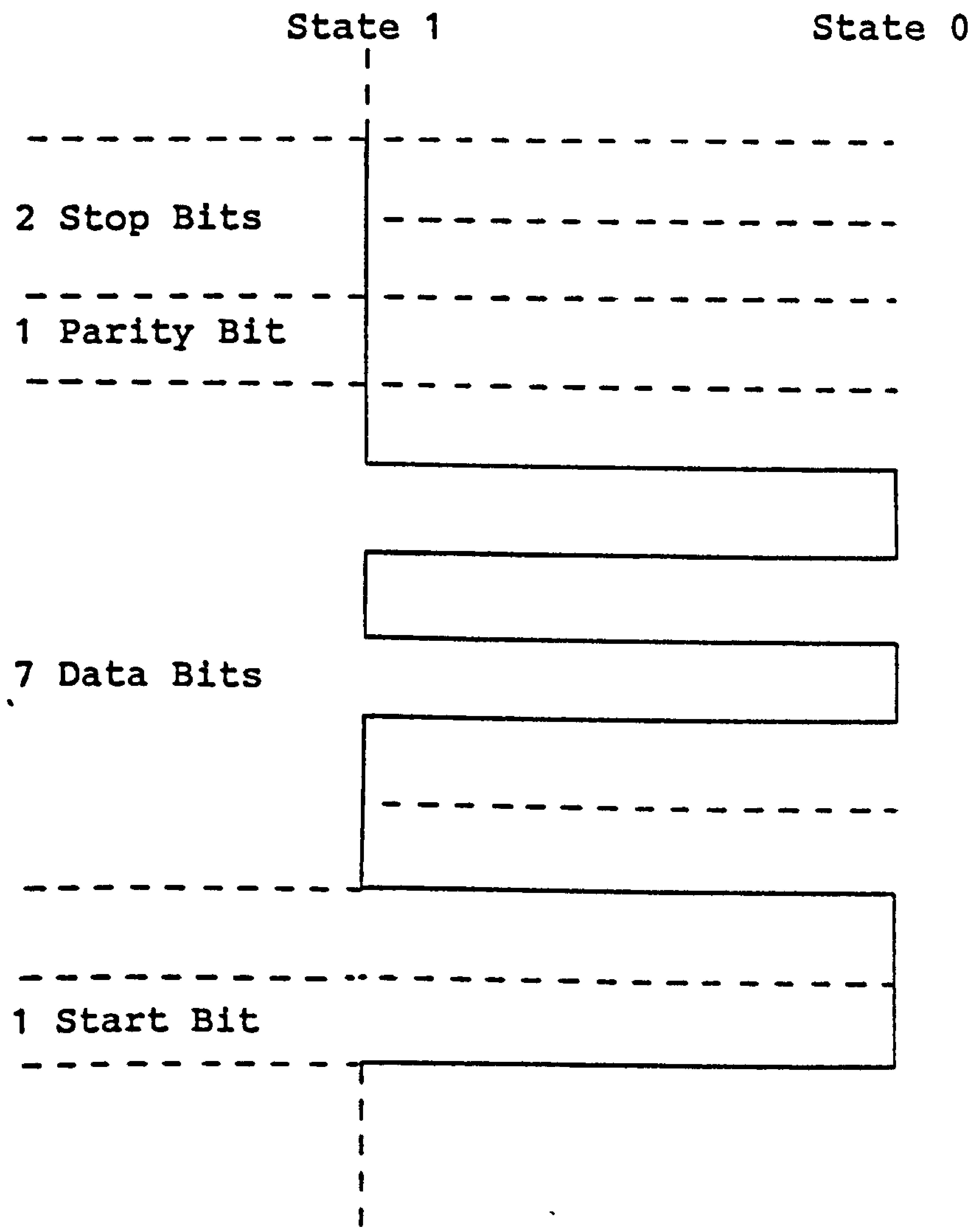


Figure 1.1 ASCII serial transmission

There are three modes of operation allowed between two communicators using an RS232 interface:

1. Simplex; this is a connection where one party can send information to the other, but no information can be transferred in the reverse direction. There is only one sender and one receiver and one channel.

2. Half duplex; in this arrangement both parties can send and receive information, but not at the same time. The communications channel only allows information transfer in one direction at any time. This uses one channel, but the direction is reversed by switching between sending and receiving equipment at each end.

3. Full duplex; both parties can send and receive information at the same time. This uses two channels.

As would be expected, direct interfacing is the most reliable and efficient method for data transfer. However, if it is not possible to return the data recorder to the office then one of the next two methods must be employed.

The second method of data transfer is possible via the use of secondary data storage. The secondary storage mediums which are presently available are magnetic tape or back-up solid state memory. It has previously been shown that magnetic tape storage is the more applicable of the two. The main advantage of solid state memory is that random access of the data is possible, but this is not a requirement of a secondary storage device, its sole purpose being to hold data until processing can occur. This leads to the problem of guaranteed long-term data security. Conventional solid state memory is volatile, but the advent of non-volatile bubble memory may lead to future applications in this area for solid state technology. This however seems unlikely, a further disadvantage being the prohibitively high cost of solid state for massive storage. At present AGA market a conventional 32k solid state external memory pack for back-up storage for their range of Geodat data recorders. It is the author's firm belief that digital mini-cassettes offer the most expedient solution to this problem, facilitating direct data transfer to the computer without the need for a data recorder in the office.

The third method of data transmission is that of data transfer via telephone networks. Telephone lines transmit an analogue modulated signal which is not directly compatible to the digital signal used for data transmission in computing. To enable data to be transmitted along telephone lines it is therefore necessary to convert the digital signal at source into a modulated form, transmit the modulated form down the line, and then reconvert the modulated signal back to its original digital format on reception. These conversions are enabled by devices called Modems (MOdulator/DEModulator), one being required at each end of the line. The ease of data transmission is governed by the quality of the telephone line being used. It is quite feasible for the national telephone system to be used, although the results are generally better if a dedicated line is used, that is, a private line used solely for data transmission. This approach is generally adopted by large companies such as the NCB, especially if they have their own internal telephone system, allowing transmission of information between various regional offices. The advantage of these dedicated lines is that the background noise levels are much lower than normal, thereby reducing the chance of data corruption. This allows higher transmission speeds to be used. Whenever data is transmitted error checking must be employed, especially if the public telephone system is being used. Nicholson (1984) reports an example of a test in the U.S.A. where he transmitted data over 1000 miles using the national telephone system without problems.

Modems often allow the user to choose between full or half duplex mode, it being normal to adopt half duplex communication as this enables a higher rate of data transmission. For national telephone systems it has been suggested that the optimum baud rate is 1200 if half duplex is available (Grant 1981). This proves to be more efficient than transmission at 300 baud using full duplex, providing that error checking is enabled for each block by parity checking. Consideration of higher speed modems is at present of limited use as the maximum transmission speed possible using a data recorder is at present limited to 1200 baud. Functions such as an auto-answer facility available on some modems may well be worth consideration, especially for larger organisations.

1.3.5 Field data coding

The electronic data recorder in effect replaces the surveyor's field book, and therefore must allow entry of all of the information required to successfully complete the task. As the information is to be processed automatically by computer, it is essential that the information is stored in a coded format which is totally unambiguous. The information required during any survey can be boken down into four main categories, namely

1. Administrative; Date, surveyor, job number etc.

2. Initialisation; Starting coordinates or reference azimuth

3. Traversing

4. Detail

It is obvious that any data recorder/ computer processor combination must be able to support a coding system which will allow entry of information concerning each of the above categories. There are so many different methods of coding used at present that it is not practical to review them all, and so the coding system introduced by the author based on the Kern R48 data recorder will be used as an example. Nicholson (1984) covers in detail the general requirements of a coding system from first principles.

The R48 data recorder supplies the operator with a series of fixed alphanumeric prompts, which appear on a continuous loop. Bearing this in mind, it was our objective to utilize these prompts in the most efficient manner. These prompt loops are themselves divided into four distinct groups, or modes, as shown below, each having their own role.

MODE 1	Measurement mode
Hor	Horizontal angle
ELE	Vertical angle
dIS	Slope distance
Pnr	Point number
Pco	Point code
SH	Signal height
E-l	Longitudinal eccentricity
E-r	Lateral eccentricity
Add	Addition value

MODE 2	STATION MODE
Snr	Station number
Sco	Station code
IH	Instrument height
tE	Temperature
Pr	Pressure
Art	Type of measurement

MODE 3	ADMINISTRATION MODE
OP	Operator
b-E	Beginning/end of job
Pro	Project number
dAt	Date
t	Time
Inr	Instrument number

MODE 4	CORRECTION MODE
nrC	Measurement number
PnC	Point number
C46	Correction 1
C47	Correction 2
C48	Correction 3
C49	Correction 4

Modes 3 and 4 are termed passive as they simply produce a printed message on the raw data listing. Mode 3 is used for any administrative information required such as the surveyor's number or the project title. Experience has shown that the use of mode 4 to store corrections can lead to confusion, and so generally it is better to eradicate errors once back in the office when the entire raw data listing can be viewed.

Modes 1 and 2 are termed active as these are directly interrogated by the computer, with any errors stored within the information being included in the calculations performed by the software. As such if a traverse is not corectly defined the whole survey will be invalid until the errors are corrected. Error messages are given by the microprocessor whenever possible. Let us consider the input of survey information into these two modes by a rigorous coding system.

Mode 2 is used solely for the input of traverse and initialisation coding. Initialisation coding will be discussed later in this section. Whilst traversing the surveyor needs to note;

1. the station being occupied
2. the station being sighted
3. whether the measurement is a backsight, foresight or sideshot
4. the height of the instrument
5. the height of the target

All of this information is necessary to compute the traverse, and so it must be possible to store this in the data recorder. Within Mode 2 there are prompts for 'station number', 'station code' and 'instrument height'. 'Station code' refers to the coding system adopted by the author for traverse definition, where

Code 50 = Foresight

Code 51 = Backsight

Code 52 = Sideshot foresight from main traverse

The number of the station presently occupied is entered in the 'station number' field. Once this information has been entered, the operator records the values by pressing the red key on the R48, and then switches into Mode 1 (the measurement mode) where the height of the target and the number of the traverse station being sighted are entered. Measurement to the target can then commence, with the red record button being pressed after each measurement. Using this method traverses can be quickly and easily defined.

When detail points are being collected the amount of information required is much less than for traverse coding as the position and height of the instrument will have already been defined. The main objective of surveying detail is that the information can be collected as quickly as possible. Therefore, coding detail in Mode 2 and then having to switch to Mode 1 to make the measurements is inefficient. It was therefore decided to perform all of the detail coding within the measurement mode, utilising the 'Pco' field. Detail coding falls into two categories, namely pure point coding with specific symbols or linework. The use of an automated system should allow the operator to almost completely draft the final plan whilst still in the field, with only a minimum of graphical editing required once back in the office. The efficiency of obtaining completeness of the plot in the field against the practical surveying efficiency will be discussed later.

Detail points are defined by a series of three digit codes in the range 150 to 200. When such a code is encountered during processing in the 'Pco' field the relevant symbol is plotted at the point. For example, code 160 represents a manhole cover, code 171 a deciduous tree, and so on. This may at first appear inferior to alphanumeric coding where 'MH' could represent a manhole cover and 'DT' a deciduous tree. However, the operator must still know that 'MH' represents a manhole cover, and not say 'MC' or 'mh'. As it is unusual for a survey to pick up more than a dozen different feature types the use of a rigorous digital coding system seems equally efficient, and in some cases may prove less confusing.

The ability to draft linework in the field requires that coding exists to start the line, continue the line, define the type of line required and construct arcs or curves if necessary. There are also occasions when it is desirable to embed a symbol within a certain line, for example, when surveying an overhead power line symbols would be needed to mark the position of the pylons themselves. Linework coding is also achieved by using the 'Pco' field in the measurement mode by the optional use of up to three codes separated by a full stop, which can be represented as 'x.yyy.zzz'. The beginning of a line is signified by code 1, this representing a pen move command to the plotter. To join a line from the present survey point to the last requires a code 2, which represents a pen draw command. The type of line is chosen by using a three digit code in the range 100 to 120, depicting different dash patterns, pen thicknesses and colours. The default is code 100 which produces a solid line drawn by pen 1 in the plotter. If embedded symbols are required then the relevant detail code is also added. As an example, if it is desired to survey the line of a drain with a dashed line and mark the position of the manholes the beginning of the line would be coded '1.105.160'. The centre point of an arc is defined using a code 3, whilst a smooth line curve is produced by using code 4.

To clarify the use of the field coding system, an example is given in Figure 1.2 of part of a simple traverse and detail survey. Note that the instrument is set up at point 101.

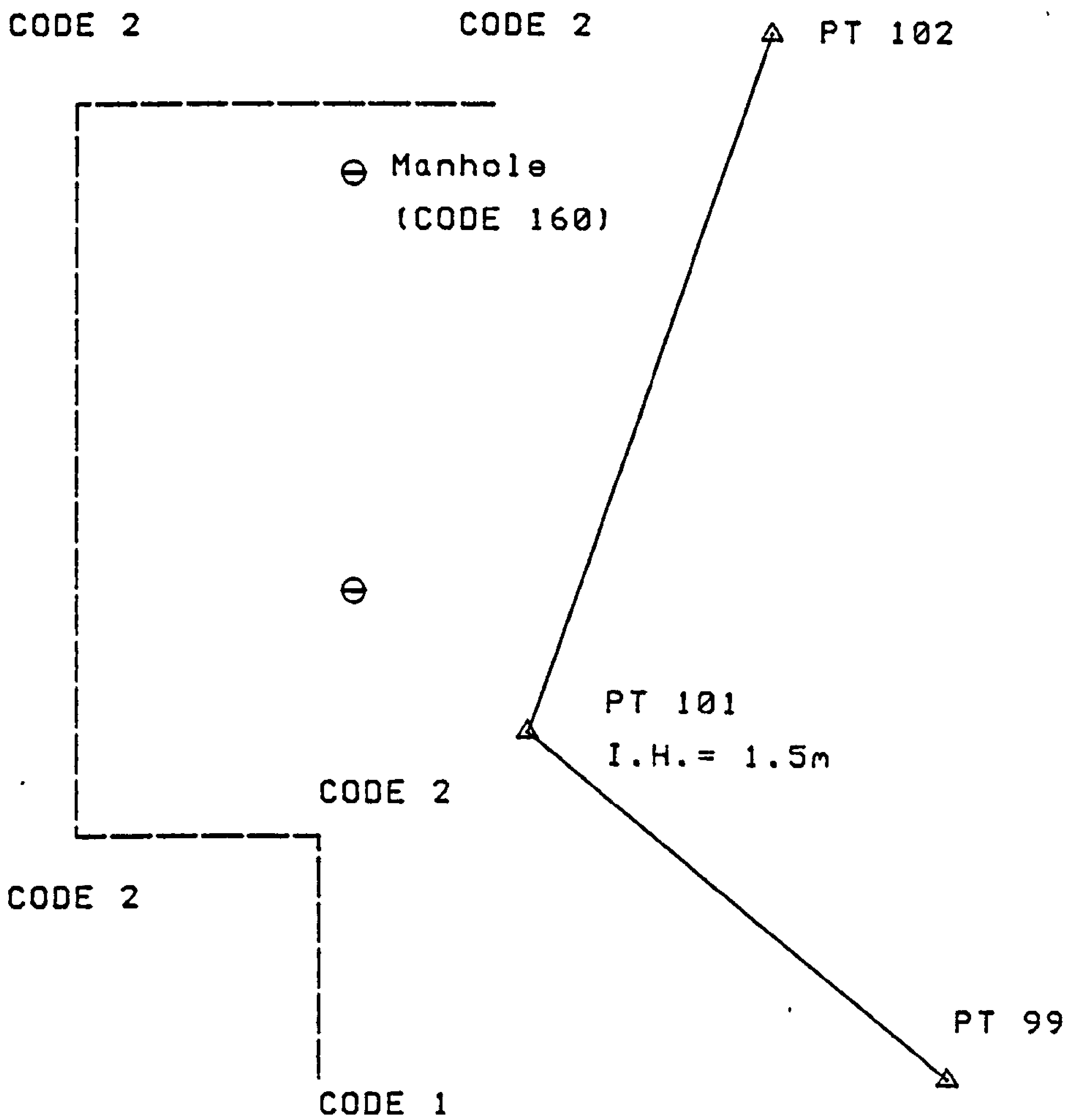


Figure 1.2 Example of field data coding

FIELD DATA CODING FOR FIGURE 1.2

FIELD	ENTRY	INTERPRETATION
		Enter Mode 2
Snr	101	Instrument at station 101
Sco	51	Backsight
IH	1.5	Instrument height = 1.5m
	(RECORD)	
		Enter Mode 1
Pnr	99	Sighting to station 99
Pco	Left blank - only used for detail points	
SH	1.605	Target height = 1.605m
	MEASURE TO STATION 99	
	(RECORD)	
		Enter Mode 2
Snr	101	Instrument at station 101
Sco	50	Foresight
IH	1.5	Instrument height = 1.5m
	(RECORD)	
		Enter Mode 1
Pnr	102	Sighting to station 102
Pco	Left blank - only used for detail points	
SH	1.47	Target height = 1.470m

MEASURE TO STATION 102

(RECORD)

=== PICK UP DETAIL FROM STATION 101 ===

--Survey the manholes--

		Remain in Mode 1
Pnr	30	Detail point 30
Pco	160	Code 160 = Manhole
SH	1.6	Detail pole set to 1.600m

MEASURE TO MANHOLE

(RECORD)

MEASURE TO NEXT MANHOLE

(RECORD)

--Survey the edge of the building as a dashed line--

		Remain in Mode 1
Pnr	32	Point number incremented
Pco	1.104	Begin dashed line
SH	1.8	Detail pole set to 1.800m

MEASURE TO BEGINNING OF LINE

(RECORD)

		Remain in Mode 1
Pnr	33	
Pco	2	Draw line to this point
SH	1.8	

MEASURE TO NEXT POINT ON LINE

(RECORD)

MEASURE TO NEXT POINT ON LINE

(RECORD)

It should be noted that when numerous points of the same type are being surveyed it is not necessary to re-enter the detail code as it is assumed to be the same until changed by the user.

The main weakness of the coding system adopted is in the entry of the initial coordinates. These have to be entered in Mode 2 in a set format, ignoring the prompts. The system recognises that coordinates are being entered by the use of code 32. The sequence is:

Sco	32
IH	Station Number
TE	Station Level
	(RECORD)

Sco	32
IH	Easting of Station
TE	Northing of Station
	(RECORD)

Orientation is enabled by the use of code 33 in the 'Sco' field with the number of the station occupied in the 'Snr' and either the azimuth or the station number being sighted entered into the 'Pnr'.

Psychologically the data recorder is the main hurdle envisaged by potential field users of an automated system. This is mainly due to, firstly, the data recorder appearing totally alien to the conventional field book and pencil, secondly, there is often a general feeling of not being able to cope with the new technology, and thirdly, there is a mistrust that the data might not be stored. With this in mind it is interesting to note the reactions of personnel trained during a series of courses run for NCB surveyors at the University. After two days of instruction and guidance using the Kern R48 associated with the Kern total station within and around the laboratory, all personnel felt confident and competent enough to complete a fully automated survey without supervision. When it was seen that the data could be processed, edited and plotted within a matter of minutes rather than hours by a manual technique, all stated that given the opportunity they would prefer to be able to use a data recorder, even in conjunction with conventional survey equipment where the angles are tapped in by hand through the keyboard, given that the relevant computing facilities were available. It has subsequently been shown by one area of the NCB that operators can become competent within one day of exposure to the data recorder (Aitchison 1984). Therefore it appears that the problem of acceptance is not as great as was first feared. Hodges (1985) points out that in Germany, where data recorders have been in more widespread use for many years, no surveyor would wish to revert to a field book if a data recorder were available. The purchase of an electronic total station would not in fact be considered unless a suitable data recorder were available. It is interesting to note that the first piece of equipment bought by the Department with this research in mind was a data recorder which was then used in conjunction with conventional instrumentation such as the Wild RDS self-reducing tacheometer and the Wild GAK-1 gyrotheodolite (Smith 1982).

1.4 The Kern E2/DM503/R48 Modular System

This section will consider the Kern E2/DM503/R48 instrument combination as an example of an electronic total station, highlighting the practical advantages of the equipment and the features required of them.

From the outset Kern have adopted a modular approach to the design of their electronic field instruments, producing a range of electronic theodolites and EDMs which are fully compatible. Plate 1.2 shows the Kern E2/DM503 with the DIF41 and HP41CV calculator. The EDMs can also be mounted onto conventional opto-mechanical theodolites provided that a special bracket is attached to the telescope. The philosophy behind modularity is to provide the surveyor, or surveying company, with the maximum amount of flexibility. As such, the optimum instrument combination can be chosen for each job. A further benefit is that if one constituent part of the system breaks down, then the other facets can still be used. At present Kern have two electronic theodolites, namely the Kern E1, with a claimed precision of 2" for a double faced pointing, and the Kern E2, with a precision of 0.5". These theodolites can be used by themselves to simply measure horizontal and zenith angles. By sliding one of the EDMs available onto the telescope until it is locked, the instrument is converted into an electronic total station, the electical contact being automatic. There are three EDMs presently available, the DM502 (accuracy [5mm+3ppm], range 1500m using 3 prisms in average conditions), the DM503 ([3mm+2ppm], 3000m), and the DM510 ([3mm+2ppm], 6000m).

Although the system cannot be defined as being coaxial, as was the HP3820A with the EDM mounted within the optical telescope, the design of the Kern instrument imitates such a system, thereby affording the same advantages. Notably this means that the path followed by the measuring beam is symmetrical about the optical line of sight, allowing slope distances and vertical angles to be measured simultaneously on both faces. This is not possible with all instruments available today when the EDM is mounted above the theodolite.

Following extensive field trials with various electronic total stations it was decided to purchase the Kern instrument with financial assistance from the National Coal Board. The original equipment bought comprised an E1 electronic theodolite, DM502 distance meter and an R48 solid state data recorder, as shown in Plate 1.3. Delivery was taken in 1981. By prior arrangement the system was updated free of charge by the Survey and General Instrument Co. on the introduction of the higher specification E2 theodolite and DM503 EDM in 1983.

Plate 1.2

The Kern E2/DM503/DIF41

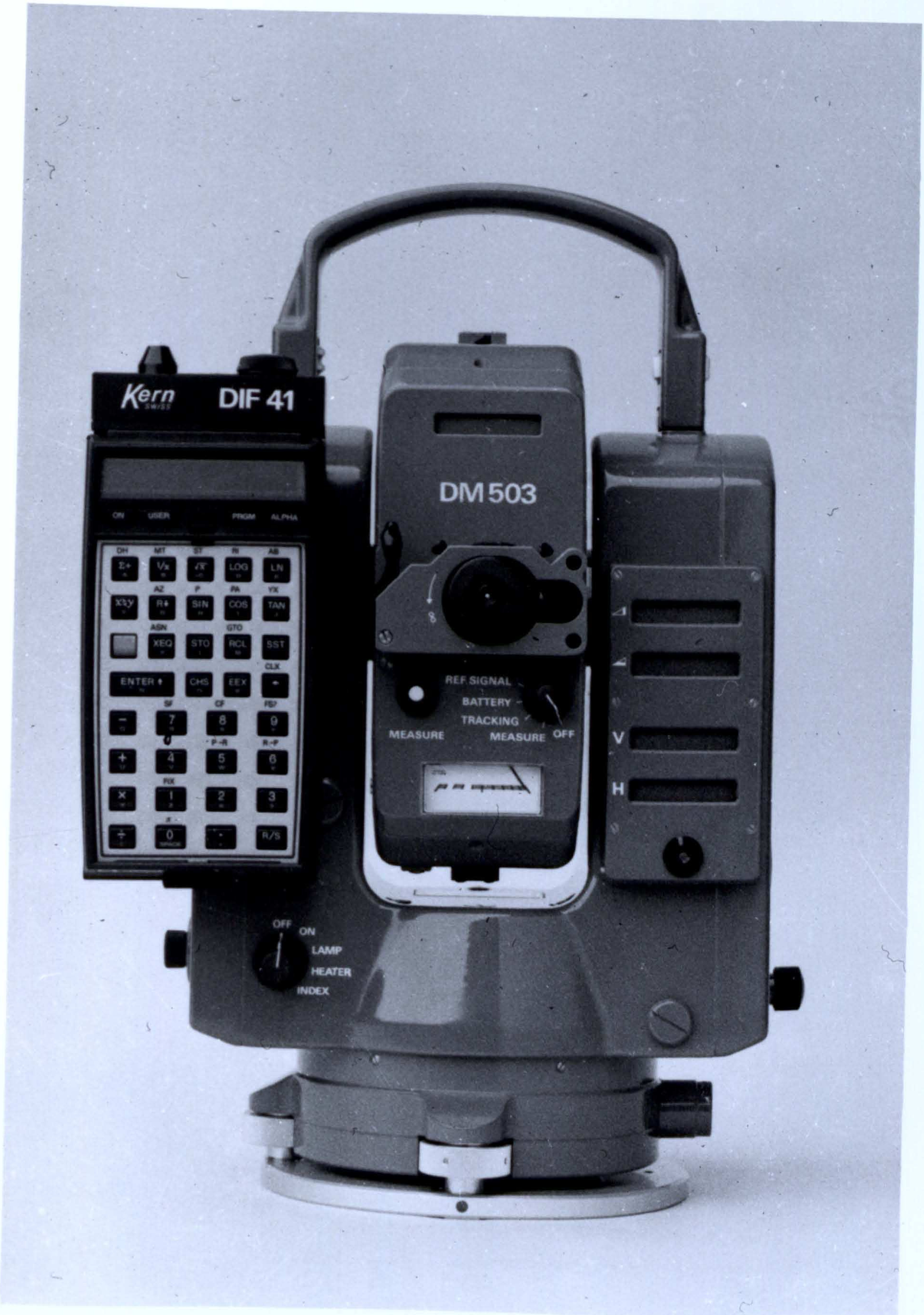

Kern
SWISS
DIF 41
DM 503
REF SIGNAL
BATTERY
TRACKING
MEASURE
MEASURE
OFF
V
H
OFF
ON
LAMP
HEATER
INDEX

Plate 1.3

The Kern E1/DM502/R48


DM502
f
SE
RE
SM
7
8
9
R↓
4
5
6
M
1
2
3
C
0
·
CHS
Kern SWISS
R 48
TRACKING
BATTERY
REF. SIGNAL
MEASURE
MEASURE
OFF
-008.043
098.486
V 105.188
H 130.120
OFF
ON
HEATER

1.4.1 The Kern E2 Electronic Theodolite

The E2 electronic theodolite has been designed to resemble the arrangement of a conventional theodolite, thereby presenting no particular problems to the observer in terms of operation and use. In addition to the standard functions, however, the E2 offers a number of special features.

Electronic components can only replace a mechanical system to a limited extent and so precision engineering is still vital in achieving a high standard of accuracy. It should be remembered that higher resolution electronics cannot compensate for general mechanical instability. However, it is now possible to detect instrument related deviations from the ideal condition, with the inbuilt microprocessors making it possible to retain these errors and apply them where necessary. Apart from stability the design of the instrument should be such that the influences caused by the internal heating are as small as possible. With this in mind the E2 operates with a power consumption of only 2.5W. The claimed accuracy of the E2 is 0.5" for a double faced pointing. To achieve this accuracy it is therefore a prerequisite that the instrument has good mechanical stability and design, accurate circle reading, an automatic compensation system and a high resolution telescope. The telescope of the E2 is identical to that used in the Kern DKM-2A one-second theodolite having a magnification factor of 32.

The mechanical stability of the theodolite is enhanced by the design of the base of the instrument. The conventional three foot screw system has been replaced by a central pivot point with two levelling screws perpendicular to it. This results in the majority of the weight being absorbed by this centrally located point. This system also greatly facilitates instrument set up and levelling, with the tilting axis height of the instrument remaining constant during levelling and the instrument always being tilted centrically to the vertical axis immediately above the station.

To achieve one-second order accuracy it is necessary to automatically take into account the effects of vertical axis tilt on both the horizontal and vertical circle readings. Tilt of the vertical axis can result from imperfect levelling, wobbling, or asymmetrical weight distribution. The magnitude of the error induced by the latter of these is discussed in Section 2.3. The measurement of the amount of tilt is enabled by the use of a compensator. In contrast to opto-mechanical theodolites, the compensator in the E2 is not situated within the optical light path of the circle scanner, but is a separate element. This allows the compensation values to be separated from the reading at any time if so desired, and the values of compensation displayed. In this way the instrument can be very accurately levelled by using the compensator values of tilt in both axes if desired, or the compensator turned off in certain circumstances, such as surveying from a vibrating platform.

The E2 compensation system measures tilt in both the telescope axis and the tilting axis, the system being based on the reflection of a spot of light from a liquid surface. The spot of light from an illumination diode is reflected from the surface of the liquid onto a large area photo-diode, which acts as a two-dimensional position detector. The position of impact is determined by the magnitude of the induced photo-electric currents in four laterally mounted electrodes. Thus the position of the light spot with respect to the reference value, or compensator zero point, can be determined in coordinate form. One coordinate is a measure of the inclination in the line of sight, the other for the inclination in the tilting axis. The resolution of the compensator is better than 0.3".

In addition to negating inclination of the vertical axis, it is also possible to account for indexing errors of the vertical circle. The index error is made up of the combined values of vertical circle zero point error (that is, the deviation of the vertical circle zero mark to the direction of the vertical axis), compensator zero point error and vertical collimation error of the telescope. By measuring a seies of double faced vertical angles to the same target after having selected the 'Index' mode on the theodolite, the overall value for the index error is displayed and subsequently applied to all vertical circle readings.

Circle measurement in the E2 is based on an incremental electro-optical measuring process, which is covered in detail by Munch (1983). Each circle comprises a glass disc with 20000 radial marks each 5.5 µm thick, separated by a space of equal width. A section of 200 marks is magnified by a factor of 1.005 and superimposed onto the diagrametrically opposite portion of the circle, creating an interference pattern. The interference produced is termed a moiré pattern. The distribution of brightness over a moiré period approximates to a sine curve, and its magnitude is detected along its length by four photo-diodes. Coarse angular measurement to the order of 30" (0.01 gon) is achieved by simply counting the number of leading edges of a square wave derived from the sine wave that pass the first photo-diode. To obtain an accuracy of 0.3" (0.1 mgon) it is only necessary to resolve each stationary moire period to 1%. This is achieved by an interpolation process using the photo-electric currents from all four photo-diodes. The angles are continuously read whilst the instrument is in use, allowing the angles to be continually displayed. The horizontal circle can be switched to zero at any time by pressing a countersunk button, or set to any azimuth by using a circle drive wheel.

1.4.2 The Kern DM503 EDM

The Kern DM503 is a compact infra-red EDM which fits symmetrically around the telescope of the E2 electronic theodolite, the combination forming an electronic total station. The measured slope distance is displayed directly on the DM503 with the reduced plan distance and the difference in level shown on the theodolite. Distance measurement can occur in two modes, the primary mode having a claimed precision of ±(3mm + 2ppm) with a measuring period of 8 seconds, the second mode being tracking with reduced accuracy but a continually updated reading every 2 seconds. The tracking mode is particularly useful for setting out points. Measurement is commenced by pressing a single button once the mode has been selected. Kern claim that the DM503 has a range of up to 3 km using one prism, 4.5 km using three prisms, and 5.5 km using seven prisms, although these figures are assuming ideal measuring conditions. It is probably more reasonable to expect about 2 km with one prism, 3 km with three prisms and a maximum range of 5 km in normal situations.

The results obtained during evaluation of the DM503 under test conditions are detailed in Chapter 2. Allowance is made for interference during the measurement cycle, and an indication of the level of interruption is displayed. If the total interruption time exceeds 2.7 seconds or the number of interruptions exceeds 200 then a warning is given and the final display exhibits an extra decimal point to indicate that the precision cannot be guaranteed. A correction factor allowing for the atmospheric conditions can be incorporated into the measurements via a set of screws on the base of the instrument. The values which are subsequently displayed are adjusted by this factor, but it is should be noted that the data which is recorded is not adjusted, that is, recorded data is uncorrupted. This feature is very important as it allows fieldwork such as setting out to be accomplished as accurately as possible whilst still permitting the computer to work from raw data, applying any necessary adjustments during computation.

The measuring principles of the DM503 are similar to those used commonly in infra-red distance meters, and uses a carrier wavelength of 0.86 um. Three modulation frequencies are used which, assuming the velocity of electromagnetic radiation in free space Co = 299792500 m/s and refractive index No = 1.00028195 produce the following measuring (or unit) lengths:-

Modulation Frequency (KHz)	Unit Length (m)
f1 = 14985.400	$U1 = \frac{Co}{2Nof1} = 10.000$

$f2 = 149.854$ $$U2 = \frac{Co}{2Nof2} = 1000.000$$

$f3 = 151.353$ $$U3 = \frac{Co}{2Nof3} = 990.096$$

For distances less than 1000m only the first two frequencies are required to determine the distance, with the resolution obtained from f1 accurate to 1 mm. For distances greater than 1000 m a frequency difference procedure is adopted using f3 and f2. The frequency difference between f3 and f2 equals 1498.54 Hz, giving a unit length of 100000 m. This frequency is therefore used to determine how many integer multiples of 1000 m are included in the distance. The advantage of using a frequency difference technique is that only a practical frequency range is required from the diode.

1.4.3 The Kern R48 data recorder

The R48 is a CMOS (complementary metal oxide semiconductor) based solid state memory data recorder, capable of storing 49152 (48k) characters, the equivalent of approximately 800 fully coded points. Due to the low power consumption of the CMOS memory intrinsic data security of up to one month is provided by the rechargable internal NiCd cells. The R48 has a 15 digit 7 segment Liquid Crystal Display which is divided so that the first 3 digits provide the alphanumeric prompts, the fourth digit, the sign, and the remaining 11 digits the recorded coding or field measurements.

The microprocessor is turned on or off using a covered switch, whilst the keyboard and display can be turned off separately by a small tumble switch. The use of this tumble switch helps to save power when the unit is not being used as well as stopping possible erroneous entries during transport from one station to the next. The coding system used for the R48 has been detailed in Section 1.3.5.

Data transfer is via a RS232 interface on the top of the unit. Data is transferred in ASCII code format with half-duplex restraint allowing error checking up to a maximum baud rate of 1200. The baud rate required can be selected by entering one of the internal R48 programs. Once data has been transferred it is not automatically lost, in fact, the only way to erase data is to enter a complex numeric code sequence.

The R48 can be connected to the E2 via a short cable directly to the theodolite, or a longer cable connected to the system battery, both enabling direct data transfer from the instrument. The unit can also be used as a hand held device for manual entry with conventional instrumentation. If connected to the battery or the E2 the R48 is powered directly from the battery and so can be used for as long as the battery lasts. When hand held there is sufficient power provided by the NiCd cells for up to 50 hours continuous use if fully charged.

The CMOS memory allows direct retrieval of all recorded data via a series of search programs initiated from the keyboard. Individual pieces of data can be found by entering a search argument, and further values can be examined by either stepping backwards or forwards through the memory.

Further details of the R48 as a recording unit can be found in Aeschlimann (1982).

Tha author has used the R48 data recorder for the last three years during a variety of survey tasks, both on the surface and underground. The unit has proved to be totally reliable, even if being used in adverse conditions such as very heavy rain, with no data ever having been lost or corrupted. The keyboard is protected by a plastic cover to help waterproof the instrument, but this has not hindered the use of the keys in any way. The R48 is very easy to use and has proved suitable and efficient for all of the survey tasks encountered during this research. When using a data recorder it is vitally important that the user has full confidence in the device; the author would have absolutely no qualms in using the R48 for even the most important survey.

CHAPTER TWO

EVALUATION OF ELECTRONIC TOTAL STATIONS

Evaluation of electronic total stations

2.1 Introduction

The introduction of instrumentation such as electromagnetic distance measurers, gyrotheodolites and electronic theodolites into the field of surveying have greatly enhanced the "tools" available to the mine surveyor. It is the duty of the profession to appraise each development with a view to the applicability of the equipment to the discipline, and where necessary, reappraise conventional survey practice and techniques so that the new instrumentation can be used to its fullest extent. It is therefore necessary to fully understand the principles of such equipment and also to evaluate their potential. The increased sophistication of such instruments also places greater emphasis on the need for routine operational performance monitoring. Only in this way can the accuracy of the results obtained in the field be guaranteed. It is therefore possible to sub-divide survey test work into two separate categories, namely evaluation and research, and routine monitoring. Both of these objectives can be achieved by the use of test facilities such as baselines and networks.

Facilities must exist for the regular routine testing of instruments on convenient and secure standard baselines and networks. The new generation of instruments have become so easy to operate that there is a tendancy to accept their results with blind faith; this must be avoided at all costs. The sophistication of the instruments in fact increases the need for detailed and exhaustive testing if the accuracy expected is to be guaranteed. Any drift in instrumental performance, due either to the passage of time or to other events, must be identified by monitoring programmes.

The necessity for research and development testing must not be overlooked. Survey instrument development is a very dynamic commercial field and the need arises for a means whereby both industrial and research personnel can assess not only the performance of new instruments but also their impact upon established survey techniques. This can only be achieved through the use of standard laboratory and field sites.

Bearing both of the above requirements in mind, a series of test facilities have been established by the Department of Mining Engineering. These facilities are used for instrument evaluation, undergraduate training, research work, and are also available to and used by mine surveyors for monitoring their equipment. As such they fill a vital role for both the University and Industry.

This chapter will briefly describe each of the facilities available and discuss the results obtained by various electronic total stations. Particular attention is paid to the results obtained on the evaluation of the Kern total stations carried out by the author. The test facilities are based at three locations, namely the Department's laboratory, a baseline at Quorn, Leicestershire, and the main test network in Llangollen, North Wales. Overall these facilities allow the evaluation of both horizontal and vertical angular accuracy, and the measurement of known distances between 12 m and 3000 m.

2.2 Test Facilities

2.2.1 The laboratory short baseline

For test purpose this facility should be an easily accessible flat line which is situated indoors, thus providing stable atmospheric conditions which can be monitored very accurately. The obvious length limitation due to the size of the building renders the baseline suitable for the comprehensive evaluation of EDM at short range. It is necessary that the line standards are determined as accurately as possible, with the distances to at least ±0.5 mm, the bearing to 3 seconds of arc and the differences in level to ±0.1 mm. Such precision renders the line available for monitoring other equipment such as gyrotheodolites, steel tapes and levels.

The laboratory short baseline is approximately 43 m long and has been used since 1966 for the evaluation of survey instruments. The line consists of two permanent stations embedded in the concrete floor of the laboratory, with three lower order intermediate stations between them. The overall length of the line is 43.1355 m, with all of the distances known to better than ±0.5 mm. The design of the two permanent stations is worthy of consideration. Both comprise a cylindrical metal plug 5 inches long and 1 inch in diameter, cemented firmly into the floor flush to the floor level. The exact position of the station is defined by a cross etched onto the metal, with a punch mark at the point of intersection. Above these stations permanent monuments have been erected, one square with four supporting legs, the other triangular with three supporting legs.

The main concern was that these monuments should not be affected by any subsidence of the laboratory floor. To secure the square monument 8 inch deep 4 inch diameter holes were drilled at the position of each leg. A rag bolt was securely cemented into each hole. At the base of each leg a plate was welded with a correct diameter hole to allow the rag bolt to pass through it, thereby firmly fixing each leg by tightening the rag bolt onto the plate. The four legs support the top plate holding the nickel plated steel mounting plate. The mounting plate is fitted with jack screws for fine level adjustment. The foundation of the triangular monument was necessarily different from that of the square monument as there was the possibility that on occasions it may have to be moved to allow large equipment to be brought into the laboratory, although in practice this has never been necessary. A three-legged monument was chosen as it requires less space and can be relevelled more easily. An 18 inch square steel plate 2 inches deep was set flush into the floor and fixed by cement and rag bolts. An 18 inch equilateral triangular steel plate, onto which the supporting legs are welded, is fixed to the base plate by spigots allowing vertical adjustment but ensuring that horizontal dislacement cannot occur. In this way the monument can quickly be dismantled and then reassembled and relevelled. The head of this monument is similar to that of the square monument. The monuments guarantee a centering error of less than 0.1 mm. Boxes permanently situated near each station contain adaptors which allow the precise centering of any make of survey instrument. The position of the monument head above the station is periodically checked using a precise optical plummet.

The three intermediate stations are simply small metal plugs set into the floor with a cross etched onto their surface. The station is also marked with a small hole into which pins can be placed. This facilitates regular checks that the line has not moved as these pins should be precisely in line when viewed from the monument. Measurements are obtained to these by erecting tripods above the stations. Measurements have been taken on the baseline for nearly twenty years using catenary taping and a variety of EDM's, including the Tellurometer MA100 and the AGA Model 6. The most probable distances for the laboratory baseline are shown in Table 2.2. To date there has been no detectable movement of any of the stations.

Apart from providing a perfect short range distance test facility, the laboratory also provides an excellent environment in which to become fully familiar with the use of any new equipment, so that there are no handling problems when the instruments are taken into the field. The base has also been used for the calibration of gyrotheodolites since 1966 and numerous gyrotheodolites have been tested on the line. It is regularly used by practising mine surveyors to calibrate their gyrotheodolites. Other survey test facilities within the mining laboratory include ten wall-mounted scales for precise levelling exercises and for the routine checking of the adjustment of levelling instruments.

Table 2.2 shows the results obtained using the four total station instruments tested so far on the laboratory baseline. As can be seen, on no occasion is there a deviation of greater than ±1 mm from the most probable distances, showing that even at very short distances high precision is obtained. Each result is a mean of three separate measurements, each corrected for the atmospheric conditions.

2.2.2 The laboratory traverse

The laboratory closed traverse provides a convenient easy access facility for evaluation of horizontal angles and short distances. Because the traverse is virtually flat this facility is not particularly useful for the evaluation of vertical angle accuracy. The facility is used extensively for undergraduate training, instrument evaluation, gaining experience of new techniques, and featured strongly in the courses run for NCB surveyors on automated survey.

The traverse runs through and around the mining laboratory at the University, and comprises 12 stations. The stations are simply small metal plugs set into the ground with a narrow diameter hole drilled into them to denote the exact station position. Angle measurements are made to white pegs which fit into the station hole. The angles have been regularly measured with various theodolites, including the one-second Kern DKM2, whilst the distances have been measured with steel tapes and a variety of EDM instruments. For the past ten years the traverse has formed part of the undergraduate survey practical course. Each year all of the angles have been measured four times by five different second order theodolites, and these results have provided the basis for calculating the most probable angles. To date these values are therefore based on at least 200 measurements. The standard errors for the horizontal angles and distances are ±2.5" and ±2.0 mm respectively. The most probable horizontal angles and slope distances are shown in Tables 2.3 and 2.4 respectively, together with the results obtained for the different total stations which have been evaluated on the traverse. It should be noted that because the lengths of the traverse legs are short, precise centering of the instrument over the station is vital. A centering error of 0.5 mm when angling between stations 20 m apart introduces an immediate error of 5 seconds of arc.

2.2.3 The Quorn baseline

In July 1974 a further distance measurement baseline facility became available at Quorn in Leicestershire adjacent to a disused railway line. The Department was approached by Balfour Beatty of Derby, the objective being to set out twelve stations in line at specified distances ranging between 80 m and 942 m which could be used for rapidly marking off and cutting power cables into accurately known lengths. The acquisition of this facility complemented the existing short laboratory baseline. The original specification was that the distances must be accurate to within 5 mm of the specified distance, and today it is considered that the actual distances are known to ±1 mm.

The survey stations consist of approximately 1 cubic metre of concrete sunk into the ground, with a central, flat, measuring plate on which the nominal distance is marked (see Figure 2.1). The exact position of the stations is denoted by a 1 mm diameter hole drilled through the measuring plate, and all measurements are taken to tripod mounted prisms centred over this hole. The measuring plate is protected by a metal cylinder with a removable cap. The stations were originally designed for a short working period (approximately 6 weeks) and so this type of station was considered sufficient, although there has been no detectable movement to this day. The stations were set

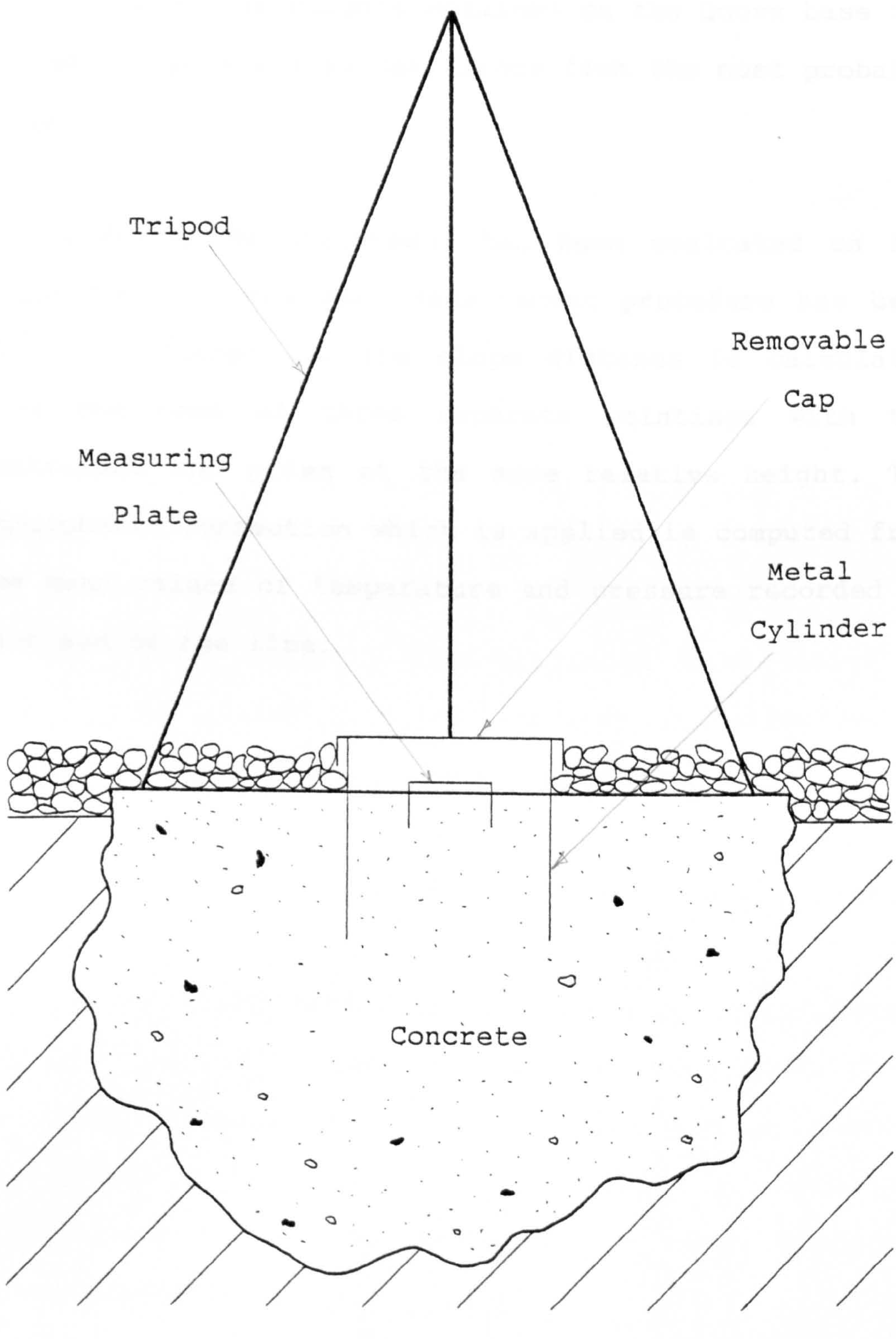


Figure 2.1 Quorn station design

out using a Tellurometer MA100 with a claimed precision of ±(1.5mm + 2ppm) (Hodges and Curl 1977). The line has been measured over 30 times with 20 different types of EDM (Hodges and Smith 1982). The results for the various total station instruments obtained on the Quorn base are listed in Table 2.5 as deviations from the most probable values.

Whenever an instrument has been evaluated on the Quorn baseline the same measurement procedure has been strictly adhered to. The slope distance is calculated from the mean of three separate pointings with the instrument and prism at the same relative height. The atmospheric correction which is applied is computed from the mean values of temperature and pressure recorded at each end of the line.

2.2.4 The Llangollen test network

2.2.4.1 Requirements of a test network

The requirements of a test network whose primary function is for the evaluation of electronic total stations are;

a) All of the parameters should be known as accurately as possible. The horizontal and vertical angles must be known to better than ±1 second of arc and the slope distances to better than ±2 mm.

b) The slope distances should range from 500 m to 5000 m.

c) A wide range of line gradients should exist to allow investigation into the accuracy of automatically reduced distances and trigonometrical levelling.

d) The network stations should be secure and stable.

e) The basic network shape should be geometrically strong, but with the possibility for some shape variation. A good basic shape should enable accurate co-ordinate determination. Various co-ordinate calculations can then be carried out following different survey procedures.

If the development of a network is being considered then particular attention must be paid to the selection of the location generally, of the positions of the individual stations to ensure intervisibility, and to the type of station used. To be of any value the network must be considered as a long term project, with probably many years of results being required before any confidence can be held in the precision of the accepted values. The long term worth of the facility will be solely dependent upon the initial care and effort taken in the design and location of the survey stations. It is probably a good idea to have some spare stations in case any are inadvertantly lost.

2.2.4.2 History of the Llangollen network

The Department of Mining Engineering has held an annual field survey course at Llangollen since 1928. It was not until the early 1970's with the possible future introduction of self-reducing EDM instruments (Hodges 1970b) that the idea for a permanent network evolved. The aim was to provide a suitable facility primarily for the evaluation of these instruments, electronic total stations when they became available, as well as the evaluation of other classes of instrument.

Llangollen offered the perfect environment in which to establish such a network. The site chosen is situated in a deep U-shaped glaciated valley through which the River Dee runs just to the east of the town. The valley is bordered to the north by a precipitous limestone escarpment, whilst to the south the valley rises some 300m above the valley floor. This location allowed long level lines in the valley floor and along the ridges, steeply inclined sights, and lines of varying humidity crossing the river and the Shropshire Union Canal. Another vital factor was that over the years a very good relationship has been developed with the local farmers and landowners. Without their co-operation such a network would be totally inconceivable.

The first station was established at the east end of the valley in 1971 in the lawn of the Bryn Howel hotel. In the same year two more stations were established, namely Ridge and Sheepfold. Ridge was inserted down to the bedrock on one of the prominent ridges on the north side of the valley. The line between Bryn Howel and Ridge was used for the first gyrotheodolite observations. Sheepfold was established on the top of the south side of the valley, again set to the bedrock. Sheepfold is the highest station in the network, and is the only station to date on the southern side of the valley.

The fourth station was established in 1973 in a field adjacent to the A5 and about 200 m from the Tyn-Y-Wern hotel. This station represents the second station in the valley bottom, and affords virtually a level sight through to Bryn Howel. The station is the deepest of any of the stations as it is located in a farmer's field and therefore had to be sunk below ploughable depth.

In 1974 the Castle and Escarpment stations were established. The Escarpment station is situated on top of the most prominent limestone ridge in the valley, and was inserted down to bedrock. Castle is located on the hill where the ruins of Castle Dinas Bran now stand. Plate 2 illustrates the topography of the valley. The photograph is taken from the Ridge station looking along the limestone escarpment. Escarpment station is situated

Plate 2

View of the Llangollen Network

from the Ridge station

on the highest visible point on the picture, whilst the ruins of the Castle Dinas Bran can just be seen in the haze on the left. The Castle station is situated just below the ruins.

The network was completed in 1979 when the Gyro station was established in a field about 200 m to the east of the Tyn-Y-Wern station. This was established to allow gyrotheodolite observations to be taken without interfering with the other survey work on the network. The network is shown in Figure 2.2. The network was initially connected to National Grid in 1976 (Gillespie 1976), however it should be noted that the internal accuracy of the network is of a higher order than that of the co-ordinates of the local Ordnance Survey control pillars. Numerous observations of many different types have been taken on the network over a number of years and a complete record of all these observations has been kept.

Complete intervisibility exists on all lines between the seven stations, with the exception of the line between the Gyro station and Bryn Howel. It is also becoming difficult to measure the distance between Bryn Howel and Escarpment because over the years a branch from a large tree has grown across the line of sight. It is still possible to measure the angles when the tree is not in leaf. The twenty lines of sight have a fairly even distribution of lengths ranging from 207 m (T-G) to

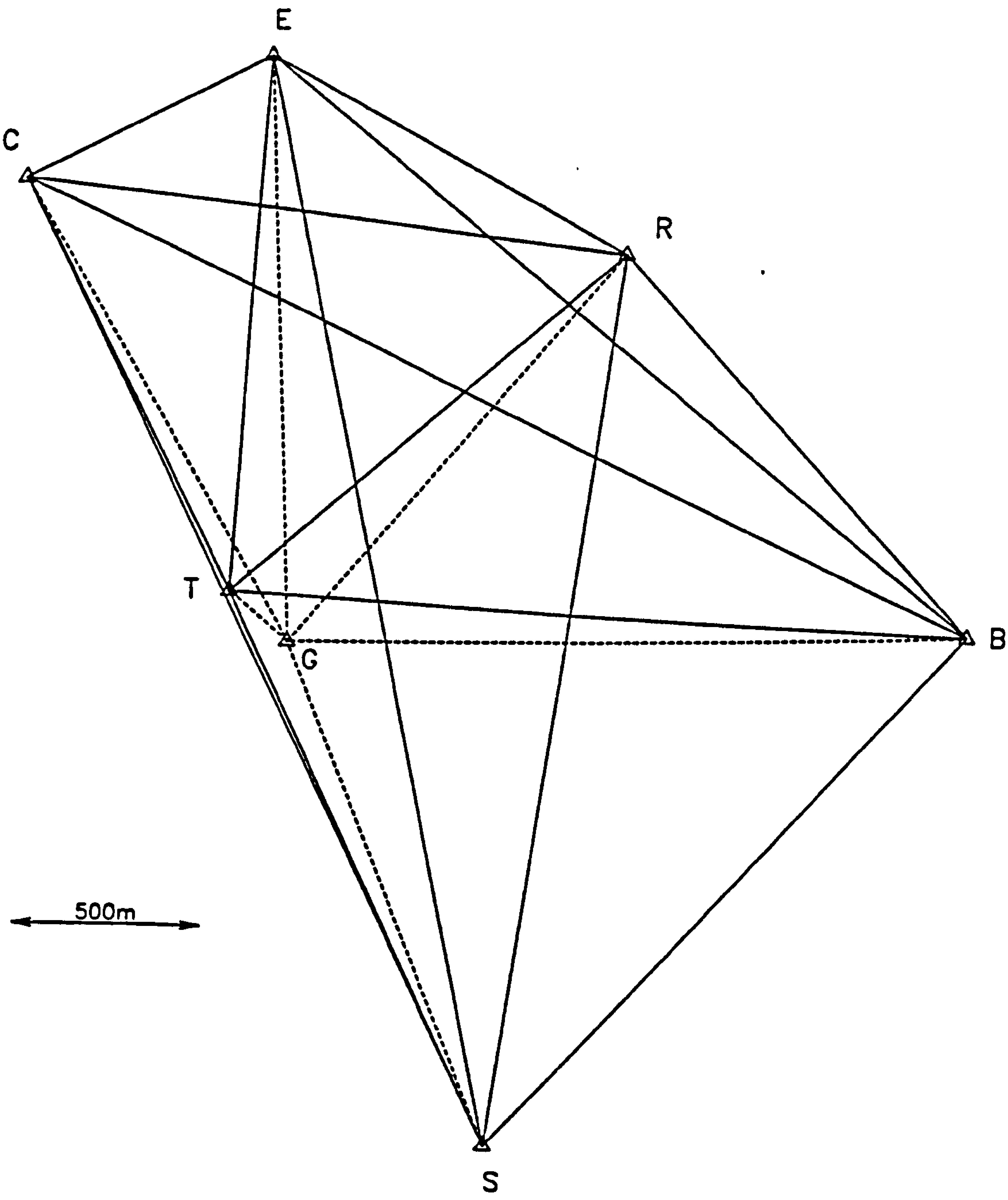


Figure 2.2 The Llangollen Network

2997 m (E-S), and differences of inclination between 17 minutes of arc (T-B) and 10 degrees of arc (T-E). Discounting G, a selection of 4 stations from the remaining 6 results in 15 braced quadrilaterals, ranging from strong shapes such as TSBR to weak configurations such as CERB. If one station were lost, the network would still contain 5 quadrilaterals.

The design of the stations themselves is shown in Figure 2.3. They consist of B.K.S. markers embedded in a concrete base. The actual position of the stations is denoted by the point of intersection of a cross etched into a circular brass plate secured in a recess on the top of the marker. When not in use the heads are smeared with vaseline and then totally covered by a steel cap. Stability of the stations has been guaranteed by augering down to solid bedrock where ever possible. Security of the stations has been assured by having the top of the stations at least 20cm below ground level, and when not in use the stations are covered by soil and turf. The only exception to this is at Sheepfold where the station is on an exposed rock in a remote location.

The angular measurements are made to specially designed targets, an example of which can be seen in Plate 2. The target consists of a heavy C.T.S. tripod which supports a ranging pole through a special adaptor. The adaptor has three wing nuts which allow fine

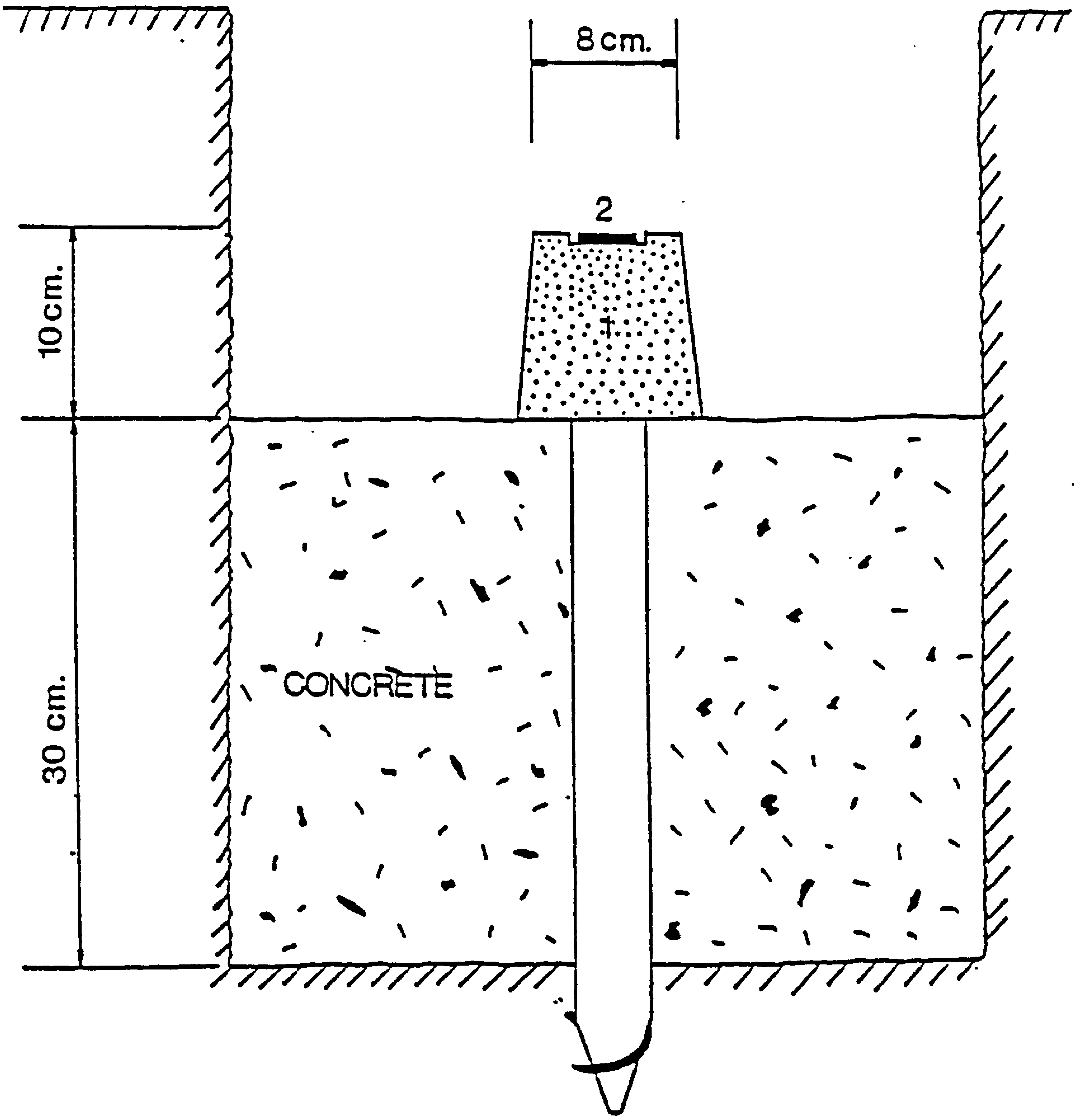


Figure 2.3 Llangollen station design

movement of the ranging pole in any direction to achieve verticality. For extra stability the ranging poles are supported at their base by a chimney which fits over the station head. The ranging poles have a special metal adaptor at their base which fits tightly into the chimney. Vertical angles are observed to a cross-piece which is held in position on the ranging pole exactly 1.500 m above the station. The cross-piece is painted orange and also has yellow reflective strips to make measurements easier in poor light conditions. The gap between the two arms of the cross-piece has been calculated to equal the width of a telescope diaphragm line over 1500 m. The robust nature of the stations is entirely necessary due to their exposed locations and the severity of the weather conditions which are encountered.

Measurements have been conducted using the six primary stations since 1975. To date there have been 45 double faced rounds of horizontal and vertical angles from each station using a Kern DKM3 theodolite. Reciprocal vertical angles have also been taken using the Kern DKM3 and a Kern DKM2. The measuring routine has been kept constant every year, with angular measurements being taken from stations in the order of their ascending heights. Therefore measurements are always taken from T first. The instrument is always set to the same height as the cross-piece of the target, that is, 1.500 m above the station, so that the vertical angles do not need adjustment to obtain the true inclination. Before measurements are taken all of the stations are checked for verticality and the cross-piece turned to face the observation station. The standard error of the results for both horizontal and vertical angles is ±0.3", and so it can be assumed that the mean angle is correct to ±1". The agreement of the angles has been so good that the mean angles are referred to as the "most probable value" for the remainder of this chapter. The standard error for the slope distances is ±1 mm, and so the slope distances can be considered to be known to ±3 mm. Whenever distances have been measured the result is taken as the mean of three separate pointings, with both the instrument and prisms set to 1.500 m. The temperature and pressure are recorded at each end of the line.

The most probable values for the horizontal and vertical angles are shown in Tables 2.6 and 2.7 respectively together with the results obtained from the various total stations. Table 2.8 shows the values for the slope distances.

To date there has been no detectable movement of any of the stations. It is considered that the network is suitable for the evaluation of electronic total stations, allowing testing over a range of vertical angles and distances representative of situations which may be encountered in precise engineering surveys. The accuracy to which the network's angles and distances are known is demonstrated if the most probable values are used to calculate the closing error of the traverse around the six main stations. The peripheral distance is over 8 km, but the results close to 5 mm in Eastings and Northings, giving a closing error of 1 in 1,110,000. The vertical closure is 12 mm, representing an error of 1 in 680,000.

For evaluation purposes three rounds of double faced angles are taken with the instrument set to 1.500 m. Distances are measured with three separate pointings and the atmospheric conditions monitored at both ends of the line. The mean of the atmospheric conditions is applied to the average measured distance to give the evaluation distance.

	Distance	HA	VA
HP3820A	±(5mm + 5ppm)	±2"	±4"
Wild TC1	±(5mm + 5ppm)	±2"	±3"
Kern E1/DM503	±(5mm + 5ppm)	±2"	±2"
Kern E2/DM503	±(3mm + 2ppm)	±0.5"	±0.5"

Table 2.1 Claimed precision of the total stations which have been tested.

Most Probable Value m	HP3820A (00237) 1979 m	Wild TC1 (1149) 1980 m	Kern DM502 (297058) 1982 m	Kern DM503 (325195) 1984 m
43.136	43.137	43.136	43.135	43.137
32.895	32.895	32.895	32.894	32.894
22.548	22.547	22.549	22.549	22.549
12.835	12.836	12.834	12.834	12.834

Table 2.2 Laboratory baseline measurements.

		Difference from most probable value		
	Most Probable Value ° ' "	HP3820A (00237) 1979 "	Kern E1 (299896) 1982 "	Kern E2 (327974) 1984 "
A	137 29 54	-02	04	07
B	185 42 33	04	07	-04
C	261 27 37	-01	-07	-06
L	90 49 54	09	02	03
M	91 36 09	-01	-02	07
N	89 04 33	04	08	-08
O	207 23 13	01	08	-10
D	151 33 23	07	-02	10
E	180 09 34	-03	-01	00
F	179 08 30	03	-03	-02
G	90 40 22	13	06	-02
H	134 54 18	-01	-02	05

Table 2.3 Horizontal angle measurements on the laboratory test traverse.

Line	Most Probable Value	Difference from the most probable value			
		HP3820A (00237) 1979	Wild TC1 (1149) 1980	Kern DM502 (297058) 1982	Kern DM503 (325258) 1984
	m	mm	mm	mm	mm
AB	30.007	+2	-1	-2	+1
BC	16.452	-2	0	-3	-1
CL	23.879	-1	-5	-2	-3
LM	49.481	0	-2	-5	-3
MN	50.214	-4	-7	-4	-5
NO	36.283	-1	-5	-7	-3
OD	20.835	-4	-2	-2	-2
DE	20.538	-4	-3	+1	0
EF	25.182	-1	0	-2	0
FG	16.820	-4	-6	-6	-7
GH	13.503	-2	0	-2	-1
HA	27.451	-2	-5	-8	-6

Table 2.4 Slope distance measurements on the laboratory test traverse.

Most Probable Value	Difference from most probable value		
m	HP3820A (00237) 1979 mm	Wild TC1 (1449) 1980 mm	Kern DM502 (297058) 1982 mm
79.997	-02	-03	+01
130.002	-02	-02	-02
149.999	-01	-03	-01
170.000	00	-02	-01
375.001	00	-02	-03
445.000	00	-01	-03
600.003	+02	-01	00
699.999	+03	-01	+03
820.002	+04	+01	+02
865.002	+02	00	+02
942.003	+01	+02	+03
	Kern DM503 (325000) 1983 mm	Kern DM503 (325195) 1984 mm	Kern DM503 (325258) 1984 mm
79.997	-12	-02	-01
130.002	-16	-03	-01
149.999	-17	-04	00
170.000	-18	-02	-02
375.001	+06	-02	-03
445.000	+05	-04	-02
600.003	-14	-07	-04
699.999	-13	-03	-04
820.002	-14	-03**	-02
865.002	+09	+02**	-01
942.003	-03	+01**	00

** Two prisms required

Table 2.5 Slope distance measurements on the Quorn baseline.

		Difference from most probable value				
Horiz Angle	Most Probable Value ° ' "	HP3820A (00237) 1979 "	Wild TC1 (1449) 1980 "	Kern E1 (299896) 1982 "	Kern E1 (302189) 1983 "	Kern E2 (327974) 1984 "
CTE	30 42 09	-01	+03	-02	-02	-02
ETB	45 12 26	00	00	00	-03	00
RTB	43 39 14	-04	-01	+02	+02	+01
BTS	61 40 10	00	+01	-01	+03	+01
STC	178 46 00	+05	-02	+01	-01	+01
SBT	49 45 11	-04	00	+04	00	+01
TBC	22 20 06	-01	+01	-02	00	-01
CBE	13 50 59	-03	+01	-01	+02	+01
EBR	08 28 55	+04	-02	+02	+04	00
RBS	265 34 49	+01	-01	-02	-05	-01
BRS	50 59 54	+02	-01	+01	-02	+01
SRT	40 40 52	-04	-01	00	+02	00
TRC	47 11 22	-01	+02	+01	-03	+04
CRE	21 55 55	+01	00	-03	+01	00
ERB	199 11 59	+02	00	+01	00	-05
ECR	33 45 01	-09	-10	+03	-02	+02
RCB	18 48 01	+01	+01	-01	+01	-02
BCT	38 06 04	+04	+01	+02	+02	+01
TCS	00 42 16	-05	-01	-06	+01	+01
SCE	268 38 39	+09	+06	-02	00	-01
REB	10 43 05	+04	-03	-02	-02	-01
BES	39 15 14	+02	-02	+05	+01	-02
SET	15 42 01	+02	+04	-04	-04	+01
TEC	58 38 44	+02	00	+01	-03	+02
CER	235 40 57	00	00	-01	+07	00
CST	00 31 43	+04	+01	-02	+03	-01
TSE	13 46 08	-07	-01	00	-05	-01
ESR	20 13 34	-04	+01	-01	+01	00
RSB	34 34 55	-02	+01	-02	-02	00
BSC	290 53 39	+03	-03	+06	+07	-01

Table 2.6 Horizontal angle measurements on the Llangollen Network.

Vert Angle	Most Probable Value ' "	Difference from most probable value: HP3820A (00237) 1979 "	Wild TC1 (1449) 1980 "	Kern E1 (299896) 1982 "	Kern E1 (302189) 1983 "	Kern E2 (327974) 1984 "
TE	+10 11 55	+05	+03	00	-01	-02
TR	+06 48 11	+04	+02	+01	-02	-01
TB	+00 16 43	+04	+02	-02	-02	-01
TS	+10 06 02	+07	+01	00	+01	+01
TC	+09 19 19	+03	+01	00	-01	00
BT	-00 17 44	+01	-03	-03	-03	-04
BC	+03 53 25	+01	+05	+05	+01	+02
BE	+05 49 30	+03	+02	+03	+03	+01
BR	+06 31 00	00	+02	+03	+02	+02
BS	+08 28 58	+05	+03	+05	+03	+02
RS	+02 55 33	+01	+04	+04	+03	+02
RT	-06 48 48	-03	-04	-03	-02	-02
RC	+01 12 08	-01	+06	+06	+02	-01
RE	+04 46 47	+06	+02	+01	-02	-02
RB	-06 31 41	-06	-05	-01	-01	-02
CR	-01 12 57	00	+03	-02	+01	-02
CB	-03 45 46	+03	+03	00	+01	00
CT	-09 19 53	-05	-01	+01	-01	-04
CS	+01 47 05	+04	-01	00	00	+02
CE	+04 26 50	+04	-01	00	-01	-01
EB	-05 50 41	+02	-01	-04	-01	+02
ES	+00 37 04	-03	+04	+02	+02	+01
ET	-10 12 32	+02	-02	-01	-02	00
EC	-04 27 13	+06	-05	-05	-01	-03
ER	-04 47 18	-04	+01	+01	+02	+03
ST	-10 06 45	00	+03	+01	00	00
SE	-00 38 20	-05	00	+03	00	+01
SR	-02 56 37	-01	-02	+03	+03	-02
SB	-08 29 54	-09	-08	-03	+03	-02
SC	-01 48 22	-02	00	-01	+03	-01

Table 2.7 Vertical angle measurements on the Llangollen Network.

		Difference from most probable value				
Line	Most Probable Value	HP 3820 (00237) 1979	Wild TC- 1 (1449) 1980	Kern DM 502 (297058) 1982	Kern DM 502 (297058) 1983	Kern DM 503 (325195) 1984
	m	mm	mm	mm	mm	mm
TB	2011.868	+04	+03	+01	00	-03
TR	1424.956	00	-03	-04	+08	00
TC	1255.642	+06	+02	-03	00	+02
TE	1474.151	00	+01	-02	+03	+02
TS	1675.594	00	+01	+03	+07	-06
BR	1398.455	+03	00	+01	+04	-12
BC	2842.558	-02	-	-02	-02	-12
BE	2469.751	+07	-	-	-	-
BS	1923.433	+02	-01	-05	+08	-02
RC	1638.552	+03	+03	00	+01	-14
RE	1105.830	-03	+03	00	+04	-08
RS	2443.902	+03	-	-04	+07	-11
CE	743.063	+04	-03	-04	+05	-04
CS	2889.948	+06	-	-06	+07	-16
ES	2999.146	+01	-	-07	+13	-23

Table 2.8 Slope distance measurements on the Llangollen network.

2.3 Evaluation results for electronic total stations

To date four electronic total stations have been extensively tested using the facilities described previously, namely, the Hewlett-Packard 3820A, the Wild TC1 Tachymat, the Kern E1/DM502 and the Kern E2/DM503. The maximum amount of care has been taken in the evaluation of each, and identical measuring procedures adopted so that the results are directly comparable. The objectives of the tests have been to establish the accuracy attainable with each instrument, and thereby prove if the manufacturer's claims are justified, and also to assess the ease of use of the equipment. Table 2.1 outlines the manufacturer's claimed precision for each instrument.

The results for the HP3820A and the Wild TC1 are described in detail by Smith (1982). Angles were not taken around the laboratory traverse with the TC1, but the standard error obtained for the HP3820A was ±5.4". This is acceptable when the length of the sights is considered. A more representative test of the angular precision is provided by the Llangollen network. The standard errors for horizontal and vertical angles with the HP3820A were ±3.8" and ±4.0" respectively, whilst those for the TC1 were ±2.6" and ±3.2". The results show that the precision of the TC1 was superior to the HP3820A. Investigations by Schofield (1981) have shown that the universal value for the standard deviation of a double face angle measurement with a 1 second theodolite is ±2.23", and so the results achieved with the TC1 were particularly impressive.

Both of the instruments measured the distances on the laboratory short baseline to within ±1 mm, whilst the results from the laboratory traverse show that the standard error for the HP3820A was ±2.6 mm compared with ±3.8 mm for the Wild. The results on the accurately known Quorn baseline show standard errors of approximately ±2.0 mm for each instrument, all of the measurements being well inside the tolerance stated by the manufacturer. Becuase of the range limitation of 2 km for the TC1, only 10 of the Llangollen distances could be measured, but the results were exceptionally good, with an overall standard error of ±2.3 mm. The results for the HP3820A were also impressive, a standard error of ±3.7 mm, with no difficulty encountered in achieving any of the distances.

The Kern E1 gave a standard error of ±5.1" on the laboratory traverse, that is, results to the same order as the HP3820A. However the instrument has been tested twice at Llangollen and shown to be more accurate than HP3820A and Wild TC1 with standard errors for the horizontal angles of ±2.3" and ±3.0", the vertical angles giving ±2.7" and ±1.9". The results show that the instrument performed to the standard approaching a one-second theodolite.

The results initially obtained with the DM502 were comparable to those obtained with the HP3820A and TC1. The distances measured in the laboratory agreed to within 1mm of the accepted value, whilst the standard error calculated from the results at Quorn equalled ±2.1 mm. The results at Llangollen the first year showed good agreement, with a standard error of ±3.6 mm, however there was a distinct reduction in precision the second year. The standard error increased to ±6.1 mm, although all of the measurements fell within the manufacturer's claim of accuracy. This result emphasises the fact that such instrumentation must be periodically checked and adjusted if necessary. Calibration of EDM equipment is just as vital today as when, for example, the Model 6 was being used, especially if high order accuracy is required.

The Kern E2 theodolite is claimed to be a first order instrument, the manufacturer's placing it between the Kern DKM2 and DKM3 instruments in a "league" of precision. The results obtained with the E2 in Llangollen thoroughly bear out this claim. The precision obtained for both horizontal and vertical angles was excellent, the standard errors being ±1.6" and ±1.9" respectively. The instrument is so easy to use that it is considered that consistently more accurate results could be obtained using the E2 instead of the DKM3. The advantage of the DKM3 is that the telescope is 40% more powerful than that of the E2, and so would become more accurate as distance of observation increased. However the distances at Llangollen range to 3km which is representative of the vast majority of first order engineering work. As a further check on the angular precision of the instrument a subtense bar test was carried out using the laboratory baseline. Sixteen angles were measured to a 2m subtense bar, the mean angle being 2°39'21.9". The distance calculated from this value equals 43.1353m, which agrees to the accepted value for the laboratory base between the two pillars of 43.1355m to 0.2mm. By working backwards from the value of 43.1355m, the subtended angle should be 2°39'21.8", that is, an angular agreement to 0.1". The standard deviation for the set of results was 1.09".

Accuracy to the order of a one-second theodolite can only be achieved if full double axis compensation exists, especially if an eccentric weight, such as a data recorder or removable battery, are associated with the instrument. It was decided to investigate the magnitude of error introduced into the vertical angle measurement if the R48 was attached to the instrument with the compensator off. Initially the instrument was precisely levelled without the data recorder using the compensator function. The data recorder was then attached to the theodolite. The compensator showed that the instrument was now 20" from the vertical in the telescope axis and 6" from the vertical in the trunnion axis, and was therefore defining a cone as it moved round. The error in vertical angle measurements was found to be in the order of 7". This illustrates the necessity for full double axis compensation if highly accurate results are to be obtained.

The E2 gave a standard error of ±4.4" around the laboratory traverse, which is comparable to the other total stations. It must be concluded that the majority of the inaccuracy is due to the effects of centering the instruments around this traverse. The laboratory traverse was conducted without using the Kern centering leg, the optical plummet being employed, and the angles were measured to pins in the stations. It was decided to investigate the accuracy that could be achieved by using the equipment as if a detail survey were being undertaken, that is, using the central leg for centering the instrument and reading angles to the distance prisms. The results showed that on average horizontal control could not be guaranteed to less than 25" over the distances considered. Although this is sufficient for detail point determination, it should be borne in mind that for precise traversing angles should not be read to the prisms, especially over short distances.

Delivered with the E2 was the first DM503 sold in the United Kingdom (Instrument No. 325000). The instrument was tested in the laboratory and the results found to be suspect. The instrument was then tested at Quorn, the results showing that for the majority of readings the instrument was operating outside the manufacturer's claimed precision (see Table 2.5). The instrument was replaced by another DM503 (325195) in time for the field survey camp at Llangollen. Before going to Llangollen the instrument was tested in the laboratory, the results being acceptable, although the output power seemed poor. The instrument was then tested at Quorn, where the initial feelings of low power output were confirmed as the three longest distances (between 820 m and 940 m) reqired two prisms. The measurements taken in Llangollen were erratic, with some of the distances falling outside the claimed precision. The instrument was again replaced (DM503 No. 325258) and this EDM tested at Quorn. The results proved consistent, with a standard error of ± 2.2 mm. When tested around the laboratory traverse the results showed good agreement, the standard error being ± 3.5 mm. The results obtained from this year's Llangollen field course are eagerly awaited.

The problems with the DM503 highlight the necessity to rigorously check all survey instrumentation. Generally the results for all of the other instruments have been excellent, providing the accuracy required for first order engineering surveys. The angular results from the Kern E2 were particularly impressive.

CHAPTER THREE

SURVEY DATA PROCESSING

Survey data processing

3.1 Introduction

Chapters 1 and 2 have considered the field instrumentation available at present to allow automation during the ground survey. This chapter will now consider the requirements to facilitate the automatic processing of the collected field data, considering both the hardware and software desirable. As such an overview of the functional components which make up a survey data processing package will be given, and then the two systems installed within the Department considered in greater detail.

At present there is a trend towards lower price hardware and software, to the extent that the use of a computer system can be considered by even relatively small operations. The rapid development within the field of microprocessor technology has primarily contributed towards this, with microcomputers now being powerful enough to handle all of a surveyor's needs. The options available to surveyors wishing to use at least a degree of computing within their organisation are considered in Section 3.7.

3.2 Hardware

Any computer system is based around the central processing unit (CPU), whether it be mainframe, mini or microcomputer based. With the recent rapid advances in microprocessor technology and the advent of 16 bit processors the definition between these categories is becoming less distinct. The 16 bit microprocessor is quite powerful enough to be able to handle all of the requirements of a survey data processing system, and the majority of systems on the market today are based on microcomputers. The exceptions at present are the large networked interactive mapping, design and information systems such as Informap and Contraves Gradis 2000. However, in the near future the microprocessor based systems will be capable of fulfilling this role when more efficient operating systems and networking become fully available. Built around the CPU are a number of peripheral components for data storage and various input/output functions. The peripherals encountered in a survey system are a mass storage device, a graphics screen, a line printer, a plotter, and if necessary, a digitiser. The selection of the peripheral equipment is vitally important and must be tailored to the exact needs of the user. The main reason for caution being advised is that the cost of graphics peripherals is very high, especially in comparison to the microprocessor itself. This point is illustrated by the fact that a high quality large-format plotter will cost up to five times the price of the microcomputer at the heart of the system.

The mass storage device must allow random access to the data to allow efficient manipulation and editing of the information. As such tape storage is not applicable to a survey system, unless as a means of keeping a permanent archive record. The storage medium must therefore be based on discs. Both hard and flexible (floppy) discs are used satisfactorily, with hard discs giving faster access times but being more expensive.

Graphic screens represent a substantial portion of the capital expenditure for a survey system, their price being dependent upon the resolution of graphics required and the option of colour graphics. At present there are three main types of graphics screen available, namely, refresh, storage and raster. Refresh and storage screens are expensive as they represent the graphics as a series of vectors, producing a fast and accurate image. The raster screens comprise a matrix of small cells called pixels, with images being created by illuminating the necessary individual cells. The graphics which result can appear coarse, this being dependent upon the resolution of the screen, that is, the number of pixels per square inch. Recent developments have lead to raster screens with higher resolution, and therefore better quality, and they now provide a viable alternative to vector graphics for the majority of requirements, even interactive screen editing.

The least costly piece of equipment is a line printer, and at present there are a wide variety to choose from. For most purposes a dot matrix printer is sufficient for the surveyor's requirements, enabling hard copies to be taken from files. It is an added advantage if the printer is capable of receiving information direct from the screen allowing a cheap method of producing hard copies of graphical informatio-n. The quality of such graphics is bound to be poor, but this facility could prove useful when intermediate plots are required.

The plotter will probably form the most expensive peripheral, the price being dependent on the size and speed of plotter purchased. Before purchase, detailed thought should be given as to the use to which the plotter will be employed. For many purposes a small A3 or A4 size plotter will be satisfactory, for example, during volumetric survey calculations. If large high quality plots are required for finished documents then a large format high precision plotter will be needed, but this need not necessarily operate at fast plotting speeds. Plotters are produced in two general forms, within which various sub-divisions exist. These are drum plotters, which tend to be popular as they are relatively cheap, and flat-bed plotters which are of a higher quality but more expensive.

Drum plotters consist of a sprocketed drum around which the drawing medium is revolved. The drum controls movement of the paper in the X direction whilst the pens are mounted on a fixed bridge along which they can travel to supply the Y direction. The plan is therefore covered by a combination of pen movement and paper rotation. Drum plotters tend to be rather slow, but have an advantage in that continuous rolls of paper can be used. This allows a number of plot files to be drawn sequentially and so it is possible to leave the plotter running overnight if there are a lot of plots required. The problem with this is that the pens tend to dry out rather quickly as they are not covered, and so it is unlikely that an overnight run would be completed successfully.

A flat-bed plotter is in principle a flat table on which the drafting material is mounted and held stationary. Above the table is a gantry which can move along the length of the table. Mounted on this gantry are the pens which are free to move along it. The drawing is completed by a combination of pen movement in the Y direction and gantry movement in the X direction. Flat-bed plotters tend to be of a higher quality and can operate a greater plot speeds. It is also possible to relocate old plans so that updated information can be added to them.

There are many variations on the general styles of plotters, two worth mentioning being the belt-bed plotter and the grit-wheel plotter. The drafting medium is mounted onto a continuous looped belt in the case of the belt-bed plotter and functions then similarly to the drum plotter. The advantage of the belt-bed is that faster speeds are attained with greater accuracy, but these units tend to be very expensive. The grit wheel plotter grips the paper between two pairs of grip wheels, thereby being able to move it in the X direction. The pens move across in the Y direction. Very high precision and speeds can be attained, but again these units are expensive. One of the main advantages of the grit-wheel plotter is that even large format plotters take up relatively little room, unlike the belt-beds and the flat-beds.

If it is necessary to input a large amount of existing graphical information into the database then this is achieved most expediantly by the use of a digitiser. There are many types of digitiser, but the most commonly used is the solid state table. A grid of conductors, commonly iron cobalt wires, is bonded into a board of insulating material. An electric current is induced in these wires by an electro-magnetic field produced from a coil in the cursor as it moves over the surface. Analysis of the induced currents thereby allows the determination the X,Y co-ordinates. The spacing of the conductors and the conversion of the analog signals determines the resolution and accuracy of the co-ordinates. Resolution to 0.001 inch is possible, although obviously the price increases with both the resolution and the size of the table. It must be remembered however that the accuracy of the co-ordinates obtained will be dependent upon the original plotting accuracy and the precision in pointing. Assuming that the original drafting is perfect, then at a scale of 1/10000, 1 mm inaccuracy in the positioning of the cursor represents 10m error in the co-ordinates stored in the database. If this magnitude of error is unacceptable then it is better to refer, where possible, to the original co-ordinate information and enter the values through the keyboard.

A broader outline of the variety of peripherals is given by Yoeli (1982), whilst a more technical approach to computer peripherals, their characterisics and interfacing is found in Wilkinson and Horrocks (1980).

3.3 Operating systems

An operating system can be defined as those procedures which control the resources available within a data processing installation. The resources include the hardware, software, data storage and retrieval, and interfaces. The operating system is usually program driven, with the specific aim of controlling all of the most basic aspects of the processor. As such, the operating system is essential to the efficient running of any data processing unit.

The concept of an operating system was not developed until about 1956, when several large companies started to write specific operating systèms for their own particular requirements. The trend today is towards standard operating systems with portability of these programs between different computers. The CPM operating system has become very popular recently, particularly in the field of business applications, whilst UNIX is rapidly becoming an international standard for scientific applications. This forms a welcome development as UNIX is one of the most powerful operating systems ever written intrinsically providing many useful program development aids. It is obviously an advantage to have a survey software package running on a standard operating system as this allows a high degree of portability and increases the possibility of developing compatible specific software.

3.4 Languages

In the same way that people use languages to communicate with each other, instructions and commands are relayed to a computer using one of many available types of strict language. Unlike human speech the language used must be strictly adhered to as any errors will cause misinterpretation or total failure. The computer acts upon instructions which are in machine code, this code bearing very little resemblance to the meaning of the program. It is therefore undesirable to program directly in machine code as firstly it is very difficult, and secondly, detecting errors is very protracted. To overcome this problem, programs can be written using a language and then converted into machine code format using an assembler or compiler program. Easily understandable languages of this type are known as high level languages, whilst conversely machine code based programming languages are termed low level. Generally a single line of a high level language will generate many lines of machine code upon compilation. Common examples of high level languages are BASIC (Beginner's All-purpose Symbolic Instruction Code) and FORTRAN (FORmula TRANslation). High level languages have often been developed with specific uses in mind such as scientific calculation or business applications.

High level languages fall principally into two main categories, namely compiled and interpreted languages.

An interpreted language will translate the program into machine code during execution of the instructions, whilst a compiled language translates all of the program into machine code during a compilation stage before execution. Because an interpreted program is being translated during processing its run time is significantly increased with respect to a previously compiled program. The main advantage of an interpreted language is that that software development is simplified as the compilation stage is not required, allowing syntax checking as the program is being written. Errors in a compiled program are not found until compilation is attempted.

BASIC is an example of an interpreted language, and proves suitable for small scale applications. However, for major tasks required within a survey system such as interactive graphics and surface modelling a compiled language proves more efficient, considerably reducing running time. An example of such a language is Pascal, which also has a further advantage in that it belongs to a class of languages which are structured. A structured language facilitates program development in an readily understandable format, thereby easing the often onerous task of subsequent program development and maintenance.

The advantage of using a compiled language has been shown during the program development of the Hasp system during this research. Originally the system used an interpreted language called HPL (High-speed Programming Language), but this has subsequently been replaced by the Pascal compiled language. The surface modelling package originally written in HPL would have a run time of approximately 45 minutes for a model containing 500 points, whereas in Pascal the time required is approximately 2 minutes. This comparison is viable as the Pascal program utilises exactly the same algorithms as the HPL software, imitating the process exactly.

3.5 Software

Detailed descriptions of various software components will be given later, but first it is useful to consider in general terms the necessary and desirable software components in a survey based processing system. The actual software configuration chosen will vary according to the individual needs.

a) Raw data input; this module allows the introduction of the raw data into the processing system. The input can be from either the keyboard or via a direct link to a data recorder or secondary data storage medium such as a tape unit. Where direct interface is concerned, the program establishes the correct transmission protocols for data transfer, and governs the transmission of data. Each different data recorder requires its own version of this program. It is also possible to enter raw data from a digitiser, but this is usually only of a graphical nature and therefore not equivalent to the processing of field data.

b) Raw data format; once the data, from whatever source, has been entered it is preferable that it is manipulated into a common format. Creation of this common format allows the data to be processed from this stage by one set of programs only, rather than needing a suite of programs to cover all of the possible input formats.

c) Raw data print; this program simply provides a listing of the raw data on the printer. It is highly desirable if the coding of the points is interpreted at this stage, aiding error checking by the operator. Apart from helping to identify any errors, the print can be used as a hard copy if such is required for archive purposes.

d) Raw data edit; this program allows errors that were detected whilst in the field or detected from the raw data print to be altered. Ideally the editing of any data should not corrupt the original raw data and so it is convenient if a separate edit file is established automatically from which any subsequent computations are made. This ensures that if any mistakes are made during editing through the keyboard, the original data is not lost.

e) Data processing; this program performs all of the calculations necessary for traverse computation and adjustment, as well as determining the co-ordinates of the detail points. At this stage co-ordinate files are formed with information concerning the traverse and detail points, and graphical files, or plot files, are created by interpreting the feature coding associated with each point. Together these files form the basis of the survey database, comprising in its simplest form of graphical coding associated with three-dimensional co-ordinates.

f) Graphical editing; once data processing is complete it is desirable to edit the information in its graphical form, either to enhance the linework, delete unwanted information, or add features such as shading or text. The most expedient method of achieving this is via interactive screen graphics, although it is also possible to obtain a plot (see below) and then edit information from this by using a digitiser. It is important that any graphical editing automatically up-dates the database in which the information is stored. The use of the digitiser is of most importance when there is a lot of existing information in plan form which needs to be integrated into the survey database, such as old mine plans.

g) Plotting; it is necessary to be able to obtain plots of the processed information, either at an intermediate stage to allow scrutiny and editing, or as a hard copy of the final plan. It should be possible to drive a variety of plotters from a single software package.

h) Surface modelling; this program should have the ability to form a digital terrain model from the data, allowing automatic interpolation of contours and the determination of volumetrics. The contours which are generated should be in a format so that, if desired, they can be added to the database and stored. The topic of surface modelling will be discussed in greater detail in Chapter 5.

g) Co-ordinate geometry; co-ordinate geometry packages are often used as a stand alone system for design work, although they have applications in the field of surveying. Geometric calculations can be performed on existing points in the database to create new co-ordinate points, the information then being applicable for setting out work. Common features might include points of intersection for extruded lines, definition of curves or generation of parallel lines.

3.6 Data preparation and database formation

The most fundamental part of the software system, and therefore worth further consideration at this point, is that of data preparation and handling, and the formation and principles of the database. The efficiency and capability of a system is proportional to the effectiveness of the data structuring, that is, the database.

The data preparation procedures include the routines necessary to derive the rectangular co-ordinates of the surveyed points, these co-ordinates providing the basis for the database. For this to be achieved it is necessary that the following software modules are included; data input from data recorders or via the keyboard, raw data editing, and calculation of the rectangular co-ordinates. It is desirable that the raw data format should be as flexible as possible due to the wide variety of input sources. Entry direct through the keyboard can be in the same format as that used for data recorders, but this can sometimes be cumbersome. As such it is convenient to operate an additional specifically designed program if keyboard entry is required. Using such a program Golik (1983) suggests that up to 150 detail points can be entered per hour. The main problem with data entry via the keyboard is that errors can easily occur which are often unnoticed. To overcome this a high level of error checking should be implemented, even though this will slow the procedure. The raw data edit program should present the information in an easily understandable tabular form, with interpretation of the coding system included. Editing is facilitated if a full screen interactive editor is available, with error checking on all input. The editor should allow alteration of any piece of data, as well as deletion or insertion of whole blocks of data.

Once the data has been edited satisfactorily, it is then processed to obtain the co-ordinates of each point. The data processing module must perform the following functions:

a) Complete a data scan to isolate traverse information from detail information

b) Calculate the co-ordinates of the main traverse stations

c) Adjust the main traverse loops by a method chosen during processing by the operator. Schofield (1979) has shown that a rigorous least squares analysis gives the least biased results, and such an adjustment procedure should be available. However, least square adjustment is time consuming and by its nature very memory intensive. Therefore it is necessary to have an alternative method which will suffice for the majority of cases.

d) Compute the co-ordinates of side traverse points or secondary traverse loops. Secondary traverse loops should also be adjusted if desired.

e) Store the adjusted traverse co-ordinates with their point identifier. It may also be necessary to store the unadjusted co-ordinates.

f) Compute the co-ordinates of the detail points and store these with their related field code. These points must then be added to the database.

Whilst forming the database it is useful to record the maximum and minimum northings and eastings associated with the information. This facilitates establishing permissable plotting scales, and is in fact necessary for structuring certain types of database. Nicholson (1984) gives a detailed account of various storage structures, but a brief outline is given below to aid a general understanding of this system fundamental.

The data storage method governs the efficiency and capabilities of the entire survey system. If the data is not structured in its storage but simply held in the order in which it is defined then the only method available to retrieve a certain piece of information is to search the entire data bank. This is obviously slow, especially where large databases are involved. By using such a technique the advantages of an efficient applications program are lost. Data can be structured by either spatial location or by data type. Subdivision by spatial location reduces the area of search within the database, allowing individual points to be accessed quickly without the entire data file being searched. This is particularly expedient for interactive screen editing, allowing rapid proximity searching for specific points. Spatial database linking of graphics features can also be incorporated, allowing the entire length of a line to become "active" by simply locating one point on the line. An example of the use of this may be for the removal of a long pipeline stored in the database which is no longer operational. If spatial linking is available then the whole line can be removed with one command if desired. Subdivision can also be achieved by the various graphical data elements in the database. There are four divisions, namely symbols, lines and curves, text, and features. The user can specify which particular element is of interest, thereby reducing the amount of data to be searched. This also allows suppression of unwanted information types for viewing or plotting, such as a given linetype.

For flexibility the database should allow subdivision into user-defined data levels, these being named by the user. For example, the storage of mine plans requires a basic mine outline superimposed with different information (that is, linetypes, symbols, text) depending on whether ventilation, geology or rescue plans are required. It may also be necessary to be able to store additional, or secondary, information concerning certain features. For example, if a fire fighting station is shown, it would be possible to register exactly what equipment was available and when it was last serviced. This type of information is memory intensive and so is usually stored outside the database, but is accessible directly through the database. At present this facility is only available on the large utilities systems such as Contraves Gradis 2000. The facility can be extended so that database elements with common complex characteristics can be isolated, for example, the positions of all dry powder extinguishers in a certain seam that have not been serviced this year.

At present there is considerable attention being paid to creating a standard form of database which would allow direct information exchange between users, even in different disciplines. This is particularly evident in the United States, however in the U.K. the Ordnance Survey are also addressing this problem (Latham-Warde 1979). The Ordnance Survey is presently producing a certain number of their plans in a standard digital format, this type of information being known as surface structure. Implementation of a standard to this level should present relatively few problems, however this is not the case if additional information is required, known as deep structure. Even in the case of surface structures it will probably be neccessary to write a conversion program to reformat the data into the database supported by the user. In the case of deep structure the range and amount of information which may be required by different users prohibits attempts at standardisation at present.

3.7 Acquisition of data processing facilities

The advent of automatic data processing over the past few years has lead to new problems for surveyors, namely deciding whether integration of computing techniques is economically viable within their organisation, and to what level the degree of automation is desirable. These problems are often enhanced when technology is seemingly advancing at such a rate that there always appears a far more suitable option just around the corner. The importance of the process of adopting an automatic processing system has been highlighted recently by the number of papers that have been presented concerning experiences in aquiring computer facilities for survey, and their subsequent introduction into production. This section is not intended to offer advice on the most expediant method of obtaining data processing facilities as each individual case warrants its own solution, but rather to show the range of options available.

The immediate decision is one of either purchasing a computer system for in-house needs or using the services of a computer bureau. If a bureau is used the data is sent to a remote data processing centre and a charge is levied in proportion to the size of the job. At present rates it has been calculated that, if only a working plot with contours is required, the cost to process 500 points every day for eighteen months is approximately equal to the capital outlay for a survey based computer system. Problems arise however due to the remote location of processing. Firstly, enhancement of the plot to a reasonable standard cannot be easily achieved, and secondly, detection and correction of errors, especially coding errors, is virtually impossible. Therefore, in the opinion of the author, the computer bureau does not provide an adequate solution if final quality plots are required, but their services should not be overlooked by small firms attempting to partially introduce automated techniques into their operation.

The purchase of a computer system will naturally involve the selection and integration of both hardware and software, the choice of one considerably influencing the adoption of the other. This is due at present to the fact that whereas there is an abundance of hardware options there are very few good software packages which are transportable. At present most of the programs are machine dependent. These problems are overcome if a complete system is purchased comprising the hardware and software. It is probably expedient to adopt this policy even if hardware, which is not directly suitable, already exists in the organisation.

If it is assumed that hardware is available, then there are three main methods of acquiring the necessary software:

a) Contracting a specialist programmer

b) Software development in-house

c) Purchase of commercially available programs

Potentially the most dangerous option is contracting a specialist to write a specific suite of programs. Although the programs will be customised to suit the exact requirements of the system there are many potential pit-falls. Firstly, it is likely that there will be no in-house programming expertise, and so the final result is dependent solely upon the professionalism of the programmer. It cannot automatically be assumed that such a computer programmer will fully grasp the application to which he is assigned. Secondly, there is no guarantee that the programs can be updated or modified as required, or even that the original consultant will available to carry out such work. It can be seen therefore, that although superficially this option appears tempting, in the long-term this approach to the development of a relatively large system is potentially counter-productive.

The development of software using in-house expertise has many advantages. The personnel used will probably have a full grasp of the intended system use through their experience within the company. Such systems are therefore tailored exactly to meet those requirements, and the programs can be written with future development in mind. Any modifications or corrections can be quickly enabled by the staff involved as they have a complete understanding of the programs. Such development is only feasible if competent staff are already employed within the organisation. Having said that, it will still probably be necessary to employ a computer specialist to act as development and system manager, as well as spending time training the existing staff to a higher level. A further disadvantage is that there is an unavoidable long lead time between conception and production of the system. This is obviously expensive both in salary terms and also in obtaining a return on the capital investment in the hardware. An interesting discussion of the merits and demerits of in-house development is given by Johnston (1982).

The third option is the most appropriate for the majority of situations, primarily because the software requirements for the majority of survey operations are fairly standard. Although there are inevitably differences in the uses envisaged by various companies, these are usually only apparent in the lengths to which it is wished to use the processed information. The final output required for the Ordnance Survey is very different to that required, say, by a colliery surveyor after completing a volumetric coal stock survey. However, the concept of automatic data acquisition and the initial processing and editing of this data is common to both. The differences only occur after this stage, where one would require interactive high quality graphics whereas for the other a simple point plot would suffice with a routine to calculate volumes. It can be seen therefore that a computer system based around a modular approach could be used by both, with the advantage of purchasing additional software as required. The software product will have been designed by programmers with a large amount of experience in the field, who will be in the position to continually update and extend the software available in keeping with technological advances. Also, such "off the shelf" systems can be put into immediate operational use, allowing immediate return for the capital outlay. The purchaser can be confident that the system is well tested and therefore proven.

There is often a feeling that purchasing a survey system from a commercial software house places the survey company totally at the mercy of the dealer. Fortunately this does not happen due to the extremely competative nature of the market. This ensures that for a system to succeed the prices must be competative, the after sales service efficient, and there be the opportunity for subsequant expansion of the system at reasonable cost. Whereas the development cost of an in-house software suite must be borne by one user, development costs for a commercial system are spread over a number of systems sold, therefore allowing the product to be more cost effective.

An interesting article has been written by Barnes and Dennis (1982) dealing with the purchase and implementation of both hardware and software. As management consultants specializing in the field of computer applications software, they offer the following advice which is worth consideration.

a) There is substantially less good software than all the enthusiastic talk and sales literature would suggest.

b) Packages which purport to address a given function actually vary immensely from one another in their design objectives, features, implementability and useability.

c) The speed at which packages can be implemented is only partially dependent on the nature of the software design, most of it has to do with an organisation's ability to plan and manage change.

d) Most applications are not easy or straightforward: "easy, straightforward systems" more often than not become difficult, complex, entangled messes when automated.

e) The phrase "standard package" has little meaning at all, beyond the fact that it is one firms standard offering; few packages look alike.

f) Not even the descriptive terms regarding applications have any standard meaning. You cannot guarantee that what you would assume to be a feature of a standard package will actually be there.

g) Be realistic when deciding which applications are to be automated. Automation for the sake of automation normally proves to be a futile exercise. Instead have a clear view of the objectives and select the system which best satisfies these.

h) There are many good programming languages, therefore keep an open mind particularly with regard to emerging trends and the value of present standards.

i) There is a definite advantage to sticking to a reasonable level of standardisation in terms of language, hardware type, file handling etc.

j) Often outside firms can do as good (or better) a job as in-house processing staff particularly when they have a detailed functional expertise.

k) The size of the software firm makes far less difference than their knowledge level, responsibility, commitment and support.

l) Customised software is often required, especially for those applications supporting the mainstream activity of the business.

m) The relationship with the software house supplying the package is of crucial importance to the success of an implementation. The aim of software selection procedures should be to team up with a dynamic, knowledgeable, competent software firm which is constantly enhancing and extending its product.

n) The key factor in the success of automation is to assess the available software objectively based on the company's individual needs and what is available now, and having selected the most appropriate system, take responsibility for its purchase and implementation.

3.8 Survey systems at the University of Nottingham

3.8.1 The Wild Geomap

The Wild Geomap system was purchased in 1982, and provided the Department with it's first computer system dedicated for research into automated survey. The underground traverse at British Gypsum's Marblaegis mine was processed and plotted using the Geomap system (see Section 4.2). The system can be purchased with a variety of peripheral hardware equipment, but is always built around a Tektronix 4054 microcomputer.

The Mining Department, with the financial support of the SERC, decided to purchase the following set of hardware components, as are shown in Plate 3:

1. Tektronix 4054 microcomputer. The 4054 has an integral high resolution (4096 x 4096 pixels) storage screen for high quality graphics, which can be used for screen editing, a standard keyboard, an internal magnetic cassette unit, and 64 kb of internal memory. The computer is also fitted with two firmware options, namely, Option 1 to allow data communications and Option 30 for dynamic graphics. The entire system is controlled using the BASIC language.

2. Tektronix 4907 file manager. The main storage device for the Geomap is a dual 8" floppy disc drive,

each disc capable of storing 630 kb. One of the drive units is used specifically for system software, whilst the other houses the data discs.

3. Volker-Craig alphanumeric screen. This screen complements the Tektronix graphics screen, with all of the system prompts generated on it. Thus the graphic screen is left uncluttered.

4. LA-DEC 120 Line printer. The line printer has a speed of 180 characters per second, and is essential in allowing hard copies of, say, data files to be studied.

5. Benson 1302 drum plotter. The Benson 1302 plotter has a maximum plotting width of 93 cm, and is capable of plotting at up to 4.5 cm/s, to an accuracy of 0.05 mm. The plotting medium can be either paper, tracing paper or polyester film. The plotting head can hold a maximum of three pens, which can be ink, fibre-tip or biro.

The software used by Geomap has been designed to be "user friendly", the operator simply following the prompts which appear on the alphanumeric screen. This means that the surveyor needs only to be shown how to use the system, rather than be required to achieve any proficiency in computer programming. The basic Geomap

Plate 3

The Wild Geomap system


GEOMAP

system is built up from software comprising several packages, which can broadly be categorised into three distinct sections, namely

1. The System Software

2. The Geodetic Computational Software

3. The Graphics Software

The system software includes the BASIC operating system and Plot 50 programs which are supplied as part of the normal Tektronix package. This category also includes the data type and map frame definitions, and the routines to define the generation of symbols and characters. The database around which the data is stored is structured according to the user defined data types, symbol table and character table. There are up to 32 levels into which the database can be divided, each of these datatypes being associated with specific line types, symbol table and character set. Each symbol table can hold a maximum of 64 symbols, whilst 95 characters are allowed per character set. This structuring allows the user to store related information in an easily accessible file, for example, the positions of major roads, without having to display the entire detail on a plan. Other features can then be overlaid if required. Map frame definition allows the user to define their own required map frame, and then plot any plan within this.

The category termed Geodetic Computational Software is responsible for raw data input, data editing and checking, station file creation, traverse definition and computation, and computation of detail points. The range covered by this section is rather more expansive than the title implies. Data input can be achieved by

1. Manual entry through the keyboard

2. Automatic transmission from a data recorder

3. Digitisation of existing plans

The software supports a large field coding system, allowing the definition of detail graphics from raw data. The author has not been able to attempt entry by digitisation, but successful data entry has been made from the Kern R48 data recorder . The R48 compatibility software had to be written by representatives of Wild as their software is protected by a secret code. This highlights a problem encountered by the Department when development was being considered, and will be discussed later. The data editing functions allow the data to be checked at all stages from data entry to final computations. From the raw data the traverse points are defined and the traverse computed. Once this is complete the detail points, with their associated codes, are calculated. Listings of the results are possible on the line printer. From this stage it is now possible to use the graphics functions available.

The Graphics Software interrogates the database and can form plot files from the information contained at the user's discretion. These can be defined by points, lines, curves and symbols. The graphical output can be displayed on the Tektronix screen and edited as necessary. There are a range of graphics editing functions designed to allow enhancement of the plot file to final presentation standards. These include line-work addition or removal, hatching, text addition etc.. Screen graphics also allow interaction with the database for screen initiated analysis and computation. For example, the information concerning a particular feature can be displayed by the point being located on the screen by the cursor.

Geomap has been developed by Wild beyond the capabilities of the system at Nottingham, with the addition of features such as contouring. The graphical presentation of the package is very good, but to an experienced operator the extensive rigorous prompting sequence makes the system slow to use and rather tedious. This is a problem encountered in all "user friendly" systems, trying to obtain a balance between efficiency of use and ease of use. The microprocessor used is, by today's standards, out of date and therefore relatively inefficient. Data access and manipulation times which were impressive a few years ago now appear rather slow. It is understood that Wild are presently developing a new system.

The Geomap, being a tailored survey computer system, allowed the Department to make the first steps into the area of survey automation and computer graphics. There was however an obvious need for active research and program development into areas of most use to the mining industry, such as volumetric surveys. Unfortunately Wild would not release the source code which was vital for us to be able to develop within Geomap, and so all of our software development has been within the HASP system, which is discussed in the next section.

3.8.2 The HASP system

In May 1982 the Department was presented on a "permanent loan" basis with a second computer system for the development of survey programs, this being the HASP system. HASP was already a successful system in both North and South America, but the installation at Nottingham represented the first in Europe. Permission was given to allow development within the system, the original aims being to modify the existing programs to suit the British surveyor and then to develop specific software for the mining surveyor. Very close links have subsequently been developed between ourselves and HASP Inc. through Survey and General Instrument Co. Ltd. of Edenbridge, Kent.

The system delivered in 1982 was based around the Hewlett-Packard 9825 desk-top computer. This was replaced in 1983 by the more powerful HP9816 200 series microcomputer with a built-in graphics sreen. Peripheral options comprise a choice of seven plotters, including all of the Hewlett-Packard range, four digitisers (including the popular Houston Instruments 7000 series), either micro-disc or Winchester hard disc drive, a Tektronix vector graphics screen or a medium resolution colour graphics VDU. The present hardware configuration at Nottingham University is shown in Figure 3.1 and is described below:

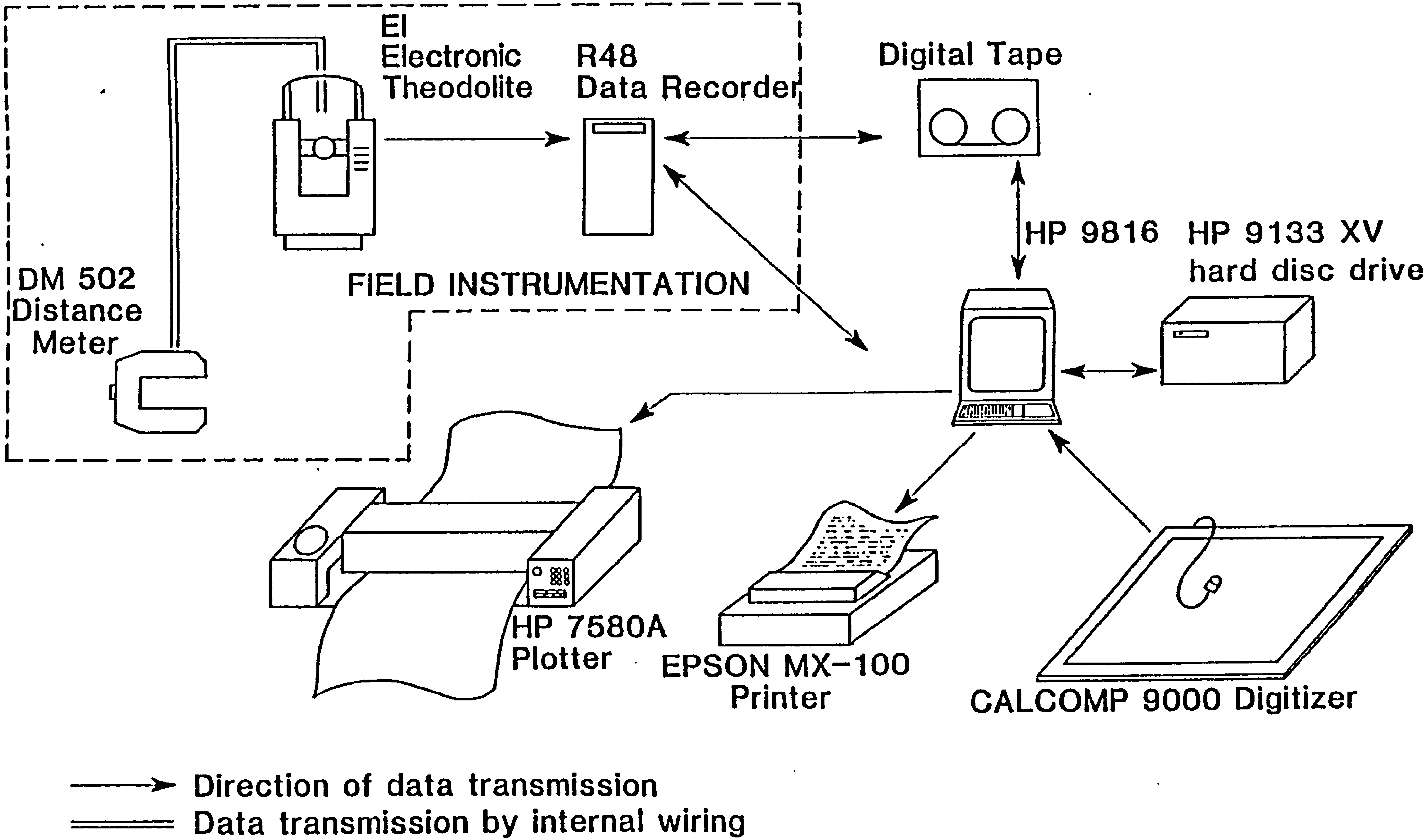


Figure 3.1 Schematic diagram of the HASP system

1. HP9816 Microcomputer. The HP9816 microcomputer is a recent and significant development being based on the powerful Motorola MC68000 microprocessor and including as standard 500 kb of random access memory which can be further expanded. This enables the utilisation of facilities on the HP9816 which in the past have required a mainframe or minicomputer. The HP9816 is supplied with BASIC and HPL (High-speed Programming Language) operating systems, but other operating systems such as Pascal and CPM 68K are also available. The 9816 includes a 9 inch CRT screen with a graphics resolution of 300 x 400, allowing prompts to be displayed, usually in menu form, and graphical display and interactive editing.

2. HP9133 XV Winchester disc drive. The Winchester disc drive has 15 Mbytes of hard disc storage, allowing rapid data access.

3. Epson MX-100 III Line printer. The Epson MX-100 is a dot matrix printer with an easily replacable 9 x 9 dot matrix print head. It has a bidirectional print speed of 100 characters per second. This printer allows mixed printing of characters in any desired size (normal, enlarged, condensed, emphasized) on the same line. In addition to printing files, the unit can also be used to dump graphics from the screen.

4. HP7580A Plotter. The HP7580A is a grit wheel plotter capable of taking paper up to A1 size, although the adjustable pinch wheel will allow any size of paper below this to be mounted. The size of the paper is detected by a set of optical paper sensors. The plotter has a maximum plotting speed of 60 cm/s if fibre tip pens are used. The pen speed and force can be selected by the operator via the instrument panel to suit whichever pen type is to be used. The instrument supports eight pens, which can be fibre tip, roller ball or ink. The plotting medium can be either paper, vellum or polyester film, preferably in pre-cut flat sheets.

5. Calcomp 9000 Digitiser. The Calcomp 9000 digitiser has a 12 button cursor and an active digitising area of 60 x 44 inches. The resolution of the digitiser is 0.001 inch over the entire area.

The most unique and powerful feature of the system is the low level programming, that is, the binary operating system. HASP have added to the intelligence in the firmware by writing a number of their own routines in machine code to optimise the efficiency of the graphics and "number crunching" routines, incorporating these routines into the operating system. This allows the functions to be called in the same way as the regular HP commands.

The software has been designed to be "user friendly" with the operator driving the system through a set of menus which appear on the screen. The main system software modules can broadly be categorised as

1. Field data processing

2. Map draughting

3. Co-ordinate geometry (COGO)

4. Surface modelling

Field data processing programs include the input of raw data from data recorders, tape units, or via the keyboard, and the necessary computation to calculate traverses and detail points leading to the creation of plot files. At present data can be received from Kern, Wild, Aga and Zeiss data recorders. The map draughting package allows graphical enhancement of plot files and governs the creation of intermediate and final plots on the HP7580A. The COGO program enables interaction with named co-ordinate points stored in the database derived from the plot files. Various geometrical constructions are possible such as parallel lines, resections,offsets, curve design and line/line intersections. The COGO software is predominantly used for design purposes. The surface modelling package was written entirely at the University of Nottingham and is based on a triangular modelling technique. The software has been designed to allow rapid formation of the ground model without interpolation from which volumes can automatically be calculated. Contours can also be interpolated and stored if desired. The surface modelling system is discussed in detail later in this thesis.

CHAPTER FOUR

UNDERGROUND APPLICATIONS OF AUTOMATED SURVEY SYSTEMS

Underground applications of automated survey systems

4.1 Introduction

The general application of electronic total stations for underground use maybe considered to be limited, mainly for the following reasons;

a) Underground control surveys primarily involve traverse work with very little detail determination. As the most effective use for an electronic total station is for the rapid accumulation of detail points by radial measurements, they are not being used to their full efficiency in this environment.

b) At the present time both the size and weight of the instruments is prohibitive to their use in cramped conditions underground. In the future it is likely that the instruments will become more compact and lighter, thereby increasing their portability.

c) For general use in mining the instruments would require flameproofing. At present special exemption is required to use an electronic instrument underground in the intake roadways of gaseous mines, and their use is often prohibited in return airways. To fully flameproof an instrument, so that it could be used without exemption in any part of the mine, would dramatically increase its weight reducing its applicability to routine survey purposes underground.

d) At present it may not be considered economically viable to purchase an electronic total station solely for use underground when the points above are considered.

Bearing in mind the afore mentioned restrictions, there are still features of electronic total stations which make them suitable for use underground. In an underground environment the limitations in space and time require that survey work is completed quickly whilst maintaining accuracy. Features such as automatic compensation and the easily read illuminated digital display facilitate these objectives. There are also benefits to be gained by using a data recorder, whether attached to an electronic instrument or used in conjunction with conventional equipment. Overall it is difficult to justify the capital outlay for an electronic total station purely for underground use, but such equipment could prove beneficial if it were made available for a wide variety of survey tasks both on the surface and underground.

This chapter will now consider two underground survey tasks at British Gypsum's Marblaegis mine which have been undertaken by the author.

4.2 Underground test traverse

Having taken delivery of the Kern E1/DM502 and the Wild Geomap system, and then gained experience in their use, it was decided to undertake a fully automated underground survey. Because the electronic total station is not intrinsically safe and not approved for use in dangerous gaseous atmospheres, it was decided to conduct the underground trials at British Gypsum's Marblaegis Mine in Nottinghamshire, which is situated just a few miles from the University, this mine being gas free.

The objectives of the survey were to complete a test traverse using a fully automated technique, without the use of any field notes or field books, and to collect a limited amount of detail in the form of the position of the support pillars. The mining method employed at Marblaegis is room and pillar extraction. Upon collection of the data using the Kern R48 data recorder, the job was to be processed solely using the Wild Geomap , allowing an assessment of the efficiency and accuracy of the processing and plotting system.

After discussions with mine surveyors at British Gypsum, a site was chosen at Marblaegis which was thought to be representative of the majority of situations encountered underground at that mine. A closed traverse consisting of ten existing stations over a total length of approximately 1600 m was selected, with individual draft lengths varying between 16 m to 603 m. This range was considered typical of the range of distances measured underground. A closed traverse was chosen so that the closing error could be quantified. By using existing stations whose co-ordinates were known a further check on the accuracy achieved could be obtained.

The use of the Kern field instrument together with the Wild Geomap caused certain problems. Firstly, Kern assume that the corrections for the atmospheric conditions will be computed and applied via the processing system, whilst Geomap requires that the correction is applied at the instrument. Hence it was impossible to apply any atmospheric correction to the results. Secondly, a special program had to be written by Wild to allow data transfer from the Kern R48. The data structure from which the Geomap operates is different to that of the Kern, and so a new coding routine had to be learnt. The coding system is outlined below.

The Wild Geomap accepts coded information as a code number followed by two information blocks. The data in the information blocks is processed depending on the code with which they are associated. Only two of the four modes on the R48 are recognised by the Geomap, as follows:

Mode 1

Hor	Horizontal Distance
ELE	Vertical Angle
dIS	Slope Distance
Pnr	Point Number

Mode 4

nrC	Code Number
C47	Information Block 1
C48	Information Block 2

All of the other blocks of information are ignored by the system. The codes which were required for the traverse definition were:

a) Code 61 - Identification of the station

Info 1 : Station number

Info 2 : Type of station

0 = Job with one station only

1 = Known station

2 = Unknown station

3 = Free station

b) Code 31 - Instrument and reflector height

Info 1 : Instrument height value (mm)

Info 2 : Prism height (mm)

c) Code 72 - Input of traverse measurement

Info 1 : Observed station number

Info 2 : Prism height (mm)

d) Code 67 - R.O. Information

Info 1 : RO station number

Info 2 : Prism height (mm)

e) Code 73 - End of traverse measurements at a station

A portion of the coding and measurement listing is shown in Table 4.1 as an example of the use of the coding system which had to be adopted. The coding shows that the instrument was at station 257 and set to a height of 1.621 m. The backsight measurement was taken to station 256, where the reflector was at 1.624 m, and the foresight to station 259 with the reflector at 1.565 m. The measurement routine of face-left backsight then foresight followed by face-right foresight then backsight had to be strictly followed for the Geomap to be able to interpret the data correctly. A further problem was encountered in that the Geomap system could not accept negative instrument and prism heights, and so it was decided that all of the levels would have to be taken to the floor. The effects of this limitation were recognised as being twofold. Firstly, there could be a slight degradation in the accuracy obtained relative to the known co-ordinates as each station would have to be plumbed down to floor level, and secondly, the levels obtained would not be comparable to the station levels

LISTING OF OBSERVATIONS :   JOB @MARTEST

75.000	Code	61	I1	256	I2	2
76.000	Code	31	I1	1621	I2	1624
77.000	Code	72	I1	256	I2	1624
78.000	Code	72	I1	259	I2	1565
79.000	Hz	0.0310	V	91.1226	D	33.680
80.000	Hz	225.4444	V	88.4534	D	327.892
81.000	Hz	45.4434	V	271.1434	D	327.890
82.000	Hz	180.0300	V	268.4740	D	33.679
83.000	Hz	0.0312	V	91.1230	D	33.679
84.000	Hz	225.4440	V	88.4530	D	327.890
85.000	Hz	45.4432	V	271.1432	D	327.892
86.000	Hz	180.0302	V	268.4740	D	33.680
87.000	Code	73				

Table 4.1 Portion of the data listing for the underground test traverse.

held by the mine surveyor. It was decided that there was little point in tape measuring the height of the station above the ground as this would most likely introduce substantial errors.

To ensure that the error introduced by plumbing stations to floor level the following procedure was adopted. A heavy plumb-bob was suspended from the station and a metal change plate placed approximately in position below the weight. This was then pressed firmly into the floor. The approximate position of the station was then defined by chalking the relevant portion of the change plate. The plumb-bob was then lowered until it was as close to the plate as possible and the exact position of the station etched into the chalk using two intersecting fine pencil lines. The plumb-bob was then removed and reset so that the position of the station was checked. It was considered that this method would be more accurate than attempting to place a pre-defined cross under the bob.

The survey commenced at 8.30 am and was completed by 2.30 pm on the 3rd of February 1983. At each station two double-faced rounds of angles were recorded, the distance being measured simultaneously with each angular reading. Hence the distances used for calculation purposes are the mean of eight measurements. All angular measurements were taken to the Kern prisms. A four-tripod traverse system was used, each of the tripods being identical allowing the instrument to be transferred from one to another. Whilst measurements were being taken from one station, the fourth tripod allowed the plumbing team to insert the next foresight station. Information was relayed to the instrument station concerning, for example, the height of the prisms, via hand-held radio sets. The conditions underground were good, with little airborne dust, and all of the traverse distances were measured comfortably to one prism.

The instrument proved very easy to use with all of the required information being obtained from a single pointing. The data was then automatically recorded using the Kern R48 data recorder. Plate 4 shows the author using the total station to pick up a detail point during the traverse. The detail pole with the prism is clearly visable in the background. To a practicing surveyor it may appear excessive to take 6 hours to complete a 10 station traverse, but during the day there were several visitors, including that of the company photographer, which inevitably slowed down the operation. There is no doubt that a greater field efficiency would be attained in the course of a "normal" underground survey than that achieved for this particular task, particularly if the equipment was used regularly by professional mine surveyors.

Plate 4

The author with the E1/DM502/R48

during the Marblaegis underground traverse

On return to the Department the Kern R48 data recorder was connected to the Wild Geomap system. The data was successfully transferred and a raw data print obtained. It was noticed that there were two corrections to be made concerning the coding used. Once these had been edited, the traverse was computed and a list of the unadjusted co-ordinates and the fractional closing error obtained. The traverse closed to 03mm in Eastings, 25mm in Northings and 19mm in level, representing a fractional closing error of 1 in 64500.

The plan of the traverse was shown on the screen together with the small amount of detail collected. The screen editing facilities were used to enhance the plan, for example, completing the fourth side of pillars, and a plot then obtained using the Benson drum plotter to a scale of 1 to 1250 (see Figure 4.1). The scale was chosen so that direct comparison could be made between our plan and the working plan at the mine. The total processing time for the job, from linking the data recorder to the computer through to obtaining the final plan, was approximately 40 minutes. Thus the whole job had been completed, checked and plotted within a days work.

The following day a comparison was made between the co-ordinates (Eastings and Northings only) obtained from the traverse and those held by British Gypsum. The agreement was excellent, as was the fit between the

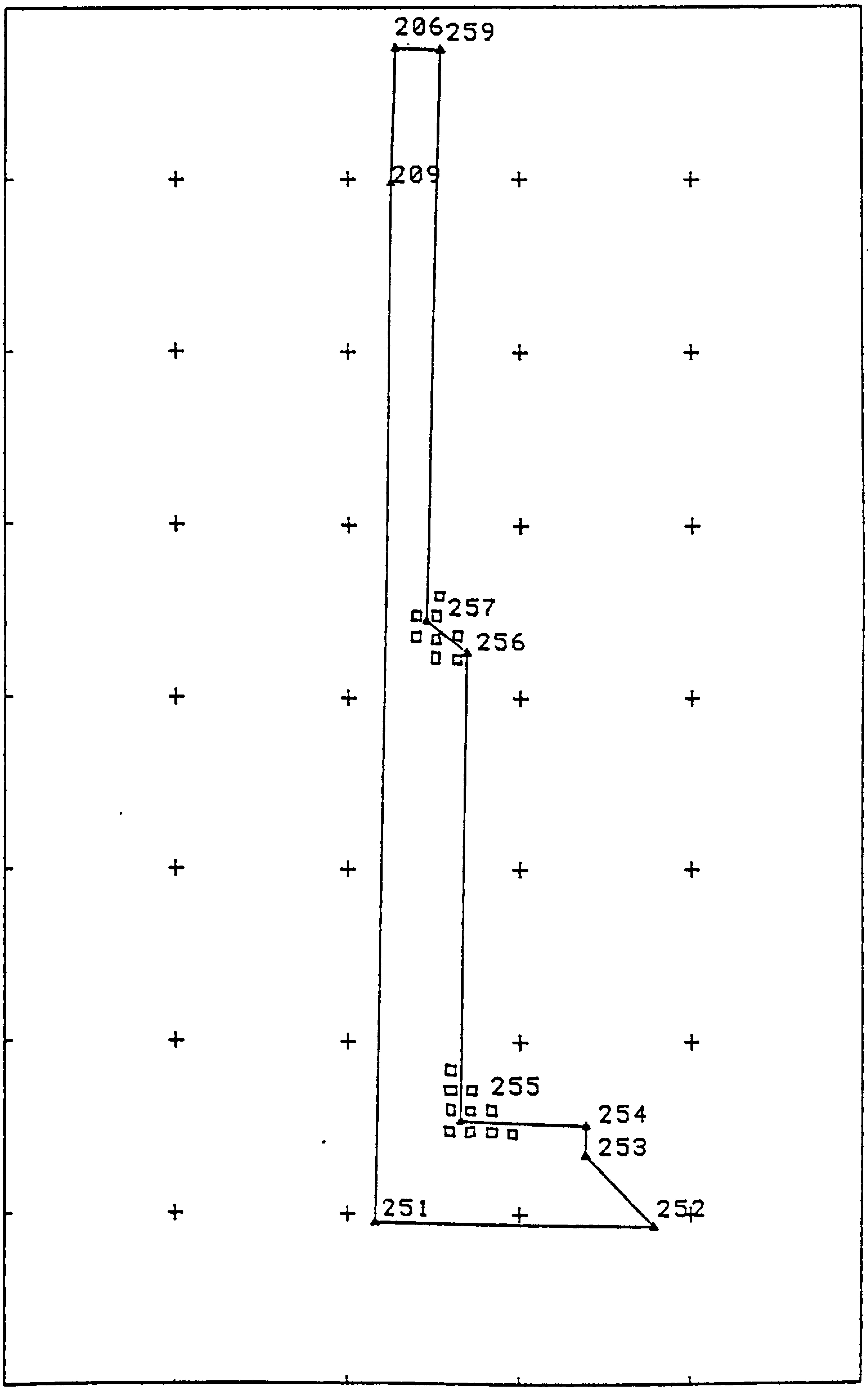


Figure 4.1 Marblaegis underground survey

automatic plot of the stations and detail with the statutory working plan stored at the mine.

It is considered that the traverse at Marblaegis mine was the first fully automated underground survey ever undertaken in the United Kingdom. The ease of use of the instrument and the efficiency and accuracy afforded by the overall automated system was both impressive and encouraging. This survey clearly demonstrates that only by the field use of new instruments and techniques are the advantages and benefits fully appreciated.

4.3 Underground quarterly tape and offset survey

Consultation with mine surveyors proved that the majority of the work undertaken below ground was not accurate traversing, but the aquisition of detail points concerning production figures. This is particularly prevalent in metalliferous mining, and situations where room and pillar extraction are used. For the majority of this type of work simple tape and offset surveys provide sufficient accuracy. The use of electronic total stations would not be particularly expedient in this type of situation, primarily because of the limited access to relevant points and the restrictions imposed on the available lines of sight. It was decided to attempt such a survey using the conventional tape and offset method, but recording the results manually using the Kern R48 data recorder so that the survey could be processed automatically. This would greatly enhance the range of application of automatic data processing in a practical environment.

British Gypsum were approached as to the possibility of conducting such a survey coincidentally with their own conventional quarterly tape and offset production survey. A suitable face was chosen at their Marblaegis mine in the BC1 district. In total there were 28 working headings comprising the face, each of which had a recently established survey station along a common cross-cut beyond the existing extent of the working plan. The bearing along which the headings were advancing was known and was common for each.

The survey took place in January 1984, by which time the HASP system had been installed within the Department. This allowed the full range of coding to be used on the Kern R48 data recorder (see Section 1.3.5) as implemented by the author. It was decided that the most expedient method would be to previously store all of the starting co-ordinates in a control file so that co-ordinate values need not be entered during the survey itself. This would facilitate the coding required as well as improve the speed with which data could be collected. The use of the control file enabled unambiguous point definition by simply entering the relevant point number during the survey.

The most expedient method of recording the tape offsets is by the use of the transverse eccentricity field (E-R) in Mode 1. Offsets are defined as being positive to the right of the line of sight from the instrument position, and vice-versa. Because the stations from which the measurements were commencing were beyond the the existing extent of the mine plan, measurements had to be taken both towards the heading and also back to tie in with the existing information. Orientation at each station was achieved by entering an azimuth value into a Code 33 block corresponding to the bearing of the advance. In this way points outbye were positioned by entering a horizontal angle of 0°, whilst points inbye were located by an angle of 180°. The vertical angle was entered as 90°, the workings being level. The distance along the tape was entered in the slope distance field, with the offset entered into the E-R field. Figure 4.2 illustrates the following example of the coding in use.

Mode 2

SNR	10		Station occupied
SCO	33		RO station or azimuth

Mode 1

HOR	0		Enter angle of 0
ELE	90		Vertical angle of 90
DIS			
PNR	2710330		Bearing of 271 03'30"
		RECORD	
DIS	3.2		Distance along tape
PCO	1		Start line
E-R	3.3		Offset 3.3m to right
		RECORD	
DIS	9.4		
PCO	2		Draw line
E-R	3.4		Offset of 3.4m
		RECORD	

DIS	10.6		
PCO	1		Start line
E-R	-3.6		Offset 3.6m to left
		RECORD	
HOR	1800000		Horizontal angle of 180
DIS	8.6		
PCO	2		Draw line
E-R	3.5		Offset 3.5m to right
		RECORD	
DIS	9.2		
PCO	1		Start line
E-R	-3.5		Offset 3.5m to left
		RECORD	
DIS	3.4		
PCO	2		Draw line
E-R	-3.3		Offset 3.3m to left
		RECORD	

Having entered the bearing of the heading and the station number occupied using the Code 33, the pillar A is defined by the first two measurements, and coded so that a straight line appears to represent its edge. The next two measurements define the large pillar (B) in a similar manner. Note that the first point of pillar B is coded with PCO = 1. This defines that a new line is to start from this position. Pillar C is picked up using the same routine.

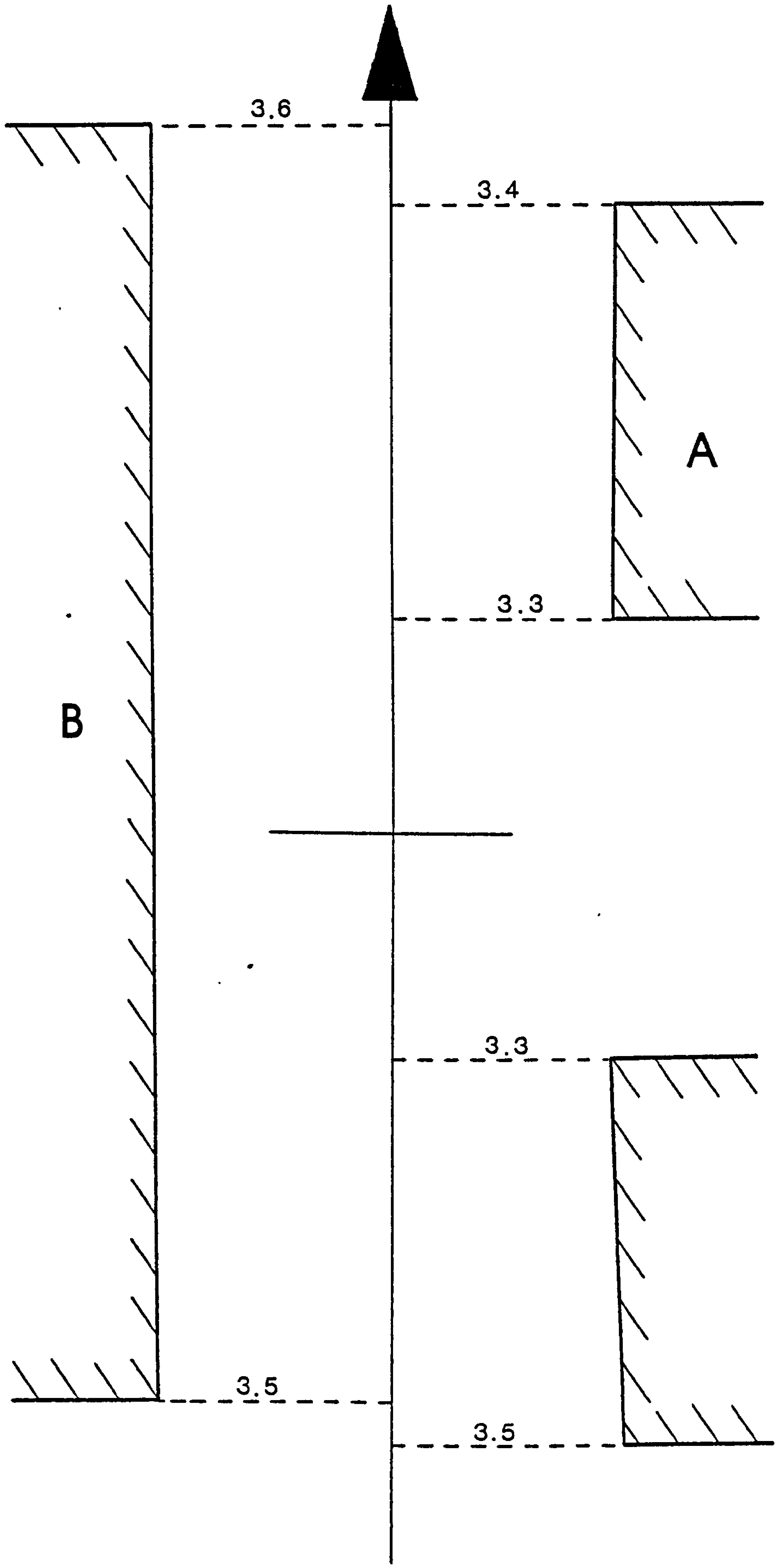


Figure 4.2 Example of tape and offset coding

A total of 5 headings were surveyed in approximately 1.5 hours, with the results also being booked in the conventional manner by the mine surveyor. Once a measurement routine had been achieved the use of the data recorder proved surprisingly easy, although care obviously was required that the correct sign was chosen for the offset values.

On return to the Department the data was transferred to the HASP computer and processed. A plot from the field data was obtained and this mounted on the digitiser to allow graphical editing. The graphical editing involved the joining of the sides of the pillars between headings. The final plot was obtained within 45 minutes of returning to the Department (see Figure 4.3). This plot was compared to the updated section of the working plan and the agreement was found to be excellent.

The ability to use the automated survey system for this type of work impressed the surveyors at British Gypsum more than the underground traverse described earlier as this was typical of the majority of their survey work underground. The results demonstrated that the data recorder has applications in conjunction with conventional equipment, and although the field time could be slightly increased, the savings in the office computation stage are large. Another advantage of automatic processing is that the data is held in a

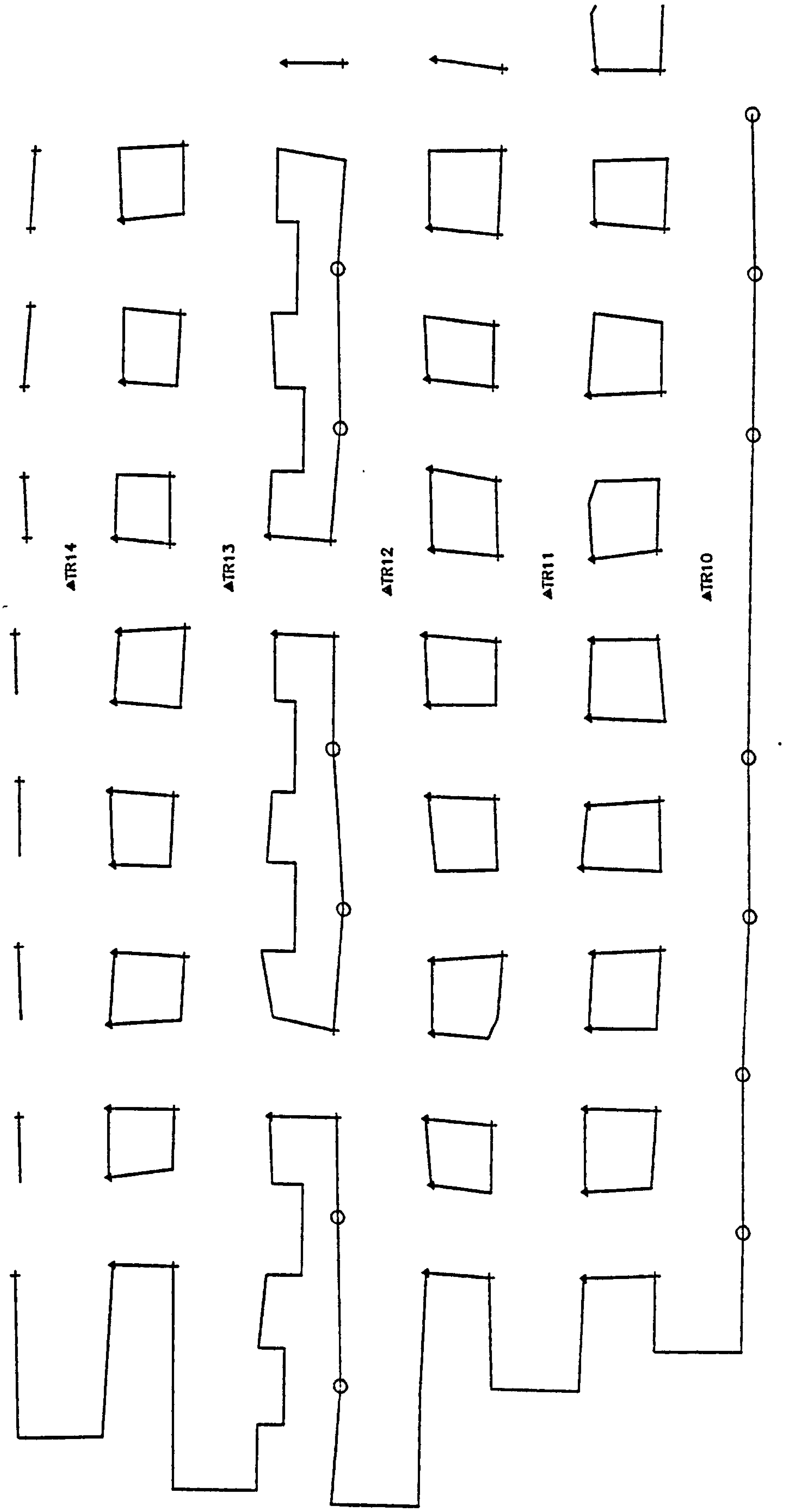


Figure 4.3 Marblaegis tape and offset survey

digital format, and so the existing mine plan can be automatically updated (assuming that it is digitally stored) once the surveyor is satisfied with the quality of the latest survey. This point will be discussed in more detail later in this thesis.

4.4 Summary

The case for purchasing and using an electronic total station just for underground survey work may appear initially not to be too convincing. However such an instrument would be of great value to the mine surveyor for many surface and underground tasks and field data recording and preparation errors are completely eliminated thus increasing productivity, accuracy and efficiency. There is no doubt in the author's mind that with further developments in field instrumentation and computers the application of automated systems in mine surveying will increase and considerable benefits will be obtained by their use. It is important therefore that they are accepted and used by practising mine surveyors.

CHAPTER FIVE

VOLUMETRIC APPLICATIONS OF AUTOMATED SURVEY SYSTEMS

Volumetric applications
of automated survey systems

5.1 Digital terrain modelling

Over the past decade considerable effort has been expended into researching computerised methods of modelling complex surfaces. The majority of this work has been concentrated on representing mathematically defined surfaces, with little research into optimal representation of irregular surfaces. Natural formations, such as the topography of an area, fall into the category of irregular surfaces, and so this is possibly the only field of interest for the surveyor. Hence only modelling techniques for irregular surfaces will be considered. The basic techniques for modelling irregular surfaces have been known for a considerable time. It is therefore surprising that to date these concepts have not been further developed, facilitating their application to a wide range of topics including digital terrain modelling. The following sections will consider and compare the methods available for surface modelling, and indicate how they may best be exploited by the surveyor.

There is always a trend within computing to emulate the manual method of solution, and in certain cases this is justifiable, especially when a new application is being considered. This explains why, traditionally, surface modelling has only been used to interpolate contours, and then derive subsequent information such as volumes and cross-sections from these contours. This in effect mimics the manual technique that would have to be adopted, and is widely employed in earthwork computations for highway and open pit design. This type of process is, by its nature, both inaccurate and inefficient when computer processing is available because not all of the available data is rigorously utilized, and, interpolation from the data progressively degrades the accuracy of the results.

If a precise surface model is created direct from the surveyed data, then any subsequent computations will be derived from the model without degradation by any interpolation techniques. The accuracy of these computations will then be solely dependent upon the precision of the terrain model obtained and not on the scale of the plan used for interpolation or the number of interpolations performed.

It is therefore desirable that the computer system should not mimic the manual technique, but should be used to obtain a rigorous surface model direct from the surveyed data. Mathematical functions are available which allow the surface to be defined through the entire data set simultaneously, in effect forming the best data fit over the entire area. This is referred to as global fitting, but at present this technique is not suitable for surveying because of the large computational power required to achieve acceptable accuracy. As it is not possible to consider the entire model area simultaneously alternative methods must be used where the data is subdivided. It is then possible to represent the surface as a contiguous set of spatially linked elements or facets. These facets can be either planar or curvilinear surfaces.

A variety of modelling techniques employing such methods have been developed and are reviewed by Rhind (1975), but there are two which have become prevalent in surveying. These are, surface modelling by rectangular grids, or, by irregular triangular networks. Both of these methods will be discussed and compared, although emphasis will be placed on the triangular network technique as this method has been implemented by the Department of Mining Engineering at Nottingham.

5.2 Surface modelling by rectangular grid

The basic principle behind this type of modelling is coverage of the data area by a regular rectangular grid. The value of the function to be modelled is calculated at each grid node by interpolation from the surrounding data. Therefore in surveying, the height at each grid point will be interpolated from the surrounding randomly surveyed points. This technique is most applicable in situations where the relationship between the data points and the function is not known, or where overall surface trends are of more importance than absolute values of the function. Rectangular grid modelling is widely used with success for analysis of geophysical data and stress patterns within mining enginering. The technique can also be used for geostatistical interpretation, especially when weighting characteristics are employed during grid formation. At present rectangular grid modelling is the most widely used technique for digital terrain modelling.

The formation of the grid simplifies subsequent computations and interpolations which may be required of the data for contouring or volumetric analysis. Interpolation within each grid cell may be linear, assuming the centre of the cell has a height which is the mean of the four nodes, or may have a curved surface blended through the four nodes, such as a hyperbolic parabola (Grist 1972). For terrain modelling linear interpolation is usually employed for the derivation of the ground contours and sections. Linear interpolation along the sides of the cells allows the contours to be followed through the data area. Often each cell is divided into four equal triangles by using the centre point and assuming that its elevation is the mean of the four nodes. Sections can be interpolated directly along each of the grid lines, or alternatively, oblique sections through the data can be calculated by linear interpolation along the grid sides at the points of intersection with the section line. The programming to achieve contours and sections by interpolation from grids is not particularly sophisticated and, when this is coupled to the well ordered data storage inherent within the method, allows efficient computation.

It is obvious that the accuracy of the method is determined totally by the creation of representative grid node values. There are many methods available to achieve the interpolation to the grid position, these varying in both overall approach and general implementation. Nicholson (1984) reviews the most common methods in use to date. The basic problem of attaining the most representative node values is usually tackled by the introduction of distance weighting functions and an overall zone of influence, or neighbourhood. The zone of influence can be dictated by a given radius from each node, or more usually by definition of the number of points which will be considered to have an influence on the node. The influence of each point within the zone of influence is determined by a distance weighting function, commonly an inverse square relationship. Many variations using the basic inverse square law have been developed to produce more precise ground models (Rhind 1975, McLain 1974).

5.2.1 Advantages of rectangular grid models

a) The processing time for grid formation is relatively small in comparison to other surface modelling techniques.

b) Interpolations upon the grid are simple to program and rapid to execute.

c) The computer storage requirements are minimised as only the elevation of the grid nodes need be stored.

d) Overall surface trends can be detected from even the most irregular data.

e) The surface will not be dramatically distorted by any single point, and so an entire model will not be significantly corrupted by a single erroneous point.

f) The smoothing effect of the process produces contours and surface projections which are aesthetically pleasing.

g) The degree of smoothing is determined by the grid density, the weighting function employed, the size of the zone of influence and the interpolation procedure adopted. Hence the user has a high level of control over the final output.

5.2.2 Disadvantages of rectangular grid models

a) The surface model is not generated directly from the surveyed data points, with an immediate interpolation procedure being employed.

b) Often the original points do not lie on the surface model produced, indicating the inaccuracies of the method.

c) All data taken from the model will be interpolated from a model which is itself interpolated, and so the accuracy of such information will have been degraded at least twice from the actual terrain surface.

d) High accuracy can only be achieved by the use of a dense grid, which will be highly redundant in uniform areas, and greatly increases processing time.

e) The form of the surface model can be altered considerably by changing the formation characteristics, showing that the model is highly parameter dependent.

f) The inherent smoothing induced by the process disguises rapid changes in elevation (see Figure 5.1). Such discontinuities are common in mining situations, for example, the benches in a quarry. Apart from a gross error in the representation of the surface, large descrepancies in volumetric work can result.

g) The method of weighting to obtain the node points is contrary to survey practice. Manual interpretation is based on the surveyor's knowledge of the site and field sketches, allowing minimal numbers of points to be surveyed. However, to ensure that the computer forms the correct approximation across discontinuities many more points need to be taken, reducing the field efficiency.

h) Linear contour interpolation in cells without the centre point calculated are not unique (see Figure 5.2).

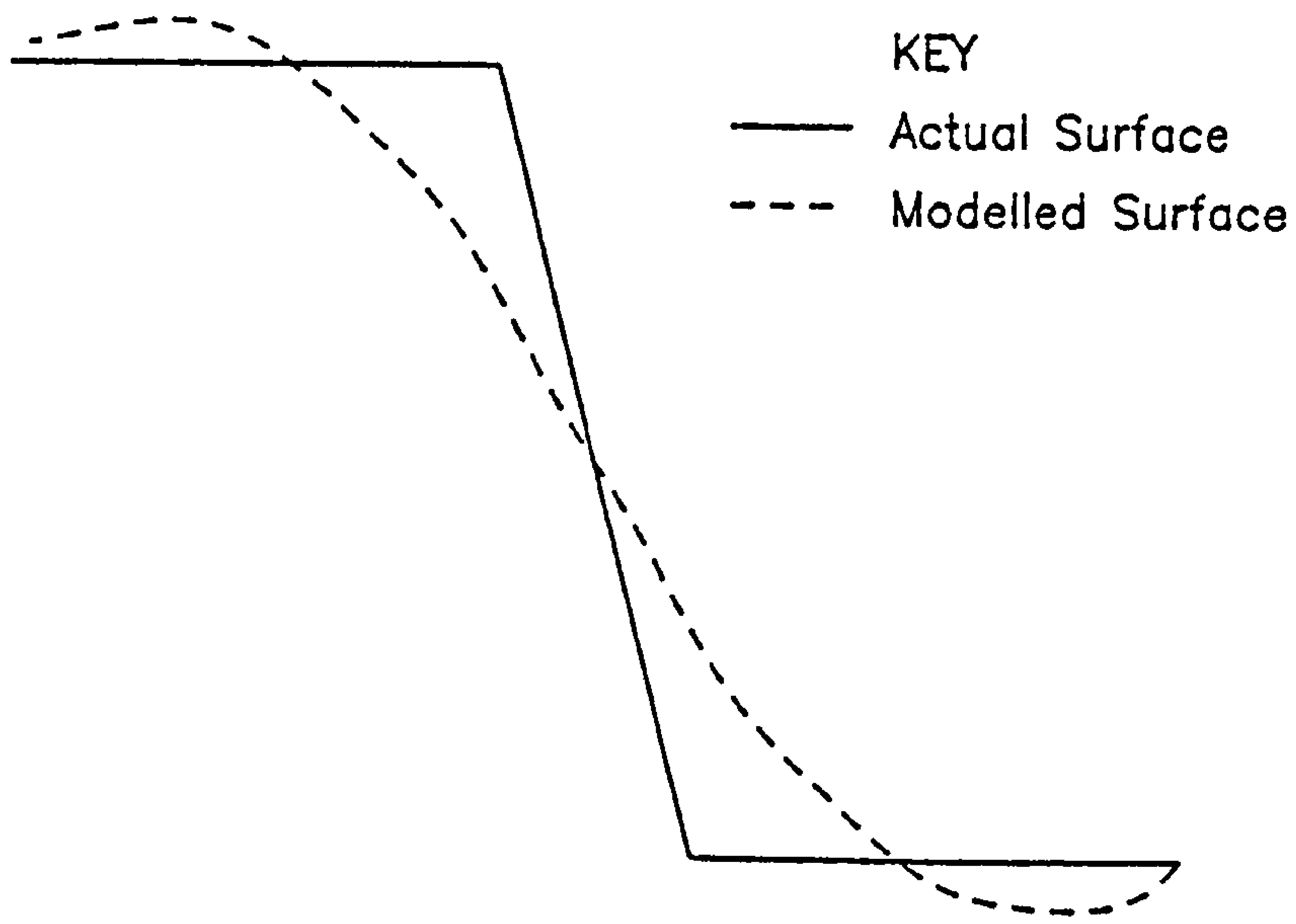


Figure 5.1 Smoothing induced by rectangular grids

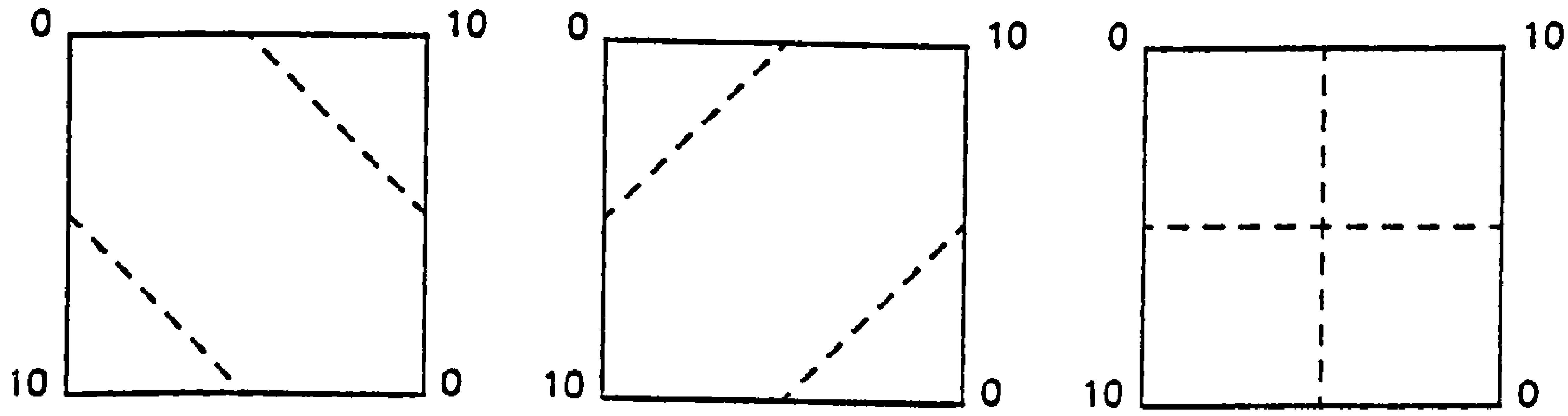


Figure 5.2 Possible contours through a rectangular grid cell

5.3 Surface modelling by triangular irregular networks

The concept behind the use of triangular irregular networks for surface modelling is fundamentally different from that employed by the rectangular grid methods. As the name suggests, this technique is based on representing the surface terrain by a series of contiguous non-overlapping triangles, the vertices of which are derived directly from the actual surveyed points. This means that there are no interpolations or weighting functions required to form the terrain model. By prudent field surveying the model created should therefore be more accurate than that achieved by the rectangular grid method. This modelling technique also allows greater flexibility if editing is required, as individual points are reflected only in the immediately surrounding triangles and do not influence points outside their immediate zone of influence.

The method of network formation is critical to the accuracy with which the terrain will be represented. The objective has got to be to obtain the best fit of triangles across the entire data area, avoiding the inclusion of badly conditioned triangles wherever possible. A badly conditioned triangle is one which is least like an equilateral triangle. There are two basic solutions available for the creation and optimisation of triangular networks, namely, searching techniques and switching techniques. Searching involves the selection of a baseline from two adjacent points and then interrogating the surrounding points to obtain the best fit to a defined geometrical parameter, such as the creation of the smallest circumcircle (Elfick 1979), thereby forming a triangle. Another baseline can now be chosen from this triangle, and so the process continues. Switching techniques involve the creation of an initially crude triangular network comprising badly conditioned triangles. Successive passes are made through the network iteratively correcting triangles until no further improvement is possible.

There are a vast number of algorithms available to implement either of the above techniques (McCullagh and Ross 1980, Yoeli 1977, De Floriani et al 1982, Gold et al 1977). It is not feasible to compare all of the different algorithms within this thesis, and so a detailed description will be given of the technique implemented within the Department on the HASP system. The volumetric surveys detailed later within this chapter have all been processed using this system.

The algorithm implemented uses a searching technique called Radial Sweep (Mirante and Weingarten 1982), so called because of the method of generating the initial crude triangular network. The first stage of the process is to locate the most central point within the data area, termed the central node. The bearings of all the other points from the central node are then calculated, and the points stored in order of ascending bearing value. Triangles are then formed from the central node to consecutive points, creating a sweep of the entire database. An example of the result from the initial sweep of the data points shown in Figure 5.3 is reproduced in Figure 5.4.

The next stage checks the boundary of the model to date for any concavities. The perimeter points are checked sequentially in groups of three to determine whether the included angle is less than 180 degrees. If this is so then a new triangle is formed using these three points, with the second point being excluded from the boundary list. This process is repeated until the condition is never encountered, at which time the perimeter of the model will be convex and the entire data area will be covered by contiguous non-overlapping triangles, as shown in Figure 5.5.

As can be seen, the network created at this time consists of badly conditioned triangles which are long and thin. This is overcome by a process of optimisation. Each link between two points represents an edge of two triangles, unless it is a boudary line. A comparison is made between the length of this existing link and the alternative link between the two unique nodes. If the existing link is longer than the alternative, then the triangles are swapped (see Figure 5.6). Before the swap

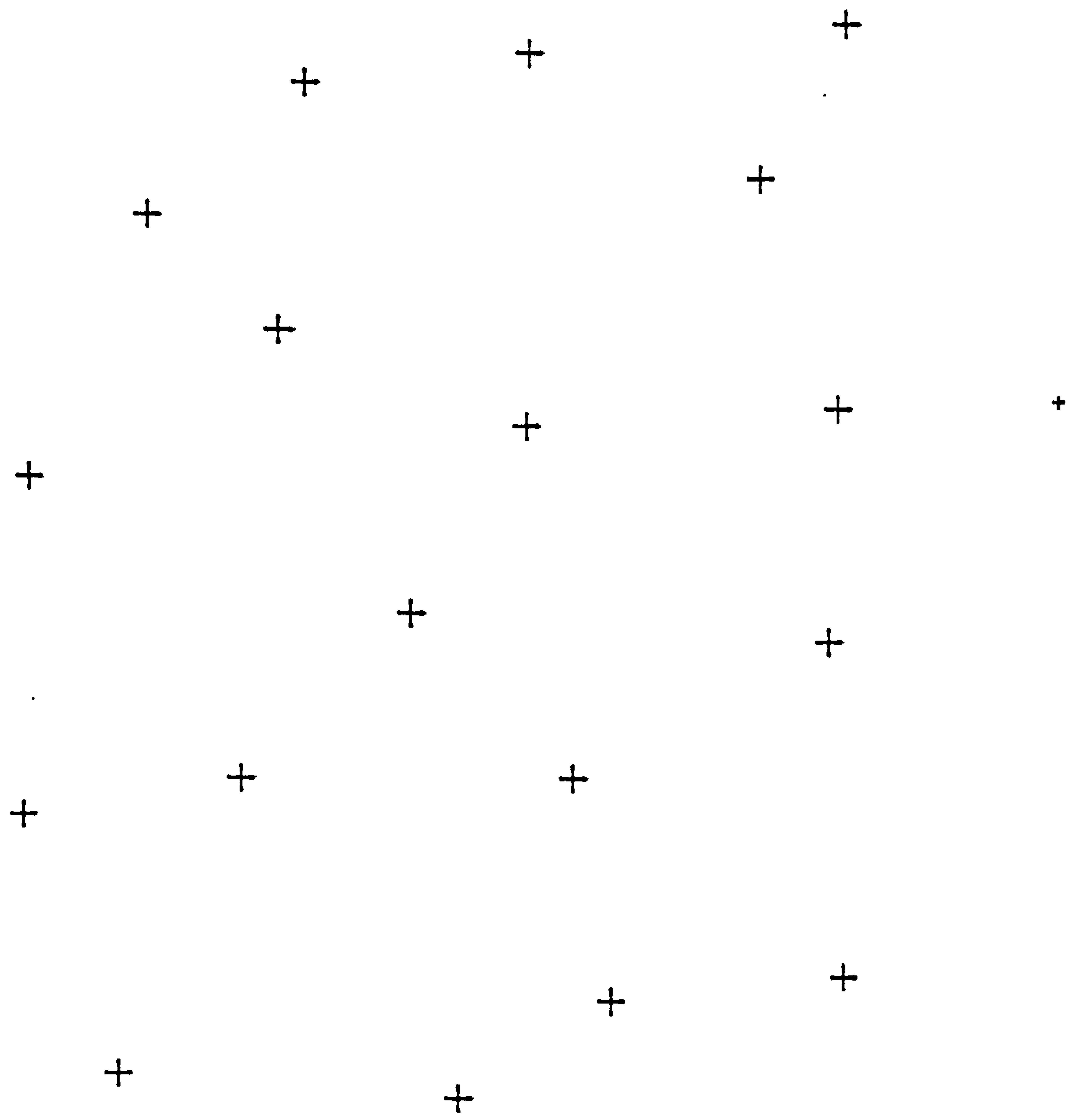


Figure 5.3 Original data points

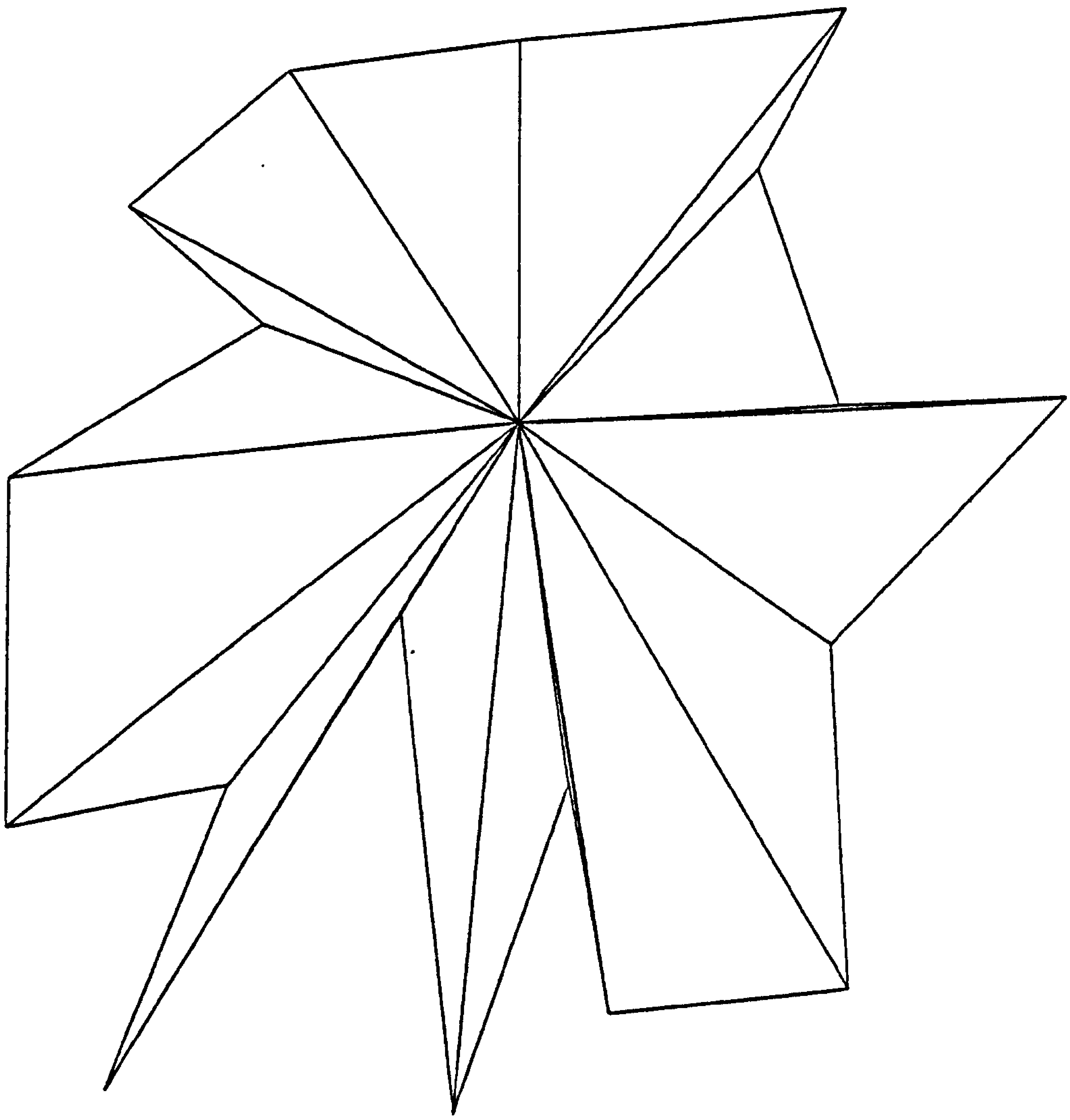


Figure 5.4 Radial sweep

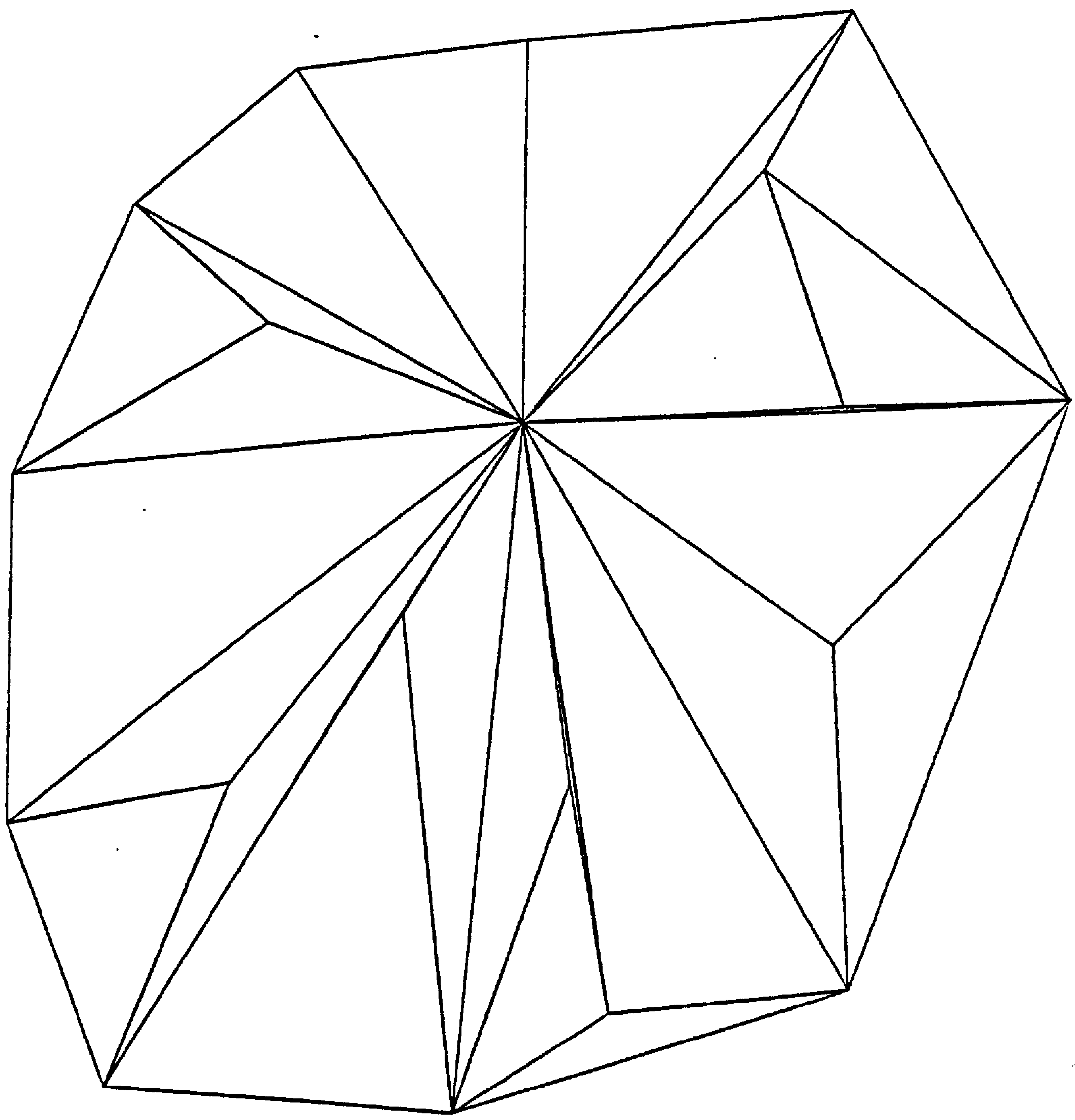
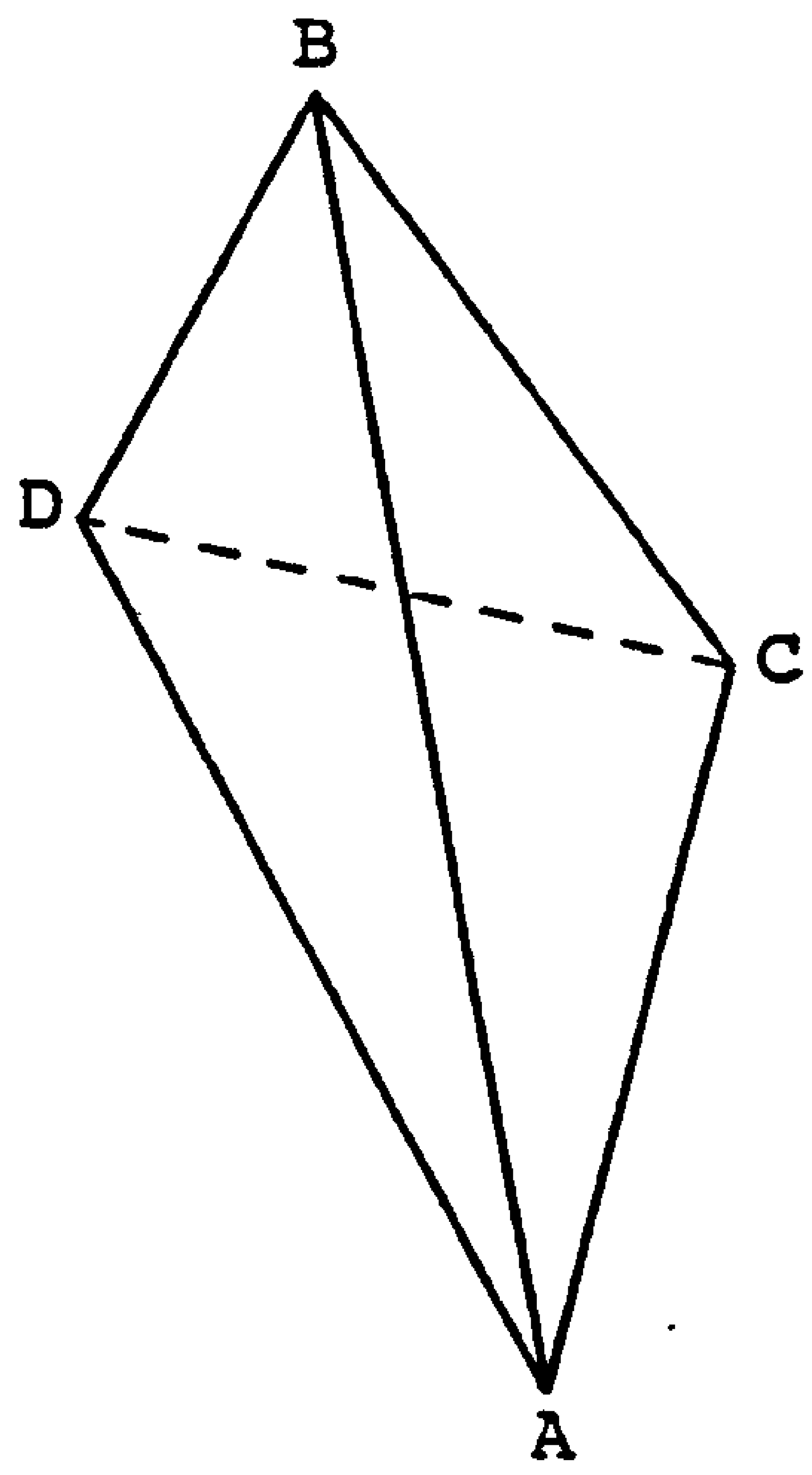


Figure 5.5 Boundary concavity infilling

can take place it must be checked that overlapping triangles will not be created. This will be the case if the quadrilateral made up of the two triangles contains an angle greater than 180 degrees (see Figure 5.7). The switching process continues iteratively until a complete pass through the database is achieved without any alterations to the triangular network. This model is now the optimised triangular irregular network for the data area (see Figure 5.8). The modelling procedure implemented in the language HPL on the Hasp system is capable of forming the terrain model of 600 points in approximately 45 minutes.

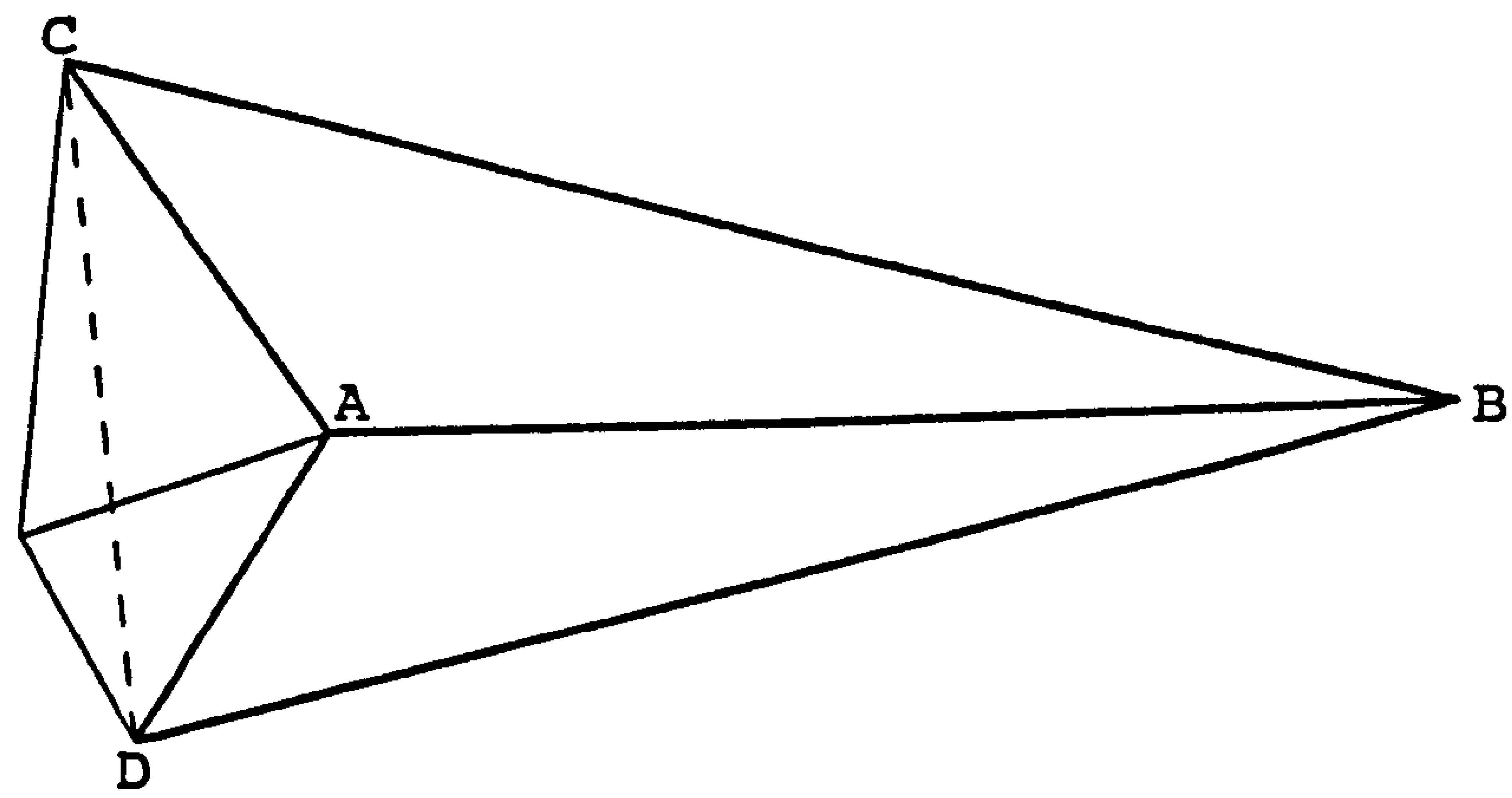
Creation of the model by this method allows certain functions to be derived directly from the optimised triangular network. The height of any point can be interpolated from the model by simply entering the X and Y co-ordinate of the point. This is possible because each triangular facet is planar and the XYZ co-ordinates are known for each vertex. Contours can be unambiguously defined by a simple linear interpolation along each edge of the triangles. Contours are defined by locating a triangle in which the contour will occur and then tracing the contour through successive triangles until either the boundary is reached or the original triangle is re-entered. Sections can be obtained by linear interpolation along the sides of each triangle which are crossed by the section line. Perhaps most significantly



Length AB>CD

Links swapped

Figure 5.6   Criteria for link switching.



AB>CD but CAD>180

Links not swapped

Figure 5.7   Testing quadrilateral parameters before link switching.

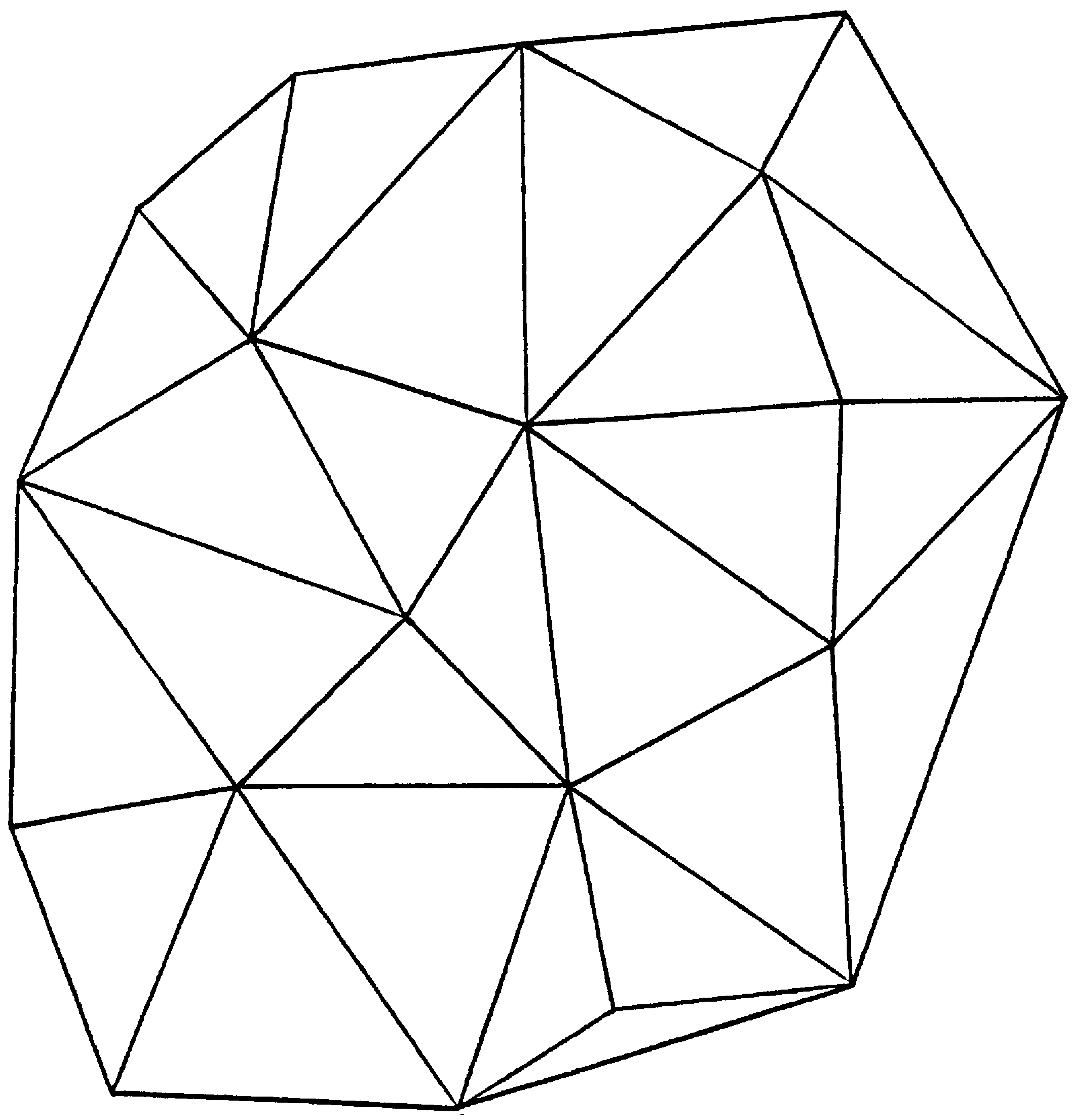


Figure 5.8 Optimised triangular network

the volumes which are derived from the model are rigorous, and do not require any interpolation. The volume enclosed below a triangular model will be the sum of each of the individual triangular prisms reduced down to a datum level (see Figure 5.9). The volume for each prism is given by the following formula;

$$V = 1/6 \times [(Z1+Z2+Z3-3D) \times (ABS[X1(Y2-Y3) + X2(Y3-Y1) + X3(Y1-Y2)])]$$

where Xn,Yn,Zn are the XYZ co-ordinates of the triangle nodes

D = the datum level

V = the volume enclosed.

To determine an enclosed volume it is necessary to form two models and obtain the volume of each. The difference between the two values is the required volume. This can only be implemented if the boundary shape of each model is identical and the same datum level is used. The volumetric surveys described later in this chapter illustrate the principles involved.

The efficiency of the model formation and subsequent analysis is dependent upon the method of data storage employed. The nature of the modelling technique lends itself to the implementation of a spatially linked database. Each node is stored as a point number with its associated three dimensional co-ordinates. The triangles

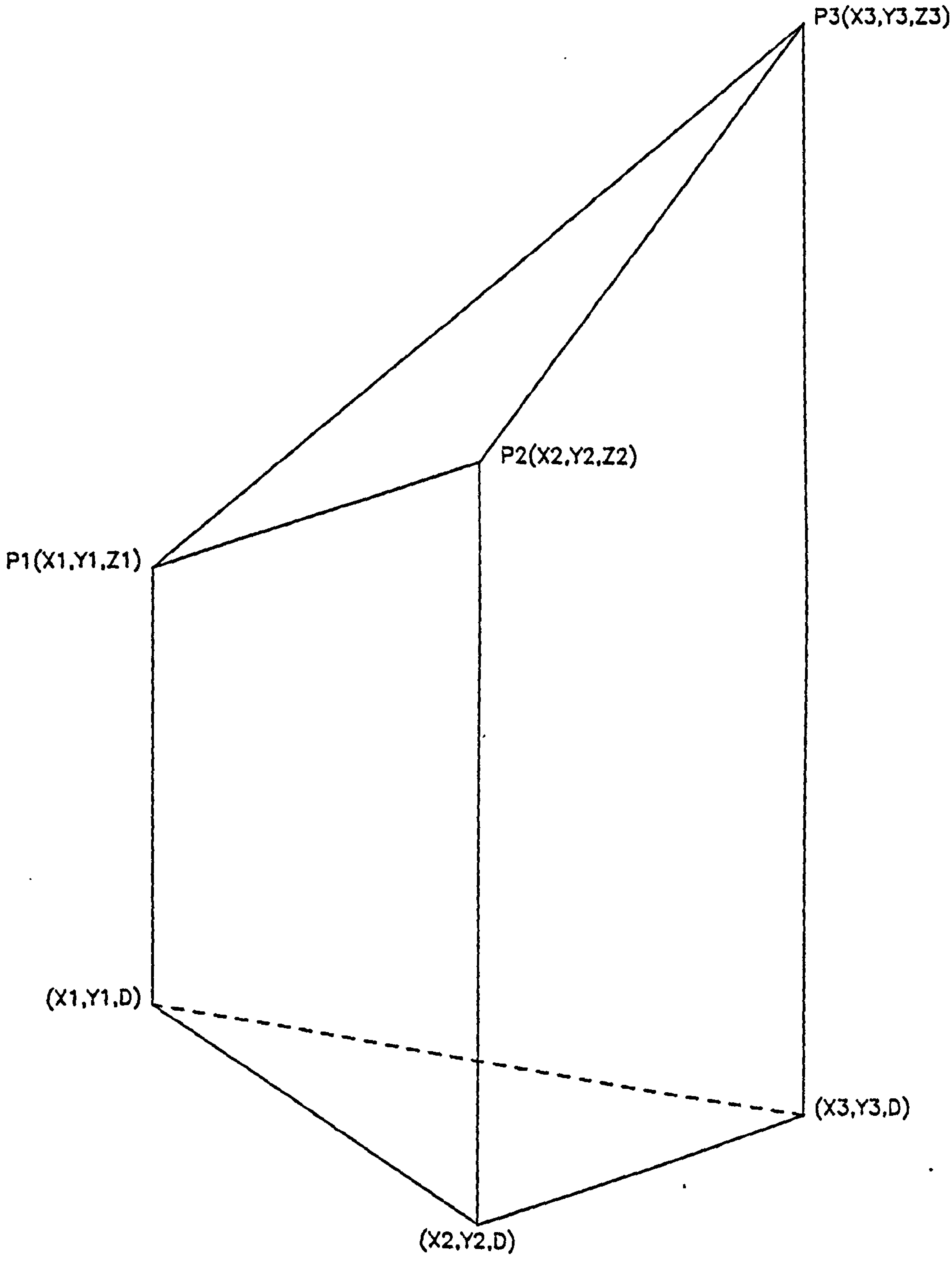


Figure 5.9 Volume of a triangular prism

are defined individually by storing their three node values and their associated links.

In general topography there are numerous examples of sudden changes in the terrain slope, such as the bottom of a valley. These features can collectively be termed as discontinuities. This type of feature is often accentuated within the mining industry, for example, the bench system used for open pit excavation. The modelling technique must be capable of recognising such features and representing them accurately. Optimisation of the triangular network is dependent solely upon the XY spatial distribution of the points in relation to each other, and so it is possible to incorrectly form the model surface as is shown in Figure 5.10. Figure 5.10 represents a valley which has been surveyed along each top and the bottom, the spatial representation of the points being shown in the plan. The triangular optimisation resulting from these points can be seen on the plan, with the distance T2-T5 being less than the distance B2-B3. An isometric representation of this surface is superimposed in the valley, the error immediately becoming apparent. This type of error is common, and so it is necessary to introduce a method forcing correct triangular formation. This is achieved by the introduction of "breaklines".

Breaklines are lines which are coded into the survey data between points and force the triangle formation by the criterion that no triangle can cross the line. The model in Figure 5.10 would form correctly if the triangles did not cross the valley, but formed down the sides of the valley. The introduction of a breakline along the line B1-B4 would achieve this aim. The HASP system has a facility whereby the operator can define which coded linetypes are to be considered as breaklines. In this way breakline information can be included alongside conventional linework for graphical enhancement.

Breakline information can be entered in the field during the survey, or can be added to the survey data subsequently during data editing. It is suggested that as much breakline information as possible is entered whilst in the field, although this can reduce the surveying efficiency as the relevant discontinuities have to be followed. The use of breaklines is demonstrated in several of the volumetric surveys discussed later in this chapter.

There are three methods commonly used for implementing breakline recognition during processing, namely constructing breaklines prior to, during, or after model formation. Elfick (1979) suggests that breaklines should be considered prior to network formation by scanning each breakline and linearly interpolating addition points in areas where it seems likely that triangles will cross the line. The amount of database searching required prohibits the use of this technique. A solution could be the indescriminate addition of extra points by linear interpolation along the line, but this will seriously reduce the operating efficiency of the system due to the large number of additional points introduced into the model. Yoeli (1977) suggests a method of breakline interpretation during network formation, but this technique is only feasible if a searching routine is used. His method basically introduced a second constraint to model formation. In adition to new triangles not crossing previously stored sides, they cannot cross any breaklines.

After consideration of the relative inefficiency of the implementation of breaklines before network formation, and the unsuitability of implementation during formation, it was decided to construct the breakline constraints after the model formation. Each breakline is traced and where triangles are found to cross the line the triangles are switched within the database. Breakline implementation in Figure 5.10 would result in the switching of the triangles so that they would become B2B3T2 and B2B3T5. If the breaklines follow adjacent data points, as is the case if they are entered in the field, then this technique does not introduce any additional points in the database and the technique is

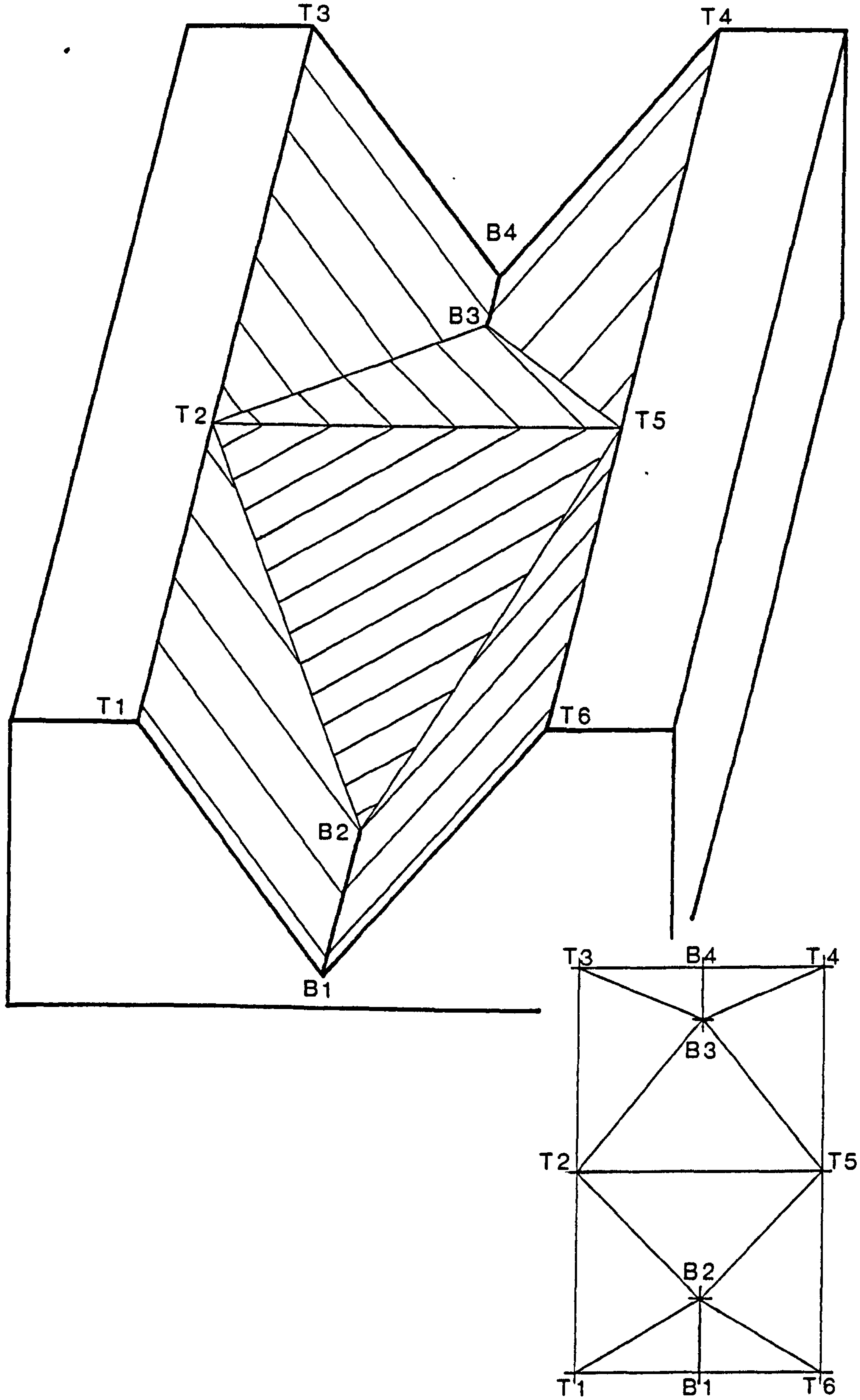


Figure 5.10 Incorrect model formation across a valley

very rapid. Additional points are sometimes required where the breakline is introduced between non-adjacent points. It is possible for the switched triangles to cross existing triangles, and if this is the case, an additional point is interpolated along the line and added to the database. This method introduces only very few points and so the efficiency is not appreciably degraded.

5.3.1 Advantages of triangular irregular network models

a) The modelled surface will pass directly through all of the original data points.

b) The accuracy of the model is dependent solely on the definition of the data points and not on the operating characteristics of the program itself.

c) The surface model created will be inherently more accurate than that produced by any other modelling technique.

d) Erroneous data points are readily identifiable and not merely smoothed into the surrounding surface.

e) Discontinuities may be taken into account by the introduction of breaklines.

f) The modelling technique can cope accurately with angular or near vertical faces.

g) The field work is efficient because an even distribution of points is not required. The field work can concentrate on picking up relevant points on surface discontinuities.

h) Contours derived from the triangular facets are unique and unambiguous.

5.3.2 Disadvantages of triangular irregular network models

a) The accuracy of the model created is highly dependent upon the correct utilisation of breaklines. Correct breakline positioning is possible for accessible surfaces, but significant errors can result if this technique is used for the modelling of hidden surfaces such as geological horizons.

b) The final model created will vary slightly according to which of the optimisation routines is employed.

c) Large amounts of data processing are involved in the creation of the model and any subsequent computations using the network. The amount of data storage space required is also large, and so the method is only applicable to fairly powerful computers with adequate memory.

d) The method is not particularly applicable for the detection of overall trends within irregular data areas.

e) The contours created often appear irregular due to their direct interpolation from the model without any smoothing effects.

5.4 Volumetric surveys

The work of a mine surveyor involves the determination of absolute volumes, whether concerning the amount of extraction from a quarry or the volume of mineral or waste stored in tips. These surveys usually involve sighting numerous detail points from a limited number of traverse stations. The nature of the work therefore lends itself to the application of automated field survey techniques, using electronic instrumentation and automatic data capture.

It was decided that software suitable for volumetric analysis was essential within any computer system designed for use within the mining survey profession. Hence the digital terrain modelling package as previously described was developed within the HASP system. Numerous fully automated volumetric surveys have been undertaken since the completion of the software in February 1983, a selection of which will now be described. Each job described has features relevant to the overall applicability of the system to the field of volumetric determination in a mining environment.

The aims of the project have been to:

a) Develop suitable software for volumetric analysis.

b) Develop an efficient field technique.

c) Determine the accuracy obtainable.

d) Investigate the overall efficiency of the system.

e) Establish the range of applicability of automated ground survey techniques within the subject.

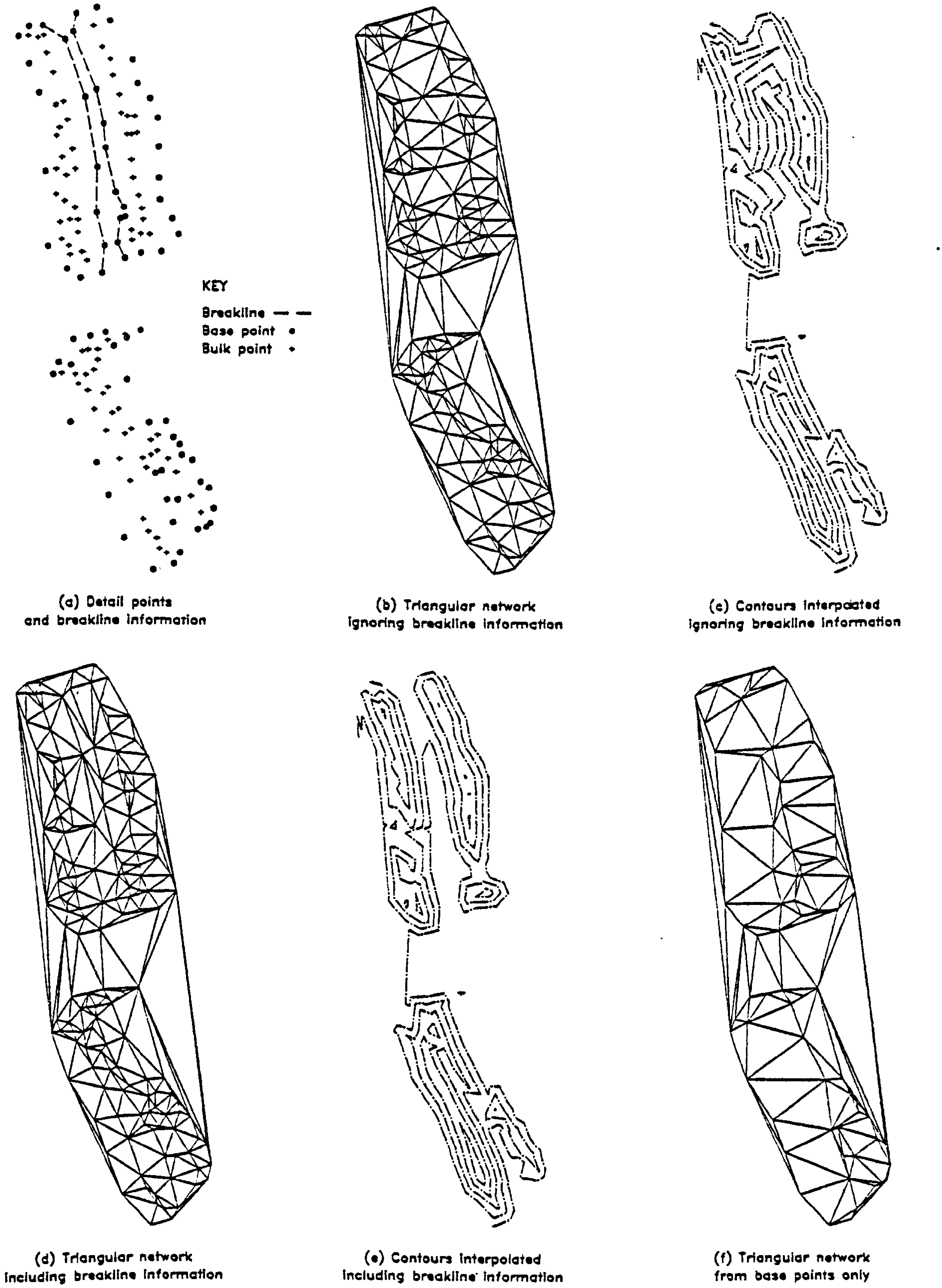
5.5 Calverton coal stockpile

Following consultation with the South Nottinghamshire Area of the NCB, the first volumetric site was chosen at Calverton Colliery. The task was to determine the volume of the small singles coal reserve held at the pit. The job was complicated by the fact that the coal was stored in two separate locations, there being three individual piles at each site. For the sake of brevity only the work at the second site will be considered in any detail, the method employed being identical at each.

Following reconnaissance of the site, which comprised three small heaps, it was decided that three traverse stations would be required. Arbitary "local" co-ordinates were chosen for one of the stations as the determination of the volume was the sole aim of the job. No attempt was made to tie the stations in to the National Grid. The survey was conducted with one man at the instrument taking the measurements and operating the data recorder, and two men moving over the site with detail poles on which were mounted a single prism. The instrument used was the Kern E1/DM502 with the Kern R48 data recorder. The detail points were coded so that points which delineated the base of the pile had a code 150, whilst those on the coal itself were coded 151. The reason for this becomes evident during data processing. A total of approximately 200 detail points were surveyed in this manner and the task was completed in 2 hours.

On returning to the office the data was transferred from the R48 to the Hasp system and processed. Figure 5.11(a) shows the positions of the base and bulk points which were picked up, as well as the breakline information which was edited into the data in the office. The necessity for the inclusion of breakline information is illustrated particularly clearly by Figure 5.11. Originally the triangular network was formed without the inclusion of any breakline information, the resultant triangular network being shown in Figure 5.11(b). From the contours interpolated from this network, shown in Figure 5.11(c), it can be seen that the gully between the the two parallel piles has been bridged, introducing an error into the terrain model. The breaklines shown in Figure 5.11(a) were then edited into the data and the model reformed including this information. The resultant network is illustrated in Figure 5.11(d). The effect of introducing the breaklines is shown very well by the contours interpolated from the new model in Figure 5.11(e). As can be seen the terrain model has now been formed correctly with a continuous gully separating the two heaps. Having accepted this model as being correct, the volume was determined down to a datum level of 0 m.

This volume was noted and the model reformed, but this time to the exclusion of all of the bulk points,



(a) Detail points and breakline information

(b) Triangular network ignoring breakline information

(c) Contours interpolated ignoring breakline information

(d) Triangular network including breakline information

(e) Contours interpolated including breakline information

(f) Triangular network from base points only

Figure 5.11 Calverton coal stockpile

that is, all of the points coded 151 were removed from the model. It now becomes clear as to why separate codes were used in the field to define the base points from the bulk points, as this facilitates excluding all of the bulk points so that the base can be modelled. This approach has proved to be the most efficient method for data collection and subsequent processing, and has been employed for all of the other volumetric surveys. The model formed from the base points is shown in Figure 5.11(f), and a volume was obtained from this network extrapolated to the same datum level, namely, 0 m. Comparison of Figures 5.11(d) and (f) shows that the boundary of each of the networks is identical, and so the volume of coal contained in the piles can be found by direct subtraction of the two volumes. The volume of coal was found to be 5062m^3 for this part of the site. It is interesting to note that the volume for the site increases to 5505m^3 if the breaklines are not included, introducing an error of 7%.

Complete data processing, including data transfer, editing, traverse computations, plotting of contoured plans and determination of the volume, required approximately 1.5 hours and was completed on the evening of the survey itself. The following day the results were taken to the colliery surveyor, who accepted the results which were then submitted to the area office. Having witnessed the survey the colliery surveyor felt that the results obtained using the automated technique were of a higher accuracy than those which would have been practically achieved using conventional tacheometric techniques. The primary reason for this is the increased field efficiency obtained with the equipment, with an estimated doubling of the number of detail points taken in the same time. It was estimated that there was at least one weeks work for the surveyor to determine the volume manually, illustrating the large time saving in the office enabled by automatic processing and plotting.

Overall the automated technique proved highly efficient, both in the field and for data processing. When the tonnage of coal was calculated by applying the density factor to the volume obtained, the agreement was found to be within 2% of the "book" value held at area. The convoluted nature of the site makes this value particularly impressive, and compares very favourably with the accepted error for such jobs of ±5%.

5.6 British Gypsum stockpile

The accuracy of the volume obtained is dependent upon the correct formation of a representative base network. If information is not available concerning the surface contours before material was dumped then a planar surface must be assumed between the surveyed base points. If the surface is not uniform then significant errors can accrue in the volumetric determination. If information is available about the original ground surface then it is important that this can be included within the base model. This principle has been proved by carrying out a stock pile survey for British Gypsum at their Marblaegis mine.

British Gypsum had dumped a substantial ore stock pile on a surface which had a valley running through it. We were approached to prove that it was possible to still use an automated technique to obtain an accurate volume in such circumstances. They provided a surface plan which showed the ground level beneath the pile, and indicated the position of the valley.

Because the data to be surveyed had to be correlated to the surface plan, two stations of known co-ordinates were used to initiate the job. The task was completed using four traverse stations, with approximately 150 detail points being surveyed. As before, the base points and the bulk points were delineated by different codes.

On return to the office the data was processed using the HASP system and a plot obtained of the surveyed detail points. The existing surface plan was then mounted on the digitiser and orientated to the plan co-ordinates. Four points on the valley were then edited into the data with their associated heights. The coding of these four points was different to the other two codes used, and the points are represented in Figure 5.12 as solid squares. The surface model was then formed through all of the surveyed points, excluding the extra base points which had just been added. The volume was found by extrapolation down to a datum level. The model was then reformed excluding the bulk points but including the four new points and the surveyed base points. The volume was found to the same datum level, thereby allowing the included volume to be calculated. If the valley on the base had not been taken into account then the volume calculated would have been too small by 550m , introducing an error of ±6%.

The importance of accurately forming the base model has been shown. The ease with which existing data could be introduced into the system and then incorporated into the modelling impressed the mine surveyors. The data processing and the inclusion of the extra points took less than 1 hour. For sites which are to be used for

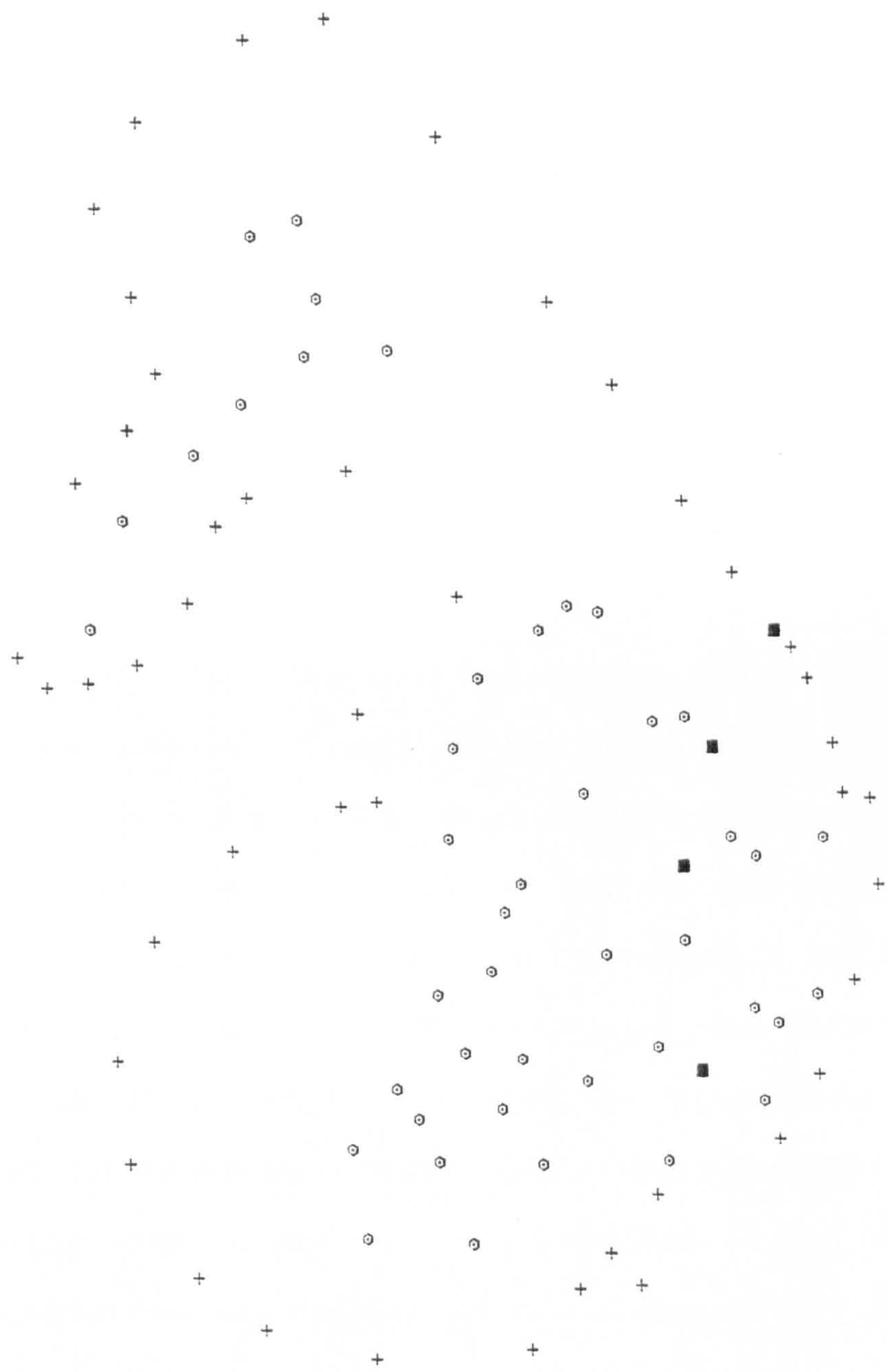


Figure 5.12 Data points for gypsum survey

dumping in the future the optimum results would be obtained if the ground surface were surveyed using an electronic total station, thereby allowing the formation of an accurate digital base from which to work.

5.7 Allerton Bywater lagoon

North Yorkshire Area of the NCB were constructing a large slurry lagoon at Allerton Bywater, and the author was asked to conduct a volumetric survey to determine the amount of earth moved by the contractors for payment purposes. This task was of particular interest because of the angular nature of the surfaces with benches and inclined haulage roads, therefore requiring the extensive utilisation of breaklines whilst in the field. The nature of the survey would have rendered any other modelling technique useless, especially as a high degree of accuracy was required.

To avoid the possibility of gross errors it was decided to use a closed traverse starting from an established survey station. Four other traverse stations were required from which all of the detail points were surveyed. One man operated the instrument whilst two others held detail poles. The nature of the site lead to most of the banks being surveyed as breaklines in the field, as is shown by Figure 5.13. The acceptability of the results when breaklines are included is reflected in the accurate representation of the contours for the site in Figure 5.14.

The contoured plan and the volume of earth moved calculated from the survey were sent to the North Yorkshire Area, and it is believed that the figure

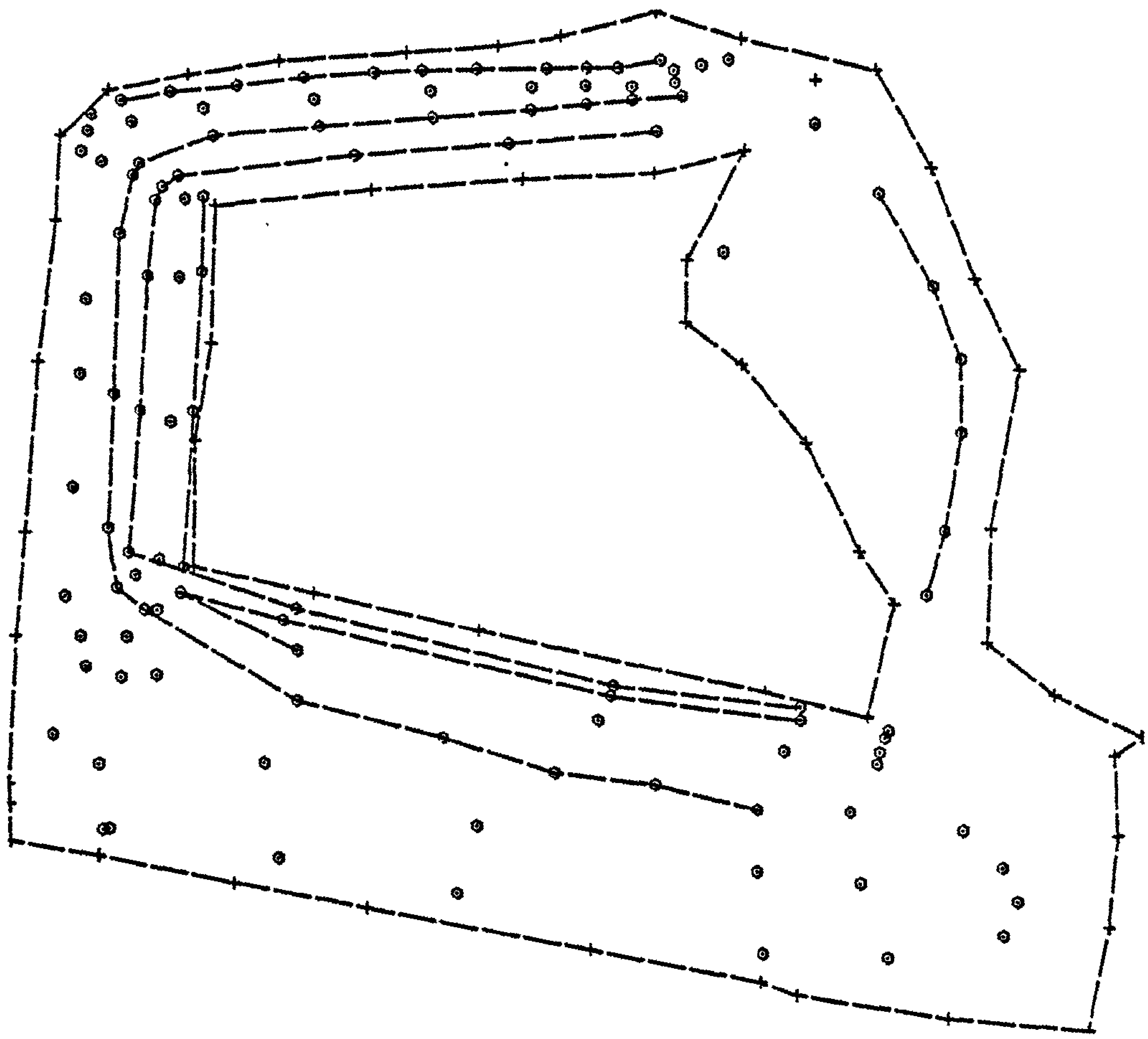


Figure 5.13 Data points and breaklines for Allerton Bywater lagoon

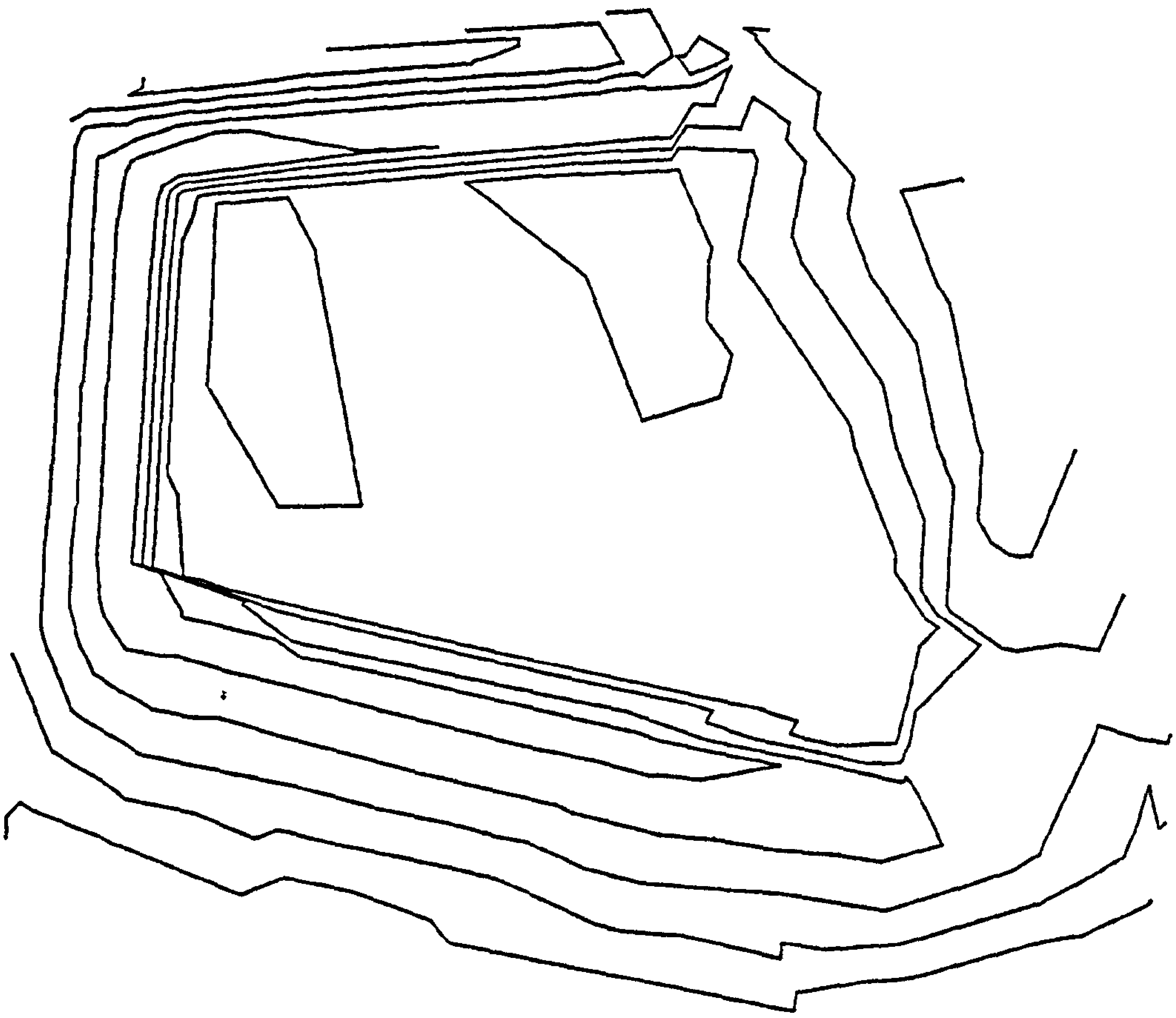


Figure 5.14 Contoured plan of Allerton Bywater lagoon

submitted was accepted for the payment of the contract. This job has shown that both the field technique and computer modelling technique are applicable to opencast mine surveying. The author has advised the same Area, after their purchase of a similar system, during a survey of a large local quarry being bought for a price dependent on the size of the extracted volume. This site was to be used for waste disposal purposes from nearby pits. The field technique was quickly mastered by the surveyors, with an overall increase in field efficiency by about a factor of 2.

5.8 Rufford coal stockpile

5.8.1 Updating survey information

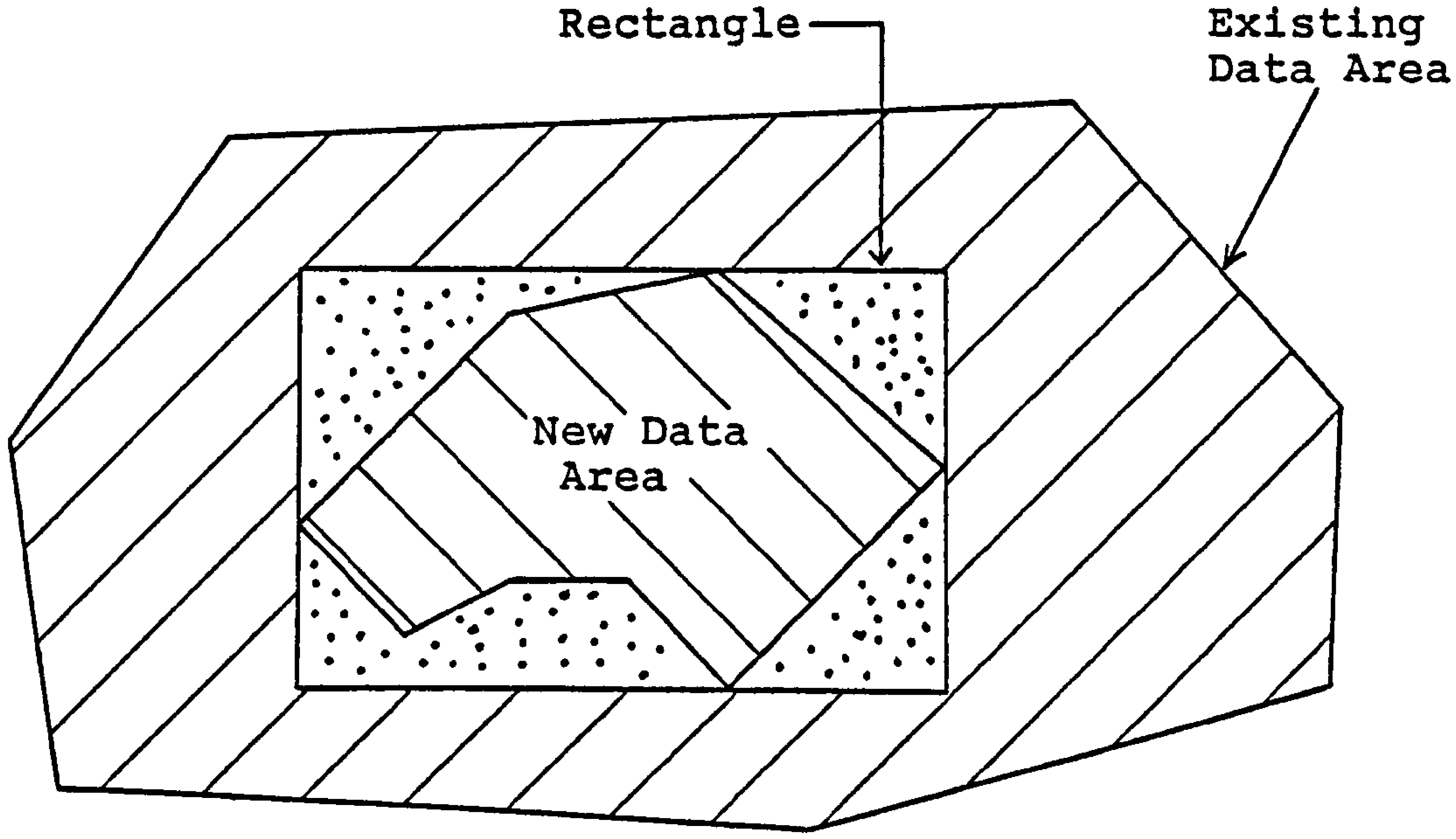
The majority of stockpile volumetric surveys can be considered as complete in themselves, and their size and intransigence often negates the requirement of establishing permanent survey stations in the vacinity of the site. However, larger volumetric surveys concerning open pit mines or large ore stocks or waste tips are often of a long term nature and many have permanent stations associated with them allowing the site to be resurveyed. This allows new survey data to be integrated into the existing information and allows only the areas of particular interest to be surveyed.

Most computer systems allow integration of new data into an existing database, although not all perform a true integration but in effect form two models. The main problem arises in determining which of the old data points are situated within the new data area and must therefore be removed. Manual techniques exist using interactive screen graphics or the digitiser, but these methods are slow and tedious, especially for large jobs. Apart from being inefficient this method can also introduce errors as the technique is not rigorous but relies on human judgement and care. It is therefore preferable to use an automatic routine to search for included data points. The method implemented on the HASP system for research purposes is automatic, and therefore rigorous. The main principle utilised is that of solid area scanning suggested by Newton and Sproull (1981). The objective of this is to determine whether or not a point lies within the boundary of a polygon, and the simple idea upon which it is based is discussed later.

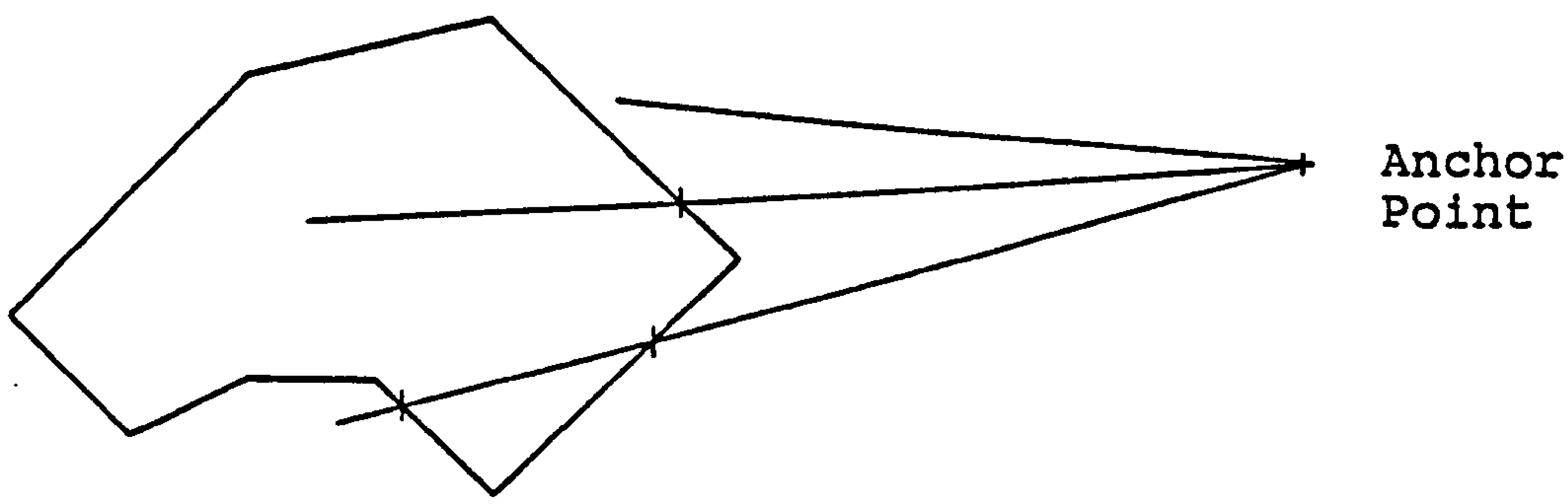
The overall process can be divided into three separate stages. Firstly, the perimeter of the new data area must be defined as a continuous polygon. This can be achieved by the use of the Radial Sweep algorithm described earlier. It is normal to assume concavity infilling for the boundary, but provision must be made for the user to force the boundary formation if a natural hollow exists within the new data set.

Once the boundary polygon has been defined for the new data, the old data stored within the corresponding area must be eliminated. This stage is split into two sections to make the data elimination efficient. Firstly, a rectangle is assumed surrounding the polygon defined by the maximum and minimum eastings and northings of the polygon, as illustrated in Figure 5.15(a). All of the data points which lie outside the rectangle are automatically retained and need not be checked again. The remaining points within the rectangle need to be tested to determine whether they lie inside or outside the boundary polygon, this being the point where the solid area scanning technique is used. An anchor point is selected well outside the co-ordinates of the rectangle, and each point within the rectangle is joined to it sequentially. The number of times that this line intersects the sides of the polygon is noted. As can be seen from Figure 5.15(b) if the number of intersections is odd then the point lies within the polygon and so is eliminated, otherwise the point lies outside the polygon and so is kept. This simple routine is particularly effective.

When all of the old data points within the polygon have been eliminated, the final stage is the introduction of the new data. The new data points are simply added to the now modified database, and the whole of the site remodelled. Only in this way can a true integration of the old and new points be obtained.



a) New data area polygon and associated rectangle of influence within the existing data area.



b) Criteria for determination of inclusion or exclusion of points within the area of the new data polygon.

Figure 5.15 Searching procedures to determine which existing data points must be excluded to allow merging of updated data.

5.8.2 Rufford coal stock surveys

The principle of being able to merge new data into an existing database has been proved by two surveys carried out at Rufford Colliery in North Nottinghamshire. The coal stock was particularly large, approximately 850 000 tons, as it is used as the stocking location for the Area. Because of its size and importance, a permanent survey pillar tied in to the National Grid has been established on the site. By commencing all of the surveys from this point and taking a reference azimuth to a lightning conductor spike on the top of one of the headframes, all surveys can be correlated. New survey information is therefore directly comparable to existing data.

The first survey took place in September 1983 using the Kern E1/DM502, and commenced from the fixed pillar. A total of 8 traverse stations were used in a closed loop to pick up approximately 400 detail points, using the same field technique as previously described. Figure 5.16 shows the traverse points (triangles), detail points and breaklines picked up in the field. The total time taken for the survey was six hours.

The optimised triangular network was formed from the surveyed data, and the resultant interpolated contours are illustrated in Figure 5.17. As can be seen the site consisted of a horse-shoe shaped pile built

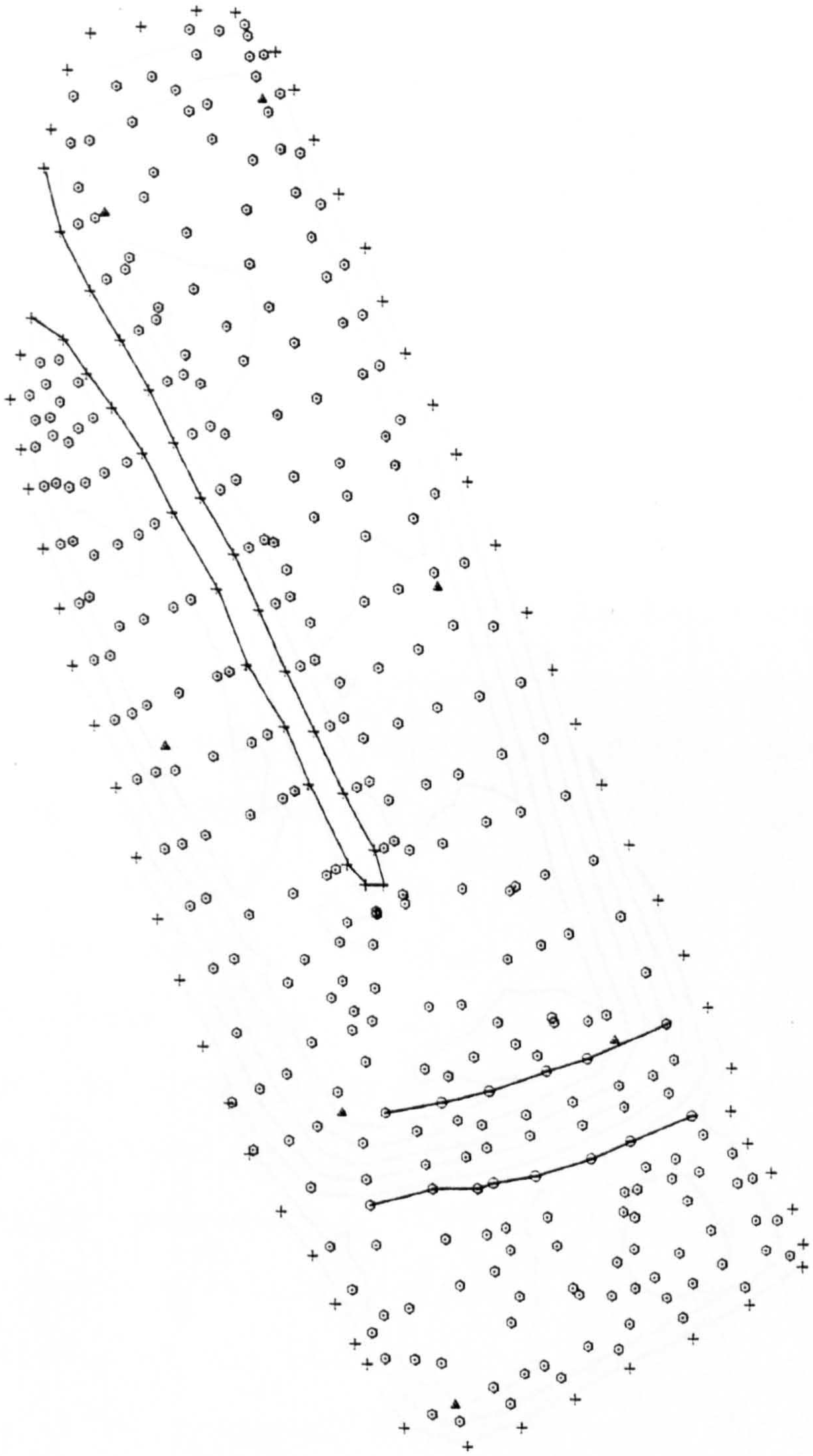


Figure 5.16 Rufford stockpile - original data points

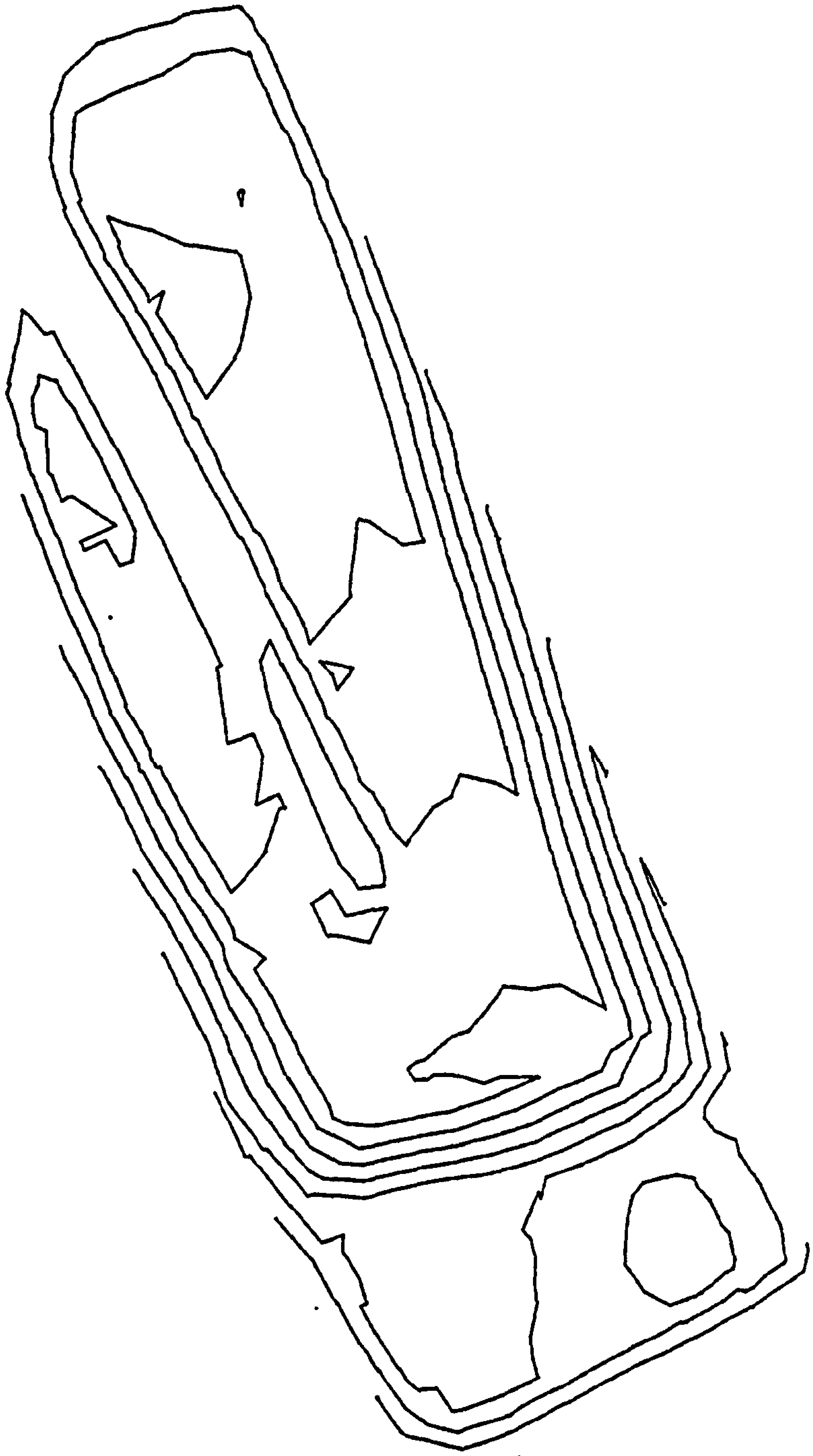


Figure 5.17 Rufford stockpile - original contours

around a locomotive siding. Relatively few detail points were required considering the size of the site because of the uniform nature of its surface. The volume was found in the usual manner after reforming the model including only the base points. The total data processing time was two hours, including plotting the contoured plan, and the following day the results were taken back to the pit.

A direct comparison between automated and conventional techniques was possible for this job as the mine surveyor had undertaken exactly the same task the previous week. Conventional techniques had required two full days in the field, the first setting out the control stations using theodolite and EDM, the second spent surveying the detail points with a tacheometer from the control stations. Field efficiency was therefore increased by at least 50%. More importantly though, the data manipulation, plotting and calculation of the volume from sections took one man over three weeks. The volume that was calculated agreed to that automatically produced to within 0.5%, proving the accuracy of the modelling technique when used properly. The efficiency of the automated technique really speaks for itself. The ratio of man hours spent in the field between conventional and automated techniques is 42 to 18 (approximately 2.3:1), whilst for processing the ratio is in the order of 120 to 2 (60:1).

The opportunity to utilize the data merging facility within the software was afforded in February 1984 when the site was revisited. A substantial amount of coal had been removed from around the railway cutting, especially from the western limb, whereas the remainder of the site had not been altered. On arriving at Rufford the first priority was to establish the extent to which changes had been made. Once this area had been established, it was decided that all of the required detail points could be collected from two instrument positions, including the permanent pillar from which the survey was to start. The field work took only two hours, the points surveyed being shown in Figure 5.18. The breaklines were introduced into the data when back at the office. It should be noted that the same codes were used for the base and bulk points as for the first job.

On returning to the Department the new data was processed and then merged into the existing data using the method previously described. No problems were encountered during the processing, the resultant integrated data being shown in Figure 5.19. The new interpolated contours are shown in Figure 5.20, and comparison with Figure 5.17 illustrates the area from which coal had been removed. The new volume was calculated, thereby allowing the volume of coal removed in the five month period to be found. This value, when multiplied by the accepted density factor, was found to be in agreement with the "book" value calculated at the out-going weighbridge to within 1.5%.

The two surveys at Rufford have afforded the most tenable idea of the accuracy obtainable using an automated survey system, and emphasised the increase in overall efficiency which such systems offer.

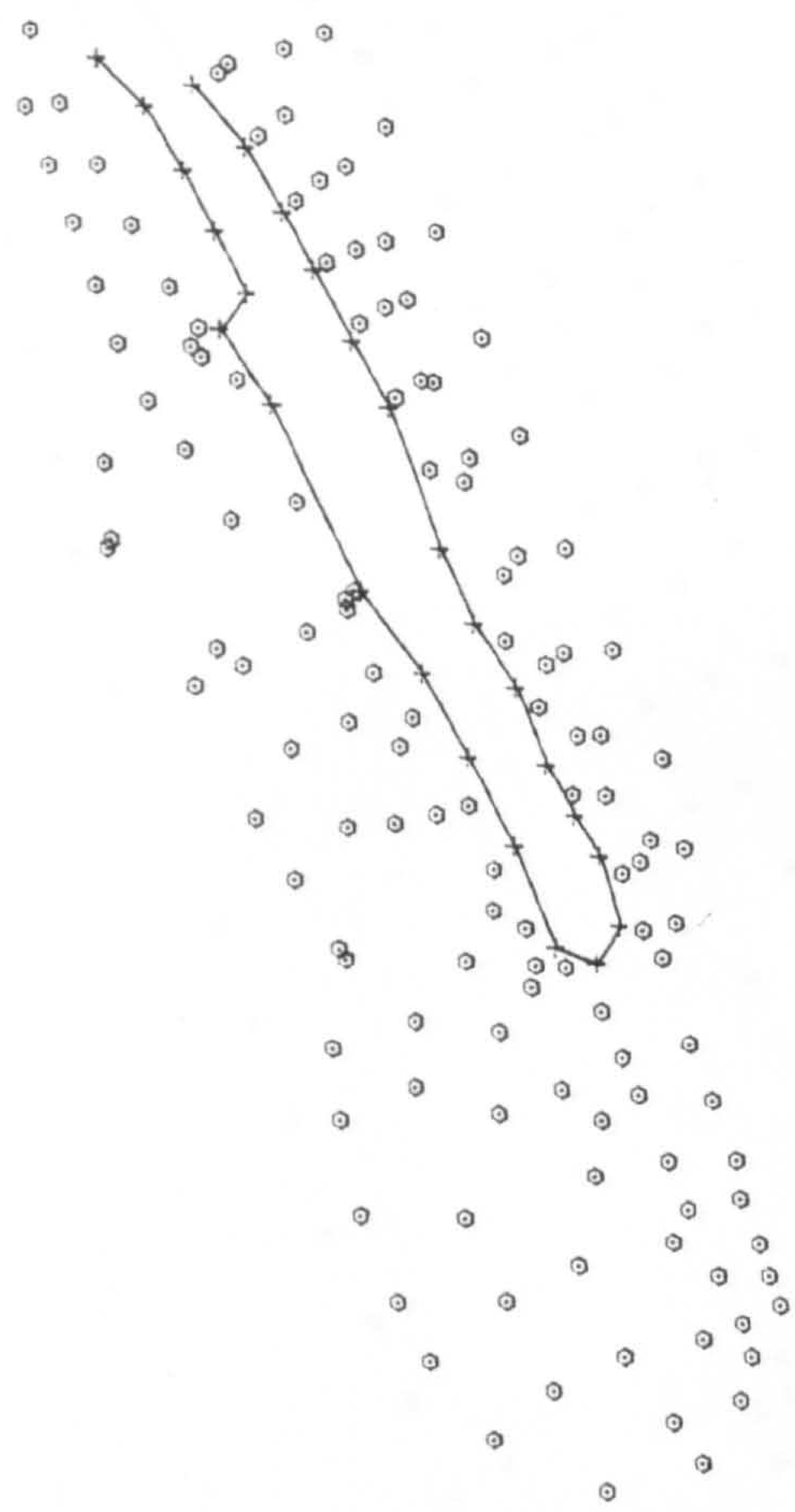


Figure 5.18 Rufford stockpile - updated points

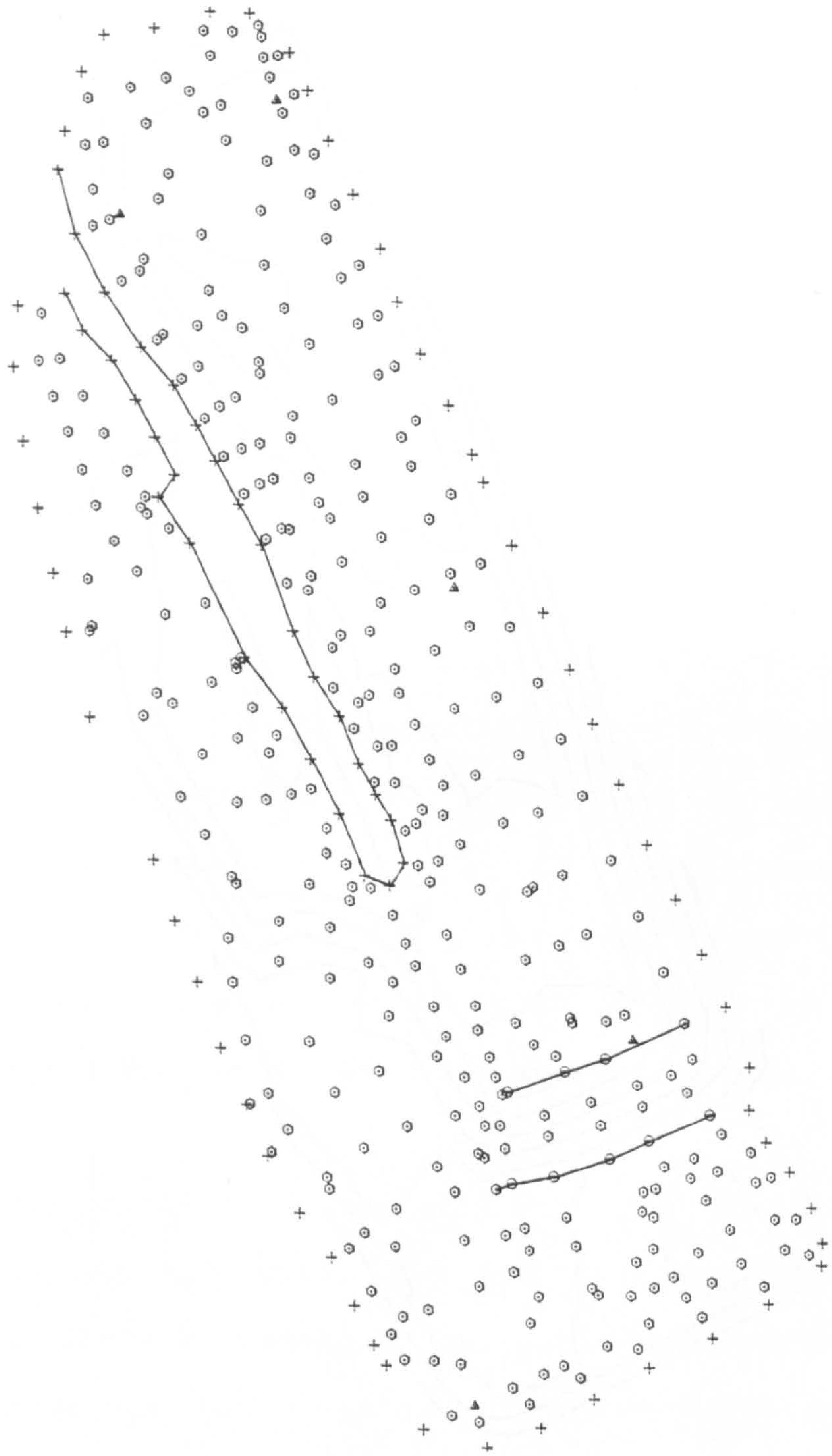


Figure 5.19 Rufford stockpile - merged data points

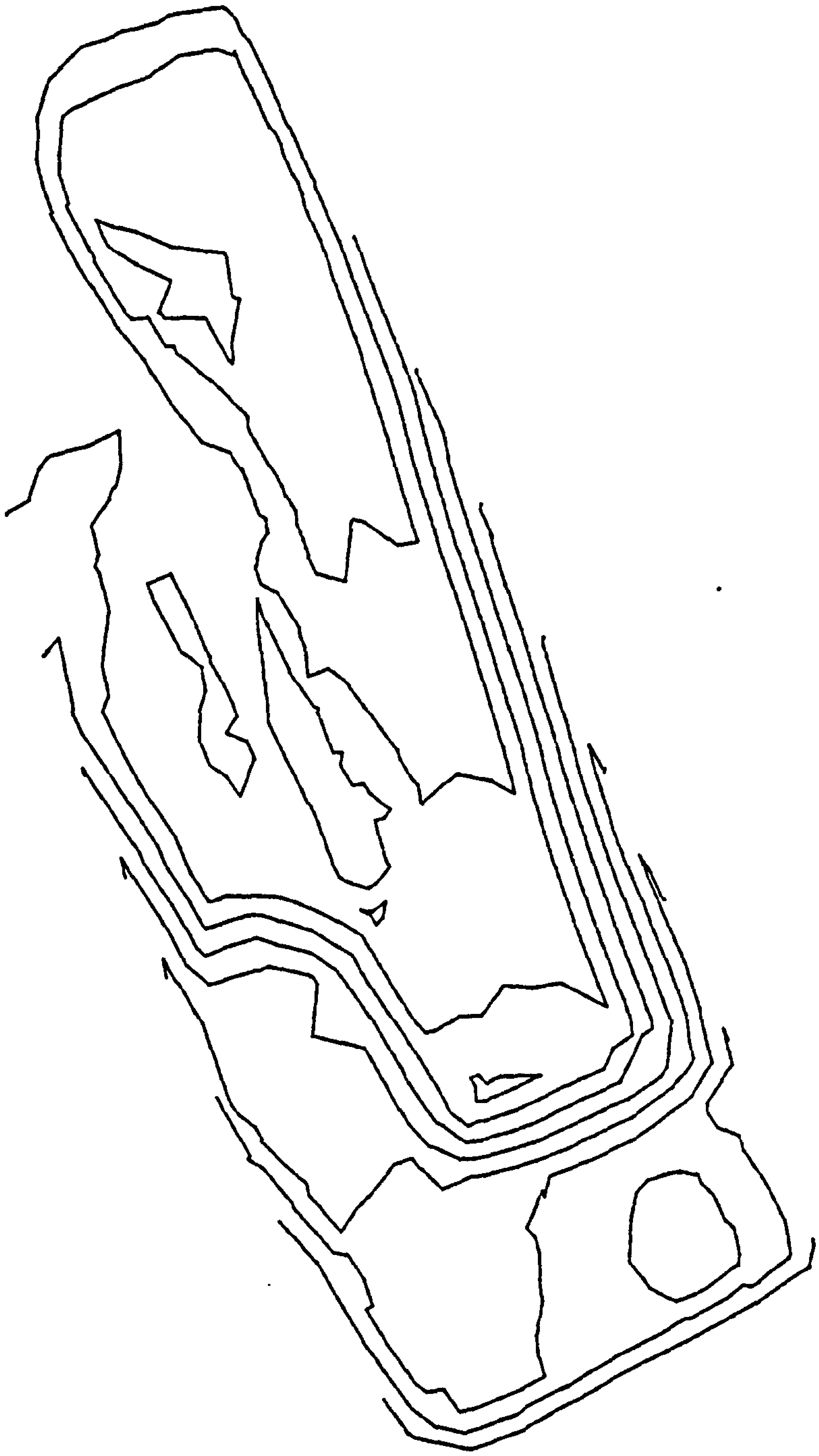


Figure 5.20 Rufford stockpile - updated contours

5.9 Sutton dirt tip

Following the encouraging results obtained from the volumetric surveys described previously, it was decided to investigate the applicability of the automated system to the complete ground survey of a dirt tip. A site was chosen in collaboration with NCB surveyors at Sutton Colliery in North Nottinghamshire in July 1984.

The magnitude of this survey was obviously much greater than any previously attempted. The dirt tip covered approximately 420000m , approximately half of which had been reclaimed as arable farmland. The site was complicated by the inclusion of a slurry lagoon at the western extremity, adjacent to which two new lagoons were being constructed. The objectives of the survey differed from previous jobs in that apart from determining the volume a fully detailed ground plan was also required, showing the position of features such as the haulage roads, conveyors and water courses.

Survey stations correlated to the National Grid existed within the area, and two of these in the pit yard were used to commence the job. From these points the traverse was continued onto the dirt tip itself. The survey was carried out by three people, one person on the instrument and two with the detail poles. Overall the survey took four days to complete with 16 traverse stations being required. A total of 800 detail points were surveyed. The positions of the last traverse stations occupied each day were marked by wooden stakes driven into the ground onto which a cross was etched, thereby enabling the survey to recommence from the same position the next day.

Great care was required during the survey because of the complexity of the field coding required to pick up the different data features, and also to ensure that the entire area was satisfactorily covered. Each evening the data collected during the day was processed and edited whilst the terrain was still fresh in the mind. The new data from each day was appended onto the existing information each evening, providing a continual check that the site was being covered completely. It is felt that this is the only practical method of coping with such a large job. It would be virtually impossible to attempt the data editing once the entire job had been completed.

The volume of the dirt tip was submitted to the colliery, together with the final enhanced contoured plan.

Although the survey took four full working days, it should be borne in mind that a large proportion of the site will not change from year to year. It was estimated by the mine surveyor that the area which had been altered between 1983 and 1984 could have been surveyed using the total station within 1 day. Having established the digital model in full only the areas of change need to be surveyed in subsequent years, and then the merge routine could be used to generate the updated plan and volume. This would cut the ground survey requirement in the following years dramatically. Bearing this in mind, it has now become practically feasible to survey such large structures from the ground, rather than being forced to use photogrammetry.

CHAPTER SIX

SUBSIDENCE AND DEFORMATION MEASUREMENT APPLICATIONS OF AUTOMATED SURVEY SYSTEMS

Subsidence and deformation measurement applications of automated survey systems

6.1 Introduction

Since the problem of subsidence first received attention towards the end of the 19th century, mine surveyors and mining engineers have attempted various methods of measuring the effects of sub-terrainian extraction on the ground surface, the main aim being to predict the amount of sudsidence likely in any situation. The majority of the effort expended in this field in Britain has been in connection with the extraction of coal at depths ranging from 100-900 m. Over the years empirical methods for subsidence prediction have been developed based on mathematical best fits from the large amount of data collected. The culmination of this work, and the profile functions developed by Orchard (1954, 1956), resulted in the introduction of the Subsidence Engineers Handbook. Subsidence curves were calculated from the results of hundreds of surveys, but little account was taken of the actual local conditions. These curves are produced for a variety of mining situations, the idea being that the subsidence to be expected from a particular face will mimic that of a similar face. Computer programs have been developed to replace the necessity for checking through the large number of curves, but these are still based on the original empirical methods.

It is reported in the NCB "Memorandum on Mining Sudsidece Research" that to date there has been very little systematic subsidence research. The amount of work has already been undertaken, both in this country and on the Continent, is indicating that a closer relationship may exist between the effects of subsidence in widely separated coalfields than has to date been thought possible, and that effects in individual parts of different coalfields may have much in common.

The traditional methods of measuring surface subsidence and displacements are by the use of precise levels and precise ground or catenary taping. Unfortunately this technique cannot measure lateral movements and so can only produce longitudinal or transverse profiles across the area of influence. The introduction of EDM which can be mounted onto theodolites has updated the field survey method, and their application to subsidence measurement is being studied (Bullock 1984). The logical progression is to investigate the applicability of electronic total stations to the measurement of surface deformation. From one sighting all of the information to obtain the three dimensional co-ordinates of the object point are measured.

Subsidence observations serve two main purposes.

Firstly, they extend the subsidence engineer's knowledge of the ground movement associated with mineral extraction from underground, and secondly, they are used to monitor the degree of surface movement to aid the assessment of compensation claims from property owners. It is estimated that in 1985 £250m will be paid by the NCB to settle subsidence damage claims (Taylor 1985). It is therefore essential that accurate research data is collected enabling the subsidence engineer to predict more accurately the likely amount of subsidence, and to better evaluate mining methods which reduce the effect. Only in this way can the amount paid in subsidence claims be practically brought under control without sterilizing huge areas of coal.

Following the successful utilisation of automated survey to surface and underground surveys in general, it was decided that the feasibility of using such equipment for subsidence monitoring should be investigated. The nature of the task dictates that long-term periods of measurement are required, and so the aims of the author have been to instigate the investigations into the accurate monitoring of surface deformation in three dimensions by automated survey techniques. The author has been primarily responsible for discussions with the relevent NCB staff, choosing suitable subsidence lines, and performing the first few sets of observations. The work to date is detailed in following sections. The results of more comprehensive investigations planned to be conducted over the next two to three years will be reported in future theses.

6.2 Aims of the research

The aims of the research project can be divided into the short-term and long-term objectives.

The short-term aims are as follows:

a) To establish sites for monitoring subsidence deformation.

b) To investigate optimum methods of field observations to obtain the most accurate results.

c) To check the consistency of these methods, this being the best way of determining the accuracy obtainable.

d) Investigate the frequency with which lines should be remeasured.

The long-term aims at present are:

a) To monitor the full deformation cycle at the sites chosen.

b) To write additional software around the database so that the results can be automatically calculated and comparisons computed.

c) To include in the software graphical representation of point movement in three dimensions with respect to time, and related to the position of the face.

d) Automatically produce transverse and longitudinal profiles if required.

e) Investigate the applications of ground modelling techniques to the area of influence.

f) Examine the possibility of instigating a national database facility to allow direct comparison of results from the entire country.

With the full co-operation of senior NCB subsidence engineers 12 possible subsidence lines were visited in the South Midlands, South Nottinghamshire and North Nottinghamshire areas. To date two sites have been chosen, both in North Nottinghamshire, which offered the broadest scope for research measurements. The first of these represents a typical urban environment survey at Ollerton, with the stations set in a Tarmacadam road. This was considered typical of the majority of subsidence surveys where the available lines are dictated by the positions of the existing road network. The second site is a disused airfield near Gamston. Two faces are to start in the summer of 1985 under the airfield, and this site provides an excellent opportunity for investigations into field techniques on lines which can be chosen at will over the area. The results from this site should be particularly interesting, and full use of this opportunity must be taken.

Work has also been carried out in conjunction with surveyors at Calverton Colliery in South Nottinghamshire to measure the subsidence effects as their dirt tip is undermined. The work carried out on these three sites is described later in this chapter.

6.3 Subsidence lines and survey stations

6.3.1 Subsidence lines

Previous experience within the NCB has shown that the following features are desirable in the selection of subsidence lines:

a) The line must extend outside the area of influence into stable ground from which measurements can begin on at least one end of the line.

b) most information is obtained from a line which is at right angles to the line of advance.

c) a further line parallel to the first is desirable as this will allow investigation into the uniformity of movement obtained.

d) a third line, at least as long as the width of the panel, should run along the centre line of the face.

e) a line sited diagonally over the zone of influence gives inconclusive results in the absence of a control line of the type mentioned above.

f) the observation stations should be placed at regular intervals so that the movements are directly comparable.

g) short intervals between stations, say less than 30m, should be avoided as there is too little difference in movement from one station to the next.

h) the stations must be tied in to the National Grid allowing correlation to the position of the face at any time.

It is recognised of course that the physical conditions on the surface will not allow the ideal lines to be found in the majority of cases. It is very important however that the points listed above are borne in mind when the lines are being chosen, and applied whenever possible. The usefulness of the results is directly proportional to the closeness with which the above criteria are adhered to.

6.3.2 Subsidence stations

It is vitally important that the observation stations are affected directly by all of the normally distributed strains over the subsidence zone. The stations must therefore be of such a design and so established that this is ensured. There are two main type of condition in which measurements are made, namely on Tarmacadam or concrete roads or paths, or, on natural ground. The type of station required for each will be discussed briefly.

6.3.2.1 Stations in roads or paths

In general Tarmacadam type roads laid on a hardcore foundation are considered elastic, and therefore faithfully reveal any surface movements. Good results have been achieved by simply using 9 inch steel bolts, sharpened at one end, which are driven into the surface until the head is flush with the road. The position for measuring purposes is defined by a cross etched into the head, or by a small diameter drilled hole.

Special difficulties arise when the road or its foundation are made of concrete. This is not elastic in its nature and so there is a tendancy for the movements detected to be caused by local strains at joints or weak points. Where concrete exists it is necessary to ensure that the station passes through the foundations and into the subsoil. The station should preferably be about 1m in length. The station should not be in direct contact with the concrete road or foundation, and so the following type of design is suggested. A cavity approximately 40cm in diameter should be excavated through the surface and foundation to the subsoil is reached. An auger is then used to drill a hole about 1m deep into which the station pipe is inserted and then grouted. It is important that the grout is only used to the top of the subsoil, leaving the top of the pipe free within the cavity in the concrete. This cavity and top of the pipe are covered and protected by a cast iron inspection box with a screw lid. The station position can be denoted by a cross or by a drilled hole. This type of station is obviously more expensive than a simple bolt, but for the results to be representative such investment in the "basics" is required.

6.3.3.2 Stations in natural ground

In natural ground a pipe or rod of about 1 m in length should be driven into the ground and cemented or otherwise firmly anchored. These stations can be very expensive and highly specialised in their design. For the majority of situations it is sufficient to simply cement a 3cm diameter pipe about 1m long into an augered hole. The position of the station for measurement purposes can be defined in the usual manner.

The least expensive and most easily inserted station would be a 1 m long 2 cm diameter steel rod, sharpened at one end. This rod would have an anchor plate welded to it at its top. This should be a trianguler plate of mild steel with 25 cm sides, the corners of which are turned down to make 5cm spikes. This plate prevents any lateral "play" or accidental vertical displacement. It is important that the rod is secured at the subsoil level, not in the surface vegetation soil.

The security of these stations must be ensured, and so they should be covered after use by the original soil and turf. Reference readings should be taken so that the stations can be located quickly.

6.4 Monitoring subsidence at Calverton

By chance, at the same time as preliminary discussions were being held with the NCB subsidence engineers, the author was informed by the mine surveyor at Calverton Colliery that they were about to monitor a subsidence line across the dirt tip as this was to be undermined, and invited to participate in the work. South Nottinghamshire have purchased an AGA 140 electronic total station and this was to be used for the job. It was suggested that a comparison could be made between the AGA and Kern instruments. Participation in this survey also allowed the author to gain valuable experience in subsidence measurements before the "research" surveys commenced.

A plan of the site showing the station positions and the line of advance of the face is shown in Figure 6.1. The face is situated in the High Hazels seam and is 460 m deep. Approximately 1.2 m of coal is being extracted. As can be seen the subsidence line was inserted in the ideal position, crossing the line of advance at right angles. The main objective of the survey was to determine the order of magnitude of subsidence created by the face so that, if necessary, reinforcement work can be carried out on the slurry lagoon to ensure its stability as it is undermined. The accuracy required was only to the order of a few centimetres, and so fairly crude stations were used.

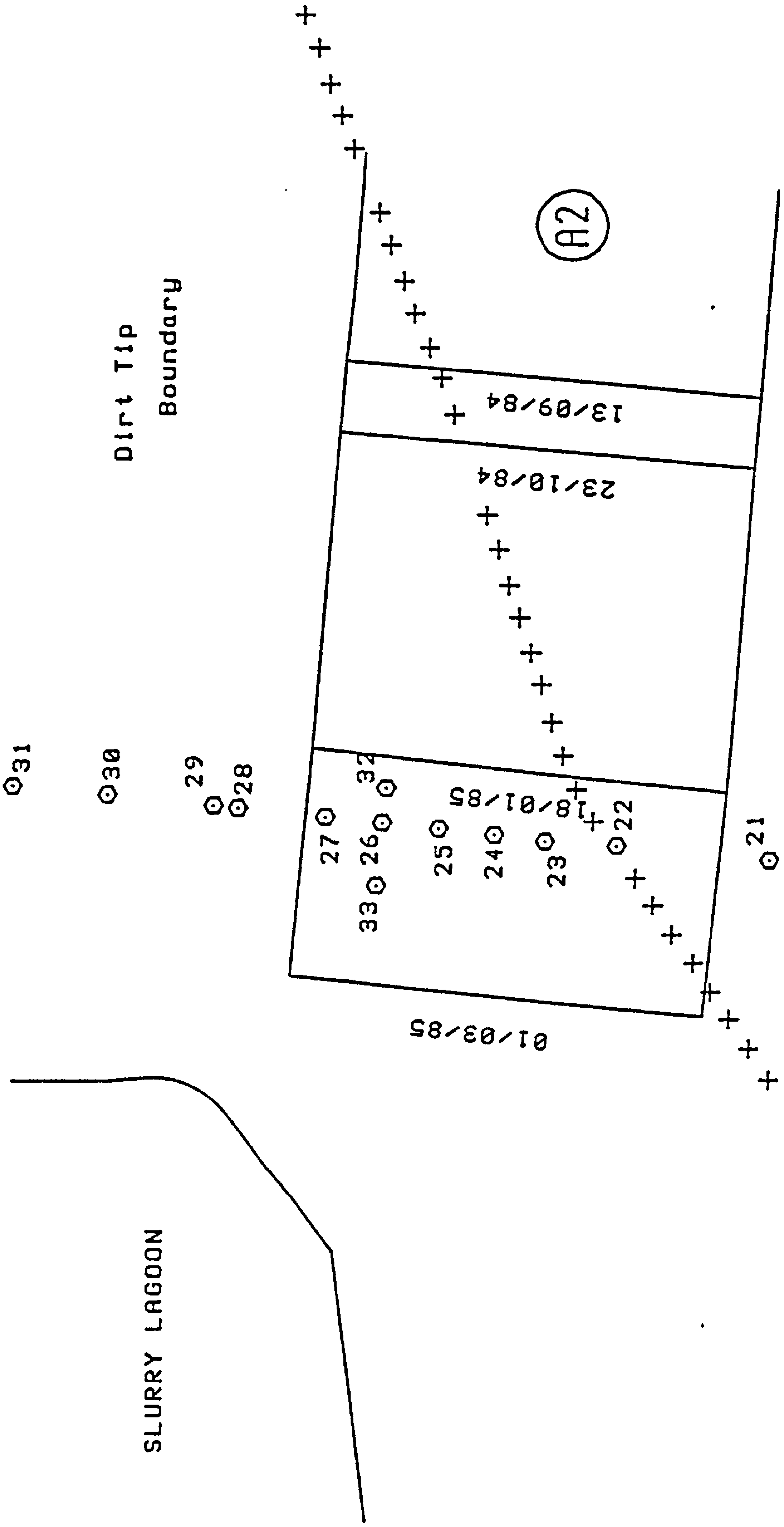


Figure 6.1 Calverton subsidence line

These consisted of 15 mm diameter iron rods about 1m in length which were driven into the dirt tip. The exact station position for measurement purposes was denoted by a cross etched onto the top of the rod. The stations themselves were accurately surveyed so as to be on the correct bearing and in a straight line. Two other stations were also inserted along the line of advance.

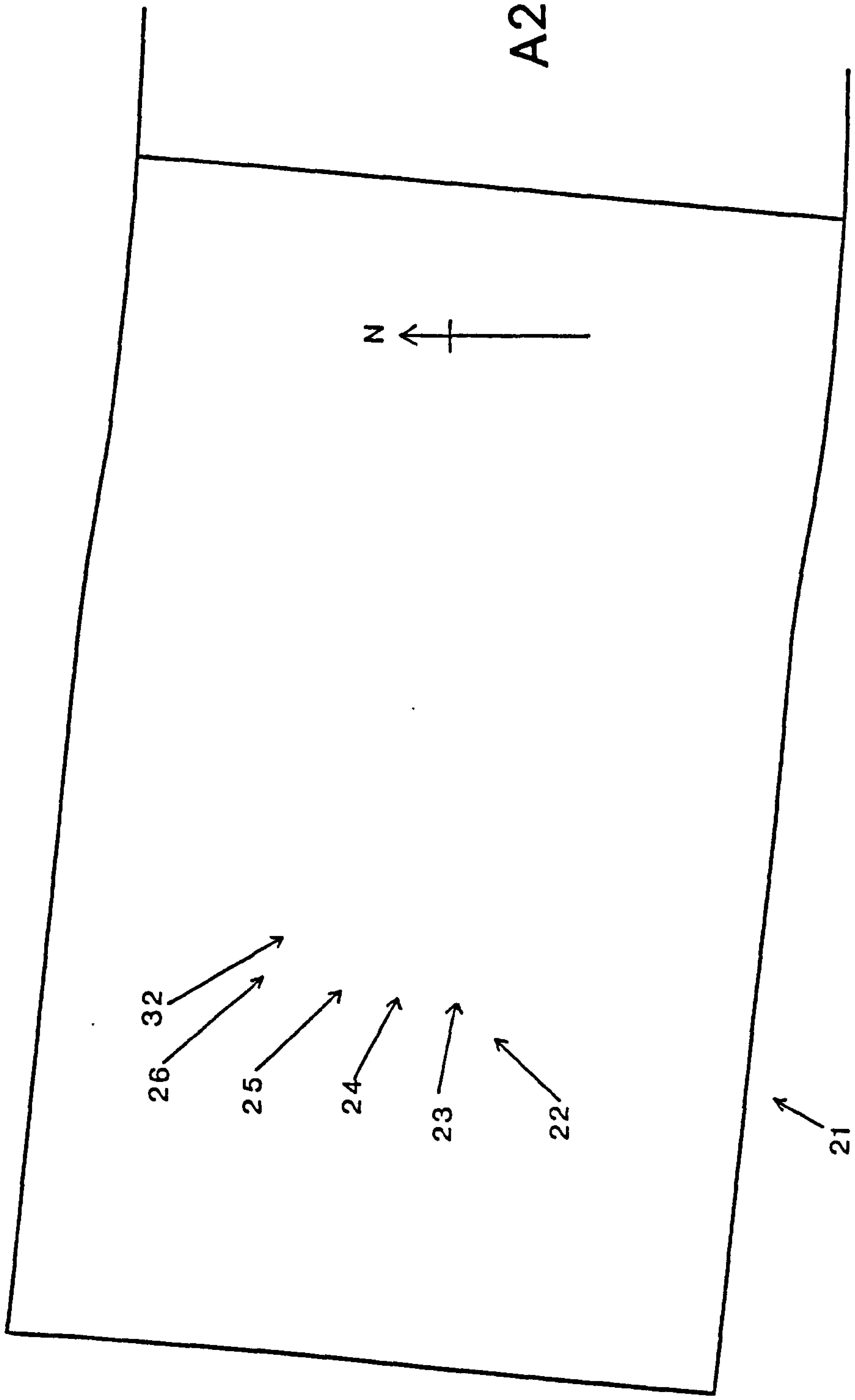
A known station outside the zone of influence in the pit yard was chosen from which to start the survey. The reference azimuth was taken to another established station, and then the foresight measurements were taken to station 26 on the dirt tip. It was decided that all of the other points would be surveyed from station 26, and so great care had to be taken when measuring to this station. The positions of the other stations could not be picked up as detail points as a detail point is defined by only one measurement, therefore not allowing angle and distance averaging from a series of pointings. This problem was overcome by using a Code 52, which represents a foresight from a main traverse station to a side traverse station. In this way two face right and two face left measurements could be taken to the point.

Because problems had previously been encountered with the accuracy of horizontal angle observations to prisms over short distances, it was decided that the horizontal angle would be measured to a pin held on the station. Having sighted to the pin, the horizontal circle was not altered as the prism was set up, and the prism was then sighted by tracking vertically upwards using the slow motion screw.

The results from the four surveys undertaken with the E2/DM503 are shown in Table 6.1. Unfortunately six of the stations have been lost during the course of the measurements because of the movement of heavy plant across the tip, but the results from the remaining stations are encouraging. The movement to date is illustrated in Figure 6.2 with lateral displacement shown as a vector to a scale of 1:10. The maximum vertical displacement is 37 cm at station 22. The results so far suggest that the axis of the subsidence is not along the centre line of the face but displaced slightly to the south. The site will continue to be monitored both by the author and by the colliery surveyor.

Station		13/09/84	23/10/84	18/01/85	01/03/85
26	E	460711.970	0.009	0.010	0.110
	N	350846.789	0.002	-0.018	-0.139
	L	99.428	-0.029	-0.011	-0.052
21	E	460691.510	0.012	0.000	0.039
	N	350624.932	0.001	0.066	0.071
	L	70.913	-0.038	-0.180	-0.224
22	E	460699.669	0.010	0.022	0.093
	N	350713.396	0.002	0.058	0.102
	L	75.969	-0.037	-0.118	-0.367
23	E	460703.376	0.001	0.038	0.121
	N	350753.627	0.003	0.036	-0.020
	L	82.053	-0.041	-0.137	-0.300
24	E	460706.114	0.014	0.026	0.115
	N	350783.357	0.000	0.031	-0.067
	L	87.905	-0.042	-0.111	-0.263
25	E	460709.056	0.003	0.017	0.108
	N	350815.128	-0.001	-0.006	-0.121
	L	93.641	-0.044	-0.101	-0.210
27	E	460714.977	0.005		
	N	350879.394	0.003		
	L	99.933	-0.038		
28	E	460719.559	0.009		
	N	350929.127	-0.001		
	L	98.825	-0.040		
29	E	460720.842	0.008		
	N	350943.046	0.000		
	L	103.308	-0.035		
30	E	460726.533	0.011		
	N	351004.811	-0.001		
	L	105.605	-0.035		
31	E	460731.606	0.011		
	N	351059.958	0.000		
	L	109.601	-0.038		
32	E	460731.923	0.013	0.020	0.091
	N	350844.949	-0.001	-0.026	-0.157
	L	97.232	-0.034	-0.111	-0.182
33	E	460675.610	0.006		
	N	350850.143	0.000		
	L	98.705	-0.045		

Table 6.1 Calverton subsidence results.



Displacement scale = 1:10

Figure 6.2 Lateral subsidence deformation of Calverton dirt tip

6.5 Monitoring subsidence at Ollerton

After close liaison with senior subsidence engineers a subsidence line at Ollerton, North Nottinghamshire, was selected for monitoring by automated survey. The site was chosen as it is typical of the majority of urban subsidence surveys. After reconnaissance of the site two stations were selected outside the probable area of influence to act as the control points for the survey. A total of 8 traverse stations have been established to cover the line, with a further 18 detail point stations. All of the stations have been established in a Tarmacadam road, allowing 9 inch bolts with rounded heads to be used. The exact position of the station is denoted by a small punch mark.

Three double faced rounds of angles and distances were used for establishing the primary traverse. The detail points were picked up using two double faced rounds of observations. Two surveys have been completed to date using an open traverse, and unfortunately the agreement between the two sets of results is not to the accuracy required. The agreement between the levels is excellent, but the northings and eastings differ on average by a factor of 2 to 3 cm. For the results to be meaningful was hoped that the results would agree to better than 5 mm. The problem has been caused by the inaccuracy of measuring horizontal angles to the prisms.

Investigations must now begin into methods of obtaining the order of accuracy required. The first priority is to obtain an attachment for the prisms which will act as a theodolite target for the horizontal angles. At present these are not available in this country, but delivery is expected shortly.

It seems unlikely that the new target will totally resolve the problem, and so it may then be necessary to consider network analysis of the results wherever possible. The author would suggest that in future any traverse of this nature must be closed, either back to the original point or to another control point outside the area of influence. The effort required to obtain acceptable results must not be underestimated. Particular care must be taken that the instrument and targets are accurately centered, and that all of the equipment is properly adjusted.

6.6 Gamston aerodrome

The second site chosen in North Nottinghamshire is ideal for research measurements of subsidence deformation as two faces are to start production in the summer of 1985 under a disused airfield at Gamston. Figure 6.3 shows a plan of the site with the faces, concrete runways and probable subsidence lines. The faces are all in the Top Hard seam and have an average depth of 700 m. The extraction width is to be 1.9 m, and so vertical deformation of up to 1.75 m is expected.

The majority of the work will concentrate around A10's face. A series of control stations are to be established to the north of the site outside the area of influence of the face and in ground which has never been affected by any mining activity. These will be correlated to the National Grid. Subsidence lines will be established along the existing runways, two of which are parallel and run across the line of advance. A third runway follows the north rib-side of the face. In addition to these three lines, further lines at right angles to the line of advance are to be established in the grass. The main advantage of this site is that subsidence stations can be established wherever desired. A further interesting possibility will be monitoring the effect that A10's has on the adjacent A12 face when production starts in about four years time. It is hoped that measurements will be made at this site for many

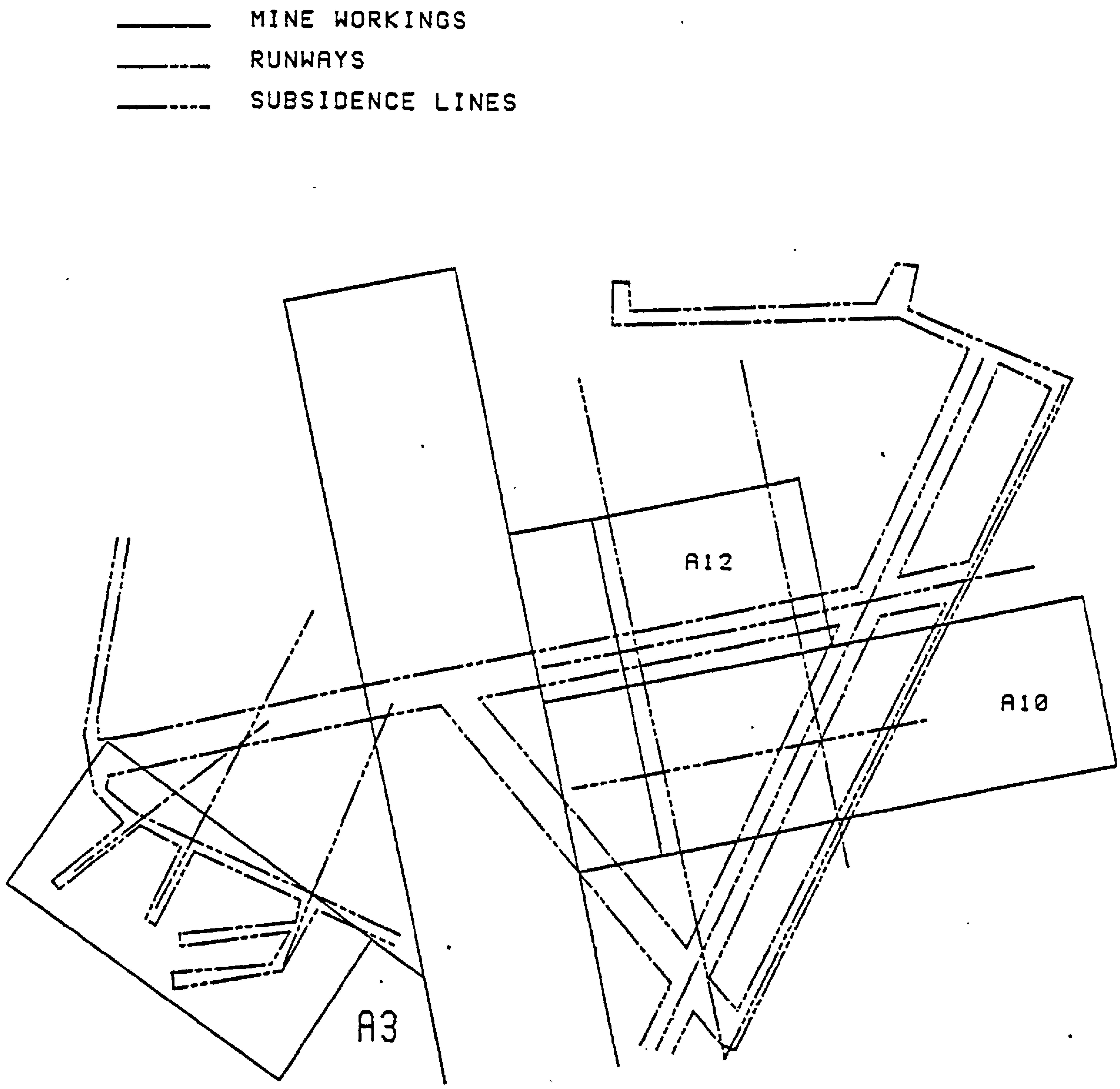


Figure 6.3 Gamston aerodrome

years.

Investigations will also take place on the subsidence caused by A3's, although this site is complicated by large aircraft hangers. It will however be possible to compare the results between the two different faces working within the same seam.

Apart from allowing subsidence lines to be placed at will, the nature of this site will also allow investigations into different measuremnent techniques and the applicability of various types of station. The results from Gamston should prove invaluable from both a practical and a research point of view.

6.7 Summary

The amount of information collected to date is obviously inconclusive, because the subject's nature requires that before useful results are obtained many months of observations are needed. Investigations must continue on the existing sites to develop optimum measurement techniques which will yield results of the correct accuracy. The problems encountered in horizontal measurement control must be overcome.

Interest within the NCB has already been stimulated, primarily because of the magnitude of the problems encountered with subsidence claims. It is important that the work is expanded so that data is collected from every area, under the control of a specialised subsidence team. The opportunity now exists for the results to be collected rapidly in the field and to be directly comparable, as they are captured as three dimensional co-ordinates. In this way it would be feasible to establish a nation-wide database of information, a feature which is sadly lacking at present. This would allow co-ordination of the investigations already proceeding within each area, which at present are usually considered as "one-off" jobs.

The distinction must be recognised between research type results and those obtained for the immediate determination of subsidence claims. The results from the latter tend to be of a lower standard of accuracy. Only the results of uniformly high accuracy are worthy of comparison. By defining field instrumentation and techniques, and by the introduction of courses to expose these to the subsidence surveyors, it will be possible to obtain the standard of results required.

CHAPTER SEVEN

FUTURE RESEARCH AND DEVELOPMENTS

Future research and developments

7.1 Introduction

Some of the applications of automated survey systems and techniques to mine surveying practice have been discussed in this thesis. The list of applications discussed is not considered exhaustive. There is no doubt that many new developments will take place in the future and that these will have a direct influence on the work of the mine surveyor. In this chapter the author would like to do some "crystal-ball" gazing and consider the main areas of research and development which will be of most benefit in the immediate future.

The research in automated mine surveying systems at the University, which has been described, will continue along the lines indicated in Section 7.4. Much of this work will be concerned with software development, although the investigations into the accuracy and applicability of new instrumentation must not be forgotten. A prime example of this is the continuation of the subsidence project commenced by the author, although there are many other applications. These may include an investigation into the new electronic co-ordinate determination systems which most instrument manufacturers are currently marketing. Co-ordinates can be determined in three dimensions to great accuracy by the simultaneous intersection of the point from two electronic theodolites. These systems are being employed in high precision engineering for monitoring and control. The applicatios in mining could include monitoring any movement in the shaft headgear and other surface structures, and for precise underground roadway deformation measurements.

Other developments are dependent upon the equipment manufacturers and other specialised research organisations, and Section 7.2 outlines the improvements which the author would like to see implemented. It is important that the opinions and wishes of the users are passed on to the manufacturers. Such contributions are willingly accepted and usually acted upon, ensuring that development continues to meet the requirements of the customers within the overall development regime.

7.2 Instrumentation

At present there appears a need for a cheaper more compact and lighter electronic total station, even if this meant a reduction in accuracy. It is not possible at present to significantly reduce the size of electronic total stations, primarily because the optics cannot be reduced whilst maintaining sufficient magnification. Further work is also needed on the reduction in size of the electronic components. By reducing the size and weight of the instruments there will be an inherent reduction in the accuracy attainable due to the reduced stability of the theodolite. However, for the majority of surveys angular measurements which are reliable to +5 seconds of arc are acceptable. The mine surveyor would still be benefiting from all the other advantages offered by the instrument such as digital readout with illumination, automatic compensation and data recording. The price will only drop for such equipment when large numbers are being sold to offset the development costs.

Lighter and more compact units may also aid the development of an intrinsically safe instrument. At present the modifications required to achieve flameproofing would make the instruments too heavy and even more unwieldy.

Although there have been massive technological advances in the methods of angle measurement, relatively little advances have been made into more definite centering of the instrument above the station itself. Centering and pointing errors, especially over short distances typical of many underground surveys, are now probably the main sourses of the error within survey measurements using electronic total stations. It is still common for instruments to rely on an optical plummet for centering the instrument, with the instrument height measured with a tape. The Kern system with a graduated centering rod, swivel tripod head and pivot instrument mount has facilitated the instrument setting to a known height above the station considerabl-y, but the verticality is dependent upon the small spot bubble on the rod centering rod. This system still does not help the mine surveyor where the majority of settings require the instrument to be below a station in the roof. The author would like to see effort expended into development of a new type of centering system, maybe with an active ground or roof station. In this way the station could act as a transmitter and the instrument as a receiver. An example could be a vertical sensing station which emits a pencil beam of light. The instrument could then be adjusted laterally until the maximum signal was detected. Such a system could be used for the fine centering after initially setting the instrument up in the conventional manner. There are numerous practical problems to be overcome, not the least of which would be the design of the station itself, but it seems ridiculous that the same centering system is employed today as has been used for many decades.

The accuracy of small infra-red EDM's which are telescope mountable has increased within the last few years from specifications in the order of ±(5 mm + 5 ppm) to ±(3 mm + 2 ppm) and their ranges have also been increased. Although this development is welcome there is a need for still greater accuracy, with the introduction of instruments accurate to ±1 mm, especially for primary traverse work and deformation measurements. A number of manufacturers are claiming that such equipment will be available by the end of 1985. It will be interesting to evaluate their performance when they become available using the Department's test facilities, the continuing evaluation of new instrumentation and techniques being the underlying theme of the research performed in mine surveying at Nottingham. Interesting results have been achieved using the AGA 140 (Farhur et al. 1983), where sub-millimetre accuracy has been obtained. The AGA 140 has a continuous mean value measurement mode where the operator leaves the instrument to continually measure the same length for as long as is thought necessary. At the end of this period the mean value is displayed, and it was using this method over measurement periods of 15 seconds that produced such outstanding results. This system appears to be the only one allowing this degree of accuracy at present.

The majority of complaints from current users of electronic total stations concern the battery units. In most cases the batteries are external to the instrument and are bulky. To guarantee a full days surveying either a large single battery is required or two or three smaller tripod mountable units must be carried. Hewlett-Packard introduced a very convenient system with their HP3820A, where the batteries were about the size of a pencil and inserted into one of the instrument standards. In this way replacements could be easily carried in a pocket without any encumbrance to the surveyor, even if many were required to complete a full days work. Wild have an internal battery within the T2000, but this only has a life of approximately 500 measurements with the EDM attached. Unfortunately if an external power source is required, the original internal battery must be removed. This is the equivalent of introducing an eccentric weight to one of the theodolite standards. This may produce inaccuracies because the T2000 is not fully automatically compensated. Lighter more efficient batteries, preferably housed within the instrument and easily replacable are definitely required. If an internal battery with sufficient power could be developed so that replacements were not required, then this would aid the production of an intrinsically safe instrument.

Unquestionably there will be considerable developments within the field of automatic data capture. The new CMOS technology will increase the the field capability and power of data recorders, allowing advanced integrated field calculations and checks, especially with the introduction of fast CMOS. This has the added advantage of maintaining a low level of power consumption. There would be obvious advantages if data interrogation could be implemented in the field, giving warnings of gross errors in measurements or if certain blocks of information had been omitted, such as forgetting to enter the target height. Kern have now implemented data output from their electronic theodolites in ASCII code format as well as the conventional Binary Coded Decimals. This facilitates direct interpretation by processors in the field. Apart from increasing the power of data recorders and extending their field capabilities, there are other fundamental changes required.

A primary requirement is that the data recorder should be situated at the prism station, not at the instrument itself. It is essential that the detail surveyed should be coded correctly. The introduction of electronic total stations has allowed detail to be easily picked up over long distances, and so there is no way for the instrument man to know exactly what feature is being defined. Two way radios can be used, and are in fact essential for the majority of automated surveys. The emphasis has now shifted away from the instrument to the detail pole. At present it is possible to transfer information down the measurement beam to the reflector. The author has used such a system for setting out purposes where the magnitude of movement required at the detail pole is received by a special attachment to the prism, namely the Kern RD10. This system is limited by the range over which the information can be transmitted; at present this is about 200 m. This type of system should be developed so that all of the measured values can be transmitted over longer distances and recorded by the remote data recorder once the field coding has been entered by the surveyor at the detail pole.

The major failing of the data recorder is that graphical information cannot be stored as an "aide memoire", in the same way that sketches are drawn in a conventional field book. It is feasible that such a facility could be introduced into data recorders by incorporating a small digitiser pad into the unit, maybe as a retractable drawer in the base. Sketch information and station numbers could be entered using the normal coding system for digitiser editing. When each sketch is complete it could be stored in a separate memory section associated with the measurement block number. Simple hard copies could then be retrieved on return to the office. This facility would greatly enhance the flexibility of the unit, especially if remote processing by someone not associated with the field work is required. The old adage that "a picture paints a thousand words" is particularly applicable to surveying.

7.3 Automatic mass digitisation

A major problem for groups with a large amount of existing graphical information who are considering adopting an automated survey system is finding a method of entering all of their information, usually held in plans, into the computer database. It is obviously important that all of their information is stored within the same database so that maximum use can be obtained from the system. Two methods are readily available for most computer systems, namely entering all of the existing information through the keyboard or by manual digitisation. For relatively small amounts of information manual digitisation offers the simplest solution, although it must be borne in mind that the accuracy of the information stored within the database will be governed by the original plotting precision and the dexterity of the digitiser operator. It is interesting to note that at Calverton Colliery, where the National Coal Board are undertaking a pilot trial of a survey based computer system, the mine surveyor responsible prefers to enter the vital information concerning the mine plan by referring to the original field notebooks and co-ordinates, which are then entered via the keyboard (Pendleton 1984). In this way there is no degradation of the accuracy of the information when entered into the computer.

Neither manual digitisation or keyboard entry provide practical solutions for larger applications. The Ordnance Survey have 220 000 large scale maps which must be transferred into digital form. It is estimated that using conventional digitisation this task will not be completed until the year 2030 (Latham-Warde 1979). Similar problems exist for the Natinal Coal Board. For example, the Western Area alone has over 40 000 existing mine plans. The problem is increased when it is considered that many of the plans are old and in poor condition, many not being oriented and correlated with the Ordnance Survey National Grid. The enormity of the problem dictates that alternative methods of digitisation must be found and evaluated. At present there are two automatic digitisation techniques available, both still under development and assessment. These involve laser or raster scanning.

7.3.1 Interactive laser systems

Interactive laser scanning digitisation has been chiefly developed by Laserscan Laboratories of Cambridge. The first system produced was the Fastrak in 1977. This has been superseded by the Lasertrak. Both systems are built around a large laser screen which allows the operator to supervise digitisation. The system automatically follows lines at the discretion of the operator, who can also take full command of the process and in effect simulate manual digitisation if desired. The screen shows the lines which have been digitised in an enhanced form ensuring that entire coverage without omissions or duplications. The high degree of user interaction facilitates full feature coding during digitisation.

The Lasertrak system digitises from a film negative which is mounted at the photochromic film plane. The image which appears on the screen is magnified by a factor of ten. Lines are automatically traced by sensing the light and dark areas on the negative. Once a line is located the laser scans the line in short sections,dete-rmining the vector for each section. Providing that the line is of the same width the system can follow dashed lines. Line crossings can be correctly interpreted if the two lines are of different widths, otherwise the operator may intervene to ensure that the correct line is followed. The laser tracks at a rate of between 2.5

and 5.5 mm/s depending on the nature of the line. It must be remembered that this speed refers to the rate over the negative, and so the speed with which an area can be digitised is dependent upon the amount of photo-reduction.

The Ordnance Survey have been evaluating both systems, and it has been reported that for urban plans the Fastrak system gives a five fold increase in efficiency over manual techniques. Evaluation of the Lasertrak is still be undertaken, although a number of systems are in use. At present the cost of the Lasertrak is proving prohibitive to its general use.

7.3.2 Raster scanning

This method involves raster scanning of the plan followed by vectorisation of the data. As such the process can be divided into two parts, the optical scanning of the plan and the raster to vector conversion of the information. The basic principle behind the conversion is as follows. The first step is to locate an illuminated pixel. This pixel is considered as being at the centre of a 3 x 3 matrix of pixels. The other eight pixels are interrogated to determine the continuation of the line. As the process continues the links are checked to determine the existence of lines, curves, symbols or characters. The conversion technique must have sufficient intelligence to interpret these features, as well as delineate line crossings and not retrace any line segments. The conversion is completely software driven, and so this technique appears to have the most rapid scope for development. Vectorisation often leads to errors at present due to the misinterpretation of the data, with much editing being required. This is particularly true for complex plans.

There is particular interest in this technique for a wide range of subjects, including printing, remote sensing and engineering drawing, as well as map "representation". This general interest should help promote and finance extra development of this technique.

The optical scanning can be achieved in a number of ways, but the most common method for digital mapping uses a drum microdensitometer. This machine's action is similar to that of a drum plotter in that the plan is attached to the drum which then rotates, providing the motion in one direction. An optical scanner is then used to pick up the information in the other direction. Many types of scanner are available, including a conventional television camera (Nagy 1983). However there are very few which give sufficient graphical and geometrical resolution for map purposes. It is generally accepted however that the main problem with this technique does not lie with the optical scanning but with the development of suitable software to perform the raster to vector conversion without excessive editing being required.

7.3.3 Summary

At present the systems discussed are not sufficiently well developed to justify their high cost to be practically applicable to the automatic digitisation of plans. They work reasonably well tracing lines, provided that there are not too many crossings, and for following contours as long as they are not too convoluted. Unfortunately a great many of the old mine plans are in a poor condition, and this further reduces the efficiency of the system, although developments are being made using photographic techniques to allow determination of lines from cracks or folds. The enormity of the task of entering all of the existing plans, and the urgency of this requirement, dictate that much research and development must be applied to this technology.

7.4 The HASP system

7.4.1 Implementation of the Pascal system

Following the successful implementation of the HASP system using HPL (High Speed Progamming Language), it was realised that extension of the system into other applications would be limited by the language speed. Although huge time savings resulted from the use of the software for general survey calculations and volumetric analysis, the interpreted nature of the language would become prohibitively slow for further applications such as planning or design, where interactive graphics would be required.

The HASP HPL system was designed purely to be a tool for the surveyor, and as such attempted to imitate the surveyor's requirements from opening his field book to production of the final plan. This resulted in new software effectively being "tagged on" to the system. It was decided that a totally revised philosophy was required for efficient expansion, with a new system developed around a central core of an efficient database and surface modelling package. In this way numerous disciplines could be built into the system by simply adding their relevent software. One of these disciplines is obviously the survey package, and the first priority has been to reimplement all of the survey software. It was decided that this system should be written in the

Pascal language as the HP9816 microcomputer supports the Pascal operating system and Pascal is a compiled language, therefore improving the processing speed.

The system has been developed around a flexible intelligent database which is fully user-definable. The surface modelling and volumetric routines used are identical in operation to those mentioned previously, but the processing efficiency of the Pascal is shown by the fact that now 1000 data points can be modelled in two minutes. In HPL it took approximately 45 minutes to model 600 points. The main advantage of this processing speed is that virtual interactive graphics are possible. Sections and profiles can be generated "instantaneously-". Crude isometric and perspective views can also be obtained rapidly. Figure 7.1 shows an isometric view of the Calverton stockpile . As can be seen, the gully between the two parallel piles is continuous, showing that the model has formed correctly. If the breakline information is removed and the surface remodelled, then the isometric view shown in Figure 7.2 is produced. The bridging effect across the gully is now evident. These simple isometric or perspective views serve two main practical purposes. Firstly, the surveyor can visualise the model created and check its authenticity easier than by looking at the interpolated contours. Secondly, a development of this technique could be useful for planning enquiries where zones of visual influence are

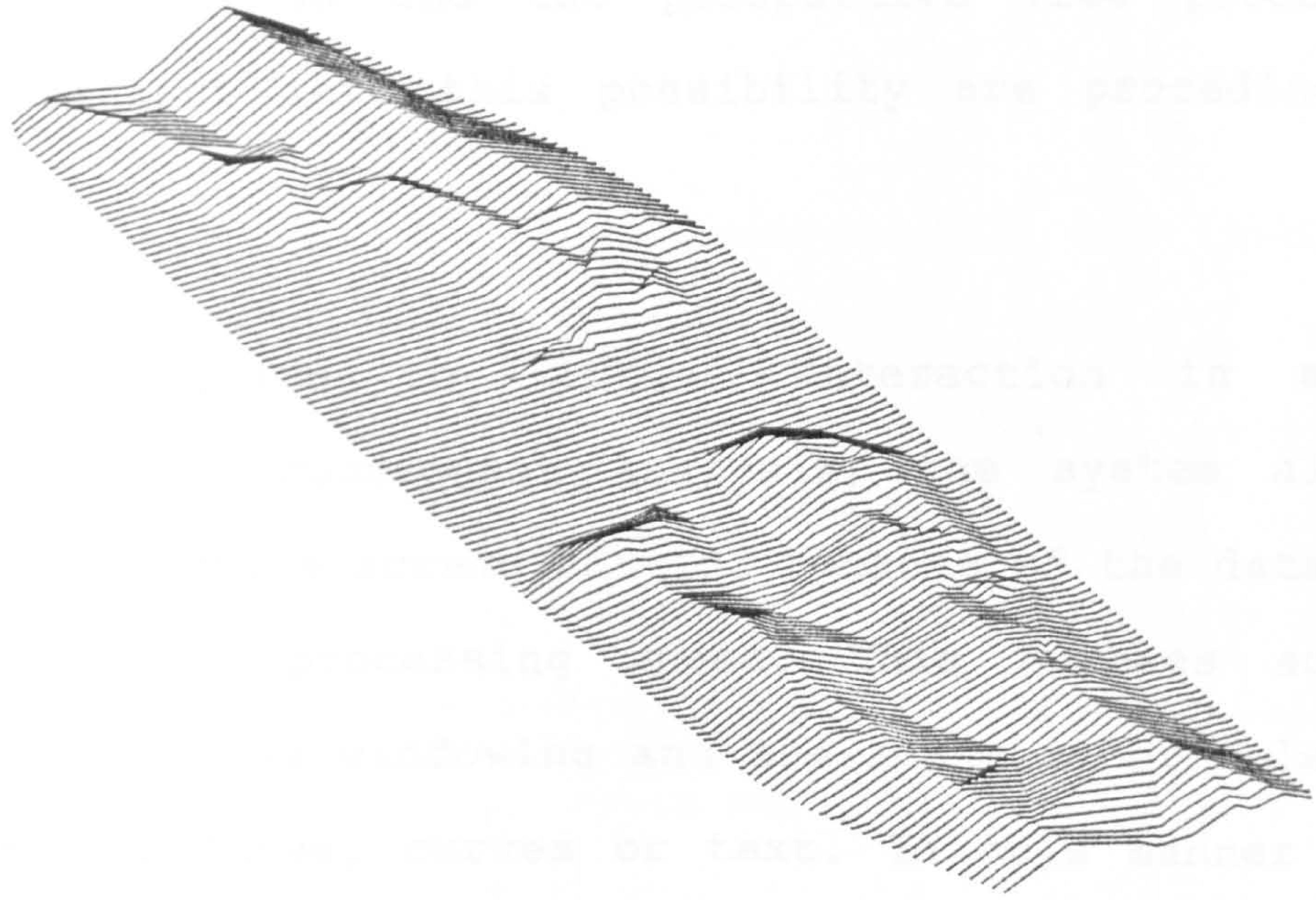


Figure 7.2 Isometric view of Calverton stockpile excluding breakline information

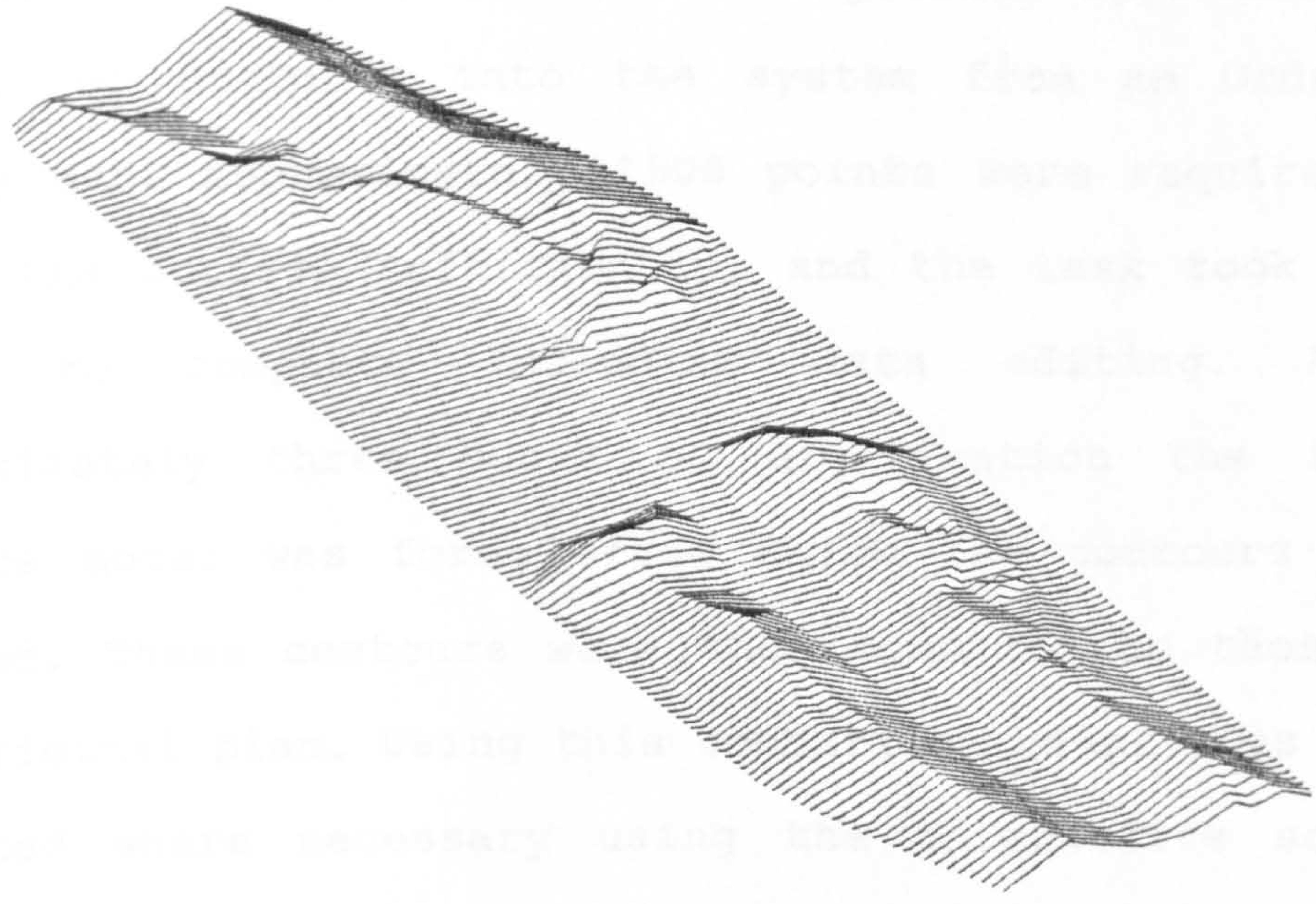


Figure 7.1 Isometric view of Calverton stockpile including breakline information

critical. The co-ordinates of any particular property could be entered and the perspective view produced. Investigations into this possibility are proceding at present.

In addition to virtual interaction in model formation and subsequent analysis, the system allows fully interactive screen editing because of the database structure and processing speed. This enables screen features such as windowing and the addition or deletion of symbols, lines, curves or text. In this manner data editing in graphical format is facilitated without the use of a digitiser, speeding the inclusion of breaklines into a model or plan enhancement before plotting.

As an exercise, the author digitised approximately 18 km of contours into the system from an Ordnance Survey map. Approximately 1500 points were required to cover the surface sufficiently, and the task took five hours to complete including data editing. After approximately three hours of digitisation the first surface model was formed from which the contours were plotted. These contours were then compared to those on the original plan. Using this comparison breaklines were inserted where necessary using the interactive screen editing, and extra points digitised where a shortage was shown. After five hours the correct digital terrain model had been achieved. This type of operation would have been virtually impossible using the HPL system because of the processing speed and lack of interactive graphics.

Initial research should investigate the insertion of design data which can then be interactively tested rigorously against the existing terrain. Such an application would be of use in highway design cut and fill calculations and open pit mine design. The spatially linked database will allow regionalised volumes to be calculated by considering the points to be included within the design area.

However, the major application which will be developed concerns the creation of an overall mine planning and design package.

7.4.2 The unified mine information system

Within the field of mining engineering there are many separate disciplines which must, at some time, refer to the information generated by the others. These include the survey, geological and planning departments. The majority of the software used within the industry is geared towards the requirements of one section to the exclusion of the rest. In the short term this is acceptable as it allows specific software to be written quickly and efficiently. However, in the long term this solution does not aid the interrelation of data from one group to the next, and therefore the full potential of the computing facilities is not reached. It is important that an urgent initiative be taken to produce a system in which each discipline has rapid access to its own data, but which at the same time can equally rapidly access the most up to date information from other sections. This can be achieved by the use of a common database for the entire system. Each user can then define their own data levels within this structure.

A very simple analogy could be as follows. The planning department want to investigate starting two new seams at Colliery X. To be able to do this they must first consider the existing working plan. This can be extracted from the database and viewed on their screen. The geological information is also required, this being viewed as an overlay to the mine plan. Various planning options can then be tried until the optimum design is found. This is obviously a very simplified example, but it serves to illustrate the overall aims of such a unified mine information system.

The author has worked in conjunctiopn with the National Coal Board's computer graphics applications research team at M.R.D.E., Bretby. The original aims of the project were to automate the mine survey office in the production of its statutory plans using a system developed from a three-dimensional modelling package called CARBS (Hartley and Ranson 1984). The system has expanded from these original aims into areas such as the automatic generation of mining reports and specific design functions (Stephenson 1984). The author was responsible for the development of an automatic underground junction design module. It was whilst working for M.R.D.E. that the author was given the opportunity to discuss the computer requirements of a wide range of disciplines with high ranking personnel. Although each group were satisfied with their own software, the benefits which would accrue from the ability to share this information with other sections was readily accepted.

Whilst the enormity of the task associated with the realisation of such an overall mine information system should not be underestimated, the author firmly believes that such a system could be developed around a database structure such as the one implemented within the HASP system. Before this can be achieved the database must be further expanded so that it can cope with additional information, particularly in the form of secondary annotation. The potential offered to the industry by such a system is indeed vast. Optimum efficiency from the computer facilities within the industry can only be achieved if such a system becomes reality.

7.5 Legislation

With the introduction of automated survey and computer storage of survey information, a new problem has been created, namely in fulfilling the legal requirement for permanent paper records to be kept. At present legislation will not allow information concerning mine surveying to be stored solely in a computer format.

This raises two problems. Firstly, field note books should be maintained as a permanent record of all survey work undertaken. The introduction of data recorders may compromise this situation, although if required hard copy prints of the raw data can be stored. Secondly, faith in computer storage must be proved if the majority of the plans which have to be kept do not have to be manually updated on paper every time.

This problem has been highlighted recently by an underground quarterly tape and offset survey conducted at a local British Gypsum mine. The surveyors have recently purchased a fully automated system including field instrumentation and data processing facilities. They wished to complete the survey using a data recorder in a similar manner to that described in Section 4.3, but were unsure of the legality of them doing so as a paper record would not be made. Eventually they performed the survey using the data recorder and a manual booking sheet so as to obtain the increased processing efficiency offered by the data recorder but covering any legal requirement. Obviously this is unsatifactory and only represents an interim solution.

The Inspectorate are aware of the rapid changes within the field of mine surveying, but it is important that the Act and Regulations are updated enabling the full use of the facilities now available. Guide lines must be implemented concerning the required methods of data storage and back-ups. The Code of Practice must be revised so as to reflect the introduction of new techniques. This has always happened in the past, for example, the introduction of gyrotheodolites and electro-optical distance measurers into the 1973 revision of the Code of Practice. The situation must be considered with some urgency.

CHAPTER EIGHT

CONCLUSIONS

Conclusions

The recent development of electronic total stations and data recorders, coupled with the rapid advances made in microprocessor technology, has enabled the introduction of automated survey systems for the mine surveyor at reasonable cost. The field instruments have been fully evaluated and the accuracy of such equipment proved. The advantages of automated mine survey systems can be summarized under three main headings, namely, increased productivity, reduced errors, and the more efficient use of resources.

Productivity can be increased dramatically through reduced time and manpower, as has been proved by the various surface and underground surveys reported in this thesis. Field efficiency is increased because of the portability of the equipment (only one instrument being required), increased speed of setting up the instrument, single sighting for both angles and distances, the inherent measuring speed, auto-reduction of horizontal and vertical distances, and the possibility of automatic data acquisition. To fully appreciate the advantages offered by such systems it is essential that field experience is gained.

The possibilty of obtaining errors is reduced because of the single sighting for angles and distances, the auto-reduction of distances, the inherent measuerment accuracy and the elimination of field booking errors by the use of a data recorder. Data collectors provide the means of electronically storing data in the field for subsequent computation in the office. The most important feature of the data recorder is that it provides the vital link between the field survey and automatic processing. The speed of data processing is dependent upon the use of a data recorder. As the data is already in a computer compatible format, processing takes place at the speed of the computer data transfer, not at the speed with which a person can manually enter the data. In addition to increasing the rate of data transfer, the use of the data recorder also eliminates the inevitable keying errors associated with manual data entry. It cannot be said that the data recorder will eliminate all field errors, but their use does eliminate office errors.

The increased efficiency and productivity offered by such systems automatically produces an overall better use of the resources available.

The recent courses organised for mine surveyors by the Department of Mining Engineering at Nottingham on the use of automated survey systems showed that the new skills required are quickly understood and assimilated. The course generated a large amount of interest and enthusiasm, and subsequently many Areas of the National

Coal Board have purchased their own electronic total stations. The increase in production by the introduction of the field equipment alone has been proved in every case. The most surprising feature is the ease with which field data coding using the data recorder has been understood and accepted. It is estimated that only one day of training in the field is required.

With the introduction of automated survey systems into mine surveying, it is possible to consider a restructuring of the personnel within, say, an Area of the National Coal Board. The increased production and efficiency may allow each Area to establish teams of surveyors with specific responsibilities. One discipline which springs readily to mind for this approach would be volumetric surveys. All of the Area's coal stocks could be surveyed using the techniques previously described in an efficient manner. In the past it has not been feasible to to survey dirt tips from the ground because of their size and the amount of time and personnel required, and so photogrammetry is used. This is expensive and often does not produce results with which the mine surveyor is totally confident. However, to date there has been no practical alternative and so the results have had to be accepted. It is now possible, as has been proved, for all of the dirt tips to be surveyed from the ground to a high degree of accuracy, and with the confidence that the task has been completed "in-house". The initial work load would be high as each tip would have to be surveyed in its entirety, but in subsequent years only the portions of the tip which have been altered would need to be resurveyed, the new data being merged into the old. The subsequent work load would therefore be significantly reduced. The capital expenditure for a fully automated system, including field equipment, hardware and software would be recouped in approximately two years of not having to pay for aerial surveys.

Another obvious area to which a team of surveyors could be assigned is that of subsidence surveys. In this way a co-ordinated effort at both Area and National level could be instigated, providing invaluable results for the subsidence engineers for prediction of deformations. The amount spent on subsidence claims at present is astronomical, and so such a research effort is essential. Development of automated field techniques using electronic total stations will provide an efficient and accurate method of obtaining this data.

It is perhaps unfair to single out specific applications as this tends to detract from the overall benefits offered by such systems. For all applications both the field and processing efficiency are dramatically increased. Such systems could theoretically be used for the majority of mine surveying tasks.

It is often said that the "art" of surveying is rapidly disappearing with the introduction of new instrumentation and technology. The author does not believe this to be so. The art is merely changing. The surveyor's field sense must now be directed towards techniques which will provide the best results with minimum effort bearing in mind the computer processing. It cannot be said that the introduction of such technology negates the need for care and accuracy in the field, as good final results are still totally dependent upon the accuracy of the field work. The introduction of automation simply allows the mine surveyor to perform his job with a greater professionalism, primarily because of the time savings which accrue. It will now be possible for him to spend more time thinking about the work to be done and in particular about the method used for the survey. In addition more field work will be possible, and the confidence in the accuracy of the results obtained increased.

As has been shown, mine surveying is at the heart of of a number of other related disciplines, such as planning. With the possible future introduction of unified mine information systems, it is inevitable that the role and status of the mine surveyor will increase. The opportunity exists for the mine surveyor to become an expert at data preparation and handling, and fulfil an important efficient role within management information. The mine surveyor will be at the hub of co-ordinating all of these other disciplines, for without spatial information the others cannot function. The advantage of automation for the mine surveyor therefore extends far beyond increasing the efficiency of field survey and data processing.

The principle activities of a mine surveyor have been listed as follows (Baxendale 1984):

a) The interpretation of the geology and mineral deposits in relation to the economic extraction thereof.

b) The investigation and negotiation of mineral rights.

c) Making, recording and calculation of mining measurements.

d) Mining cartography.

e) Investigation and prediction of mine working on the surface.

f) Mine planning in the context of the local environment and subsequent rehabilitation.

It has been conclusively shown that the opportunities offered by automated data processing systems and the development of a unified mine information system would directly influence the efficiency of each of the above facets. It is vitally important that an urgent initiative is taken in their introduction into the field of mine surveying.

ACKNOWLEDGEMENTS

Acknowledgements

I would like to express my debt and gratitude to the many colleagues and friends who have helped me during the period of this research. In particular I would like to mention the following:

Professor D.J.Hodges, my supervisor, for his constant enthusiasm and support throughout the research project, and whose foresight initiated the research into automated survey.

My fellow research students past and present (Dr. John Nicholson and John Alderson), who have made up the "team".

Mr. P. Rosik, the laboratory technician with special responsibility for surveying, for his meticulous maintenance of the survey equipment and considerable assistance with field work.

Mr. D. Wallis, Managing Director of Survey and General Instrument Co. Ltd. and Mr. R. Hogan, President of HASP Inc., for their generous support and assistance.

Mr E. Levitt and Mr. T. Taylor, past and present Chief Surveyors of the Natioal Coal Board, for their interest, encouragement and practical discussion.

Mr. H. Moreland, former Chief Surveyor and Mineral Estates Manager of British Gypsum, for his considerable assistance.

The S.E.R.C. for their financial support.

Claire, for her patience and assistance in checking the final draft.

Last, but by no means least, I would like to express my gratitude to the many colleagues and friends, too numerous to mention, from the NCB, British Gypsum and other organisations for their critical judgement, enthusiasm and practical assistance during the course of this research. May the results be of particular benefit to you.

APPENDICES

Appendix i

Automated survey references

D.J.Hodges
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D.J.Hodges
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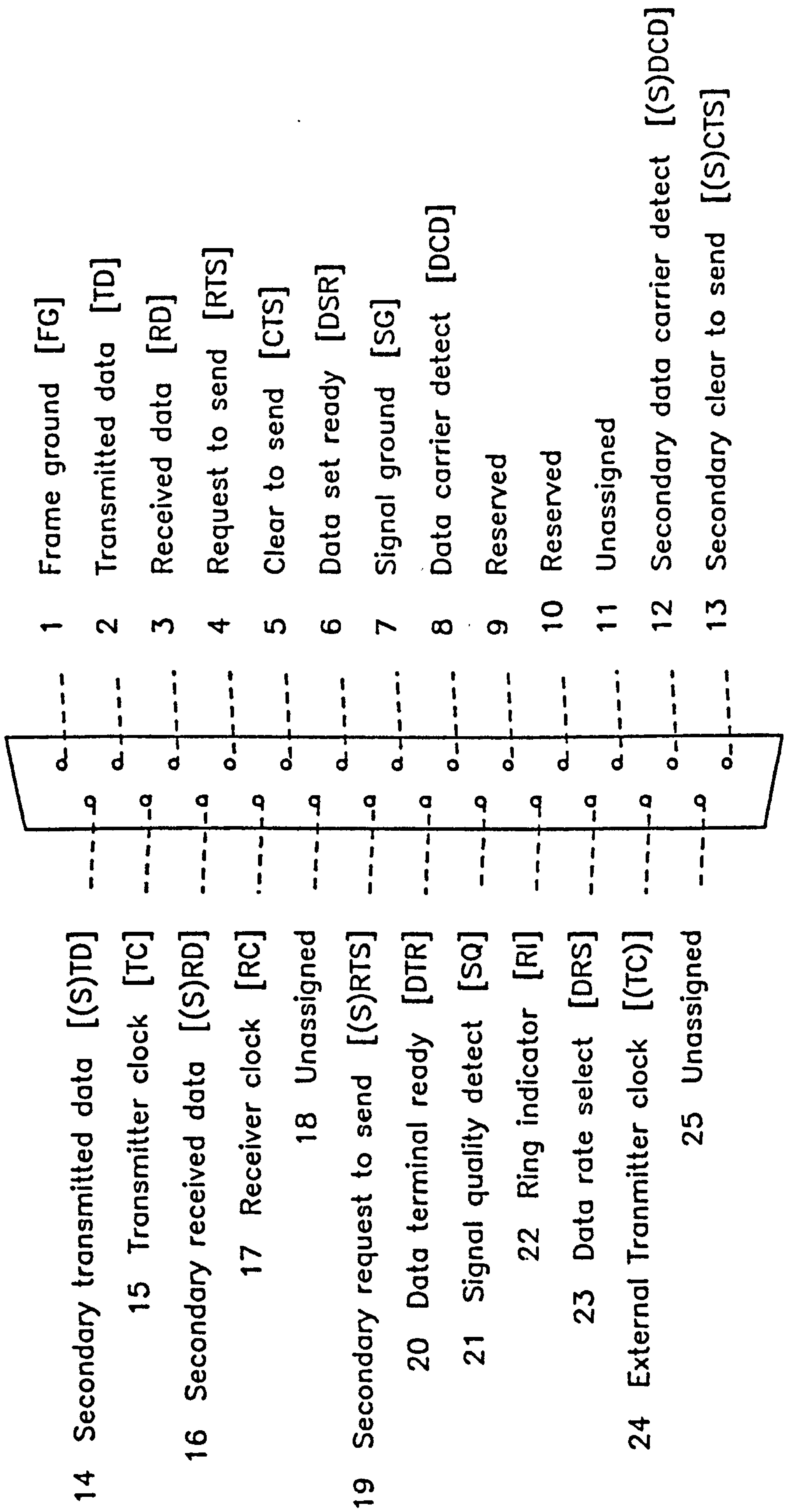
Appendix 1 ASCII code chart

BITS B7 B6 B5 / B4 B3 B2 B1				Ø Ø Ø	Ø Ø 1	Ø 1 Ø	Ø 1 1	1 Ø Ø	1 Ø 1	1 1 Ø	1 1 1
				CONTROL		HIGH X & Y GRAPHIC INPUT		LOW X		LOW Y	
B4	B3	B2	B1								
Ø	Ø	Ø	Ø	NUL 0	DLE 16	SP 32	0 48	@ 64	P 80	\ 96	p 112
Ø	Ø	Ø	1	SOH 1	DC1 17	! 33	1 49	A 65	Q 81	a 97	q 113
Ø	Ø	1	Ø	STX 2	DC2 18	" 34	2 50	B 66	R 82	b 98	r 114
Ø	Ø	1	1	ETX 3	DC3 19	# 35	3 51	C 67	S 83	c 99	s 115
Ø	1	Ø	Ø	EOT 4	DC4 20	$ 36	4 52	D 68	T 84	d 100	t 116
Ø	1	Ø	1	ENQ 5	NAK 21	% 37	5 53	E 69	U 85	e 101	u 117
Ø	1	1	Ø	ACK 6	SYN 22	& 38	6 54	F 70	V 86	f 102	v 118
Ø	1	1	1	BEL 7	ETB 23	' 39	7 55	G 71	W 87	g 103	w 119
1	Ø	Ø	Ø	BS 8	CAN 24	(40	8 56	H 72	X 88	h 104	x 120
1	Ø	Ø	1	HT 9	EM 25	) 41	9 57	I 73	Y 89	i 105	y 121
1	Ø	1	Ø	LF 10	SUB 26	* 42	: 58	J 74	Z 90	j 106	z 122
1	Ø	1	1	VT 11	ESC 27	+ 43	; 59	K 75	[91	k 107	{ 123
1	1	Ø	Ø	FF 12	FS 28	, 44	< 60	L 76	\ 92	l 108	¦ 124
1	1	Ø	1	CR 13	GS 29	– 45	= 61	M 77	] 93	m 109	} 125
1	1	1	Ø	SO 14	RS 30	. 46	> 62	N 78	∧ 94	n 110	~ 126
1	1	1	1	SI 15	US 31	/ 47	? 63	O 79	_ 95	o 111	RUBOUT (DEL) 127


1 Frame ground [FG]
2 Transmitted data [TD]
3 Received data [RD]
4 Request to send [RTS]
5 Clear to send [CTS]
6 Data set ready [DSR]
7 Signal ground [SG]
8 Data carrier detect [DCD]
9 Reserved
10 Reserved
11 Unassigned
12 Secondary data carrier detect [(S)DCD]
13 Secondary clear to send [(S)CTS]
14 Secondary transmitted data [(S)TD]
15 Transmitter clock [TC]
16 Secondary received data [(S)RD]
17 Receiver clock [RC]
18 Unassigned
19 Secondary request to send [(S)RTS]
20 Data terminal ready [DTR]
21 Signal quality detect [SQ]
22 Ring indicator [RI]
23 Data rate select [DRS]
24 External Tranmitter clock [(TC)]
25 Unassigned

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