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Engineering Geology of the Wrexham Area

by

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INTRODUCTION

This report describes the engineering geology of the Wrexham district comprising an area of 225 km^2, contained within National Grid 10 km squares SJ 35,25 (Quadrants NE and SE) and 34 (Quadrants NW and NE). The study was undertaken as part of an applied geology mapping project of the area by the British Geological Survey (BGS), part funded by the Department of the Environment (Contract No. PECD/7/1/290). The report appertaining to the project as a whole provides information on stratigraphy and mineral reserves and contains the Thematic Element Maps referred to within this report.

Data used in the compilation of this report were obtained from 66 site investigation reports of varying quality and content. From these geotechnical test results were abstracted and engineering design considerations noted after having identified the stratigraphy of the lithology tested. The test results were incorporated into a database and used to determine the engineering geology units (see below). The engineering comments were analysed and summarized into three categories of design considerations: foundations, excavatibility and suitability as fill material, and slope stability. Where no information was available, comments were not provided, except where reference could be made to the relevant comments for similar deposits found in the neighbouring Deeside district contained within BGS Technical Reports WA/88/2 and WN/88/7 (Campbell and Hains 1988, Crummy and Culshaw 1988). The text is so arranged that a description of each component lithology within each engineering geology unit is followed by the relevant engineering comments. Where there were sufficient data, tables of summary values of geotechnical parameters for lithologies within the engineering geology unit have been prepared. In addition extended box plots have been provided to aid in the interpretation of some of the data, for example by plotting the variation of moisture content, liquid and plastic limits, undrained cohesion and N values for cohesive soils (Figure 1). In a similar manner, Figure 2 shows the SPT N values and undrained cohesion for predominantly granular deposits.

Two engineering geology maps have been prepared, one for engineering soils (Drift), the other for engineering rocks (Bedrock), showing the distribution of the engineering geology units. This distinction and the difference between these maps and the geology maps is discussed below.

THE GEOTECHNICAL DATABASE

Classification of the geological formations into units with similar engineering properties (engineering geology units) was carried out using geotechnical data extracted from site investigation reports for sites located in, or within 2 km of, the study area. Because much of the area is rural, the coverage of these reports, and hence the geographical coverage of the database, is limited. In general, the reports are of two types in terms of their areal coverage; firstly they relate to development and other sites around urban areas (for example, Wrexham, Bangor-is-y-coed and Rhosllanerchrugog) and, secondly, they relate to road developments (in particular the A483(T) Wrexham bypass). The distribution of boreholes for which geotechnical data are available is shown on Thematic Element Map (3) The engineering geology of the various formations described in the report was assessed by analysis of the geotechnical database and supplemented by taking account of comments, recorded in the site investigation reports, relevant to engineering behaviour problems and hazard, to provide a summary appraisal of engineering experience in the area.

Summary values for geotechnical parameters for the various formations are presented in Tables 1 - 24. The geotechnical data used here to classify geological formations in engineering terms are not necessarily representative or comprehensive. For some formations (for example the Minera Formation) no geotechnical data are available. For others (for example the Kinnerton Sandstone Formation) data are limited to those from a small number of boreholes. The geographical spread of data across the outcrop and subcrop areas of most formations is also limited. The various tests for which results are tabulated should all have been carried out to the appropriate British Standard. However, experimental and operator error may result in variation in results between one contractor and another, and between one report and the next. As very little information is presented in the site investigation reports in relation to these possible errors, the data, as compiled, will inevitibly include some which are inaccurate to a greater or lesser degree, resulting in a greater spread of results than would probably be found within any one report. However, whilst assessing the site investigation data prior to databanking, efforts were made to reject clearly erroneous test results, the remaining records being accepted as valid. Nevertheless, the tabulated data statistics remain useful guides to the engineering properties of the various formations provided these points are considered and over-interpretation is avoided. It should be stressed that the summary geotechnical values given in the tables ought to be used as a general guide only and not as a substitute for adequate site investigation, or in detailed design calculations.

Geotechnical test data were obtained from 4979 individual 'samples' or test points. A 'sample' here refers to a specimen of soil or rock which is removed for testing, a test point to a position in a borehole at which one of the in situ tests (for example, shear vane or SPT) is carried out. Results of the following geotechnical tests and measurements were abstracted from the site investigation reports and entered into the database.

1. Standard penetration test (SPT)
2. Rock quality designation (RQD)
3. Moisture content
4. Liquid limit
5. Plastic limit
6. Bulk density
7. Dry density
8. Specific gravity
9. Particle size analysis
10. pH (acidity/alkalinity)
11. Sulphate content (of soil and groundwater)
12. Triaxial compression (drained and undrained)
13. Consolidation
14. Compaction
15. California bearing ratio (CBR)

For most samples only a few of these tests were carried out, and rarely was a full range of test results available for any particular engineering geological unit. Tables defining various parameter classes recorded in the summary geotechnical data (Tables 1 - 24) are present in Appendix A and outline descriptions of the geotechnical tests are presented in Appendix B. Appendix C contains a key to the lithology codes used in Figures 4, 8, 9 and 12, and Appendix D an explanation of extended box plots (Figures 1 and 2).

The geotechnical data were entered onto manuscript proforma and then keyed into a computer database. For this purpose an IBM compatible micro-computer and commercially available software were used for database creation and storage. Backup copies of the database are held by the Engineering Geology Research Group of the British Geological Survey. Validation and analysis of the stored data set to provide a statistical assessment of the geotechnical properties and the relevant graphical plots, was carried out using a commercial statistics and graphics software package. Results from this analysis were used to produce the summary geotechnical data in Tables 1 - 24 and as a basis for the assessment of the engineering geological characteristics of the various geological formations. For each geotechnical parameter in the tables the values quoted represent the number of samples, the median value (50th percentile), and where the number of samples is equal to or greater than 10, the lower and upper quartiles (25th and 75th percentiles respectively). These values are considered to represent the spread of data for each parameter more accurately than by quoting the mean, standard deviation and range, since the latter are sensitive to atypical values often giving rise to misleading results (Hallam 1990).

The distribution and material descriptions of 'fill' and 'made ground' in the study area are presented on Thematic Element Maps 3, 5 and 6. No assessment is made in this section of the report of problems related to waste disposal and the engineering implications of these sites. The material, and hence geotechnical variability of these areas make them difficult to classify in general engineering terms. Therefore, for planning purposes it should be appreciated, that the suitability of any potential development site in the study area will be dependent not only on the engineering characteristics of the in situ rocks and soils but also on the proximity of areas of fill and made ground and their influence on the integrity of any proposed structure (for example in terms of low and variable bearing capacities, variable compressibility and anomalous drainage characteristics).

ENGINEERING CLASSIFICATION OF ROCKS AND SOILS

The division of the rocks and soils of the Wrexham area into classes of materials of like engineering characteristics (engineering geological units) has been based on an assessment of the recorded geotechnical parameters, as determined in the various tests, and lithology. Although the engineering geology maps are based on the mapped lithostratigraphic boundaries all these boundaries are not necessarily relevant to the designation of engineering geological units. This results in a classification scheme which does not exactly correspond to the mapped local stratigraphy. For example, the Coed-yr-Allt Formation and Erbistock Formation of the Upper Coal Measures (UCM) are differentiated on the solid geology map Thematic Element Map 1 but are grouped together under the category of 'Interbedded, moderately strong sandstones and mudrocks' since they are composed of similar lithologies with broadly corresponding engineering characteristics. However, in Tables 1 - 24, geotechnical data are given for each stratigraphic formation. This allows summary geotechnical data to be extracted on the basis of the stratigraphy shown on the geological maps and in borehole logs.

In engineering terms, the rocks and soils of the area can be divided into seven engineering geology units:

1. Rock
2. Fill, made ground
3. Peat
4. Normally consolidated/medium dense heterogeneous soils
5. Overconsolidated heterogeneous soils
6. Overconsolidated cohesive laminated and medium dense layered soils
7. Dense non-cohesive soils

The spatial distribution of these materials [with the exception of fill and made ground, which are shown on Thematic Element Maps (3, 4, 5 and 7)] are shown on Thematic Element Maps 8 and 9. The two engineering geological maps are presented in terms of 'bedrock' and 'superficial deposits' to allow comparison with the geological maps [Thematic Element Maps (1) and (2)]. Some gradation between the states of rock and soil (in engineering terms) occurs in the case of the highly to completely weathered mudrocks of the Bettisfield and the Ruabon Marl Formations which weather to a soft to stiff silty clay.

ENGINEERING GEOLOGICAL CLASSIFICATION OF THE SOLID FORMATIONS (ROCK)

The solid formations of the Wrexham area have been divided into five engineering geological units on the basis of their geotechnical and lithological characteristics. Geotechnical data for many of the formations are limited, and in some cases none are available. The relationship between these units and the lithostratigraphic units are set out below.

It should be noted that, within the project area, there are three small areas of Ordovician rocks, each less than 100 m across, in the bottom of limestone quarries at Minera and in the bed of the adjacent Aber Sychnant. The rocks consist of grey, cleaved turbidite siltstones and mudstones for which no geotechnical data are available. Because of their very small extent, these rocks are not shown on the Engineering Geology of Solid map (Thematic Map 8) and are not considered further in this report.

Engineering Geological Units	Geological Unit
1. Limestones	i) Minera Formation ii) Cefn Mawr Limestone iii) Loggerheads Limestone
2. Strong Sandstones	i) Ruabon Marl Formation sandstones ii) Bettisfield Formation sandstones iii) Halkyn Formation sandstones
3. Interbedded mudrocks and moderately strong sandstones	i) Erbistock Formation ii) Coed-yr-Allt Formation
4. Weak sandstones	i) Chester Pebble Beds Formation ii) Kinnerton Sandstone Formation
5. Mudrocks	i) Ruabon Marl Formation mudstones and shales ii) Bettisfield Formation mudstones, shales and siltstones iii) Halkyn Formation shales

ENGINEERING GEOLOGICAL CLASSIFICATION OF THE DRIFT (SUPERFICIAL) DEPOSITS (SOIL)

The soils of the study area have been divided into six engineering geological units, as indicated previously. The relationship of these units to the lithostratigraphic classification of the soils are:

Engineering Geological Units		Geological Units
1. Fill and made ground		Fill and Made ground
2. Peat		Peat
3. Normally consolidated/medium dense heterogeneous soils	i)	Alluvial deposits of presently active rivers
	ii)	River terrace deposits
	iii)	Head deposits
4. Overconsolidated heterogeneous soils	i)	Till (Boulder clay)
5. Overconsolidated cohesive laminated and medium dense layered soils	i)	Laminated clay till
	ii)	Glacial silt
6. Dense non-cohesive soils	i)	Glacial sands and gravels

ENGINEERING GEOLOGY OF THE SOLID FORMATIONS (ROCK)

1. LIMESTONE

This unit comprises the Logggerheads Limestone, the Cefn Mawr Limestone and the Minera Formation. Their outcrop is restricted to the sparsely populated western area of the district and no geotechnical data are available.

All three Limestones are about 60 m thick each around Minera and are composed of predominantly light grey, strong packstones and grainstones, with calcite mudstones. However, there are differences of significance to engineering behaviour. Near the top of the the Loggerheads Limestone there are irregular bedding plane surfaces with hollows or pits, up to 0.5 m deep, within which light grey clays are preserved. These have been interpreted as potassic bentonites (altered volcanic ash) and represent a preserved palaeosol. In the middle part of the Cefn Mawr Limestone a 3 - 4 m thick shale bed has been identified but has not been shown on the geology map. The upper parts of the formation are very mudstone-rich and can contain harder chert nodules. Within the Minera Formation there are massive cross-laminated fine to medium grained, occasionally pebbly, calcareous and quartzitic strong sandstones of up to 25 m thick.

The strength of the rock mass as a whole will be dependent on the frequency and thickness of interbedded argillaceous bands and structural discontinuities such as jointing and faulting. The possible occurrence of solution features such as open or infilled cavities and swallow holes cannot be totally ruled out, and may present a potential hazard to engineering activities.

DESIGN CONSIDERATIONS

i) Foundations

There are disused mineral workings within veins in the area south and west of Minera. These features may be air, water or soil filled and may in each case reduce the bearing capacity and cause excessive differential settlement unless the soundness of the rock below the foundation is proved by test borings. Many of the shafts have not been capped and present a danger to proposed schemes.

ii) Excavatability and suitability as fill material

The dilation and frequency of near-surface fractures renders the limestone rippable for about 5 m below rockhead. In more massive limestone, blasting may be necessary. The limestone is reported as being suitable for use as a fill material after crushing and is classified as a rock for compaction purposes. The proportion of mudrock is probably insufficient to affect the quality of the limestone fill. The limestone should be assumed to be frost-susceptible for design purposes and this should be taken into account for calculations of minimum pavement thickness.

iii) Slope stability

Four landslides have been identified at NGR SJ 253 494. Three are of the order of 100 m^2 in area, with the fourth very much larger, covering an area of 150,000 m^2. They occur within the Minera Formation (which contains sandstones) and are situated in a steep sided valley. The strata dip at 10° to the ESE, and bedding planes will probably daylight in the valley side, which is steeper than 15°. It is possible that failure has taken place along the bedding planes as they dip in a direction parallel to the dip of the valley sides.

Cuttings in shaly limestones with mudstone layers should not be steeper than 1:1 as weathering of argillaceous layers may lead to their erosion and subsequent loss of support to limestone blocks possibly leading to toppling failure.

2. STRONG SANDSTONES

This engineering geological unit encompasses the sandstones within the Halkyn Formation, Bettisfield Formation and Ruabon Marl Formation. Data for the Bettisfield Formation sandstones are presented in Tables 1 and 2. The limited data on Halkyn Formation sandstones are presented in Table 3. No data are available for the Ruabon Marl Formation sandstones, and reference has been made to the relevant comments by Campbell and Hains (1988).

a) Halkyn Formation sandstones

These rocks comprise a group of sandstones at the base of the formation and the Gwespyr Sandstone at the top. The basal group are between 260 m and 360 m thick and comprise slightly to moderately weathered, massive-bedded, fine to medium grained, quartzitic sandstones with thin conglomerates, intercalated with cherts and mudstones. The Gwespyr Sandstone is up to 50 m thick, but is around 12 m thick in the south of the study area. It is slightly to moderately weathered, cross-bedded, buff, fine to coarse grained, strong and feldspathic.

Near rockhead the sandstones may be weathered to a weak rock and heavily fissured with clay infilling the fissures. A median rock quality designation (RQD) value of 19 for moderately weathered sandstones is an indication of the degree of fracturing.

DESIGN CONSIDERATIONS

i) Foundations

No information regarding the bearing capacity of these sandstones was available. SPT 'N' values for the moderately weathered material are high with a median value of 117. However, this value was determined from a very small sample of five. The above comments on weathering should also be taken into account.

ii) Excavatability

For the more massive, strong sandstones, explosives may be required to break up the rock to facilitate excavation. Weathered sandstone near to rockhead may be ripped or dug.

b) Bettisfield Formation sandstones

The Bettisfield Formation sandstones are grey to greyish brown medium grained moderately strong to strong, often with thin coal and argillaceous bands and partings. Some are thinly laminated to very thinly bedded in the order of 2.0 m total thickness, whereas others have been recorded around 9.0 m thick but possessing many coal and shale partings. The mass strength will vary due to changes in bed thickness and the presence of carbonaceous and argillaceous intercalations, and strength anisotropy can be expected. The degree of fracturing is reflected in the low median RQD value of 39 for moderately weathered sandstones. Near rockhead the sandstones are highly, sometimes completely, weathered and are present as dense sand with sandstone fragments. At about 1.5 m below rockhead they are moderately weathered.

DESIGN CONSIDERATIONS

i) Foundations

The degree of weathering is a major factor in controlling the bearing capacity of the sandstones. At one site SPT 'N' values of between 61 and 73 were obtained for highly to completely weathered material. From this figure the maximum safe net bearing capacity was estimated at 300 kPa (pad and strip footings).

For the moderately weathered sandstone, a maximum safe net bearing capacity of 500 kPa (pad and strip footings), and 1500 kPa (pile foundations) was determined from extrapolated SPT 'N' values of 130. These 'N' values are consistent with those presented in summary Tables 19 and 20.

Higher values of bearing capacity may be possible but confirmation is necessary by, for example, in situ plate or pile loading tests. Care should be taken to ensure the absence of weaker argillaceous beds which could be overstressed by the adoption of higher bearing values.

Of more importance to foundation design within Coal Measures strata are the possible presence of disused coal and/or ironstone workings at shallow depth. It is strongly emphasized that adequate provision be allowed for a record search into the possibility of abandoned workings beneath a site, together with a drilling and sampling programme which aims to determine the nature and thickness of the sandstone unit and the extent and depth of any workings. This is particularly relevant when piled foundations are considered for heavy structures. Bell (1988) provides some useful information with respect to locating potentially dangerous shafts and provides a comprehensive list of references. Also differential settlement due to subsidence may have to be taken into consideration in areas of thin drift cover.

ii) Excavatability and suitability as fill material

Weathered material may be removed by digging whereas more fresh sandstones will probably require ripping.

Solid sandstone rock is suitable as embankment fill if care is exercised during selection and excavation. Use as a high grade fill is not generally recommended when the sandstone is thinly interbedded with argillaceous or carboniferous bands.

c) Ruabon Marl Formation sandstones

These chiefly comprise blue-green, coarse and pebbly grits referred to as Espley Rocks which are confined mainly to the lower half of the succession south of the river Dee. There is a prominent yellow or white, hard, fine-grained sandstone at the base of the succession near Ruabon (Wedd et al. 1928).

Values of uniaxial compressive strength range from around 10 MPa to about 81 MPa with a mean of 51 MPa (16 tests). Initial tangent modulus of elasticity values range from 1.4 to 8.3 GPa.

DESIGN CONSIDERATIONS

i) Foundations

No geotechnical data or comments were available relevant to bearing capacity and foundation design. Bearing capacity may be expected to be good but weaker argillaceous beds, where present beneath the sandstone, would be susceptible to over-stressing, thus reducing the apparent bearing capacity.

ii) Excavatability

The sandstone will be difficult to excavate by digging and therefore, will probably, require ripping.

3. INTERBEDDED MUDROCKS AND MODERATELY STRONG SANDSTONES

This engineering geological unit consists of strata of the Erbistock Formation and the Coed-yr-Alt Formation. No data were available for the latter, which outcrops in a narrow band about 900 m wide striking approximately N-S across the centre of the area, and pinching out around Wrexham. It is approximately 140 m thick and composed of greyish-white sandstones, in part highly calcareous, pale-grey, black or locally bright red shales and purple mottled marls. There are at least two coals of variable thickness and thin bands of limestone, one of which constitutes the basal bed to the formation (Wedd et al. 1928).

In comparison, the Erbistock Formation strata are estimated to be in the order of 1000 m thick, of which about 500 m are present in the study area. However, this may be due in part to repetition of strata due to unrecognised faults. They outcrop to the east of Wrexham, striking approximately N-S, and are unconformably overlain by the Kinnerton Sandstone Formation. The strata of the Erbistock Formation are composed of purple, red, grey and brown thinly bedded mudstones, siltstones and shales, which are generally weak, and reddish brown, fine grained, thinly bedded, micaceous sandstones which are moderately strong.

Data on the Erbistock Formation Strata are presented in Tables 4 to 8. The mudstones are very susceptible to weathering and are typically completely weathered to a soft to hard, silty clay to a depth of 1 - 3 m below rockhead. The natural moisture content for the highly weathered material has a median value of 10%. This is quite low in relation to the median plastic limit of 20.5% with a median liquid limit of 34.5%. The median plasticity index is also low at 14%, and the material plots as a clay of low plasticity on the Casagrande plasticity chart, (Figure 3). Occasionally there are weathered clay layers between stronger sandstone layers. The completely weathered mudstones have a median SPT 'N' value of 102, whereas the moderately weathered mudstones have a median SPT 'N' value of 130.

The sandstones, in comparison are less weathered than the mudstones, and a median SPT 'N' value of 229 has been obtained for moderately weathered sandstone. They are up to 1.5 m thick and readily fissile due to closely spaced micaceous bedding planes. Uniaxial compressive strength measurements on two rock cores yielded values of 29.3 and 40.8 MPa, indicating the sandstone to be moderately strong. The modulus of deformation lay between 1209 MPa and 1994 MPa in a 1 m depth with the ratio of the first cycle to the third cycle almost 0.6, indicative of micro-fissuring. Some joints have been recorded as inclined at up to 80°.

The mudrocks are not readily fissile, though they can be shaly. They are heavily jointed, causing a low median RQD value of 33 for moderately weathered siltstones, but jointing is reported as being less frequent than in the sandstones which has a median RQD value of 46 for moderately weathered material. The moderately weathered siltstones have a SPT 'N' value of 200, similar to that of the sandstones (229).

DESIGN CONSIDERATIONS

i) Foundations

The degree and extent of weathering are critical factors in relation to the engineering behaviour of these rocks. Care must be taken to ensure that strata are not overstressed, bearing in mind the thinness of the sandstones, its fissile tendency and the presence of highly weathered argillaceous beds.

ii) Excavatability and suitability as fill material

The presence of highly weathered zones and the extensive jointing should enable excavation by digging, though ripping may be necessary for some of the stronger siltstone and sandstone horizons. During excavation water may be encountered, especially in the Alyn valley where artesian water conditions were reported. Few data on suitability as fill were available. One statement described the material as "vulnerable to weathering."

4. WEAK SANDSTONES

This engineering geological unit consists of sandstones from the Chester Pebble Beds Formation and the Kinnerton Sandstone Formation. They are present in the east of the district but concealed beneath superficial deposits and no exposure has been mapped. This, coupled with the sparsely populated rural nature of the area means that very few geotechnical test data were obtained. Tables 22 to 24 contain data for the sandstones of the Kinnerton Sandstone Formation. The sandstone, when fresh, is described as red, coarse grained and strongly cemented. However, the sandstone is found to be weathered by the removal of the cement which leads to disintegration so that the material resembles a dense to very dense sand. This can be difficult to distinguish from the overlying drift when the latter is also very sandy. Frequently the sand may be locally derived from the sandstone unit itself and only slightly reworked. In the Bangor-on-Dee area around 2.5 m of sandstone completely weathered to a very dense sand, lies above moderately weathered sandstone. The moderately weathered sandstone contains silty sand partings and selectively weathered bands along the bedding planes, which are inclined at up to 15° . Median RQD values of 22 and 15 for the fresh and slightly weathered material respectively give an indication of the degree of jointing.

DESIGN CONSIDERATIONS

i) Foundations

No information regarding the bearing capacty of this sandstone was available. A median SPT N value of 120 for the moderately weathered sandstone was determined, and extrapolation values of more than 900 were recorded in fresh to slightly weathered material, but the number of values is not sufficient to be statistically valid. Bored and cast-in-place piles may be affected by waisting or washout from artesian water in the uncemented material which has been reported as giving rise to 'blowing' conditions, and casing will be required to support the granular material and exclude groundwater.

5. MUDROCKS

This engineering geological unit encompasses the dominantly argillaceous formations of the Bettisfield Formation, the Ruabon Marl Formation, and the subordinate shales of the Halkyn Formation. Information is largely restricted to those mudrocks of the Bettisfield Formation which are presented in Tables 12 and 13. The few data for the Ruabon Marl Formation are presented in Table 14. No data were available for the Halkyn Formation mudrocks.

a) Bettisfield Formation mudrocks

The argillaceous rocks of the Bettisfield Formation are composed mainly of mudstones and shales with less frequent siltstones and ironstones. The grey siltstones are present generally as seatearths within a sequence of thick, interbedded mudstones, siltstones and coals, and contain frequent irregular fractures which may have been induced by the presence of relict root structures. Less frequently, there are stronger siltstones up to 6.0 m thick. These more massive siltstones may represent local channel infill deposits and therefore may vary in thickness laterally. RQD values of 40 have been recorded which indicates that they are less fractured than the seatearths, for which the median RQD value of 15, is more typical.

The mudstones and shales have very similar engineering characteristics. They are moderately weak rocks and become weaker with weathering. The completely weathered rock is a firm to stiff, brown and grey, laminated, fissured silty clay with litho-relicts. The weathering zone has been observed to depths of about 4.0 m for completely weathered rock but the degree of weathering will decrease beneath this depth. Moderately weathered rock has been recorded at depths of 35 m below ground level. The mudstones and shales contain many discontinuities and the majority of RQD values are zero for the moderately weathered material.

DESIGN CONSIDERATIONS

i) Foundations

The presence of shallow mine workings for coal and ironstone present a potential hazard to foundations. Adequate provision should be made for research into the existence of abandoned workings beneath the site. If suspected, the drilling and sampling programme should aim to determine their nature and depth. Bell (1988) discusses methods for the location of potentially dangerous shafts. The presence of frequent faults may result in zones of shattered rock which may present a problem due to low bearing capacity.

ii) Excavatability and suitability as fill material

The weathered mudstones and shales should be diggable but the fresher material may require ripping. Because of their susceptibility to softening on contact with water, excavations in these materials should be protected against unnecessary wetting. No data were available from site investigation reports regarding suitability as fill material. In the adjacent Deeside area, the rocks were considered suitable only for low embankments where there was no alternative. This was because natural moisture content was too high, they weathered rapidly, and swelled. The swelling potential of weathered mudrocks in the Wrexham area is discussed by Entwisle (1989) in an accompanying report to this one. Entwisle determined the mineralogy, index parameters and densities of weathered mudstones from an opencast coal mine at Sydallt (SJ 3145 5485) and related these properties to swelling behaviour measured in the laboratory. In broad terms, swelling potential is mainly influenced by the clay mineralogy, the natural moisture content and the extent of weathering of the material. He concluded that for the small number of samples tested, the swelling potential was low. However, the rocks sampled were highly weathered and the plasticity indices were low.

Fresher mudstone with a low natural moisture content will respond by swelling to the physical and chemical changes induced by exposure to the elements when reworked, for example during the construction of embankments. Where plasticity indices are high, (Liquid Limit >60, Plastic Limit >35), as found in rocks of weathering grades III to VI in the Deeside area, it is suggested that measurement of their swelling characteristics would be prudent.

iii) Slope stability

Several landslips were observed during geological mapping and are shown on Thematic Element Map 2. They are located on the very steep valley sides of a tributary of the river Alyn, and probably originated in the

Pleistocene as a result of oversteepening of the valley due to glacial processes. Small movements still occur, probably as a result of undercutting of the toe of the slipped mass by the stream. No geotechnical investigation has been undertaken of the landslips; however, in the Deeside area a few landslips around Holywell were recorded where the failure planes appeared to be located in weathered mudstone/shale. Where slopes steeper than about 7° are present, investigation should determine if any slope movement has taken place and to check the effect of any proposed structure upon slope stability.

For cuttings, side slopes have been recommended at 1V:4H with drainage, particularly where the groundwater table is high. Precautions may have to be taken to prevent weathering and swelling.

b) Ruabon Marl Formation mudrocks

The predominant argillaceous rocks of this sub-group are blue grey and purple, fissured, thinly laminated mudstones. They are completely weathered to a stiff to very stiff grey brown, silty, calcareous clay to 1.0 m below rockhead and are highly to moderately weathered to at least 1.5 m below rock head. Geotechnical data for the mudstones are limited and shown in Table 14. The majority of RQD values are zero, indicating the extent of discontinuities within the moderately weathered material. It is stated in the report for the adjacent Deeside area (Campbell and Hains 1988) that the mudrocks of the Ruabon Marl Formation probably have similar geotechnical properties and engineering behaviour as mudstones of the Buckley Formation. The weathered mudstone of the Buckley Formation is classified as a clay of low to intermediate plasticity (CL and CI) and low compressibility with a medium to high rate of consolidation. Strength determinations indicate the clay to be firm to stiff, but, because of the fissured nature of the material it is difficult to obtain intact samples. Tests probably underestimate the strength of the clay which, therefore, is probably very stiff in situ with shear strengths probably greater than 500 kPa. SPT 'N' values exceeded 50 even in the weathered zone.

DESIGN CONSIDERATIONS

i) Foundations

No information was available for the project area. However, for pile foundations in the nearby Deeside area, allowable end bearing pressures of about 200 kPa have been assumed with allowable shaft resistance of around 150 kPa. Piles were recommended to be taken 3.0 m into the rock through the weathered zone.

ii) Excavatability and suitability as fill material

The weathered material should be easily diggable. The more massive nature of the less weathered material may require ripping.

ENGINEERING GEOLOGY OF THE DRIFT (SUPERFICIAL) DEPOSITS (SOIL)

1. FILL AND MADE GROUND

Fill and made ground materials most commonly comprise mining and quarrying waste and domestic and industrial refuse. There may be material such as crushed stone, pulverised fuel ash (PFA), and demolition rubble, the remains of previous land use on apparently undeveloped sites. The exact composition, thickness and geotechnical properties will vary widely, not only from site to site, but also within the sequence of materials underlying the site. The geotechnical behaviour is unpredictable but, in general, the fill and made ground may be highly compressible, loose, weak and possibly toxic. Areas of fill and made ground are shown in Thematic Map 2. When investigating older landfill sites it may be prudent to anticipate the presence of methane gas, generated from decaying domestic refuse, since some landfill sites were not designed so as to vent safely this potentially explosive gas.

Colliery Waste

Mining waste is prominent in the area of the disused Gresford Colliery where it has been tipped on the sand and gravel plateau, on the valley side and on the flood plain of the river Alyn, at NGR SJ 386 562. Here it reaches a thickness of 22.3 m. It is composed of mixed, generally unlayered, loose to dense, coarse to fine colliery discard which is predominantly dark grey/black shale and siltstone containing coal and coal dust. Burnt discard occurs in layers up to 6.5 m thick.

Colliery waste tips are vulnerable to spontaneous combustion during excavation, handling and placing. The main factors to consider are:

a) a sufficiently high combustible carbon content to provide a fuel (generally over 25%),
b) a sufficiently high iron pyrites content, oxidation of which generates the heat for spontaneous combustion,
c) a sufficient availability of oxygen to sustain the combustion.

Test results for samples taken from the tips mentioned above indicate that the amount of combusible carbon is sufficient to cause fire. However, the iron pyrites content was considered too low to generate spontaneous combustion, but this could not be totally ruled out. The temperature of the colliery waste was not found to exceed 17° C. Smoke has been observed by the author, issuing from a spoil tip at Hafod (NGR SJ 312 469).

DESIGN CONSIDERATIONS

i) Slope engineering

Without available oxygen, combustion does not take place. It has been stated that on new embankments it is generally considered that adequate compaction of the shale is sufficient to limit the amount of available oxygen.

In cuttings the slopes of 1V:2.5H have generally been recommended to cater for localised instability in mixed material but slopes should generally be as flat as possible to reduce the "oxygen draught" into the face of the tip. They should be protected with a thicker than average cover of clay or top soil, and adequate surface water drainage provided.

Stability analyses have been carried out for proposed cut and embankment slopes within colliery waste:

A 4 m high embankment above 22 m of colliery shale, overlying natural sand and gravel; embankment design slope of 7V:2H, existing slope of colliery shale of 1V:3.5H.
Strength parameters:
Shale: $c' = 20$ kPa $\phi' = 21°$ Bulk density = 1.8 Mg/m^3
Sand and gravel: $c' = 0$ kPa $\phi' = 35°$ Bulk density = 1.75 Mg/m^3

The factor of safety against failure at the shale/original ground surface interface was found to be 1.74.

Similar parameters were used in an analysis of an 11 m (max) deep cutting within colliery shale. For a design slope of 1V:2.5H, the factor of safety against circular or sliding failure was equal to or greater than 1.5. No stability problems were anticipated.

ii) Sulphate content

The sulphate content in the colliery waste sampled varied from 8 to 121 parts per 100,000. In conclusion, it was recommended that all types of concrete in any structure which might come into contact with the colliery shale should be sulphate resistant.

2. PEAT

Geotechnical data on peat are limited, and are presented in Table 15.

Peat was found to occur in the form of lenses within alluvial deposits, and occurrences have been documented for the river Clywedog at Queenspark, Wrexham and the river Alyn near Gresford. It may also be found associated with soft clays in kettle holes and can attain thicknesses of between 10 and 20 m. Kettle holes are located in the glacial sands and gravels between Wrexham and Gresford, and are approximately circular, marshy depressions. Upland peat is found in many places in the mountainous region, the most conspicuous spreads occurring on and near Moel-Fferna, Cerrig-duon and Pen-Plae (Wedd et al. 1928).

Peat is usually associated with very soft, grey, organic clays and is, itself, usually very soft, dark brown or black. It can be fibrous or decayed to an amorphous silty clayey material. Thickness can vary up to 1.2 m. It is highly compressible with high moisture contents, Atterburg limits and low density. A median moisture content value of 133% was obtained for 16 samples in the area.

DESIGN CONSIDERATIONS

i) Foundations

In some cases, the complete removal followed by replacement with more competent fill has been advised when developing over peat, especially when constructing embankments. The lower-most fill layer should be free-draining and non-plastic and its upper surface should be above the flood plain level for construction in river valleys. However, for a light structure, a raft foundation has been suggested with a bearing value of 48 kPa, giving rise to consolidation settlement of 25-50 mm occurring soon after loading. It is important to consider the potential presence of peat beneath a thin covering of alluvial sands or clay. The peat will have a great influence on the settlement of structures due to consolidation when shallow foundations are used. It is common for groundwater in the vicinity of peat to be acidic and degrade buried concrete structures of inappropriate composition, and to attack buried service pipes. The use of appropriate resistant construction materials should be considered.

ii) Excavatability and suitability as fill

Peat and peaty soils should be easily diggable and the excavated material will be unsuitable for re-use except for general landscaping purposes. Waterlogged peat may flow into excavations and may require close-boarded supports or sheet pile walls prior to excavation.

3. NORMALLY CONSOLIDATED/MEDIUM DENSE HETEROGENEOUS SOILS

a) Alluvial deposits of active rivers

The most extensive areas of alluvium are associated with the rivers Alyn, Clywedog and Dee. The deposits are located within the broad, flat-lying flood plain of the latter, but are restricted to relatively narrower expanses in the other two valleys. Alluvial deposits are also found within many of the smaller water courses, for example Black Brook, which are tributaries of the larger rivers.

Geotechnical data for the alluvium are restricted mainly to the above mentioned river valleys, and are presented in Tables 16 - 18. Analysis of the data indicated that the numerous lithologies present could be grouped into three broadly distinct units exhibiting similar geotechnical properties (Figure 4) but their relative proportions and sequence probably vary unpredictably from location to location. The units are, clays and silts, sand with fines, and sand and gravels. Within the Alyn valley, the upper deposits are of soft grey silty clay, often underlain by peat, of around 1.5 m thickness. These deposits overlie medium dense, light brown, clayey fine sand which can contain fine to coarse gravel, and is around 3.0 m thick, but can reach be to 6.0 m. With increasing depth the deposit grades into dense sands and gravels, which are probably of late glacial origin.

The recent alluvial sands and gravels are medium dense and often contain cobbles. They can occur within predominantly sandy unit as a buried channel or at the surface associated with the active river channel. This unit ranges in thickness from 0.5 m to 7.0 m.

The alluvial deposits of the river Clywedog near Queenspark are composed of the same units as those described in the Alyn valley, however, they are present in a different sequence, demonstrating their unpredictable nature. Here, buried beneath made ground, there is a very soft to soft dark brown and black spongey, slightly silty, decomposed peat. Its thickness varies between 0.15-1.15 m. Beneath the peat there is a layer of soft, light grey and greyish brown sandy, slightly organic, clayey silt which varies in thickness from 0.8 to 1.8 m. Medium dense, brown, silty, fine sand underlies the silt and is at least 4.0 m thick. Within this sand unit, a medium dense sandy gravel unit was found, up to 1.3 m thick.

Histograms for the clay and silt unit showing the frequency of Cv and Mv class values for a small number of tests (Figures 5 and 6) and also the Casagrande plasticity chart (Figure 7) indicate it to be a soft, compressible, silty clay or clayey silt of low to intermediate plasticity (CL to CI).

DESIGN CONSIDERATIONS

i) Foundations

There are no comments within the reports analysed concerning foundation design within the sands and gravels, or the clay and silt unit.

Comments appertaining to the sand with fines are limited. It has been reported to be able to sustain safe net bearing pressure of 350 kPa. Vibroflotation has been suggested as a way of increasing the density of the sand. Sulphate and pH determinations indicate that no special precautions are usually required for concrete structures below the water table. A single value indicating Class 2 sulphate concentrations (Anon.

1981) was recorded for the clay and silt sub unit.

Attention is drawn to the comments above regarding the association of acidic groundwater with peat.

ii) Excavatability and suitability as fill material

Both the clays and silts and sand with fines should be excavatible by digging. Their high moisture contents and soft nature indicate that they are unsuitable for use as fill material.

Problems may be anticipated when excavating adjacent to water courses where high water tables are present. Sheetpile cut-offs may be employed to maintain dry excavations, or water inflow may be controlled by deep wells or well-point dewatering. Support of trenches is advisable to ensure stability.

b) River Terrace Deposits

These deposits are found in the valleys of the rivers Alyn, Clywedog and Dee and are deposits of post-glacial fluviatile origin which are in their present position due to the rejuvenation of the water courses, leading to downcutting through the succession. The deposits are predominantly sands and gravels, the material being mainly derived from glacial drift. There are some silty clays/clayey silts within the sands and gravels, which probably represent overbank deposits which do not amount to more than 1.5 m in thickness. The relative proportions of lithologies present are shown in Figure 8. The broadest extent of river terrace deposits is found in the area around Rossett and Burton Hall, north of the river Alyn. Here they form a spread more than 4 km wide.

Geotechnical data for both gravels and clays are very limited and are presented in Tables 19 and 20. Table 6 shows that, for the clays, only six 'N' values and ten moisture contents were found. This may indicate their limited occurrence in comparison with the gravels. For the gravels geotechnical data were available on particle size distribution moisture content and SPT 'N' values.

The gravel is up to 7 m thick and ranges from a medium dense, silty, sandy gravel to a silty sand and gravel with numerous cobbles and boulders, and tends to become dense with increasing depth. The clay is described as being firm, yellow brown, silty and can contain pockets of peat. It has also been described as brown, clayey, sandy silt with gravel.

No comments on engineering characteristics of these deposits were found.

c) **Head deposits**

Head has not been mapped within the study area and, consequently, is not shown on the Drift Geology map (Thematic Element Map 2). In general, head deposits are heterogeneous soils derived from both solid and superficial source material which have been transported by the processes of solifluction and creep. The composition can be expected to vary according to the nature of the parent materials lying upslope. Typically the material is cohesive, and resembles a sandy silty clay with gravel. The deposits form a thin veneer on many upland hillslopes and thicken within minor valley sides and floors.

No geotechnical data were available for head in the study area; however, a deposit referred to as "hillwash" was identified which is located at the base of valley slopes in the Alyn valley. It is described as a "stiff sandy clay with gravel similar to boulder clay." In the neighbouring Deeside area, the head was found to be between 1 and 5 m thick [Campbell and Hains (1988)].

DESIGN CONSIDERATIONS

i) Foundations

Where head is a thin surface deposit, it is usually removed before placing foundations. In cases where head is thicker, it is important to bear in mind its heterogeneous nature, and that it can be highly compressible and have a low shear strength (approaching residual strength along relict shear planes) and may give rise to excessive settlement. Piled foundations may be considered in areas of thick head deposits, but it is important to determine the bearing capacity of the underlying strata.

ii) Excavatibility and suitability as fill material

Where the head is relatively coarse grained and overlies finer deposits, perched water-tables may be found within it. Running conditions can be expected and water control measures may be required. As the head is probably no greater than 5 m in thickness, the material should be readily diggable by excavators. Suitability as fill cannot be assessed here as the material is heterogeneous. It should be borne in mind that the composition is dependant on local source material, though it may contain material from other sources. Stability of pit sides may be poor in loose material and require close boarding support.

iii) Slope Stability

As head deposits are formed by mass movement processes, there is a strong possibility that relict shear planes are present. Movement may take place along these shear planes when the equilibrium of forces acting on the slope are altered. This can happen when drainage paths are blocked leading to increases in pore water pressures in the slope, by loading at the top or by removal of support at the base of the slope. All head-covered hillslopes are potentially unstable and even sites on low slope angle slopes covered by head should be treated with caution because strength parameters are at, or near, their residual values and relict shear planes may be present. Slopes with surface bulges probably have a history of mass movement and shear planes within the head are almost certainly present. Trial pit excavation and detailed logging during excavation, are recommended. Logging of only the sides of an excavated pit will not necessarily reveal the shear planes.

4. OVERCONSOLIDATED HETEROGENEOUS SOILS - TILL

Till (previously referred to as 'boulder clay') is an extensive deposit up to 60 metres thick, found in association with glacial sands and gravels. It covers much of the study area, including the eastern plains to the south of Wrexham, (where it is thickest) but restricted to valley floors of the hills to the west. Around Wrexham, and to the north, the till is overlain by glacial sands and gravels.

The deposits in this engineering geology unit are heterogeneous and contain material fragments ranging in size from clay to boulders (Figure 9). The unit does not include those deposits of probable glacio-lacustrine origin, that is, laminated/varved clays and silts, which exhibit different geotechnical properties and have been placed in the 'overconsolidated cohesive laminated and medium dense layered soils' engineering geological unit.

The till deposits are typically red-brown to dark brown, silty, sandy clay with fine to coarse gravel, cobbles and less often, boulders. There are pockets, seams and bands of sand within the till and also similar inclusions of laminated clay.

Geotechnical data for the till are shown in Table 21 and have been obtained from a large geographical area. This confirms the widespread nature of the deposit. The clay has a low to intermediate, sometimes high plasticity (CL to CI and CH) (Figure 10) and low to high compressibility. The surface of the deposit can be weathered to a light brown or orange brown colour with mottling and fissuring, down to a depth of 2.5 m. Geotechnical properties, such as consistency, are variable and are influenced by lithology, depth and weathering. Figure 11 is a plot of undrained cohesion with depth and SPT N value with depth. It shows an increase in strength with depth, but softer zones can be present at depth and very stiff zones exist close to the surface. The variation of lithology and the degree of weathering make generalisations and predictions about engineering behaviour difficult.

DESIGN CONSIDERATIONS

i) Foundations

A maximum net bearing pressure of 150 kPa for the design of footings at least 1 m below ground level, with a factor of safety of 3 against shear failure, and maximum long term settlement less than 25 mm, has been proposed for the till. Maximum safe bearing capacities of firm till have been calculated at 115 kPa (strip footings) and 135 kPa (square footings). These increase for stiff till to 180 kPa (strip footings) and to 215 kPa (square footings). Where the till is soft, vibroflotation techniques or precast concrete friction piles may be adopted. Bored piling is not advised where till is underlain by glacial sands and gravels with artesian water conditions. There should be no deterioration of good quality dense concrete made from ordinary Portland cement due to sulphate attack.

ii) Excavatibility and suitability as fill material

Excavations into the clay may be dug using wheeled excavators, and the sides of the excavations should stand well for short time periods. However, the clay will rapidly soften on exposure to water, and collapse may occur. Lateral support should be provided to the sides of all deep vertical excavations. On reaching the formation level a blinding of lean concrete should be applied to the clay to prevent softening. There is also the strong possibility of running sand conditions where water-bearing sand and gravel bodies are intercepted. At high moisture contents and where the till contains layers of sand, the till is probably not suitable for re-use as fill. At low moisture contents it may be considered for fill, especially if compacted with sand and gravel in alternating layers.

5. OVERCONSOLIDATED COHESIVE LAMINATED AND MEDIUM DENSE LAYERED SOILS

a) Laminated clay till

This deposit is composed of grey, laminated, silty clay which contains bands of silt and fine sand, and is up to 27 m thick in some places. It differs from till in that it is seldom sandy or gravelly and exhibits different geotechnical properties, being noticably softer, less dense, and more plastic. The geotechnical data are presented in Table 22. The different lithologies present in till and glacio-lacustrine clay till are shown in Figures 9 and 12, and it is clear that the former is sandier and more gravelly. The laminated clay till may be covered with till or alluvium at the surface and it has not been distinguished on the geology map, being mapped as till. The thickest development has been observed in the east of the study area, around the Wrexham Industrial Estate. This deposit has been identified by examination of borehole logs alone. Consequently its apparent absence/infrequent occurrence beneath the river Dee flood plain in the east of the area may be unrepresentative because of the small number of borehole logs available for this area.It is important to confirm the type of till present in this area, as the laminated till exhibits significantly different engineering behaviour to till. Figure 13 is a plot of undrained cohesion against depth. Between ground level and around 5 m cohesion varies from 5 kPa to 275 kPa. Below 5 m, shear strength is more consistent and ranges between 5 kPa and 160 kPa. Figure 14 is a plot of moisture content against depth. There is a general trend of increase in moisture content with depth, lower values are more common in the top 5 m. This may indicate that the deposit is desiccated down to at least 5 m, and that shear strength will be high in the desiccated zone and then will decrease below the zone before increasing with depth. The clay is fissured down to 8 m below ground level, may be a result of desiccation. The presence of a well- developed laminated structure gives rise to strength anisotropy, shear strength values being much lower in the horizontal plane, that is, sub-parallel to the laminae. The presence of silt inclusions can give rise to misleading triaxial test results, and the occurrence of permeable silt and fine sand horizons can result in softening of the adjacent clay. These can also act as drainage pathways and so increase the rate of consolidation, or can cause inflow, swelling and heave at the bottom of excavations. The clay has an intermediate plasticity, (CI) (Figure 15) and medium compressibility.

DESIGN CONSIDERATIONS

i) Foundations

A maximum safe net bearing capacity of 215 kPa for spread foundations at shallow depth has been calculated. For 450 mm diameter friction piles, a net safe adhesion of 8.5 kN/m length has been advised, and a total end bearing value of 21 kN. Sulphate concentrations greater than Class 1 have not been recorded.

ii) Excavatibility and suitability as fill material

The material may be dug using wheeled plant. The trench sides should stand well in the short term. Shoring may be required in deeper excavations. Exposure to rain may lead to softening and collapse. Also, on reaching the formation level, the clay should be protected with a blinding of lean concrete. The clays are suitable as structural fills so long as they are not wetted to the extent that the natural moisture content will exceed the optimum moisture content. The clay is not considered frost susceptible. A design CBR of 3% has been suggested for road pavements.

b) Glacial Silt

The glacial silt deposits are located in the valley of the river Alyn from The Wilderness to Singret, and to the south-east of Wrexham near King's Mills and east of Cefn Park. Here, they form a fairly large spread.

They were deposited as fine basal sediments of the Wrexham delta terrace sequence, deposited from melt waters issuing from the north west of the area, in Late Glacial times.

The silts are fairly well bedded and red and grey in colour. However, overlying sands impart a light brown colouration. The silts are underlain by relatively impermeable till and may be water bearing.

Geotechnical data for the deposits are not very comprehensive and include test results for silts found within the laminated clay till and glacial sands and gravels. They are shown in Table 23. In general the silts are medium dense, of low plasticity and medium compressibility.

DESIGN CONSIDERATIONS

i) Excavatibility and suitability as fill material

The silts can develop running conditions as they are water bearing. Problems have been encountered when sinking mine shafts. In the Alyn valley a spring line is present at the silt/till interface, which affected the routeing and design of a road embankment. When excavating, sheet pile cut-offs may need to be employed, or water inflow controlled by deep wells or well-point dewatering. The silts have been described as being unsuitable as fill.

6. DENSE NON-COHESIVE SOILS - GLACIAL SANDS AND GRAVELS

The glacial sands and gravels of the Wrexham delta terrace form an extensive spread in the centre of the study region beneath, and to the north of, Wrexham. Less extensive lenses and bands are present within the till (boulder clay) below the terrace. A thickness of about 26 m is typical but in the Gresford area the deposit forms a plateau where the deposits have been observed to be up to 38 m thick.

The main deposit is a medium dense to dense, grey brown, well-sorted sand and gravel with occasional cobbles. There are layers of interbedded, medium dense, clean sands, and sands containing an appreciable amount of silt, clay and sometimes lignite. In addition there are bands, about 1 m, thick of thinly interbedded silts and soft silty clay. The geotechnical data available are presented in Table 24.

DESIGN CONSIDERATIONS

i) Foundations

For well sorted sand and gravels, maximum safe bearing capacities of 200 to 400 kPa for shallow spread foundations have been recommended. Where there is a clay content, a lower value drops to 200 kPa has been used.

Clayey, silty fine sands have recommended maximum safe bearing capacities of 130 to 160 kPa for shallow spread foundations, and for clays, the maximum safe bearing capacities have been recommended at 190 kPa (pad footings) or 160 kPa (strip footings).

The heterogeneous nature of the deposit can give rise to variations in geotechnical properties over the site and differential settlements are a possible problem.

There should be no deterioration of good quality dense concrete, made from ordinary Portland cement, due to sulphate attack.

ii) <u>Excavatability and suitability as fill material</u>

The deposits are water bearing and give rise to many spring lines where they are underlain by less permeable strata. During excavation, provision must be made to prevent instability due to running conditions, by means of shoring and groundwater control. High hydrostatic pressures have been recorded, and there is also the likelihood of perched water. Where the deposits contain a significant proportion of matrix clay, softening and deterioration may result from contact with inflowing water.

The heterogeneity of the material is such that suitability as fill material can only be assessed after examining the lithology specific to each site. The silts have been described as being unsuitable as fill.

iii) <u>Slope stability</u>

For cuttings, side slopes of 1V:2H have been recommended for glacial gravels, reducing to 1V:3H in less coarse deposits. Drainage of the slopes or their covering with grass has been advocated. For embankments, slopes of 1V:2H have been constructed when using a mixture of well-graded and uniformly-graded materials, adequately compacted.

LANDSLIPS

Nine landslips have been observed in the Wrexham area, during geological mapping, located on a number of lithologies but were not classified, by landslip type. Their locations are shown on Thematic Element Map 2. All occur on steep valley sides where the angle of inclination of the slope exceeds 15° and where the toe is being undercut by streams. Eight of the landslips are old features which probably originated in Pleistocene times when valley sides became oversteepened and unstable due to glacial processes. Periodically smaller scale movements take place as a result of undercutting of the toe of the landslips, which reduces support of the slipped mass. Only one of the landslips (NGR SJ 326 486) is thought to be of recent origin. It was probably initiated by erosion of the valley side by its occupying stream. Of the remainder of the landslips indicated on the Thematic Element Map, one is situated within glacial till (NGR SJ 337 485) and probably results from local instability of the valley side due to undercutting by the occupying river.

At NGR SJ 253 494 four landslips have been identified, one being very much larger than the others. It covers an area of approximately 150,000 m^2, whereas the others cover areas around 100 m^2. They are situated in a steep sided valley, where the strata comprise limestone underlying sandstone of the Minera Formation,, dipping at 10° to the ESE. It is possible that failure has taken place along bedding planes which dip in a direction parallel to the dip of the valley sides.

A landslip at NGR SJ 323 548 has been identified within mudrocks of the Coed-yr-Allt Formation overlain by sands and gravels.

The four largest landslips are situated on the flanks of a very steep sided NE-SW trending valley, (around NGR SJ 295 550) occupying a section approximately 3.5 km in length. They have taken place on Bettisfield Formation mudrocks which are covered by glacial till and sands and gravels. It is significant to note that two of these landslips have originated near to the junction between mudrocks and overlying sandstones, strata of contrasting hydraulic conductivities.

The presence of landslips should be suspected where any of the above combinations of factors indicated above are found, even though landslipping may not be indicated on published maps. Should a development be proposed in such an area, investigation should not only determine the presence or absence of landslipping, but should obtain the necessary soil strength parameters to enable a stability analysis to be carried out for the slope profile which will exist after development.

Relict shear planes are often present within head deposits, and have been discussed above. It is emphasised here that all head covered hillslopes are potentially vulnerable to mass movement, and even low angle sites should be treated with caution. Slopes with surface bulges probably have a history of mass movement and shear planes within the head are almost certainly present where strength parameters will be close to their residual values. Trial pitting excavation and detailed logging during excavation are recommended. Often shear planes are exposed when the bucket of the excavator pulls away the material along the plane of the shear, and they can be identified by their polished surfaces (often slickensided) and sometimes grey gleyed colouration. Logging the sides of an excavated pit alone will not necessarily reveal the shear planes.

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APPENDIX A - Tables defining Geotechnical Parameter Classes

COEFFICIENT OF VOLUME COMPRESSIBILITY M_v

Class	Description of Compressibility	M_v m^2/MN	Examples
5	Very high	> 1.5	Very organic alluvial clays and peats
4	High	0.3 -1.5	Normally consolidated alluvial clays, e.g.estuarine clays
3	Medium	0.1 -0.3	Fluvio-glacial clays. Lake clays
2	Low	0.05-0.1	Boulder Clays
1	Very low	< 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF CONSOLIDATION C_v

Class	C_v m^2/year	Plasticity Index Range	Soil Type	
1	< 0.1		CLAYS:	Montmorillonite
2	0.1 - 1	> 25		High plasticity
3	1 - 10	25 - 15		Medium plasticity
4	10 - 100	< 15		Low plasticity
5	> 100		SILTS	

After Lambe and Whitman (1979)

SULPHATES IN SOILS AND GROUNDWATERS

Class	Total SO_3 %	SO_3 in soil 2:1 water extract grams/litre	SO_3 in groundwater parts in 100 000
1	< 0.2		< 30
2	0.2-0.5		30-120
3	0.5-1.0	1.9-3.1	120-250
4	1.0-2.0	3.1-5.6	250-500
5	> 2.0	> 5.6	> 500

After Anon. (1981a)

APPENDIX B - Geotechnical Tests and their applications

FIELD TESTS

The Standard Penetration Test (SPT)

The standard penetration test (SPT) is a dynamic test carried out at intervals during the drilling of a borehole. A standard 50 mm diameter split barrel sampler is driven into the soil at the bottom of the hole for a distance of 450 mm by the blows of a standard weight (65 kg), falling through a standard distance (0.76 m). The number of blows (N) required to drive the last 300 mm is recorded. [Test details are given in Anon. (1981b)].

A modification of the test for hard material and coarse gravel uses a solid cone instead of a cutting shoe and is called a cone penetration test (CPT).

Although this is a field test which is subject to operational errors, the SPT is widely used to give an indication of the relative density of granular soils (very loose to very dense) and the consistency of cohesive soils (very soft to hard). Correlations have also been made between SPT and the bearing capacity of a soil.

The results of the SPT are meaningful up to and including an N-value of 50, corresponding to very dense granular soils and hard cohesive soils. The SPT is also frequently used in harder materials, ie. rocks and heavily overconsolidated soils or 'mudrocks', in which case the test is normally terminated before the shoe has been driven the full 300 mm. Rather than extrapolate the number of blows to represent the full 300 mm of test, the amount of penetration in mm for 50 blows can be quoted. When the results are given in this manner the test is referred to as the Rock Penetration Test (RPT). The relationship between the two methods of quoting the results is tabulated below:

Relative Density/Consistency	SPT	RPT
Very loose/very soft	< 5	
Loose/soft	5 - 10	
Medium dense/firm	10 - 30	
Dense/stiff	30 - 50	
Very dense/hard	> 50	300 - 200
Rock/Heavily overconsolidated soils		< 200

Rock Quality Designation (RQD)

Rock quality designation (RQD) was introduced by Deere (1964) to give an indication of rock quality in relation to the degree of fracturing from drill cores. It is defined as the sum of the core sticks in excess of 100 mm in length expressed as a percentage of the total length of core drilled. The parameter takes no account of the degree of fracture opening or the fracture condition and does not distinguish between fracture spacings of more than 100 mm. RQD has been used with uniaxial compressive strength to give an indication of excavatibility and as one input for the classification of rock masses to assist in the design of tunnel support systems (Bieniawski 1974, Barton et al. 1974).

LABORATORY TESTS

INDEX TESTS

Moisture Content

The moisture content of a soil sample is defined as the ratio of the weight of water in the sample to the weight of solids, normally expressed as a percentage, ie:

$$\textbf{Moisture content, m} = \frac{\text{weight of water}}{\text{weight of solids}}$$

[Standard test proceedure is given in Anon. (1975)]. Moisture content is a basic soil property and influences soil behaviour with regard to compaction, plasticity, consolidation and shear strength characteristics..

Atterberg or Consistency Limits (Plasticity Tests)

As moisture is removed from a fine-grained soil it passes through a series of states, i.e. liquid, plastic, semi-solid and solid. The moisture contents of a soil at the points where it passes from one stage to the next are known as 'consistency limits'. These limits are defined as:

Liquid Limit (LL) The minimum moisture content at which the soil will flow under its own weight.

Plastic Limit (PL) The minimum moisture content at which the soil can be rolled into a thread 3 mm diameter without breaking up.

The range of moisture content over which the soil is plastic is known as the **plasticity index (Ip)**, and is defined as:

$$Ip = LL - PL$$

[Test procedures are given in Anon. (1975)]

The factors which control the behaviour of the soil with regard to consistency are the nature of the clay minerals present, their relative proportions, and the amount and proportions of silt, fine sand and organic material. A soil may be classified in terms of its plastic behaviour by plotting plasticity index against liquid limit on a standard plasticity (or Casagrande) chart. The consistency limits also give an indication of soil strength and compressibility.

Density

Density of a soil, ie the mass per unit volume, may be measured in various ways.

The total or **bulk density** is the mass of the entire soil element (solids + water) divided by the volume of the entire element.

The **dry density** is the mass of dry solids divided by the volume of the entire soil element.

Density measurements are simple if an undisturbed specimen of known, or easily measured, volume is obtained. If this is not possible in the field, the sand replacement method is used to determine the volume of a hole from which the soil sample is excavated by filling with a measured quantity of dry, uniformly graded sand of known density. Density measurements are usually expressed as Mg/m^3 and full test details are given in Anon. (1975).

Soil density measurements may be used to assess various earth loads such as soil mass, overburden pressure, surcharge pressure and earth pressure on retaining walls.

Specific Gravity

The specific gravity of a soil is the ratio of the weight of dry solids to the weight of an equal volume of water (ie the weight of water displaced by the solids). It is, therefore a dimensionless parameter. Full test details are given in Anon. (1975). Specific gravity is a basic soil property and represents an average for the particles of different minerals present in a soil sample. The parameter is used to enable calculation of other basic soil properties. For example: specific gravity (G), moisture content (m), voids ration (e) and degree of saturation (S) are given by the useful relationship:

$$G \cdot m = S \cdot e$$

Particle Size Analysis

The particle size distribution of a soil is determined by sieving and sedimentation. A sample of soil is dried, weighed and sieved to remove the fraction greater than 20 mm in size. It is then immersed in water with a dispersing agent such as sodium hexametaphosphate to break up soil aggregates. The sample is then wet sieved to remove particles less than 63 µm. The fraction retained on the 63 µm sieve is dried and passed through a nest of sieves of mesh size ranging from 20 mm to 63 µm. The fraction retained on each sieve is weighed and the cumulative percentage passing each sieve is calculated. A grading curve of percentage passing against sieve size is plotted.

The fines which passed through the 63 µm sieve are graded by sedimentation. A representative subsample is made up into a suspension with distilled water, placed in a tall jar and made up to a volume of 500 ml. It is then agitated vigorously and allowed to settle. Samples are removed by pipette from a given depth at specific times, dried and the contained solids weighed or, alternatively, hydrometer readings of the soil-water suspension are recorded at specific time intervals. The size distribution can then be calculated using Stokes' Law which relates settling time to particle size. The entire grading curve for coarse and fine material can then be plotted. Full details are given in Anon. (1975).

Particle size distribution is used for classifying soil in engineering terms (Anon. 1981b). Particle size distribution curves will give an indication of soil behaviour with regard to permeability, susceptibility to frost heave or liquefaction, and will give some indication of strength properties. Particle size analysis does not, however, indicate structure and will not distinguish between a sandy clay and a laminated sand and clay which may behave very differently in situ, but may show similar particle size distribution in a bulk test sample.

CHEMICAL TESTS

pH

About 30 g of soil are weighed and placed in 75 ml of distilled water in a beaker. The mixture is stirred and allowed to infuse overnight. A glass electrode connected to a pH meter is then placed in the stirred mixture and the pH reading taken. The electrode and meter may also be used to determine the pH of groundwater samples; pH may also be determined colorimetrically. Details are given in Anon. (1975).

The pH of soil or groundwater is important when designing concrete structures below ground surface. Ordinary Portland cement is not recommended in situations with a pH below 6, high alumina cement can be used down to pH 4 and supersulphated cement has been used to pH 3.5. Acidic groundwaters can also cause corrosion in buried iron pipes.

Sulphate

The sulphate content of soil is determined by leaching a weighed sample of soil with hydrochloric acid and precipitating the dissolved sulphate by the addition of an excess of barium chloride. The precipitate is then filtered, ignited in a furnace and weighed.

The sulphate content of groundwater or an aqueous soil extract is determined by passing the water through a column of strongly-acidic cationic exchange resin activated with hydrochloric acid. The groundwater or soil-water washings are collected and titrated against standardised sodium hydroxide solution, using a suitable indicator. From the amount of sodium hydroxide used during titration the quantity of dissolved sulphates can be determined and expressed in terms of SO_3 content, as grams per litre or as parts per 1000 000. Full test details are given in Anon. (1975).

It is important that the sulphate content of groundwater and soil is known as ordinary Portland cement deteriorates in the presence of sulphate. Knowledge of sulphate concentrations enables a suitable sulphate resisting or high alumina cement to be used in appropriate concrete mixes for applications below ground level.

STRENGTH TESTS

Triaxial Compression Test

The triaxial compression test is the most widely used test for determining the shear strength of cohesive soils and a number of different methods may be used depending on the application of the results.

In general terms, an undisturbed cylindrical specimen (usually 76 mm x 38 mm) is placed between rigid end caps and covered with a rubber membrane. The assembly is then placed in a triaxial cell which is filled with water, taking care that all air is removed. The confining water pressure in the cell is then maintained at a prescribed constant value while the axial load on the specimen is increased at a constant rate of strain. The test continues until the specimen shears or a maximum vertical stress is reached. Vertical displacement and axial load on the sample are measured during the test. The test is repeated on two further specimens (from the same sampling point) at different confining pressures. From the results obtained from the three tests, a standard graphical construction (based on the Mohr-Coulomb failure criterion) enables the measured principal stresses to be plotted so that the shear strength of the soil can be determined in terms of its cohesive and frictional components (ie. cohesion, C, and angle of internal friction, ϕ).

The test may be carried out with the sample either drained or undrained (with or without pore pressure measurement), and the type of test will depend upon the site conditions and type of engineering works being undertaken.

An **unconsolidated-undrained (UU) test** is used for foundations on normally consolidated clay soils (where drainage would be slow). The test normally takes only a few minutes, as pore pressures are not allowed to dissipate, and is thus often known as a **quick-undrained (QU)test.** The strength parameters determined in this test are the total or apparent undrained cohesion and friction values (C_u and ϕ_u, respectively).

In a **consolidated-undrained (CU) test,** free drainage of the specimen is allowed under the cell pressure for 24 hours before testing (that is, the sample consolidates). The drainage valve is then closed and the load increased rapidly to failure. This test is applicable to situations where a sudden change in load takes place after a period of stable conditions (eg. as a result of rapid drawdown of water behind an earth dam).

A **consolidated-undrained test** with pore pressure measurement may also be carried out. In this test, the measurement of pore pressure enables calculation of the effective strength parameters, $C'$and ϕ' (sometimes referred to as the "true" cohesion and "true" angle of internal friction), in addition to the undrained parameters, C_u and ϕ_u.

A **drained (CD) test** is suitable for sandy soils or for clay embankments in which drainage blankets have been laid. Free drainage of the sample is allowed during both the consolidation and loading stages of the test, with the sample loading applied at a rate slow enough to allow dissipation of pore pressures. The test conditions enable the determination of the effective strength parameters, C' and ϕ'.

CONSOLIDATION and COMPACTION TESTS

Consolidation Test

If a saturated cohesive soil is subjected to an increase in loading the pressure of the water in the pore spaces will increase by the same amount as the applied stress. The water will therefore tend to flow towards areas of lower pressure at a rate controlled by the soil permeability. The removal of water causes a decrease in volume of the soil, a process known as consolidation.

The consolidation parameters are measured in the laboratory by placing a disc of soil confined in a metal ring, in a water filled cell. A constant normal load is applied to the disc and its decrease in thickness measured with time. When it reaches a constant thickness for a given load, the load is increased (usually doubled) and the readings repeated. The loading is continued depending on the soil type and the structure for which the data is required. The coefficient of volume compressibility, M_v (m^2/MN), can then be calculated. This is a measure of the amount of volume decrease that will take place for a given increase in stress. The coefficient of consolidation, C_v (m^2/year) is also calculated, and is a measure of the rate at which the volume change will take place for a given increase in stress. The coefficient of permeability (k) also can be calculated from results obtained in the consolidation test where:

$$k = C_v \cdot M_v \cdot 0.31 \times 10^{-9} \quad \text{m/s}$$

Consolidation test results are important for foundation design and calculating the likely settlements that will take place during and after construction. The test results also enable the planning of phased construction stages to allow full consolidation settlement (dissipation of pore pressures) to take place prior to successive load stages.

Compaction

The compaction test determines the moisture content (the 'optimum') at which a soil may be compacted to its maximum dry density. A quantity of soil (5 kg) is compacted in a standard mould using a standard rammer (2.5 or 4.5 kg) which is dropped from a standard height (300 mm or 450 mm) a standard number of times (27). The density of the compacted soil is then measured and its moisture content determined. The procedure is then repeated using the same soil at different moisture contents.

The dry density of the compacted soil is plotted against its moisture content and the moisture content at which maximum compacted density may be achieved is read from the curve. [Details are given in Anon. (1975)].

The results of the compaction test are used to determine the optimum moisture conditions at which to place a given soil as general or embankment fill.

California Bearing Ratio (CBR)

The California Bearing Ratio test is an empirical test carried out in the laboratory, or in the field, which compares the resistance of a soil to penetration by a standard plunger to the resistance to penetration shown by a standard crushed stone:

$$\text{CBR} = \frac{\text{Measured force}}{\text{'Standard force'}}$$

However, there are various ways of preparing samples for the test. The samples may be either undisturbed or remoulded. Remoulded samples may be compressed into a standard CBR (or Proctor) mould under a static load, or dynamically compacted into it, at the required moisture content, either to achieve a specific density or by using a standard compactive effort. Undisturbed samples may be taken on site in a CBR mould, either from natural ground or from recompacted soil such as an embankment or a road sub-base. Specimens may be tested in the mould as prepared (or as recieved) or after soaking in water for several days.

For soaked CBR tests on remoulded soil at maximum compaction, for example, the test normally involves a series of samples which are compacted in a 152 mm diameter mould at moisture contents around the optimum. A surcharge weight is placed on the soil which is then immersed in water for four days. The mould is placed in a load frame and a plunger 48.5 mm in diameter is forced into the sample to a penetration of 2.5 and 5 mm. The CBR value is determined as the higher of the ratios of the resistance at 2.5 mm and 5 mm penetration to the standard resistance of crushed stone at the same penetrations. [Details are given in Anon. (1975)].

The CBR value of recompacted soil is very sensitive to variations in moisture content and dry density. Some typical laboratory CBR values for British soils compacted at natural moisture content are indicated below:

Type of soil	Range of PI (%)	Range of CBR * (%)
Clay	40 - 70	1 - 3
Silty clay	about 30	3 - 5
Sandy clay	10 - 20	4 - 7
Silt	0	1 - 2
Sand (poorly graded)	NP	10 - 20
Sand (well graded)	NP	15 - 40
Sandy gravel (well graded)	NP	20 - 60

* Lower values relate to water table depth 600 mm below formation level. Upper values to water table 600 mm below formation level (after Anon. 1970).

In the field test, the plunger is jacked into the ground against the reaction of a heavy lorry. Field values are usually lower than laboratory values and the results of these in situ tests are not directly comparable with laboratory test results. The laboratory test in the CBR mould is recognised as the standard test. The results of the CBR test are used to assess the suitability of soils for use as base, sub-base and sub-grade in road construction.

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APPENDIX C

Key to Lithology Codes

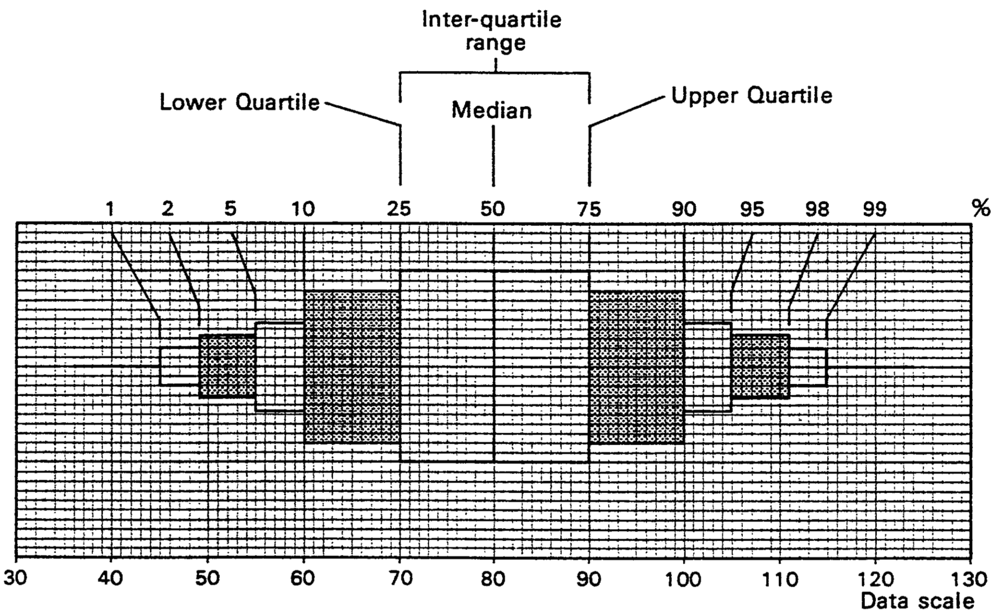
C	=	Clay
M	=	Silt
S	=	Sand
G	=	Gravel
K	=	Cobbles
O	=	Organic

These symbols are used in combination to provide a lithological description, the predominent fraction being represented by a capital, for example, Cms = sandy silty clay; SG = sand and gravel

APPENDIX D

EXTENDED BOXPLOTS OF GEOTECHNICAL DATA

Statistical data summaries for some of the geotechnical parameters are presented graphically as extended boxplots. These plots are constructed from selected percentiles of the data, a percentile being the data value below which a given percentage of the data falls. For example, if the 10th percentile of a batch of 'N' values is 57 then 10% of the 'N' values will be less than 57, and 90% will be greater. In the boxplots shown here the following percentages have been used: 1, 2, 5, 10, 50, 75, 90, 95, 98 and 99. The 25th, 50th and 75th percentiles are more commonly known as the lower quartile, the median and the upper quartile respectively. The example below shows a plot for a large data batch, with the percentiles annotated:



The values of the percentiles are read from the horizontal data scale. In this example the median (50th percentile) has a value of 80. Hence half of the data in this batch have values below 80 and half have values above 80. Similarly it can be seen that 2% of the values fall below 49 and therefore 98% above. The variability or spread of the data can be determined from symmetrical pairs of the percentiles. In this example 90% of the data values fall between 55 and 105 (the 5th and 95th percentiles). A commonly used measure of spread is the Inter Quartile Range (IQR), i.e. the difference between the upper and lower quartiles, which here is 90 - 70 = 20. For the actual data plots the horizontal data scale is drawn on a logarithmic basis in order that spreads of equal proportional change are represented by the same width.

The number of available data values is statistically very important. To a first approximation, the statistical significance of the data summary is proportional to the square root of this number. The height of each box within the plots is therefore drawn in direct proportion to the square root of the number of data values that fall within it. The vertical scale used is arbitrary, but consistent for all the plots presented. A detailed plot, as shown above and incorporating all eleven of the listed percentiles, can only be used where the data batch is of adequate size. The number of percentiles (and therefore boxes) used in each plot is determined by the criteria that the outermost boxes each 'contain' at least three data values and that at least two further values fall beyond these boxes. Where, for instance, the number of data values is between 20 and 59, only four boxes will be shown, with outer percentiles at 10% and 90%. The lines drawn beyond the outer boxes extend to the minimum and maximum values in the data batch. The statistical significance that can be given to each data summary is therefore reflected in both the height of the plot and the number of boxes that it contains. As the outer boxes of any plot are necessarily based on a minimal number of data values, the quantitive information that they portray should be treated with great caution. The tail lines beyond these boxes will have virtually no statistical significance.

This graphical form of statistical presentation has been devised to provide the reader with a rapid and reliable assessment of the 'centre' and spread of each data batch, the relative confidence that should be placed in these and the distinctions between batches for different geotechnical parameters or geological formations.

For the analysis and summary of the geotechnical data base, the approach has been to use robust rather than conventional or 'classical' statistics. The data has been 'validated' only in the sense that gross or obvious errors have been deleted. Of necessity it has been derived from existing site investigation reports and allocated to the geological formations recognised in this project. It is inevitable that the data will be subject to several sources of error. The spatial distribution of the data values is dependent on the locations of the reported investigations and would rarely fulfill the requirements for statistical sampling. An examination of the frequency distributions from this and other areas has shown the assumption of normal (Gaussian) or other mathematically simple distribution is rarely satisfactory.

In these circumstances the conventional summary statistics, such as the mean, and standard deviation (and particularly skewness and kurtosis) can be very misleading and fail to portray the more reliable bulk of the data. The original 'box and whisker' plot has been extended here to provide more information on the tails of the distributions. The selected percentiles have been chosen as those most useful to engineers, although they should be adequate for a statistical reconstruction of the distributions. This latter objective is not wholely achieved, in that those parameters dependent on moisture contents have almost invariably been recorded in whole percentages. The resultant distributions may therefore be coarsely discrete and the percentiles of limited statistical accurancy.

The hypothetical plot shown above illustrates the relative widths of the boxes for an approximately normal (Gaussian) distribution. An indication of the skewness, and even the kurtosis, of the actual data plots may be obtained from a comparison with this plot.

FILE FORMAT

No. of samples	
Median	
Lower quartile*	Upper quartile*

* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)	
	12
117	
99	135

ROCK CORE PARAMETERS

RQD (%)	
	22
39	
14	64

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These sandstones are grey to greyish brown medium grained moderately strong to strong. They often contain thin coal and argillaceous bands and partings. Some are thinly laminated to very thinly bedded in the order of 2 m, others are around 9 m thick, possessing many coal and shale partings. Care should be taken not to overstress weaker argillaceous horizons, and to ensure the absence of near surface abandoned coal or ironstone workings within underlying strata.

Table 1 Summary geotechnical data for Bettisfield Formation Sandstones (Moderately Weathered)

FILE FORMAT

	No. of samples
Median	
Lower quartile*	Upper quartile*

* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)	
	23
47	
36	61

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
(%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	(Mg/m^3)	(Mg/m^3)		CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION ϕu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION ϕ' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
Near rockhead the sandstones are highly to completely weathered and present as dense greyish brown sand, around 1.5 m thick with sandstone lithorelicts. Care should be taken to ensure the absence of near surface abandoned coal or ironstone workings within underlying strata. Weathered material may be excavated by digging.

Table 2 Bettisfield Formation Sandstones (Highly to Completely Weathered)

FILE FORMAT

No. of samples		
	Median	
Lower quartile*		Upper quartile*

* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)		
		5
	117	
92		200

ROCK CORE PARAMETERS

RQD (%)		
		5
	19	
17		34

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY	SILT	SAND	GRAVEL
(%)				(Mg/m^3)	(Mg/m^3)		(%)	(%)	(%)	(%)

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These rocks contain massive bedded sandstones and conglomerates which are either quartzitic or feldspathic. They are generally slightly to moderately weathered and moderately strong to strong. Ripping may be utilised where moderately weathered, but blasting may be required where fresher and more massive.

Table 3 Summary geotechnical data for Halkyn Formation Sandstone (Slightly to Moderately Weathered)

FILE FORMAT

No. of samples
Median
Lower quartile* / Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
22
130
56 / 260

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY: LIQUID LIMIT (%)	PLASTICITY: PLASTIC LIMIT (%)	PLASTICITY: PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION: CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
15 8 6 10										

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION: Mv CLASS[2]	CONSOLIDATION: Cv CLASS[3]	COMPACTION: MAXIMUM DRY DENSITY (Mg/m^3)	COMPACTION: OPTIMUM MOISTURE CONTENT (%)	C.B.R. (%)

STRENGTH

TOTAL STRESSES: COHESION Cu (kPa)	TOTAL STRESSES: ANGLE OF INTERNAL FRICTION Øu (°)	EFFECTIVE STRESSES: COHESION C' (kPa)	EFFECTIVE STRESSES: ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
The moderately weathered mudstones are described as hard reddish-brown silty clays of low plasticity with lithorelicts of mudstone. These are heavily jointed, shaly but not readily fissile, enabling excavations by digging perhaps after ripping, and occur interbedded with more competent sandstones. On exposure to water the material will deteriorate rapidly due to softening and become less strong. Artesian water conditions occur in the Alyn valley.

Table 4 Summary geotechnical data for Erbistock Formation Mudstones (Moderately Weathered)

FILE FORMAT

	No. of samples
Median	
Lower quartile*	Upper quartile*
* where No. of samples ≥10	

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
15 102 64 172

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
(%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	(Mg/m^3)	(Mg/m^3)		CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
14 10 7 12	6 35	6 21	6 14							

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
The highly to completely weathered mudstones behave as a soft reddish-brown plastic silty clay, of low plasticity, 1 - 3 m thick, becoming stiffer with depth. The material is easily diggable. Difficulties may arise during wet weather which will further soften the clay and lead to a reduction in strength.

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

Table 5 Summary geotechnical data for Erbistock Formation Mudstones (Highly to Completely Weathered)

FILE FORMAT

	No. of samples
Median	
Lower quartile*	Upper quartile*

* where No. of samples $\geq$10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)	
	41
200	
73	354

ROCK CORE PARAMETERS

RQD (%)	
	16
33	
16	59

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
26 (No. of samples); 7 (Median); 6 (Lower quartile); 9 (Upper quartile)										

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION ϕu (^{o})	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION ϕ' (^{o})

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
Fresh - completely weathered siltstones. These are thinly bedded, grey and reddish-brown moderately strong micaceous siltstones. They are interbedded with mudstones which are typically more weathered to a plastic clay. Artesian conditions are associated with this formation in the Alyn valley.

Table 6 Summary geotechnical data for Erbistock Formation Siltstones (Moderately Weathered)

FILE FORMAT

No. of samples		
	Median	
Lower quartile*		Upper quartile*

* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)		
		11
	86	
56		100

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
(%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	(Mg/m^3)	(Mg/m^3)		CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
8 8.5										

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
See Table 6

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

Table 7 Summary geotechnical data for Erbistock Formation Siltstones (Highly to Completely Weathered)

FILE FORMAT

No. of samples
Median
Lower quartile* Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
12
229
64 464

ROCK CORE PARAMETERS

RQD (%)
12
46
21 77

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These are thinly bedded grey and brown fine to coarse grained moderately strong micaceous sandstones. They are readily fissile due to closely spaced bedding planes, and have rare joints. Because they are interbedded with weaker argillaceous strata, care must be taken not to overstress the sandstones. Ripping may be necessary during excavation. Artesian water conditions are associated with this formation in the Alyn valley.

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

Table 8 Summary geotechnical data for Erbistock Formation Sandstones (Moderately Weathered)

FILE FORMAT

	No. of samples
Median	
Lower quartile*	Upper quartile*

* where No. of samples $\geq$10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)

ROCK CORE PARAMETERS

RQD (%)	
	5
22	

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
(%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	(Mg/m^3)	(Mg/m^3)		CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
Fresh - moderately weathered sandstones. This formation comprises red coarse grained sandstones which are strongly cemented when fresh. The fresh rock lies beneath a cover of completely weathered sandstone which is present as a dense sand. These moderately weathered sandstones contain silty sand partings due to selective weathering along bedding planes. The weathered material can be water-bearing and give rise to 'blowing' conditions.

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

Table 9 Summary geotechnical data for Kinnerton Sandstone Formation Sandstone (Fresh)

FILE FORMAT

No. of samples
Median
Lower quartile* / Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)

ROCK CORE PARAMETERS

RQD (%)		
		14
	15	
4		38

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
(%)				(Mg/m^3)	(Mg/m^3)					

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
See Table 9

Table 10 Summary geotechnical data for Kinnerton Sandstone Formation Sandstone (Slightly Weathered)

FILE FORMAT

No. of samples
Median
Lower quartile* Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
9 120

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
See Table 9

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

Table 11. Summary geotechnical data for Kinnerton Sandstone Formation Sandstone (Moderately Weathered)

FILE FORMAT

No. of samples
Median
Lower quartile* Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)

ROCK CORE PARAMETERS

RQD (%)	
	51
0	
0	30

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These argillaceous strata weather to a firm to stiff brown and grey laminated and fissured silty clay with lithorelicts. Moderately weathered strata have been recorded where the rockhead lies at 35 m below ground level. The material may be excavated by digging, but ripping may be necessary where it is less strongly weathered, which will be aided by the many discontinuities present. The material is susceptible to weathering when wetted, and swell potential should be assessed. They are generally not suitable as structural fill.

Table 12 Summary geotechnical data for Bettisfield Formation Mudstones and Shales (Moderately Weathered)

FILE FORMAT

No. of samples
Median
Lower quartile* Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)

ROCK CORE PARAMETERS

RQD (%)
10
15
0 42

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION ϕu (^{o})	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION ϕ' (^{o})

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
The siltstones are usually interbedded with less competent shales, mudstones and coals, where they are present as seatearths. In addition they form stronger, more massive beds up to 6 m thick. Where the siltstones are interbedded with less competent strata, care should be taken not to overstress them. The seatearths contain many irregular discontinuities which are largely absent in the more massive siltstones.

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

Table 13 Summary geotechnical data for Bettisfield Formation Siltstones (Moderately Weathered)

FILE FORMAT

No. of samples
Median
Lower quartile* / Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)

ROCK CORE PARAMETERS

RQD (%)
16
0
0 / 21

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
(%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	(Mg/m^3)	(Mg/m^3)		CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These fissured and thinly laminated mudstones are weathered to a stiff grey brown silty calcareous clay with lithorelicts to at least 1.5 m below rock head. The clay is of low to intermediate plasticity, low compressibility, and has a medium to high rate of consolidation. The weathered material should be easily diggable.

Table 14 Summary geotechnical data for Ruabon Marl Formation Mudstones (Moderately Weathered)

FILE FORMAT

No. of samples
Median
Lower quartile* Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
9
8

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
16 133 92 202										

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
The peat is very soft dark brown or black and fibrous, or decayed to an amorphous silty clay. It is associated with very soft dark organic alluvial clays, and is up to 1.2 m thick. It is highly compressible, will rapidly consolidate and settlements will be large. Removal and replacement is advocated, which should be attained using excavators. Water-logged peat may flow into excavations. Acidic groundwater is usually associated with peat.

Table 15 Summary geotechnical data for Peat

FILE FORMAT

No. of samples
Median
Lower quartile*   Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
24
15
9   23

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY: LIQUID LIMIT (%)	PLASTICITY: PLASTIC LIMIT (%)	PLASTICITY: PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION: CLAY (%)	PARTICLE SIZE DISTRIBUTION: SILT (%)	PARTICLE SIZE DISTRIBUTION: SAND (%)	PARTICLE SIZE DISTRIBUTION: GRAVEL (%)
70	20	18	18	25			4	4	6	6
22	35	21	15	1.99			10	49	35	5
17 26	29 44	19 24	13 21	1.83 2.06						

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION: Mv CLASS[2]	CONSOLIDATION: Cv CLASS[3]	COMPACTION: MAXIMUM DRY DENSITY (Mg/m^3)	COMPACTION: OPTIMUM MOISTURE CONTENT (%)	C.B.R. (%)
8	8			
3	3			

STRENGTH

TOTAL STRESSES: COHESION Cu (kPa)	TOTAL STRESSES: ANGLE OF INTERNAL FRICTION Øu (°)	EFFECTIVE STRESSES: COHESION C' (kPa)	EFFECTIVE STRESSES: ANGLE OF INTERNAL FRICTION Ø' (°)
15	15		
30	0		
11 45	0 0		

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These deposits are soft grey silty clays and clayey silts around 1.5 m thick, often associated with peat and found in the valleys of active rivers. They are compressible soils and offer low bearing capacities. They are easily excavated by digging and are not suitable as structural fill material.

Table 16 Summary geotechnical data for Alluvium (Clays and Silts)

FILE FORMAT

No. of samples
Median
Lower quartile* / Upper quartile*
* where No. of samples ≳10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
78
19
10 / 28

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY: LIQUID LIMIT (%)	PLASTICITY: PLASTIC LIMIT (%)	PLASTICITY: PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION: CLAY (%)	PARTICLE SIZE DISTRIBUTION: SILT (%)	PARTICLE SIZE DISTRIBUTION: SAND (%)	PARTICLE SIZE DISTRIBUTION: GRAVEL (%)
79							2	10	12	13
19							7	18	66	7
15 22								14 20	53 77	2 25

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION: Mv CLASS[2]	CONSOLIDATION: Cv CLASS[3]	COMPACTION: MAXIMUM DRY DENSITY (Mg/m^3)	COMPACTION: OPTIMUM MOISTURE CONTENT (%)	C.B.R. (%)

STRENGTH

TOTAL STRESSES: COHESION Cu (kPa)	TOTAL STRESSES: ANGLE OF INTERNAL FRICTION Øu (°)	EFFECTIVE STRESSES: COHESION C' (kPa)	EFFECTIVE STRESSES: ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS

These deposits comprise medium dense light brown clayey fine sand with occasional gravel. It is generally around 3 m thick, but reaches up to 6 m. They are found within the valleys of active rivers. Vibroflotation has been suggested as a means to increase the density of the sand. Problems may arise when excavating adjacent to water courses. They are generally not suitable for use as fill material.

Table 17 Summary geotechnical data for Alluvium (Sand with Fines)

FILE FORMAT

No. of samples
Median
Lower quartile* / Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
179
26
17 36

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
(%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	(Mg/m^3)	(Mg/m^3)		CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
52								23	52	52
10								8	26	65
7 12								3 10	11 35	58 79

CHEMISTRY

pH	SO_3[1] CLASS
5	6
7.7	1

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION $\emptyset u$ (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION $\emptyset'$ (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
This deposit comprises medium dense silty sand and gravel with occasional cobbles. They are often associated with active river channels, or can be found within predominantly sandy units. They range in thickness from 0.5 to 7 m. They are often water-bearing as they lie within river valleys, and sheet pile cut-offs may be employed, or well point dewatering, to maintain dry excavations.

Table 18 Summary geotechnical data for Alluvium (Sand and Gravel)

FILE FORMAT

No. of samples Median Lower quartile* Upper quartile* * where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
130 24 17 37

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT	PLASTICITY			BULK DENSITY	DRY DENSITY	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
(%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	(Mg/m^3)	(Mg/m^3)		CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
48 8 6 11								19 8 6 10	27 35 25 40	28 60 45 67

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These deposits are chiefly medium dense silty sands and gravels with numerous cobbles and boulders. They are found in present river valleys and were laid down when the river base level was higher. They are up to 7 m thick.

Table 19 Summary geotechnical data for River Terrace Gravels

FILE FORMAT

	No. of samples
Median	
Lower quartile*	Upper quartile*

* where No. of samples $\geq$10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)	
	6
19	

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)		PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
		LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
	10										
15											
8	23										

CHEMISTRY

pH	SO_3[1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
This deposit ranges from a yellow brown silty clay which can contain pockets of peat, to a brown clayey sandy silt with gravel. They occur as thin bands no more than 1.5 m thick within river terrace gravels.

Table 20 Summary geotechnical data for River Terrace Clay

FILE FORMAT

	No. of samples
Median	
Lower quartile*	Upper quartile*

* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

	STANDARD PENETRATION TEST (N-value)
No. of samples	369
Median	24
Lower quartile	19
Upper quartile	45

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

	MOISTURE CONTENT (%)	PLASTICITY: LIQUID LIMIT (%)	PLASTICITY: PLASTIC LIMIT (%)	PLASTICITY: PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION: CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
No. of samples	642	214	211	211	231	107	23	23	25	28	28
Median	19	32	17	16	2.16	1.73	2.67	10	36	36	16
Lower quartile	14	25	15	11	2.08	1.68	2.66	4	32	25	6
Upper quartile	23	41	20	20	2.23	1.86	2.76	18	45	43	25

CHEMISTRY

	pH	SO_3 CLASS[1]
No. of samples	20	24
Median	7.25	1
Lower quartile	7.0	
Upper quartile	7.9	

CONSOLIDATION AND COMPACTION

	CONSOLIDATION: Mv CLASS[2]	CONSOLIDATION: Cv CLASS[3]	COMPACTION: MAXIMUM DRY DENSITY (Mg/m^3)	COMPACTION: OPTIMUM MOISTURE CONTENT (%)	C.B.R. (%)
No. of samples	54	53	8	8	9
Median	3	3	2.0	10	8

STRENGTH

	TOTAL STRESSES: COHESION Cu (kPa)	TOTAL STRESSES: ANGLE OF INTERNAL FRICTION Øu (°)	EFFECTIVE STRESSES: COHESION C' (kPa)	EFFECTIVE STRESSES: ANGLE OF INTERNAL FRICTION Ø' (°)
No. of samples	325	317		6
Median	130	0		31.5
Lower quartile	90	0		
Upper quartile	190	0		

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS

This deposit is very heterogeneous. It is predominantly a red-brown silty sandy clay with fine to coarse gravel, cobbles and boulders. There are pockets and bands of often water bearing sands and gravels within the till. The clay is of low to high compressibility and consolidation settlements will be small.
Excavations in the clay should stand well in the short term, but will deteriorate with wetting.
Suitable for re-use as structural fill at low moisture contents.

Table 21 Summary geotechnical data for Glacial Till (Boulder Clay)

FILE FORMAT

	No. of samples
Median	
Lower quartile*	Upper quartile*

* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)	
	376
19	
15	25

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT		PLASTICITY								BULK DENSITY		DRY DENSITY		SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
		LIQUID LIMIT		PLASTIC LIMIT		PLASTICITY INDEX									CLAY	SILT	SAND	GRAVEL
(%)		(%)		(%)		(%)				(Mg/m^3)		(Mg/m^3)			(%)	(%)	(%)	(%)
	698		147		146		146				213		199					
23		44		22		22				2.06		1.68						
20	26	39	49	19	24	19	25			1.99	2.10	1.56	1.75					

CHEMISTRY

pH		SO_3[1] CLASS
	11	11
7.7		1
7.1	8.3	

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)
5	5			
3	3			

STRENGTH

TOTAL STRESSES				EFFECTIVE STRESSES		
COHESION Cu (kPa)		ANGLE OF INTERNAL FRICTION Øu (°)		COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)	
	253		191			10
80		0			22	
50	120	0	0		20	23

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS

This deposit comprises grey laminated silty clay containing bands of silt and fine sand. The uppermost 5 m are desiccated and shear strength decreases with depth. Strength anisotropy can be expected due to laminated structure. Excavations should stand well in the short term but will deteriorate with wetting. Suitable for re-use as structural fill at low moisture contents.

Table 22 Summary geotechnical data for Laminated Clay Till

FILE FORMAT

	No. of samples
Median	
Lower quartile*	Upper quartile*

* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
34
26
21 55

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
26	8	8	8	7	5	5				
15	35	19	14	2.07	1.77	2.72				
8 27										

CHEMISTRY

pH	SO_3 [1] CLASS

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)

STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)
9	9		
110	7		

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These are well bedded red and grey clayey silts and silty clays. They commonly develop running conditions during excavation. They are unsuitable for use as structural fill materials.

Table 23 Summary geotechnical data for Glacial Silt

FILE FORMAT

No. of samples
Median
Lower quartile* Upper quartile*
* where No. of samples ≥10

IN SITU TESTS

PENETRATION TESTS

STANDARD PENETRATION TEST (N-value)
1691
29
17 46

ROCK CORE PARAMETERS

RQD (%)

LABORATORY TESTS

INDEX PARAMETERS

MOISTURE CONTENT (%)	PLASTICITY			BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE DISTRIBUTION			
	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)				CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)
553							19	157	229	211
10							8	5	50	45
6 16							6 9	3 10	25 87	8 68

CHEMISTRY

pH	SO_3 [1] CLASS
29	57
7.2	1
6.9 7.7	

CONSOLIDATION AND COMPACTION

CONSOLIDATION		COMPACTION		C.B.R.
Mv CLASS[2]	Cv CLASS[3]	MAXIMUM DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	(%)
		17	17	
		1.9	10	
		1.82 2.08	7.5 11	

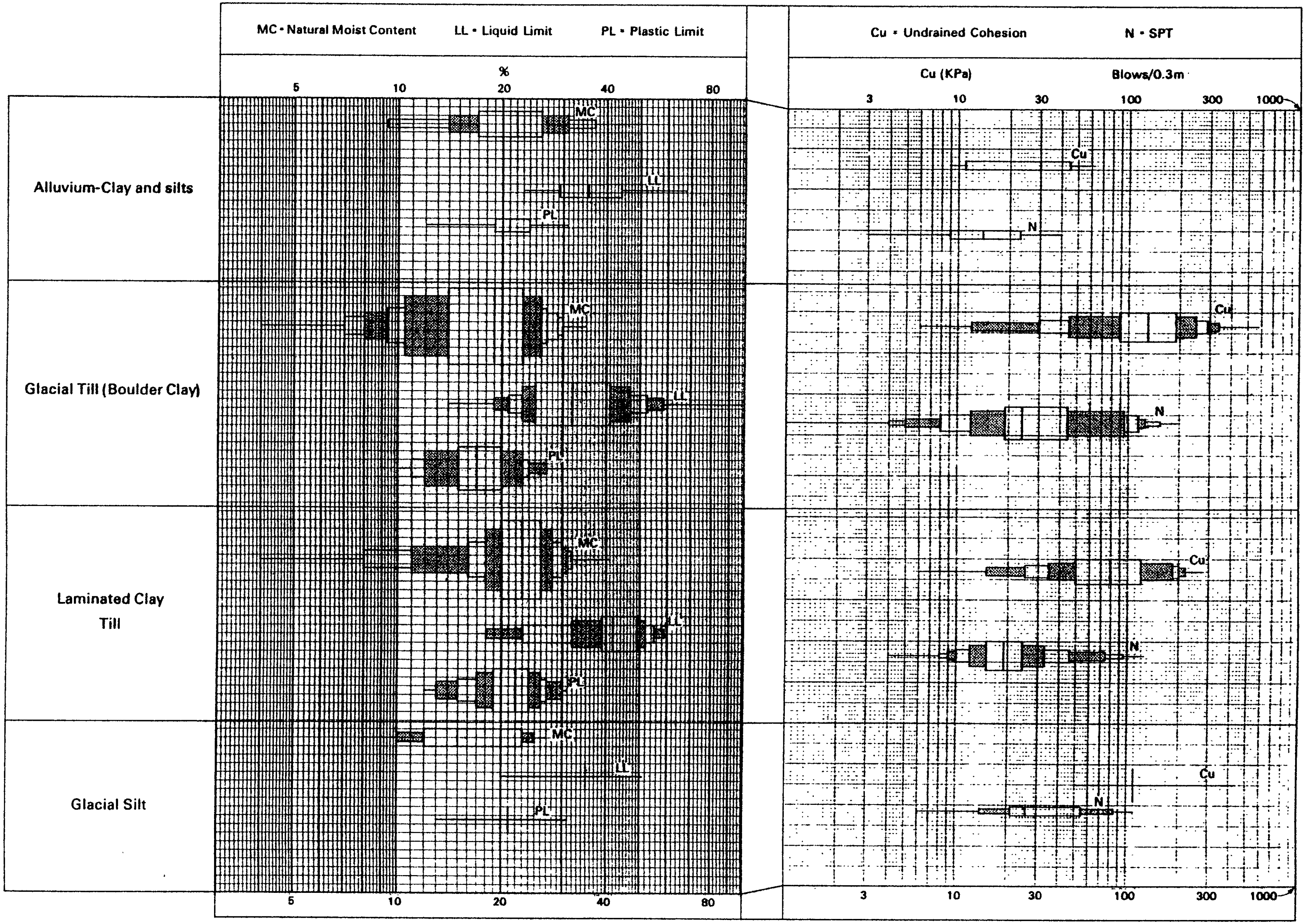
STRENGTH

TOTAL STRESSES		EFFECTIVE STRESSES	
COHESION Cu (kPa)	ANGLE OF INTERNAL FRICTION Øu (°)	COHESION C' (kPa)	ANGLE OF INTERNAL FRICTION Ø' (°)
15	13		
50	0		
39 75	0 0		

1 Sulphate classes defined in Appendix A.
2 Coefficient of Compressibility (Mv) classes defined in Appendix A.
3 Coefficient of Consolidation (Cv) classes defined in Appendix A.

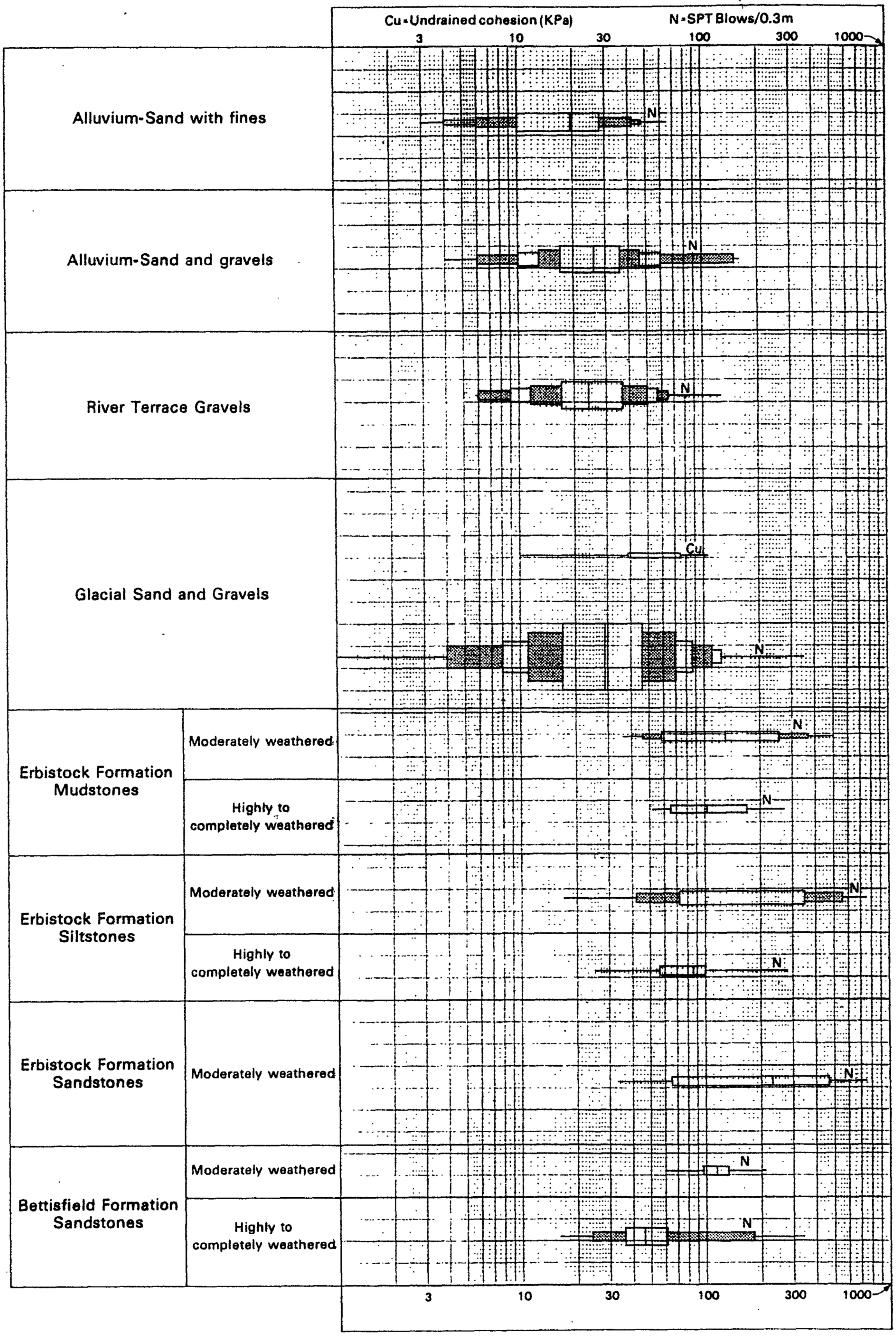
ENGINEERING GEOLOGICAL DESCRIPTION AND COMMENTS
These deposits are medium dense to dense grey-brown sand and gravels with occasional cobbles, medium dense clean sands and sands containing silt and clay. The heterogeneous nature of the deposit requiring its continual sampling over the site area to assess variations in bearing capacity and suitability as fill material. They are often water bearing. Thicknesses of up to 38 m have been recorded.

Table 24 Summary geotechnical data for Glacial Sands and Gravels



Diagrammatic Representation and Selected Parameter Values for Cohesive Lithologies using Extended Box Plots

Figure 1



Diagrammatic Representation of Cu and N values for Selected Lithologies using Extended Box Plots

Figure 2

Plasticity Diagram for Weathered Erbistock Formation Mudstones

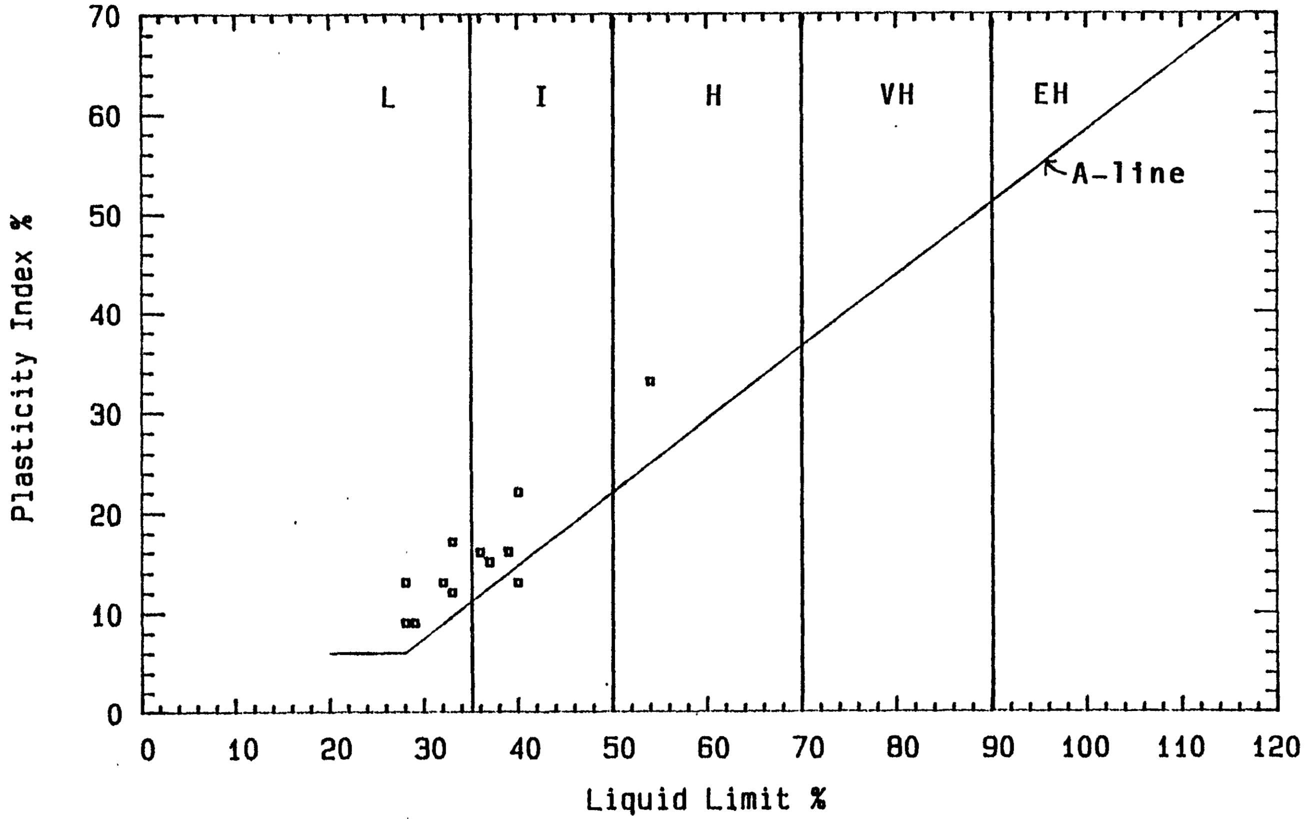


Figure 3

Frequency Histogram for Alluvial Lithologies

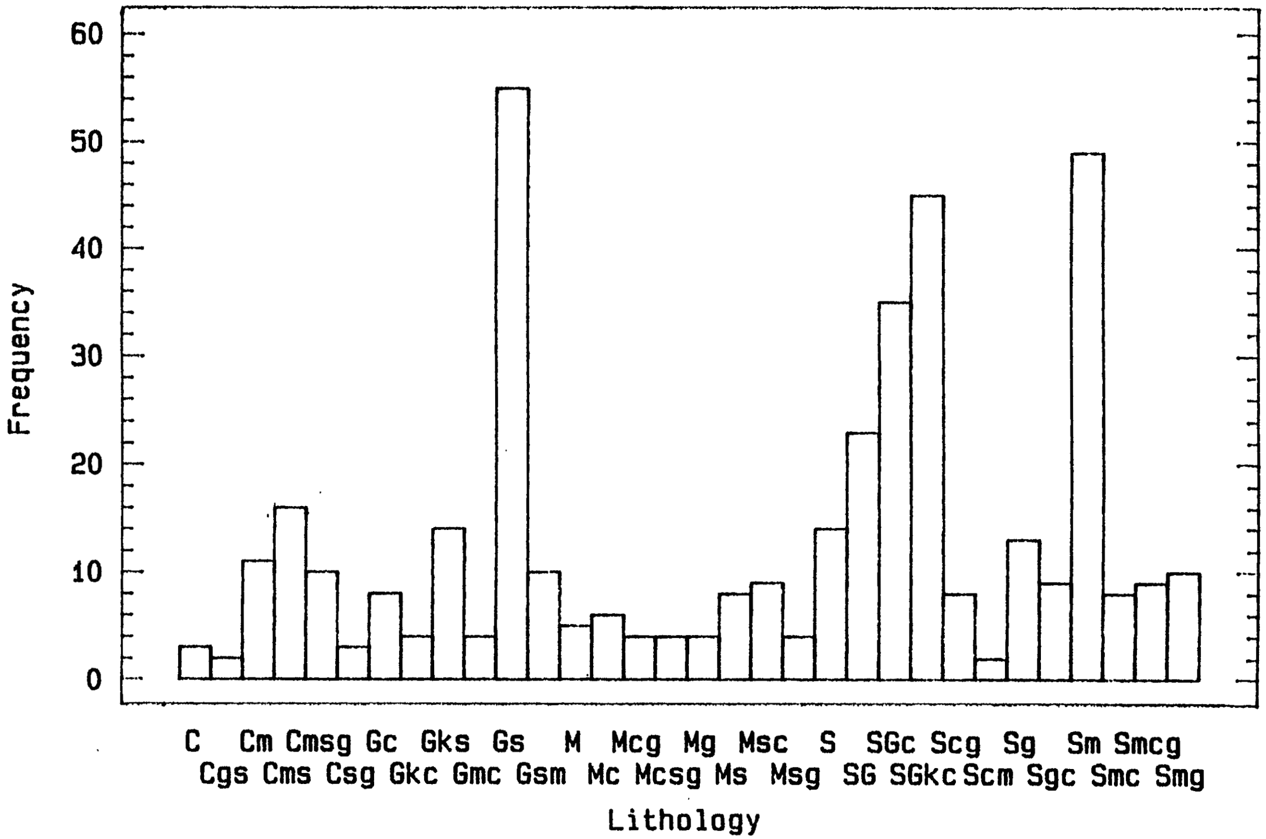


Figure 4

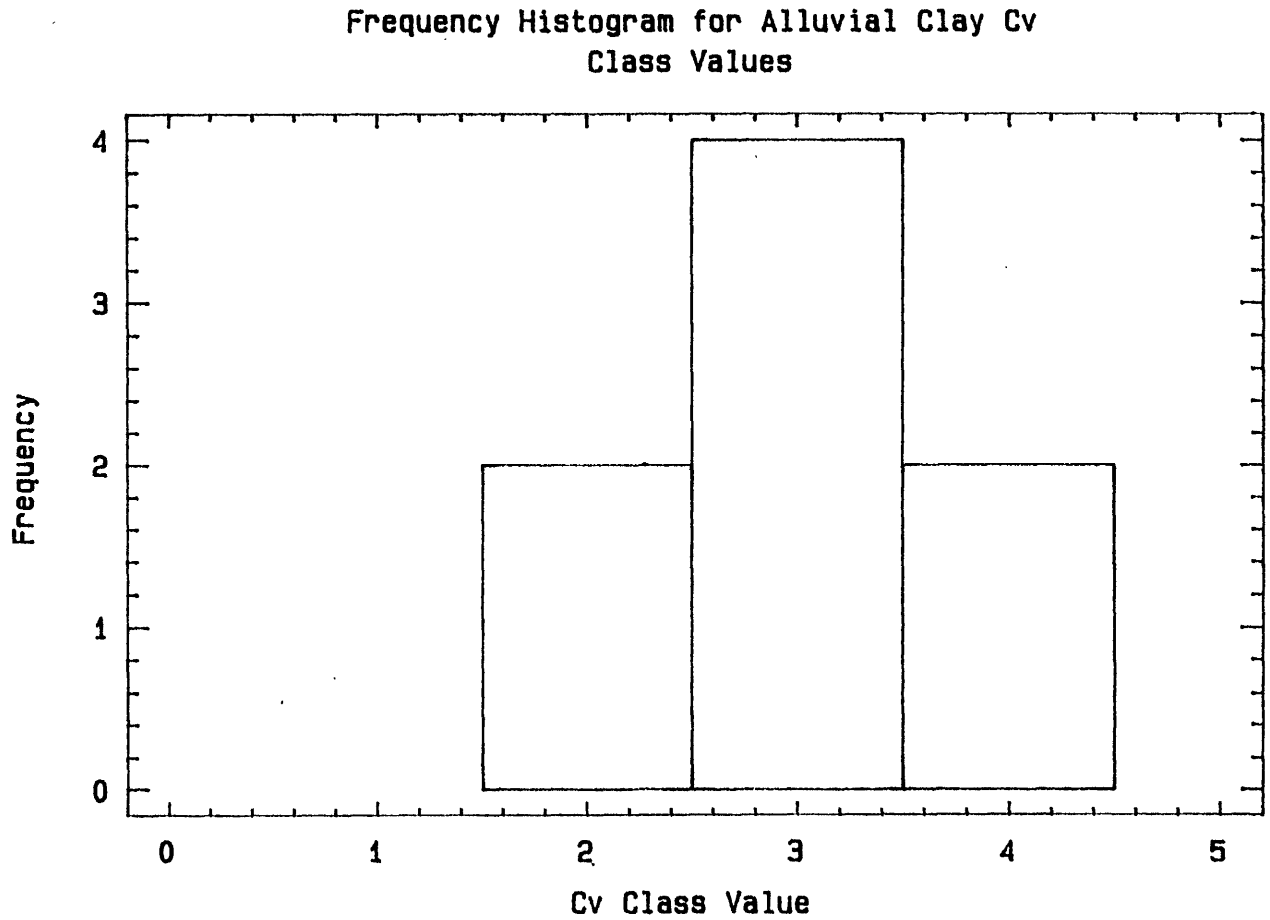

Frequency Histogram for Alluvial Clay Cv
Class Values
Frequency
0
1
2
3
4
0
1
2
3
4
5
Cv Class Value

Figure 5

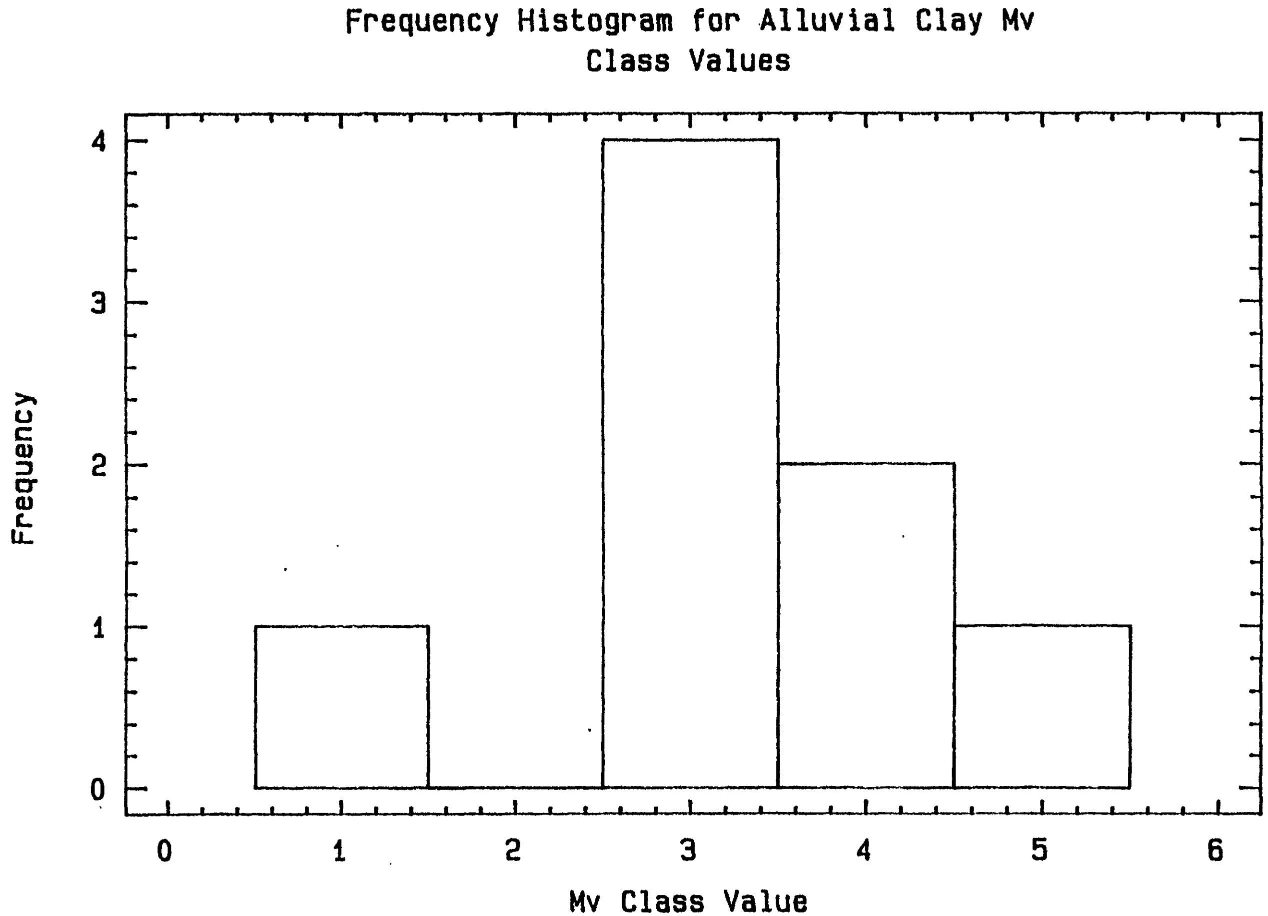

Frequency Histogram for Alluvial Clay Mv
Class Values
Frequency
0
1
2
3
4
0
1
2
3
4
5
6
Mv Class Value

Figure 6

Plasticity Diagram for Alluvial Clays
and Silts

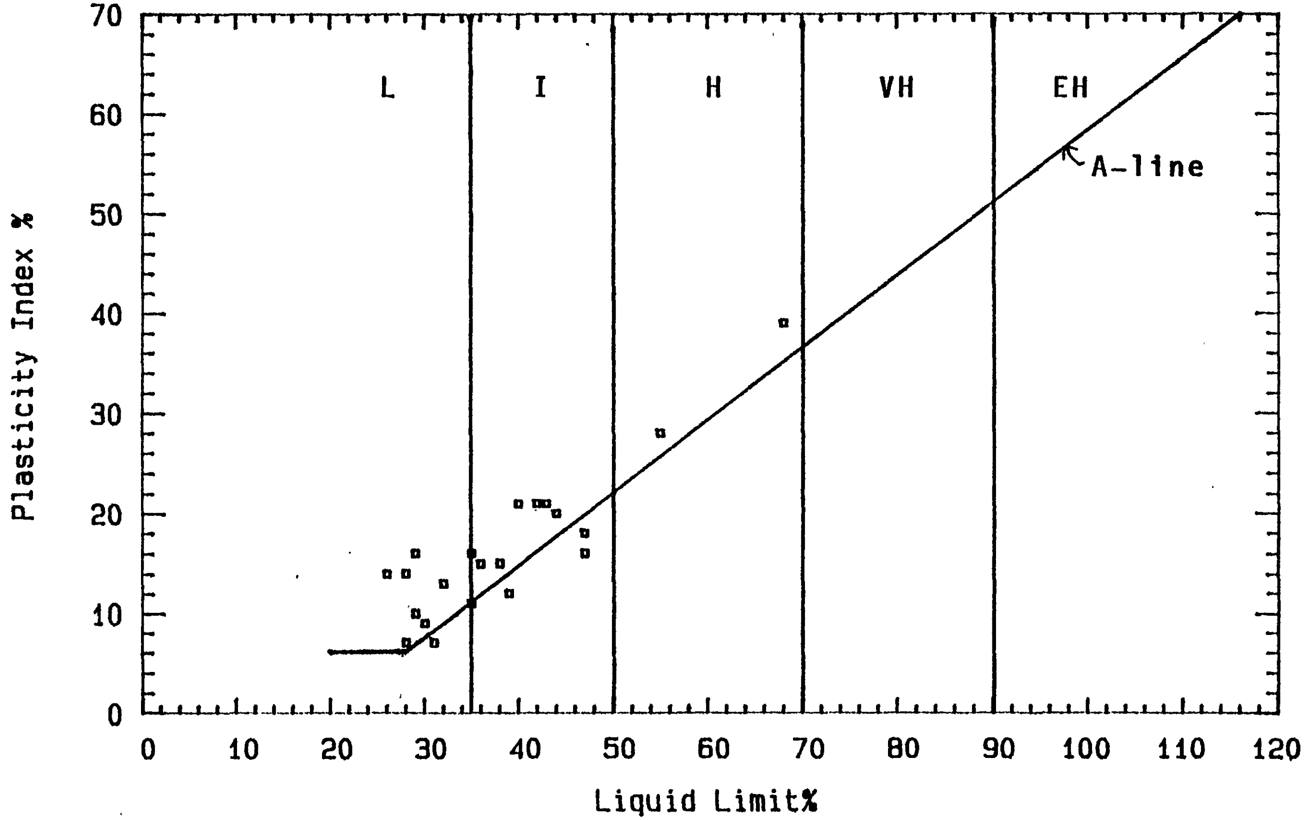


Figure 7

Frequency Histogram for River Terrace Lithologies

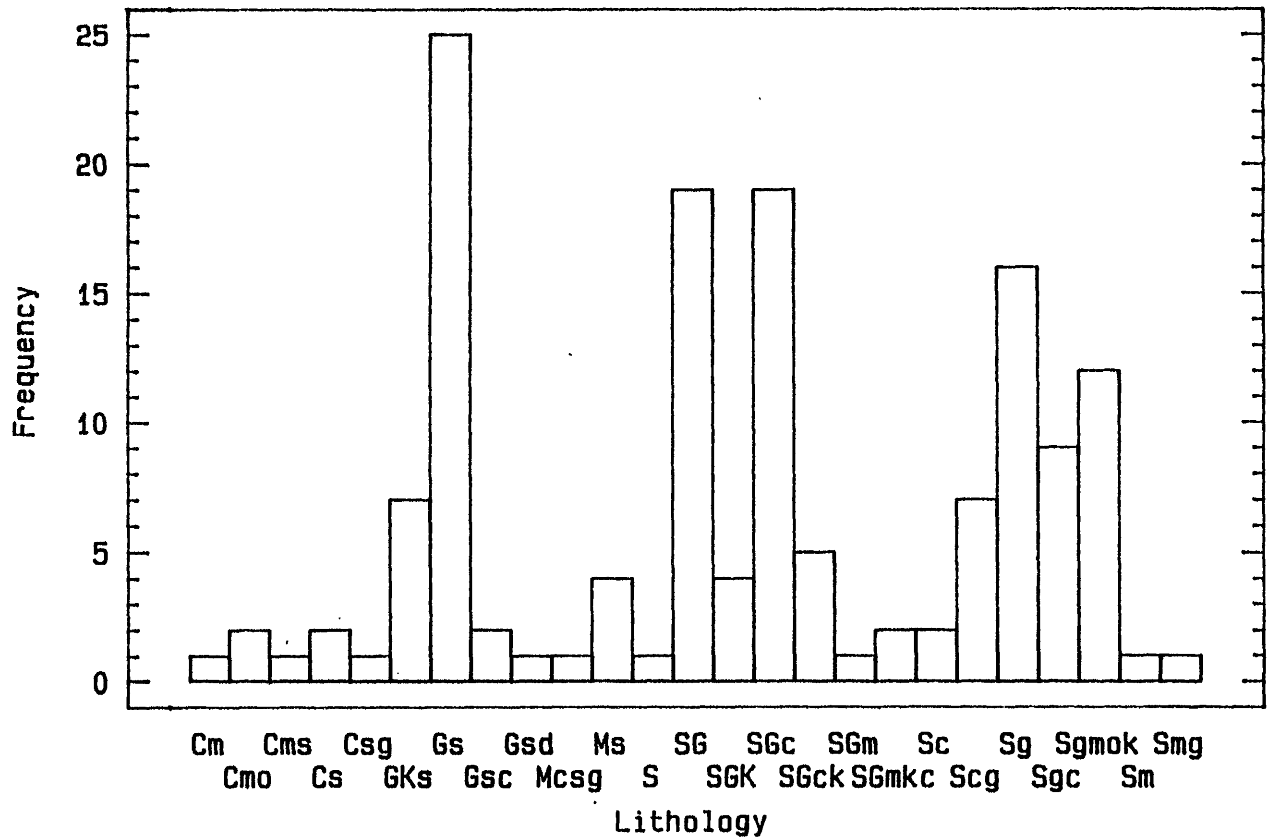


Figure 8

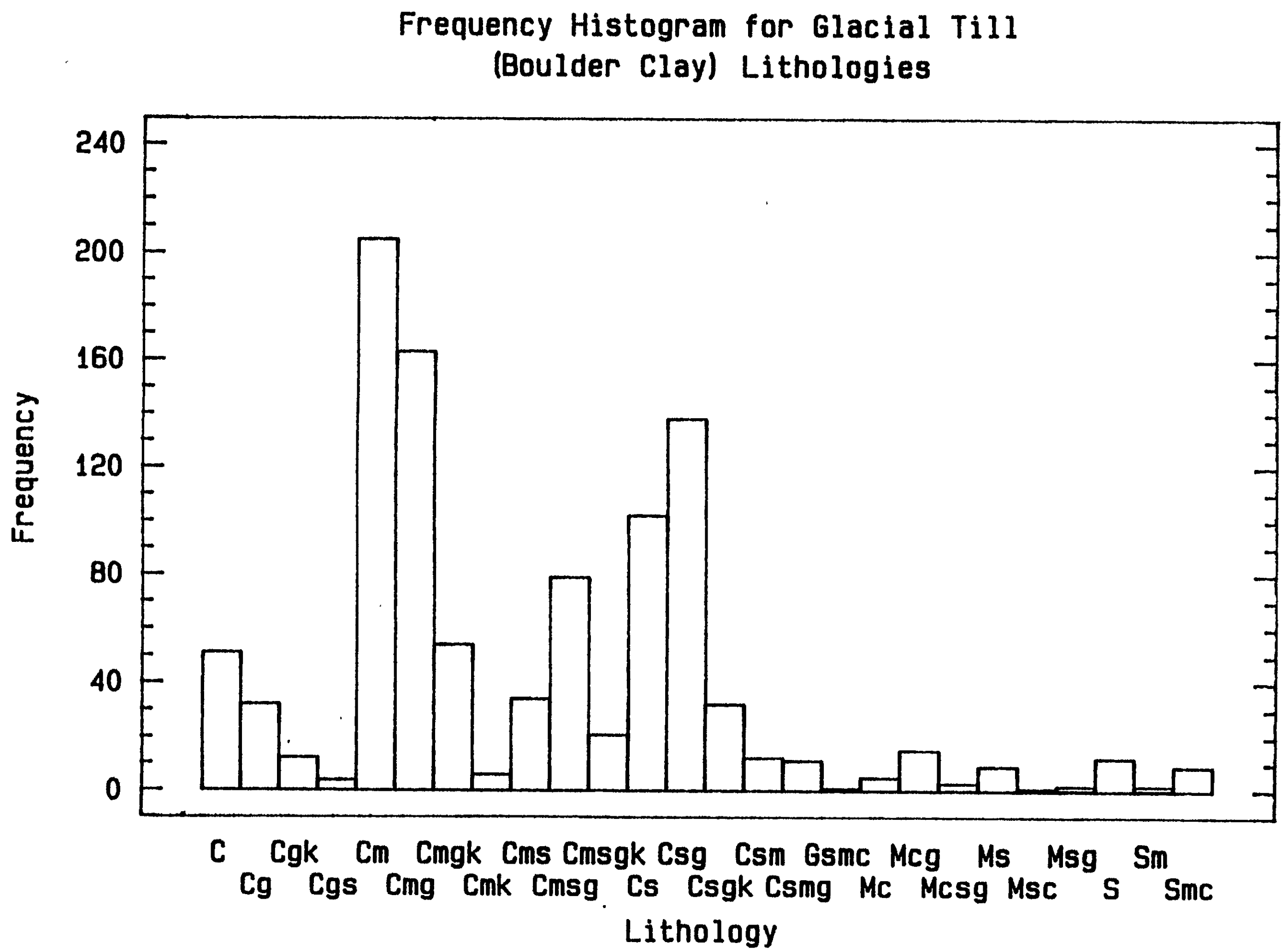

Frequency Histogram for Glacial Till
(Boulder Clay) Lithologies
Frequency
240
200
160
120
80
40
0
C
Cg
Cgk
Cgs
Cm
Cmg
Cmgk
Cmk
Cms
Cmsg
Cmsgk
Cs
Csg
Csgk
Csm
Csmg
Gsmc
Mc
Mcg
Mcsg
Ms
Msc
Msg
S
Sm
Smc
Lithology

Figure 9

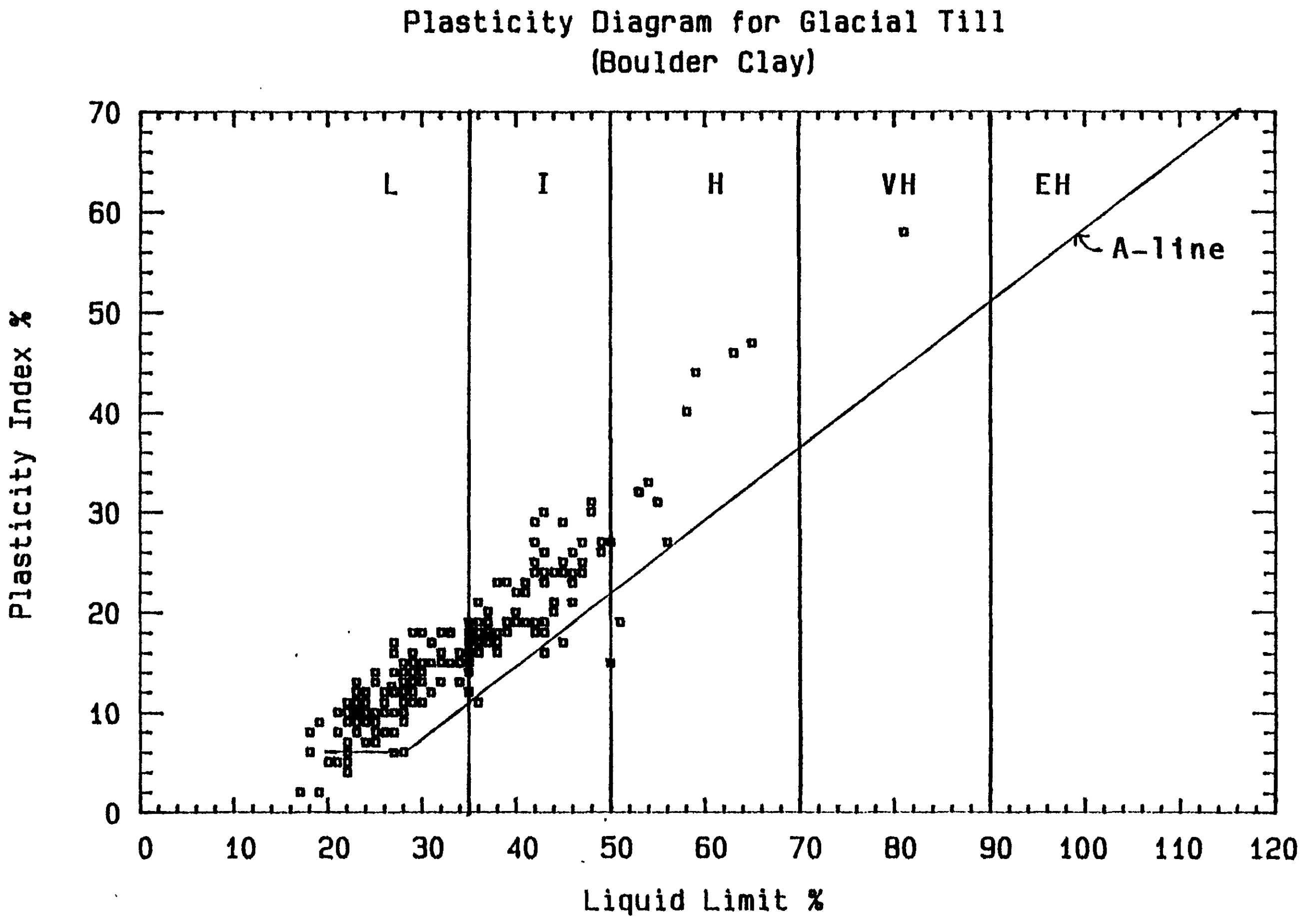

Plasticity Diagram for Glacial Till
(Boulder Clay)
L
I
H
VH
EH
A-line
Plasticity Index %
0
10
20
30
40
50
60
70
0
10
20
30
40
50
60
70
80
90
100
110
120
Liquid Limit %

Figure 10

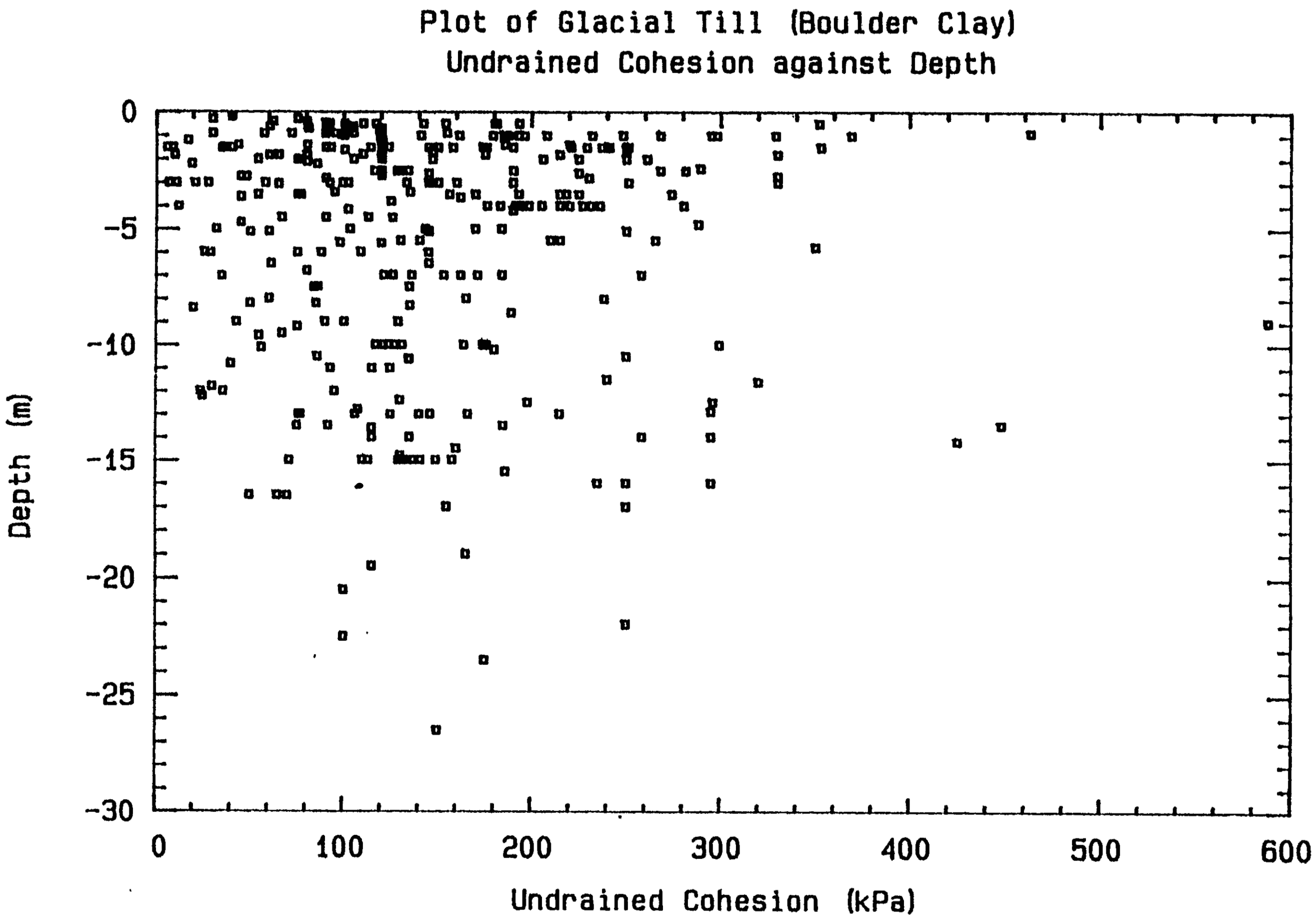

Plot of Glacial Till (Boulder Clay)
Undrained Cohesion against Depth
Depth (m)
0
-5
-10
-15
-20
-25
-30
0
100
200
300
400
500
600
Undrained Cohesion (kPa)

Figure 11

Frequency Histogram for Laminated Clay
Till Lithologies

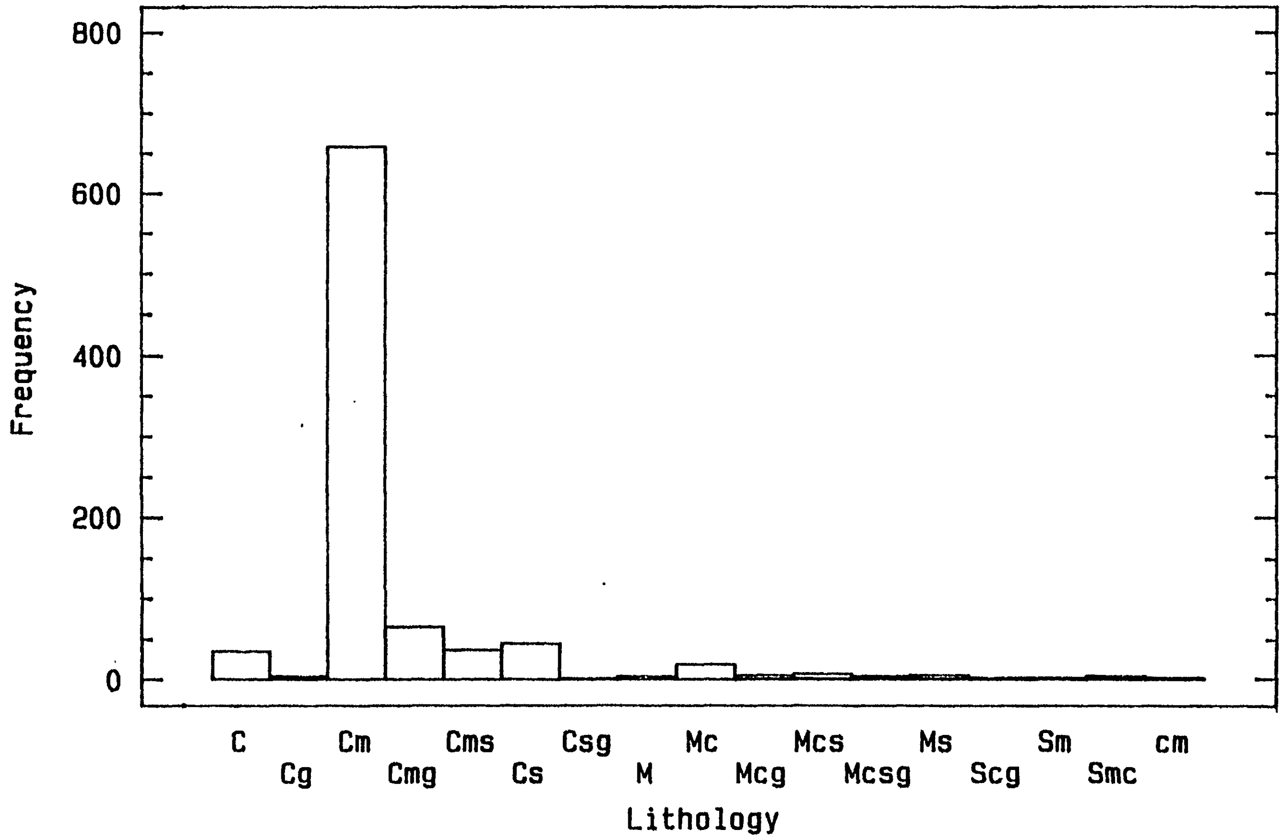
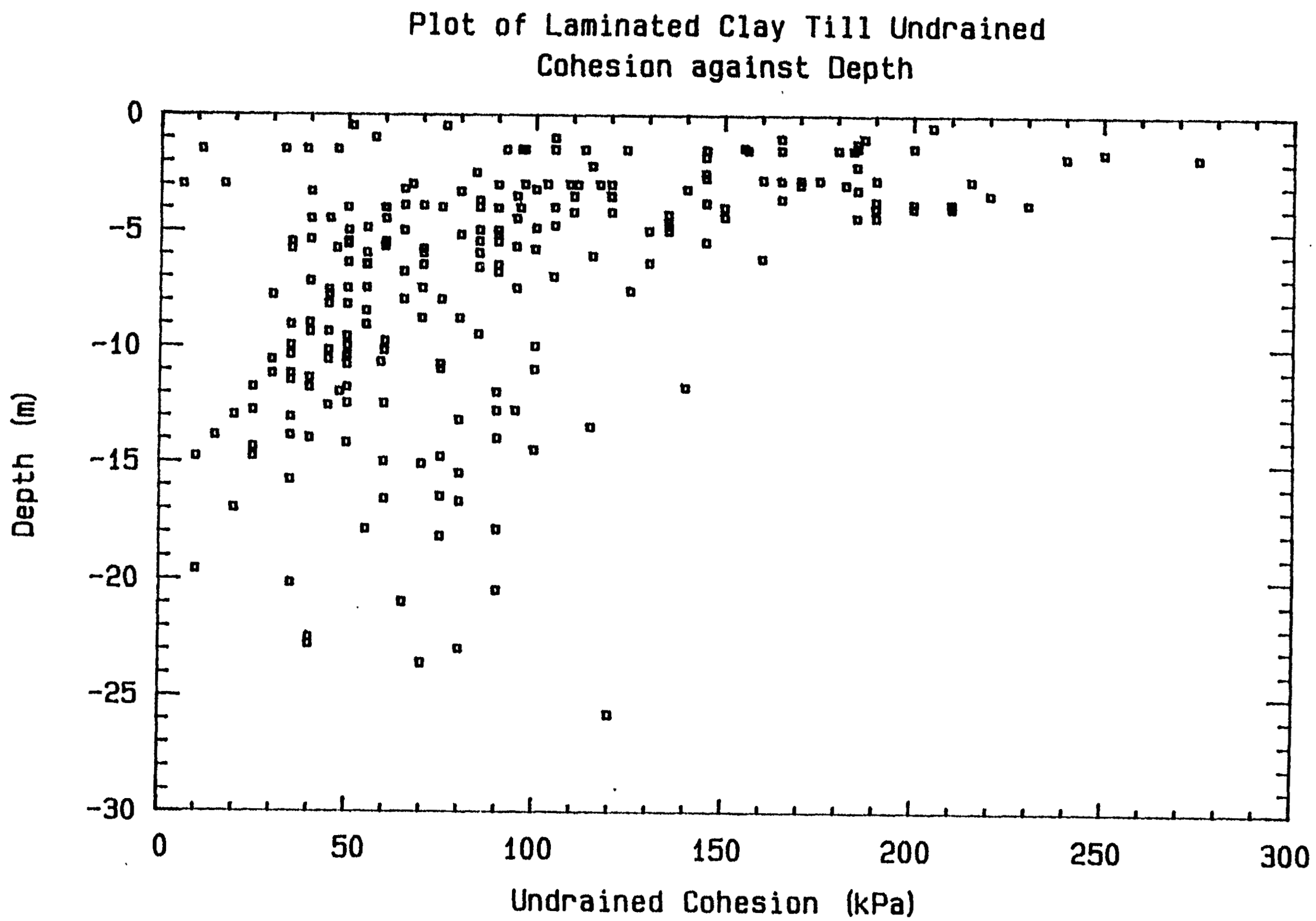


Figure 12



Plot of Laminated Clay Till Undrained
Cohesion against Depth
0
-5
-10
-15
-20
-25
-30
Depth (m)
0
50
100
150
200
250
300
Undrained Cohesion (kPa)

Figure 13

Plot of Laminated Clay Till Moisture
Content against Depth

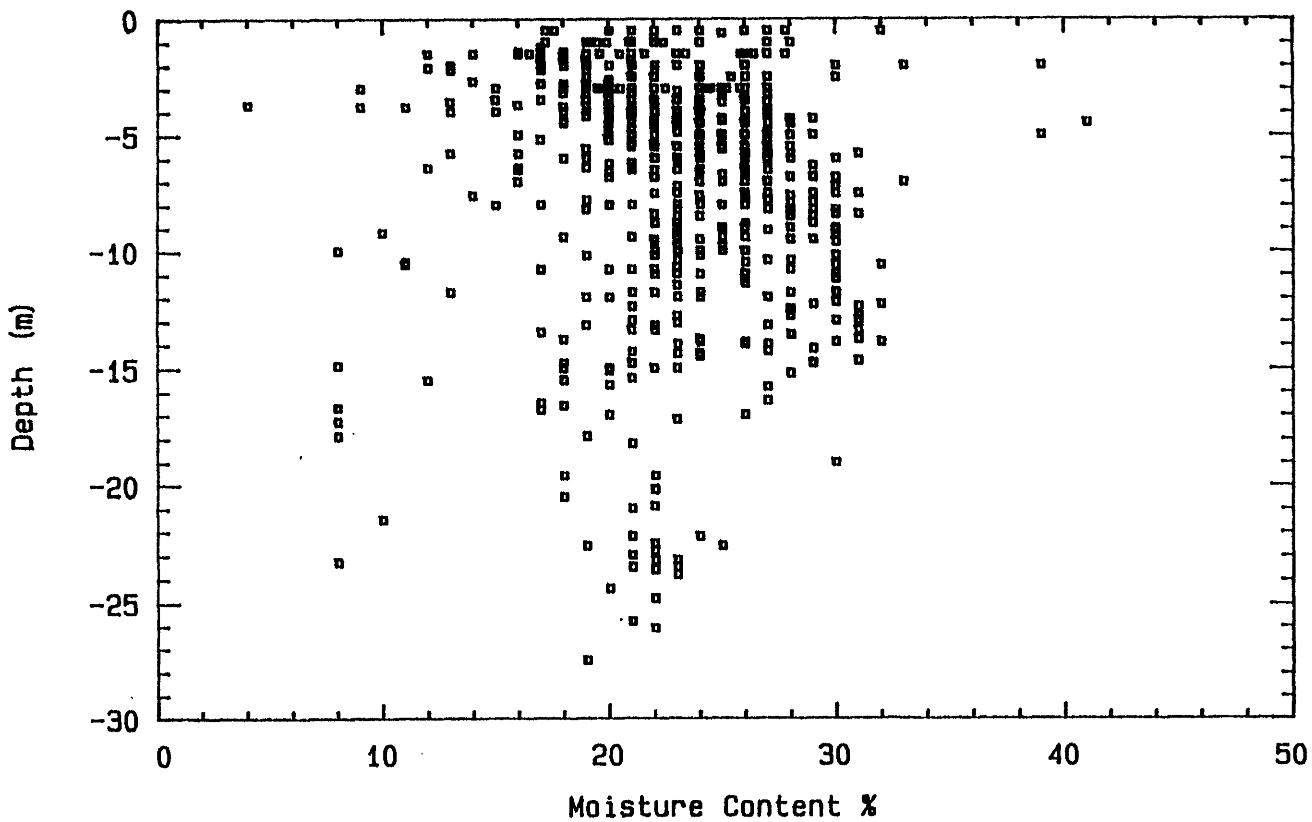


Figure 14

Plasticity Diagram for Laminated Clay
Till

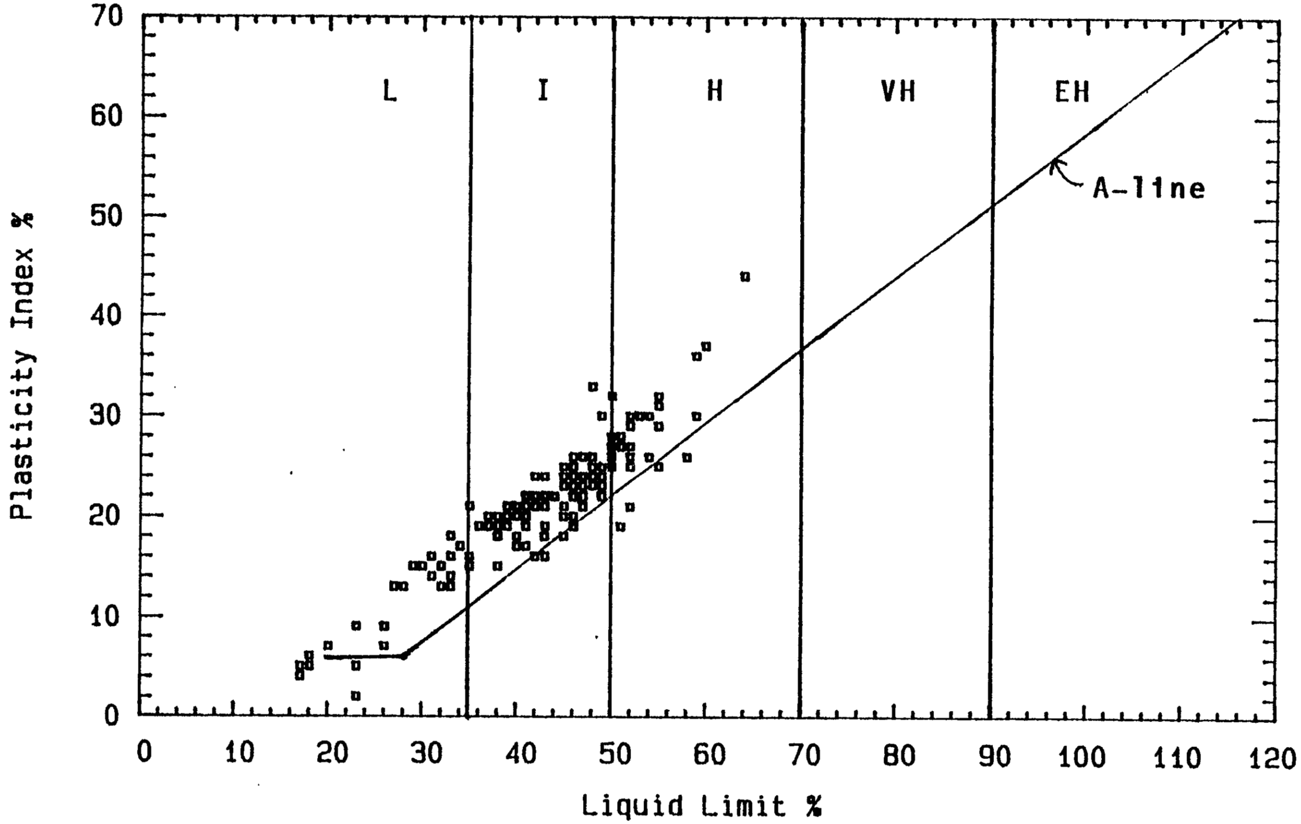


Figure 15