DESIGN OF AN EXPERT SYSTEM FOR GROUND INVESTIGATION

Volume 2

by

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CONTENTS

Appendix 4.1

SCOTTISH OFFICE'S RULES

FOR GROUND INVESTIGATION

SA: PRELIMINARY GROUND INVESTIGATION

This is a dummy rule, which offers a choice between: Desk Study; Site Reconnaissance; Field Techniques; and Laboratory Tests.

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SA1: DESK STUDY

Explanation:

It is good practice at this stage to collect all the desk study and preliminary investigation information together. This will allow a review of the geotechnical information and an assessment of what further work is required.[1]

As a first stage in a ground investigation, the kinds of information indicated on the menu line above may be required. Where there is a choice of site, information obtained from this study may well influence such choice. Much information may already be available about a site in existing records.[2]

Preliminary information on ground investigation at the site of a projected new road or improvement of an existing road is obtained from published maps and memoirs of several kinds, the records and advice of official bodies, available literature, air photographs, local engineering works, and site inspection.

Most sources of information should first be studied at the desk. The desk study can provide information about a site an early stage which is valuable at all stages of the work. It is not expected that all the sources mentioned will be available or will prove useful for any one project, but each project has its particular problems, for which a useful source of information may exist. The information is available at a low cost compared with that obtained by direct sub-surface exploration, and at an earlier date. The full use of these sources can save money by allowing more economical ground investigations to be planned, and can provide information which may be hard to obtain in other ways, for example, the distribution and character of the geological deposits likely to be encountered, ground-water conditions, unstable slopes, mine workings and mineral deposits, surface features, land use, type and density of vegetation, and engineering data from earlier works.[3]

The subdivision in this stage, MAPS, AVAILABLE LITERATURE, REMOTE SENSING and OTHER, will provide clues for obtaining information from individual sources.

[1] SH2/88 1988 SDD P.6 2.9 DESK STUDY WHOLE PARA.
[2] BS5930 1981 BSI P.6 4.2 DESK STUDY FIRST PARA.
[3] LR403 1976 TRRL PP.1-2 1 INTRODUCTION

References:

TM SH 2/88: 1988. Ground investigation. Scottish Development Department, New St. Andrew's House, Edinburgh EH1 3SZ.
BS 5930: 1981. Code of practice for site investigations. British Standard. British Standard Institution, 2 Park Street, London W1A 2BS.

Weltman, A.J. and Head, J.M. 1983. Site investigation manual. CIRIA (Construction Industry Research & Information Association) Special Publication 25 and PSA (Property Services Agency) Civil Engineering Technical Guide 35.
LR 403, 1976. Preliminary sources of information for site investigations in Britain. TRRL.
Clayton, C.R.I., Simons, N.E. and Matthews, M.C. 1982. Site investigation - a handbook for engineers. Granada Publishing.
Hawkins, A.B. 1986. Site investigation practice: assessing BS 5930. (Engineering Geological Special Publication No 2). Geological Society, Burlington House, Piccadilly, London W1V 0JU.
Colwell, R.N. 1983. Manual of remote sensing. Falls Church, Va. American Society of Photogrammetry, USA.
Sabins, F.F. 1978. Remote sensing - principle and interpretation. W.H.Freeman and Company, San Francisco, USA.

Mandatory:

The feasibility, in terms of geological conditions and the engineering problems they pose, of any road scheme should be ascertained at the very outset of any investigation. The British Geological Survey should be consulted for all schemes likely to involve large earthworks, major structures and tunnels or where geological problems are believed to exist. Such consultation is particularly useful where more than one choice of route is under consideration.[1]

[1] SH2/88 1988 SDD PP.3-4 2.4 CONSULTATION WITH BGS 2.4.1

Expert Opinion:

Collecting available documentary material relevant to the site or sites is essential and should never be omitted. In addition, documentary material relating to the history, topography, geology and hydrology of almost all parts of the U.K. is readily and very cheaply available. Where possible, it is advisable to purchase this type of information to form a growing collection. [Separate details of sources of this information are given in appropriate sections of the program.] [2]

[2] CLAYTON et al 1982 P.12 SOURCES OF INFORMATION FIRST PARA.

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SA11: MAPS

Explanation:

Collecting and collating maps of various kinds is the first step in the first stage of a ground investigation. The sources of information that may be needed are listed in the menu line.

The Ordnance Survey (OS) maps provide excellent coverage at a variety of scales for surface features.

The British Geological Survey (BGS) issues a series of geological maps and memoirs which should be studied to determine the expected stratigraphy. It is helpful to collect papers, textbooks, and other publications relating to geology and conditions at the site.[1]

The Soil Survey of Scotland (SSS) publishes maps and information concerning surface soils mainly from the agricultural point of view.[2]

The 'land use' maps are based on the OS maps and indicate land use at the time of preparation.

'Other' maps may include Admiralty Charts which can supplement the OS maps in some areas.[3]

Maps here are divided into several groups: Topography, Geology, Soil, Land Use and Other. Sources of information are obtained by consulting individual rules.

[1] CIRIA25 1983 PP.15-16 1.3.1 DESK STUDY
[2] SH2/88 1988 SDD P.2 2.1.2
[3] CIRIA25 1983 PP.130,15 APPENDIX 1 SOURCES OF INFORMATION 1.3.1 DESK STUDY

References:

TM SH 2/88: 1988. Ground investigation. Scottish Development Department, New St. Andrew's House, Edinburgh EH1 3SZ.
BS 5930: 1981. Code of practice for site investigations. British Standard. British Standard Institution, 2 Park Street, London W1A 2BS.
Weltman, A.J. and Head, J.M. 1983. Site investigation manual. CIRIA (Construction Industry Research & Information Association) Special Publication 25 and PSA (Property Services Agency) Civil Engineering Technical Guide 35.
LR 403, 1976. Preliminary sources of information for site investigations in Britain. TRRL.
Clayton, C.R.I., Simons, N.E. and Matthews, M.C. 1982. Site investigation - a handbook for engineers. Granada Publishing.

Advisory:

Preliminary information on ground investigation at the site of a projected new road, or improvement of an existing road, is obtained from published maps and memoirs issued by the British Geological Survey (BGS). In addition to published information the BGS maintain records of strata encountered in boreholes, shafts etc. and these can be inspected by arrangement at their libraries in Edinburgh and Keyworth (Nottinghamshire) and at local offices in Newcastle-upon-Tyne, Belfast and Exeter. Limited access to BGS published maps and documents is also available at the BGS Information Point in the Geological Museum, London. Universities which have a department of geology may have specialised knowledge of ground conditions in their area and are therefore another possible source of information. The British Regional Geology booklets produced by the British Geological Survey and published by HMSO provide a good deal of information on local geology and are suggested as a good starting point for a desk study. From these, sufficient information can be obtained to plot the approximate geological structure on a longitudinal section of a route.[1]

[1] SH2/88 1988 SDD PP.1-2 2.1 STUDY OF ... 2.1.1 WHOLE PARA.

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SA111: TOPOGRAPHICAL MAPS

Explanation:

Topographical maps are usually the first maps consulted, and of greatest use are those produced at various scales by the Ordnance Survey (OS) which are related to the National Grid.[1]

Topographical data can be obtained from:
1. current Ordnance Survey Topographical Maps;
2. other topographical maps;
3. historical maps;
4. unpublished sources.[2]

[1] CIRIA 25 1983 P.129
[2] LR 403 1976 P.13

References:

See References in Desk Study.

Advisory:

For surface features, the Ordnance Survey (OS) maps provide excellent coverage at a variety of scales. The 1:25 000 sheets give a broad coverage, with greater detail shown on the 6 inch to 1 mile sheets. Contours, and usage, water courses and other surface features are identified. Information regarding the presence of wooded areas, steep slopes, springs, overhead power lines, airport flight paths, rights of way, and availability of water should be noted during the desk study, because they could have a significant bearing on the proposed works, and upon the plant and equipment which may be used for the investigation. The local topography and hydrology should be studied, noting water courses, potential aquifers, and whether flooding could occur.[1]

Old maps can provide information relating to past uses of sites, and should be studied in conjunction with current issues.

Expert Opinion:

Topographical data can be obtained from:
1. current Ordnance Survey Topographical Maps;
2. other topographical maps;
3. historical maps;
4. unpublished sources.[2]

OS maps:
1:25 000 for preliminary assessment, drainage patterns, etc., but contours may have been interpolated;
1:10 000 (or 6 inch) for more detail;
1:2500 or 1:1250 for detailed site investigation;
1:50 000 for general planning and location;
1 inch (1:63 360) for clear contours;
1:250 000 for motorways and roads;
1:625 000 Route Planning Map, revised annually, for recent motorways and roads;
OS Gazette of Great Britain for map references.[3]

Non-OS maps:
Bartholomew's Half Inch for clear presentation of relief.[3]

Historical data:
Old maps may show:
1. concealed mineshafts, adits, and wells;
2. demolished buildings, factories, and sewage farms;
3. progress of tipping: filled ponds, pits and quarries;
4. topography beneath all made and flooded ground;
5. changes in stream and river courses, coasts and slip areas.[5]

Unpublished data:
The Ordnance Survey can supply:
triangulation and levelling data;
revisions in advance of publication.
DOE Map Library have surveys of public rights of way.
Other sources are: County Libraries, County Record Offices, County Engineers, National Library of Scotland, British Museum.[4]
Inquiries concerning availability of unpublished map data should be made confidentially at the Desk Study stage.

[1] CIRIA 25 1983 P.15 1.3.1
[2] LR 403 1976 P.13
[3] LR 403 1976 P.13.
[4] LR 403 1976 P.14.
[5] LR 403 1976 SECTION 8.3 PP.15-16 REVIEWS SOURCES AND USE

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SA112: GEOLOGICAL MAPS

Explanation:

The first reaction of an experienced site investigation engineer to a new problem or site will almost certainly be to look at a geological map of the area. With experience, a great deal of valuable information can be obtained from a knowledge of the location and stratigraphy of the site.[1] Once the geological maps and memoirs have been studied to determine the expected stratigraphy, it is helpful to collect papers, textbooks, and other publications relating to geology and soil conditions at the site.[2]

There are four groups of geological maps.
1. The British Geology Survey.
2. Large scale maps for 'serious' work.
3. Small scale maps for planning purposes.
4. Various other maps.[3]

Note that coverage of certain types of maps may not be particularly recent. Please contact the Regional BGS Office when these are needed. In addition to geological maps, the British Geological Survey (BGS) publishes various written sources of information. The associated information should be collected and consulted together with the maps. Details are given under the item AVAILABLE LITERATURE.

[1] CLAYTON et al 1982. P.16
[2] CIRIA 25 1983 P.16
[3] LR 403 1976 P.2.

Expert Opinion:

Published and unpublished geological maps that are available fall into the following categories:
1. 1 in. to 1 mile and 1:50 000.
2. 1:25 000 (2.5 in. to 1 mile) and 1:21 120 (3 in. to 1 mile).
3. 6 in. to 1 mile (1:10 560).

1 in. to 1 mile and 1:50 000:
1 in. to 1 mile (1:63 360) maps are being replaced by the 1:50 000 maps. The majority of cover now existing remains at a scale of 1 in. to 1 mile. These maps are available in 'solid', 'drift', or 'solid and drift' versions.

1:25 000 (2.5 in. to 1 mile) and 1:21 120 (3 in. to 1 mile):
A few maps of this scale are available, some of which give engineering geology and geotechnical details.

6 in. to 1 mile (1:10 560):
Only a few maps of this series are available for purchase, for areas of Northern Ireland, London and for coalfield areas, The great value of this series, however, lies in the copies held in the British Geological Survey Library, in the Geological Museum, and known as the 'County Series'. These maps can be referred to and hand copied, and provide an excellent starting point for geological investigations.[1]

Geological maps are probably the most important source of preliminary ground investigation. The principal source is the BGS. Some OS outlets carry stocks of local BGS maps. Otherwise, the maps are obtainable from: The British Geological Survey, Merchison House, West Mains Road, Edinburgh EH9 3LA; or the headquarters at: Exhibition Road, London SW7 2DE;or the other Regional Office, as reference, at: Nicker Hill, Keyworth, Nottingham NG12 5GG

Libraries at the Survey Offices carry copies of out-of-print maps for inspection purposes.[2]

The most concise and clear method of presenting geological data is on a geological map. Such maps are prepared at a variety of scales for a variety of purposes.[3]

Large scale geological maps for:

types of material and structures:	1:50 000 (or 1 inch) solid and drift versions
detailed geological information:	1:10 000 (or 6 inch)
drift thickness and rock head:	6 inch transparent overlays
new towns and classic areas:	1:20 000
ground water conditions:	hydro-geological maps variable scales[4]

Small scale geological maps for planning purposes:
1:625 000 solid geology;
1:250 000 (1/4 inch) geological series;
Stanford's Geological Atlas of Great Britain, includes text reviews;
1:1 000 000 solid and drift ('superficial deposits'): Atlas of Britain and Northern Ireland, Oxford University Press;
1:625 000 Planning Maps, Ordnance Survey: Coal and Iron, Limestone, Gravel and Associated Sands: c/w text.[3]

[1] CLAYTON et al 1982 PP.18-19
[2] CIRIA 25 1983 P.130
[3] BEAVIS 1985 ENGINEERING GEOLOGY P.155 8.3
[4] LR 403 1976 P.2

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SA1121: SOLID GEOLOGICAL MAPS

Explanation:

A map of solid geology shows the distribution of the formations that would be exposed at the surface if the ground were free of all drift deposits (i.e. of surface deposits of alluvial, glacial and aeolian material and peat).[1]

'Solid' maps do not show so clearly the extent of any drift that may exist at the ground surface, which is a serious disadvantage in site investigation.[2]

These maps should be used to abstract information concerning the sedimentary, metamorphic or igneous rocks, which lie beneath the drift deposits, through the area of the project, and notes made of any hazards, such as dip of strata, faults, dyke and sill, and so on, that might have an influence on the project.[3]

For the sources of information of Solid Geological Maps, please refer to ADVICE concerning GEOLOGICAL MAPS.

[1] LR 403 1976 PP. 4-5
[2] CLAYTON et al 1982 P.19
[3] REFER TO CLAYTON et al 1982 P.19; LR 403 1976 PP. 5-6

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SA1122: DRIFT GEOLOGICAL MAPS

Explanation:

A drift map shows the distribution of the surface, or drift, deposits (i.e. alluvial, glacial and aeolian material and peat), showing the solid geology only in those areas that are free of drift. Thin drift may not be shown.[1]

All deposits vary both in thickness and in geotechnical properties. In order to help decisions and judgement concerning the amount of investigation required, notes should be taken from these maps concerning the key soil types in the areas of interest.

Particular points that should be noted may include:

1. glacial and related deposits;
2. buried channels;
3. river terraces;
4. springs and seepage;
5. swallow-holes;
6. unstable ground:
   - landslips;
   - foundered strata;
   - escarpments.[2]

Drift geology maps should be used not only to flag the key soil types that may be expected through the project but also to emphasis the hazards that might endanger structures. The types of hazard may include:
1. cambering, valley bulging, gulls and dip/fault movements (often, hard rock overlies clay on the sides of valley);
2. chalk and limestone outcrops (these may be associated with infilled swallow holes, which can be reactivated by the change of surface drainage patterns as a result of construction).[3]

For the sources of information of Solid Geological Maps, please refer to the ADVICE OF GEOLOGICAL MAPS.

[1] LR 403 1976 P. 5
[2] REFER TO LR 403 1976 PP.7-8
[3] REFER TO CLAYTON et al 1982 P.18

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SA1123: SOLID AND DRIFT GEOLOGICAL MAPS

Explanation:

Maps of the Geological Survey series are published for the British Geological Survey (BGS) by the Ordnance Survey. Many maps exist in both 'solid' and 'drift' editions (rock and superficial deposits respectively).[1]

'Solid and drift' maps give the fullest information since they not only give the boundaries of drift materials, but indicate the positions of boundaries between solid strata, where these occur below drift deposits. Whilst it is not usual to find more than one type of map for each location, where there is a choice 'solid and drift' is to be preferred.[2]

For parts of the country having only small amounts of drift deposits, only a single 'solid and drift' edition is published by the BGS.[3]

For the sources of information of Solid Geological Maps, please refer to ADVICE on GEOLOGICAL MAPS.

[1] CIRIA 25 1983 P.130
[2] CLAYTON et al 1982 P.19
[3] LR 403 1976 P.5

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SA1124: ENGINEERING GEOLOGICAL MAPS

Explanation:

When planners have laid out a broad design for development, more detailed environmental geological studies will be required. These will include detailed geological, geomorphological and hydrogeological mapping and geotechnical investigations. Specific area maps and reports will be prepared as a basis for detailed design and construction of the various elements of the project.[1]

Engineering geological maps for an engineering project will show the following:
1. Geomorphological features, including unstable areas, areas of erosion and deposition.
2. The distribution of rock and soil types, their character, stratigraphical relationships, structural features, and physical and engineering properties.
3. Weathering conditions, including thickness of weathered zone, grades of weathering, and properties of weathered rocks.
4. Hydrogeological conditions, including water table and fluctuations, aquifer properties, springs, and groundwater quality.[2]

[1] BEAVIS 1985 ENGINEERING GEOLOGY P. 187
[2] BEAVIS 1985 ENGINEERING GEOLOGY PP.155-156;
DEARMAN 1991 ENGINEERING GEOLOGICAL MAPPING P.119

Expert Opinion:

A very broad cover of general engineering geological mapping of the soils and rocks of the UK is afforded by the two sheets of the solid geology of the whole country published at 1:625 000.[1] For details of recent publications of maps of Scotland, enquiry can be made to BGS, Murchison House, West Mains, Road, Edinburgh, EH9 3LA.

Some information from BGS by phone (09/10/1991, Librarian: 031-667 1000) is as follows:

BGS maps, published:
Engineering geology maps:
  Upper Forth Estuary: 8 x 1:50 000; c/w report.
  Cromarty Firth: 6 x 1:50 000; c/w report.
Environmental geology maps:
  Several published, especially for Midland Valley:
    for each area, 6 or 7 maps showing drift geology,
    drift thickness, shallow mines, etc.
Miscellaneous maps:
  Clyde drift study.

Unpublished maps:
Unpublished maps require special enquiry; and the following information needs to be checked with TRRL Scotland, Craigshill West, Livingston, West Lothian EH54 5DU.

Map showing Construction Materials in West of Scotland:
  drawn for SDD by Babtie.
Interpretation of Soil Maps for Civil Engineering: only a few exist; enquire:
  SSS (Soil Survey of Scotland)
  Scotland university Departments of Civil Engineering.
Maps showing Types of Field Drainage; and other Interpretation of Soil Maps: only a few exist; enquire:
  SSS (Soil Survey of Scotland)
  DAFS (Department of Agriculture and Fisheries for Scotland)
    at headquarters in Edinburgh or at local headquarters.
  Scottish Agriculture College Advisory Service, Local Office.
  Scottish university Departments of Agriculture.

Also refer to the ADVICE of GEOLOGICAL MAPS.

[1] DEARMAN 1991 ENGINEERING GEOLOGICAL MAPPING P.119

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SA113: SOIL MAPS

Explanation:

Clearly, the classification of parent material is most useful for preliminary desk studies, but in addition most geological maps do not consider near surface deposits in sufficient detail for many engineering purposes. Housing, building and temporary works often require very shallow foundations, and soil survey records can therefore be of help in these situations. Additionally, obvious hazards such as peat and landslipping may be identified.[1]

For engineering use, best results are obtained by comparing the soil and geological maps. Soil maps may give a better picture of the drift materials, especially where the geological mapping is old. Soil maps may also give a better indication of lithological type and its variations, and poor drainage and areas with peat deposits are readily distinguished.[2]

[1] CLAYTON et al 1982 P.24
[2] LR 403 1976 P.8

Expert Opinion:

Pedological information relates to the properties of the upper 1.5 m or so of soil, and is primarily of agricultural interest. The soil in this zone does, however, indirectly reflect the type and condition of the underlying drift and solid strata, though modified by the effects of weathering, agriculture and vegetation. The information is particularly useful where drift maps are not available and, since drainage characteristics form part of the soil classification, some indication of the permeability (and hence probable grain size) can be obtained from the descriptions. Evidence of poorly-drained soils or waterlogged conditions is presented on these maps, and the identification of these areas can be subsequently confirmed, for example, from air photos.[1]

It is not necessary to understand fully the pedological basis of soil mapping in order to make practical use of the maps, for they are generally provided with a detailed key in which the geographical association, parent material, texture, subsoil characteristics and drainage class of each soil series are described.[2]

Published soil survey maps exist at scales between 1:1 000 000 and 1:10 560, but the majority of useful cover is provided by the 1:63 360 and 1:25 000 sheets.[3]

Maps of the Soil Survey:
1:63 360: with sheet location and numbers for the New Series geological maps. Memoirs accompany many of the maps which cover some 20% of the country. A further 30% of reconnaissance and other small-scale surveys have been added to the coverage.[4]
1:25 000: are now widely available in Britain, with sheet explanatory text.[3]

Soils maps, NON-SSS:
For information about pedological maps other than those issued by the Soil Survey of Scotland, consult either LR 403: 1976 Section 4.2 p.9, or the Soil Survey of Scotland, the local office of the Scottish Agricultural College, or the local office of DAFS.[5]

The Soil Survey maps are available from:
1. The Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen AB9 2QJ (for the Soil Survey of Scotland);
2. The Soil Survey of England and Wales, Rothamstead Experimental Station, Harpenden, Herts AL5 2JQ[6]

[1] CIRIA 25 1983 P.130
[2] LR 403 1976 P.8
[3] CLAYTON et al 1982 P.24
[4] CIRIA 25 1983 P.131 AND LR 403 1976 P.9
[5] LR 403 1976 P.9
[6] CIRIA 25 1983 P.131

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SA114: LAND UTILIZATION MAPS

Explanation:

The use to which land is put, and its agricultural value, reflect the geology, topography, soil and ground conditions. These factors will affect route planning, land values and the management of the soil survey and construction work.[1]

The coverage of land use maps is incomplete, but where these are available they may provide some guide to land uses which could have associated hazards, and might show up industrial waste land or reclaimed land, for example, in a way that might not be apparent from other maps.

[1] LR 403 1976 P.9

Mandatory:

If a site has been used for other purposes in the past, this can have a significant effect on present intended use. A careful visual inspection of a site and the vegetation it sustains may reveal clues suggesting interference with the natural subsoil conditions at some time in the past, for example, underground mining, opencast mining, quarry operations, waste tips, industrial complexes and other earlier use, and presence of ancient monuments.[1]

Advisory:

The use of land is divided into the following 15 main groups shown on The Land Utilization Maps:
1. Settlement (residential and commercial)
2. Derelict Land (including abandoned tips)
3. Arable
4. Orchards
5. Heathland
6. Rough Land
7. Unvegetated Land
8. Industry
9. Transport
10. Open Spaces
11. Grass
12. Market Gardens

13. Woodlands
14. Moorland
15. Water and Marsh[2]

In the Industry group (8), Extractive Industries and Active Tips are mapped separately. Grass infested with juncus rush, an indication of damp conditions, is designated with a special symbol. Mapped sub-divisions of Heathland, Moorland and Rough Land include Wet Heath, Heather Heath and Dunes.[3]

Expert Opinion:

Land utilization survey maps:
Land values and some geotechnical information can be inferred from land use maps:
1. Second Land Utilization Survey, 1:25 000, Edward Stanford Ltd.;
2. Land Use Survey Handbook, 1965. A.Coleman & K.R.A.Maggs;
3. First Land Utilization Survey, 1 inch, 1930, is more complete.[2]

Agricultural land classification maps:
Land values and some planning information can be inferred from agricultural land classification maps. They may be available from The Soil Survey of Scotland, Macaulay Institute Aberdeen[3]

Land Utilization of Scotland:
For information relating to this, direct enquiries to The National Library of Scotland, Edinburgh. Completed maps may be inspected at that Library.[4]

Second Land Utilization survey maps (England and Wales):
1:10 560 (6 inches to 1 mile) and 1:25 000 series maps can be examined at King's College, Strand, London WC2; (a small payment and prior arrangement is required). These latter are available from Edward Stanford Limited, 12-14 Long Acre, London WC259

[1] BS 5930 1981 IBS PP.6-7 SECTION 5
[2] LR 403 1976 P.10
[3] LR 403 1976 P.9
[4] CIRIA 25 1983 P.131

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SA115: OTHER MAPS

Explanation:

Other maps may be available which have an indirect bearing on the ground investigation. Maps published in journals, monographs, and books written to describe particular areas or topics may also be helpful.

These maps may include:
1. Admiralty charts and hydrographic publications;
2. Meteorological information;
3. Hydrological information;
4. Seismological information.

Expert Opinion:

Geological hazards are a particular problem in ground investigation processes. Attention should be paid to areas on maps where hazards may occur. The main types of hazards which might be noted at this stage are:
1. floods;
2. landslides;
3. moving sand in arid regions;
4. soil erosion.[1]

Admiralty charts and hydrographic publications:
Information is available for nearly all the navigable tidal waterways of the world to various scales. Further information can be obtained direct from Hydrographic Department, Ministry of Defence, Taunton, Somerset

Meteorological information:
The Meteorological Office collects and publishes meteorological information in the United Kingdom and from ocean weather stations. These observations are published in various forms and all enquiries should be addressed to The Director General, Meteorological Office, London Road, Bracknell, Berks RG12 2SZ

Hydrological information:
Information can be obtained from publications of 'The Surface Water Year Book of Great Britain', 'Ground Water Year Books', and 'Soil and Moisture Deficit Bulletin'.

Seismological information:
Computer listings or computer plot of earthquakes occurring in the United Kingdom and elsewhere may be obtained from Global Seismology Unit, Institute Of Geological Sciences, Edinburgh.[2]

[1] REFER TO BEAVIS 1985 ENGINEERING GEOLOGY P.193
[2] ALL INFORMATION FROM BS 5930 1981 IBS PP. 123-124

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SA12: LITERATURE

Explanation:

Any publications which are relevant to the current site should certainly be consulted, e.g. geological memoirs, regional geological guides, mineral assessments, etc. Note that some of these may be directly linked with particular maps.

There are also unpublished and internal documents or local knowledge which may be particularly useful during desk study.

Mandatory:

British Standard Code of Practice BS 5930: 1981 Site Investigations and CIRIA Special Publication No 25 Site Investigation Manual should be used as a general guide to planning and execution of site work.[1]

Information from any previous ground investigations carried out in the general area may be relevant. Any interpretative reports from these investigations should be treated with caution, but the factual reports may give the Designer a valuable insight into the prospective ground conditions likely to be encountered.[2]

Information relevant to the site, the immediate environment and the proposed structure should be collected and collated. Typical preliminary information includes:
1. permitted use and restrictions;
2. approaches and access;
3. Ordnance Survey data (past and present);
4. local authority records to determine past and recent site history;
5. local memoirs on past and present land use;
6. aerial photocoverage;
7. geological information and memoirs;
8. utilities and services;
9. mining and mineral potential;
10. sources of construction materials.[3]

[1] SH2/88 1988 SDD P.2 2.1.3
[2] SH2/88 1988 SDD P.2 2.1.4
[3] CIRIA25 1983 P.15 1.3.1 DESK STUDY

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SA121: PUBLISHED REPORTS

Explanation:

Large scale geological reports for:
specific detailed information: 1-inch Sheet Memoirs;
coalfield and mining: Coalfield Papers and Economic Memoirs;
borehole results: Report Series (annually) and both the above;
additional information: District Memoirs, and
Handbooks of the 2 1/2 inch
maps; all from BGS.[1]

Small scale geological reports:
Handbook of the Regional Geology of Scotland, 5 vols, BGS;
Geological Society: Geology of Scotland;
Geology of England and Wales
Stanford's Geological Atlas of Great Britain, includes text reviews.[1]

In addition to geological maps, the British Geological Survey (BGS) publishes various written sources of information, and will also give access to unpublished information. The most important published works are Regional Guides and Sheet Memoirs.

Regional Guides:
Seventeen regional guides are published, covering England, Wales and Scotland. For the non-geologist, each Handbook on the Regional Geology of Great Britain provides a simple guide to a large section of the country and these are therefore a good starting point for the fact-finding survey.

Sheet Memoirs:
More specific and detailed information, including lists of exposures, can be obtained for a particular 1 in. to one mile geological map in the form of the sheet memoir. Sheet memoirs contain detailed information on the local nature of each of the strata, descriptions of the exposures in the area, borehole and well records and ground water supply details. In addition, slope stability and mineral resources are sometimes discussed. Only some of the available 1 in. maps are covered by sheet memoirs available for purchase, but those which are at present out of print can be referred to at the BGS.[2]

Economic and coalfield memoirs:
'Economic and coalfield memoirs' are similar to sheet memoirs, but cover a wider area of specific interest.[2] Refer to Mineral Assessment Reports which are listed in the book 'British Geological Survey' published by HMSO.

Ground water information:
Where information on ground water is required before subsurface exploration takes place, it may be found in the BGS water supply memoirs and their well catalogues. In addition to giving information on water levels and water supply details, such as hardness and quality, well catalogues can give valuable information on the depths of different soil types.[5]

River information:
For monthly discharges of British rivers see Surface Water Year Book of Great Britain HMSO.
For areas subject to flooding BGS hydrogeological maps (if available).[3]

Coastal information:
Admiralty charts show topography, composition of bottom, nature of coastline and foreshore, obstructions, areas not to be obstructed, and river courses; see:
1. Catalogue of Admiralty Charts and Hydrographic Publications;
2. Admiralty Chart No.5011 Explanation of symbols ...;
3. Mariner's Handbook (N.P.No.100), for interpretation of charts;
4. Admiralty Tide Tables vol.1 European Waters.[4]

Guide to the Coalfield: 1979. Kusay, G.E. and Watson, E.K.:
The Guide takes the records of current mining activities for coal, stratified ironstone, shale and fireclay and shows a map of the National Coal Board Areas, upon which has been superimposed the name of the geologist working in each area. This information should provide a starting point for assessing the effects of future developments of these mines on a proposed structure.[6]

Catalogue of Abandoned Mines: 5 Vols. 1928 - 1931 & Supplements: 1930 - 1939. HMSO:
The Catalogue gives the names and locations of mines whose plans were deposited upon abandonment with the Mines Department. These lists are now out of date, but more recent information can be obtained from the Plans Record Offices at the regional offices of the NCB.[6]

Miscellaneous Mines in Great Britain: 1975. Mining Records
Office of the Health and Safety Executive:
The current miscellaneous mine details are included in the pamphlet. Other information can be obtained from The Health and Safety Executive Library, Baynards House, 1 Chepstow Place, London W2.

Abandoned miscellaneous mines and quarries records are held at The Health and Safety Executive, Abandoned Mines Office, Regina House, 259-269 Old Marylebone Road, NW1 5RR[6]

Directory of Quarries and Pits: 1973. Quarry Managers Journal:
The Directory contains details of quarries in operation. Details of the quarries listed in this volume are given according to geographical location and also on the basis of their main products. Many of the listed materials extracted by quarrying such as ball clay, chalk, china clay, fluorspar, and spar calcite are not relevant to Scotland.[6]

Soil survey records:
These soil survey records consider deposits from ground level to a depth of about 1-1.5 m. The properties of these materials are related not only to vegetation and weathering, but more importantly to the materials lying beneath them. Soil scientists therefore consider solid and drift geology, geomorphology and the physical and chemical properties of their materials, and carry out interpretation of air photographs during the preparation of the soil survey records. The end result is the division of soils into different types of 'soil series', each of which is defined on the basis of its drainage, parent material and profile.[6]

[1] LR 403 1976 TRRL P.3.
[2] CLAYTON et al 1982. P.19
[3] LR 403 1976 P.12.
[4] LR 403 1976 P.13
[5] CLAYTON et al 1982 P.20
[6] CLAYTON et al 1982 P.23

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SA122: UNPUBLISHED REPORTS

Explanation:

The BGS offices also hold various types of unpublished information which may be particularly useful during a desk study. These include out of print sheet memoirs, records made during mapping for the 6 in, County Series (known as 'field slips'), and the Field Unit Borehole Collection. The Field Unit Borehole Collection may be especially useful as it contains previous site investigation records.[1]

Unpublished site-investigation reports for roads (the borehole logs and soil-test results) may be seen at the TRL.[2]

At the DESK STUDY stage inquiries to BGS and TRRL should of course be confidential.

[1] CLAYTON et al 1982 P.19
[2] LR 625: 1974 TRRL P.13

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SA123: LOCAL KNOWLEDGE

Explanation:

Mining records:
BGS (British Geological Survey, Edinburgh/Keyworth) is the major sources of mining information. They generally hold data from all boreholes over 20m deep, in addition to ground investigation reports. Even though some of the information may be confidential, its existence should at least be revealed. Consultation with BGS, Edinburgh, is expected on all but the simplest jobs.

Ross J.W.H & Co.(Mining Engineers, Glasgow) is a company which bought up all historical records. Consultation should be available at the address - 10 Annfield Place, Glasgow G31. Tel. 041-554 2166.

TRL (Transport Research Laboratory, Scottish Branch) have ground investigation data from trunk roads in Scotland. Information required can be obtained from:

Craigshill West
Livingston
West Lothian EH54 5DU
Tel. Livingston (0506) 31921

Meteorological office records:
Although meteorological data are collected from many local weather stations, the Meteorological Office at Bracknell, Berkshire, is the central organisation in the U.K. dealing with weather records and forecasts.

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SA124: OTHER DOCUMENTS

Explanation:

Journal papers and conference proceedings can also be consulted, e.g. Geological Society of Glasgow, Geological Society of Edinburgh, Quarterly Journal of Engineering Geology, Journal of the Geological Society, etc., but note that detailed literature reviews are time consuming and costly.

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SA13: REMOTE SENSING

Explanation:

Remote-sensing methods are useful for recognising areas subject to natural hazards, such as earthquakes, landslides, volcanic eruptions, and floods. Satellite imagery is also useful for assessing the damage caused by these hazardous events and for planning relief and rehabilitation efforts.[1]

[1] SABINS 1978 REMOTE SENSING - PRINCIPLES AND INTERPRETATION P.381

Expert Opinion:

Remote sensing involves the detection of electromagnetic radiation which is either reflected or emitted from the surface of the Earth. The reflection, absorption, emission and scattering of electromagnetic energy by an object provides a unique spectral signature related to its physical properties. The remote sensing system comprises three essential elements: the sensor, the platform carrying the sensing system, either aircraft or satellite, and, finally, the system of data recording or data transmission.[1]

Infra-Red, False Colour Infra-Red and Multi-spectral photography are techniques that have been attempted in Great Britain to ascertain the position of mine shaft, adits, underground cavities, unstable ground and other geological features. To date, generally speaking, these techniques have not revealed anything more than could have been obtained from conventional black and white air photography although infra-red and false colour infra-red techniques have been found to be helpful in locating water sources. Air photography incorporating these techniques is not generally available, and may have to be specially flown.[2]

[1] HAWKINS 1986 ASSESSING BS 5930 P.119 PHYSICAL BASIS OF RS
[2] SH2/88 1988 SDD P.3 2.3 WHOLE PARA.

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SA131: AIR PHOTOS

Explanation:

Air photographs can play an important part in the investigation of engineering sites because they provide an overall view which can reveal surface features, ground conditions, and evidence of past use and natural changes which may be of importance in site development. Ground-based photo interpretation is also useful. SOEND has full air photo cover of Scotland.[1]

[1] LR 1085 1983 P.1

References:

LR 369: 1970. Air-photograph interpretation for road engineers in Britain. TRRL.

LR 1085: 1983. Air-photographs for investigation of natural changes, past uses and present condition of engineering site. TRRL.

Expert Opinion:

General types of aerial photograph:
1. black and white: This is the most common type of aerial photograph and is normally sufficient in most site investigation applications.
2. colour: This can provide additional information, and is most effective for geological interpretation. However, it is more expensive and less readily available. It therefore tends to be of limited use in site investigations.
3. infra-red (in colour or black and white): These photographs record reflected radiation in the visible part of the spectrum, but the films used are also sensitive to reflected infra-red radiation in the wavelength range from 0.7-0.9 microns that is invisible to the naked eye but may help to show up anomalies. It is particularly useful for studying drainage patterns, but it has been used infrequently in site investigation because of the cost involved, and the specialized technology which has to be used and the knowledge required for interpretation.[1]

Typical uses of air photos are for identification of:
geological structure, lithology;
soils, soil moisture regime;
geomorphology, surface processes, changes with time;
unstable slopes, tips, cliffs;
subsidence, swallow-holes;
hydrology, flooding;
history of past use of site;
industrial sites.

Air photos are also used to provide site records and general surveillance.

Ground-based photogrammetry is used for studying cliffs.[2]

The scale of aerial photos is approximate:
1:10 000: frequently chosen;
5 km^2 covered by each print (230 x 230 mm).
1:5000 to 1:25 000: general scales for the initial survey;
each photo covers a little over 1 km^2 to
30 km^2;
These scales provide information on soil features, buildings, or tracks.

There are two methods of obtaining aerial photography of a particular area:
1. by specially commissioning air photography of the area. This is generally expensive and only carried out for large scale site investigations (e.g. major road and motorway schemes).
2. by purchasing copies of existing air photography from commercial or government bodies:

In Scotland:
The Air Photographs Officer
Scottish Development Department
New Andrews House
St. James Air Photography Centre
Edinburgh EH1 3SZ

In England:
The Central Register of Air Photographs
The Department of Environment
Lambeth Bridge House
Albert Embankment
London SE1

In Wales:
Air Photographs Officer
Central Register of Air Photography for Wales
The Welsh Office
Room G 003
Crown Offices
Cathays Park
Cardiff CF1 3NQ

In Northern Ireland:
The Deputy Keeper of Records
Public Record Office of Northern Ireland
66 Balmoral Avenue
Belfast BT9[3]

[1] CLAYTON et al 1982 PP.28-29
[2] LR 1085 1983 APPENDIX 1 PP.32-34 HAS A FULL CHECK LIST OF NATURAL AND MAN-MADE FEATURES.
[3] ALL INFORMATION FROM CLAYTON et al 1982 P.62, CIRIA 25 1983 PP.133-134;
AVAILABLE AIR PHOTO COVER IS LISTED IN LR 1085: 1983 SECTION 3 PP.3-8.

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SA132: SATELLITE

Explanation:

The very small scale images produced by the Landsat satellites allow regional trends in geology and land use to be interpreted. These photographs can be extremely useful in the preliminary reconnaissance for minerals.[1]

The use of earth satellites to acquire images has changed the concepts of image scale. The relative scales of images are designated as follows:
small scale < 1:500 000
intermediate scale 1:50 000 to 1:500 000
large scale > 1:50 000
Sensor systems on high-altitude aircraft and satellites can acquire photographs and images at very small scales.[2]

[1] CLAYTON et al 1982 PP.31-32
[2] SABINS 1978 P.7

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SA133: OTHER

Explanation:

Thermal Infra-Red images record patterns of heat radiated from materials in the wavelength range 3-14 microns.

Radar imaging is an active system that supplies its own illumination. SLAR (Sideways Looking Airborne Radar) imagery can be acquired in the dark and through cloud cover.[1]

[1] SABINS 1978 P.119-231

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SA14: OTHER SOURCES

Explanation:

Other sources of information are existing in-house experience, and perhaps existing ground investigation reports from adjacent sites which are held in-house.

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SA2: SITE RECONNAISSANCE

Explanation:

At an early stage, following the Desk Study, a thorough visual examination should be made of the site. The extent of ground adjacent to the site which should also be examined is a matter of judgement and will depend upon geomorphology, geology and topography and the nature of the earthworks envisaged.[1]

The purpose of the site reconnaissance is to confirm, amplify and supplement the information collected during earlier stages of the ground investigation.[2]

Included within Site Reconnaissance are all those aspects of collection of information which cannot be performed confidentially. It is essential that the process of Desk Study should not alert property owners and others who might potentially have views on, or be affected by proposed road construction works. It is for this reason that some of the items included under the heading Site Reconnaissance are essentially desk based searches for additional information, but ones that cannot be carried out without revealing the fact that a particular project is under consideration.

Information concerning Site Reconnaissance can be obtained through consultation of individual procedures in this section.

There are six sub-divisions within the section on Site Reconnaissance:
- Unpublished Information;
- Past Experience & Local Knowledge;
- Field Reconnaissance;
- Construction Material Survey;
- Surface Geological Mapping;
- Further Photo Interpretation.

[1]. SH2/88 SDD PP. 4-5 2.6.1 AND BS5930 1981 BSI P.6 4.3
[2]. LR 403 1976 TRRL P.18 SECTION 12

References:

BS 5930: 1981. Code of practice for site investigations.
TM SH 2/88: 1988. Ground Investigation. SDD.
LR 1085, 1983. Air photographs for investigating natural changes, past use and present condition of engineering sites. TRRL.
LR 403, 1976. Preliminary sources of information for site investigations in Britain. TRRL.
LR 369, 1970. Air photograph interpretation for road engineers. TRRL.
Weltman, A.J. and Head, J.M. 1983. Site investigation manual. CIRIA (Construction Industry Research & Information Association) Special Publication 25 and PSA (Property Services Agency) Civil Engineering Technical Guide 35.
Clayton, C.R.I., Simons, N.E. and Matthews, M.C. 1982.3 Site investigation - a handbook for engineers. Granada Publishing.

Mandatory:

For the site reconnaissance survey the following should be available:
- site plan;
- district maps or charts;
- geological maps;

aerial photographs.

Permission for access to the site should be sought from both owner and occupier.[1]

Where evidence is lacking at the site, or verification is needed on a particular point of detail (e.g. flood levels or details of changes in site levels) reference should be made to sources of local information such as local authority Engineer's or Surveyor's Offices, historical records and local inhabitants.

Advisory:

During the field reconnaissance survey, geomorphological features, geological conditions, and geotechnical characteristics should be noted. In addition, any obstructions on the site or hazardous areas should be inspected, noted, and marked carefully. Further, an appraisal should be made of: stable angles of slopes; types of construction materials; availability of fills (both natural and industrial); and any other information, such as settlement cracks or signs of building distress in adjacent properties, which may be beneficial to the study.

Where adjacent structures show signs of distress, it is essential to obtain information on the structures and their foundations. On extensive or more complex projects, the appraisal may include the production of engineering geological maps and/or plans with an evaluation of terrain based on outcrops of the underlying soils, vegetation cover, occurrence of slips, springs and other water courses, slope angles and topographical contours.[2]

Where the available geological maps are insufficiently detailed for the investigation in question, it may be necessary to carry out additional geological mapping.[3]

It may be invaluable when carrying out the site inspection to talk to local inhabitants about the past uses of the site.

Further air photograph interpretation may be needed at a later stage.

In Unpublished Information, several sources of information which may affect the choice of site and planning of ground investigation for the project are provided. These can supplement the information already collected during the Desk Study.

Any aerial photography which has covered the project area will assist the visual examination on the ground.[4]

[1]. REFER TO BS5930 1981 BSI P.125 C.1
[2]. CIRIA 25 1983 P.17
[3]. BS5930 1981 BSI P.9 SECTION 9
[4]. REFER TO SH2/88 SDD PP.5 2.6.2

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SA21: UNPUBLISHED INFORMATION

Explanation:

The purpose of the site reconnaissance is to confirm, amplify and supplement the information collected during earlier stages of the ground investigation.[1] Therefore, information concerning the project area, both published and unpublished, should be as complete as possible.

There are two groups in this stage:
Review of the previous work;
Reminder of the additional unpublished information that may be needed.

In practice, Site Reconnaissance may be carried out some years after the Desk Study. The engineers involved in a project may not be fully aware of the data obtained earlier in the investigation. For the REVIEW the user should look back over the published information which has been collected in previous stages. The second group, i.e. TOPO, GEOL, PEDO,... ARCHAE, will remind the user of the types of unpublished information that may be available.

[1]. LR 403 1976 TRRL P.18 SECTION 12

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SA211: REVIEW OF PREVIOUS WORK

Explanation:

The engineer should review previous work which has been done in the earlier stage, Desk Study. Available internal reports and sources of data should be examined if further clarification is needed.

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SA212: TOPOGRAPHICAL DATA

Explanation:

In the period between the publication of readily available maps and the present, changes may have occurred in the ground surface topography of the project site. Data from the most recent survey will be very valuable and should be considered in the Ground Investigation.

Unpublished topographical data can be obtained from several sources:
1. The Ordnance Survey can supply:
   triangulation and levelling data;
   revisions in advance of publication.
   Note that confidential inquiries can be made to the Ordnance Survey, so that some assessment of availability of unpublished topographical data should be possible at the Desk Study stage.
2. DOE Map Library has surveys of public rights-of-way.
   The address is:
   Map Library of Department of Environment
   Prince Consort House
   27 Albert Embankment
   London SE1 7TF
3. Other sources are: County Libraries; County Record Offices; County Engineers; National Library of Scotland; British Museum.[1]

[1] LR 403 1976 TRRL P.14.

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SA213: GEOLOGICAL INFORMATION

Explanation:

Usually, records of boreholes or shafts can reveal the conditions of strata in ground. These unpublished records are maintained by some authorities and organisations. Consultation is available by appointment with them. In addition, the staff of the BGS can be consulted for a preliminary appraisal of the geological conditions at a proposed site.

Unpublished geological information may be available from:
1. Field Unit Borehole Records Collection, BGS;
2. Ground Investigation Reports Collection, TRL Scotland, Livingston;
3. National Coal Board;
4. 6 inch Field Slips, BGS.[1]

[1]. LR 403 1976 TRRL P.3. UNPUB GEOL INFO & ENQU

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SA214: PEDOLOGICAL INFORMATION

Explanation:

Pedological information can generally provide the geographical association, parent material, texture, subsoil characteristics and drainage class of each soil series. The unpublished information relevant to those aspects should be sought at the stage of Site Reconnaissance because further information may have been obtained recently.

There are a number of organisations which may be consulted.

The Soil Survey has records or copies of all known reliable pedological soil surveys, and copies of manuscript maps may be made available to enquirers before publication.

For unpublished pedological information, consult either the Soil Survey of Scotland, the local office of the Scottish Agricultural College, or the local office of the Department of Agriculture and Fisheries for Scotland.[1]

Unpublished Land Utilization Survey information may be available by arrangement with the Director, at King's College, London, or Edward Stanford Ltd. The completed manuscript maps of surveys in Scotland may be inspected at the National Library of Scotland, Edinburgh.[2]

[1]. LR 403 1976 TRRL PP.8-9 4.1 & 4.2
[2]. LR 403 1976 TRRL P.10 5.1

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SA215: WATER INFORMATION

Explanation:

The title here relates to information concerning Ground-water, River, and Coastal conditions.

For Ground-water information:
Unpublished ground-water information may be available from the Hydrogeological Department of BGS, who will wish to see a plan showing depths of proposed cuttings.
Unpublished, non-confidential well records may be seen by appointment at the National Well Collection Record (at BGS Head Office, Keyworth and Scottish regional office, Edinburgh).[1]

For River Information:
For monthly discharges of British rivers:
DOE Water Data Unit,
river authorities.
For areas subject to flooding:
river authorities.[2]

For Coastal Information:
For more detailed information than published:
Admiralty Chart Establishment;
local harbour authorities.[3]

[1]. LR 403 1976 TRRL P.3 2.2.2
[2]. LR 403 1976 TRRL P.12 7.1
[3]. LR 403 1976 TRRL P.13 7.2

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SA216: MINING RECORDS

Explanation:

Mines abandoned before 1872 may be unrecorded. Otherwise try:
a. BGS;
b. Firms of mine surveyors, mining companies;
c. Chief Valuer, Department of Inland Revenue, Edinburgh;
d. Local planning authorities;
e. British Coal: Plans Records Office, Edinburgh (coal and oil shale mines); Regional Office, Fife (opencast); Area Chief Surveyor's Office (subsidence);
f. British Steel Corporation Iron Ore Mining Division, Scunthorpe;
g. Mining Record Office, Health and Safety Executive; Divisional Offices of the Mines and Quarries Inspectorate.[1]

[1]. SH2/88 SDD P.24 APP.A & LR 403 1976 TRRL PP.11-12. 6.1

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SA217: SITE REPORTS

Explanation:

Existing engineering works in the area may be inspected and enquiries may be made of the engineers responsible for them. Site investigation reports should be examined where available. They can give general information on the thickness of the different strata in the area, their local lithological character, and the depth of the water table. They can also give general information on their geotechnical properties, and on the procedure and the type of equipment required for their site investigation. Site investigation reports for major roads are held by the British Geological Survey[1] (Edinburgh and Keyworth) and Ground Investigation Reports Collection by TRL Scotland, Livingston.

[1]. LR 403 1976 TRRL P.17 11

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SA218: ARCHAEOLOGICAL INFORMATION

Explanation:

It has been found that on average a new road may damage or destroy at least one archaeological site every half mile. Many sites are protected by Acts of Parliament; all should be noted and referred to the Chief Inspector of Ancient Monuments; archaeologists need time to record them.[1]

OS maps may show them.

OS Archaeology Division, Scottish Office Ancient Monuments Division & National Monuments Record, County Museums, etc., may know the whereabouts of potential archaeological sites.

Field survey and air photograph interpretation for identification and location of archaeological features require a trained eye, and may extend into the excavation phase of construction.[1]

[1]. LR 403 1976 TRRL P.15 8.2

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SA22: PAST EXPERIENCE

Explanation:

Past experience and local knowledge may often help in the understanding of the site, e.g. excavations on or near the site may have been made in the recent past by Statutory Undertakers for the installation of gas, water, or electricity mains or telephone lines, or for construction of sewers. Enquiries made of appropriate bodies may produce useful information about subsoil conditions.[1]

Very localised and distinctive changes in the appearance of crops and vegetation may indicate filled pits and quarries or other changes in subsoil conditions. Enquiries of farmers and other local inhabitants will frequently yield useful information.[2]

[1]. SH2/88 1988 SDD P.5 2.7 & CIRIA 25 1983 P.16 1.3.1
[2]. SH2/88 SDD PP. 4-5 2.6.1

Advisory:

In the process of absorbing past experience and local knowledge, not only may existing engineering works in the area be inspected and enquiries be made of the engineers responsible for them but also site investigation reports should be examined where available.[1]

Similarly, local people may be able to give information on matters such as premises, use of the site or the location of wells, springs or mine shafts. Archaeological and industrial-archaeological societies and caving clubs may have information on the location of old structures, mines and natural cavities.[1] Records may include such things as transmission lines, telephone lines, ancient monuments, trees subject to preservation orders, gas and water pipes, electricity cables, sewers and so on.

The next stage of the Preliminary Ground Investigation is the Field Reconnaissance itself. This reconnaissance will proceed more smoothly if every effort has been made to accumulate as much unpublished and published information as possible concerning the site of the project.

[1]. LR 403 1976 TRRL P.17 SECTION 11.

Expert Opinion:

Information based on local experience may be available from local authorities, statutory undertakers, libraries and local industries. The list may include:
a. local builders and civil engineering contractors;
b. local authority engineers and surveyors;
c. local statutory undertakers (e.g. British Gas, British Telecom, etc.);
d. local archives;
e. local inhabitants;
f. local clubs and societies;
g. local schools, colleges and universities.[2]

Site investigation reports contain general information of sites and past experience of engineers. The reports for Trunk Roads in Scotland are held by Transport Research Laboratory Scotland, Craigshill West, Livingston, West Lothian EH54 5DU. Enquiries can be made by appointment with them.

[2]. CLAYTON et al 1982 P.68

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SA23: FIELD RECONNAISSANCE

Explanation:

When all the information about the site, that can be obtained from existing maps and records, has been obtained and available air photographs have been examined, a thorough examination of the site should be made by inspecting the whole route on foot.[1]

The walk-over interpretation should evaluate the potential engineering behaviour of the route terrain, including areas of actual and potential instability, high settlement, and poor drainage, to advise on possible alignment changes, construction procedures, costs, and the fuller investigations to follow.[2]

Puzzling features seen on the air photographs should be examined to determine their nature. A preliminary examination and description should be made of the materials on the site. There will also be particular locations, such as areas of instability, where ground conditions may be difficult or may call for special measures, and so will require special examination during the site inspection.[1]

[1]. LR 403 1976 TRRL PP.17,18 SECTION 12
[2]. LR 591 1973 P.21 11.4 2ND PARA

Advisory:

Many features of the site will have already been located by studying the preliminary sources of information, but it will still be necessary to confirm them in the field.

The Civil Engineer should be the key man, leading the work and in administrative control, but he should have the assistance of an Engineering Geologist, especially during the initial stages.[1]

For a successful reconnaissance, first of all the preliminary corridor of interest should be selected. The areas where the ground conditions may be difficult and complicated need to be marked for special examination.[2] The width of the area investigated should be sufficient to define the geology and geomorphology of the site but should also include areas on which contractors may deposit soil, especially on unstable slopes.[3] It is essential that all the information concerning the site is studied thoroughly before carrying out a walk over survey. This will allow a greater understanding of the significance of features seen on and around the site and enable more effective research of local records. The features which should be inspected and noted include:

(i) geomorphology; and
(ii) solid and drift geology.[4]

Pay more attention to areas where there may be mines and tunnels, landfill, isolated pits and cellars, made ground, contaminated sites, and other hazards.

Expert Opinion:

A detailed list of equipment that may be useful for the site inspection is given in [5]. The following list should be reviewed in order to decide which items are essential.

Notebook, pencil, measuring tape, compass, camera, clinometer, binoculars, Abney level;

topographical and geological maps, site plans, preliminary geotechnical maps and section, block diagrams;

air photographs, viewing-board, viewing aid, pocket stereoscope, 'Chinagraph' pencil;

wooden pegs, portable hand-auger, Mackintosh prospecting tool, geological hammer, trowel;

polythene bags, ties and labels;

penknife, hand lens(X10);

50 per cent hydrochloric acid (in small polythene dropping bottle with screw cap);

plumb line.[5]

A knowledge of the geological origins of features and deposits on the site is invaluable for the engineering geologist to help plan a site investigation and to assist in the interpretation of features that are noted and to assess their effect on the project.

LR 591: 1973 p.18 has a summary of events in the Quaternary;
for background reading see:
 Holmes, A. 1965. Principles of physical geology.
 Sparks, B.W., West, R.G. 1972. The Ice Age in Britain.[6]

[1]. LR 591 1973 TRRL P.23
[2]. LR 403 1976 TRRL P.18 SECTION 12
[3]. LR 591 TRRL 1973 P.8.
[4]. CLAYTON et al 1982 P.68
[5]. CLAYTON et al 1982 P.64 AND LR 403 1976 TRRL P.18 SECTION 12
[6]. LR 591 1973 TRRL P.17 11.3

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SA231: GEOMORPHOLOGY

Explanation:

Many geomorphological features will be observed during a site inspection. You can find that the ground surface frequently reveals signs of sub-surface conditions that need special investigation. Such signs should be noted:

(i) General features. Note slope angles, type of slope (convex or concave), sudden changes in slope angle, scarps, lobes of material, wooded slopes, quarrying or excavation from the toe of a slope.

(ii) Glacial features. Note mounds and hummocky ground in more-or-less flat country, U-shaped valleys, overflow channels.

(iii) Mass movement. Note hummocky broken, terraced ground, breaks in slope, arcuate scars, tension cracks, leaning trees, small steps in hill slopes, hedges or barriers on upslope side, structures situated on or adjacent to a landslip, recent movement of fences and hedges.[1]

[1]. SH2/88 SDD P.4 2.6.1 & LR 403 1976 TRRL P.18 12.1 & CLAYTON et al 1982 PP.64-65.

Expert Opinion:

The relative importance and significance of geomorphological features can be assessed in the field with experience. This information can give a guide to geology. Some examples are as follows:
 steep scarp slope: hard rocks resistant to erosion;
 mound and hummock: perhaps till and glacial sand and gravel;
 U-shape valley: often associated with glacial deposits;
 terraced ground on hill slopes: landslipping;
 inclined tree trunk: soil creep;
 structures with settlement: compressible or unstable soils;
 etc.

For those ares which are difficult to examine using air photographs, such as wooded slopes, more attention must be paid to their field examination.[1]

[1]. LR 403 1976 TRRL P.18 12.1 & CLAYTON et al 1982 PP.64-65 &

BS 5930 1981 BSI APP.C & CIRIA 25 1983 P.17 1.3.2

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SA232: GEOLOGICAL ASSESSMENT

Explanation:

In field reconnaissance the scrutiny of solid and drift geology will be helpful for geological assessment. The checklist given below details those features which should be inspected and noted:

(i) Exposure. Note and describe the exposures of rock and soil which may be found in cliffs, stream and river beds, quarries, pits, railway or road cuttings. Note and describe discontinuities such as fissures, joints, bedding planes, faults, swallow-holes.

(ii) Solid and superficial geology. Observe exposures, geomorphological features, land use, vegetational changes which may be used in conjunction with the geological map of the site and air photographs. Also note the presence and availability of possible construction materials (for details see SITE RECONNAISSANCE/MATERIAL).

(iii) Groundwater and surface water. Note springs, seepages, unusual vegetational features, seepage erosion, groundwater levels in shallow wells. Note ponds, streams, active soil erosion, the growth of water loving grasses on higher ground, investigate history of flooding and assess likelihood of flooding.[1]

Special notes should be taken of mines and tunnels, landfill, isolated pits and cellars, made ground, contaminated sites and other hazardous areas.

The aims here are to confirm any features detected from maps and air photographs; to amplify the information that is available; to gain considerable knowledge about the subsoil conditions of the site.

[1]. SH2/88 SDD PP.4-5 2.6-7 & LR 403 1976 TRRL P.19 12.2-3 &
CLAYTON et al 1982 PP.65-66.

Advisory:

Although most adverse geological conditions can be accommodated by appropriate geotechnical design, there is some advantage in seeking to choose road alignments in order, for example, to avoid areas of major slope instability, which can be identified through careful geological assessment at the time of preliminary ground investigation. Geological assessment is a useful aid in a broad planning approach, providing an early and clear warning of adverse geological conditions.[1]

Expert Opinion:

The noting and formal description of geological appearances found in the site visit will benefit geological assessment, whereas the specialist field knowledge and skills of an engineering geologist will give much assistance to the engineer. The Engineering Geologist should be trained in geological processes, stratigraphy, geological structures, soil mechanics, rock mechanics, civil engineering; and he should have extensive practical experience. When a geologist is being commissioned to give advice on a problem of engineering geology, care should be taken to ensure that he has this necessary and particular background of training and experience to support his judgements.[2]

Proper assessment of geological phenomena can indicate geological conditions which may cause geotechnical problems, for instance:

flat ground associated with rivers or streams is likely to be associated with the presence of deposits of compressible alluvium;

soils in areas of extensive drift deposits may also be compressible;

natural cavities may exist in limestone, chalk, and saline deposits;

presence of permeable materials such as limestone, chalk or gravel may give rise to large fluctuations in ground water level;

reeds, rushes and willows indicate presence of wet ground and poor drainage conditions, and possible peat deposits;

high groundwater and poor drainage may be associated with lowland fens, or highland bogs and moors;

unusual crops and vegetation may indicate the presence of filled pits and quarries;

brown discolouration of the water of streams may signify areas of peat;

springs and seepages will give clues concerning the ground-water regime;

gullies and similar features may indicate a likelihood of flooding;

etc.[3]

[1]. LR 591 1973 TRRL P.8 5.2
[2]. LR 591 1973 TRRL P.17.
[3]. SH2/88 SDD PP.4-5 2.6-7 & LR 403 1976 TRRL P.19 & CLAYTON et al 1982 PP.65-66 & LR 591 1973 TRRL PP.5 & 8 & BS 5930 1981 BSI APP.C & CIRIA 25 1983 P.17 1.3.2

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SA233: GEOTECHNICAL CONSEQUENCES

Explanation:

Geotechnical properties of the soils at the site can be recognised from the field reconnaissance by observing, touching, and describing. Geomorphological features and geological conditions may be used to aid the recognition of the soil type. In this stage, the engineer should envisage what type of problems will be encountered, what soil properties will be required, what soil types will be expected, what type of structure will be constructed, what exploration techniques will be selected to provide geotechnical information appropriate to the proposed works.[1]

Superficial deposits are often the cause of geotechnical problems and hence attention should be paid to the notes concerning drift geology given under DESK STUDY/MAPS/GEOLOGICAL MAPS. Easy access to the site for drilling equipment and other site vehicles should be assessed as should the distance between sources of construction material and the site. Preliminary site selection should now be possible.

[1]. CIRIA 25 1983 P.18

Expert Opinion:

A good description of the soil in the area of interest will be very helpful in planning the next step, Field Techniques. For example, expected preferred methods of exploration, sampling, and in-situ tests, etc. can be identified. Guidance to site identification and description of coarse, fine and organic soils is given in Table 6 of BS 5930 (p.101). A primary description of the essential mass and material characteristics of soils is as follows:

consistency (from very soft to very hard);
bedding (interbedding or interlaminated);
discontinuities (open, closed or infilled);
state of weathering;
colour;
particle shapes and composition;
soil name, based on grading and plasticity.[1]

Furthermore, Geotechnical Consequences will reflect other steps in the Preliminary GI:

engineering geological or geomorphological mapping;
associated techniques[2];
approximate analysis of certain slopes in rock areas;
simple engineering geophysics;
hand auger surveys;
backhoe pits.

Also, in this stage, information should be gathered for the design of the main GI:

layout and depths of pits, trenches, boreholes, drillholes;
additional air photo interpretation;
engineering geophysics;
engineering geological mapping;
in-situ tests;
other tests.[3]

See also LR 591: 1973 Table 2 p.20, which has a check list of features to be considered and subsequent investigation to be made.

Samples of soil may be taken for moisture content measurement and index tests. Where it is necessary to sample or prove the extent of certain superficial deposits such as peat, then the Mackintosh prospecting tool or a hand auger may be used.[4]

[1]. CIRIA 25 P.92 & BS 5930 PP.100-104
[2]. Q.Jl.Eng.Geol.5(4),293-381;1972
[3]. LR 591 1973 TRRL P.21.
[4]. CLAYTON et al 1982 P.65

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SA24: MATERIAL

Explanation:

It is important to identify potential or existing local sources of construction materials, since the cost of transporting bulk construction materials, such as sand and aggregates can be prohibitive if the distance between the source and the site is great.[1]

The objectives when identifying materials are: general assessment of the site; possible use as construction materials; location of potential sites for running material to spoil. The first objective has already been considered, the latter two will be dealt with here.

During the reconnaissance, natural and artificial exposures which can be examined near the road-line include: quarries; gravel and sand pits; cuttings; ditches; stream banks; rock outcrops; temporary trenches and small excavations made by public utility undertakings. Rocks and soils that occur in the area should be examined as well. Hand digging and augering may be used.[2]

A list of construction materials for which sources may be required is given in BS 5930 (1981):

(a) topsoil.
(b) fill for earthworks and reclamation.
(c) road base and surfacing materials.
(d) concrete aggregates.
(e) stone for building, rip rap or pitching.
(f) water.[3]

The effect on the environment of extracting any of these materials for construction purposes should be considered.

The books below may be useful as aids to identification of construction material at sites:

Methods of field identification of soils in: Code of Practice for Site Investigation (BS 5930: 1981).

Engineering geology and soils classification: Field description of soils and rocks (Geological Society of London Professional Handbook, Graham West: 1990).

Simple methods for field identification of minerals: Minerals, rocks and gemstones (R.Borner: 1962); Elements of Field Geology (G.W.Himus & G.S.Sweeting: 1972, 3rd edition).

Colour illustration: The Hamlyn Guide to Minerals, Rocks and fossils (W.R.Hamilton, A.R.Woolley and A.C.Bishop: 1974).[2]

Preliminary identification of fossil bearing rocks: British Palaeozoic fossils (British Museum (Natural History): 1964); British Mesozoic fossils (British Museum (Natural History): 1964); British Caenozoic fossils (British Museum (Natural History): 1963).

[1]. CLAYTON et al 1982 P.65 (iv)
[2]. LR 403 1976 TRRL P.20.
[3]. BS 5930 1981 BSI P.126 D.7

Expert Opinion:

Superficial deposits, such as plateau gravel, river terrace gravels, glacial sands and gravels are often excellent sources of sand and aggregate. Waste heaps may provide common fill or road base material. Fossils should be collected and details of their location noted as these will help a geologist to make an accurate identification of the strata. Old quarries and pits should be noted as potential sites for running material to spoil. Materials at the surface may be more weathered than those more deeply buried, and rock at depth may be completely different from that at ground level. More details concerning the identification of rock can be obtained by consulting the Knowledge-Based System for Ground Investigation: Rock.

Samples may need to be collected for classification tests (keep them sealed in labelled polythene bags). Immediate simple tests on site to assess hardness and reaction to hydrochloric acid, and inspection with a hand lens, will be helpful in identification of materials.

The following equipment may be required: hand auger; spade; geological hammer; trowel; polythene bags; labels; hand lens x10; 50 % hydrochloric acid in small polythene dropping bottle with screw cap. c.f. Field Reconnaissance, Advice.[1]

[1]. LR 403 1976 TRRL P.20;
CLAYTON et al 1982 P.65.

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SA25: GEOLOGICAL MAPPING

Explanation:

The object of geological mapping is the elucidation of the character, distribution, sequence, and structure of the soils and rocks underlying the area. Where existing information is insufficiently detailed for the investigation in question, it may be necessary to carry out additional geological mapping. The data used for geological mapping may be supplemented by geophysical investigations and interpretation of aerial photographs. The map will need to be revised and completed when the full site investigation has been carried out.[1]

[1]. BS 5930 1981 BSI P.9;
LR 403 1976 TRRL P.20

Expert Opinion:

Much preliminary published, unpublished and field-collected information related to the surface of the site will have been provided by the previous work. It is possible to present this information by means of preliminary mapping and interpretation. An understanding of geomorphological features may be valuable in interpreting the nature and distribution of soils and rocks. Hydrogeological conditions and man-made features should be recorded. Methods used for geological mapping are introduced in a number of books:
1. GEOLOGY IN THE FIELD (Robert R. Compton. 1985. John Wiley & Sons);
2. ELEMENTS OF FIELD GEOLOGY (G.W.Himus & G.S.Sweeting. 1972. University Tutorial Press Ltd).

Further information and examples of engineering geological mapping are given by:
1. THE PREPARATION OF MAPS AND PLANS IN TERMS OF ENGINEERING GEOLOGY (Geology Society Engineering Group Working Party. Q.J.Eng.Geol., 1972, 5(4),297-367), gives details of the classification and mapping of rocks and soils; map symbols for geological boundaries and features, and for boreholes and for other locations of site investigation; and also gives specimens of different types of map.
2. ENGINEERING GEOLOGICAL MAPPING FOR CIVIL ENGINEERING PRACTICE IN THE UNITED KINGDOM (W.R.Dearman & P.G.Fookes. 1974. Q.J.Eng.Geol., 1974, 7(3), 223-256), gives a detailed illustrated review of engineering geological mapping, describing maps and plans produced for different phases of the work and for special purposes.

For the presentation of geological maps, points to note on geotechnical maps and plans are:

clear keys;
direct observation distinguished from inference and interpretation;
degree of certainty of boundaries & features shown by suitable mapping conventions;
significant geomorphological features;
observations on dip, jointing, fissures, outcrops, exposures;
ground water conditions;
positions of boreholes, pits, and other observations.[1]

[1]. BS 5930 1981 BSI P.9;
LR 403 1976 TRRL P.21

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SA251: DATA COLLECTION

Explanation:

Data for surface geological mapping can be worked up from those notes which have been taken at previous stages and from existing maps. The information should contain whatever factors correlate with the geology in the area of interest. These may include:
boundaries between materials;
extent of drift including peat;
positions of dykes;
rock outcrops;
joint patterns;
faults;
fissures;
unstable ground;
difficult areas;
unusual areas;
springs and seepages;
swallow holes;
mine working and subsidence;
salt subsidence;
type of materials; etc.

On tunnel lines, the following are particularly important:
buried channels;
interface between rock and soil;
rock faults, shatter zones and fissured or heavily jointed rock;
ground water levels.[1]

[1]. LR 403 1976 TRRL PP.18ff.

Advisory:

Natural and artificial exposures may provide data, including the orientation, frequency and character of bedding and joint discontinuities, weathering profiles, and the nature of the junction between superficial and solid formations. Such information should only be used as a guide to conditions likely to be present at the site. Caution is needed in extrapolating data; geological structures, such as faults and other major discontinuities, may only have a restricted extent.

Recording of geological information should be undertaken at all stages of the works, revising early maps as ground conditions are exposed by excavation, and recording the existing ground conditions.[1]

Expert Opinion:

Data from aerial photographs and from existing geological maps and reports should be pencilled tentatively on a base map. The field mapping can then be planned on the basis of key areas described in the literature, as well as of major exposures and routes of access.[2]

[1]. BS 5930 1981 BSI P.10 SECTION 9
[2]. COMPTON 1985 P.88 5-5

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SA252: INTERPRETATION

Explanation:

Interpretation is a continuous process which should begin in the preliminary stages of data collection and should proceed as information from the ground investigation becomes available.

An essential part of the interpretative work is, for most sites, the plotting of the inferred geological structure on sections. This is required for design purposes, for assessing the volumes of various soils to be excavated and also, in many instances, for investigating stability problems. An important part of the interpretation will be the assessment of bearing capacity and stiffness of finished earthworks for pavement design. The interpretation should identify site hazards and help to make decisions of what exploration and testing needs to be carried out, and where appropriate, what reductions in the original programme are possible.[1]

[1]. SH2/88 SDD P.15;
BS 5930 1981 BSI P.88

Mandatory:

The data interpretation should aim to identify and propose solutions to any problems which have been shown to exist and to seek to explain any anomalies in the factual information, and to draw an overall picture of site conditions exploring the ranges within which soil properties have been found to vary, seasonal changes, and changes to soil conditions which may be brought about by the construction process.[1]

Advisory:

The interpretation of the results which have been examined in the preliminary sources of information and of the site inspection may be incorporated in provisional maps, overlays, sections and block diagrams.[2]

Some unfavourable conditions should be interpreted with particular care, including the following:
slopes that are unstable or liable to be made so by engineering works;
materials which may require very shallow slopes in cuttings;

unrippable rock above formation level;
soft material requiring excavation below formation level;
areas with material unsuitable as fill, above formation level;
areas with saturated sands and silts above formation level;
seasonal variations of ground water, especially those which rise to or above the ground surface;
areas liable to flooding, springs, areas requiring special drainage measures;
locations liable to snow drifting, icing, fog or high wind speeds;
mineworkings and shafts, swallow holes, cavernous ground, areas liable to subsidence;
mineral deposits;
ground movements which may occur during the life of the road due to: withdrawal of support from beneath it or the area adjacent to it due to extraction of coal, rock salt or other materials, or as a result of collapse of old pit props and pillars;
natural subsidence;
quarrying or tipping causing slope instability.[3]
etc.

[1]. SH2/88 SDD P.14 & 15 2.21
[2]. LR 403 1976 TRRL P.20.
[3]. LR 403 1976 TRRL P.21;
LR 591 1973 TRRL P.8

Expert Opinion:

The following publications may be helpful in the interpretation of data:
1. INTERPRETING GROUND CONDITIONS FROM GEOLOGIC MAPS (United States Geological Survey. 1949. Geological Survey Circular 46. (United States Department of the Interior)), and
2. INTERPRETING GEOLOGICAL MAPS FOR ENGINEERS (E.B.Eckel. 1952. Symposium on surface and subsurface reconnaissance. Special Technical Publication No. 122, pp. 5-15. (American Society for Testing Materials.)) This describes the interpretation of geological maps for engineering purposes, including the production of a geotechnical map from a geological map.
3. INTERPRETATION AND MAKING OF GEOLOGICAL MAPS (S.Ray. 1965. Calcutta.)

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SA26: FURTHER PHOTO INTERPRETATION

Explanation:

All engineers or engineering geologists engaged in ground engineering should have a familiarity with air-photograph interpretation and make good use of air photographs to provide additional information on ground conditions for use both in the site investigation phase of the work and during construction. In addition to their use for giving information on general conditions and surface features, air photographs may also be used to draw conclusions on ground conditions of engineering significance, such as soil type, drainage conditions, and the presence of marshy areas, unstable ground, rock outcrops.

Typical uses of air photos have been listed in the previous stage, DESK STUDY/AIR PHOTO. At this stage further air photograph interpretation should be carried out in combination with all available data obtained from the site.

In the interpretation of geological structures from air photographs, significant features have first to be detected, and then their geological significance has to be interpreted. Lineaments visible on air photographs are important elements in the interpretation of geological structure, and may be evident in tone, relief or vegetation.[1]

[1]. LR 1085 1983 TRRL PP.1 & 22;
LR 369 1970 TRRL PP.2 & 4

Advisory:

Air photograph interpretation should be combined with the study of geological maps and other sources of ground information, and with the site inspection. Some of the principles of photo interpretation are as follows:

1. Analyse the elements in the photographic image which are usually present and which together represent the scene. The various elements include tone, colour, shadow, shape, size, pattern and texture.
2. Consider the different characteristics of each set of available air photo cover, which depend on the particular conditions under which they were obtained. The particular circumstances of an air-photo sortie relate to emulsion type, focal length of the camera lens, time of year, date, time of day, scale, obliquity, and length and direction of shadows.

The interpretation of data collected during the previous stages should be carried out in terms of: solid geology; superficial geology; geomorphology; instability; made ground; site access; site drainage; and archaeology. The interpretation of aerial photographs will be of little value if the field data have not been recorded.[1]

[1]. LR 1085 1983 TRRL PP.10-14 & CLAYTON et al PP.34-44

Expert Opinion:

LR 369: 1970, LR 591: 1973 and LR 1085: 1983 together review both air photo interpretation and ground-based photo interpretation, giving full reading lists. Methods may use existing cover or may require specially commissioned sorties.

LR 1085: 1983 Appendix 1 pp.32-34 has a full check list of natural and man-made features which may be identified from air photographs.

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SA3: FIELD TECHNIQUES

Explanation:

Field techniques are used to verify and expand information which may have been collected previously and provide a means of producing the detailed information necessary for economic and safe geotechnical design. Field techniques may combine in situ testing with recovery of samples for laboratory testing (see LABORATORY TESTING section). The objective should be to use in situ and laboratory tests to identify potential construction problems or hazards.

Before commencing Field and Laboratory Tests, all relevant information should be considered together to obtain a preliminary conception of the ground condition and the engineering problems that may be involved.[1]. This will include in particular, data from previous Ground Investigations, collected from the sources discussed in previous stages, Desk Study and Site Reconnaissance. Consideration of all available data will assist in planning the amount and types of field and laboratory testing that are required.

This stage is concerned with Field Techniques which include:
- Trial pits and borings;
- Sampling;
- In-situ testing.

[1] BS5930 1981 BSI P.8 7.2; CIRIA 25 1983 P.17

References:

TM SH 2/88: 1988. Ground investigation. Scottish Development Department, New St. Andrew's House, Edinburgh EH1 3SZ.
BS 5930: 1981. Code of practice for site investigations. British Standard. British Standard Institution, 2 Park Street, London W1A 2BS.
Weltman, A.J. and Head, J.M. 1983. Site investigation manual. CIRIA (Construction Industry Research & Information Association) Special Publication 25 and PSA (Property Services Agency) Civil Engineering Technical Guide 35.
LR 625, 1974. Guidance on planning, directing and reporting site investigations. TRRL.
LR 828, 1978. Site Investigation in Scotland. TRRL.
Hawkins, A.B. 1976. Site Investigation Practice: Assessing BS 5930.
Clayton, C.R.I., Simons, N.E. and Matthews, M.C. 1982. Site investigation - a handbook for engineers. Granada Publishing.
BRE Report: 1979. Bridge foundations and substructures. HMSO
ICE Specification: 1989. Specification for ground investigation. Thomas Telford.
DTp Specification: 1987. Specification and method of measurement for ground investigation. HMSO.
Road Research Laboratory: 1952. Soil mechanics for road engineers. HMSO
Robb, A.D. 1982. Site investigation. ICE Works Construction Guides. Thomas Telford.

Advisory:

It is always advisable to carry out a single complete soils survey where this will be effective and economical. Inconveniences to land or property owners will thus be minimised. A preliminary ground investigation may be carried out for a feasibility report prior to publication of line orders and public notification of a route. The carrying out of any further work on site after publication of the line order, but before or during a Public Enquiry is undesirable. The main investigation should normally be undertaken after confirmation of the line orders.[1]

Expert Opinion:

The success of a ground investigation is partly dependent on the ability of the planning engineer to envisage what type of problems will be encountered. The soil properties required are identified by consideration of the soil types expected, the type and possible extent of works, and the possible use of ground improvement techniques.

By considering the probable sequences of strata and the stresses which will be imposed on the soil, some assessment may be made of the depths to which the boreholes should be taken and at what depths data are required. The extent and type of construction for which the investigation is being carried out will influence the distribution of boreholes, trial pits or test locations, but it is modified according to the expected variability of the soil conditions. Assessment of groundwater conditions forms an important part of the full appraisal of a site.[2]

Having gathered together the information mentioned above, the planned use of field techniques can be developed accordingly.

Although trial pits and borings, sampling, and in-situ testing are described in separate sections, it is necessary to coordinate the planning of their layout and distribution. Detailed guidance is given in each section.

In summary:
- trial pits and borings are required for direct inspection of ground conditions;
- sampling will be used for laboratory testing to determine index properties and mechanical properties;
- in-situ testing can often provide a rapid method of confirming lateral continuity of strata as well as providing some additional quantitative information concerning the mechanical properties of the soil.

An understanding of what type of ground investigation is to be carried out is a fundamental requirement in planning sampling and testing. The types of ground investigation include:
- sites for new works;
- defects or failures of existing works;
- safety of existing works;
- material for constructional purposes.

For detailed information refer to BS 5930: 1981. Clause 8.

In planning ground investigations, particular attention should be paid to the safety of personnel. A list of statutory regulations which may apply to ground investigations is given in BS 5930: 1981. Appendix F. pp. 131-132.

[1] SH2/88 CLAUSE 2.19 P.13
[2] CIRIA25:1983. PP. 18-19

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SA31: TRIAL PITS & BORINGS

Explanation:

A considerable variety of methods of ground investigation exists, consisting of those in which samples are retrieved from the ground for description and testing and those in which the properties of the soil are described or measured in-situ. The two exploration methods, trial pitting and boring, may have functions as follows:

ground conditions can be inspected in them or with samples removed from them;
samples can be taken for laboratory tests from them;
some types of in-situ tests can be carried out in them.

Shallow trial pits provide an economical method of examining in-situ conditions, whereas exploration by means of boring is a well established technique, and may be used exclusively or may supplement trial pits.[1]

Whereas the samples retrieved from trial pits can be large, disturbed or undisturbed, the samples from boreholes are small diameter, sometimes disturbed and only undisturbed in clayey soils. However, trial pits have a limited depth.

No hard and fast rules can be given for the depth and spacing of exploratory holes. This will depend very much on the Engineer, the anticipated ground conditions and the type of structure. Each site should be individually assessed, together with the proposed development.[2]

The purpose of performing trial pits and borings during the preliminary ground investigation is to:

establish stratigraphy
provide sufficient geological information to enable the main ground investigation to be designed in the light of the anticipated geology and expected choice of structures.

[1] CIRIA 25:1983. PP.29,30
[2] SH2/88:1988 P.8;
CIRIA25:1983 P.20;
BS5930:1981 P.10

Advisory:

Details of soil conditions discovered in trial pits and borings should be notified to British Geological Survey, Merchison House, West Mains Road, Edinburgh EH9 3LA for addition to their databank.

Two basic methods of exploration are trial pitting and boring. The selection of appropriate exploration methods for proposed works depends on the following main factors:

1. the topography, type of ground to be investigated and ground-water conditions
2. the type of works envisaged and technical requirements
3. amount of existing information
4. expected variability of subsoil
5. external constraints such as the availability of plant, access, costs and time available. However the technical

requirements of the investigation, rather than cost, should be the overriding factor in the selection of investigatory methods.

In unconsolidated superficial deposits, trial pits are generally more appropriate, greatly increasing the quality and accuracy of the information that is obtained.[6] Borings will be necessary if great depths are to be investigated, or where groundwater problems are anticipated.[1]

More details can be obtained by consulting individual sections.

Safety should be taken into account throughout the process of ground investigation. If personnel are to enter trenches or pits more than 1.2 m deep, then measures must be taken either to support the sides or to batter back the sides.[2]

The points of exploration, e.g. boreholes, soundings, pits, should be so located that a general geological view of the whole site can be obtained with adequate details of engineering properties of the soils and of ground water conditions. For road schemes it is important that the position of exploratory holes is staggered about the centreline to ensure sufficient transverse coverage of the site. If there is any likelihood of the road profile being altered then a view must be taken on whether the investigation should allow for this. For foundations, it has traditionally been proposed that the trial excavations should be located outside the proposed foundation areas[3]

If only a strip is to be surveyed, as is usual for a road, a single line of borings along the centre line, a double line offset about 15 to 30 m on each side, or a triple line with some holes along the centre line and some offset alternately to each side along the approximate edges of the intended carriageway is usually sufficient, but if a wide area is to be surveyed the best way of covering the ground is probably with a grid. Normally the borings are required at intervals of about 100 m. The interval between the borings depends entirely on the nature of the soil encountered and may be as much as about 300 m in very uniform ground, or as little as about 15 m in quickly changing ground such as glacial deposits.[4]

More holes will be required at critical points such as locations of expected structures. At expected locations of cuttings a series of three points across the section is recommended.

Some experience concerning the spacing of explorations is summed up as follows:

- Foundations (of bridge, of small buildings, etc.):
  - for important structures, usually,
    - spacing is 10 to 30 metres, or
    - density is 10 to 100 per hectare, but
  - for small structures,
    - in plan area, at least 3 points;
  - for groups of identical structures,
    - at least 1 point per unit.
- Cut, Fill, Quarry, Roadline, etc.:
  - for important work, would be 10 to 30 metres, but
    - wider spacing allowed depending on ground conditions;
  - for culverts and other small works,
    - not less than 3 points.

Where engineering difficulty and complicated ground, such as suspected buried valleys, old slipped areas, etc., rigid or preconceived patterns of pits/bores/soundings should be avoided.[5]

[1] CIRIA 25:1983 SECTION 1.3.4 P.19
[2] CLAYTON et al: 1982 P.145;
CIRIA 25: 1983 SECTION 2.1 P.29;
SPECIFICATION FOR GI: 1989 P.13
[3] SH2:1988 P.8;
BS5930:1981 P.10;
CIRIA 25:1983 SECTION 1.3.4 P.20 19
[4] SOIL MECHANICS FOR ROAD ENGINEERS:1952 SECTION 8.23 P.140
[5] SH2:1988 P.8;
BS5930:1981 P.10;
CIRIA 25:1983 SECTION 1.3.4 P.20 19;
CLAYTON et al:1982 PP.295-296
[6] LR 828: 1978 TRRL P.7

Depth of Investigation

The depth of exploration is governed by the depth to which the new project will affect the ground and ground water or be affected by them. Normally, exploration should be taken below all deposits that may be unsuitable for foundation purposes, e.g. made ground and weak compressible soils, including the case where weak strata are overlain by a layer of higher bearing capacity. The exploration should be taken through compressible cohesive soils likely to contribute significantly to the settlement of the proposed works, generally to a depth where stress increases cease to be significant, or deeper. If rock is found, a penetration of at least 3 m in more than one borehole may be required to establish whether bedrock or a boulder has been encountered, unless prior knowledge of the local geology obviates this.

For certain types of works, some recommendations for exploration DEPTH are available as follows:
Foundations for structures:
for raft or strip or pad foundations,
at least 1.5 times width of the loaded area below its base;
for pile foundations,
to refusal point or 1.5 times building width below the expected base of piles;
exceptions can be made where strong rock is encountered.
Cuttings, quarries:
sufficient to permit assessment of the stability of the future slopes;
proving the full depth of any relatively weak strata;
ground water conditions should be determined.
Fills:
for filling a depression,
sufficient to assess the likely amount of any settlement;
for raising a site above the natural level,
sufficient to check possible deep shear failure;
normally, equal to the height of the embankment;
but, if settlements are critical, equal to the embankment width.
Road lines:
sufficient to determine the frost susceptibility;
sufficient to obtain samples for stiffness/strength determination over the depth that will be affected by the formation construction and operation;
sufficient to determine the drainage conditions;

usually, 2 to 4 m below the proposed formation level.

It is not always necessary that every exploration should be taken to depths recommended above. In many instances, it will be adequate if one or more boreholes are taken to those depths in the early stages of the field work to establish the general ground profile, and then the remainder sunk to some lesser depths which earlier exploration has shown to be relevant to the problem being considered.[7]

[7] SH2:1988 P.8;
BS5930:1981 PP.10-11;
CIRIA 25:1983 P.21-22;
BRE REPORT: 1979 P.10;
RRL:1952 P.139

Expert Opinion:

Knowledge concerning SELECTION OF EXPLORATION METHODS can be obtained from references as following:
BS 5930: 1981. Section three;
CIRIA 25: 1983. Clause 1.3.4;
Clayton et al: 1984. Chapter four;
LR 625: 1976. Section seven.

The first decision of what exploration method is appropriate can be made according to the type of works and type of soil on the project area. An outline classification is given here:

BORING is suitable for:
normally consolidated or lightly-overconsolidated clays;
overconsolidated clays;
glacial tills;
fine-grained granular deposits;

TRIAL PITTING is suitable for:
shallow investigations such as for pavements;
investigation above the water table;
medium and coarse-grained granular deposits;
fill (made ground).

Detailed information of suitability can be obtained from:
CIRIA 25: 1983. Section 1.4. pp.22-28;
BS 5930: 1981. Clause 12. pp.12-14;
LR 625: 1976. Section 7. pp.16-18.

Some guidance concerning the depth and spacing of exploratory holes is given under PrelimGI/Field Techniques/Trial Pits & Borings/ADVICE(2), more detailed guidance can be found in:
TM SH2: 1988. Clause 2.11.2 p.8;
BS 5930: 1981. Clauses 10.5 - 10.7. pp. 10-11;
CIRIA 25: 1983. Section 1.3.4. pp. 20-22;
BRE Report: 1979. Section 2.4. p.10;
CLAYTON et al: 1982. Chapter 9. pp.294-299;
RRL: 1952. Section 8.20. p.139.

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SA311: TRIAL PITS

Explanation:

Shallow trial pits permit the in situ condition of the ground to be examined in detail both laterally and vertically; they provide access for taking samples and for carrying out in situ tests; and they provide a means of determining the orientation of discontinuities in the ground. Shallow trial pits can readily be extended into trenches in order to trace any particular feature, and in suitable ground this method is very efficient and economical.[1] Information here describes techniques for digging and logging them.

Other techniques such as shafts, trenches, and adits are also mentioned here.

For Location and Spacing of Exploration Points, and Depth of Investigation, please refer to the rules under the heading:
PrelimGI/Field Techniques/Trial Pits & Borings/ADVICE

[1] BS5930:1981 CLAUSE 18.1 P.18

Expert Opinion:

The trial pit is an excavation at model scale and provides a guide to feasibility of excavations. The advantage is provided by the speed, mobility, flexibility and economic benefits of excavators when compared with traditional borehole techniques. The disadvantages associated with trial pitting are that the depth of working is limited; existing services are more at risk; there can be dangers arising from working close to an excavation and machine; relic pits in foundation or cutting areas can cause problems during project construction. The last two can be overcome if appropriate methods are adopted.

Trial pits and trenches are very suitable for:
- examining variable deposits and the structure of soils above the water table;
- taking large disturbed and undisturbed samples;
- supplementing the less detailed information of a borehole survey;
- giving the required information on structure including bedding, fracturing and slip planes.

For shallow excavation in soil and soft rock trial pits may be cheaper than drilling but they become expensive when timbering is required.

Adits and shafts are needed for deeper investigations of this type, but are not usually employed in site investigation for roads except for specific problems such as the location of old mine workings in critical areas.

Pits and similar excavations should be located outside proposed structure positions, otherwise excessive settlement can occur at their position.[1]

[1] CIRIA 25:1983 P.30;
ASSESSING BS5930:1986 P.185;
LR 625:1976 SECTION 7.3 PP.17-18

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SA3111: TRIAL PITS, TECHNIQUES

Explanation:

Trial pits provide the best method of obtaining very detailed information on strength, stratification and discontinuities in soil. Very high quality block samples can be taken only from trial pits.

Trial pits may be excavated by either hand digging or machine excavation. In general machine excavation is used for shallow pits, whereas hand excavation is used for deep pits which must be supported. In the limited space of a trial pit, which is often 1.5 m x 3 m in plan area at ground level, it is usually impossible to place supports as machine excavation proceeds. The depth of trial pits is usually 2-4 m, maximum about 5-6 m. (But trial pits have been excavated to as much as 15m.[2]) Shallow trial pits provide a cheap method of examining near-surface deposits in situ, but the cost increases dramatically with depth, because of the need for support when the depth is more than 1.2 m and entry by personnel is necessary.[1]

[1] BS5930: 1981 P.18;
CIRIA25: 1983 PP.29-30;
CLAYTON et al: 1984 P.144;
SPEC.FOR GI: 1989 P.13
[2] LR 828: 1978 P.7

Expert Opinion:

Shallow trial pits can be excavated by wheeled offset backactor excavators such as the JCB 3c, MF50, etc., which have a digging depth of only about 3.5 - 4.0 m, and may not be able to move easily across wet steeply sloping sites.

Deeper pits may be excavated by JCB 6c, Hymac 580 and Poclain 90 excavators to a depth of about 6 m, or by excavation from within larger pits with ramped access.

Deeper pits or pits where access is difficult can be excavated by 3600 slew-tracked hydraulic excavators.

Very deep pits can only be economically excavated by machine if their sides are very stable, when they can be dug to the required depth without requiring support. In some soil conditions (e.g. chalk) it has been found possible to excavate pits to a 12 m depth using a 22RB tracked rope-operated excavator with a heavy rope grab, but under these conditions an elaborate safety cage must be provided to protect engineers and geologists engaged upon logging the face of the excavation.

Shafts bored by piling rigs may be used for in-situ examination of soil for exceptionally heavy or deep foundations. In suitable ground conditions shafts approximately one metre in diameter can be bored using large power-driven augers. Temporary liners are used to support the sides in unstable ground, and to provide the necessary protection for personnel working in the shafts, who should only obtain access within appropriate safety cages. There are several problems with this method: hire charges are expensive; smear zone around the edge of the hole; block sampling is difficult in a confined working space; and pumping is necessary if the excavation is carried out below the prevailing groundwater table. Seepage forces may affect the properties being measured.

Backfill of the pits and trenches must be carried out as soon as practicable. The backfilling must be compacted in such a manner that no subsequent depression is formed during the maintenance period. Any surplus should be heaped proud over the pit site.[1]

More detailed information concerning techniques can be found under the heading 'SAMPLING'.

[1] BS5930 PP.18-19;
CIRIA25 PP.29-30;
CLAYTON et al PP.144-146;
SPEC.FOR GI P.13

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SA3112: TRIAL PITS, LOGGING

Explanation:

Trial pits should be logged on site by a qualified engineer or geologist, but the logging may be modified and amplified as necessary to take into account any test results which subsequently become available. A convenient scale for the logging of trial pits should be chosen for presentation on an A3 sheet which can be reduced to A4. The trial pit log should be accompanied by a plan showing such details as approximate dimensions and orientation of the pit.[1]

[1] CIRIA25:1983 PP.99&102

Expert Opinion:

Trial pits are generally logged by describing the materials encountered along a vertical line in one or more faces of the pit. If the soil is highly variable, all the faces should be described in detail and a scale drawing made of each face. In some cases, it may be necessary to describe the materials in the floor of the pit. Discontinuities where present should be described in all the faces of the pit. In situations where more than one face is examined in detail, a plan of the pit should be drawn and the respective faces labelled and orientations noted on the plan in order to identify the various pit face logs. It is often useful to take photographs of each face of the pit for future reference.[1]

The section of each trial pit should show the strata encountered and the positions of samples and in situ tests, and details of structures such as dip, faults, joints, fissures, cleavage, shear planes and slip planes. Observations and sketches of the degradation of the face of a trial pit in the days or weeks following its opening-up can provide information on the stability of temporary faces that may be useful for example in the construction phase of the work but this is not often possible in practice because of the need to backfill holes and leave the site tidy and safe.[2]

The general data common to trial pitting logs may include:
title of investigation;
report number;
name of client;
location detailed by a grid reference;
date of pitting;
weather and environmental conditions;
pit number and sheet number;
type of plant;
type and depth of any services or drains encountered;
datum ground level at a reference point on the highest pit edge;

dimensions of pit at surface and alignment with respect to North;
scale sketches of sides and base of the pit showing strata;
records of groundwater;
positions of tests, samples, water in-flow, joint survey lines;
photographs of pit sides (cleaned) and spoil;
quantity and rate of pumping;
side stability and support used;
rate of progress in hard strata;
installation details of any standpipes and piezometers;
water level readings in all previously installed standpipes and piezometers;
time spent other than in advancing the pit;
time spent backfilling, details of the reinstatement carried out.[3]

Legends: soil information for logs, as well as for maps, is diagrammatically indicated by the use of standard symbols. The symbols recommended are given by:
BS 5930: 1981. Table 11 and 12, pp.117-118;
CIRIA 25: 1983. Figure 67, p.105.

Examples of trial pit logs can be found in:
CIRIA 25: 1983. Figure 66, p.104.
LR 625: 1974. Figures 11, 12.

[1] CLAYTON et al:1982 P.311
[2] LR 625:1974 TRRL SECTION 8.1 PP.18-19
[3] BS5930:1981 CLAUSE 40.2.6.2 PP.88-89;
ASSESSING BS5930:1986 COX et al P.187;
SPEC.FOR GI:1989 CLAUSE 9.4 P.20

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SA312: BORINGS

Explanation:

Exploration by means of boring and the recovery of samples is a well established technique, and may be used either on its own or in addition to trial pits.

A large number of methods are available for advancing boreholes to obtain samples or details of strata. The principal methods are:
hand auger;
light cable percussion;
mechanical augers;
wash boring.[1]
If high quality samples are required for laboratory testing then it may be necessary to adopt other boring techniques: see advice given under 'SAMPLING'.

The techniques and logging for boring are provided here and the methods of sampling from boreholes are introduced under the heading 'SAMPLING'.

For Location of Spacing of Exploration Points, and Depth of Investigation, please refer to the rules under the heading: PrelimGI/Field Techniques/trial Pits & Borings/INFORMATION

[1] BS5930:1981 PP.19-20;
CIRIA 25:1983 PP.30-36;
CLAYTON et al:1982 PP.146-147

Expert Opinion:

A wide variety of boring and drilling techniques are used for site investigation purposes and it may be important, particularly when assessing the validity of information, to know the system employed. Boring for investigation of soft formations in the British Isles is most commonly done by techniques described variously as 'cable and tool' or 'shell and auger', the tools and precise method depending on the conditions being encountered.[1]

Hand auger boring is an economic method with the merits of light equipment and portability. It is convenient for the recovery of soil in a systematic way so that the depth can be properly established. In practice, it is sometimes difficult to prevent contamination of samples as they are recovered. The method is more frequently used during preliminary investigations. Hand auger is suitable:
for cohesive soil free of gravel or granular material;
for shallow exploration, maximum depth about 5 m, above the ground watertable;
where access for machinery is impossible.
It is not suitable:
where the soil is unstable, e.g. uncemented sands and gravels;
where ground water flows into the hole;
for clays containing gravel, cobbles or boulders.

Light cable percussion boring is generally employed throughout Britain for routine soil exploration to depths in excess of 3 m. It is an adaptation of standard well-boring methods, and generally uses a mobile rig specially designed for ground investigation work. Very accurate information can be provided by this method, subject only to the competence and care of the operator. The rig is very light, and can be readily towed with a four-wheel drive vehicle. It is also very easy to erect. In stiff clays, sufficient water may be added to assist the cutting action, but excess water could lead to undue increase in moisture content.

Light cable percussion is suitable :
for dry cohesive soils, using clay cutter;
for cohesionless soils, using shell or bailer;
for hard layers, using chisel.
It is not suitable :
where space for the rig is particularly restricted;
where water supply is difficult;
for coarse gravels above the groundwater level.

The rotary auger rig is a heavier and more powerful machine. Although it is often fast and reliable to produce site investigation holes, in view of the large size of the rigs, their cost and sampling restrictions, this technique is not widely used. A hollow stemmed auger is a useful feature in unstable soils and a solid stem auger is used in stiff clays.

Rotary auger rig is suitable :
for cohesive soils;
for stiff clay;
where an inspection shaft is needed.

It is not suitable :
for cohesionless soils;
for frequent sampling and testing;
where access for heavy vehicles is impossible.

Wash boring is best suited to sands, silts and clays. It is seldom used for ground investigation in Britain, because the technique is unsuited to the typical mixed soils, and will not penetrate gravels or rock. The technique may be used where rapid progress is desirable through soft or unconsolidated deposits such as occur in investigation for dredging operations.[2]

[1] ROBB:1982 P.4
[2] BS 5930:1981 PP.19-20;
CIRIA 25:1983 PP.30-36;
CLAYTON et al:1982 PP.148-157;
LR625:1974 P.17;
ROBB:1982 PP.4-9

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SA3121: BORINGS, TECHNIQUES

Explanation:

The techniques for boring are concerned with the methods of Hand Auger, Light Cable Percussion, Rotary Auger Rig and Wash Boring.

The simplest exploration borehole is by hand auger, and is limited in depth to a few metres. The majority of deep exploration is carried out using light cable percussion or rotary augering equipment. There are various types of plant, each with particular advantages, such as speed of boring, manoeuverability, quality of sampling or versatility. The selection of rig is particularly important when variable ground conditions are likely to be encountered.

Many of the most frequently used sampling and in situ testing methods can be carried out with a wide variety of boring rigs, so that the accessibility or labour costs can often be controlling factors regarding rig selection. For rough terrain or inaccessible locations, light rigs are advantageous.

The operation of boring and drilling rigs is frequently dependent on the supply of water, and its absence at a site may make it necessary to pump a mains supply over large distances or to use towed water bowsers.[1]

TV and borehole cameras may be used inside a relatively small hole (75 - 150 mm diameter) and can, therefore, be used with conventional drilling methods to examine deep features.[2]

The suitability and feasibility of different techniques are discussed under the heading 'TRIAL PITS & BORINGS/BORINGS'.

[1] CIRIA 25:1983 PP.19,30
[2] CLAYTON et al:1982 P.146

Expert Opinion:

Boring is often carried out using a cable percussion rig and attachments such as shells, clay cutters or corers, augers, chisels and sinker bars. The diameter of a borehole should be sufficient to ensure that the boring can be completed to the scheduled depth and that samples of the specified diameter can be obtained. The minimum diameter of borings or internal diameter of casing should be 150 mm. Where hand auger boring is specified the minimum diameter should be 100 mm.

Generally, water should not be used to assist the advance of the borehole except in the case of dry coarse soils. Where the borehole penetrates below the water table and disturbance of the soils is likely, a positive hydrostatic head should be maintained in the borehole.[1]

The techniques for boring are described below.

1. Hand auger method:

The common types of hand auger are: posthole auger; small helical auger; Dutch auger; gravel auger. The most commonly used auger is the posthole or Iwan auger of diameter between 100 and 200 mm. Hand augers are used by one or two men, who press down on the cross-bar as they rotate it thus advancing the hole. The auger and drill rods are usually lifted out of the borehole without the aid of a tripod, and no borehole casing is used. Boreholes up to 200 mm diameter may be made in suitable ground conditions to a depth of about 5-6 m.

2. Light cable percussion:

The hole is made by forcing the auger downwards at the bottom of the hole, while rotating it. The size of borehole casings and tools are generally 150 mm, 200 mm, 250 mm, and 300 mm giving a maximum borehole depth of about 60 m in suitable strata. The drill tools work on a wire rope using the clutch of the winch for the percussive action, and may consist of either a clay cutter, a shell or bailer, or chisel. The clay cutter and shell bring up disturbed material which is generally sufficiently representative to permit identification of the strata. The light cable percussion has 1000 to 1500 kg capacity and most commonly uses 150-200 mm diameter casing and tools, but in sandy soils more casing sizes will often be needed to reduce friction. The minimum size possible in Britain is 150 mm dia., since this is the smallest size allowing the use of the British Standard General Purpose 100 mm sampler.

3. Rotary auger rig:

The augers normally use a continuous-flight auger with a hollow stem. When augering, the hollow stem is closed at its lower end by a plug, which may be removed so that the sampler can be lowered down through the stem and driven into the soil below the auger bit. Typically, augers with hollow stems of approximately 75 mm and 125 mm dia. produce boreholes of about 150 mm and 250 mm dia. respectively, to a depth of 30 m to 50 m. An internal stem diameter of 150 mm is necessary for the conventional sampling equipment, or 75 mm for SPT equipment. A solid stem auger can be used in stiff clays, which stand unsupported when the auger is withdrawn for sampling.

4. Wash boring method:

Wash boring is normally carried out using 65 mm borehole tools and borehole casing. The drill rig consists of a simple winch and tripod. The ground at the bottom of the borehole is broken up by the percussive action of a chisel bit, and washed up to the surface by water that is pumped down the hollow drill rods. The bit can be removed and replaced by heads for sampling or in situ tests when the stem of the auger is withdrawn from the hole. Several such heads have been specifically developed for use with wash boring equipment, particularly the SPT.[2]

Boreholes and drillholes should be carefully backfilled as the casing is withdrawn. More detailed information on techniques can be found under the heading 'SAMPLING'.

Illustrations of common types of hand auger are given in:
CIRIA 25: 1983. Figure 7 p.31;
Clayton et al: 1982. Figure 4.4 p.149.

Illustrations of typical light cable percussion boring rigs, facility and equipment are given in:
CIRIA 25: 1983. Figures 9, 10, 12 pp.32,33,35;
Clayton et al: 1982. Figures 4.5, 4.6 pp.151,152;
Robb: 1982. Figures 1, 1(b), 1(c), 1(d), 3 pp.5,6,8,9.

Illustrations of rotary auger rig are given in:
CIRIA 25: 1983. Figure 13 p.36;
Clayton et al: 1982. Figures 4.7, 4.8, 4.9, 4.10 pp.154-156;
Robb: 1982. Figures 4, 5, 6 pp.10,11.

For light cable percussion, a summary of basic performance data relating to typical rigs is given in:
CIRIA 25: 1983. Table 2 p.32.

An illustration of a borehole camera is given in:
Clayton et al: 1982. Figure 4.2 p.147

[1] CIRIA 25:1983 P.30
[2] BS 5930:1981 PP.19-20;
CIRIA 25:1983 PP.30-36;
CLAYTON et al:1982 PP.148-157;
LR625:1974 P.17;
ROBB:1982 PP.4-11.

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SA3122: BORINGS, LOGGING

Explanation:

The information presented on the foreman or driller's log, the sample description sheets prepared by the site engineer, and the results of in situ and laboratory tests, are summarised for presentation in the report as a borehole log. Being an interpretation of data which may at times be inconsistent and contradictory, they can only be finalised when the appropriate field and laboratory work has been completed. It is important that all the relevant data collected by the driller, once checked and amended where necessary, should be recorded.[1]

[1] BS 5930:1981 CLAUSE 40.2.6.1 P.88;
CIRIA 25:1983 SECTION 5.6 P.99

Expert Opinion:

The method of presentation of the data is a subject on which there can be no hard and fast rules. In principle, the borehole logs should give a picture in diagrams and words of the ground profile at the particular point where the hole was bored. The extent to which minor variations in soil types should be recorded, together with any discrepancies and discontinuities, will depend on the various purposes for which the information will be used.

All borehole logs are a compromise between what it is desirable to record and what can be accommodated. What is actually presented will need to be considered individually for each investigation. Where the data are copious, it may be preferable to record part of them elsewhere in the report, with a cross-reference on the logs. The clauses which follow indicate the desirable data which a well prepared borehole log may contain.

The following should be recorded on logs:
- title of investigation;
- report number;
- name of client;
- location detailed by a grid reference;
- date of boring;
- weather and environmental conditions;
- type and depth of any services or drains encountered;
- borehole number and sheet number;
- type of boring;
- make of plant used;
- ground level related to Ordnance datum;
- diameter of borehole;
- diameter of casing and depth to which taken;
- the depths at which any water was added;
- a depth scale such that the depth of sampling, tests and change in strata can be readily determined;
- records of groundwater;
- description of each stratum;
- the type of samples and the depths from which they were taken
- the depths and full details of all in situ tests;
- depths of hard strata and time spend in penetration;
- installation details of any standpipes and piezometers;
- water level readings in previously installed standpipes and piezometers;
- details of time spent other than in advancing the borehole;
- details of backfilling and/or grouting;
- depth of termination of borehole.[1]

Finally, a summary or condensed log may be necessary.

Legends: soil information for logs, as well as for maps, is diagrammatically indicated by the use of standard symbols. The symbols recommended are given by:
- BS 5930: 1981. Table 11 and 12, pp.117-118;
- CIRIA 25: 1983. Figure 67, p.105.

Examples of typical logs of data from boreholes are illustrated in the documents below:
- BS 5930: 1981. Figures 27, 29, 30, pp.90,91,94-96;
- CIRIA 25: 1983. Figure 64, p.101.

[1] BS5930:1981 CLAUSE 40.2.6.1-2 PP.88-89;
SPEC.FOR GI:1989 CLAUSE 9.2 P.19

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SA32: SAMPLING

Explanation:

Site data are of two types, those available from existing information and surface reconnaissance which have been discussed under the headings of 'DESK STUDY' and 'SITE RECONNAISSANCE', and those obtained from boreholes and trial pits (which are to be discussed in this stage) and those obtained from the associated testing program which will be discussed after.

The object of subsurface exploration, to determine the nature of the sub-soil, usually requires the acquisition of soil samples either to allow visual examination of the soil by an engineer or to permit survey of physical or mechanical properties to be carried out partly or wholly in the laboratory.

The selection of sampling technique depends on the quality of the sample that is required, and the character of the ground, particularly the extent to which it will be disturbed by the sampling process. Several different equipments which may be used for sampling of soils and weak rocks are described in TECHNIQUES. Guidance is given there on the ground types for which each type of equipment is suitable.[1]

When the programme of sampling is being prepared it is particularly important to be aware of the requirements for sample quality that will be associated with the laboratory testing that is envisaged. It is expensive to obtain high quality samples, and it may not be possible to return to the site if the quality of sample that has been obtained turns out to be inadequate. The programmes of field testing and sampling and of laboratory testing need to be prepared concurrently.

[1] BS 5930:1981 CLAUSE 19.1 P.20;
CIRIA 25:1983 SECTION 2.4 P.39;
LR625:1974 SECTION 5 P.8;
CLAYTON et al:1982 CHAPTER 5 P.172

Advisory:

TYPES OF SAMPLE:

British site investigation practice for soil at present commonly divides samples into the following categories:
(a) Disturbed samples:
small disturbed samples ('jars'); and
large disturbed samples ('bulk bags').
(b) Undisturbed samples:
block samples;
open drive samples; and
piston drive samples.

AMOUNT OF SAMPLING:

The amount of sampling and testing necessary for any survey should be carefully assessed. Large numbers of samples of a particular soil should not be taken and subjected to a full range of tests, many of them expensive to perform, when the characteristics and classification of that soil are already well known. It is very important that sampling points should be placed so as to give the essential information required on the geological structure, the nature and distribution of the materials present, and their geotechnical properties, and to do so in the most economical way.

QUALITY OF SAMPLE:

Selection and sampling procedure should be by assessment of the quality of the sample required. Various classes of sample have been recognised, ranging from high quality Class 1 samples to poor quality Class 5, depending on the properties which can be reliably determined, as outlined below:

- Class 1: index tests, moisture content, density, strength and deformation characteristics;
- Class 2: index tests, moisture content, grading, density and remoulded strength in some clays;
- Class 3: index tests, moisture content;
- Class 4: index tests;
- Class 5: strata identification only.

(Class 1 and 2 samples are generally referred to as 'undisturbed', Class 3, 4, and 5 as 'disturbed')

Sample quality is dependent, among other things, on the type of soil being sampled, the type and condition of the equipment, and the skill with which it is used. The use of high grade equipment does not necessarily guarantee sample quality. In general, the weaker material is the most significant in an investigation, and is usually the most difficult to secure in an undisturbed condition.

Disturbed: The following classes of disturbed sample can generally be expected from the various methods of boring and sampling:

- Class 3: from dry excavations and from dry boreholes sunk either by a clay cutter using cable percussion equipment or by an auger.
- Class 4: obtained in cohesive soil from excavations, or from boreholes sunk either by a clay cutter using cable percussion equipment, or by an auger, in conditions where water is present.
- Class 5: in non-cohesive soil from wet excavations or from any borehole sunk by a shell using cable percussion equipment or from any borehole sunk by a method in which the drill debris is flushed out of the borehole, e.g. rotary, wash boring.

Undisturbed: Truly 'undisturbed' samples cannot be taken from boreholes. In some cases, whatever sampling methods are used, it will only be possible to obtain samples with some degree of disturbance, i.e. class 2 at best.

FREQUENCY OF SAMPLING:

The frequency of sampling required depends on the information already available, the technical objectives of the investigation, and the number of test results necessary to permit a reasoned assessment of the properties of the soil. The sample and/or test locations must therefore be such that all changes of stratum are recorded. In addition, a number of extra samples and test results are required to assess variation of the properties of a stratum with depth.

In sand and gravel, at the top of each new stratum and thereafter at 1 m intervals of depth, a SPT should be carried out using the split barrel sampler if the soil is suitable; at the top of each new stratum and thereafter at 1.5 m intervals of depth, a disturbed sample should be obtained from the drill tools.

In cohesive soil, at the top of each new stratum and thereafter at 1.5 m intervals of depth, a 100 mm sample should be obtained; at each metre of depth, a disturbed sample should be obtained from the drill tools.

For structures, the maximum distances between undisturbed or bulk disturbed samples measured centre to centre should be 1 m for the first 5 m below foundation level, and 1.5 m thereafter.

For embankments, the maximum distances between undisturbed or bulk disturbed samples measured centre to centre should be 1 m for the first 5 m below existing ground level and 1.5 m thereafter as required, covering the depth of influence of the loaded area.

For cuttings, the maximum distances between undisturbed or bulk disturbed samples measured centre to centre should be 1 m both above formation level and below to as great a depth as is required.[1]

[1] SH2/88 CLAUSE 2.12.1 P.9;
CIRIA 25:1983 SECTION 2.5.1-2 PP.48-49,
SECTION 1.3.4 PP.19-20;
LR625:1974 SECTION 5 P.8;
CLAYTON et al:1982 CHAPTER 5 P.175;
ROBB:1982 PP.13-14;
SPEC. OF DTp FOR GI:1987 SECTION 6.3 P.13

<u>Expert Opinion:</u>

Choice of the sampling plan forms an essential part of the design of the ground investigation. The suggested stages are listed in:
LR 625: 1974. Table 1, p.9.

The mass of soil sample required for various laboratory tests is given by:
BS 5930: 1981. Table 1, p.21.
Clayton et al: 1982. Table 5.2, p.176.

After sampling the ground, backfilling boreholes and trial pits should be carried out using soil from the excavation or boring process. Methods for backfill are introduced in:
BS 5930: 1981. Clause 18.9, p.20;
CIRIA25: 1983. Section 2.7, pp.50-51;
Spec. of ICE for GI: 1989. Clauses 4.5, 6.6, pp.9, 13;
Spec. of DTp for GI: 1987. Clause 2.18, p.9.

If soils are unusually complex, or very detailed sampling is necessary, a method of DOUBLE-HOLE SAMPLING may be required, in which separate holes are used for strata identification and for recovery of samples for laboratory testing. This is described in:
BS 5930: 1981. Clause 22.4, p.43;
CIRIA25: 1983. Section 1.3.4, p.20.

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SA321: SAMPLING, TECHNIQUES

Explanation:

Of a very large number of sampling techniques devised worldwide, few are in current use in the U.K. Here, the widely used tools are:

1. General purpose open tube sampler: suitable for firm to stiff clays, but is often used to retrieve disturbed samples of weak rocks, soft or hard clay and also clayey sand or silts; with high area ratio (30%).

2. Thin-walled open tube sampler: suitable for soft and firm soils; with low area ratio (10%).

3. Stationary piston sampler: suitable for soft sensitive clays, non-cohesive fine-grained soils (where samples are not required for strength tests), and firm clay.

4. Continuous soil sampler: continuous retrieval of soft alluvial soils, but complex, expensive equipment and costly to operate.

5. Bishop sand sampler: sampling silts and sands below the water table, but compressed air must be available.

6. Block sample: normally taken in cohesive soil; can be used to retrieve representative volumes of fissured or otherwise structured material from pits, but great care required.

There are three main techniques for obtaining samples in soils:
- (a) taking disturbed samples from the drill tools or from excavating equipment in the course of boring or excavation.
- (b) drive sampling, in which a tube or split tube sampler having a sharp cutting edge at its lower end is forced into the ground either by a static thrust or by dynamic impact, e.g. by tools 1, 2, 3, 4, 6.
- (c) taking block samples specially cut by hand from a trial pit, shaft or heading, e.g. by 6.

Samples obtained by techniques (b) and (c) will often be sufficiently intact to enable the soil structure within the sample to be examined.[1]

[1] BS5930:1981 P.20ff;
CIRIA 25:1983 P.39ff;

Expert Opinion:

GENERAL PURPOSE OPEN TUBE SAMPLER:

This technique has been adopted for routine use, and usually consists of a 100mm internal diameter (ID) tube (U100) which is capable of taking soil samples up to 450 mm in length.

When driving U100 samplers into the ground, it can be instructive for comparative purposes to note the number of blows to drive the tube over its depth range. The alternative method of pushing the sample tube into the ground using a jacking system is more costly, but gives superior samples.

While open-tube sampling is a simple process, several important points should be borne in mind when these samples are being taken. The base of the borehole should have no more than 100 mm depth of loose or disturbed material, which can pass into the over-drive space at the top of the sampler. In practice, the control of depth is sometimes not sufficiently accurate to take full advantage of this, and there is a danger of over-driving the sampler. The depth of the borehole and the distance the sampler is driven should be very carefully monitored by measurements on the drill rods. Errors in such recording are probably responsible for more disturbance of samples recovered than any other single cause. To reduce friction, the inside of the sampler should be clean and very lightly oiled.

THIN-WALLED OPEN TUBE SAMPLER:

These samplers have various internal diameters of between 75 and 250 mm. The walls of the drive tubes are thinner than the open-tube sampler which limits their use to soft to firm fine-grained cohesive soil. To reduce stress relief in these soils, the boreholes should remain topped up with water. This type of sampler is not used extensively in Britain, and the equipment is not at present widely available.

STATIONARY PISTON SAMPLER:

The sampler permits penetration of the disturbed zone of soil generally present at the base of a borehole, prior to the taking of the sample, and also reduces disturbance as the sample enters the tube. Piston samplers range in diameter from 54 to 250 mm, although the large sizes are not in common use. The soils in which the piston sampler is suitable are generally softer than those where open-tube equipment is employed, and more sensitive to sampling disturbance.

CONTINUOUS SOIL SAMPLER:

Continuous soil sampling can produce samples up to 30 m in length in soils such as recent fine-grained alluvial deposits. This is of particular value for identifying the soil fabric and gives results superior to those which can be obtained by consecutive drive sampling. There are two systems: Swedish and Delft. The Swedish foil sampler is not normally used in Britain. The Delft system employs a floating piston, uses lighter equipment and offers two sizes of sample, a 2Mg machine giving 29 mm diameter samples, and a 10Mg machine giving 66 mm diameter samples. When using these samplers, it is important to know the limit of the depths of the alluvial soils beforehand, to prevent damage to the sampler, and a preliminary sounding may be necessary.

BISHOP SAND SAMPLER

The Bishop compressed air sampler may be used for sand below the water table. It comprises a sample tube within a small diving bell, which is fitted to a compressed air line. The inner (sample) tube is of internal diameter 50 mm, and can be extended below the base of the diving bell.

BLOCK SAMPLE:

Block samples are cut by hand from material exposed in excavations. In most cases, such samples are taken from pits. The procedure is often used for obtaining specially orientated samples, and, in such cases, both the location and orientation should be recorded before the sample is separated from the ground.[1]

BACKFILLING BOREHOLES AND TRIAL PITS:

After sampling the ground, all the exploratory holes except those which are intended for in-situ tests should be backfilled carefully. This is an important part of an investigation. Open holes or incorrectly filled holes are hazardous, and may lead to difficulties with groundwater during construction. Backfilling is generally carried out using spoil from the excavation or boring process.

Boreholes and drillholes should be carefully backfilled as the casing is withdrawn. Excavated material can be punned in a borehole with a weighted shell, and grout should be employed to backfill drillholes. Large lumps of clay, stone or pieces of rock should not be used as they can temporarily bridge across the hole. A backfilled borehole acts as a seepage path, and if connected to an aquifer, can cause water to issue from the ground, or conversely, lead to pollution of the aquifer.

Even grouted boreholes are not completely successful in preventing seepage because of the softening effects of the boring operation. Where boreholes penetrate strata with artesian groundwater, grouting is particularly difficult, and casing may be required above ground level to equalise the water pressure before grouting can be carried out. Otherwise a pressure head has to be applied. Grout backfills usually consist of cement or a 4:1 cement:bentonite mixture.

In the case of trial pits, it is difficult to prevent some settlement taking place after backfilling. The replaced material must be compacted as well as possible by filling in layers, and using the self-weight of the excavator for compaction. However, even well-compacted backfill in pits leaves paths for transmission of water, and may cause instability or seepage problems. If pits are close to existing structures, they should be backfilled with lean-mix concrete to within 300 mm of the surface.[2]

[1] CIRIA 25:1983 SECTIONS 2.4.1-6 PP.39-48;
BS 5930:1981 CLAUSES 19.4-7,19.9 PP.22-26
[2] CIRIA 25:1983 SECTIONS 2.7 P.50;
BS 5930:1981 CLAUSES 18.9 P.20

The area ratio gives a measure of the mechanical disturbance of the soil, being the ratio of the volume of soil displaced by the sampler tube in proportion to the volume of the sample. The definition is given by:
BS 5930: 1981. Figure 1, p.23;
CIRIA25: 1983. Figure 17, p.40.

Full details of application, advantages and disadvantages of different sampling methods are described in :
CIRIA25: 1983. Sections 2.4.1-6, pp.39-48;
BS 5930: 1981. Clauses 19.4-7,19.9, pp.22-26.

Illustrations of common samplers are given in:
BS 5930: 1981. Figures 1-4, pp.23-25,27;
CIRIA25: 1983. Figures 17-24, pp.40-47.

Samples may have cost a considerable sum of money to obtain and should be treated with great care. Advice on the handling and labelling of samples is given by:
BS 5930: 1981. Clauses 19.10.1-4, 19.10.6, pp.26,28-29,30;
CIRIA25: 1983. Section 2.6.1, p.49.

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SA322: SAMPLING, LOGGING

Explanation:

Full records should be kept of the nature of all materials recovered from boreholes and trial pits; samples should be retained for more detailed examination and testing and for reference purposes. Each change of soil type, consistency, or condition should be noted. The material recovered should be described, and if there is reason to believe that it is not representative of the material in the ground, this should be recorded on the log and taken account of in the interpretation. For instance, large particles may be too large to enter the sampling device readily, fine material may be washed out during the sampling process, or the material may be broken up by chiseling.[1]

The sample description is a part of a borehole log. It is provided by the site engineer. The sample logging should be carried out at the same time as the procedures of putting down boreholes or digging trial pits.

[1] LR625:1974 SECTION 8.3 P.19

Expert Opinion:

The following information may be recorded in the log:
- title of investigation;
- report number;
- name of client;
- name (or number) of borehole;
- date of sampling;
- weather and environmental conditions;
- name of soil, based on grading and plasticity;
- weight, shape and size of sample;
- type of sampler;
- levels of sampling, at top and bottom of sample;
- colour of sample;
- field strength, refer to consistency or compactness;
- mineralogical composition;
- structure of sample, bedding, fractures, etc.;
- records of groundwater;
- details of time spent for the sampling procedure;
- quality of sample, by identifying Classes 1-5;
- method of sample preservation;
- transportation of sample.[1]

[1] SPEC. of DTp FOR GI:1987 CLAUSE 6.12 P.14;
LR625:1974 SECTION 8.3 PP.19-20

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SA33: IN-SITU TESTS

Explanation:

Field tests are generally desirable where it is considered that the mass mechanical characteristics of the ground may differ appreciably from the characteristics determined by laboratory testing. In addition, in situ testing often provides an opportunity to test a much larger volume of soil than can be tested in any single laboratory test.

Sampling inevitably causes disturbance to the soil, which may be considerably reduced in in-situ testing. Because there is less soil disturbance, particularly that associated with stress relief, this means that in-situ testing may yield more representative results. In addition, some types of soil do not readily lend themselves to good sampling, or may require the use of expensive sampling techniques outside the normal scope of routine investigation. Such soils include very soft or sensitive soils, stony soils, sands and gravels. When conditions such as these are encountered an in-situ test may provide the best means of obtaining engineering design parameters.

The various forms of in-situ test that are commonly conducted are described in this stage. They are as follows:

- probing, including:
  - SPT,
  - CPT,
  - probing,
  - Mackintosh probe;
- vane test, including:
  - tests in boreholes,
  - direct vane tests;
- pressuremeter tests;
- plate bearing tests;
- shallow tests, including:
  - density,
  - CBR;
- permeability and ground water tests;
- special tests, including geophysical and other tests.

It should be borne in mind that many field tests are expensive and should not be undertaken before obtaining a comprehensive understanding of the geology and nature of the ground.[1]

[1] BS5930:1981 CLAUSE 24 P.47;
CIRIA 25:1983 P.68;
CLAYTON et al:1982 P.229

Advisory:

The material tested in-situ by a field test is analogous to a laboratory sample, and can be considered as a 'field sample'. The in-situ conditions of a field sample may be affected by the process of gaining access to the test position, e.g. digging a trial pit, but, generally, the disturbance is very much less than that involved in the recovery of a laboratory sample.

The selection and preparation of samples in the field is subject to the same requirements as for laboratory samples, to ensure that they are representative.

The size of sample tested in a field test will depend on the nature of the ground and type of test. Field tests may be necessary where the preparation of representative laboratory samples is complicated by one or more of the following conditions:

(a) There is difficulty in obtaining samples of adequate quality owing to the lack of cohesion in the soil or irreversible changes in mechanical properties, resulting from changes in the pore pressure, degree of saturation and stress environments during sampling, and from physical disturbance resulting from the sampling procedure.

(b) There is difficulty in determining the in-situ conditions such as those of pore pressure, degree of saturation, and stress environments for reproduction in the laboratory testing.

(c) Sample disturbance due to delays and transportation from remote sites may be excessive.[1]

(d) The spacing of the discontinuities in the mass being conridered may be such that a sample representing the mass, including the discontinuities, would be too large for standard laboratory test equipment. Discontinuities that are present may govern the geomechanical response of the material on the scale of the structure concerned.

The locations and levels of all field tests should be recorded as described under 'SAMPLING'.

[1] BS5930:1981 CLAUSE 24 P.47

Expert Opinion:

PROBING AND PENETRATION TESTING:

Probing from the surface probably represents the oldest method of investigating the depth to a hard stratum where the overburden is weak and not unduly thick.

The simplest probe is used where other means of site investigation have disclosed relatively thin layers of very soft soils overlying much harder ones. The thickness of the soft stratum may be determined over a wide area very quickly and economically.

The Standard Penetration Test (SPT) is used worldwide to a greater extent than any other in-situ test, mainly because it is simple and inexpensive. Its purpose is to obtain an indication of the relative density of sands and gravels, although it is also used to obtain an indication of the character of silts, clays and weak rocks.

The static cone penetration test (CPT) is relatively quick to carry out, and cheap in comparison with boring, sampling and laboratory testing. It has traditionally been used to predict driving resistance, skin friction, and end bearing capacity of driven piles in non-cohesive soils. It is also the preferred substitute for SPT in soil conditions where the results of that test are suspect, such as granular soil below ground water level, loose sands, or fissured clays. It is also widely used in recent soft deposits. The test is also commonly used as a rapid and economic means of interpolating between boreholes.

For dynamic probing, the commonly used device is the Macintosh probe. The main use of this apparatus is to interpolate data between boreholes; check rapidly and cheaply that conditions on neighboring sites are similar; and compare the results from SPTs and CPTs. It is unsuitable in soils containing occasional cobbles or boulders, which may easily be mistaken for bedrock. In Scotland it is widely used as a means of proving the depths of peat deposits.[2]

VANE TEST:

A vane test is carried out in clays up to 'stiff' in consistency to determine the undrained shear strength, and can be operated in an exploratory borehole, or to a limited depth by direct penetration from the surface using purpose-designed equipment. The test is often carried out to augment piston sampling. It is normally restricted to fairly uniform cohesive fully-saturated soils, and is used mainly for clay having an undrained shear strength up to about 100 kPa. The results are questionable in stronger clays, or if the soil tends to dilate on shearing, or is fissured.

PRESSUREMETER TESTS:

There are three main types of pressuremeter available:

(a) The Menard pressuremeter, installed into a preformed borehole.
(b) The Cambridge self-boring type, which creates its own hole as it is installed.
(c) The Stressprobe, which is pressed into the soil from the base of a borehole.

The Menard pressuremeter test is used in a wide range of materials, from soft soils to moderately weak rock, some gravels and fills, for determination of stiffness, 'creep pressure' and 'limit pressure'. The Cambridge self-boring pressuremeter and the Stressprobe device give similar information, the former is more widely used onshore and is particularly suited to measuring the shear strength of clays and to estimating the in-situ horizontal stress conditions. The self-boring pressuremeter can be fitted with a porewater pressure transducer to enable effective stress measurements to be carried out. It is suitable in clays, silts and sands.

PLATE BEARING TESTS:

The traditional plate bearing test is a vertical bearing tests which involves measurement of penetration of a rigid plate into a soil or weak rock under an applied load. In soils, the test is carried out to determine the deformation and shear strength characteristics of the ground.

Plate bearing tests are expensive and time consuming. Plate bearing tests can be carried out at or near the ground surface in shallow pits or trenches or at depth in the bottom of a borehole, pit or adit. However, the cost increases with the depth and plate bearing tests in boreholes are only rarely carried out in practice. They are generally performed in cohesive soils which can be augered and supported with temporary casing.[3]

SHALLOW TESTS -- DENSITY, CBR:

The shallow tests include in-situ density tests and in-situ California Bearing Ratio (CBR) Test. The former are used in the control of the compaction of embankments. Both are used in connection with the design of road and airfield pavements and in the control of the compaction of sub-grades on which they rest through the determination of bulk density. The CBR test employs design curves, and is an empirical method used to estimate surface soil condition and required pavement thickness. The test is unsuitable for soil containing particles larger than 20 mm and may be unsatisfactory for sands.[7]

PERMEABILITY AND GROUND WATER:

The determination of in-situ permeability by tests in boreholes involves the application of hydraulic pressure in the borehole different from that in the ground, and the measurement of the flow due to this pressure difference. The pressure in the borehole may be increased by introducing water into it, which is commonly called a falling head or inflow test, or it may be lowered in a rising head or outflow test. The applied head may be held constant, and the resulting flow recorded, or may be allowed to vary and resume its equilibrium value, with the rate at which the head changes being monitored.

The determination of ground water pressures is of the utmost importance since they have a profound influence on the behaviour of the ground during and after the construction of engineering works. To measure ground water pressures accurately, it is generally necessary to install special measuring devices called piezometers. The ground water pressure may vary with time due to seasonal, tidal, or other causes, and it may be necessary to take measurements over an extended period of time in order to investigate such variations.

SPECIAL TESTS -- GEOPHYSICAL AND OTHER TESTS:

The term special tests is used here to denote both non-standard tests and those tests which particular expert interpretation.

Geophysics is a specialised subject normally requiring expert advice, supervision and interpretation. For small projects, geophysical methods may be limited to the detection of voids and buried channels. For larger sites, with exploration of, for example, rock head level below an alluvial overburden, geophysical techniques generally become more economic. Broadly speaking, geophysical surveys are used in one of two roles. Firstly, to allow a choice to be made rapidly and economically between a number of alternative sites for a proposed project, prior to detailed design, and secondly to supplement a boring program in the detailed site investigation at the chosen site.[4]

Large-scale field trials are not standard tests, and, if required, should be designed to suit the individual requirements of the proposed works and the particular ground on which or within which these are to be performed.

Natural or man-made conditions on a site sometimes create phenomena which may be used to assess parameters which are otherwise difficult to assess or which may be used as a check on laboratory measurements. This is the method of back analysis.[5]

The correct choice of test methods and procedures is one of the most important decisions to be made during the planning and progress of a ground investigation. In order to obtain reasonable estimates of parameters from tests it is necessary to consider the following factors:

1. Are the tests relevant to the particular problems being considered?
2. Is the volume of soil affected by the test as representative as possible of the soil in the mass?
3. Consideration should be given to the methods available for interpreting the test data.
4. On major projects the possibility of making a more accurate assessment of parameters by carrying out large scale testing and/or full scale trials should be considered.[6]

[2] BS5930:1981 PP.33,44;

CIRIA25:1983 PP.68,69
[3] CIRIA25:1983 P.79
[4] ASSESSING BS5930:1986 P.86
[5] BS5930 P.66,67
[6] ASSESSING BS5930:1986 MARSLAND PP.289-290
[7] BS5930 P.63

Figures and Tables of in-situ tests are given in books as follows:
For SPT:
CIRIA 25: 1983. Fig.41 p.69
Clayton et al: 1982. Fig.7.1 p.231; Table 7.1 p.232
For CPT:
BS 5930: 1981. Figs.11,12 p.45,46
CIRIA 25: 1983. Figs.51,52 pp.82,83
Clayton et al: 1982. Fig.7.4 p.236
For vane:
CIRIA 25: 1983. Fig.44 p.73.
Clayton et al: 1982. Fig.7.7 p.242
For pressuremeters:
CIRIA 25: 1983. Figs.45,47-48 pp.75,77-78
Clayton et al: 1982. Fig.7.13, 7.16 p.249,252
For plate bearing tests:
BS 5930: 1981. Fig.18 p.61
CIRIA 25: 1983. Figs.49,55,56 pp.80,86,87
Clayton et al: 1982. Fig.7.18 p.256
For density:
CIRIA 25: 1983. Fig.57 p.88
For CBR:
CIRIA 25: 1983. Fig.50 p.80
For permeability
BS 5930: 1981. Fig.6 p.31
CIRIA 25: 1983. Figs.28-30,32 pp.53-55,59
Clayton et al: 1982. Fig.8.1, 8.3 p.277,280
For geophysical methods in ground investigation:
BS 5930: 1981. Table 3 p.68
Clayton et al: 1982. Table 3.5 pp.140-143
For seismic refraction:
CIRIA 25: 1983. Fig.58 p.90
Clayton et al: 1982. Fig.3.1 p.93
For electric resistivity:
CIRIA 25: 1983. Fig.59 p.91
Clayton et al: 1982. Fig.3.18 p.123

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SA331: IN-SITU PROBING TESTS

Explanation:

There are several tests described and compared under this title. They are: Probing; Standard Penetration Test (SPT); Static Cone Penetration Test (CPT); and Dynamic Macintosh Probe.

The simplest probe is a sharpened steel rod which is pushed or driven into the soil until it meets resistance. The method has many limitations, and a variety of more sophisticated devices has been developed in an attempt to overcome these and to extend the use beyond that of detecting a hard stratum, in order to give some measure of the allowable bearing capacity of the soils present. Two distinct types of probe have been developed: one where the probe is driven into the soil by means of some form of hammer blow; the other where the probe is forced into the soil by a static load.

The Standard Penetration Test (SPT) is a dynamic penetration test. It has the advantage that the equipment is rugged and can give a useful guide in ground conditions where it may not be possible to obtain borehole samples of adequate quality, e.g. gravels, sands, silts, clay containing sand or gravel, and weak rock. If "undisturbed" samples are suspect, e.g. silty or very sandy clays, or hard clays, SPTs can provide a rough check on the strength. The equipment comprises a split tube with a driving head and either a heavy duty cutting shoe or a solid cone point. It can be used both above and below the ground water table. The blow count (N value) may be used directly in empirical formulae for bearing capacity and settlement estimates, and for estimation of relative density and angle of shearing resistance. The test values may vary with diameter of borehole.

Cone Penetration Tests (CPTs) are static cone penetration tests which may be either mechanical (read manually), or electrical. The mechanical cone is provided with a jacket which prevents soil entering the guide tubes, and a friction sleeve of 15 000 mm2 surface area can be incorporated above the jacket so that soil adhesion can be measured. It can be used to provide a preliminary soil profile when boreholes are lacking and provide continuous and detailed profiles to show variations in strata. Mechanical penetrometers are subject to errors, particularly in weak soils, and the electric cone is preferred. Piezocone tests using cone penetrometers fitted with electrical transducers for measuring end bearing, local side friction and pore water pressures have become standard, particular for use in alluvial soils.

The Macintosh "Prospector" probe is a commonly used form of dynamic probing which employs a system of rods with a conical hard-wearing point, the rods being driven by a form of drop hammer. The fact that the rod is slightly smaller in diameter than the base of the cone prevents, to some extent, shaft friction from influencing the results, but at depth in certain soils this factor has to be taken into account. Shaft friction is eliminated by boring a hole to the depth required for each test or by providing the probe with a sleeve around the rod. The size of the cone, mass of hammer and the distance through which the constant mass is allowed to fall have not been standardised, and hence there is no substantial body of practical experience behind the test, although some published data are available linking the results of Macintosh probing tests in certain soils with soil parameters determined by other methods.

Besides the tests described above, there is another method called static-dynamic penetration testing. The probing equipment combines the SPT method and that of the static cone penetrometer, and is used for non-cohesive soils, particularly those with thin coarse or dense layers. The information is used in conjunction with that from boreholes.[1]

[1] CIRIA 25:1983 PP.68ff,81ff;
BS5930:1981 PP.43ff;
CLAYTON et al:1982 PP. 230ff

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SA332: IN-SITU VANE TESTS

Explanation:

The vane equipment comprises four blades arranged in a cruciform on the end of rods, which are extended from the ground surface or bottom of borehole to the test level. Other smaller types of vane are available that are used independently of boreholes, inserted from the ground surface or into the sides or bottom of trial pits.

When the vane is to be used from a borehole, the vane and a protective casing are forced into the ground by jacking. However, it is not always possible to penetrate to the desired stratum without the assistance of preboring. At the require depth the vane is pushed out beyond its protective casing and is rotated by hand cranking via a worm and pinion gear.

The vane test permits in-situ measurement of the peak undrained strength of sensitive clays with cohesion generally up to 100kPa. The remoulded shear strength may also be measured in-situ by continuing to rotate the vane to large rotations. The results should be used in conjunction with laboratory derived values of cohesion and measurement of plasticity index in order that an assessment of the validity of the results may be made. The method of testing causes little disturbance to the soil. The results are affected by the pressure of silty or sandy pockets. or significant organic content in the clay.[1]

[1] CIRIA 25:1983 P.72ff;
CLAYTON et al:1982 P.241ff

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SA333: PRESSUREMETER TESTS

Explanation:

In a pressuremeter test, a cylindrical probe is inserted into the ground and expanded laterally by compressed air or gas. The applied pressures and resulting deformations are measured and from these the strength and deformation characteristics of the ground can be investigated. The loading applied by the pressuremeter may not be representative of the loading to be applied by some future geotechnical structure, and this needs to be borne in mind in interpretation of results, particularly in horizontally layered ground.

The Menard pressuremeter employs an expanding cylindrical probe inside a pre-formed socket in the ground. Typically 'NX' core diameter (76 mm) holes are used for the test zone. In gravels, a slotted steel casing surrounds the probe and is driven into the base of the borehole. Depending on the ground conditions, some disturbance may occur during boring or insertion of the probe so that values of initial stiffness are not representative of the behaviour of the undisturbed soil, and should be used with care. More reliable values of stiffness can usually be obtained by performing small cycles of unloading and reloading.

The self-boring pressuremeter has the same functions as the borehole device, and was developed to be installed with minimal disturbance to the soil. It consists essentially of an upper part similar to a conventional pressuremeter with an inflatable rubber membrane, and a lower cutting head. The instrument has been proved in a variety of soil types, to depths of up to 80 m, through sands and even very stiff clays. Disturbance of the soil using this test is minimised. Radial movement is measured directly in the expanding section and the pressure: deformation data can be interpreted to give values of in-situ horizontal stress, shear stiffness, and strength properties.

The Stressprobe pressuremeter is a similar instrument which has been successfully used for offshore testing in deep water in different ground conditions, including stiff clays, soft clays and calcareous sands. It has also been developed for land-based use. The pressuremeter has been successfully tested in both soft and stiff cohesive soils. Its head consists of a hollow stainless steel cylinder surrounded by an inflatable membrane protected from damage by a series of stainless steel strips. The cylinder has a cutting shoe at its lower end which enables the instrument to be jacked into the soil beyond the base of the borehole with minimum disturbance to the surrounding soil, and allows a core of disturbed soil to pass up within the body of the cylinder and to be retrieved for subsequent inspection.[1]

[1] CIRIA 25:1983 PP.75ff;
CLAYTON et al:1982 PP.248ff

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SA334: PLATE BEARING TESTS

Explanation:

Plate bearing tests can be carried out in pits or boreholes. The diameter of the plate used should, so far as practicable, be equal to that of the borehole, provided that care is taken to eliminate cohesion or friction on the side of the plate. For a hole-diameter to plate-diameter ratio greater than about 3:2, there will be unloaded soil around the plate and the parameters being measured will be those relevant to a load at a free surface and not to a load applied at depth under confined conditions, which may be more appropriate for applications.

The interpretation of plate bearing tests is subject to scale effects. Prototype footings or foundations will usually be of different size from the plate that is tested. Several plate sizes and shapes have been used. The choice depends on the problem being studied. Plate bearing tests may be performed on small diameter plates (from 150 mm) for rapid testing with a limited reaction provided from the weight of the excavating plant, for example. Alternatively specially constructed tests using large plates (frequently 1m but up to 3m diameter) may be performed with tensile reaction provided by ground anchors, piles, or kentledge.

Plate tests are usually carried out either under a series of maintained loads or at a constant rate of penetration. In the former, the ground is allowed to consolidate under each load before a further increment is applied; this will provide information concerning the drained deformation characteristics and also the drained strength characteristics if the test is continued to failure. In the latter, the rate of penetration is generally sufficiently high that little or no drainage occurs, and the test gives the corresponding undrained deformation and strength characteristics.

Plate loading tests are carried out when accurate information is required concerning the vertical stress-strain response of the ground, and excessive disturbance would be expected during sampling. However, there is a possibility that the results of plate tests may also be affected by disturbance occurring during the preparation of the plate bearing surface, particularly for tests below the water table. In order to obtain good depth coverage, a number of tests may be required at vertical intervals of the order of four times the diameter of the plate.[1]

[1] BS 5930:1981 P.59ff;
CIRIA 25:1983 PP.80,86,87;
CLAYTON et al:1982 P.255ff

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SA335: SHALLOW IN-SITU TESTS

Explanation:

Shallow tests may include in-situ density and CBR method.

Most in-situ density tests use some form of replacement method, with removal of a representative sample of soil from the site and determination of its mass, and the volume that it occupied before being removed, to determine in-situ density. Mass determination is common to all methods and is straightforward. The variations lie in the several procedures used for measuring the volume and these depend upon the nature of the soil being tested. All methods require physical access to the soil in-situ, and are therefore normally restricted to soil within 2 m or so of the surface, although they can equally well be used in deep shafts or headings. The following methods of test are in general use:

(1) Sand replacement method: different sizes of hole and pouring cylinder are used for fine, medium and coarse grained soils. The method cannot be used in soils where the volume of the hole cannot be maintained constant. It also loses accuracy in soils where it is difficult to excavate a smooth hole because the sand cannot easily occupy the full volume.

(2) Core cutter method: depends upon being able to drive a cylindrical cutter into the soil without significant change of density and to retain the sample inside it so that the known internal volume of the cylinder is completely filled. It is therefore restricted to fine soils that are sufficiently cohesive for the sample not to fall out, and to chalk soils or completely weathered rock free of stones. The method is generally less accurate than the sand replacement method because driving the sampler tends to alter the density of the soil.

(3) Weight in water method: is applicable to any soil where representative samples occur in discrete lumps which will not disintegrate during handling and submersion in water. In practice the method is mainly restricted to cohesive soils.

(4) Water displacement method: is an alternative to the weight in water method and has the same limitations.

(5) Rubber balloon method: is an alternative to the sand replacement method using water contained in a rubber membrane to refill the hole from which soil has been taken, with the limitation that it is not suitable for very soft soil in which the volume of the hole cannot be maintained constant.

Test results from density tests are often variable, and it is therefore important to carry out at least three tests at any given location.

California Bearing Ratio Test (CBR):

This method covers the determination of the CBR of a soil tested in-situ, with a selected overburden pressure, by causing a cylindrical plunger to penetrate the soil at a given rate and comparing the relationship between force and penetration into the soil with that for a standard material.

The test is unsuitable for any soil containing particles of largest dimension greater than 20 mm because the seating of the plunger on a large stone may lead to an unrepresentative result. The test is of dubious value with sands because it tends to give results much lower than the laboratory tests on which the design charts are based. The test is most suited to clay soils, subject always to the soil under test being at equilibrium moisture content.

In-situ CBR tests have sometimes been carried out in conjunction with in-situ density and moisture content tests and then linked with laboratory compaction tests. A judicious study of all the resulting data leads to reasonable design parameters for suitable soils.

Attempts have sometimes been made to use the test as a means of controlling the compaction of fill or natural formations, but they have not usually been successful, as CBR cannot be directly related to design in-situ densities, and the procedure cannot be recommended.[1]

[1] BS 5930:1981 PP.55ff
CIRIA 25:1983 PP.80,88

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SA336: IN-SITU PERMEABILITY TESTS

Explanation:

Permeability:
For most types of ground, field permeability tests yield more reliable data than those carried out in the laboratory, because a larger volume of material is tested, and because the ground is tested in situ, thereby avoiding the disturbance associated with sampling.

In coarse sands, and gravels, constant or variable head permeability tests can be carried out through the base of a fully cased borehole (open borehole test), provided a supply of clean water is available. If the temperature of the added water is significantly lower than the temperature of the soil, there is a risk of air coming out of solution and affecting the results. It is desirable to carry out both falling and rising head tests, because falling head tests may underestimate permeability and rising head tests may overestimate it. The open borehole test is a relatively low cost method of obtaining permeability information, but it is very approximate, since sedimentation or loosening of the soil may occur, particularly in falling or constant head tests.

In silt or clay, the open borehole method is not suitable, and a piezometer is usually installed. Observation of in-situ flow characteristics using a piezometer provides a large-scale technique for determination of permeability and consolidation parameters, and the values that are obtained are generally more reliable than those obtained from laboratory tests on alluvial soils. Increase of water pressure in a borehole or piezometer during the process of permeability measurement may lead to swelling of the clay, and a change in effective stress state which is not appropriate to the foundation design problem. In-situ permeability tests are time consuming and expensive.

Ground water:
All the methods of determining ground water pressures require some flow of water into or out of the measuring device before the recorded pressure can reach equilibrium with the actual ground water pressure.

The simplest method of determining the ground water level is by observation in a borehole or excavation that is open or fitted with a perforated tube. Such methods should be treated with great caution, since sufficient time is not usually allowed for the water level to stabilise. Moreover, the levels from which the water is entering the borehole may not always be known, since these are affected by the use of temporary borehole casings. If there is conflicting borehole information relating to the groundwater, complex conditions should not be automatically assumed based on these simple observations, unless there are good stratigraphical reasons for this. In such circumstances, detailed instrumentation and recording should be carried out to identify the actual groundwater conditions.

For most conditions, it is preferable to use a standpipe piezometer, which may be just a simple perforated tubes, or other form of piezometer which will permit measurement of the water pressure at discrete locations in the ground.

Standpipes are normally used to record standing water levels for simple hydrostatic groundwater conditions. A frequently used standpipe piezometer is the Casagrande type. The main advantage is its simplicity. Moreover, it can also be used to determine the permeability of the ground in which the tip is embedded. The main disadvantage of the standpipe is the length of time taken to reach equilibrium or to respond to changes in porewater pressure in soils of relatively low permeability.

Other piezometers are hydraulic piezometers, electrical piezometers, and pneumatic piezometers. The hydraulic ones, which respond more rapidly than the Casagrande type and can also be used for in-situ measurements of permeability, are required for earthworks and construction monitoring. The electric transducer types and pneumatic measurement systems are fitted with a low air-entry value filter to discourage the entry of gas bubbles but they cannot be checked for saturation, and the porous tips cannot be de-aired after installation. If the fluid within the pore pressure measurement system is not saturated then the estimates of pore pressure may be seriously in error.[1]

[1] BS5930:1981 PP.30ff
CIRIA25:1983 PP.51ff
CLAYTON et al PP.276ff

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SA337: SPECIAL TESTS IN THE FIELD

Explanation:

Geophysical tests are described in this stage.

Geophysical methods most often used rely on contrasts of acoustic impedance (which is a function of density and stiffness), void space, or resistivity properties between the ground types being investigated, and the results obtained require careful correlation with borehole data. The greater the contrast between the geophysical properties of the strata exploited in the test, the more reliable the results. Adequate borehole coverage and considerable experience in this field are essential, to ensure correct interpretation of the observations. The successful application of geophysical methods depends on their suitability for a specific geotechnical problem. The methods introduced here are as follows:

Seismic refraction;
Cross-hole/down-hole seismic; and

Electrical resistivity.

So far the usefulness of geophysical methods of ground investigation for road-works has not been demonstrated except in limited applications and such methods should not be employed without prior consultation with the Materials Section of the Chief Road Engineer's Office.[1]

Other tests may include Large-scale trials and back analysis methods, and more information concerning these is available under the individual sections.

[1] SH2/88 P.17

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SA3371: SEISMIC REFRACTION TESTS

Explanation:

Seismic refraction is possibly the most important and most used technique in engineering geophysical investigations. This is because if used in the correct manner under favourable conditions, it can provide reliable quantitative data relating to the geological section across a site. The seismic refraction method can also provide the necessary data for assessing the quality of a soil mass in engineering terms.[1] The technique may be used to locate boundaries within the ground between materials having different values for the acoustic impedance for passage of shear or compression waves. The acoustic impedance depends on the density, stiffness, porosity, and structure of the material.

The seismic method of investigation may be considered if the soils and the boundaries between them fulfill the following requirements:

1. information not required below approximately 30 m depth (to obtain information at greater depths will require the use of large explosive charges);
2. the interfaces between the strata should approximate to inclined or horizontal planes;
3. each stratum should be of sufficient thickness, and of sufficiently different acoustic impedance from its neighbours, to appear as a significant change in velocity on the time-distance plot;
4. the velocity of wave propagation should increase with the depth of each succeeding formation.

The seismic refraction method is used for delineation of depth to bedrock at shallow depth (30 to 40 m) in horizontal or sloping strata. It is an economic technique when compared with boreholes for investigating large areas. But it is more expensive than resistivity surveys.[2]

[1] CLAYTON et al:1982 P.92
[2] CIRIA 25:1983 PP.89ff;
BS5930:1981 P.69

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SA3372: CROSSHOLE/DOWNHOLE SEISMIC TESTS

Explanation:

Crosshole/downhole seismic testing is a valuable technique for ground investigation, since it can be used to produce detailed profiles of compression (P) and shear (S) wave velocities. These velocity profiles can then be used to compute profiles of elastic moduli which may be useful for analysis of deformations of geotechnical structures. Crosshole/downhole seismic testing, however, should never be used alone, but should always form part of a coordinated ground-investigation program. The crosshole/downhole survey should tie in with existing boreholes, and all available geological information should be used in the interpretation process. In fact, one of the primary disadvantages of the crosshole/downhole method is the requirement of boreholes for conducting the tests; thus, the use of any existing boreholes at a site assumes dual importance. The primary advantage, however, is subsurface resolution which is not possible with surface methods.[1]

The downhole method requires a single borehole which is drilled and accurately logged. A special geophone/hydrophone is lowered down the hole to a depth corresponding to the base of a soil layer. Using a shot point located close the top of the hole, the average velocity of the material above the detector can be determined from the shot/detector travel time. If the detector is now raised to the top of the layer and another shot fired from the same shot point, the difference in travel times can be used in conjunction with the logged thickness of the layer to determine the average wave velocity of the layer. This process may be repeated for all strata encountered in the borehole.

The crosshole method requires two boreholes to be drilled and accurately logged. The energy source is placed in one borehole and the detector in the other. The levels of the energy source and detector are adjusted such that they are the same. The travel-time measured by this configuration allows the wave velocity of a layer to be determined. The source and detector are raised up the boreholes together in order that the wave velocity of each layer encountered may be determined. Clearly, for dipping strata the two boreholes should be aligned along the strike, The velocities determined by this technique are likely to be different from those found using the downhole technique because of velocity anisotropy.[2]

These tests are highly specialised and have not been widely used in ground investigations for trunk roads.

[1] DWAIN et al:1981 GEOPHYSICS VOL.46 P.23
[2] CLAYTON et al:1982 P.115

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SA3373: ELECTRICAL RESISTIVITY TESTS IN THE FIELD

Explanation:

The resistivity survey is a commonly used technique for investigating simple geological problems and detecting saturation boundaries in permeable formations. A current is usually passed into the ground surface through two metal electrodes, and the potential difference measured between two similar electrodes. With suitable deployment of the electrodes, the system may be used to provide information on the geo-electrical stratification of the ground (depth probes), lateral changes in resistivity (constant separation traversing), or local anomalous areas (equipotential survey). The latter may be used to locate swallow holes or hidden mine shafts for example. The unsuspected presence of electrical conductors, e.g. pipes or cables, under the site will, of course, render the results unreliable. The interpretation of the results obtained by this method does not always provide a definite solution, particularly as the number of layers increases, because it involves curve matching with idealised conditions.

The method is of relatively low cost and while the fieldwork may be simple to perform, the interpretation is not simple, and requires skilled and trained personnel. It is suited for exploration for shallow foundations and can be used to investigate large areas economically compared with boreholes. However, it is rather inaccurate for depth prediction ($\pm 20\%$) and requires correlation with borehole data.[1]

[1] CIRIA25:1983 PP. 91,92;
CLAYTON et al:1982 121ff

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SA3374: OTHER SPECIAL TESTS IN THE FIELD

Explanation:

Large-scale field trials:
Large-scale field trials are carried out in such a manner that the ground is tested on a scale and under conditions comparable with those expected to prevail at the time of construction. Such trials are, however, likely to be costly in terms of instrumentation, technical support and co-ordination of results. Some trials may also require the development of specialised monitoring equipment.

Several techniques can be used in ground investigation to monitor displacements and strains associated with known or suspected ground mass movements resulting from slope failures, foundation displacements, mining subsidence and ground response in large scale field trials.

On large projects, field trials can provide the necessary design parameters, and valuable construction data on excavation, handling and placing, resulting in considerable savings and enhanced safety. Many aspects of ground or soil performance are regularly explored using full-scale trials: for example, construction methods, such as pile tests, ground anchor tests, and compaction tests for earthworks; and construction expedients, such as grouting trials, evaluation of drainage techniques for speeding up consolidation, trial blasts for use of explosives, and dewatering trials.

Back analysis:
Natural or man-made conditions on a site sometimes create phenomena which may be used to assess parameters which are otherwise difficult to assess or which may be used as a check on laboratory measurements. Examples of such phenomena are slope failures, and settlement of structures. It may be possible, starting from the observed phenomena, to perform a back analysis and, in the case of a slope failure, to arrive at shear strength parameters which fit the observed facts. Back analysis of settlements is also possible, but care is required in assessing actual loadings and the times for which they have acted. For a back analysis to be effective, it should be accompanied by a full investigation to determine the ground and ground water conditions.[1]

[1] BS 5930:1981 PP.66ff

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SA4: LABORATORY TESTS

Explanation:

During site reconnaissance work, preparations should be made to compile a tentative laboratory schedule. Plans for laboratory testing and field testing and sampling should be developed concurrently. On a large scheme, laboratory tests are often performed at the same time as the field investigation, as an integral part of ground investigation. The need for laboratory tests will often dictate the type and frequency of sample to be taken, and may therefore control the method of forming boreholes. The decision as to the type of sample required will require some prior knowledge of the ground conditions.

The aims of laboratory testing of samples of soil may be summarised as follows:
1. to identify and classify the samples with a view to making use of past experience with materials of similar geological age, origin and condition; and
2. to obtain soil parameters relevant to the technical objectives of the investigation.[1]

Several groups of laboratory testing are described here, they are as follows:
1. classification and index tests;
2. strength and deformation tests;
3. compaction tests;
4. permeability tests; and
5. chemical tests.

[1] CIRIA 25:1983 PP.13,102;
CLAYTON et al:1982 P.356;
BS 5930:1981 P.70

References:

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Advisory:

Current thinking in ground investigation is tending to supplement tests in the laboratory with both field testing and back analysis of the behaviour of existing structures which have been monitored. Although in many cases a field test will give more realistic results because of reduced problems of sample disturbance, reliable predictions generally result from laboratory tests when the data derived from them are used with skill and experience. Sample quality, sample size, and test conditions will influence test results.

Nevertheless the measurement of soil properties by means of laboratory tests offers a number of advantages, as follows:
1. Full control of the test conditions, including boundary conditions, can be exercised.
2. Laboratory testing generally permits a greater degree of accuracy of measurements than does field testing.
3. Control can be exercised over the choice of material which is to be tested.
4. A test can be run under conditions which are similar to, or alternatively which deliberately differ from, those prevailing in situ, as may be appropriate.
5. Changes in conditions can be simulated, as can the conditions which are likely to occur during or after completion of construction.
6. Tests can be carried out on soils which have been broken down and reconstituted, or processed in other ways.

All samples should be examined individually before compiling a laboratory schedule of testing. Each time a specimen is taken from the sample for testing, the sample should be re-examined. When it is known that no further testing is likely to be required, the remainder should be extruded, split, examined and described, particularly noting details of fabric and structure.

When designing a laboratory schedule, a list of properties required for design calculations should be summarised for each soil type. It is then relatively straightforward to determine the types and quantities of tests required. However, the choice of laboratory testing is partly governed by the size and quality of the sample obtained. It is therefore necessary to consider this aspect at the field investigation stage - and the importance of concurrent planning of field and laboratory work should be apparent.

Where laboratory tests are covered by British Standards, the methods of test and reporting should be in accordance with these. Where tests are non-standard, the appropriate information should be provided in the report.[1]

[1] CIRIA 25:1983 P.102;
BS 5930:1981 PP.75-76;
HEAD:1980 VOL.1 P.2

Expert Opinion:

Most common laboratory tests on soil are described in:
BS 5930: 1981. Table 4, pp.71-73.

A summary of basic laboratory tests appropriate to geotechnical problems is given in:
CIRIA 25: 1983. Table 9, p.109.

Typical quantities of samples required for various soil tests are given in:

BS 5930: 1981. Table 1, p.21;
CIRIA 25: 1983. Table 8, p.107.

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SA41: SOIL CLASSIFICATION

Explanation:

Soil classification is carried out in order to categorise the soil on any site within a small number of different groups. Each soil group may consist of a stratigraphically defined geological unit. Often,however, it may ignore geological boundaries because the essence of the soil group should be that materials within it have (or are expected to have) similar geotechnical properties. Particle size, plasticity and organic content may be more important to the geotechnical engineer than time of deposition. The three main tools used to classify soil are soil description (discussed under SAMPLING/LOGGING), particle size distribution analysis, and index (liquid and plastic limit) testing.[1] In this section, classification tests are divided into these three groups:
1. Moisture content and voids radio;
2. Particle size distribution; and
3. Index properties.

[1] CLAYTON et al:1982 P.358

Advisory:

Soil classification has an important role to play in reducing the costs and increasing the cost-effectiveness of laboratory testing. Together with detailed sample description, classification tests allow the soils on a site to be divided into a limited number of separate groups, each of which is estimated to contain materials of similar geotechnical character. Subsequent, more expensive and time-consuming, tests to determine geotechnical parameters for design purposes may then be made on limited numbers of samples which are selected to be representative of the soil group in question.

MOISTURE CONTENT, VOIDS RATIO, DENSITY

While these may not be strictly regarded as classification tests, knowledge of the value of some density or volumetric parameter will be required as a guide to classification of natural soils and as a control criterion in recompacted soils, and is measured on samples used for most field and laboratory tests.[4]

Several tests come under this title. They are: moisture content, voids ratio, saturation, specific gravity of soil particles, in-situ density, and air voids ratio.

The moisture content of a soil is the characteristic which is most frequently determined, and can be measured for most types of soil where reasonably intact samples are available. The test is frequently carried out in association with other soil tests. If determined in conjunction with liquid and plastic limits of cohesive soil, a crude indication of the undrained shear strength can be obtained.

Voids ratio, and degree of saturation, are important factors relating to the compaction of soils. Voids ratio is used as an index for assessment of the relative density of sands. However, the main application of voids radio is in the analysis of data from consolidation tests performed in an oedometer.

It is rarely possible to use specific gravity as an index for soil classification. But knowledge of the specific gravity is essential in relation to some other soil tests, especially for calculating porosity and voids ratio, and is particularly important when compaction and consolidation properties are considered. The specific gravity must also be known for the computation of particle size analysis from a sedimentation test.

Determination of in situ density of soil is important for many geotechnical applications. In practical problems associated with earthworks and foundations, the weight of the soil itself exerts forces which have to be taken into account in the analysis. It is therefore necessary to know the bulk density of the soil, from which these forces can be calculated. The bulk density of natural soil is usually determined from laboratory measurements on undisturbed samples, whereas the measurement of bulk density in the field can be referred to under 'FIELD TECHNIQUES/IN_SITU/SHALLOW TESTS'.[1]

PARTICLE SIZE DISTRIBUTION:

A soil consists of an assemblage of discrete particles of various shapes and sizes. The object of a particle size analysis is to group these particles into separate ranges of sizes, and so determine the relative proportions, by dry weight, of each size range. Two separate and quite different procedures are used, in order to span the very wide range of particle sizes which are encountered. These are the procedures of sieving and sedimentation.

Sieving methods give the grading of soil coarser than silt (particle sizes greater than 0.06 mm). The proportion passing the finest sieve represents the combined silt/clay fraction. The relative proportions of silt and clay can only be determined by means of sedimentation tests which should be carried out when there is a real need for this information.[2]

INDEX PROPERTIES:

1. Liquid and plastic limits for cohesive soils

For every clay soil there is a range of moisture contents within which the clay has a plastic consistency, and the liquid and plastic limits provide a means of quantifying this plastic range, and their difference is defined as the plasticity index of the soil. Originally, it was suggested by Atterberg that the liquid limit was the maximum water content at which the clay could be prepared for it just to be able to deform plastically and not flow as a liquid. It was suggested that the plastic limit was the lowest water content at which the clay could be prepared for it to be able to deform plastically and not crumble when deformed.

The liquid and plastic limits are used to classify cohesive soil and used as an aid to classifying the fine fraction of mixed soil. They may be used to correlate soil strata occurring in different areas of a site, or to investigate in detail the variations of soil properties which occur within a limited zone. Results of liquid and plastic limit tests can also be applied to the selection of soils for use as compacted fill in various types of earthworks construction.

2. Maximum and minimum void ratios for cohesionless soils

Standard procedures are used to determine the loosest and densest packings of granular cohesionless soils, and hence the maximum and minimum void ratios, or minimum and maximum densities. Knowledge of the actual void ratio or density of the soil then permits the relative density to be estimated.

The application of maximum and minimum densities relates only to granular soils, and to sands in particular. These limiting densities of sands are not so widely used as the liquid and plastic limits of clays. Nevertheless the assessment of relative density can give some indication of the possible effects of loading or of disturbance on sand. This is particularly important where a sand deposit is likely to be affected by vibration, such as from machinery, or pile driving, or by earthquake shock. In loose sand or silt deposits below the water table, vibration or shock could result in liquefaction and collapse of the grain structure. It is therefore desirable to have some means of assessing how loose a 'loose' deposit is, so that appropriate remedial measures can be taken if necessary.[3]

[1] HEAD:1980 PP.50,113-114,272;
BS 5930:1981 P.71;
CIRIA 25:1983 P.109
[2] HEAD:1980 P.143;
BS 5930:1981 P.71
[3] HEAD:1980 PP.52,60,114;
BS 5930:1981 P.71
[4] BS1377: 1990. Part 2 Clause 3 p.2

Expert Opinion:

Moisture content:
BS 1377: 1990. Part 2 Clause 3 p.2;
Head: 1980. Section 2.5 p.61.

Particle size distribution:
BS 1377: 1990. Part 2 Clause 9 p.30;
Head: 1980. Chapter 4 p.143.

Liquid and plastic limits:
BS 1377: 1990. Part 2 Clauses 4,5 pp.5,13; Fig. 1 p.7;
Head: 1980. Section 2.6 p.66.
Figs. 2.11,2.13.2.16 pp.69,72,75.

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SA411: MOISTURE & VOIDS RATIO TESTS IN LABORATORY

Explanation:

Moisture content:

The moisture content of a soil is assumed to be the amount of water within the pore space between the soil grains which is removable by oven drying at 105-110 degree Centigrade, expressed as a percentage of the mass of dry soil. The period required for 'drying' is usually between 12-24 h.

The reasons for carrying out moisture content test on soils fall into three categories:
1. To determine the moisture content of the in-situ soil, using undisturbed or disturbed samples.
2. To determine the plasticity and shrinkage limits of fine-grained soils, for which moisture content is used as the index. (see LABORATORY/CLASSIFICATION AND INDEX/INDEX)
3. To measure the moisture content of samples used for laboratory

testing, usually both before and after test. This is normally done on all test samples as a routine procedure.

Voids ratio:

The amount of void space within a soil has an important effect on its mechanical and hydraulic characteristics, such as shear strength and permeability. Two expressions are used to provide a measure of the void space -- namely 'voids ratio' and 'porosity'. They can be derived when moisture content, bulk density and specific gravity are already known. Relationships can be developed between density, moisture content, specific gravity, voids ratio, porosity and degree of saturation of soils.

Specific gravity:

Specific gravity is used in conjunction with other tests, such as sedimentation and consolidation. Values commonly range between 2.55 and 2.75, and a more accurate value is required for air voids determination. Determination of specific gravity is particularly necessary where spoil heap, industrial waste or organic material is concerned.

Soil containing substantial proportions of heavy or light particles can give erratic values of specific gravity. A number of repeat tests may be needed to obtain a reliable average value for this type of soil.

Density:

Measurement of the density of soils is often overlooked, but it can be just as important as the measurement of moisture content. It is good practice to measure the density of all undisturbed samples tested in the laboratory. In the analysis of the stability of a slope, such as an embankment or the sides of a cutting, the weight of soil provides the main force, but it is also significant in calculating the bearing capacity and settlement of foundations for other structures.

The density tests fall into three categories, which are based on three different principles for the measurement of volume. These are:
1. Linear measurement.
2. Water displacement.
3. Water immersion (Weighing in water)

Air voids ratio and degree of saturation:

Air voids ratio and the degree of saturation can be calculated if moisture content, bulk density and specific gravity are already known. They are used in the analysis of compaction tests.[1]

[1] BS 5930:1981 P.71;
HEAD:1980 PP.50,51,58,114,269,271

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SA412: PARTICLE SIZE DISTRIBUTION TEST

Explanation:

A particle size distribution (PSD) analysis is a necessary index test for soils, especially coarse soils, in that it presents the relative proportions of different sizes of particles.

From this it is possible to tell whether the soil consists of predominantly gravel, sand, silt or clay sizes, and to a limited extent which of these size ranges is likely to control the engineering properties. Some applications of particle size analysis in geotechnology and construction are as follows:

1. Selection of fill materials: soil used for the construction of embankments.
2. Selection of road sub-base materials: a particular grading specification for each layer of a road sub-base.
3. Design of drainage filters: the grading specification for a filter layer for the adjacent ground, or of the next filter layer.
4. Evaluation of groundwater drainage: the drainage characteristics of the ground.
5. Selection of construction materials: sands and gravels for use as concrete aggregates.
6. Dynamic compaction: an indication of the feasibility of improving poor ground by dynamic compaction.

The methods to be used for determining the particle size distribution in soils depend upon:

1. Size of the largest particle present: determines the size of sample required.

2. Range of particle sizes: determines the method to be used, such as whether or not a sedimentation test is required.

3. Soil characteristics: governs the complexity of the testing and depends on whether the soil is granular and 'clean' (no fines); predominantly granular with fines; or decidedly cohesive.

4. Stability of soil grains: decides the initial preparation of the soil for testing, because special care is needed if particles are easily broken down mechanically or chemically.

The methods for determining PSD may include the following:

1. Dry sieving test: For clean sands and gravels, the simple dry sieving method can be used. If the sample contains particles of medium to large gravel size, the composite dry sieving may be required.

2. Wet sieving test: For soil containing silt or clay, wet sieving should be used to wash and remove the fine particles which pass a 63 micron sieve. The retained material can then be dry sieved. Composite sieving is nearly always necessary unless sand is the coarsest material present.

3. Sedimentation test: For predominantly clayey and silty soils containing sand, a sedimentation test should be used for the material passing through the 63 micron sieve, the material retained is dry sieved.

4. 'Boulder clay': For gravelly sandy silty clay, a special treatment by the 'boulder clay' method is used. This type of soil is found, for example, as glacial till, and is often loosely called 'boulder clay'. This indicates a soil, usually of glacial origin, which contains enough clay to give it cohesion and is well-graded from clay through to gravel or cobble-size particles. This type of soil is the most difficult on which to carry out a particle size analysis. The procedure can be very time-consuming and the calculations are less straightforward than for tests on soils of less broad grading.[1]

[1] HEAD:1980 PP.145,151-153,177

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SA413: INDEX PROPERTY TESTS IN LABORATORY

Explanation:

The index tests, or limit tests considered here relate only to cohesive soils, often including silts, and are often referred to as their plasticity characteristics.

The liquid limit, plastic limit and shrinkage limit are known collectively as the Atterberg limits. The liquid and plastic limits provide the most useful way of identifying and classifying fine-grained cohesive soils. Particle size tests provide quantitative data on the range of sizes of particles and the amount of clay present, but say nothing about the type of clay. Clay particles are too small to be examined visually (except under an electron microscope), but the Atterberg limits enable clay soils to be classified physically, and the probable type of clay minerals to be assessed.

The following tests for determination of the Atterberg Limits are introduced here:
1. Cone penetrometer;
2. Casagrande apparatus;
3. One-point method;
4. Plastic limit;
5. Shrinkage limit;
6. Limiting densities.

Cone penetrometer:

This is the British Standard preferred method for determining the liquid limit of soils. The test is carried out on remoulded soil, the fraction passing a 425 micron sieve being used. It is based on the measurement of penetration into the soil under its own weight of a standard cone with tip angle 30 degree and of specified mass 80g. At the liquid limit the cone penetration is 20 mm.

Results obtained by the cone method have been proved to be more consistent, and less liable to experimental and operator errors, than those obtained by the Casagrande method. The cone method may not be any quicker to perform, but it is fundamentally more satisfactory, because the mechanics of the test depend directly on the static shear strength of the soil.

Casagrande apparatus:

The method devised by Casagrande was for 40 years the universally recognised standard method for the determination of the liquid limit of clay soils. This has now been superseded in Great Britain by the cone penetrometer test, although the Casagrande procedure is retained in the British Standard as a subsidiary method.

The test is carried out on remoulded soil, the fraction passing a 425 micron sieve being used. The Casagrande procedure introduces a dynamic component and has been found to be somewhat operator sensitive.

One-point method:

The Casagrande one-point method is useful as a 'rapid' test, or when only a very small amount of soil is available. However, the result is likely to be less reliable than that obtained using the cone penetrometer.

Plastic limit:

In the plastic limit test, the soil is rolled into a thread, of 3 mm diameter, and moulded continuously until the thread shears both longitudinally and transversely. The first crumbling point is the plastic limit.

This test is used to determine the lowest moisture content at which the soil is plastic. It can be carried out only on soils with some cohesion, on the fraction passing a 425 micron sieve. The test may be carried out either on soil in its natural state or on air-dried soil which has been remixed with water. The test is usually carried out in conjunction with the liquid limit test.

Shrinkage limit:

When the water content of a fine-grained soil is reduced below the plastic limit, shrinkage of the soil mass continues until the shrinkage limit is reached. At that point the solid particles are in close contact and the water contained in the soil is just sufficient to fill the voids between them.

Clays are more susceptible to shrinkage than silts and sands. In most cohesive soils the shrinkage limit is appreciably below the plastic limit. In silts the two limits are close together and may be difficult to measure.

There are two tests for the determination of the shrinkage limit and the BS test for linear shrinkage.

1. TRRL method: can be used with undisturbed or remoulded specimens. It was developed for use with standard 38 mm or 51 mm diameter undisturbed samples. This method is the more elaborate, and would appear to be more versatile and to offer greater accuracy. It is particularly important that the apparatus that is used for this test should be maintained in good condition and in a laboratory where this test is not often performed, the results may well be unreliable.

2. ASTM method: can be also used with undisturbed or remoulded specimens. This method requires simple apparatus, but involves the use of exposed mercury. Adequate ventilation is essential, together with precautions to guard against spillage and availability of treatment facilities if spillage does occur.

3. Linear shrinkage: gives the percentage linear shrinkage of a soil. It can be used for soil of low plasticity, including silts, as well as for clays.

Limiting densities:

The maximum and minimum void ratios (or minimum and maximum densities) are index properties for granular soils. The tests mentioned here require only simple equipment and they give results which are reliable enough for most engineering applications.

Kolbuszewski (1948) suggested that the following procedures be used for obtaining limiting porosities of sands:

1. Maximum void ratio/minimum density. A measuring cylinder containing dry, well mixed sand is inverted several times.

2. Minimum void ratio/maximum density. Dry sand is vibrated in three layers in a compaction cylinder.[1]

[1] HEAD:1980 PP.50,55,58,67,69,73,84,93,134,138,139;
KOLBUSZEWSKI:1948 'AN EXPERIMENTAL STUDY OF THE MAXIMUM

AND MINIMUM POROSITIES OF SANDS', PROC.2ND.INT.CONF.SOIL MECH.AND FOUND.ENG.,ROTTERDAN,VOL.1,P.165

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SA42: STRENGTH-DEFORMATION

Explanation:

The behaviour of soil under stress is generally more complex than that of other materials with which the civil engineer has to deal. Not only do soils of different types differ considerably in their resistance to deformation under stress, but such deformation depends upon the moisture content, bulk density and internal structure of the soil (and hence on the previous stress history) and upon the way in which the stress is applied. Furthermore, the soil beneath a foundation is seldom homogeneous and large variations in strength may occur in both the vertical and horizontal planes.

Two characteristics of soils that are related to deformation rather than to shear strength may also be determined.

1. The stress-strain relationship which may be partly expressed in terms of 'elastic constants', Young's modulus, E, and Poisson's ratio, v.

2. The relationship between horizontal and vertical stresses in soil that is in a state of equilibrium, i.e. the 'coefficient of earth pressure at rest', denoted by Ko.

The principal tools available for determination of strength and deformation characteristics in a typical geotechnical testing laboratory might be various forms of direct shear and triaxial apparatus, the laboratory vane and fall-cone apparatus, and the California Bearing Ratio (CBR) apparatus.[1]

[1] RRL:1952 P.346;
CLAYTON et al:1982 P.370;
HEAD:1986 P.1028

Advisory:

Every building or structure which is founded in or on the earth imposes loads on the soil which supports the foundations. The stresses set up in the soil cause deformations of the soil, which can occur in three ways:

1. By elastic deformation of the soil particles.

2. By change in volume of the soil resulting from the expulsion of fluid (water and/or gas) from the voids between the solid particles.

3. By the slippage of soil particles, one on another, which may ultimately lead to the sliding of one body of soil relative to the surrounding mass.

The first of these is negligible for most soils at the typical stress levels that occur in practice. The second is known as consolidation. The third is the process known as shearing and may lead to failure when shear stresses set up in the soil mass exceed the maximum shear resistance which the soil can offer, i.e. its shear strength.

This section deals with the measurement of the strength and deformation properties of soils in the laboratory by several methods as follows:

CBR:
The California Bearing Ratio (CBR) test is an empirical test for estimating the bearing value of highway sub-bases and subgrades. The test follows a standardised procedure, which is performed by pushing a standard plunger into the soil at a fixed rate of penetration, and measuring the force required to maintain that rate. From the resulting load-penetration relationship the CBR value can be derived for the soil in the condition at which it was tested. It is important to appreciate that this test, being of an empirical nature, is strictly valid only for the application for which it was developed, i.e. the design of airport runway foundations.[1]

Fall cone test:
The fall cone (laboratory cone penetrometer) that is used for determination of the liquid limit of soils can also be used to estimate the undrained strength of cohesive soils. The technique is widely used in Scandinavia to provide a quick measurement of strength and is being increasingly used in other parts of the world particularly for soft clays.

Laboratory vane shear:
For soft clay, the laboratory vane shear test is an alternative to undrained triaxial testing for determination of undrained strength where the preparation of the specimen may have an adverse effect on the measured strength of the soil. Experience has shown that the results of the laboratory vane test are compatible with the results of unconfined compression tests (refer to 'Unconfined compression test' below).

The laboratory vane enables the low shear strength of very soft soils (i.e. strengths less than 20kN/m2) to be measured. It is difficult to measure such strengths by other means apart from the fall-cone. However, the small size of the laboratory vane makes the device unsuitable for testing samples with fissuring or fabric, and therefore it is not very frequently used. The results should be viewed as providing only a semi-quantitative indication of shear strength, and the values used with caution in design applications.[2]

Shear box/ring shear:
The shear box test is the simplest, the oldest and the most straightforward procedure for measuring the shear strength of soils. It is also the easiest to understand, but it has a number of shortcomings, such as the fact that the soil specimen is constrained to fail along a predetermined plane of shear; drainage conditions within the soil cannot be controlled; the stresses on the failure plane are distributed unevenly; etc.

Shearbox tests include standard shearbox tests and large shearbox tests. The 60 mm square shearbox has been for many years the commonest size used in Britain; this is used for the standard 'quick' shearbox test. The same principles apply to a 100 mm square shearbox which has been introduced more recently. The large shearbox is used for specimens which are about 300 mm square and can accommodate soils containing particles up to 37.5 mm.

If residual strength parameters are required then tests should be carried out on annular specimens in the ring shear apparatus. Because of its cost and complexity this apparatus has failed to find a place in site investigation testing laboratories, but a simpler form of ring shear test may well be more widely available in future years. Residual strength properties have also be determined by back and forth shearing within a conventional shear box.[3]

Oedometer:
The oedometer consolidation test is used for the determination of the consolidation characteristics of soils of low permeability. The two parameters normally required are:

(1) The compressibility of the soil (expressed in terms of the coefficient of volume compressibility; also known as modulus of volume change), which is a measure of the amount by which the soil will compress when loaded and allowed to consolidate.

(2) The time related parameter (expressed in terms of the coefficient of consolidation) which indicates the rate of compression and hence the time-period over which consolidation settlement will take place.[4]

Time-dependent consolidation of soils is controlled by permeability and stiffness: coefficient of consolidation is a composite and less fundamental parameter.

Permeability of soils can be determined from oedometer tests indirectly, from interpretation of time-dependent deformations. Permeability can also be determined directly by performing constant head or falling head tests on the soil sample contained within the oedometer, as described in section 'PERMEABILITY'.

Unconfined compression tests:

Unconfined compression tests are more reliable procedures for measuring undrained shear strength parameters of soils than direct shear tests. The basic unconfined compression test is a rapid substitute for the undrained triaxial test, although it is suitable only for saturated non-fissured cohesive soil.[5]

In unconfined compression tests, undrained strengths measured with different devices in the field and in the laboratory are usually different and care should be taken both in comparing values of strength and in selecting values to be used in geotechnical design.

Triaxial compression tests:

Triaxial compression tests are more versatile and in many ways more reliable than shear box tests, and can be used with most types of soil. They can also represent more realistically the stress conditions prevailing in the ground.

Undisturbed specimens of most soils can be used for triaxial tests. Recompacted soils of all types, and remoulded clays can also be tested. Specimens of cohesionless soils such as sands can be difficult to prepare and these are perhaps more conveniently tested in the shearbox apparatus. The maximum particle size should in general not be greater than about 20-25% of the sample diameter, and it is preferable to keep the maximum particle size below about 10% of diameter. Soils containing gravel-size particles therefore require large diameter specimens, 100 or 150 mm diameter. Soils such as stiff fissured clays which contain discontinuities or other surfaces of potential weakness, and other non-homogeneous soils should also be tested in the form of samples which are large enough to contain representative volumes of soil fabric.

The standard triaxial test is intended mainly for use with fine-grained homogeneous cohesive soils.[6]

Special tests:

Special tests may include triaxial extension tests and stress path triaxial tests which can be used for the measurement of the shear strength of soils, additional to the basic tests described under 'Triaxial Compression Tests'.

In extension tests, failure is induced under the action of the confining pressure as the axial stress is gradually reduced, reproducing the stress changes that occur at the bottom of an excavation as the overburden is removed. In another case (tests with decreasing confining pressure), failure occurs under constant axial load as the confining pressure is decreased, corresponding to the stress path followed in active movement of retaining walls, or excavation of cuttings.

Use of the stress path method in the laboratory enables the field stress changes, past, present and future, to be modelled much more realistically than by using conventional test procedures alone.[7] The stress paths to be followed in the triaxial tests are selected by the geotechnical engineer after consideration of the stress changes and stress levels that are likely to occur in the ground as a result of geotechnical construction.

[1] HEAD:1982 PP.469
[2] BS 5930:1981 P.72;
HEAD:1982 PP.541,572;
CLAYTON et al:1982 P.374
[3] BS 5930:1981 P.72;
HEAD:1982 PP.510,540;
CLAYTON et al:1982 P.375
[4] BS 5930:1981 P.73;
HEAD:1982 P.651
[5] BS 5930:1981 P.72;
HEAD:1982 PP.583
[6] BS 5930:1981 P.72;
HEAD:1982 PP.583,600,617
[7] HEAD:1986 PP.971,987,995,1076

Expert Opinion:

California Bearing Ratio test:
BS 1377: 1967.
Head: 1982. Chapter 11 p.469; Fig. 11.26 p.500.
Laboratory vane test:
BS 1377: 1990. Part 7 Clause 3 p.2; Fig. 1 p.28;
Head: 1982. Section 12.8 p.572; Fig. 12.58 p.573.
Shearbox tests:
BS 1377: 1990. Part 7 Clauses 4,5 pp.4,11;
Figs. 2,3 pp.29,30;
Head: 1982. Sections 12.5,12.6 pp.542,562;
Figs. 12.34,12.35,12.51.
Ring shear test:
BS 1377: 1990. Part 7 Clause 6 p.16; Fig. 4 p.31;
Head: 1982. Figs. 12.1,12.2 pp.511,512.
Odeometer:
BS 1377: 1990. Part 6?
Head: 1982. Chapter 14 p.651; Fig. 14.3 p.653.
Unconfined compression test:
BS 1377: 1990. Part 7 Clause 7 p.19; Fig. 5 p.32;
Head: 1982. Section 13.5 p.601;
Figs. 13.19,13.20,13.22 pp.602,607,609.
Triaxial compression tests:
BS 1377: 1990. Part 7 Clause 8 p.22; Fig. 10 p.37;
ibid. Part 8 Clauses 7,8 pp.15,19; Figs. 1,2, pp.4,7;
Head: 1982. Section 13.6 p.616; Fig. 13.38 p.624.
Triaxial extension:
Head: 1986. Section 19.5 p.987; Fig. 19.11 p.989.
Stress path tests:
Head: 1986. Chapter 23 p.1076.

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SA421: CBR TEST IN LABORATORY FOR PAVEMENT DESIGN

Explanation:

The California Bearing Ratio (CBR) test is the most widely used of a number of empirical penetration type tests. It is perhaps the most adaptable of these tests, for it can be carried out in the laboratory on most types of soil ranging from heavy clay to material of medium gravel size.

The CBR test was originally devised to provide a rational method of design for flexible pavements (such as macadam or asphalt), but it can also be applied to the design of rigid (concrete) pavements and granular base courses. Test data are applicable to the design of airfield runways and taxiways as well as roads. Standard design charts are used by engineers to determine the thickness of construction required corresponding to the CBR value, depending upon the anticipated traffic conditions in terms of axle loadings and traffic frequency.

The test is relatively quick and simple, and gives an immediate result. It can be carried out on undisturbed or recompacted materials. The CBR value is a dimensionless number, and is not related to fundamental soil properties governing shear strength or compressibility. Attempts have been made to relate CBR value to other parameters for particular soils, but no satisfactory relationships have been obtained for general application. For instance, the CBR test should not be used to estimate the bearing capacity of ground for foundations. The result should be regarded as an index property, the application of which is restricted to pavement construction.

The CBR test is a constant rate of penetration test in which a standard plunger is pushed into the soil at a constant rate and the force required to maintain that rate is measured at suitable intervals. The load-penetration relationship is drawn as a graph from which the loads corresponding to standard penetrations are read off and expressed as ratios (percent) of standard loads. The accepted percentage is known as the California Bearing Ratio value of the soil in the condition in which it was tested. The CBR value can be regarded as an indirect measure of the shear strength of the soil, but it cannot be related directly to shear strength parameters. The CBR is derived form an ad hoc test and is not based on theoretical concepts.

The observed performance of road pavements in the UK has provided empirical data from which the CBR value can be obtained from particle size or plasticity index.[1]

[1] HEAD:1982 PP.472,476-477,478;
CLAYTON et al:1982 P.371

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SA422: LABORATORY FALLING CONE FOR STRENGTH MEASUREMENT

Explanation:

The falling-cone test has been described under 'CLASSIFICATION AND INDEX TESTS' for determination of the liquid limit of soils. The technique can also be used to estimate the undrained strength of cohesive soils.

Standard commercial equipment provides cones of 60 and 30 degree tip angles and of different masses. Different combinations of cone tip angle and mass are used for different strength ranges. The chosen cone is positioned in contact with an exposed face of the soil sample - for example, in its sampling tube - and then allowed to fall under its own weight. Charts are provided from which the measured cone penetration can be converted into an estimate of undrained strength.

The fall-cone test is particularly suited to rapid strength estimation for uniform clays. It is not suitable for materials which contain a significant content of sand or gravel sized particles. This test has been widely used in Scandinavia and is becoming more widely used in other parts of the world.[1]

[1] HANSBO, S:1957 A NEW APPROACH TO THE DETERMINATION OF THE SHEAR STRENGTH OF CLAY BY THE FALL-CONE TEST. PROCEEDINGS ROYAL SWEDISH GEOTECHNICAL INSTITUTE NO.14;
WOOD, D.M.:1985 SOME FALL-CONE TESTS. GEOTECHNIQUE 35, 1, PP.64-68

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SA423: LABORATORY VANE STRENGTH TEST

Explanation:

In the vane test a four-blade vane is pushed into the soil and then rotated. The torque required to cause rotation of the cylinder of soil enclosing the vane is measured, and this enables the undrained shear strength of the clay to be calculated. A repeat test immediately after remoulding the soil by rapid rotation of the vane provides a measure of the remoulded strength, and hence the sensitivity.

The laboratory vane test has the same principles as the in-situ vane test but is on a smaller scale, being designed for testing samples in the laboratory. The vanes on the field equipment may be up to 150 mm long and 75 mm wide, but the standard laboratory apparatus has a vane measuring 12.7 by 12.7 mm.

The vane apparatus is particularly suitable for soils such as soft, sensitive clays having shear strengths of 20 kPa or less, from which it would be extremely difficult to prepare undisturbed specimens for other types of test. Soft samples can be tested in the sampling tube with the minimum of disturbance. However, the test can also be carried out on soft remoulded soils, for instance in a compaction mould.

Another type of apparatus using the same principle is the pocket shearmeter, or pocket vane. The small hand-held device is applied to the surface of the soil and rotates a relatively thin disc of soil. It can be used on site, for instance on the sides of pits, trenches and embankments; and in the laboratory on the ends of tube samples or on the faces of block samples. The instrument should be regarded as an aid to the visual classification of soil in the zone inspected, and not as a substitute for other methods of measuring shear strength for design purposes.
The shear strength of the zone of soil tested is measured by pushing the vanes into the soil and turning the knob until a maximum reading is achieved on the dial. This is calibrated to read directly in shear strength units.

The standard vane can be used for measuring shear strengths up to 100 kPa. Alternatively, a large vane can be fitted, which gives greater sensitivity when measuring shear strengths below 20 kPa, and a smaller vane is available for extending the range up to 250 kPa.[1]

[1] HEAD:1982 PP.511,572,578-579

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SA424: SHEARBOX TEST FOR STRENGTH & DEFORMATION IN LABORATORY

Explanation:

STANDARD SHEARBOX:

The shearbox apparatus was developed originally for the determination of the angle of shear resistance of recompacted sands. It provides the most direct means of relating angle of shearing resistance to the voids ratio, and of determining the critical voids ratio (or critical density) of dry sands or of saturated sands which do not contain fine material in sufficient quantity to impair the drainage characteristics.

The shearbox should not be used to determine the immediate undrained shear strength of cohesive soils, because of uncertainty concerning the drainage conditions, and for these materials the triaxial test is usually more satisfactory. For non-cohesive soils the specimen can be more readily prepared than for the triaxial test. The small 60 mm square shearbox is suited only to soil containing particles that will not pass a 3.35 mm sieve.

One of the main applications of shearbox testing in recent years has been the measurement of the residual shear strength of overconsolidated clays by shearing the sample to and fro after measuring the peak drained strength.[1] However, where knowledge of residual strength is required (i.e. for fine-grained cohesive soils), ring shear tests are usually preferred.

LARGE SHEARBOX:

The usual size of a large shearbox is 305 mm square, requiring a specimen about 150 mm thick, and is suitable for soils containing particles up to 37.5 mm. Triaxial testing of these materials is impracticable unless exceptionally large equipment is available.

The shear strength of gravelly soils is rarely a critical factor for foundations, but it is significant in the design of embankments which incorporate gravel fill material. Shear strength can also be used as a means of classifying road construction materials and granular sub-bases.

Other materials besides gravels containing particles up to 37.5 mm or even occasional 50 mm particles can also be tested in a large shearbox where triaxial testing would be impracticable. These materials include shale, industrial slag, brick rubble, colliery spoil. Provided that the material is free draining, the quick testing procedure may be used to determine the angle of shear resistance; otherwise slow (drained) tests are necessary.

This apparatus can also be used for testing large block samples of undisturbed soil. It can be used for measuring the shear strength along surfaces of discontinuities, such as fissures or shear zones, in large samples of overconsolidated clays; and the shear strength of clay laminations present in some sandstones.[2]

[1] BS 5930:1981 P.72;
HEAD:1982 PP.538,539
[2] BS 5930:1981 P.72;
HEAD:1982 PP.539-540

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SA425: OEDOMETER TEST

Explanation:

Although more sophisticated consolidation tests using larger samples are now available, the laboratory oedometer test using a sample of 75mm diameter is still recognised as the standard test for determining the consolidation characteristics of homogeneous clays.

The test is carried out by applying a sequence of some four or eight vertical loads to a laterally confined specimen having a height of about one quarter of its diameter. The vertical compression under each load is observed over a period of time, usually up to 24 h. Since no lateral drainage is allowed it is a one-dimensional test, from which the one-dimensional consolidation parameters are derived.

Two parameters can be determined from the oedometer consolidation test.

1. Compressibility: Whenever a load, such as that due to a structural foundation, is placed on the ground, some degree of settlement will occur even if the applied pressure is well within the safe bearing capacity of the soil. The limitation of settlements to within tolerable limits is sometimes of greater significance in foundation design than limitations imposed by bearing capacity requirements derived from shear strength.

2. Time effects: Settlements in sands and gravels take place in a short time, usually as construction proceeds, and these rarely cause major problems. But in clay soils, because of their low permeability, settlements can take place over much longer periods - months, years, decades, even centuries, after completion of construction. Estimates of the rate of settlement, and of the time within which settlement will be virtually complete, are therefore important factors in foundation design.

For foundations of structures, consolidation tests are carried out on specimens prepared from undisturbed samples taken from clay strata not only from immediately below the future foundation but also from considerable depth. Data obtained from these tests, together with classification data and a knowledge of the loading history of the clay, enable estimates to be made of the time-dependent settlement behaviour of foundations.

Soft soils, such as alluvial silts and clays and some fills, are too weak to carry any but the lightest of foundation loads unless the shear strength is first increased by consolidation, which can be effected by pre-loading the ground with a surcharge of temporary fill. Laboratory consolidation tests can be used to estimate the extent of the resulting settlement, but the rate of settlement is often under-estimated. Field tests are more reliable for indicating whether provision of means for accelerating the consolidation, such as the installation of sand drains, is justifiable.

For inorganic clays the oedometer test provides a reasonable estimate of the amount of settlement. However, the rate of settlement is often under-estimated, that is, consolidation occurs more rapidly than predicted from oedometer test data using the theory of consolidation.

The most reliable means of obtaining coefficient of consolidation, c, on which calculations for the rate of settlement are based, is to determine the coefficient of volume compressibility, m, from laboratory oedometer consolidation tests and to measure the permeability, k, in the field, and then to use the equation

$$c = k/m$$

to calculate c.[1] It is simpler, but less reliable, to determine c directly form the results of the oedometer consolidation.

Natural clays often possess anisotropic permeability characteristics as a result of their geological histories, with horizontal permeabilities often significantly greater than vertical permeabilities. Standard oedometer tests usually measure only the vertical deformation and flow characteristics, whereas the rate of consolidation in the field may be governed by horizontal flow.

Hydraulic oedometers, or Rowe cells, in which drainage may be either vertical as in the conventional oedometer or radial to a circumferential drain can be used to assess separately vertical and horizontal permeability of one-dimensionally compressed samples, and hence to estimate anisotropy of permeability of natural soils. Rowe cells are available with diameters 75, 150 and 250mm so that it is relatively straightforward to ensure that the sample tested contains representative soil fabric. Rowe cells provide the possibility of testing soils with the pore water under pressure, thus making it easier to ensure full saturation of the soil, which is particularly important where flow characteristics are to be measured.[2]

[1] HEAD:1982 PP.651,652,673(EQN.),680,681-682
[2] HEAD:1986 PP. 1129-1196.

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SA426: UNCONFINED COMPRESSION TEST

Explanation:

Unconfined compression tests are quick compression tests to measure the shear strength of soils in terms of total stresses, by means of axial compression tests on cylindrical specimens. The methods of test here are as follows:

(1) Standard laboratory test using a load frame, either hand operated or machine driven, which can accommodate a wide range of specimen sizes.

(2) Test with a traditional portable autographic apparatus, which can be used either in the laboratory or in the field, and is normally used for 38 mm specimens.

(3) Measurement of the remoulded strength of saturated clays, for the determination of their sensitivity (the remoulded strength is best determined immediately after measuring the undisturbed strength).

A cylindrical specimen of soil is subjected to a steadily increasing axial load until failure occurs. In the unconfined test the axial load is the only force or stress which is applied. The rate of loading is such that failure occurs within a relatively short time, usually between 5 and 15 min from the start of the test.

The results of an unconfined compression test on a perfectly undisturbed sample are approximately the same as those of a consolidated-undrained test performed on the same sample under a confining pressure. This relationship makes it possible in principle to obtain information concerning the stress-strain characteristics of a clay under consolidated-undrained conditions without the need for triaxial apparatus. However, the reliability of unconfined compression strengths is strongly dependent on the extent of sample disturbance and it will not usually be appropriate to base values of deformation parameters on the results of unconfined compression tests.[1]

[1] HEAD:1982 PP.581,582;
TERZAGHI:1967 P.99

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SA427: TRIAXIAL TESTS FOR STRENGTH & DEFORMATION IN LABORATORY

Explanation:

In the conventional triaxial test, a cylindrical specimen of soil is subjected to a steadily increasing axial load until failure occurs. The specimen is first subjected to an all-round confining pressure, which is then maintained constant as the axial load is increased. The rate of loading in undrained tests is such that failure occurs within a relatively short time, usually between 5 and 15 min. Triaxial compression tests may be of several different types:
(a) undrained
(b) undrained with measurement of pore water pressure
(c) consolidated undrained
(d) consolidated undrained with measurement of pore water pressure
(e) consolidated drained
(f) multi-stage triaxial test

By far the most commonly used of these tests is the standard or unconsolidated undrained test without pore pressure measurement. There is a large amount of experience in its use and many partly empirical methods are available to use the parameters so obtained in the design of foundations and other sub-structures. The reliability of the results of unconsolidated undrained tests is very dependent on the degree of sample disturbance that has occurred. Tests in which the sample has been consolidated to a specified initial effective stress state are usually preferred.

The remaining tests have more specific uses. The tests are normally carried out on nominal 100 mm or 38 mm diameter specimens, as appropriate.

In Britain it is common practice to test a set of three identical 38 mm diameter specimens, taken at one horizon from a 100 mm diameter sample in a U-100 tube or piston sampling tube (Standard Triaxial Test). Tests on specimens of large diameter, i.e. 100 mm and upwards are referred as Larger Diameter Triaxial Tests.

Several techniques have been used for multi-stage drained and undrained triaxial tests. The test is useful where there is a shortage of specimens, and its main use is with 100 mm nominal diameter specimens, only one of which can be prepared from each sampling tube.

The main advantage of multistage testing is in the saving of time and material when only one large sample is available for testing, and when small specimens are impracticable. This applies particularly to soils containing relatively large-scale features such as gravel in boulder clays, or discontinuities such as fissures, which cannot be adequately represented in a small specimen.

The use of lubricated end platens leads to improved uniformity of stress and deformation in all types of triaxial test and hence to improved estimates of strength and stiffness. It also enables the height to diameter ratio of all samples to be reduced to 1:1 (from 2:1), thus enabling several 100 mm diameter specimens to be cut from each standard sampling tube, which is useful when a limited number of undisturbed samples is available.[1]

[1] BS5930:1981 P.72;
HEAD 1982 PP.581,582,616
HEAD 1986 P.971

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SA428: SPECIAL TESTS FOR STRENGTH & DEFORMATION IN LABORATORY

Explanation:

Triaxial extension tests:

This type of test is relevant to the condition in which the vertical stress decreases while the horizontal stresses remain substantially unchanged, such as occurs at the bottom of an excavation as the overburden is removed. A similar condition applies if the horizontal stress is increased while the vertical stress remains constant. Standard triaxial test equipment can be used for this test with a few minor modifications.

In construction of retaining walls, or excavation of cuttings the soil is subjected to shear stresses by the progressive decrease of the lateral pressure while the vertical stress remains substantially constant. This condition can be simulated to some extent, though not truly reproduced, in the laboratory, by running a triaxial extension test with decreasing confining pressure and constant axial stress. Failure is induced by reducing the cell pressure from an initial value chosen to correspond to the initial in-situ stress.

Stress paths in triaxial testing:

The stress path method is a systematic approach to stability and deformation problems in soil mechanics. Stress path plots are relevant to improved methods of presentation of data from routine laboratory triaxial tests.

During a laboratory test on a soil sample, or as load is applied to a mass of soil in the ground by a foundation, each element of soil experiences changes in its state of stress. A stress path gives a continuous representation of the relationship between the components of stress at a given point as they change. The use of a stress path provides a geotechnical engineer with an easily recognisable pattern which assists him in identifying the mechanism of soil behaviour. It also provides a means of selecting and specifying the sequence of stresses to be applied to a sample in a test for a particular purpose, so that the stress path followed in the laboratory may bear some relationship to the stress changes that are expected in the field. [1]

Soil behaviour is extremely non-linear and dependent on stress level and stress history. Accurate estimates of deformations of geotechnical structures under working loads cannot be expected unless these factors are taken into account in planning and interpreting a programme of laboratory testing.

[1]. HEAD:1986 PP.987,995,1076

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SA43: COMPACTION TESTS

Explanation:

Many civil engineering projects require the use of soils as 'fill' material, the most usual being:
(1) To refill an excavation, or a void adjacent to a structure (such as behind a retaining wall).
(2) To provide made-up ground to support a structure.
(3) As a sub-base for a road, railway or airfield runway.
(4) As a structure in itself, such as an embankment, including reinforced earth.

When soil is placed as an engineering fill, it is nearly always necessary to compact it to a dense state, so as to obtain satisfactory engineering properties which would not be achieved with loosely placed material. Compaction on site is usually effected by mechanical means such as rolling, ramming or vibrating. Control of the degree of compaction is necessary to achieve a satisfactory result at reasonable cost. Laboratory compaction tests provide the basis for control procedures used on site.

There are several different standard laboratory compaction tests. The test selected for use as the basis for comparison will depend upon the nature of the works, the type of soil and the type of compaction equipment used on site. Compaction tests may include the following:

Proctor maximum dry density
Vibrating hammer

Moisture condition values.[1]

[1] HEAD:1980 PP.268,279

Advisory:

Compaction of soil is the process by which the solid soil particles are packed more closely together by mechanical means, thus increasing the dry density. It is achieved through the reduction of the air voids in the soil, with little or no reduction in the water content. Compaction tests furnish the following basic data for soils:

(1) The relationship between dry density and moisture content for a given degree of compactive effort.
(2) The optimum moisture content for the most efficient compaction -- that is, the moisture content at which the maximum dry density is achieved under that compactive effort.
(3) The value of the maximum dry density so achieved.

Item (1) is expressed as a graphical relationship from which items (2) and (3) can be derived. The latter are the moisture and density criteria, against which the compacted fill can be judged if in-situ measurements of moisture content and density are made.

The compaction tests introduced here are as follows:

1. Proctor test (2.5kg rammer method):
2. Vibration test (vibrating hammer method):
3. Moisture condition test:

Proctor test (2.5kg rammer method):

This test is sometimes called the 'moisture-density relationship' test. It is generally suitable for soils containing particles no larger than 20 mm. The detailed procedure depends on whether or not the granular material is susceptible to crushing during compaction. A similar test known as the 'heavy' compaction test makes use of a 4.5kg rammer. If the soil contains particles coarser than 20mm but mostly finer than 37.5mm then compaction tests can still be performed but it is necessary to use a larger mould.

Vibration test (vibrating hammer method):

This test is applicable to granular soils passing the 37.5 mm sieve. The principle is similar to that of the 'Proctor' procedure, except that a vibrating hammer is used instead of a drop-weight rammer, and a larger mould (the standard CBR mould) is necessary.

Moisture condition test:

This test has been developed for use in construction control of earthworks to assess rapidly whether a material is at a moisture condition suitable for placing, in relation to the specified upper limit of moisture content.[1]

[1] BS1377:1990 PART 4 P.2;
HEAD:1980 PP.268,281,291,306

Expert Opinion:

Proctor test:
BS 1377: 1990. Part 4 Clause 3.3 p.5; Fig.4 p.29;
HEAD: 1980. Fig. 6.7-6.9 p.282,283; Section 6.5.2 p.281.

Vibrating hammer method:
BS 1377: 1990. Part 4 Clause 3.7 p.9; Fig.7 p.32;
HEAD: 1980. Fig. 6.18,6.19 p.292,293; Section 6.5.4 p.291.

Moisture condition value:
BS 1377: 1990. Part 4 Clause 5 p.15; Fig.8 p.33;
HEAD: 1980. Fig. 6.29 p.307; Section 6.6.5 p.306.

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SA431: PROCTOR METHOD FOR COMPACTION TESTS IN LABORATORY

Explanation:

The Proctor compaction test covers the determination of the dry density of soil passing 20 mm test sieve, when it is compacted in a specified manner over a range of moisture contents. The range includes the optimum moisture content at which the maximum dry density for this degree of compaction is obtained. In this test a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into a compaction mould of capacity 1 litre.[1]

Where the soil contains no more than 30% by weight of material which is retained on the 20mm sieve, including some particles which are retained on the 37.5mm sieve, then the Proctor compaction test should be performed in a CBR mould. The test can also be performed with higher levels of compactive effort, using a rammer of mass 4.5kg and a fall height of 450mm.

[1] BS 1377:1990 PART 4 CLAUSE 3.3 P.5

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SA432: VIBRATING HAMMER FOR COMPACTION TESTS IN LABORATORY

Explanation:

This test, using a vibrating hammer, covers the determination of the dry density of soil, which may contain some particles up to coarse gravel size, when it is compacted by vibration in a specified manner over a range of moisture contents. The range includes the optimum moisture content at which the maximum dry density for the specified degree of compaction is obtained. In this test the soil is compacted into a CBR mould using an electrically operated vibrating hammer.

The test is suitable for certain soils containing no more than 30% by mass of material retained on the 20 mm test sieve, which may include some particles retained on the 37.5 mm test sieve. It is not generally suitable for cohesive soils.[1]

[1] BS 1377:1990 PART 4 CLAUSE 3.7 P.9

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SA433: MOISTURE CONDITION VALUES IN LABORATORY

Explanation:

In the moisture condition test the minimum compactive effort required to produce near-full compaction of a sample of soil passing a 20 mm sieve is determined. The procedures cover the determination of the moisture condition value (MCV) of a sample of soil and the determination of the variation of MCV with changing moisture content. A rapid procedure for assessing whether or not a sample of soil is stronger than a precalibrated standard is also included.

The test is based on the principle that the density produced in a given soil depends solely on the moisture content and the compactive effort used. At moisture contents in excess of optimum, where the zero air-voids line is approached, an increase in compactive effort produces little or no change in density for constant moisture content. If the specified upper limit of moisture content for a given compactive effort is in this zone, a comparison of densities produced by different compactive efforts will indicate immediately whether the moisture content of the material is above or below the specified upper limit.[1]

[1] BS 1377:1990 PART 4 CLAUSE 5 P.15;
LR 750:1976 P.1;
HEAD:1980 SECTION 6.6.5 P.306

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SA44: PERMEABILITY TESTS IN LABORATORY

Explanation:

The permeability of a soil is a measure of its capacity to allow the flow of a fluid through it. The fluid may be either a liquid or a gas, but geotechnical engineers are usually concerned only with liquid permeability, and the liquid is usually understood to be water.

Permeability can be calculated from the results of consolidation stages of oedometer tests (see LABORATORY/STRENGTH AND DEFORMATION/OEDOMETER) but more reliable values of permeability can be obtained by direct measurement as described here.

Procedures for the direct measurement of permeability of soils in the laboratory use two different types of test:

(1) Constant head test - for soils of high permeability, such as sands.
(2) Falling head test - for soils of intermediate and low permeability, such as silts and clays.

Only inorganic soils should be tested in the laboratory. The permeability characteristics of highly organic soils such as peats are variable and complex and field trials may be required in order to obtain realistic values. Field measurements of permeability, (see under 'FIELD TECHNIQUES'), can take into account features such as the soil fabric, and eliminate the disturbance that will be associated with obtaining laboratory samples, and are for that reason often more satisfactory than laboratory tests.[1]

Natural clays often possess anisotropic permeability characteristics as a result of their geological histories, with horizontal permeabilities often significantly greater than vertical permeabilities. Standard oedometer tests usually measure only the vertical deformation and flow characteristics, whereas the rate of consolidation in the field may be governed by horizontal flow.

Hydraulic oedometers, or Rowe cells, in which drainage may be either vertical as in the conventional oedometer or radial to a circumferential drain can be used to assess separately vertical and horizontal permeability of one-dimensionally compressed samples, and hence to estimate anisotropy of permeability of natural soils. Rowe cells are available with diameters 75, 150 and 250mm so that it is relatively straightforward to ensure that the sample tested contains representative soil fabric. Rowe cells provide the possibility of testing soils with the pore water under pressure, thus making it easier to ensure full saturation of the soil, which is particularly important where flow characteristics are to be measured.[2]

[1] HEAD:1982 CHAPTER 10 PP.398,456
[2] HEAD:1986 CHAPTER 24 PP.1129-1196

Advisory:

Soils consist of solid particles with voids between them. The permeability is determined by applying a hydraulic pressure difference across a sample of soil, which is fully saturated, and measuring the consequent rate of flow of water through these voids. The permeability of any particular soil is strongly dependent on the current void ratio of that soil. Natural soils usually have permeability characteristics which are somewhat anisotropic. Anisotropy of permeability can have a major influence on field rates of consolidation of clays.

The flow of water through soils of all types, from 'free-draining' gravels and sands to 'impervious' clays, is governed by the same physical laws. The difference between the permeability characteristics of extreme types of soil is merely one of degree, even though a clay can be ten million times less permeable than a sand. Clays, and some other materials such as concrete, contrary to casual observation, are not completely impermeable, although they may appear to be so if the rate of flow through them is no greater than the rate of evaporation loss. The method used for measuring permeability depends upon the characteristics of the materials.[1]

Constant head test:

The constant head procedure is used for the measurement of the permeability of sands and gravels containing little or no silt. The most common permeability cell (permeameter) is 75 mm diameter and is intended for sands containing particles up to about 5 mm. A larger cell, 114 mm diameter, can be used for testing sands containing particles up to about 10 mm, i.e. medium gravel size. Much larger apparatus may be specially available to accommodate samples containing gravel particles up to 75 mm.

The constant head permeability cell is intended for testing disturbed granular soils which are recompacted into the cell, either by using a specified compactive effort, or to achieve a certain dry density, and hence voids ratio.[2]

Falling head test:

For measuring the permeability of soils of intermediate and low permeability (less than 10-4 m/s), i.e. silts and clays, the falling head procedure is used. In the falling head test a relatively short sample is connected to a standpipe which provides both the head of water and the means of measuring the quantity of water flowing through the sample. Several standpipes of different diameters are normally available from which can be selected the diameter most suitable for the type of material being tested.

In permeability tests on clays, much higher hydraulic gradients than are normally used with sands can be applied, and are often necessary to induce any measurable flow. The cohesion of clays provides resistance to failure by piping at gradients of up to several hundred, even under quite low confining or surcharge pressures. Dispersive clays, however, are very susceptible to erosion at much lower gradients. Modern experimental techniques provide the possibility of measuring permeability of clays samples using controlled flow techniques with rather low hydraulic gradients. Effective stress changes associated with application of high heads in permeability tests can cause significant changes in void ratio and hence permeability.

The falling head principle can be applied to an undisturbed sample in a sampling tube and to a sample in an oedometer consolidation cell.[3]

Permeability is not a fundamental property of soil, but depends upon a number of factors summarised as follows:
(1) Particle size distribution.
(2) Particle shape and texture.
(3) Mineralogical composition.
(4) Voids ratio.
(5) Degree of saturation.
(6) Soil fabric.
(7) Nature of fluid.
(8) Type of flow.
(9) Temperature.
Items (1), (2) and (3) are invariable for a given soil. Items (4) and (5) depend upon the placing and treatment of the soil, and items (7), (8) and (9) relate only to the permeability fluid. Item (6) relates to the state of the natural soil in-situ, and its effect is of crucial significance.[4]

[1] HEAD:1982 SECTION 10.1.2 P.398
[2] HEAD:1982 SECTION 10.6 P.427
[3] HEAD:1982 SECTION 10.7 P.449
[4] HEAD:1982 SECTION 10.1.5 P.399

Expert Opinion:

For constant head permeability tests:
BS 1377: 1990. Part 5. Section 5; & Part 6. Sections 4 & 6.
Head: 1982. Section 10.6 p.427,
downward flow: Figs. 10.5,10.23 pp.409,434;
upward flow: Fig. 10.6 p.409.

For falling head permeability tests:
Head: 1982. Section 10.7 p.449; Figs. 10.8,10.38 pp.411,452.

For typical permeability values:
Head: 1982. Section 10.4.5 p.423; Table 10.1 p.423.

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SA45: CHEMICAL TESTS

Explanation:

During ground investigation it is often necessary to carry out laboratory tests to determine the effects of the subsoil or groundwater on concrete to be placed as foundations. Chemical tests may also be used to check the soundness of aggregates for concrete or soil cement, to determine if electrolytic corrosion of metals will take place, or simply to act as index tests.

Full chemical composition of soils is often required to complete the interpretation of mineralogical analysis. The detailed chemical composition of soil is usually of little interest for civil engineering purposes, but the presence of certain constituents can be very significant. These include organic matter, sulphates, carbonates and chlorides. The pH reaction (acidity or alkalinity) of the groundwater can also be of importance.

The chemical tests have been grouped here as follows:
(1) Soil mineral chemical tests: include organic content, ignition loss, sulphate content, carbonate content and chloride content.
(2) Pore water chemistry tests: include dissolved solids, acidity or alkalinity (pH value) and analysis of dissolved ions.
(3) Other tests: include resistivity, redox, bacteriological and radioactivity measurements.

Chemical tests for the presence of other substances would normally be carried out by a specialist chemical testing laboratory, as could the tests referred to above if adequate facilities are not available in the soil laboratory.[1]

[1] CLAYTON et al:1982 P.393;
HEAD:1980 CHAPTER 5 P.217

Advisory:

In the quantitative chemical analysis of soils by far the biggest source of possible error is in the selection of the test sample. Usually a very small quantity of dried soil is required at the outset, and it is essential that this sample be truly representative of the original sample. The proper procedure of mixing, riffling and quartering must be rigidly adhered to. Short cuts in this procedure lead to inconsistent results.

Results of chemical tests on soils should be regarded as an indication of the order of magnitude of constituents for classification purposes rather than as precise percentages.

Sulphate content, chloride content, and organic matter content in aggregate or materials intended for use as soil cement can seriously affect the behaviour of the finished product. Apart from any damaging chemical effects, these materials may have very low strengths in their solid form. When dispersed throughout the mix, high organic contents in material used for soil cement can interfere with hydration, while chlorides may lead to unsightly efflorescence and in large quantities will attack the steel in reinforced concrete and cause rapid deterioration due to the spalling of the cover. Sulphate contamination of aggregate will retard the set of concrete.

Organic contents are also of use in classifying organic soils such as peats or organic silts and clays. Some of the standard correlations between index properties and strength and deformation characteristics are influenced by presence of significant proportions of organic matter. For most purposes the determination of 'loss on ignition' or ash content is sufficient, but it should be remembered that this method tends to yield organic contents which may be up to 15 per cent too high because the oven-dried specimen is fired at about 800-900 degree Centigrade and clay minerals and carbonates are altered.

Soil conditions which may lead to corrosion may be detected on the basis of a low apparent resistivity. Soils with an apparent resistivity of less than 10 ohm-metre will be highly corrosive. Alternatively pH value, redox potential, and the presence of soluble salts may be used as a guide. In most situations involving the installation of steel into disturbed soils (for example, piles at depth) electrolytic corrosion is not a problem because oxygen is not available. In shallow anaerobic situations, however, if the soil is near neutral pH then sulphate reducing bacteria may attack. A low redox potential indicates the reducing conditions under which the bacteria will flourish; bacteriological analysis will be necessary when these conditions are encountered in recent organic deposits such as tidal mud flats or rubbish tips.[1]

[1] CLAYTON et al:1982 PP.393-394;
HEAD:1980 CHAPTER 5 P.217

Expert Opinion:

Some information concerning chemical tests for soils and groundwater, which includes notes on their use and their limitations, is given in:
Head: 1980. Table 5.1 pp.218-219.

Typical test data and calculation forms for chemical tests can be found in:
BS 1377: 1990. Part 3. Appendix A. pp. 33-41.

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SA451: SOIL MINERAL TESTS IN LABORATORY

Explanation:

Soil mineral chemical tests include organic content, ignition loss, sulphate content, carbonate content and chloride content.

Organic matter content:

Organic matter in soil is derived from a wide variety of animal and plant remains, so there can be a great variety of organic compounds. They can all have undesirable effects on the engineering behaviour of soils. These can be summarised as follows:
(1) Bearing capacity is reduced.
(2) Compressibility is increased.
(3) Swelling and shrinkage potential due to changes in moisture content is increased.
(4) The presence of gas in the voids can lead to large immediate settlements, and can affect the derivation of consolidation coefficients from laboratory tests.
(5) The gas can also give misleading shear strength values derived from total stress tests.
(6) The presence of organic matter (e.g. in peat) is usually associated with acidity (low pH), and sometimes with the presence of sulphates. Detrimental effects on foundations could result if precautions are not taken.
(7) Organic matter is detrimental in soils used for stabilisation for roads.

A measure of the organic content of soils is necessary in order to make allowance for these effects.

Ignition loss:

This test is used for determining the proportion by mass that is lost from a soil by ignition at a specified temperature.

The mass loss on ignition is related to the organic content of certain soils, such as sandy soils that contain little or no clay, or chalky material, peats and organic clays containing more than about 10% organic matter. However it should be recognized that, in some soils, factors unrelated to organic content could be responsible for the major proportion of the mass loss on ignition.

Sulphate content:

Sulphate in soil can cause disintegration of precast members, such as slabs and concrete pipes, and of concrete structures and structural items (such as piles), and can lead to corrosion of metal pipes placed in contact with the soil.

Measurement of the sulphate content enables the ground conditions to be classified according to potential sulphate attack. Appropriate precautionary measures, such as the use of sulphate-resisting cement or of a richer, denser concrete mix, can be taken during construction.

Please also refer to information included under 'Analysis of dissolved ions' of 'PORE WATER CHEMICAL'.

Carbonate content:

Knowledge of the carbonate content of soils is useful for the following reasons:
(1) Carbonate content can be used as an index to assess the quality of chalk as a foundation material. A high carbonate content means a low clay mineral content, and usually indicates a relatively high strength.
(2) In cemented soils and soft sedimentary rocks the carbonate content can indicate the degree of cementing.
(3) In road construction chalky subgrades are susceptible to frost action.
(4) The carbonate content of chalk or limestone is an indication of its suitability for the manufacture of cement.

Chloride content:

Chloride content is most often used as an indication of whether or not the groundwater is sea-water, or whether the soil has been affected by sea-water. In some coastal situations, the concentration of sodium chloride in the groundwater can be very much higher than that in sea-water. High concentration can also be present in soils and permeable rocks not now directly in contact with sea-water.

Aqueous solutions of chlorides cause corrosion of iron and steel including steel reinforcement in concrete. If the presence and concentration of chlorides is known, suitable preventative measures can be taken in the design and construction of buried or underwater reinforced concrete structures.[1]

[1] BS1377:1990 PART 3;
HEAD:1980 SECTION 5.4 PP.230-232

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SA452: PORE WATER CHEMICAL TESTS IN LABORATORY

Explanation:

Pore water chemistry tests include dissolved solids, acidity or alkalinity (pH value) and analysis of dissolved ions.

Total dissolved solids:

The test is used for determining the total amount of dissolved solids in a sample of water, e.g. groundwater, irrespective of the actual substances.

The result obtained by this method may not be exact, especially if ammonium salts are present, but it is sufficiently accurate for practical purposes where only an indication of the amount of dissolved salts is required.

pH value:

Excessive acidity or alkalinity of the groundwater in soils can have detrimental effects on concrete buried in the ground. Even a moderate degree of acidity can cause corrosion of metals. Measurement of the pH value of the groundwater reveals these potential dangers so that preventive measures can be taken.

In the stabilisation of soils for roads, some resinous materials are unsuitable for alkaline soils, yet may be satisfactory with neutral or slightly acid soils.

As well as being used for the above purposes, the pH value is usually determined whenever the sulphate content is measured.

Analysis of dissolved ions:

Groundwater containing dissolved sulphates can attack concrete, and other materials containing cement, placed in the ground or on the surface. A reaction takes place between the sulphates and the aluminate compounds in cement, causing crystallisation of complex compounds. The expansion which accompanies crystallisation induces internal stresses in the concrete, which results in mechanical disintegration.

There are two methods of analysis for determining sulphate content. They are:
(1) the gravimetric method for acid extracts, water extracts and ground water samples;
(2) the ion-exchange procedure for water extracts and ground water samples only.

Please refer to the test under 'Sulphate content' of 'SOIL MINERAL CHEMICAL' as well.[1]

[1] BS1377:1990 PART 3;
HEAD:1980 SECTIONS 5.4,5.6,5.10 PP.230,238,265

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SA453: OTHER LABORATORY CHEMICAL TESTS

Explanation:

Other tests include resistivity, redox, bacteriological and radioactivity.

Resistivity:

The test is used for the determination of the electrical resistivity of samples of soil in the laboratory. The resistivity value indicates the relative capability of the soil to carry electric currents from which the corrosiveness of the soil can be deduced.

There are three types of test: disc electrodes method; Wenner probe method; and open container method.

In the first, disc electrodes are fitted to the end of a cylindrical undisturbed or compacted soil sample. A voltage is applied across the electrodes, the current flowing between them is measured, and the application of Ohm's law enables the electrical resistance to be derived from which the soil resistivity is calculated.

In the second method four probe electrodes are inserted into the sample in a Wenner configuration: a current is passed between the outer electrodes and the resistance between the two inner electrodes is determined by balancing a bridge circuit, from which the soil resistivity is calculated. This is the same principle as used for the in-situ soil resistivity test described under 'IN-SITU TEST'.

The third method is similar to the first except that it applies to free-draining soil which is compacted into a rectangular box fitted with end electrodes, and is flooded with water before applying the voltage.

Air voids in the sample can cause high resistances and can restrict contact between the soil and the electrodes. In some instances it may be better to use only the fine fraction of the soil, e.g. the material passing a 2 mm test sieve.

Redox potential:
The method is used to measure the electro-chemical potential between a platinum electrode and a saturated calomel reference electrode in contact with the soil.

The pH of the soil also has to be determined to enable the standardised redox potential to be calculated.

The redox potential provides a means of assessing whether a soil is conducive to the activity of sulphate-reducing bacteria, which causes corrosion of metals. These bacteria, which are present in most soils, flourish under reducing conditions (low redox-potential) and become dormant under oxidising conditions (high redox potential).

Changes in soil properties can cause enhanced corrosion where continuous buried metals, e.g. steel pipelines, pass from one soil type to another.

Redox potential results are of significance only for soil samples that have not been disturbed. Tests on soils that have been recompacted in the laboratory are of questionable value because of the change in properties resulting from unavoidable exposure to the atmosphere and undisturbed specimens are desirable.

Bacteriological test:

The test is used for indicating whether corrosion is likely to be developed by bacteria in soils.

Sulphate-reducing bacteria can corrode iron and steel under neutral or alkaline condition. These bacteria flourish under anaerobic conditions (i.e. where oxygen is absent), and their presence is indicated by the presence of sulphides. They may also flourish under aerobic conditions (i.e. in the presence of oxygen) in the presence of sulphates.

Tests for the presence of aggressive bacteria require the facilities of a specialist chemical testing laboratory and undisturbed specimens are required. For bacteriological tests these should be air-sealed and in sterilised containers.[1]

Radioactivity:
In certain special situations it may be appropriate to test for radioactivity of soil samples.

[1] BS5930:1981 P.73;
BS1377:1990 PART 3;
HEAD:1980 SECTIONS 5.4.6 P.232

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SB: MAIN GROUND INVESTIGATION

Explanation:

The main ground investigation should be planned in the light of knowledge of site conditions already gained and of the probable dispositions of cuttings, embankments, structures, likely temporary works and effects on adjacent properties. Where problems are known to exist the appropriate measures to determine their character and magnitude should be allowed for in the contract.

The main ground investigation should be planned to provide sufficient information to tenderers for the main contract to assess and price the works.[1]

[1] SH2/88 P.6,7

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SB1: PRELIMINARY GROUND INVESTIGATION REVIEW

Explanation:

Before proceeding with the Main Ground Investigation, the Preliminary Ground Investigation program should be checked to see if all the data required have been accumulated and to identify any gaps in the Preliminary GI which should be filled.

Where there is a time delay between the Preliminary Ground Investigation and Main Ground Investigation, it may be necessary to review the results of Preliminary Ground Investigation report and in more extreme cases repeat some aspects of the Desk Study Work.

Even where the Main Ground Investigation immediately succeeds the Preliminary work, planning will be enhanced by reviewing and acting upon the results of the earlier investigation.

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SB2: FIELD TECHNIQUES

Explanation:

Field techniques are used to verify and expand information which may have been collected previously and provide a means of producing the detailed information necessary for economic and safe geotechnical design. Field techniques may combine in situ testing with recovery of samples for laboratory testing (see LABORATORY TESTING section). The objective should be to use in situ and laboratory tests to identify potential construction problems or hazards.

Before commencing Field and Laboratory Tests, all relevant information should be considered together to obtain a preliminary conception of the ground condition and the engineering problems that may be involved.[1]. This will include in particular, data from previous Ground Investigations, in particular the Preliminary Ground Investigation which will have been performed in accordance with the advice contained in this program. Consideration of all available data will assist in planning the amount and types of field and laboratory testing that are required.

The areas and depths of:
1. material to be excavated from cuttings acceptable as fill,
2. material to be excavated from cuttings whose acceptability as fill is doubtful, or which may be moisture susceptible,
3. soft compressible soils beneath road formation level, and
4. any other adverse ground conditions encountered should be located by extending and increasing the frequency of the boring, drilling or probing as the investigation proceeds. [2]

This stage is concerned with Field Techniques which include:
1. Trial pits and borings;
2. Sampling;
3. In-situ testing.

[1] BS5930 1981 BSI P.8 7.2; CIRIA 25 1983 P.17
[2] SH2/88 P 6,7

References:

As in Rule SA3.

Advisory:

It is always advisable to carry out a single complete soils survey where this will be effective and economical. Inconveniences to land or property owners will thus be minimised. The main investigation should normally only be undertaken after confirmation of the line orders.[1]

Expert Opinion:

The success of a ground investigation is partly dependent on the ability of the planning engineer to envisage what type of problems will be encountered. General information concerning the ground conditions will have been obtained from the Preliminary Ground Investigation, and preliminary decisions concerning likely types of structures and geotechnical constructions will have been made. The soil properties which need to be identified from the investigation will require consideration of the soil types expected, the type and possible extent of works, and the possible use of ground improvement techniques.

By considering the probable sequences of strata and the stresses which will be imposed on the soil, some assessment may be made of the depths to which the boreholes should be taken and at what depths data are required. The extent and type of construction for which the investigation is being carried out will influence the distribution of boreholes, trial pits or test locations, but it is modified according to the expected variability of the soil conditions. Assessment of groundwater conditions forms an important part of the full appraisal of a site.[2]

Having gathered together the information mentioned above, the planned use of field techniques can be developed accordingly.

Although trial pits and borings, sampling, and in-situ testing are described in separate sections, it is necessary to coordinate the planning of their layout and distribution. Detailed guidance is given in each section.

In summary:
1. trial pits and borings are required for direct inspection of ground conditions;
2. sampling will be used for laboratory testing to determine index properties and mechanical properties;
3. in-situ testing can often provide a rapid method of confirming lateral continuity of strata as well as providing some additional quantitative information concerning the mechanical properties of the soil.

An understanding of what type of ground investigation is to be carried out is a fundamental requirement in planning sampling and testing. The types of ground investigation include:
1. sites for new works;
2. defects or failures of existing works;
3. safety of existing works;
4. material for constructional purposes.
For detailed information refer to BS 5930: 1981. Clause 8.

In planning ground investigations, particular attention should be paid to the safety of personnel. A list of statutory regulations which may apply to ground investigations is given in BS 5930: 1981. Appendix F. pp. 131-132.

[1] SH2/88 CLAUSE 2.19 P.13
[2] CIRIA25:1983. PP. 18-19

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SB21: TRIAL PITS & BORINGS

Explanation:

A considerable variety of methods of ground investigation exists, consisting of those in which samples are retrieved from the ground for description and testing and those in which the properties of the soil are described or measured in-situ. The two exploration methods, trial pitting and boring, may have functions as follows:
- ground conditions can be inspected in them or with samples removed from them;
- samples can be taken for laboratory tests from them;
- some types of in-situ tests can be carried out in them.

Shallow trial pits provide an economical method of examining in-situ conditions, whereas exploration by means of boring is a well established technique, and may be used exclusively or may supplement trial pits.[1]

Whereas the samples retrieved from trial pits can be large, disturbed or undisturbed, the samples from boreholes are small diameter, sometimes disturbed and only undisturbed in clayey soils. However, trial pits have a limited depth.

No hard and fast rules can be given for the depth and spacing of exploratory holes. This will depend very much on the Engineer, the anticipated ground conditions and the type of structure. Each site should be individually assessed, together with the proposed development.[2]

[1] CIRIA 25:1983. PP.29,30

[2] SH2/88:1988 P.8;
CIRIA25:1983 P.20;
BS5930:1981 P.10

Advisory:

Details of soil conditions discovered in trial pits and borings should be notified to British Geological Survey, Merchison House, West Mains Road, Edinburgh EH9 3LA for addition to their databank.

Two basic methods of exploration are trial pitting and boring. The selection of appropriate exploration methods for proposed works depends on the following main factors:

1. the topography, type of ground to be investigated and ground-water conditions
2. the type of works envisaged and technical requirements
3. amount of existing information
4. expected variability of subsoil
5. external constraints such as the availability of plant, access, costs and time available. However the technical requirements of the investigation, rather than cost, should be the overriding factor in the selection of investigatory methods.

In unconsolidated superficial deposits, trial pits are generally more appropriate, greatly increasing the quality and accuracy of the information that is obtained.[6] Borings will be necessary if great depths are to be investigated, or where groundwater problems are anticipated.[1]

More details can be obtained by consulting individual sections.

Safety should be taken into account throughout the process of ground investigation. If personnel are to enter trenches or pits more than 1.2 m deep, then measures must be taken either to support the sides or to batter back the sides.[2]

The points of exploration, e.g. boreholes, soundings, pits, should be so located that a general geological view of the whole site can be obtained with adequate details of engineering properties of the soils and of ground water conditions. For road schemes it is important that the position of exploratory holes is staggered about the centreline to ensure sufficient transverse coverage of the site. If there is any likelihood of the road profile being altered then a view must be taken on whether the investigation should allow for this. For foundations, it has traditionally been proposed that the trial excavations should be located outside the proposed foundation areas.[3]

If only a strip is to be surveyed, as is usual for a road, a single line of borings along the centre line, a double line offset about 15 to 30 m on each side, or a triple line with some holes along the centre line and some offset alternately to each side along the approximate edges of the intended carriageway is usually sufficient, but if a wide area is to be surveyed the best way of covering the ground is probably with a grid. Normally the borings are required at intervals of about 100 m. The interval between the borings depends entirely on the nature of the soil encountered and may be as much as about 300 m in very uniform ground, or as little as about 15 m in quickly changing ground such as glacial deposits.[4]

More holes will be required at critical points such as locations of expected structures. At expected locations of cuttings a series of three points across the section is recommended.

Where the sites of bridges are known with reasonable accuracy, sufficient exploratory holes should be put down to enable the geological structure of the ground to be plotted in some detail and the engineering properties established. The extent of the boring or excavation will depend on how much is already known of ground conditions and whether spread or piled foundations are envisaged. It is important that exploratory holes for structures are accurately located at the required positions. Errors in positioning are likely to result in the need for further work as a later stage.

The extent of the proposed investigation affecting structures should be agreed with those responsible for any technical approval of those structures.[7]

Some experience concerning the spacing of explorations is summed up as follows:
Foundations (of bridge, of small buildings, etc.):
- for important structures, usually,
  - spacing is 10 to 30 metres, or
  - density is 10 to 100 per hectare, but
- for small structures,
  - in plan area, at least 3 points;
- for groups of identical structures,
  - at least 1 point per unit.

Cut, Fill, Quarry, Roadline, etc.:
- for important work, would be 10 to 30 metres, but
  - wider spacing allowed depending on ground conditions;
- for culverts and other small works,
  - not less than 3 points.

Where engineering difficulty and complicated ground, such as suspected buried valleys, old slipped areas, etc., rigid or preconceived patterns of pits/bores/soundings should be avoided.[5]

[1] CIRIA 25:1983 SECTION 1.3.4 P.19
[2] CLAYTON et al: 1982 P.145;
CIRIA 25: 1983 SECTION 2.1 P.29;
SPECIFICATION FOR GI: 1989 P.13
[3] SH2:1988 P.8;
BS5930:1981 P.10;
CIRIA 25:1983 SECTION 1.3.4 P.20 19
[4] SOIL MECHANICS FOR ROAD ENGINEERS:1952 SECTION 8.23 P.140
[5] SH2:1988 P.8;
BS5930:1981 P.10;
CIRIA 25:1983 SECTION 1.3.4 P.20 19;
CLAYTON et al:1982 PP.295-296
[6] LR 828: 1978 TRRL P.7
[7] SH2/1988 P7,8

Depth of Investigation

As in Rule SA31.

Expert Opinion:

As in Rule SA31.

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SB211: TRIAL PITS

Barring editorial changes, as in Rule SA311.

-----oooooOoooooo-----

SB2111: TRIAL PITS, TECHNIQUES

As in Rule SA3111.

-----oooooOoooooo-----

SB2112: TRIAL PITS, LOGGING

As in Rule SA3112.

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SB212: BORINGS

Barring editorial changes, as in Rule SA312.

-----oooooOoooooo-----

SB2121: BORINGS, TECHNIQUES

As in Rule SA3121.

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SB2122: BORINGS, LOGGING

As in Rule SA3122.

-----oooooOoooooo-----

SB22: SAMPLING

Explanation:

The object of subsurface exploration, to determine the nature of the sub-soil, usually requires the acquisition of soil samples either to allow visual examination of the soil by an engineer or to permit survey of physical or mechanical properties to be carried out partly or wholly in the laboratory.

The selection of sampling technique depends on the quality of the sample that is required, and the character of the ground, particularly the extent to which it will be disturbed by the sampling process. Several different equipments which may be used for sampling of soils and weak rocks are described in TECHNIQUES. Guidance is given there on the ground types for which each type of equipment is suitable.[1]

When the programme of sampling is being prepared it is particularly important to be aware of the requirements for sample quality that will be associated with the laboratory testing that is envisaged. It is expensive to obtain high quality samples, and it may not be possible to return to the site if the quality of sample that has been obtained turns out to be inadequate. The programmes of field testing and sampling and of laboratory testing need to be prepared concurrently.

[1] BS 5930:1981 CLAUSE 19.1 P.20;
CIRIA 25:1983 SECTION 2.4 P.39;
LR625:1974 SECTION 5 P.8;
CLAYTON et al:1982 CHAPTER 5 P.172

Advisory:

TYPES OF SAMPLE:

As in Rule SA32.

AMOUNT OF SAMPLING:

As in Rule SA32.

QUALITY OF SAMPLE:

As in Rule SA32.

FREQUENCY OF SAMPLING:

The frequency of sampling required depends on the information already available, the technical objectives of the investigation, and the number of test results necessary to permit a reasoned assessment of the properties of the soil. The sample and/or test locations must therefore be such that all changes of stratum are recorded. In addition, a number of extra samples and test results are required to assess variation of the properties of a stratum with depth.

In soft alluvial soils it may be very difficult to ascertain what sizes of samples should be taken from what levels to represent fairly the ground as a whole in order to provide reasonably accurate information about bearing capacity and consolidation characteristics. Advance boring by a continuous
sampling machine with visual inspection can be of the greatest assistance in making decisions about the sampling and testing appropriate to the soils encountered.

In sand and gravel, at the top of each new stratum and thereafter at 1 m intervals of depth, a SPT should be carried out using the split barrel sampler if the soil is suitable; at the top of each new stratum and thereafter at 1.5 m intervals of depth, a disturbed sample should be obtained from the drill tools.

In cohesive soil, at the top of each new stratum and thereafter at 1.5 m intervals of depth, a 100 mm sample should be obtained; at each metre of depth, a disturbed sample should be obtained from the drill tools.

For structures, the maximum distances between undisturbed or bulk disturbed samples measured centre to centre should be 1 m for the first 5 m below foundation level, and 1.5 m thereafter.

For embankments, the maximum distances between undisturbed or bulk disturbed samples measured centre to centre should be 1 m for the first 5 m below existing ground level and 1.5 m thereafter as required, covering the depth of influence of the loaded area.

For cuttings, the maximum distances between undisturbed or bulk disturbed samples measured centre to centre should be 1 m both above formation level and below to as great a depth as is required.[1]

[1] SH2/88 CLAUSE 2.10.7, P8 & 2.12.1 P.9;
CIRIA 25:1983 SECTION 2.5.1-2 PP.48-49,
SECTION 1.3.4 PP.19-20;
LR625:1974 SECTION 5 P.8;
CLAYTON et al:1982 CHAPTER 5 P.175;
ROBB:1982 PP.13-14;
SPEC. OF DTp FOR GI:1987 SECTION 6.3 P.13

Expert Opinion:

As in Rule SA32.

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SB221: SAMPLING, TECHNIQUES

As in Rule SA321.

-----oooooOoooooo-----

SB222: SAMPLING, LOGGING

As in Rule SA322.

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SB23: IN-SITU TESTS

As in Rule SA33.

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SB231: IN-SITU PROBING TESTS

As in Rule SA331.

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SB232: IN-SITU VANE TESTS

As in Rule SA332.

-----oooooOoooooo-----

SB233: PRESSUREMETER TESTS

As in Rule SA333.

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SB234: PLATE BEARING TESTS

As in Rule SA334.

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SB235: SHALLOW IN-SITU TESTS

As in Rule SA335.

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SB236: IN-SITU PERMEABILITY TESTS

As in Rule SA336.

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SB237: SPECIAL TESTS IN THE FIELD

Explanation:

Geophysical tests are described in this stage.

Geophysical methods most often used rely on contrasts of acoustic impedance (which is a function of density and stiffness), void space, or resistivity properties between the ground types being investigated, and the results obtained require careful correlation with borehole data. The greater the contrast between the geophysical properties of the strata exploited in the test, the more reliable the results. Adequate borehole coverage and considerable experience in this field are essential, to ensure correct interpretation of the observations. The successful application of geophysical methods depends on their suitability for a specific geotechnical problem. The methods introduced here are as follows:

Seismic refraction;
Cross-hole/down-hole seismic; and
Electrical resistivity.

So far the usefulness of geophysical methods of ground investigation for road-works has not been demonstrated except in limited applications and such methods should not be employed without prior consultation with the Materials Section of the Chief Road Engineer's Office.[1]

[1] SH2/88 P.17

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SB2371: SEISMIC REFRACTION TESTS

As in Rule SA3371.

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SB2372: CROSSHOLE/DOWNHOLE SEISMIC TESTS

As in Rule SA3372.

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SB2373: ELECTRICAL RESISTIVITY TESTS IN THE FIELD

As in Rule SA3373.

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SB3: LABORATORY TESTING

Explanation:

Plans for the laboratory testing and field testing and sampling forming the Main Ground Investigation should be developed concurrently. On a large scheme, laboratory tests are often performed at the same time as the field investigation, as an integral part of ground investigation. The need for laboratory tests will often dictate the type and frequency of sample to be taken, and may therefore control the method of forming boreholes. The decision as to the type of sample required will require some prior knowledge of the ground conditions.

The aims of laboratory testing of samples of soil may be summarised as follows:
1. to identify and classify the samples with a view to making use of past experience with materials of similar geological age, origin and condition;
2. to obtain soil parameters relevant to the technical objectives of the investigation. [1]

Several groups of laboratory testing are described here, they are as follows:
1. classification and index tests;
2. strength and deformation tests;
3. compaction tests;
4. permeability tests; and
5. chemical tests.

[1] CIRIA 25:1983 PP.13,102;
CLAYTON et al:1982 P.356;
BS5930:1981 P.70

References:

As in Rule SA4.

Advisory:

As in Rule SA4.

Expert Opinion:

As in Rule SA4.

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SB31: SOIL CLASSIFICATION

As in Rule SA41.

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SB311: MOISTURE & VOIDS RATIO TESTS IN LABORATORY

As in Rule SA411.

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SB312: PARTICLE SIZE DISTRIBUTION TEST

As in Rule SA412.

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SB313: INDEX PROPERTY TESTS IN LABORATORY

As in Rule SA413.

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SB32: STRENGTH-DEFORMATION

As in Rule SA42.

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SB321: CBR TEST IN LABORATORY FOR PAVEMENT DESIGN

As in Rule SA421.

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SB322: LABORATORY FALLING CONE FOR STRENGTH MEASUREMENT

As in Rule SA422.

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SB323: LABORATORY VANE STRENGTH TEST

As in Rule SA423.

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SB324: SHEARBOX TEST FOR STRENGTH & DEFORMATION IN LABORATORY

As in Rule SA424.

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SB325: OEDOMETER TEST

As in Rule SA425.

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SB326: UNCONFINED COMPRESSION TEST FOR STRENGTH IN LABORATORY

As in Rule SA426.

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SB327: TRIAXIAL TESTS FOR STRENGTH & DEFORMATION IN LABORATORY

As in Rule SA427.

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SB328: SPECIAL TESTS FOR STRENGTH & DEFORMATION IN LABORATORY

As in Rule SA428.

-----oooooOoooooo-----

SB33: COMPACTION

As in Rule SA43.

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SB331: PROCTOR METHOD FOR COMPACTION TESTS IN LABORATORY

As in Rule SA431.

-----oooooOoooooo-----

SB332: VIBRATING HAMMER FOR COMPACTION TESTS IN LABORATORY

As in Rule SA432.

-----oooooOoooooo-----

SB333: MOISTURE CONDITION VALUES IN LABORATORY

As in Rule SA433.

-----oooooOoooooo-----

SB34: PERMEABILITY TESTS IN LABORATORY

As in Rule SA44.

-----oooooOoooooo-----

SB35: CHEMICAL TESTS

As in Rule SA45.

-----oooooOoooooo-----

SB351: SOIL MINERAL TESTS IN LABORATORY

As in Rule SA451.

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SB352: PORE WATER CHEMICAL TESTS IN LABORATORY

As in Rule SA452.

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SB353: OTHER LABORATORY CHEMICAL TESTS

As in Rule SA453.

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SB4: SPECIAL STUDY

Explanation:

Special points of engineering significance may require a more detailed survey of one area or aspect of the site. Such special investigations may be carried out during or after the main investigation and may require special advice or techniques.

Special ground investigation studies may be required to cover:
1. field trials;
2. back analyses;
3. groundwater and pollution;
4. climate and hydrology;
5. materials; and
6. other points.

References:

BS 5930: 1981. Code of practice for site investigations. British Standard. British Standard Institution, 2 Park Street, London W1A 2BS.
BS 1377: 1990. Methods of tests for Soil for civil engineering purposes. Parts 1-9. British Standard Institution.
LR 625: 1974. Guidance on planning, directing and reporting site investigations. TRRL.

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SB41: FIELD TRIAL

As in Rule SA3374, Part 1.

-----oooooOooooo-----

SB42: BACK ANALYSIS

As in Rule SA3374, Part 2.

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SB43: GROUNDWATER-POLLUTION

Explanation:

Special observations may be needed where ground-water conditions are likely to be important, for example where the road will be in cutting, note should be taken of existing drainage features such as springs, seepages, natural ponds and streams.

The water table often has a profile that passes through the standing-water level in boreholes and permanent surface water and is a subdued replica of the surface topography. However, this profile is affected by a large number of unpredictable factors such as lateral flow, artesian conditions, drawdown, and the different pemeabilities of different strata, and these factors make accurate interpolation difficult or impossible with the amount of information usually available. For important structures, it may be necessary to determine contours of water-table depth by means of observation over the area.

Samples of ground water should be taken from each boring in which water is found in order to determine whether sulphates or acidity are present to an extent to be likely to damage any concrete, cement-stabilised soil or cement grout. Test procedures are given in BS 1377: 1990 Part 3.

If groundwater runoff occurs from moorland or peaty areas, it is necessary to perform acidity tests.[1]

Pollution effects associated with existing ground at the site of construction works, with neighbouring sites, or with the movement of materials from the construction area may need to be considered.

[1] LR 625:1974 PP.23-24

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SB44: CLIMATE-HYDROLOGY

Explanation:

It may be necessary to study climatic and hydrological factors in order to check whether these will influence the construction process or the choice of materials for construction. In carrying out the this task, the following aspects should be considered :
1. if any part of the route will be subject to flooding;
2. if there are spring-lines or seepage in the area of the works;
3. if ground-water lowering or special drainage measures will be required during excavation or to stabilize slopes;
4. if corrosive or sulphate-bearing ground waters are present that may affect the road or its installations and structure; [1]
5. if structures or parts of the roadway will be subjected to

particularly strong winds or precipitation of rain or snow.

[1] LR625:1974 PP.14-15

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SB45: MATERIALS

Explanation:

The study of materials is related to the selection of sources of aggregate. This is not necessarily central to the ground investigation, but may be required as part of the planning of the overall road project.

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SB46: OTHER

Explanation:

(other special studies)

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STANDARD ENTRIES IN THE ORIGINAL ASCII FILES

This is a copy of the dummy ASCII file used when first compiling rules for the Scottish Office's system. The eight sections mentioned in the text are shown in bold type.

Name:sa_stand
ShortName:Standard
Recnum:0
Question:
Choice:0
Menu:
MenuExplanation:
MenuShort:
Explanation:
Standard Explanation (t)
Information:
Standard Information (u)
Advice:
Standard Advice (v)
References:
Standard Reference (w)
Mandatory:
Advisory:
Expert Opinion:
End:

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Appendix 8.1

RULES FOR TESTS

@$START OF F7THELP1.DAT, X.X., ... November 26, 1993

@$100000 Classification tests
Specifications for soil classification tests follow here.

110100 Field Description
110200 Laboratory Description
110300 Moisture Content
110400 Wet Sieve Test / Particle size distribution
110500 Clay Content
110600 Liquid Limit
110700 Plastic Limit
110800 Organic Carbon
110900 Dry Density
111000 Porosity
111100 Specific Gravity

@$110100 Field Description
Description of soil in the field shall be in accordance with BS 5930: 1981: Section 41 ff.

@$110200 Laboratory Description
Description of soil in the laboratory shall be in accordance with BS 5930: 1981: Section 41 ff.

Comment
See BS 1377: Part 1: 1990: Section 3.2 Description of soils.

@$110300 Moisture Content
Tests for moisture content are subdivided thus:
  definitive method;
  rapid methods:
    microwave drying;
    sand bath method;
    calcium carbide bomb method;
  chalk, saturation moisture content of.

@$110310 Definitive method
BS 1377: Part 2: 1990: Section 3.2 Oven-drying method.

Comments
The basic method is drying to constant weight at 105-110 C. If gypsum is present then drying is at 80 C.

[Section 3.2.3.1.2.

The Standard includes:
  correction to 425 micron fraction
  correction for absorption in porous particles
  correction for dissolved salts

[Section 3.2.4.

Variations
If the 'matrix moisture content' is to be measured, then the specification must state which size of material is to be tested. (The matrix moisture content is the moisture content of the fine material only.)

Comments
The wording of BS 1377: Part 2: 1990 Sections 3.1 and 3.2.2.1 implies that microwave drying may be used as a definitive method provided that the restrictions noted above are observed; but some engineers may not accept this interpretation. The Standard does not specify a method for microwave drying.

Variations
Microwave drying may be used provided (1) that the soils contain neither clay nor organic matter; (2) that preliminary tests have shown that the soil does not exceed 110 C at any time during the course of the tests; and (3) that check tests show that microwave drying yields the same result as conventional oven drying.

[Sections 3.2.2.1, 3.2.2.1, & 3.1.

If microwave drying is proposed, the laboratory must agree the specification with the Project Engineer before starting work.

@$110320 Rapid method
The rules for choosing rapid methods of moisture content determination appear to be:

cohesionless sands and silts:	calcium carbide
free of organic matter, clay, and gypsum:	sand bath
free of organic matter and clay:	microwave

@$110330 Microwave drying
BS 1377: Part 2: 1990: Section 3.2 permits microwave drying as a rapid method; but the specification is not given.

Variations
Microwave drying may be used provided (1) that the soils contain neither clay nor organic matter; (2) that preliminary tests have shown that the soil does not exceed 110 C at any time during the course of the tests; and (3) that check tests show that microwave drying yields the same result as conventional oven drying.

[Sections 3.2.2.1, 3.2.2.1, & 3.1.

If microwave drying is proposed, the laboratory must agree the specification with the Project Engineer before starting work.

@$110340 Sand bath method
BS 1377: 1975: Test 1(B) Determination of the moisture content: Subsidiary method (sand bath method).

Comments
BS 1377: Part 2: 1990: Section 3.2 permits sand bath drying as a rapid method; but the specification is not given.

The method should not be used if gypsum, calcareous matter, or organic matter are present, BS 1377: 1975.

Head, 1980, vol.1 p.64 Section 2.5.3 also includes this method.

@$110350 Calcium carbide method
If the calcium carbide method of moisture content measurement is proposed, the laboratory must agree the specification with the Project Engineer before starting work. The manufacturer's instructions must be followed; and the apparatus must be calibrated for each type of soil to be tested.

Comments
BS 1377: Part 2: 1990: Section 3.2 permits the calcium carbide method as a rapid method; but the specification is not given. Head, 1980, vol.1 p.61 Section 2.5.1 also mentions this method, saying that the manufacturer's instructions must be followed.

The calcium carbide method is normally restricted to cohesionless sands and silts only.

@$110360 Chalk
BS 1377: Part 2: 1990: Section 3.1 saturation moisture content of chalk: immersion in water method.

@$110400 Wet Sieve Test / Particle size distribution
The rules for particle size analysis appear to be:

very large particles present:
cohesive: boulder clay method
non-cohesive: hand sorting, dry sieving
clean sands and gravels: dry sieving
sands and gravels with fines: wet sieving
fine soils with sand or gravel: wet sieving, sedimentation
extremely fine soil: sedimentation

Sedimentation is treated in the next Section under Clay Content.

BS 1377: 1990 takes wet sieving as the definitive method; but the following order is more convenient.

Comment
The definition of a boulder is obscure. Earth Manual: 1974 p.2 uses 12 inches; but British practice is 8 inches or 200 mm, see BS 5930: 1981. However, the only definition of what exactly is to be 200 mm that has been found is given by both Head, 1980, vol.1 p.167 and Akroyd, 1957, p.64, both of whom agree that the particles should be measured using frames with square apertures; this appears to be equivalent to saying that it is neither the largest nor the smallest but the intermediate 'principal' diameter which rules.

@$110410 Boulder clay method
Head, 1980, vol.1 pp.177-182 Section 4.6.7 'Boulder Clay'.

Comment
Check Head's recommendations before accepting them as a specification.

@$110420 Hand sorting
Head, 1980, vol.1 pp.166-168 Section 4.6.3 Cobbles and Boulders.

Comments
Check Head's recommendations before accepting them as a specification. Note especially his choice of dispersing agent, which implies that ordinary British soils are to be tested.

@$110430 Dry sieving
BS 1377: Part 2: 1990: Section 9.3 Determination of particle size distribution: Dry sieving method.

Comments
Here, dry sieving refers to the sieving of the soil as it is received apart from the removal of large particles.

BS 1377: 1990 permits dry sieving only if it gives the same result as wet sieving to BS 1377: Part 2: 1990: Section 9.2. See Section 9.3.1.

Variation of the specification
If large particles have been removed by hand before the sample has been sieved, the proportion by weight of the removed particles shall be reported as a percentage of the original sample.

[Glasgow University Rule.

@$110440 Wet sieving
BS 1377: Part 2: 1990: Section 9.2 Determination of particle size distribution: Wet sieving method.

Comments
The procedure for wet sieving in BS 1377: 1990 consists of a preliminary wet sieving followed by a subsequent dry sieving.

A second riffled sample is required if the particle size distribution is to be extended below 63 microns, either to separate the silt and clay fractions, or for a fuller analysis.

Variations of the specification
If large particles have been removed by hand before the sample has been sieved, the proportion by weight of the removed particles shall be reported as a percentage of the original sample.

[Glasgow University Rule.

A second riffled sample shall be obtained for a fine analysis as indicated in Section 9.2.3.

To avoid ambiguity, the aperture sizes of the sieves to be used should be specified.

If necessary, the specification should be modified to prevent oven-drying of the soil before it is tested.

If necessary, a dispersing agent other than sodium hexametaphosphate should be specified.

@$110500 Clay Content
The test may be conducted in accordance with either of:

BS 1377: Part 2: 1990: Section 9.5 Determination of particle size distribution: Sedimentation by the hydrometer method.

BS 1377: Part 2: 1990: Section 9.4 Determination of particle size distribution: Sedimentation by the pipette method.

Comment
Formerly, the pipette method was preferred to the hydrometer, but it now seems to be agreed that the hydrometer is sufficiently accurate, and it is more robust.

Clauses to specify a specific method follow.

@$110510 Clay Content, hydrometer

BS 1377: Part 2: 1990: Section 9.5 Determination of particle size distribution: Sedimentation by the hydrometer method.

Comment
Please see the variations below.

@$110520 Clay Content, pipette

BS 1377: Part 2: 1990: Section 9.4 Determination of particle size distribution: Sedimentation by the pipette method.

Comment
Please see the variations below.

@$110530 Clay Content, general
Whichever method of obtaining the clay content has been specified, some of the following variations may be needed.

Variations of the specification
The material shall be tested either in its natural state or after wet sieving as is found to be appropriate.
[Section 9.4.1 or 9.5.1.

The material shall be tested either in its natural state without wet sieving.
[Section 9.4.1 or 9.5.1.

The material shall be tested after wet sieving.
[Section 9.4.1 or 9.5.1.

If after wet sieving, less than 10 % of the material passes the 63 micron sieve, the requirement for this test is cancelled.
[Section 9.4.1 or 9.5.1.

If necessary, the specification should be modified to prevent oven-drying of the soil before it is tested.
[Section 9.4.1 or 9.5.1.

If necessary, a dispersing agent other than sodium hexametaphosphate should be specified.

[Section 9.4.5.1 or 9.5.5.1.

@$110600 Liquid Limit

There are four common tests for Liquid Limit:

cone penetrometer	preferred method
Casagrande apparatus	acceptable alternative
one point versions of both	faster
	requires less soil
	relies on an assumption
	only if LL < 120 %

@$110610 Cone penetrometer

BS 1377: Part 2: 1990: Section 4.3 Determination of the Liquid Limit, Cone penetrometer method (definitive method).

Comment
Please see the variations below.

@$110620 Cone penetrometer, one point method

BS 1377: Part 2: 1990: Section 4.4 Determination of the Liquid Limit, One-point cone penetrometer method.

Comment
Please see the variations below.

@$110630 Casagrande apparatus

BS 1377: Part 2: 1990: Section 4.5 Determination of the Liquid Limit, Casagrande apparatus method.

Comment
Please see the variations below.

@$110640 Casagrande apparatus, one point method

BS 1377: Part 2: 1990: Section 4.6 Determination of the Liquid Limit, One-point Casagrande method.

Comment
Please see the variations below.

@$110650 Liquid Limit, general

Whichever method of obtaining the liquid limit has been specified, some of the following variations may be needed.

Comments
BS 1377: Part 2: 1990; Section 4.2.1 requires particles > 425 microns to be removed; but this may be inappropriate, e.g. for puddled clay.

BS 1377: Part 2: 1990; Section 4.2.1 permits the removal by hand of particles > 425 microns from 'many clay soils'; but use common sense and caution if specifying this option.

Variations
Particles > 425 microns shall be removed by wet sieving.

Coarse particles shall be removed by hand, wet sieving is not required.

The test shall be performed on the whole sample.

Comment
Many soils may change due to bacterial or chemical action; so it may be necessary to write a special rule to prevent this from happening, in particular by stating the temperature of storage and limiting the length of delay before testing. The following suggestions have been made:
for tropical halloysitic soils, below 27 degrees C [1];
for soils containing bacteria, below 5 degrees C [2].
Storage below 0 degrees C may alter the soil structure without freezing all the water or stopping all bacterial action.

[1] Mr.Robertson, per.comm. [2] Glasgow University Rule.

Variations
The sample shall be kept at its natural moisture content until tested.

The sample may be air-dried before testing.

The sample shall be kept below 27 degrees Centigrade until tested.

The sample shall be stored at 5 degrees Centigrade until tested.

The sample shall be stored below 0 degrees Centigrade until tested.

@$110700 Plastic Limit
BS 1377: Part 2: 1990: Section 5.3 Determination of the plastic limit.

Variation
The sample shall be prepared and stored in the same way as for the Liquid Limit test.

@$110800 Organic Carbon
BS 1377: Part 3: 1990: Section 3 Determination of the organic matter.

Comments
1. This method, which uses dichromate oxidation, is known as Walkley and Black's method, Section 3.1.
2. Duplication of specimens is usual. However, it may be necessary to make a number of tests in order to obtain a mean value and an indication of the reliability of the results; this would require that you write your own Variation. See Section 3.1.
3. The Standard requires the removal of sulphides from the soil if they have been found, Sections 3.4.3 and 3.4.4.
4. The Standard requires the removal of chlorides from the soil if they have been found, Sections 3.4.5 and 3.4.6.

Variation
Duplicated specimens shall be tested.

@$110900 Dry Density
There are four properties which may be determined here:

in-situ density;
mass density;
maximum and minimum densities.

There are also several tests for each. The whole series is currently placed under one heading in the score base.

@$110910 In-situ density
There are five methods for determining the in-situ density of soil, they are:

Core cutter method	cohesive w/o coarse
Small pouring cylinder method	fine-medium grained
Large pouring cylinder method	fine-coarse grained
Nuclear methods	fine-coarse grained
Water replacement method	coarse grained

@$110911 Core cutter method
BS 1377: Part 9: 1990: Section 2.4 In-situ density tests: Core cutter method for cohesive soils free from coarse-grained material

@$110912 Small pouring cylinder method
BS 1377: Part 9: 1990: Section 2.1 In-situ density tests: Sand replacement method suitable for fine- and medium-grained soils (small pouring cylinder method)

@$110913 Large pouring cylinder method
BS 1377: Part 9: 1990: Section 2.2 In-situ density tests: Sand replacement method suitable for fine- and medium- and coarse-grained soils (large pouring cylinder method)

@$110914 Nuclear methods
BS 1377: Part 9: 1990: Section 2.5 In-situ density tests: Nuclear methods suitable for fine- and medium- and coarse-grained soils

Comment
Safety precautions must be observed.

@$110915 Water replacement method
BS 1377: Part 9: 1990: Section 2.3 In-situ density tests: Water replacement method suitable for coarse-grained soils

@$110920 Mass density
There are three methods for determining the mass density of soil, they are:

Linear measurement method: soil formed into regular shape;
Immersion in water method: lumps without re-entrant angles;
Water displacement method: lumps without re-entrant angles.

Head, 1980, vol.1 p.119 suggests that water displacement is simpler than immersion (and weighing) in water but less accurate.

@$110921 Linear measurement method
BS 1377: Part 2: 1990: Section 7.2 Determination of density, Linear measurement method.

Comment
Cohesive samples of regular shape.

@$110922 Immersion in water method
BS 1377: Part 2: 1990: Section 7.3 Determination of density, Immersion in water method.

Comment
Lumps of soil; no re-entrant angles; size > 100 mm.

@$110923 Water displacement method
BS 1377: Part 2: 1990: Section 7.4 Determination of density, Water displacement method.

Comment
Lumps of soil; no re-entrant angles; size > 100 mm.

@$110930 Maximum and minimum densities
There are two pairs of methods for determining the maximum and minimum density of soil, they are:

Maximum density of sands
Minimum density of sands
Maximum density of gravelly soils
Minimum density of gravelly soils

Variations
Head, Vol 1: 1980: p.114 Section 3.4.4 Limiting Densities gives alternative methods.

@$110931 Maximum density of sands
BS 1377: Part 4: 1990: Section 4.2 Determination of the maximum density of sands.

@$110932 Minimum density of sands
BS 1377: Part 4: 1990: Section 4.4 Determination of the minimum density of sands.

@$110933 Maximum density of gravelly soils
BS 1377: Part 4: 1990: Section 4.3 Determination of the maximum density of gravelly soils.

@$110934 Minimum density of gravelly soils
BS 1377: Part 4: 1990: Section 4.5 Determination of the minimum density of gravelly soils.

@$111000 Porosity
There appears to be no direct test for porosity in BS 1377: 1990. Calculation is the usual method; mercury intrusion is sometimes used but is hazardous.

Variations
Porosity shall be calculated from dry density and particle density (specific gravity).

Porosity shall be determined by mercury intrusion; the laboratory must agree the specification with the Project Engineer before starting work.

@$111100 Specific Gravity
There are three methods for determining particle density, syn. specific gravity:

gas jar method	soils with 90 % finer than 37.5 mm
small pyknometer method	soils finer than 2 mm
large pyknometer method	non-cohesive soils finer than 20 mm

@$111110 gas jar method
BS 1377: Part 2: 1990: Section 8.2 Determination of particle density, Gas jar method

Comment
Please see the variations below.

@$111120 small pyknometer method
BS 1377: Part 2: 1990: Section 8.3 Determination of particle density, small pyknometer method

Comment
Please see the variations below.

@$111130 large pyknometer method
BS 1377: Part 2: 1990: Section 8,4 Determination of particle density, large pyknometer method

Comment
Please see the variations below.

@$111140 Specific Gravity, general
It may be necessary to add clauses along the following lines:
1. Normally, the specimens shall be oven dried at 105-110 C.
2. If the particle density may be changed due to loss of water of hydration, specimens should be dried at not more than 80 C..
3. BS 1377: 1990 specifies two duplicate determinations.

@END OF F7THELP1.DAT. BS 1377: 1990.

@START OF F7THELP2, X.X., ... November 26, 1993

@$200000 Compaction tests
1 Number of sub-groups in this group
4 Number of tests

G 210100 Moisture Condition Value
G 210200 Proctor compaction test
G 210300 Dietert compaction test
G 210400 Chalk crushing test

@$210100 Moisture Condition Value
There are three methods based on the moisture condition value, which, together with suggested uses, are:

MCV/moisture content	for site investigation
MCV of a sample	for construction control
Rapid assessment of strength	for rapid construction control

@$210110 MCV/moisture content
BS 1377: Part 4: 1990: Section 5.5 Determination of the MCV/moisture content relation of soil

@$210120 MCV of a sample
BS 1377: Part 4: 1990: Section 5.4 Determination of the MCV of a sample of soil at its natural moisture content

@$210130 Rapid assessment of strength
BS 1377: Part 4: 1990: Section 5.6 Rapid assessment of whether or not a soil is stronger than a pre-calibrated standard

@$210200 Proctor compaction test
There are five methods of determining the dry density/moisture content relationship included here:

light compaction, up to medium-gravel
light compaction, up to coarse-gravel
heavy compaction, up to medium-gravel
heavy compaction, up to coarse-gravel
vibratory compaction

The choice of light, heavy, or vibratory compaction should be chosen to suit the type of compaction plant expected to be used.

Comment
All five tests have variations for soil particles which are/are not susceptible to crushing.

@$210210 light compaction, up to medium-gravel
BS 1377: Part 4: 1990: Section 3.3 Determination of dry density/moisture content relationship: Method using 2.5 kg rammer for soils with particles up to medium-gravel size

@$210220 light compaction, up to coarse-gravel
BS 1377: Part 4: 1990: Section 3.4 Determination of dry density/moisture content relationship: Method using 2.5 kg rammer for soils with some coarse gravel-size particles

@$210230 heavy compaction, up to medium-gravel
BS 1377: Part 4: 1990: Section 3.5 Determination of dry density/moisture content relationship: Method using 4.5 kg rammer for soils with particles up to medium-gravel size

@$210240 heavy compaction, up to coarse-gravel
BS 1377: Part 4: 1990: Section 3.6 Determination of dry density/moisture content relationship: Method using 4.5 kg rammer for soils with some coarse gravel-size particles

@$210250 vibratory compaction
BS 1377: Part 4: 1990: Section 3.7 Determination of dry density/moisture content relationship: Method using vibrating hammer

@$210300 Dietert compaction test
This is a standard test in iron foundries. It is included in TM SH2/88.

@$210400 Chalk crushing test
BS 1377: Part 4: 1990: Section 6 Determination of the chalk crushing value (CCV).

@END OF F7THELP2. BS 1377: 1990.

@START OF F7THELP3, X.X., ... November 26, 1993

@$300000 Strength tests
4 Number of subgroups in this group

G 310000 Triaxial tests$
G 320000 Shear box tests
G 330000 Static and dynamic probing tests
G 340000 Miscellaneous strength tests

@$310000 Triaxial tests$
There are 10 tests of determination of the shear strength under different conditions in triaxial compression.

G 310100 UU w/oPP(sgl)
G 310200 UU w/oPP(mti)
G 310300 UU c/wPP(sgl)
G 310400 UU c/wPP(mti)
G 310500 CU w/oPP(sgl)
G 310600 CU w/oPP(mti)
G 310700 CU c/wPP(sgl)
G 310800 CU c/wPP(mti)
G 310900 CD (sgl)
G 311000 CD triaxial test, multi-stage

@$310100 UU w/oPP(sgl)
BS 1377: Part 7: 1990: Section 8 Determination of the undrained shear strength in triaxial compression without measurement of pore pressure (definitive method).

Variations
The following points must be specified:

1. Type of sample, undisturbed, remoulded, or compacted.
2. For undisturbed samples: orientation of sample;
   for remoulded samples: moisture content of samples, and method of remoulding;
   for compacted samples: moisture content, either the dry density to be achieved or the compactive effort to be applied, and method of compaction.
3. Size of test specimens.
4. Number of test specimens to be tested.
5. Cell confining pressures.
6. Rate of strain.

Comment
This is often referred to as the unconsolidated-undrained triaxial compression test without measurement of pore pressure, single stage.

Undrained strength of cohesive soil, not necessarily saturated, at constant confining pressure under strain-controlled loading.

@$310200 UU w/oPP(mti)
BS 1377: Part 7: 1990: Section 9 Determination of the undrained shear strength in triaxial compression with multistage loading and without measurement of pore pressure.

Variations
The following points must be specified:

1. Type of sample, undisturbed, remoulded, or compacted.
2. For undisturbed samples: orientation of sample;
   for remoulded samples: moisture content of samples, and method of remoulding;
   for compacted samples: moisture content, either the dry density to be achieved or the compactive effort to be applied, and method of compaction.
3. Size of test specimen.
4. Number of stages at which specimens are to be tested.
5. Cell confining pressure for each stage.
6. Rate of strain.

Comment
This is often referred to as the unconsolidated-undrained triaxial compression test without measurement of pore pressure, multi-stage.

Undrained strength of cohesive soil, not necessarily saturated, at constant confining pressure under strain-controlled loading.

@$310300 UU c/wPP(sgl)
Unconsolidated-undrained triaxial compression test with measurement of pore pressure, single stage.

This test is not in BS 1377: 1990, so the specification must be written to suit the work in hand.

@$310400 UU c/wPP(mti)
Unconsolidated-undrained triaxial compression test with measurement of pore pressure, multi-stage.

This test is not in BS 1377: 1990, so the specification must be written to suit the work in hand.

@$310500 CU w/oPP(sgl)
Consolidated-undrained triaxial compression test without measurement of pore pressure, single stage.

This test is not in BS 1377: 1990, so the specification must be written to suit the work in hand.

@$310600 CU w/oPP(mti)
Consolidated-undrained triaxial compression test without measurement of pore pressure, multi-stage.

This test is not in BS 1377: 1990, so the specification must be written to suit the work in hand.

@$310700 CU c/wPP(sgl)
BS 1377: Part 8: 1990: Section 7 Consolidated-undrained triaxial compression test with measurement of pore pressure.

Comments
Effective strength of saturated soil after isotropic consolidation at constant confining pressure under strain-controlled loading.

The specification for Consolidation is in Section 6, but no reference to it seems necessary.

Variations
The following points must be specified:

1. Type of sample, undisturbed, remoulded, or compacted.
2. For undisturbed samples: orientation of sample;
   for remoulded samples: moisture content of samples, and method of remoulding;
   for compacted samples: moisture content, either the dry density to be achieved or the compactive effort to be applied, and method of compaction.
3. Size of test specimen.
4. Number of specimens to be tested.
5. Cell confining pressures.
6. Rate of strain.
7. The method of saturation, either:
   The specimens shall be saturated by increments of cell pressure and back pressure in accordance with BS 1377: 1990: Part 8: Section 5.3.
   The specimens shall be saturated at constant moisture content in accordance with BS 1377: 1990: Part 8: Section 5.4.
8. Cell pressure increment during saturation.
9. If following Section 5.3:
   Incremental volume changes shall be calculated in accordance with Section 5.3.2 (g).
   Total volume change shall be calculated in accordance with Section 5.3.2 (j).

@$310800 CU c/wPP(mti)
Consolidated-undrained triaxial compression test with measurement of pore pressure, multi-stage

This test is not in BS 1377: 1990, so the specification must be written to suit the work in hand.

@$310900 CD (sgl)
BS 1377: Part 8: 1990: Section 8 Consolidated-drained triaxial compression test with measurement of volume change.

@$311000 CD triaxial test, multi-stage
Consolidated-drained triaxial compression test with measurement of volume change, multi-stage

This test is not in BS 1377: 1990, so the specification must be written to suit the work in hand.

@$320000 Shear box tests

There are four apparatus for determination of shear strength by using the shear box.

The ring shear apparatus is preferred by some engineers to determine the drained residual shear strength parameters of remoulded clays.

In the laboratory shear boxes, the specimens are either tested dry or submerged and allowed to consolidate. There are both slow and rapid versions of each test, so the result may be in terms of either total or effective stress. The standard shear box is suitable for particles up to 2 mm; the large shear box is suitable for particles up to 20 mm. The large shear box should also be used if the soil has large scale structure. Both boxes can be used for residual shear strength.

The in-situ apparatus is used when the laboratory boxes are too small. etc.

G 320100 Standard shear box test
G 320200 Large shear box test
G 320300 Residual shear box test
G 320400 In-situ Direct shear test
G 320500 Ring shear test

@$320100 Standard shear box test

BS 1377: Part 7: 1990: Section 4 Determination of shear strength by direct shear (small shearbox apparatus).

@$320200 Large shear box test

BS 1377: Part 7: 1990: Section 5 Determination of shear strength by direct shear (large shearbox apparatus).

@$320300 Residual shear box test

The residual shear box test may use either the standard or the large shear box.

Use +1 to record the Title straightaway; move to the relevant section; use +2 to record the Prompt; then move on to the variations, which are the same for both versions of the test.

G 320310 Standard shear box
G 320320 Large shear box

@$320310 Residual shear box test, standard box

BS 1377: Part 7: 1990: Section 4 Determination of shear strength by direct shear (small shearbox apparatus) with measurement of residual strength.

@$320320 Residual shear box test, large box

BS 1377: Part 7: 1990: Section 5 Determination of shear strength by direct shear (large shearbox apparatus) with measurement of residual strength.

Comment

See also Head, 1982, vol.2 pp.565 ff.

Variations

The following points must be specified:

1. Type of sample, undisturbed, remoulded, or compacted.

2. For undisturbed samples: orientation of sample relative to the plane of shear;
for remoulded samples: moisture content of samples, and method of remoulding;
for compacted samples: moisture content, either the dry density to be achieved or the compactive effort to be applied, and method of compaction.

3. Size of test specimen.

4. Number of specimens to be tested.

5. Normal pressures to be applied.

6. Rate of strain: for both shear boxes, the standard choices are:

The rate of displacement shall be set for a rapid test in accordance with Section 4.5.3.2 (a).

The rate of displacement shall be set for a slow test in accordance with Section 4.5.3.2 (b).

7. For both shear boxes:

The change in specimen thickness against cumulative horizontal displacement for each specimen shall be reported as indicated in Section 4.7 (k).

8. If measurement of residual strength is required, one of the following methods of reversal must be specified:

For the standard shear box, there are three possibilities. (a) machine drive reversal; (c) rapid multi-reversal by hand; (b) either machine or hand. (a) seems to assume that no excess pore pressures will develop within the failure plane; (b) allows such excess pore pressures to dissipate; (c) tends to prevent such dissipation.

[Section 4.5.5.5.

8.a. Machine drive reversal and re-shearing shall be used following Section 4.5.5.5 (a).
8.b. Either machine drive reversal and re-shearing or reversal by hand and re-shearing shall be used following Section 4.5.5.5 (a) or (b).
8.c. Any of the methods of reversal specified in Section 4.5.5.5 may be used.

For the large shear box, there are two possibilities, the second of which is rapid multi-reversal by machine.

[Section 5.5.5.2.

8.d. Machine drive reversal and re-shearing shall be used following Section 5.5.5.2 (a).
8.e. Either of the methods of reversal specified in Section 5.5.5.2 may be used.

9. Section 4.5.5.8 specifies that cycles of reversal must be continued until a repeatable residual value of the shear resistance has been obtained; some engineers may wish to specify either a maximum or minimum number of reversals, in which case the value of shear resistance (stress) obtained at the end of each cycle should be reported.

@$320400 In-situ Direct shear test
In-situ direct shear tests shall be conducted in general accordance with BS 5930: 1981: Clause 30 In situ shear tests as instructed by the Project Engineer.

Explanation
Read Clause 30 before letting a contract, and make sure that the scale of testing is fully understood on both sides. This implies that an extended specification will be written. The draft given here will almost certainly need elaboration.

This test is expensive in comparison with the other tests in this series, .

Variation
The shear box shall be ... mm square by ... mm high; the maximum vertical force shall be ... kN; the maximum horizontal force shall be ... kN; the maximum horizontal displacement shall be ... mm.

@$320500 Ring shear test
BS 1377: Part 7: 1990: Section 6 Determination of residual strength using the small ring shear apparatus.

Comment
The rate of displacement is specified in Section 6.4.5.1.

Variations
The following points must be specified:

1. Moisture content at which the soil is to be remoulded, and method of remoulding;
2. Number of specimens to be tested.
3. Pressures to be used for consolidation, see Section 6.4.2.1.
4. The procedure for forming the shear plane.
5. Number of stages at which specimens are to be sheared.
6. Normal pressures to be applied during shear stages.

@$330000 Static and dynamic probing tests
There are 12 tests for determination of the penetration resistance in-situ. Reference to Meigh, 1987, may be helpful when specifying these tests.

G 330100 Dynamic probing, hand driven, vertical
G 330200 Dynamic probing, hand driven, raking
G 330300 Dynamic probing, static recording, vertical
G 330400 Dynamic probing, static recording, raking
G 330500 Dynamic probing, mechanical recording, vertical
G 330600 Dynamic probing, mechanical recording, raking
G 330700 Static probing, hand driven, vertical
G 330800 Static probing, hand driven, raking
G 330900 Static probing, static recording, vertical
G 331000 Static probing, static recording, raking
G 331100 Static probing, mechanical recording, vertical
G 331200 Static probing, mechanical recording, raking

@$330100 DyHandVert
Dynamic probing by hand in vertical position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$330200 Dynamic penetration test, hand driven, raking
Dynamic probing by hand in raking position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$330300 DySticVert
Dynamic probing with static recording in vertical position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$330400 DySticRake
Dynamic probing with static recording in raking position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$330500 DyMechVert
Dynamic probing with mechanical recording in vertical position.

BS 1377: Part 9: 1990 gives two tests, SPT and DP, under this heading; but CPT is similar:

SPT for use in boreholes, mainly in sands
DP for use without boreholes, often in variable soils
CPT as DP, less robust, but more precise.

G 330510 SPT, Standard Penetration Test
G 330520 DP, Dynamic Probing
G 331100 CPT, Cone Penetration Test

@$330510 SPT, Standard Penetration Test
BS 1377: Part 9: 1990: Section 3.3 Determination of the penetration resistance using the split-barrel sampler (the standard penetration test SPT).

Comments
This test is a dis-continuous penetration test which also yields samples.
Section 3.3.3.1 allows both wash boring and shell and auger boring, but not jetting through an open tube sampler; but may often be preferable to obtain a virtually continuous series of split barrel samples.
Section 3.3.4.2 requires the number of blows per 75 mm penetration of both the seating and test drives to be recorded, but Section 3.3.5 makes their reporting optional.

This test is also described in BS 5930: 1981: Clause 21.2 Standard penetration test.

Variations
It may be necessary to specify whether either wash boring or shell and auger boring should or should not be used.

The number of blows per 75 mm penetration of both the seating and test drives shall be reported.

It may be necessary to specify whether casing or drilling mud should or should not be used to stabilise the hole.

On completion of the test, all holes shall be backfilled.

The method of backfilling may also need to be specified.

The number of tests, their location, and the depth of each must also be specified. This is often best done by reference to a schedule or drawing, unless these details are to be determined by an Engineer on site as the work proceeds.

@$330520 DP, Dynamic Probing
BS 1377: Part 9: 1990: Section 3.2 Determination of the dynamic probing resistance using the 90 deg. cone (dynamic probing DP)

Comments
This test is a semi-continuous rate of penetration test; but there are pauses to rotate the rods. In addition to the driving resistance, the torque required to rotate the rods is also measured.
Section 3.2.4.4 implies that the interval between rotation of the rods and measurement of the torque is normally one metre.
The normal interval of reading is 100 mm, Section 3.2.2.
Section 3.2.4.2 permits preboring.
Section 3.2.4.4 permits the use of casing, drilling mud, and water in the holes.

Variations
The test shall be conducted using the heavy version of the apparatus in accordance with column DPH of Table 1 of the Standard.

The test shall be conducted using the super heavy version of the apparatus in accordance with column DPSH of Table 1 of the Standard.

Use of a damper must be approved by the Project Engineer before testing commences.

Use of preboring must be approved by the Project Engineer before testing commences.

The maximum interval between rotation of the rods and measurement of the torque required for this rotation shall be one metre.

It may be necessary to specify whether casing, drilling mud, or water, should or should not be used to minimize rod friction.

On completion of the test, all holes shall be backfilled.

The method of backfilling may also need to be specified.

The number of tests, their location, and the depth of each must also be specified. This is often best done by reference to a schedule or drawing, unless these details are to be determined by an Engineer on site as the work proceeds.

@$330600 DyMechRake
Dynamic probing with mechanical recording in raking position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$330700 StHandVert
Static probing by hand in vertical position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$330800 StHandRake
Static probing by hand in raking position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$330900 StSticVert
Static probing with static recording in vertical position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$331000 StSticRake
Static probing with static recording in raking position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$331100 StMechVert
BS 1377: Part 9: 1990: Section 3.1 Determination of the penetration resistance using the fixed 60 deg cone and friction sleeve (static cone penetration test CPT).

Comments

This test is static probing with mechanical recording in vertical position. It is a continuous rate of penetration test. Pore pressure and sleeve friction may be measured optionally.

Section 3.1.1 permits the use of penetrometers where readings are taken at ground level through inner push rods.

Section 3.1.2.10 permits the thrust reaction to be provided by either screw anchors or ballast.

The normal rate of penetration is 20 mm/sec, Section 3.1.4.7.

The maximum interval between readings is 200 mm, Section 3.1.4.8.

Variations
A penetrometer tip with electrical sensors as defined in Section 3.1.2.4 shall be used.

A friction sleeve shall be used in accordance with the Standard.

A two-directional inclinometer shall be used in accordance with the Standard.

Piezometric sensors shall be used in accordance with the Standard.

Screw anchors shall be used in accordance with Section 3.1.2.10.

The thrust reaction shall be provided by ballast in accordance with Section 3.1.2.10.

On completion of the test, all holes shall be backfilled.

The method of backfilling may also need to be specified.

The number of tests, their location, and the depth of each must also be specified. This is often best done by reference to a schedule or drawing, unless these details are to be determined by an Engineer on site as the work proceeds.

@$331200 Static penetration test, mechanically driven, raking
Static probing with mechanical recording in raking position

This test is not in BS 1377: 1990, so the specification must be sought elsewhere and written to suit the work in hand.

@$340000 Miscellaneous strength tests
11 Number of tests

G 340100 CBR-Lab
G 340200 CBR-Situ
G 340300 CBR-Penetro
G 340400 PlBearShlow
G 340500 PlBearB/H
G 340600 Presrmeter
G 340700 Vane-Lab
G 340800 Vane-Situ
G 340900 HandPenetro
G 341000 UncnfStren
G 341100 UndrStren

@$ 3 40100 CBR-Lab
BS 1377: Part 4: 1990: Section 7 Determination of the California Bearing Ratio (CBR)

Variations:

Method of preparation

1. The test shall be performed on undisturbed samples.

2. The samples shall be prepared by Method (1), Static Compression with Tamping, in accordance with Section 7.2.3.2.

The load to be used must also be specified.

3. The samples shall be prepared by Method (2), Static Compression in Layers, in accordance with Section 7.2.3.3.

The load to be used must also be specified.

4. The samples shall be prepared by Method (3), Light Dynamic Compaction by Rammer to the Specified Density using the 2.5 kg rammer, in accordance with Section 7.2.4.2.

The density to be obtained must also be specified.

5. The samples shall be prepared by Method (3), Heavy Dynamic Compaction by Rammer to the Specified Density using the 4.5 kg rammer, in accordance with Section 7.2.4.2.

The density to be obtained must also be specified.

6. The samples shall be prepared by Method (4), Vibrating Compaction to the Specified Density, in accordance with Section 7.2.4.3.

(Comment: This method is suitable for granular soils.)

The density to be obtained must also be specified.

7. The samples shall be prepared by Method (5), Light Dynamic Compaction Using the 2.5 kg Rammer, in accordance with Sections 3.3 and 7.2.4.4.

The moisture content to be used must also be specified.

8. The samples shall be prepared by Method (5), Heavy Dynamic Compaction Using the 4.5 kg Rammer, in accordance with Sections 3.5 and 7.2.4.4.

The moisture content to be used must also be specified.

9. The samples shall be prepared by Method (5), Intermediate Dynamic Compaction by Rammer to the Specified Effort, in accordance with Section 7.2.4.4.

10. The Specified Effort shall be achieved by compacting the specimen in five equal layers, giving each layer 30 blows of a 4.5 kg rammer falling through 450 mm.

The moisture content to be used must also be specified.

11. The samples shall be prepared by Method (6), Vibrating Compaction with Specified Effort, in accordance with Section 7.2.4.5.

(Comment: This method is suitable for granular soils.)

The moisture content to be used must also be specified.

Density and moisture content to be achieved

1. The samples shall be tested at a moisture content of ... %.
2. The samples shall be tested at ... moisture contents equally spaced between ... and ... %.

3. The samples shall be tested at the Optimum Moisture Content determined by Test ......
4. The samples shall be tested at ... moisture contents equally spaced between values which are ... % below and ... % above the Optimum Moisture Content determined by Test ......
5. The samples shall be tested at a dry density of ... Mg/cubic metre.
6. The samples shall be tested at ... dry densities equally spaced between ... and ... Mg/cubic metre.
7. The samples shall be tested at the Maximum Dry Density determined by Test ......
8. The samples shall be tested at ... dry densities equally spaced between values which are ... Mg/cubic metre below and ... Mg/cubic metre above the Maximum Dry Density determined by Test ......

Whether the test is to be carried out on one end or on both ends of the specimen & Whether a test is required in the soaked condition

1. The test shall be carried out on the top of the specimen only without soaking.
2. The test shall be carried out on the top of the specimen only after soaking.
3. The test shall be carried out on both ends of the specimen without soaking.
4. The test shall be carried out on both ends of the specimen after soaking.
5. The test shall be carried out on the top of the specimen without soaking and on the bottom of the specimen after soaking.

The amount of surcharge to be applied to the specimen for the test and during soaking if applicable

Comment:
2 kg on 152 mm dia = 70 mm of superimposed construction.

Variations:
1. The surcharge during the penetration test shall be ... kg.
2. The surcharge during both soaking and the penetration test shall be ... kg.
3. The surcharge during soaking shall be ... kg, and the surcharge during the penetration test shall be ... kg.

@$340200 CBR-Situ
BS 1377: Part 9: 1990: Section 4.3 Determination of the in-situ California Bearing Ratio (CBR).

Comment:
Common surcharges appear to be 4.5, 9 or 18 kg on 250 mm dia.

Variations:
The surcharge during the penetration test shall be ... kg.

The number of tests, their location, and the depth of each must also be specified. This is often best done by reference to a schedule or drawing, unless these details are to be determined by an Engineer on site as the work proceeds.

Bulk density is often also requested.

@$340300 CBR-Penetro
A field estimate of California Bearing Ratio may be made using a special small pocket penetrometer calibrated in CBR.

G 340900 HandPenetro

@$340400 PlBearShlow
BS 1377: Part 9: 1990: Section 4.2 Determination of the settlement characteristics of soil for lightly loaded foundations by the shallow pad maintained load test.

Comment:
See Section 4.2.1 for when to use this test.

Variations:
The following points must be specified:

Length and breadth of the pad.

Depth at which the pad is to be founded.

Whether a cast in-situ or a prefabricated pad is to be used.

The maximum net bearing pressure to be applied to the ground during the loading test. This should be not less than 1.2 times the greater of the maximum net bearing pressure or the design net bearing pressure which will be applied to the foundation.

The number of equal increments into which the maximum net bearing pressure is to be divided; at least two increments should be used.

The duration for which the maximum net bearing pressure is to be maintained. With fill materials, a minimum period of 30 days is recommended, and 50 days is preferable; longer periods may be required for some soft natural soils.

@$340500 PlBearB/H
BS 1377: Part 9: 1990: Section 4.1 Determination of the vertical deformation and strength characteristics of soil by the plate loading test.

G 340510 Constant rate of penetration test
G 340520 Incremental loading test
G 340530 Further variations for both tests

Comment:
There are two versions of this test:

constant rate of penetration = undrained loading characteristics
incremental loading test = drained loading characteristics

Additional information will be found in BS 5930: 1981: Clause 21.6 Plate tests ff.

Some general variations follow here.

Variations:
The following points must be specified:

Whether the test is to be carried out at the ground surface, in pits, trenches or adits, or at depth in the bottom of a borehole.

Whether final preparation of the test level is to be done by hand (to remove smeared and disturbed material)

diameter of plate:
300 mm minimum
750 mm minimum for undrained deformation modulus [1]
5 times the average spacing between fissures
5 times the nominal size of the coarsest material present

Diameters up to 1000 mm have been used for heavy foundations and when men are required to descend the borehole to clean out the bottom.

[BS 5930: 1981: Clause 29.1.6.3.

If necessary, it may be necessary to specify whether ground-water lowering is necessary; or whether the borehole should be cased and sealed to exclude ground-water.

Temporary ground support may be required for excavation; but it may be better to make the contractor responsible for all aspects of safety rather than to specify one precaution in isolation.

@$340510 Constant rate of penetration test

The test shall be conducted in accordance with Section 4.1.6.4.1 Constant rate of penetration test.

The following additional points must be specified:

Rate of penetration.

BS 5930: 1981: Clause 29.1.6.3 mentions 2.5 mm/min; but this value is not necessarily always appropriate.

This test is continued until the penetration is equal to 15 % of the plate diameter, so there is no need to specify the maximum pressure to be applied.

G 340530 Further variations for both tests

@$340520 Incremental loading test

The test shall be conducted in accordance with Section 4.1.6.4.2 Incremental loading test.

The following additional points must be specified:

The maximum net bearing pressure to be applied to the ground during the loading test.

Section 4.1.6.4.2 is vague as to the maximum pressure which is to be applied during the test. Following Section 4.2.2.2, which strictly does not apply here, the following is suggested. If possible, the maximum net bearing pressure to be applied to the ground during the loading test should be not less than 1.2 times the greater of the maximum net bearing pressure or the design net bearing pressure which will be applied to the foundation.

The number of equal increments into which the maximum net bearing pressure is to be divided.

The effect of Section 4.1.6.4.2 appears to be as follows. If the maximum pressure to be applied during the test is less than or equal to the design bearing pressure, the load during the test should be applied in five more-or-less equal cumulative increments. If a greater pressure is to be applied during the test, then the number of increments should be increased proportionately.

G 340530 Further variations for both tests

@$340530 Further variations for both tests

Intermediate cycles of unloading and reloading.

These should be specified if an indication of the relative amounts of reversible (elastic) and irreversible deformation are required.

Parameters to be determined

Reaction loading system
tension piles (normally with their centres at three times the plate diameter from the centre of the plate).
kentledge
against an existing structure

Temperature measurements, e.g. if the level of the deformation measuring system may be affected.

Comment:
Classification tests including moisture content, Atterberg Limits, and particle density, are specified automatically in Section 4.1.6.7.

Variation:
Dry density is often also required

@$340600 Presrmeter
BS 5930: 1981: Clause 21.7 Pressuremeter tests.

BS 5930: 1981: Clause 21.7 lists several types of pressuremeter:

Menard soil and weak rock, the most common type
Baguelin soil; self-boring (LPC)
Windle soil; self-boring (Camkometer)
McKinlay glacial till and weak weathered rocks
Rocha stronger rocks
Goodman even stronger rocks

Further details will be found in Mair & Muir Wood, 1987.

You must supply your own specification.

@$340700 Vane-Lab
BS 1377: Part 7: 1990: Section 3 Determination of shear strength by the laboratory vane method.

shear strength and sensitivity of soft to firm cohesive soil

@$340800 Vane-Situ
BS 1377: Part 9: 1990: Section 4.4 Determination of the in-situ vane shear strength of weak intact cohesive soils.

Comments
The test is normally restricted to fairly uniform cohesive fully-saturated soils, and is used mainly for clay up to 100 kN/sq m undrained shear strength.

Additional information will be found in BS 5930: 1981: Clause 21.3 Vane test.

Variations
1. Direct penetration from the surface using a vane protecting shoe shall be used in accordance with Section 4.4.4.2.
2. Tests shall be conducted at the bottom of a borehole in accordance with Section 4.4.4.1.

@$340900 HandPenetro
The Vicksburg penetrometer measures cone penetration resistance down to about 3 metres but is usually restricted to 1 metre depth. There are correlations with CBR and with trafficability of the soil.

G 340202 CBR-Situ
G 340300 CBR-Penetro

@$341000 UncnfStren
There are two versions of this test:

load frame method definitive method
autographic method intended for use on site

The Standard test estimates the undrained strength of the soil. It can only be used for cohesive soil, which should be saturated and non-fissured.

It might also be used for the total strength of unsaturated soil, but this is not included in the Standard.

G 341010 Load frame method
G 341020 Autographic method

@$341010 Load frame method
BS 1377: Part 7: 1990: Section 7.2 Determination of the unconfined compressive strength: Load frame method

G 341030 Variations

@$341020 Autographic method
BS 1377: Part 7: 1990: Section 7.3 Determination of the unconfined compressive strength: Autographic method

G 341030 Variations

@$341030 Variations
The following points must be specified:

1. The test shall be conducted on undisturbed samples.
2. Moisture content at which the soil is to be remoulded, and method of remoulding;

@$341100 UndrStren
A test for 'undrained strength' is included separately in the score base; but it now seems that undrained strength has already been covered by several of the other strength tests.

@END OF TEST33.DAT. BS 1377: 1990.

@START OF F7THELP4, X.X., ...July 23, 1993 3:37 AM

@$ 400000Consolidation tests
1 Number of sub-groups in this group
4 Number of tests

G 410100 Standard oedometer test
G 410200 Rowe cell
G 410300 Triaxial consolidation test
G 410400 Anisotropic consolidation test

@$410100 Standard oedometer test
BS 1377: 1990: Part 5: Section 3 Determination of the one-dimensional consolidation properties.

Comments:
The test is used for the primary consolidation phase of cohesive soils. It can also be used for the secondary consolidation phase. Values of the coefficient of consolidation obtained from this test should be treated with caution. For silts and sands, Ko-consolidation in a triaxial cell is preferable.

Variations:
1. The sequence of loading and unloading must be specified. The usual procedure is:

loading by doubling the applied pressure at each stage;
unloading using at least half the number of loading stages.

A second load-unload cycle, possibly to a higher pressure, may be specified.

Further suggestions are given in the Standard.

2. If the secondary consolidation characteristics are required, these must be specified explicitly. It may be advisable to specify the length of time for which observations of secondary consolidation are to be continued; Section 3.6.5.2 requires the linear portion of the secondary compression curve to be continued to cover one complete cycle of log time, but it seems to imply that some extrapolation would be permissible.

@$410200 Rowe cell
BS 1377: 1990: Part 6: Section 3 Determination of consolidation properties using a hydraulic cell.

Variations:
There are an unusually large number of variations for this test.

Permeability
If Test 060304, Determination of permeability in a hydraulic consolidation cell, has also been requested, the two tests should be made together, and the necessary additions to the specification should be added here.

Permeability measurements shall be made in accordance with BS 1377: Part 6: 1990: Section 4 Determination of permeability in a hydraulic consolidation cell.

Direction of flow of water
If Test 060304 has also been requested, it will be necessary to specify the direction of flow of water to be used when measuring permeability. The possibilities are:

downward flow
radial inward flow
radial outward flow

These are covered in turn below.

downward flow
The permeability measurements shall be made using downward flow of water in accordance with Section 4.8.

radial inward flow
The permeability measurements shall be made using radial inward flow of water in accordance with Section 4.8.

radial outward flow
The permeability measurements shall be made using radial outward flow of water in accordance with Section 4.8.

Size of test specimen
The maximum permitted size of particle is one-sixth of the specimen height, Sections 3.3.1.2 and 3.3.4.2. Section 3.3.1.1 gives the height/diameter ratio as between 1/2.5 and 1/4. Following Head, 1986, vol.3 p.1133, the dimensions of the usual apparatus are:

cell diameter, mm	75	151	252
recommended specimen height, mm	30	50	90
maximum permitted particle, mm	5	8	15

The scale of the soil fabric must also be considered when specifying the specimen size.

Type of sample
1. Undisturbed samples shall be prepared from sample tubes in accordance with Section 3.3.2.

2. Undisturbed specimens shall be prepared from block samples in accordance with Section 3.3.3.

3. Undisturbed specimens shall be prepared from a suitably trimmed exposure on site in accordance with Section 3.3.3.

4. Specimens shall be compacted into the cell in accordance with Section 3.3.5.

The following must also be specified:

Moisture content
Number of layers
Compactive effort

5. Specimens shall be compacted into the cell in accordance with Section 3.3.6.

The following must also be specified:

Moisture content
Number of layers
Dry Density to be achieved

6. Specimens shall be compacted into the cell in accordance with Section 3.3.7.

The following must also be specified:

Moisture content
Number of layers
Dry Density to be achieved

7. The Moisture Content at which the specimens are compacted shall be ... %.

8. The number of layers used for compaction shall be .... .

9. The compactive effort used shall be equivalent to that specified in BS 1377: 1990: Part 4: Section 3.3 Method using 2.5 kg rammer for soils with particles up to medium-gravel size.

10. The compactive effort used shall be equivalent to that specified in BS 1377: 1990: Part 4: Section 3.5 Method using 4.5 kg rammer for soils with particles up to medium-gravel size.

11. The Dry Density to which the specimens are compacted shall be ... Mg/cubic metre.

Loading conditions

Section 3.1.2 defines two methods of loading the top of the specimen, each of which can be used with four drainage conditions. Fig. 1 of the Standard is helpful in understanding these. The two methods of loading the top of the specimen are:

free strain (flexible loading) version: applies a uniform stress to the top of the sample;

equal strain (rigid loading) version: ensures that the top of the sample remains plane.

If Test 630400 has been requested, equal strain must be chosen.

It will be necessary to specify which version to use:

free strain;
equal strain.

The 'free strain' version of the test shall be used.

The 'equal strain' version of the test shall be used.

Drainage conditions

It will be necessary to specify the type of drainage to be used. If Test 060304 has been requested, either two-way vertical drainage or drainage for radial permeability must be chosen.

one-way vertical drainage
two-way vertical drainage
drainage radially outwards
drainage radially inwards
drainage for radial permeability with inward flow
drainage for radial permeability with outward flow

one-way vertical drainage:
The procedure for consolidation with one-way vertical drainage shall be used in accordance with Section 3.5.

two-way vertical drainage:
The procedure for consolidation with two-way vertical drainage shall be used in accordance with Section 3.6.

drainage radially outwards:
The procedure for consolidation with drainage radially outwards shall be used in accordance with Section 3.7.

drainage radially inwards:
The procedure for consolidation with drainage radially inwards shall be used in accordance with Section 3.8.

drainage for radial permeability with inward flow:
The procedure for consolidation with drainage radially inwards shall be used in accordance with Section 3.8 after installing a peripheral drain in accordance with Section 4.7.3.

outward drainage for radial permeability with outward flow:
The procedure for consolidation with drainage radially outwards shall be used in accordance with Section 3.7 after installing a central drain in accordance with Section 4.7.3.

Pressure measuring point
Section 3.1.3 states that the location of the pore pressure measurement point (when required) should be specified before starting a test; but the body of the Standard seems to give explicit instructions for this. A safe course might be to specify this point as follows:

The location of the pore pressure measurement point shall be approved by the Project Engineer before testing commences.

Sequence of effective pressure increments and decrements
The pressure increments to be applied during all the stages of the tests must be specified.

The first stage is to apply back pressure to achieve full saturation whilst applying confining pressure to prevent swelling. Section 3.5.2 may be helpful when specifying the pressure increments to be applied.

The second stage is undrained loading. Section 3.5.3 may be helpful when specifying the pressure increments to be applied.

The third stage is consolidation. Section 3.5.4 may be helpful when specifying the pressure increments to be applied; but the corresponding sections in the relevant test specifications contain additional remarks and should also be consulted.

The fourth stage is unloading. Section 3.5.5 may be helpful when specifying the pressure increments to be used.

The fifth and final stage is dismantling, for which pressure increments are irrelevant.

Terminating of primary consolidation and swelling

The specimen is usually considered to be saturated when the value of du/ds >= 0.95, where s = pressure; an alternative criterion may be necessary, see Section 3.5.2.3.11, also Section 3.8.2 if relevant.

Swelling is usually considered to be complete when there is no further change in confining pressure. However, the time for this may be excessive; or, in soils such as laminated clays, other problems may arise. An alternative criterion may be necessary, see Sections 3.5.2.2 and 3.3.1.2.

Sections 3.5.4.5 and 3.6.4 seem to suggest that the end of primary consolidation can be specified in terms of pore pressure dissipation; but Sections 3.7.4 and 3.8.4 seem to favour the use of settlement curves, especially for laminated clays. Regardless of which version of the test is to be performed, all four Sections should be consulted before finalising the criterion to be used.

Secondary compression

If the secondary consolidation characteristics are to be obtained during the third stage, these must be specified explicitly. There is a cross reference to BS 1377: 1990: Part 5: Section 3.6.5, which should be consulted. In any case, it may be advisable to specify the length of time for which observations of secondary consolidation are to be continued; BS 1377: 1990: Part 5: Section 3.6.5.2 requires the linear portion of the secondary compression curve to be continued to cover one complete cycle of log time, but it seems to imply that some extrapolation would be permissible.

Void ratio

The void ratio shall be plotted against log p' in accordance with Section 3.5.7.3.

It may be better not to specify the Section here, otherwise the treatment of the coefficient of consolidation may be inconsistent.

Coefficient of consolidation

The coefficient of consolidation shall be plotted against log p' in accordance with Section 3.5.7.3.

The method of calculation of the coefficient of consolidation varies from case to case, so perhaps either no Section should be specified here or the appropriate Sections should be specified if the method of calculation is itself to be specified.

It may be desirable to specify the method of calculation which is to be used to obtain the coefficient of consolidation. The Standard gives four methods with variations for each version of the test. The first method indicated cannot be used for two-way vertical drainage. The fourth method can be used only for radial outward drainage with free strain loading.

The coefficient of consolidation shall be calculated by the appropriate version of the pore pressure dissipation method.

The coefficient of consolidation shall be calculated by the appropriate version of the method of log time curve fitting.

The coefficient of consolidation shall be calculated by the appropriate version of the method of square-root time curve fitting.

The coefficient of consolidation shall be calculated by the appropriate version of the method for free strain loading (special power curve fitting).

Soil fabric
Colour photographs shall be obtained to define the soil fabric in accordance with Section 3.5.6.5.

Additional graphs
A graph of permeability against log p' shall be plotted.

A graph of permeability against void ratio shall be plotted.

@$410300 Triaxial consolidation test
BS 1377: 1990: Part 6: Section 5 Determination of the isotropic consolidation properties using a triaxial cell.

Variations:
This test has a large number of variations.

Permeability

If Test 060303, Determination of permeability in triaxial cell, has also been requested, the two tests should be made together, and the necessary additions to the specification should be added here.

Permeability measurements shall be made in accordance with BS 1377: Part 6: 1990: Section 6 Determination of permeability in a triaxial cell.

Size of test specimen
The size of test specimen must be specified; the usual size is 100 mm dia x 100 mm high; samples from 38 mm dia upwards may be used (Section 5.1.1).

Type of test specimen
If Test 060303 has also been requested, it will be necessary to specify whether undisturbed or remoulded samples are to be used, and if remoulded the method of remoulding.

Method of saturation
There are two procedures for saturation:

Saturation by increments of cell pressure is the faster method.

Saturation at constant moisture content is necessary when swelling of the specimen would significantly affect measured pore pressure changes.

Further advice about saturation will be found in Section 5.4.1.

Saturation shall be achieved by increments of cell pressure and back pressure in accordance with Section 5.4.3.

It may be necessary to specify that the volume of water taken in shall be calculated.

The volume of water taken in by the specimen during saturation shall be calculated in accordance with Section 5.4.3.8.

Saturation shall be achieved at constant moisture content in accordance with Section 5.4.4.
swelling

Section 5.6.2.1 requires B to be plotted against either cell pressure or pore pressure if saturation was achieved by the application of increments of back pressure, i.e. by the method of Section 5.4.3; Section 5.4.3.13 also suggests that B may be plotted against pore pressure response to cell pressure changes. Similar plots are possible but are not suggested by the Standard if saturation was achieved at constant moisture content, i.e. by the method of Section 5.4.4. In any case, it seems necessary to specify what is wanted.

Values of the pore pressure coefficient, B, shall be plotted against cell pressure.

Values of the pore pressure coefficient, B, shall be plotted against pore pressure, u.

Values of the pore pressure coefficient, B, shall be plotted against pore pressure response to cell pressure, du.

<u>Drainage conditions</u>
It will be necessary to specify the method of drainage. This is normally from the top of the specimen with pore pressure measurement at the bottom (Section 5.1.2).

<u>Direction of flow of water</u>
If Test 630300 has also been requested, it will be necessary to specify the direction of flow of water to be used when measuring permeability. Downward flow appears to be the more usual, because Section 6.8 gives directions for this version only.

The permeability measurements shall be made using downward flow of water in accordance with Section 6.8.

The permeability measurements shall be made using upward flow of water in accordance with a suitably modified version of Section 6.8.

<u>Sequence of effective pressure increments and decrements</u>
The sequence of loading must be specified. The usual procedure is loading by doubling the applied effective pressure at each stage; and a minimum of three stages is normally specified, (Section 5.5.1). Fewer stages may be appropriate if only permeability is required.

If the swelling characteristics are to be obtained, these must be specified.

Swelling characteristics shall be obtained in accordance with Section 5.5.2.9.

The sequence of unloading must be specified. There seems to be no established procedure, but unloading using at least half the number of loading stages would be in line with the normal practice in oedometer testing, see BS 1377: 1990: Part 5: Section 3.

The back pressure during consolidation must also be specified, because Section 5.5.1 only gives the normal procedure:

During both triaxial consolidation and unloading, the back pressure shall not be reduced below the level of pore pressure in the final step of the saturation stage, or 300 kPa, whichever is the greater.

During triaxial consolidation, the back pressure shall not be reduced below the level of pore pressure in the final step of the saturation stage, or 300 kPa, whichever is the greater.

Termination of primary consolidation and swelling
It will be necessary to specify criteria for saturation, for the end of primary consolidation, and if required for the end of swelling.

The specimen is usually considered to be saturated when the value of B = du/ds >= 0.95, where s = pressure; an alternative criterion may be necessary, see Section 5.4.1.

Primary consolidation is usually taken to be complete when 95 %
of the excess pore pressure has dissipated, see Section 5.5.2.6.

Secondary compression

Section 5.1.3 states that if the secondary consolidation characteristics are to be obtained during the third stage, these must be specified explicitly; but makes no further reference to secondary consolidation. BS 1377: 1990: Part 5: Section 3.6.5, should be consulted. In any case, it may be advisable to specify the length of time for which observations of secondary consolidation are to be continued; BS 1377: 1990: Part 5: Section 3.6.5.2 requires the linear portion of the secondary compression curve to be continued to cover one complete cycle of log time, but it seems to imply that some extrapolation would be permissible.

Void ratio
Values of void ratio shall be calculated and a graph of voids ratio against log p' shall be plotted in accordance with Section 5.6.

Additional graphs
A graph of permeability against log p' shall be plotted.

A graph of permeability against void ratio shall be plotted.

@$410400 Anisotropic consolidation test
This refers to non-standard tests in triaxial apparatus. The specification should be written to suit the job in hand.

@END OF F7THELP4. BS 1377: 1990.

@START OF F7THELP5, X.X., ... July 23, 1993 3:45 AM

@$500000 Ground water levels
1 Number of sub-groups in this group
4 Number of tests

After specifying which test to use, it will be necessary to specify both the details of installation and the frequency and duration of readings.

G 510100 Borehole
G 510200 Stand pipe Simple stand pipe
G 510300 PiezStdPi Standpipe piezometer
G 510400 PiezPneum Pneumatic piezometer, etc.

@$510100 Borehole
This test is not in BS 1377: 1990, so the specification must be written to suit the work in hand.

G 512000 Installation

Comment
Although all inflows of water into either boreholes or excavations should be recorded, interpretation of the results is often difficult, see BS 5930: 1981: Clause 20.2.2 Observations in boreholes and excavation.

@$510200 Stand pipe
Ground water levels shall be measured in general accordance with BS 5930: 1981: Clause 20 Ground water, using a stand pipe in general accordance with BS 5930: 1981: Clause 20.2.3 Standpipe piezometers except that a simple perforated tube may be used.

The arrangement of the perforations shall be in accordance with
Drawing ....

The drawing should specify: the inner diameter of the stand pipe; the diameter of the perforations; the length of tube which is to be perforated; the arrangement of the holes within this length, e.g. angular spacing, lateral spacing, and whether staggered longitudinally.

G 512000 Installation

@$510300 PiezStdPi
Ground water levels shall be measured in general accordance with BS 5930: 1981: Clause 20 Ground water, using standpipe piezometer in general accordance with BS 5930: 1981: Clause 20.2.3 Standpipe piezometers.

It may be necessary to specify the type of piezometer to be used.

G 512000 Installation

@$510400 PiezPneum
Ground water levels shall be measured in general accordance with BS 5930: 1981: Clause 20 Ground water.

G 510410 Hydraulic piezometer
G 510420 Electrical piezometer
G 510430 Pneumatic piezometer

Comment
The present scorebase does not recognise hydraulic and electrical piezometers, so they are included together here temporarily.

@$510410 Hydraulic piezometer
An hydraulic piezometer in general accordance with BS 5930: 1981: Clause 20.2.4 Hydraulic piezometers shall be used.

G 512000 Installation

@$510420 Electrical piezometer
An electrical piezometer in general accordance with BS 5930: 1981: Clause 20.2.5 Electric piezometers shall be used.

G 512000 Installation

@$510430 Pneumatic piezometer
A pneumatic piezometer in general accordance with BS 5930: 1981: Clause 20.2.6 Pneumatic piezometers shall be used.

G 512000 Installation

@$512000 Installation
It will be necessary to specify where the 'boreholes' are to be located and the depth at which measurements are to be made.

It may be necessary to prevent the use of driven piezometers by specifying that the piezometers should be installed in boreholes.

It may be necessary to specify that either the sides or the bottom of the borehole should be cleaned to remove smeared material of low permeability.

It may be necessary to specify an external filter to prevent fine particles entering through the perforations.

It may be necessary to specify the use of gravel outside the piezometer tip to provide a permeable path into the piezometer.

It may be necessary to specify that the borehole should be sealed either above or below the strata in which the ground water level is to be measured.

G 513000 Readings

@$513000 Readings
It will be necessary to specify how frequently measurements are to be made and for how long the series of measurements is to be continued.

@END OF F7THELP5. BS 1377: 1990.

@START OF F7THELP6, X.X., ...July 23, 1993 3:46 AM

@$600000 Permeability tests
3 Number of sub-groups in this group

G 610000 Indirect estimation of permeability
G 620000 Field tests
G 060300 Laboratory tests

@$610000 Indirect estimation of permeability
2 Number of tests
Hazen's method is for granular soils; Miles' for cohesive.

G 610100 Hazen's estimate from texture
G 610200 Miles' estimate from structure

@$610100 Hazen's estimate from texture
Permeability shall be estimated from texture using Hazen's method and Casagrande's correction in accordance with Terzaghi and Peck, 1967, pp.50-51.

@$610200 Miles' estimate from structure
Hydraulic conductivity of unsaturated near-surface soil may sometimes be estimated from the soil structure, see Notes from Lincold Drainage School*, and take expert advice.

[* held by Dr.Smart.

@$620000 Field tests
After specifying which test to use, it will be necessary to specify the details of installation.
6 Number of tests

G 620100 Betw-2B/Hs
G 620200 C/Head-Out
G 620300 C/Head-In
G 620400 V/rising
G 620500 V/falling
G 620600 Packer-Test
G 620900 Installation

@$620100 Betw-2B/Hs
Field permeability test between two boreholes, following the general procedure of BS 5930: 1981: Clause 21.4.4.

G 620900 Installation

Comment:
BS 5930: 1981 gives only scant details, and a fuller specification would be advisable.

@$620200 C/Head-Out
Permeability shall be determined by a constant head outflow procedure in accordance with BS 5930: 1981: Clause 21.4.4 Permeability: Constant head test, following the general procedure of Clause 21.4.

G 620900 Installation

Comment:
Constant head tests are normally conducted as inflow tests.

@$620300 C/Head-In
Permeability shall be determined by the constant head inflow procedure in accordance with BS 5930: 1981: Clause 21.4.4 Permeability: Constant head test, following the general procedure of Clause 21.4.

G 620900 Installation

Comment:
It may be necessary to specify whether or not Gibson's variant is to be used.

Variations:
Gibson's method may not be used without the prior consent of the Project Engineer.

If necessary, Gibson's method may be used.

@$620400 V/rising
Permeability shall be determined by the rising head procedure in accordance with BS 5930: 1981: Clause 21.4.3 Permeability: Variable head test, following the general procedure of Clause 21.4.

G 620900 Installation

@$620500 V/falling
Permeability shall be determined by the falling head procedure in accordance with BS 5930: 1981: Clause 21.4.3 Permeability: Variable head test, following the general procedure of Clause 21.4.

G 620900 Installation

@$620600 Packer-Test
BS 5930: 1981: Clause 21.5 Tests in boreholes: Permeability: Packer test, following the general procedure of Clause 21.4.

G 620900 Installation

Comment:
It may be necessary to specify the diameter of the borehole. Clause 21.5.1 states that 76 mm is usual for the 'Lugeon' test, but adds that the test is not very sensitive to the diameter of the borehole unless the length of borehole under test is small. In all cases, the diameter used must be known.

Variations:

The diameter of the borehole shall be 76 mm (N size).

The diameter of the borehole shall be ... mm.

The diameter of the borehole shall be reported.

Comment:
Single packer tests are more expensive but are generally thought to be more reliable because: only one packer has to be made good against leakage; leakage past the packer can be monitored; and possible deterioration of the borehole with time is avoided.

Variations:
Single packer tests shall be used after advancing the borehole successively to the specified depths.

Double packer tests shall be used after the borehole has been completed.

Comment:
CIRIA 25: 1983: Section 3.3.3 suggests 50 % overlap. Testing at wide intervals determined a priori is generally not to be recommended.

Variations:
The depths at which tests are to be conducted shall be such as to give a 50 % overlap between successive test lengths.

The depths at which tests are to be conducted shall be determined on site using television inspection in conjunction with the borehole logs.

The depths at which tests are to be conducted shall be determined on site from the borehole logs.

The depths at which tests are to be conducted shall be in accordance with the schedule provided.

Comment:
It will probably be necessary to specify the maximum injection pressure to be used. A rule of thumb quoted in BS 5930 gives 12-17 kPa per meter; but these figures may not be appropriate. CIRIA 25: 1983: Section 3.3.3 suggests that the maximum packer pressure should be 75 % of the 'estimated effective stress'; but the packer pressure must also be considered.

Variations:
The packer pressure shall be as high as practicable without causing heaving of the ground or fracturing of the soil or rock up to 17 kPa per metre depth below ground level.

The maximum injection pressure shall be as high as practicable without causing leakage past the packers.

The maximum injection pressure shall be ... kPa.

Comment:
BS 5930 suggests five tests at 33, 67, 100, 67, 33 % maximum pressure; but effective use of CIRIA 25: 1983: Fig 38 to check whether symptoms of trouble are present may require seven or more tests to be made.

Variations:
At each depth, a series of tests shall be made in accordance with Clause 21.5.5 Execution of test.

The number of tests in each series shall be 7 at 25, 50, 75, 100, 75, 50, 25 % maximum injection pressure, respectively.

For each series of tests, a plot of injection pressure vs. flow shall be drawn and compared with CIRIA 25: 1983: Fig 38 to check whether symptoms of trouble are present.

Comment:
It will probably be wise to specify that leakage shall be monitored.

Variation:
Leakage past the upper packer shall be monitored by a dip well arrangement.

@$620900 Installation
The explanations which follow will cover a series of points concerning installation. Please use +6 to enter your own specification immediately after any which are relevant to the proposed work.

It will be necessary to specify where the 'boreholes' are to be located and the depth at which measurements are to be made.

It may be necessary to prevent the use of driven piezometers by specifying that the piezometers should be installed in boreholes.

It may be necessary to specify that either the sides or the bottom of the borehole should be cleaned to remove smeared material of low permeability.

It may be necessary to specify an external filter to prevent fine particles entering through the perforations.

It may be necessary to specify the use of gravel outside the piezometer tip to provide a permeable path into the piezometer.

It may be necessary to specify that the borehole should be sealed either above or below the strata in which the ground water level is to be measured.

@$630000 Laboratory tests
4 Number of tests

The usual choices are:

Constant head test	k = 10**-5 to 10**-2 m/s [1]
Variable head test	k < 10**-4 m/s [2]
In triaxial apparatus	low-medium permeability [3]
In Rowe cell	low permeability, non-uniform soil [4]

[1] BS 1377: Part 5: 1990: Section 5.1.2. [2] Head, 1982, vol.2 p.449. [3] BS 1377: Part 6: 1990: Section 6.1.1. [4] BS 1377: Part 6: 1990: Section 3.1.1, Head, 1986, vol.3 p.1129.

G 630100 Constant head test
G 630200 Variable head test
G 630300 In triaxial apparatus
G 630400 In Rowe cell

@$630100 Constant head test
BS 1377: Part 5: 1990: Section 5 Determination of permeability by the constant head method.

Comment:
The internal diameter of the cell must be specified. The usual sizes are 75 mm and 100 mm dia. Section 5.2.1 states that this diameter should be 12 times the maximum particle size.

Comment:
Tests are normally made on disturbed specimens. The method of placing the material into the cell must be specified:

hand tamping;
placing under water to achieve the minimum density possible;
placing under water with hand tamping to achieve the specified densities;
placing under water with vibration to achieve the specified densities.

Hand tamping
Specimens shall be compacted into the cell using hand tamping in accordance with Section 5.4.2.

The following must also be specified:

moisture content;
number of layers;
compactive effort.

Placing under water to achieve the minimum density
Specimens shall be compacted into the cell by placing under water to achieve the minimum density possible in accordance with Section 5.4.2.

Placing under water with hand tamping
Specimens shall be compacted into the cell by placing under water with tamping to achieve the specified density in accordance with Section 5.4.2.

The following must also be specified:

number of specimens to be tested;
The densities at which these specimens are to be tested;

Placing under water with vibration
Specimens shall be compacted into the cell by placing under water with vibration to achieve the specified density in accordance with Section 5.4.2.

The following must also be specified:

number of specimens to be tested;
the densities at which these specimens are to be tested.

Comment:
The direction of flow of the water must be specified:

downward flow, this is the usual choice;
upward flow;
upward flow with the top surface of the sample unrestrained
to investigate piping effects.

downward flow
The permeability measurements shall be made using downward flow of water in accordance with Section 5.5.

upward flow
The permeability measurements shall be made using upward flow of water in general accordance with Section 5.5.

upward flow to investigate piping effects
The permeability measurements shall be made whose upper surface is unrestrained using upward flow of water in general accordance with Section 5.5 in order to investigate piping effects.

@$630200 Variable head test
Permeability shall be determined by the falling head procedure in accordance with Head, 1982, Section 10.7 vol.2 pp.449 ff.

Variations:
If an alternative size of cell body is proposed, its use must be approved by the Project Engineer before testing begins.

1. Undisturbed specimens shall be prepared from a suitably trimmed exposure on site using the core cutter type of cell body in accordance with Sub-section (4) on p.453.

2. Undisturbed specimens shall be prepared from block samples using the core cutter type of cell body in accordance with Sub-section (4) on p.453.

3. Undisturbed specimens shall be prepared from piston sampler tubes using the core cutter type of cell body in accordance with Sub-section (4) on p.453.

4. Undisturbed specimens shall be prepared from conventional sample tubes using the core cutter type of cell body in accordance with Sub-section (4) on p.453.

5. Undisturbed specimens shall be tested in U-100 sample tubes in accordance with Section 10.7.3 on pp.455.ff.

6. Specimens shall be tested in oedometer cells in accordance with Section 10.7.4 on pp.456.ff.

In this case, full details of what is intended to be done must be specified.

7. Specimens shall be tested in compaction moulds in accordance with Section 10.7.5 on pp.457.ff.

In this case, full details of what is intended to be done must be specified.

@$630300 In triaxial apparatus
BS 1377: Part 6: 1990: Section 6 Determination of permeability in a triaxial cell.

If permeability is to be measured in this way, it must be done as part of Test 410300 Triaxial consolidation test.

@$630400 In Rowe cell
BS 1377: Part 6: 1990: Section 4 Determination of permeability in a hydraulic consolidation cell.

If permeability is to be measured in this way, it must be done as part of Test 040102 Determination of consolidation properties using a hydraulic cell.

@END OF F7THELP6. BS 1377: 1990.

@START OF F7THELP7, X.X., ...July 23, 1993 3:48 AM

@$ 700000 Chemical tests
1 Number of sub-groups in this group
8 Number of tests

G 710100 Soil sulphate
G 710200 Water-Sulfa
G 710300 Stand-Carbn
G 710400 Simpl-Carbn
G 710500 pH Value
G 710600 Chloride Content
G 710700 Field Resistivity
G 710800 Field redox potential

Comment:
Two replicates is regarded as the minimum; in some cases, more replicates may be required.

@$710100 Soil sulphate
The sulphate content of the soil shall be determined by BS 1377: Part 3: 1990: Section 5 Determination of the sulphate content of soil and ground water.

At least two specimens shall be tested.

It may be necessary to specify one or more of the following:

The acid-soluble sulphate content of the soil shall be determined.

The water-soluble sulphate content of the soil shall be determined.

The total sulphur content of the soil shall be measured by the method given in BS 1047.

@$710200 Water-Sulfa
The dissolved sulphates in the ground water shall be determined by BS 1377: Part 3: 1990: Section 5 Determination of the sulphate content of soil and ground water.

At least two specimens shall be tested.

@$710300 Stand-Carbn
The carbonate content of the soil shall be determined by the method of BS 1881: Part 124.

Comment:
This may be taken as the standard method. The simplified method is suitable if the carbonates exceed 10 % (m/m) and an accuracy of about 1 % is sufficient, c.f. next test.

Variation:
At least two specimens shall be tested.

@$710400 Simpl-Carbn
BS 1377: Part 3: 1990: Section 6 Determination of the carbonate content.

Comment:
There are two versions of this test.

The rapid titration method is the simpler and suitable if the carbonates exceed 10 % (m/m) and an accuracy of about 1 % is sufficient.

Section 6.1 implies that the gravimetric method is preferable.

Variations:
At least two specimens shall be tested.

The rapid titration method of Section 6.3 may be used.

The gravimetric method of Section 6.4 shall be used.

@$710500 pH Value
BS 1377: Part 3: 1990: Section 9 Determination of the pH value.

Comment:
This method uses a calomel electrode to measure the pH of a suspension of the soil material in water.

The method may also be used for the pH of the ground water.

Variation:
At least two specimens shall be tested.

@$710600 Chloride Content
BS 1377: Part 3: 1990: Section 7 Determination of the chloride content.

Variation:
At least two specimens shall be tested.

Comment
The test is intended for the chloride content of soil, and there are two main versions of it. The water-soluble method may be used if the chlorides have been introduced in sea water; but the acid-soluble method is more robust.

There is also a quick test, see Section 7.2.3.3, which might be sufficient for some purposes.

The test can also be used for the chloride content of ground water, but the method of BRE CP 2/79 [1] is preferable.

[1] Current Paper CP 2/79; Building Research Establishment, Garston, Watford, Herts.

Variations:
It may be necessary to specify one or more of the following:

The acid-soluble chloride content of the soil shall be determined.

The water-soluble chloride content of the soil shall be determined.

Only the qualitative check for chlorides indicated in Section 7.2.3.3 is required.

The chloride content of the ground water shall be determined.

The chloride content of the ground water shall be determined using Mohr's method in general accordance with BRE Current Paper CP 2/79, see Section 7.1.1.

@$710700 Field Resistivity
BS 1377: Part 9: 1990: Section 5.1 Determination in-situ of the apparent resistivity of soil.

Variation:
The number, location and depth of the tests to be made must be specified.

Comment:
The test is intended to warn about potential problems of corrosion of pipelines, etc. The depth of the test should be the same as the depth of the proposed pipeline.

Note that this is an a.c. test; there is a d.c. test used by geologists for a different purpose.

The results will be distorted by buried pipelines, ferruginous soil, boulders, concrete, etc.

BS 1377: Part 3: 1990: includes three laboratory tests for resistivity, which are not included in the current version of the score base. These tests can be applied to compacted soils, etc.; however, Section 10.1.3 states that they should be interpreted by a specialist, and they are therefore treated as special studies here.

Laboratory Resistivity
BS 1377: Part 3: 1990: Section 10.2 Measurement of resisivity: disc electrodes method.

BS 1377: Part 3: 1990: Section 10.3 Measurement of resisivity: Wenner probe method.

BS 1377: Part 3: 1990: Section 10.4 Measurement of resisivity: open container method.

@$710800 Field redox potential
BS 1377: Part 9: 1990: Section 5.2 Determination in-situ of the redox potential of soil.

Comment:
The test is intended to warn about potential problems of corrosion caused by anaerobic microbes.

BS 1377: Part 3: 1990: includes a laboratory test for undisturbed soils, which is not included in the current version of the score base. This test should be applied only to undisturbed samples, which must be tested immediately after sampling. Section 11.1.3 states that it should be interpreted by a specialist, and it is therefore treated as a special study here.

Laboratory redox potential
BS 1377: Part 3: 1990: Section 11 Determination of the redox potential.

Variations:
The number, location and depth of the tests to be made must also be specified.

It may also be appropriate to specify that samples be collected for microbiological examination, see Section 5.2.2.6.

Comment:
pH is required at the same locations for use in the calculation in Section 5.2.5.; it is specified automatically in Section 5.2.4.10.

@END OF F7THELP7. BS 1377: 1990.

@START OF F7THELP8, X.X., ...November 8, 1993

@$800000 Miscellaneous tests
1 Number of sub-groups in this group
6 Number of tests

G 810100 Linear Shrinkage
G 810200 Free Swell
G 810300 Frost Heave
G 810400 Ero-Pinhole
G 810500 Ero-Crumb
G 810600 Erosion-Dispersive test

@$810100 Linear Shrinkage
Three shrinkage tests are included here (temporarily):

Volumetric shrinkage (definitive method).
obtains shrinkage curve automatically.
Volumetric shrinkage (subsidiary method).
smaller sample, remoulded, passing 425 micron sieve;
obtains shrinkage curve optionally.
Linear shrinkage.
remoulded, passing 425 micron sieve.

G 810110 Volumetric shrinkage (definitive method).
G 810120 Volumetric shrinkage (subsidiary method).
G 810130 Linear shrinkage.

@$810110 Volumetric shrinkage (definitive method)
BS 1377: Part 2: 1990: Section 6.3 Determination of shrinkage characteristics: Volumetric shrinkage (definitive method).

Comments:
This test measures the shrinkage of a sample of soil using immersion in mercury.

For use as the definitive mehtod, the specified precautions must be observed; otherwise, the results are less reliable.

The definitive version uses undried material; but, if air drying is to be permitted, the method of drying must be specified.

[Section 6.2

Variations:
Undisturbed, remoulded or compacted soil may be used.

[Section 6.2

It may be necessry to remove the larger particles, although this would not be possible for the definitive method for undisturbed soil in accordance with Section 6.2.

Particles > 425 micron shall be removed by hand.

[Section 6.2

Section 6.3.4 requires that undisturbed cylindrical specimens shall be prepared in accordance with BS 1377: Part 1: 1990: Section 8.3 Preparation of cylindrical specimen direct from sampling tube.

Section 6.3.4 requires that undisturbed cylindrical specimens shall be prepared in accordance with BS 1377: Part 1: 1990: Section 8.4 Preparation of cylindrical specimen of smaller diameter than sampling tube.

Section 6.2 requires that undisturbed cylindrical specimens shall be prepared in accordance with BS 1377: Part 1: 1990: Section 8.5 Preparation of cylindrical specimen from undisturbed block sample.

Section 6.2 requires that cylindrical specimens shall be prepared using the specified compactive effort in general accordance with BS 1377: Part 1: 1990: Section 7 Preparation of disturbed samples for testing.

The compactive effort to be used must also be specified.

Cylindrical specimens shall be prepared at the specified density in general accordance with BS 1377: Part 1: 1990: Section 7 Preparation of disturbed samples for testing.

The density to be achieved must also be specified.

In all cases, the size of specimen to be tested must be specified. The following are usual:

specimen diameter: 38mm to 51mm
specimen length: 1 diameter to 2 diameters.

[Section 6.3.1.

Comment:
When checking, enquire whether excessive cracking occurred, see Section 6.3.5.7.

@$810120 Volumetric shrinkage (subsidiary method)
BS 1377: Part 2: 1990: Section 6.4 Determination of shrinkage characteristics: Volumetric shrinkage (subsidiary method).

Comments:
This test measures the shrinkage of a pat of soil material using immersion in mercury.

It may be necessary to specify how the coarser particles are to be removed, see Section 6.4.4.1.

Variations:
Particles > 425 microns shall be removed by wet sieving.

Coarse particles shall be removed by hand, wet sieving is not required.

Wherever possible, undried soil in the natural state should be used; but, if air drying is to be permitted, the method of drying must be specified.

Soil in the natural state shall be used without air drying.

Comment:
It is also necessary to specify whether the shrinkage curve is to be obtained.

Variation:
The shrinkage curve during drying shall be obtained.

@$810130 Linear shrinkage
BS 1377: Part 2: 1990: Section 6.5 Determination of shrinkage characteristics: Linear shrinkage.

Comments:
This test measures the shrinkage of a bar of soil whilst lying in a mould.

It may be necessary to specify how the coarser particles are to be removed, see Section 6.5.4.1.

Variations:
Particles > 425 microns shall be removed by wet sieving.

Coarse particles shall be removed by hand, wet sieving is not required.

Wherever possible, undried soil in the natural state should be used; but, if air drying is to be permitted, the method of drying must be specified.

Soil in the natural state shall be used without air drying.

@$810200 Free Swell
Both swelling amount and swelling pressure are included here, swelling pressure being always required in the BS procedure. Therefore, the first specification following is always required, the second being optional. (This does not quite match the term 'free swell' used in the score base.)

The swelling pressure shall be determined in accordance with BS 1377: Part 5: 1990: Section 4.3 Measurement of the swelling pressure.

The amount of swelling shall be determined in accordance with BS 1377: Part 5: 1990: Section 4.4 Measurement of swelling.

Variations:
It may be necessary to specify the size and orientation of the specimen.
[Sections 3.3. and 3.2.1.1.1.

Comment:
It will be necessary to specify the type of specimen.
[Section 3.3.

Variations:
Undisturbed samples of soil taken from a sampling tube shall be used.
[Section 3.3.2.

Undisturbed samples of soil taken from an excavated block sample shall be used.
[Section 3.3.2.

Compacted soil shall be used; in this case, details of compaction must be specified.

Comment:
It will be necessary to specify the initial equilibrium pressure.

Variations:
Initial equilibrium shall be attained under a small seating load in accordance with Section 4.3.3.1.

Initial equilibrium shall be attained under a pressure equal to the in situ pressure in accordance with Section 4.3.3.1.

Initial equilibrium shall be attained under a pressure of ... kPa in accordance with Section 4.3.3.1.

If the measurement of amount of swell has been specified, then the unloading sequence required in Section 4.4.3.3 must be specified.

If the measurement of swelling pressure/amount is to be followed by consolidation, then the procedure to be followed must be specified, see Section 4.3.3.6.

@$810300 Frost Heave
Frost heave shall be determined in accordance with BS 1377: Part 5: 1990: Section 7 Determination of frost heave and with BS 812: Part 124.

Comment:
Undisturbed, remoulded or compacted soil may be used. Use of Section 8.4 is included below, although BS 1377 includes only Sections 8.3 and 8.5.

Variations:
Undisturbed cylindrical specimens shall be prepared in accordance with BS 1377: Part 1: 1990: Section 8.3 Preparation of cylindrical specimen direct from sampling tube.

Undisturbed cylindrical specimens shall be prepared in accordance with BS 1377: Part 1: 1990: Section 8.4 Preparation of cylindrical specimen of smaller diameter than sampling tube.

Undisturbed cylindrical specimens shall be prepared in accordance with BS 1377: Part 1: 1990: Section 8.5 Preparation of cylindrical specimen from undisturbed block sample.

Specimens shall be compacted in accordance with BS 812: Part 124: Clause 9. (unchecked).

Comment:
The particle size distribution, the plasticity index of the fines fraction (if appropriate) and the optimum moisture content and maximum dry density must all be obtained, see Section 7.2.1.

@$810400 Ero-Pinhole
BS 1377: Part 5: 1990: Section 6.2 Determination of dispersibility: pinhole method.

Variation:
The standard test uses pure water; if the water likely to cause erosion is known to be salty, a varied specification might be used.

@$810500 Ero-Crumb
BS 1377: Part 5: 1990: Section 6.3 Determination of dispersibility: crumb method.

Variation:
The standard test uses a dilute solution of sodium hydroxide; pure water might be satisfactory but does sometimes fail.

@$810600 Erosion-Dispersive test
BS 1377: Part 5: 1990: Section 6.4 Determination of dispersibility: dispersion method.

@END OF F7THELP8. BS 1377: 1990.

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