MANUAL

SITE INVESTIGATIONS

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DESIGN AND ENGINEERING PRACTICE

USED BY

COMPANIES OF THE ROYAL DUTCH/SHELL GROUP

PREFACE

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The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

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NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

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APPENDICES

1. INTRODUCTION

1.1 GENERAL

This manual sets out the survey and investigation activities required for obtaining data, with respect to the physical parameters of the site conditions which will affect proposed civil engineering structures for a project.

It is intended for use for oil refineries, chemical plant, gas plants, storage facilities, terminals, etc. and, where applicable for exploration, production and new ventures.

Unless otherwise authorized by SIPM, the distribution of this manual is confined to companies belonging to or managed by the Royal Dutch/Shell Group, and to contractors nominated by them.

As a rule, the requirements of this manual shall be adhered to. However, national and/or local regulations may exist in which some of the requirements are more stringent.

The contractor shall determine by careful scrutiny which of the requirements are the more stringent, and which combination of requirements will be acceptable as regards safety, economic and legal aspects.

In all cases, the contractor shall inform the principal of any deviation from the requirements of this manual which is considered to be necessary, in order to comply with the national and/or local regulations. The principal may then negotiate with the authorities concerned with the object of obtaining agreement to follow this manual as closely as possible.

All publications referred to in this manual are listed in Section 10.

Where cross references are made, the number of the section or sub-section referred to is shown in brackets.

1.2 MINIMUM REQUIREMENTS

The minimum requirements as laid down in this manual shall be applied as far as is relevant to every site investigation.

Supplementary to these minimum requirements, all work shall be carried out in accordance with recognized and accepted theories, methods, codes of practice and standards, and applying the principles of good engineering practice.

Examples of acceptable standards and codes of practice are given in the text of this manual.

2. DEFINITIONS

For the purpose of this manual, the following definitions shall hold:

Shall and **Should** - the word 'shall' is to be understood as mandatory and the word 'should' as strongly recommended to comply with the requirements of this manual.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction.
The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorized to act for the Principal.*

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction and commissioning for the project. The Principal may sometimes under take all or part of the duties of the Contractor.

The **Survey Contractor** is the party appointed by the Principal or the Contractor which carries out one or more of the activities of the Site Investigation.

* For Group operating companies having a service agreement with SIPM or SICM, the term 'Principal' shall be taken as referring to SIPM-MFEE/3.

3. SURVEY CRITERIA

3.1 TYPE AND SCOPE OF SURVEYS

3.1.1 General

The type and the scope of a survey will depend upon the purpose for which the survey is required and on the circumstances under which the survey is to be carried out. The various types of survey and the scope of these used in site investigations in accordance with this manual are described below.

3.1.2 Preliminary and General Investigations

A 'preliminary investigation' and a 'general investigation' are both required to determine the conditions for the civil engineering structures and works, and the problems which will be encountered.

These surveys can be made in a number of different ways, and the method(s) selected will depend on the prevailing conditions and related problems.

Both the 'preliminary investigation' and the 'general investigation' are normally initiated by and carried out on behalf of the principal.

3.1.3 Detailed Investigations

A 'detailed investigation' is usually an additional survey to an existing general investigation.

It should be carried out by the contractor in view of his ultimate responsibility for the civil engineering work, the design of structures and their foundations, applicable construction activities, etc.

3.1.4 Verification Surveys

In the event of a contractor opting to use the results of available/existing investigations carried out on behalf of the principal or a third party, and agreeing to accept the recommendations of such investigations within the terms of his contract, the contractor shall carry out a 'verification survey'.

As the purpose of a 'verification survey' is to verify the data established by earlier investigations and to provide confirmation of the bases on which the relevant recommendations have been made, it is intended that its scope should be limited to what is considered necessary in this respect.

Subject to the results of the 'verification survey' being in agreement with the results of previous investigations, within acceptable limits, the contractor shall take the responsibility for all survey data and related reports and recommendations used for design and construction.

3.1.5 Clarification Surveys

In the event that survey data from whatever investigation, analysis or observation, appear to be in contradiction to the corresponding equivalent data obtained from other or earlier surveys, a 'clarification survey' shall be carried out.

It is intended that the scope of the clarification should be limited to the extent necessary to determine the cause of the contradiction in data and thereby obtain resolution within acceptable limits.

3.2 APPLICATION OF SURVEYS TO PROJECTS

3.2.1 General

The outlines given in this manual provide guidance by indicating those items which should be considered for each investigation or survey, and describe the methods which shall be used to obtain the data required.

Some items may not necessarily apply to all projects.

The investigations/surveys discussed and described in this manual are:

a) Geotechnical investigations, (6.)
   - Soily substratum, (6.2)
   - Rocky substratum and cemented soils, (6.3)
b) Geodetic and topographical survey, (4.)
c) General geological survey, (5.)
d) Hydrological and environmental data collection, (7.)
e) Hydraulic survey (Rivers, Canals, Lakes and Sea), (8.)
f) Pollution survey, (9.).

As a qualifying addition to geotechnical investigations, this manual includes a description of the laboratory testing which shall be carried out in support of the field work, (6.4).

3.2.2 Minor Projects

For small projects and extensions to existing facilities and structures, available survey (or design) data can be used, provided such data are verified by means of a 'verification survey'.

Such a 'verification survey' may sometimes have the scope of a detailed investigation.

3.3 EXISTING SERVICES AND FACILITIES

In the event of site investigations within or close to locations having existing services and facilities, every precaution shall be taken to protect such services and facilities from damage or interference during the execution of the work required by the various surveys and investigations described in this manual.

Before commencing any site investigation which will require excavations, borings or penetration testing of the soil/rock, the nature and location of all existing services and facilities on the site and adjacent areas shall be ascertained. This preliminary investigation shall cover all such services and facilities aboveground and underground, and some manual excavation may sometimes be necessary.

The principal shall be notified in writing should these investigations reveal any services or other objects of which there is no previous record. A description, dimensions, levels related to reference datum points and other appropriate details of such services/objects shall be recorded accurately and supplied to the principal.

For those services which can be cut off during the course of the survey, a certificate or permit to work shall first be obtained from the principal or other responsible body, confirming that such services have been isolated and that it is safe to proceed with the site investigation. In the case of those services and facilities which need to be maintained operational, the principal shall specify exactly what these are and what requirements shall be met whilst the investigations are being carried out. The contractor, or other party, carrying out the investigations shall be responsible for strict adherence to all safety regulations in force at the location concerned.

In the event that a service or facility is cut or otherwise damaged accidentally, it shall be made good as directed by the principal.

3.4 SITE SELECTION GUIDE

3.4.1 General

The selection of a construction site for a refinery, gas plant, chemical plant, terminal or harbour shall be based on economical and technical considerations, taking into account the development plans of the local government for the area concerned.

When determining the situation, layout and design criteria for the facility or structures, the following aspects of civil engineering design shall be considered:

1) Topography:
   - available area (versus area required, including the requirements for future extensions)
   - variation in ground levels
   - ground level relative to open water level
   - obstacles, roads, rivers, coastlines, bushes, etc.
2) Geology/Geotechnics:
   - seismic risk (if relevant)
   - presence of faults/cavities
   - bearing capacity, settlements and stability (short and long term)
   - earth moving requirements
   - borrow and quarry resources
   - chemical properties/stability, durability, degree of weathering of substratum/subsoil.
3) Geo-hydrology:
   - groundwater level and variations thereto
   - groundwater flow/permeability
   - chemical properties of groundwater, and its possible aggressiveness
   - surface run-off
   - drainage requirements (surface and subsurface).
4) Meteorology:
   - ambient temperature of air and water
   - precipitation
   - wind (cyclonic/typhonic conditions, if relevant)
   - pollution/contamination
   - vegetation
   - observations with respect to cooling water intake/outfall.
5) Hydrography:
   - waves
   - currents
   - tides
   - morphology
   - character of rivers (including debris)

3.4.2 Specific Scope

Because the requirements of different projects are so diverse in relation to the physical characteristics of the intended or preferred location, it is not possible to lay down the specific scope for the site selection survey or the specific criteria which must be met in every case.

3.4.3 Report

The report of the site selection survey shall include the following information:

a) A list of all sources of information consulted, and of all data collected.

b) A site visit report (when relevant).

c) An appraisal of the physical conditions at the site.

d) Correlation of data from preliminary investigations.

e) Scope of work for further detailed investigations, where applicable.

f) Possible limitations on the proposed project(s), including future extensions.

g) Conclusions relative to site selection.

It should be emphasized that incorrect conclusions from the investigations are more often arrived at through forced interpretation of the data in favour of the development rather than through lack of ability to evaluate those data correctly. It is important to ensure, therefore, that no factor is assumed to be favourable until that assumption is supported by all available data.

4. GEODETIC AND TOPOGRAPHICAL SURVEY

4.1 SITE SURVEY

4.1.1 General

The project location should be established on a topographical map (to a scale of 1 : 50 000 or less). If no map is available, a rough survey and sketch map shall be made of the area showing, inter alia, the plan and governing elevations of watercourses, and the situation and character of important cultural and occupational features such as woods, swamps, pastures, roads, railways, canals and major civil engineering structures and buildings. Aerial photography may often be justified to support this work.

Further information shall be collected in the form of:

- contour maps of the site area to a scale of 1 : 50 000 or less, if available
- bathymetrical maps of the site area to a scale of 1 : 50 000 or less, if available
- reference points for triangulation for topographical and bathymetrical surveys.

When the site of a project has been fixed as a result of the preliminary investigations, a project location map should be prepared and based on an accurate field survey. The scale of the map should be such as to provide a one-metre contour interval at least within the construction area. Outside this area, a larger contour interval may be used, particularly in rugged country or over water.

4.1.2 Field Survey

The accuracy and completeness of such a field survey shall be such as to provide all the information needed for the design of the civil engineering structures. For projects of major importance, such a survey shall include the following:

1) A triangulation system laid out for the control of later on-site construction surveys. This shall include a carefully surveyed base line located centrally, and a limited number of points permanently monumented and documented, which shall be placed strategically and accurately related to the plant and/or national grid system.

2) A coordinate system as a control for the location of drill and test holes, etc., for subsurface investigations. If a tie-in to an existing coordinate system is not practical, a local coordinate system shall be established before the commencement of any drilling or other subsurface investigations.

3) All survey maps shall clearly indicate which coordinate system has been used.

4.2 TOPOGRAPHICAL SURVEY FOR SOIL INVESTIGATIONS

Prior to the commencement of an investigation, the levels and locations of all points of the soil survey shall be determined accurately and recorded on an appropriate drawing.

5. GENERAL GEOLOGICAL SURVEY

5.1 GENERAL

Geological studies are essential for site investigation for all major projects, and may be desirable even for minor projects if the geological/geotechnical/geohydrological/ seismic conditions of the proposed site require an engineering geological investigation, (6.3.2).

Geological studies should be put in hand at the very beginning of the site investigation and continued throughout the other studies and tests (geophysics, drilling, shafts and galleries, rock mechanics, etc.).

Integration of the geological studies with the engineering geological investigations (as described in 6.3.2) is a logical follow up in areas where such investigations are required.

5.2 OBJECTIVES

These can be summarized as follows:

1) To provide an understanding of the geological history of the project area, that is of the processes from which the present geological situation at and around the site has been developed. In particular, it is important to determine the following:
   - any processes that are still active or potentially active:, these could include erosion and/or deposition, slope creep, landsliding, fault movement, subsidence and volcanic activity
   - the possible effects of the active processes on the engineering works, both during construction and when in service
   - possible changes to the effects of active or previously active processes, or to the existing geological condition (e.g. change to the existing stress or hydrological condition) which could arise from the engineering works, and whether any remedial action will be necessary
   - the seismic character of the area.
2) To determine the regional stratigraphy and the distribution of the major rock units, and to define the boundaries and the form of the interface between the major rock units.
3) To explain the geomorphology of the project area in terms of the regional stratigraphy, structure and geological history.
4) To obtain an appreciation of the existing regional groundwater conditions.
5) To form a logical basis for the location and investigation of sources of construction materials.
6) To draw attention to important geological features (e.g. faults and landslide boundaries) passing through or close to the site, but not actually exposed or recognizable at the site. Thus the regional studies should result in a series of questions to be answered during the more detailed studies carried out later in the actual site area.

5.3 ACTIVITIES

The amount of time and money spent on general geological studies will depend upon the size and complexity of the project, and on the amount of regional geological information already available. The activities involved will usually comprise some or all of the following:

1) Examination of existing regional geological maps, cross sections and reports.
2) Interpretation of aerial photographs.
3) Interpretation of ground photographs.
4) Ground reconnaissance over previously mapped areas and remaking the map(s) of important areas, taking into consideration the objectives of the project.

This primary study of the available data shall be supplemented, if applicable, by a field survey which should indicate the following as a minimum:

- the general character of the site and the degree of uniformity of the geological structure
- the location and character of possible faults, disturbed zones and cavities
- the classification of soils/rocks as to age and origin, their composition/properties/durability/chemical stability, and the processes which may affect the composition and properties
- an assessment of the seismic sensitivity of the area derived from historical data and observations (6.3.2.9)
- the availability of aggregates and cementing materials for construction (borrow and quarry resources)
- the geotechnical properties of the substratum materials (e.g. compressibility, weatherability, etc.)
- examination of possible drainage problems.

The conclusions of this study shall indicate whether an engineering geological investigation as described in this manual, (6.3.2), is required.

6. GEOTECHNICAL INVESTIGATIONS

6.1 GENERAL

6.1.1 Codes and Standards

Unless otherwise specified, all surveys and related activities required by this manual shall be carried out in accordance with the following codes/standards/ specifications, the latest issue of which shall be used unless otherwise prescribed:

ASTM Volume 04.08	:	Natural Building Stones:, Soil and Rock
ASTM Volume 11.01	:	Water (I)
ASTM Volume 11.02	:	Water (II)
ASTM D 420	:	Recommended Practice for Investigation and Sampling Soil and Rock for Engineering Purposes
ASTM D 653	:	Definitions of Terms and Symbols relating to Soil and Rock Mechanics
ASTM D 1452	:	Practice for Soil Investigation and Sampling by Auger Borings
ASTM D 1587	:	Thin-Walled Tube Sampling of Soils
ASTM D 2487	:	Classification of Soils for Engineering Purposes
ASTM D 3441	:	Deep, Quasi-Static Cone and Friction Cone Penetration Tests of Soil
ASTM E 380	:	Metric Practice
BS 5930	:	Code of Practice for Site Investigation
ISSMFE	:	Report of the sub-committee on standardization of penetration testing in Europe

Various sections/clauses of this manual refer more specifically to individual standards/codes, and to specific clauses within them. In these cases, the use of such references is mandatory and shall be considered as the minimum requirements for the definition and execution of the work concerned.

6.1.2 Units of Measurement

SI units shall be used throughout all surveys and related activities. In the context of this work, the practice described in ASTM E 380 shall be followed as far as is practical.

Reference should be made also to DEP 00.00.20.10-Gen.

6.1.3 Engineering Classification, Terms and Symbols

The terms and symbols used in this manual and in the work to be carried out shall be in accordance with ASTM D 653, as far as applicable.

The soil shall be classified in accordance with ASTM D 2487.

Other terms and symbols which are in accordance with normal standard practice for the area or locality concerned may be used.

6.2 FIELD WORK - SOILY SUBSTRATUM

6.2.1 General

The field work for the subsurface investigation of a soily substratum shall include but will not necessarily be limited to:

- penetration testing, if possible DCPT's
- borings
- sampling of soil and groundwater.

6.2.2 Dutch Cone Penetration Testing (DCPT)

In general, the main part of the survey should consist of DCPT's (the ratio between DCPT's and borings being around 10:1.) Approximately 15 per cent of the DCPT's should be carried out using an electrical cone penetrometer with a friction sleeve providing continuous registration of cone resistance and local side friction. The remaining 85 per cent of the DCPT's may be carried out using a simple (standard) cone penetration device, i.e. a mechanical cone without friction sleeve, providing only an intermittent or non-continuous registration of cone resistance. An example of how field measurements should be presented is given in Appendix I.

The following requirements and procedures shall be adhered to:

- The equipment, test procedure and reporting shall comply with the requirements of the standards/codes referred to in this manual.
- Depending on the subsoil conditions, and the purpose of the investigation, DCPT's can be either:
  - heavy DCPT's using 20t equipment (normally used for the design of pile foundations, and for gathering information on the deeper substratum)
  - light DCPT's using 10t equipment (normally used for determining foundations for earth works and storage tanks, and for raft foundation problems) or
  - shallow penetration tests (to a depth of a few metres) to check in-situ density, compaction, etc.
- To ensure close correlation between soil and DCPT data, the survey contractor shall carry out a heavy DCPT using electrical cone penetration adjacent to each boring. The DCPT shall precede the boring, and shall not be further than one metre from it.
- In tests where early refusal is met, the contractor shall consult and agree with the principal on the location of the next test.
- The survey contractor shall ensure that the cone and rods are clean, in good alignment and in good condition.
- All measuring devices shall be calibrated before commencing site work, and the calibration certificates shall be submitted to the principal.
- The survey contractor shall have available at site sufficient spare parts in good condition to ensure the work programme is not jeopardized by lengthy stoppages.

In cemented soils and in soils containing boulders, pieces of rock and cemented parts, the results of DCPT's might be misleading. A great many other factors enter into the interpretation of such tests, and it is a matter of judgement whether the results should be used without having the results of proper borings for a guide.

6.2.3 Borings

Borings shall be carried out to obtain:

- information on the type of soil
- samples which can be examined at site or in the laboratory
- data for correlation with the results of penetration tests, (a.o. DCPT's)
- information on groundwater.

In cases where it is not possible to obtain adequate DCPT data, Standard Penetration Test (SPT) values shall be determined in the borehole at intervals of 3 metres, and at each change of strata.

The following requirements and procedures shall be adhered to:

- The method of taking samples, their handling and preservation shall be in accordance with the relevant ASTM standard practices.
- Samples shall not be allowed to remain in the open for more than one hour, and they shall be protected at all times from exposure to temperatures below 5°C and above 35°C.
- Bulk samples shall be taken continuously. They shall be representative of the zone from which they have been taken. Within the limits of the zone being sampled, all recovered soil shall be placed on a suitable tray, care being taken to retain the fines of water bearing granular soils.
- In cohesive soils, undisturbed samples should be taken at 2-metre intervals and at changes of strata. In cohesionless soils, representative samples should be taken at 2-metre intervals and at changes of strata.
- All samples shall be durably labelled for identification, and indelible ink shall be used in order that the identification does not deteriorate with time.
- Samples sent to the laboratory for testing shall be packed and transported in such a way that undisturbed samples arrive in an undisturbed state.
- Samples taken from overconsolidated clay shall be preserved in such a manner as to exclude swelling of the samples.
- The survey contractor shall retain all samples in safekeeping until completion of the construction works. Thereafter, the samples may be disposed of on receipt of written consent from the principal.
- The survey contractor shall submit the name of his proposed testing laboratory in his tender for the work, for approval by the principal.

6.2.4 Groundwater Sampling

Groundwater samples are required for chemical analysis. The procedure shall be as follows:

- The samples should be taken at (permanent) stand pipe locations, and at depths of 1, 2, 3 and 5 metres below groundwater level. The stand pipes shall penetrate to a depth of 7.5 m below groundwater level.
- Care shall be taken to ensure that the samples are truly representative of the water bearing stratum, and that they have not been contaminated or diluted by surface water or by water which has been used for boring.
- Water samples shall be taken as soon as possible after the water bearing stratum has been met in the borehole. The water in the borehole shall be removed first, either by pumping or baling, as far as is possible, and then the sample shall be taken from that water which collects by seepage.
- Other water bearing strata occurring at levels above the point of sampling shall be sealed off.
- A minimum of one litre shall be collected into a clean glass or inert plastic bottle, rinsing the bottle three times with the water being sampled before filling.
- Water samples shall be analysed as soon as possible after the sampling procedure in order to prevent deterioration of the water affecting the analysis.
- Water samples required from boreholes, test pits, etc., shall generally be taken at one metre below groundwater surface level.

6.2.5 Groundwater Level and Pore Water Pressure Measurements

Groundwater level should be determined in stand pipes, taking into account possible changes in pore water pressure in deeper soil strata (piezometric pore pressures).

Determination of pore water pressure and variations thereto with depth or over a period of time shall be carried out using an electrical pore pressure gauge.

6.2.6 Liquefaction Susceptibility

The liquefaction susceptibility shall be determined with the aid of DCPT's and relative density determination. A combined measurement of cone penetration and pore water pressure ('piezo cone penetration testing') generally gives the most reliable information. If DCPT's cannot be carried out, the SPT method or the pressure meter method shall be used.

Refer Appendix I, figures I-4 to I-8.

6.2.7 Horizontal Subgrade Reaction Coefficient

Horizontal subgrade reaction coefficients (e.g. for P-Y data) should be determined with the aid of pressure meter tests. These tests shall be carried out at 3-metre intervals and at each change of strata.

Refer Appendix I, figure I-8.

6.2.8 Soil Sample Testing

Soil sample testing in the field or in the laboratory shall comprise but will not necessarily be limited to determination of the following:

- grain size distribution of sandy and silty soils
- silt content of sandy and silty soils (with the application of a peptizer in order to prevent clogging of silt particles)
- unit mass of soil (normally in saturated state)
- Atterberg limits of clay and silty soils.

6.2.9 Factual Reporting Requirements

Depending on location and size and on the urgency with which preliminary information is required for design, or for determining the magnitude of further site investigation, some of the following reports may not be necessary.

The principal and the contractor shall decide whether field reports will be submitted in the described manner, or if the information is to be included in the preliminary records.

6.2.9.1 Field Reports

The survey contractor shall prepare a daily report which shall be submitted to the principal within 24 hours of the completion of the exploratory holes to which it refers.

This report shall include the information set out below, as relevant.

6.2.9.1.1 Information for Boring Reports:

a) job name, location, coordinates and ground level
b) contractor's name
c) exploratory hole reference number
d) boring data referred to depth
e) SPT values (where applicable)
f) equipment used.

6.2.9.1.2 Information for Dutch Cone Penetration Testing Reports:

a) as for items a) through f) in (6.2.9.1.1)
b) penetrometer tip figure
c) type of thrust machine used

d) method used to provide reaction force
e) method of tip advancement
f) recording method
g) condition of rods and tips after withdrawal
h) special difficulties encountered, e.g. early refusal, relocation of test, etc.
j) field results of cone resistance and friction resistance.

6.2.9.2 Preliminary Records

The survey contractor shall prepare a preliminary record which shall be submitted to the principal in duplicate within seven working days after the completion of the investigation to which it refers.

The preliminary record shall be in a form approved by the principal, and shall include the information set out below, as relevant.

6.2.9.2.1 Information for Boring Records

a) as for items a) through f) in (6.2.9.1.1)
b) the elevation of each stratum referred to datum
c) symbolic legend of strata and incorporating a suitable scale
d) engineering description of each stratum and summary of groundwater conditions
e) SPT method (where applicable).

6.2.9.2.2 Information for Dutch Cone Penetration Testing Records

a) as for items a) through j) in (6.2.9.1.2)
b) graphs of cone resistance
c) graphs of friction resistance (where applicable)
d) graphs of friction ratio (where applicable)
e) inclination of tip (where applicable).

The survey contractor shall demonstrate and show the correlation between soil type and DCPT data and, where applicable, the correlation between the various DCPT methods/ cones/devices used, as well as the correlation between SPT and DCPT.

6.2.9.3 Final Report

The survey contractor shall prepare a final report on completion of the investigation concerned, and shall submit this to the principal within the time specified.

This report shall summarize and complete the information previously submitted by means of the field reports (6.2.9.1) and the preliminary records (6.2.9.2), and shall include the following information:

1) factual information:

   a) exploratory hole records

   b) on site test records

   c) DCPT records

   d) laboratory test records (6.4)

   e) locations of exploratory holes, DCPT's and stand pipes.

2) geotechnical assessment

   General geotechnical advice on foundations, earthworks and drainage, highlighting the feasible foundation solutions (such as shallow foundations, piled foundations), settlement behaviour, stability aspects, etc.

3) borings

   The report shall include borehole records with all the information required by (6.2.9.2.1) modified as necessary in the light of laboratory testing and further examination of the samples.

   On site test results may be given in 1.a) above, where appropriate, or otherwise presented in tabular or graphical form.

4) DCPT's

The report shall include DCPT records with all the information required by (6.2.9.2.2).

5) laboratory tests

The summaries of the laboratory tests (6.4) shall be presented in tabular form.

Where the survey contractor is required to submit recommendations for the design of the structure, plant, etc., he shall present the information concisely and in the form agreed. The recommendations shall be supported by simple plans and sections of particular feature, which shall incorporate exploratory hole locations and records, and the referred geology.

6.2.10 General Advice based on Survey Data

6.2.10.1 General Foundation Advice

The prime purpose of the general foundation advice is to provide the means for assessing the most feasible solution for the foundations required for the different types of structures such as storage tanks, jetties, process units, flare stacks, slug catchers, buildings, pipe tracks, bridges, culverts, roads, etc.

General foundation advice shall be based on the results of the Soil Investigation Programme, and on information which may be available from previous geological, geotechnical and topographical surveys.

Typical examples of the types of structure to be supported shall be provided by the principal.

All calculations and design methods applicable to the suggested solutions shall be given. For shallow foundations, for example, the methods used to arrive at bearing capacities and settlements shall be given. Similarly for piled foundations, and for each possible type of pile, the methods used to derive the negative and positive skin friction and point bearing capacities shall be given, also the driveability and, if applicable, the settlement behaviour.

The general foundation advice submitted by the survey contractor shall include but will not necessarily be limited to the following:

1) shallow foundations:
   - bearing capacities
   - settlements (total and differential) to be anticipated
   - time/settlement behaviour.
2) tank foundations:
   - total and differential settlements to be expected at tank centre and at tank shell
   - time/settlement behaviour.
3) pile foundations:
   - type of piles
   - bearing capacity of piles (axial and lateral)
   - total and differential settlements expected for single piles, for rows of piles and for a group of piles
   - driveability
   - negative skin friction.
4) The effect of sandfill over the complete site, or over parts of it.

   In places where the subsoil is poor, special advice shall be given in respect of settlements and differential settlements.
5) advice on foundations for vibrating machinery.
6) dolphins and jetties:
   - type of piles

- bearing capacity of piles (axial and lateral)
- total and differential settlements expected for rows of piles and for a group of piles
- driveability
- long term behaviour/creep (vertically and horizontally).

7) advice on the location of specified heavy structures, stacks, etc. with respect to the soil conditions.

6.2.10.2 General Drainage, Earthworks and Site Preparation

Advice regarding drainage, earthworks and site preparation shall be related to the results of the Soil Investigation Programme and shall include:

- discussion of groundwater table
- influence of earthworks and future structures on groundwater table
- future site elevation recommended
- discussion of aggressiveness of groundwater and soils
- liquefaction sensitivity and possible compaction requirements
- roads and railways
- buried pipelines
- settlement behaviour
- influence of works/constructions on adjacent structures.

6.3 FIELD WORK - ROCKY SUBSTRATUM AND CEMENTED SOILS

6.3.1 General

The field work for the subsurface investigation of rocky substratum, (i.e. hard and soft rock, rock with soily overburden, soils with boulders or rock fragments, weathered formations, etc.) or cemented soils shall include but will not necessarily be limited to the following:

- engineering geological investigation
- geophysical survey
- borehole investigations
- penetration testing in the event of soily overburden or heavily weathered rock, refer (6.2).

6.3.2 Engineering Geological Investigation

6.3.2.1 General

In addition to the requirements of the General Geological Survey (5.), the following shall be determined at sites considered complicated from the geological standpoint:

- topographical features, such as depressions or gullies, saddles, local steep or flat areas, lineaments, etc.
- geological surface features, such as delineation of individual areas covered by rock out crops, talus, boulders, surface soils, etc.
- rock and soil substance features, such as rock and soil types and their boundaries, zones of decomposed or weathered rock with mineralized zones, including general observations with regard to strength, deformability, permeability, anisotropy, etc.
- geological structures, such as joints, cracks, sheared zones, crushed zones, etc.
- groundwater features, such as delineation of areas of swampy ground, positions of springs or seepages, observations on the properties of the groundwater, e.g. chemical analysis, aggressivity, hardness, pH level, temperature, etc.

The maps prepared for presenting the above information and observations shall be supplemented by copies on which interpretative information has been written in. All facts and the interpretation thereof shall be clearly stated and easily recognizable.

6.3.2.2 Discontinuities

Possible discontinuities or defects in the substratum shall be investigated in detail. This shall include:

1) information as to their probable origins, and
2) an engineering description of infilling material, condition of joint surfaces, strength of wall rock, etc.

6.3.2.3 Detailed Comment

If relevant, detailed comments shall be given on the following:

- foundations:

  safety against sliding, settlement, internal or external erosion

- formations to be excavated:

  resistance to excavation by various types of earthmoving equipment, stability of slopes, support requirements, dewatering, etc.

- sources of construction materials:

  suitability for use as rockfill, aggregates or filler material, including observations on the workability of the deposits concerned.

6.3.2.4 Weathering

The section in the report on weathering (i.e. the outcome of past chemical and physical activity over the geological time scale) shall describe the distribution and engineering pro perties of the weathered materials. In the case of foundation investigations, the description shall be supported by maps or cross sections showing the location of the base of the main weathered zone.

6.3.2.5 Weatherability

The section in the report on weatherability (i.e. the susceptibility of the formation to future weathering over a human time scale) shall discuss the possibility of the natural weathering processes being accelerated by the disturbance to the existing natural conditions brought about by the civil engineering or structural work itself. Conclusions shall be based on previous experience and knowledge, and shall be supported by the results of laboratory tests.

6.3.2.6 Special Formations

When the site includes special formations, for instance, **salt, gypsum, talc, organic deposits,** etc.,these shall be described in a separate section of the engineering geological report, which shall also contain:

- the results of laboratory or field tests to determine the characteristics of the particular formation, e.g. solubility, resistance to erosion, swelling, gas emanations, etc.
- reference to previous experience of similar formations, and to any problems these may have caused to completed structures.

6.3.2.7 Karst Phenomena

Where karst phenomena are observed (i.e. limestone terrain characterized by caverns, sinkholes, potholes and underground streams, and where there are no surface streams or lakes) the report shall comment specifically on the following:

- location of cavities, e.g. in which geological layer(s) they occur, whether in the rock substances or along joints and faults, direction and extent in plan, and extent in depth
- degrees of karstification (the value of the void ratio, and how it was determined)
- age and origin of the karst, its present activity, and the nature and compactness of the infilling material.

Rocks other than carbonate rocks can also give rise to karst-like phenomena. Such other rocks include salt, gypsum formations and certain lava sheets.

6.3.2.8 Groundwater

In the case of excavations and underground constructions, all information appertaining to groundwater, e.g. surface flows, springs, groundwater table, chemical analysis of the water, etc., shall be included in a separate chapter of the engineering geological report, in the section on permeability. Conclusions in regard to the drainage characteristics, water tightness or hardness, groutability and durability of the rock formation shall be presented, supported by the results of in-situ tests and, if available, by experience of similar rock masses. The report shall emphasize any observed changes of permeability.

6.3.2.9 Seismicity

A separate section of the report shall be devoted to seismicity, and in it shall be assembled all published data on the seismic phenomena observed in the area of the site. This will complement data obtained from seismological observations, if there is evidence of these phenomena.

For important works, maps depicting epicentres and their respective magnitudes and regional maps showing maximum observed or deduced intensity shall be included.

Convincing evidence of seismic phenomena, if apparent, e.g. active faults, earth slides, rock falls, etc., shall be carefully described in the report, and the risks on the possible liquefaction of the soil shall be discussed.

For important structures, an independent seismological report based on a deep study of these phenomena for the area concerned shall be commissioned.

6.3.2.10 Changes to the Site

Civil engineering structures and/or works may induce significant changes to the site, and these shall be evaluated in a separate section of the engineering geological report. This section shall also conclude with recommendations on measures which should be taken to avoid or alleviate any problems caused by such changes.

Changes which may be encountered can be:

- morphological:

  slides, settlements, etc.

- mechanical:

  changes in cementation, cohesion, strength, etc.

- hydraulic:

  changes in the underground water flow, in the groundwater table, in the pressure gradients, in the dewatering pattern, in permeability, etc.

It is necessary to indicate the likelihood and probable extent of any changes, and also to determine the possible effect of the such changes on the engineering works.

6.3.2.11 Optimal Use

Throughout the engineering geological investigation, optimal use shall be made of borehole investigations, the geophysical survey, the geotechnical investigations of the soily substratum (6.2), and the laboratory investigations (6.4).

6.3.2.12 Reliability of Results

As the engineering and geological inputs are so interdependent in such investigations, a close and active cooperation between the individual specialists concerned is necessary at every stage of the preparatory work, and in the drafting of the final engineering geological report.

When the reliability of the conclusions and recommendations may be inhibited by lack of sufficient tangible evidence or experience, the survey contractor shall identify where additional studies are required to provide the required degree of confidence.

6.3.3 Geophysical Survey

6.3.3.1 General

The use of geophysical methods in site investigations is recommended in some instances, and particularly in the case of large structures (e.g. large storage tanks), important facilities, etc. Applying these methods in feasibility studies and in different stages of design, as well as in the control of the substratum conditions, is plainly justified in many cases.

Geophysical methods should be considered as indirect methods and shall be used only by experienced personnel.

6.3.3.2 Objectives

In conjunction with other methods, geophysical methods are intended to obtain maximum knowledge of rock masses at shallow and at relatively great depths beneath project sites. Specific objectives include the identification of the over-burden and rock types: , in many cases, tectonics, the degree of compactness, soundness, weathering, decompression and permeability can also be investigated.

The use of geophysical methods allows a better site investigation programme, such as the strategic location as well as the possible reduction in the extent of other exploration methods (boreholes, penetration tests, pits, shafts and galleries), and can confirm results obtained by in-situ tests of the physical characteristics of the rock/soil mass. These methods can also give useful data to complete geological and tectonic profiles and maps, and sometimes offer the best means of determining the elevation of bedrock, phreatic level, extent of decompression of a rock/ soil mass, depth of alluvium, depth of weathering, etc.

Site investigation through geophysical and other methods, shall be closely correlated at detailed level with the engineering geological investigation.

A description and possible applications of the various methods is given in Appendix II.

6.3.4 Borehole Investigations and other Field Tests

6.3.4.1 General

One of the most direct processes of subsurface site exploration for geotechnical knowledge and investigations consists of borehole drilling. Planning of boreholes depends on the geological engineering knowledge available, on type and stage of engineering works and on the investigation to be performed inside them.

Two general types of boring are used percussion and rotary. Although the equipment and procedures used show some minor differences, practice has demonstrated that there are certain basic principles for each type. A description of both methods is given in Appendix III.

6.3.4.2 Diameter of Borehole

For drilling in solid and stable rock, borehole diameters not less than 45 mm, and generally from 76 mm to 150 mm, are recommended. The more commonly used diameters are between 76 mm and 100 mm.

For drilling in very weak rock zones, borehole diameters larger than 150 mm are required. In certain cases, particularly where large instruments have to be inserted, diameters between 200 mm and 300 mm can be used.

If core recovery is essential, the influence of rock structure and the depth to be attained will determine the required borehole diameter. In general, the larger the diameter the more successfully can the investigations be performed. Diameters commonly used are given in Appendix III, Table III-1. Diameter NX is frequently the best size for obtaining the quality and quantity of information desired.

For boreholes which need to be large enough to allow personnel to descend, the diameter shall be not less than 800 mm. Drillings of even larger diameters (1800-2000 mm) have been successful.

In formations which are difficult to sample, or in which it is necessary to sample the filling of joints or other rock features, using large diameter boreholes may not be the most advisable solution.

6.3.4.3 Borehole Depths

For general feasibility exploration of subsurface conditions from the engineering geological standpoint, it is necessary first to establish the required borehole depths. These depend on the substrata conditions and the dimensions of the structures being considered.

For foundations, each case shall be considered individually. The borehole depth as well as the orientation and distribution of the borings shall be determined by consideration of the following parameters:

- shape and size of construction foundation area
- construction load
- the influence of adjacent structures
- geological conditions
- regularity, or irregularity, of layers.

For rock slopes, rock excavations, etc., the borehole depth also depends on the dimensions of the structure and its applied loadings.

6.3.4.4 Orientation of Borings

In general geological investigations of a particular area, the exploration will depend on the expected strata sequence or on the structure of the rock. For reasons of economy, the borings should be oriented in such a way as to obtain the maximum amount of information from the minimum number of borings.

In the case of foundations, it is necessary to take into account the direction of the principal applied loads and the possible effect these could have on incremental movements of the foundations, and their direction.

Boreholes for water and for grouting tests should be drilled in a direction normal to the discontinuity planes (stratification, joints, schistous planes, etc.).

6.3.4.5 Number of Borings

The number of borings necessary depends on the homogeneity, or inhomogeneity, of the area being investigated. The greater the irregularity the greater is the number of borings needed, with a corresponding reduction in drill spacing, in order to define the homogeneous areas.

For foundations, borings should be spaced in accordance with the importance of the structure to be built with the overall requirement that the distance between two adjacent borings shall not be greater than 100 metres. A minimum of two borings is required for structures of any importance. For structures on a slope, more borings may be required which should be drilled in a straight line so that a geological cross section can be drawn from the results. In the case of roads and earth constructions, a borehole spacing of 20 m to 100 m is generally used.

6.3.4.6 Sampling

The core extraction or taking of samples shall be carried out in such a way as to obtain maximum recovery of core with minimum disturbance to the sample.

The number of samples to be tested depends on the strata sequence and on the kind of data needed. Samples should be selected such that two similar pieces of each type of rock are available for testing.

As soon as each sample is obtained, a waterproof cover should be put around it in order to preserve the natural water content. Special recovery apparatus and methods (e.g. the integral sampling method) may be necessary when sampling some kinds of argillaceous, schistous or easily weatherable rock.

6.3.4.7 Boring Data

The data which shall be recorded for each boring, the so called 'boring log', shall include the following:

- position and elevation of boring location
- borehole direction, orientated from North, and inclination
- method of boring and drilling machine
- borehole diameter, and a record of the different hole diameters if it has been necessary to reduce diameter whilst drilling.

In addition to the above, the boring log should include information as follows:

- pierced strata sequence
- elevation of groundwater table, always measured at the start of the drilling operation
- drilling resistance
- drilling time and daily rate of progress
- pressure on cutting head
- energy lost through vibration during the course of drilling
- core recovery
- colour of flush water
- eventual flush water losses
- special observations and events, e.g. drill pipe fracture, equipment malfunction or lost in hole, etc.

- exact time and location of sample extraction.

The report (as compiled from all relevant documentation) should include the following:

- additions and/or corrections arising from comparison with standard specifications
- eventual core records
- colour photographs of the core samples to an appropriate scale, showing the borehole number and elevation of the core.

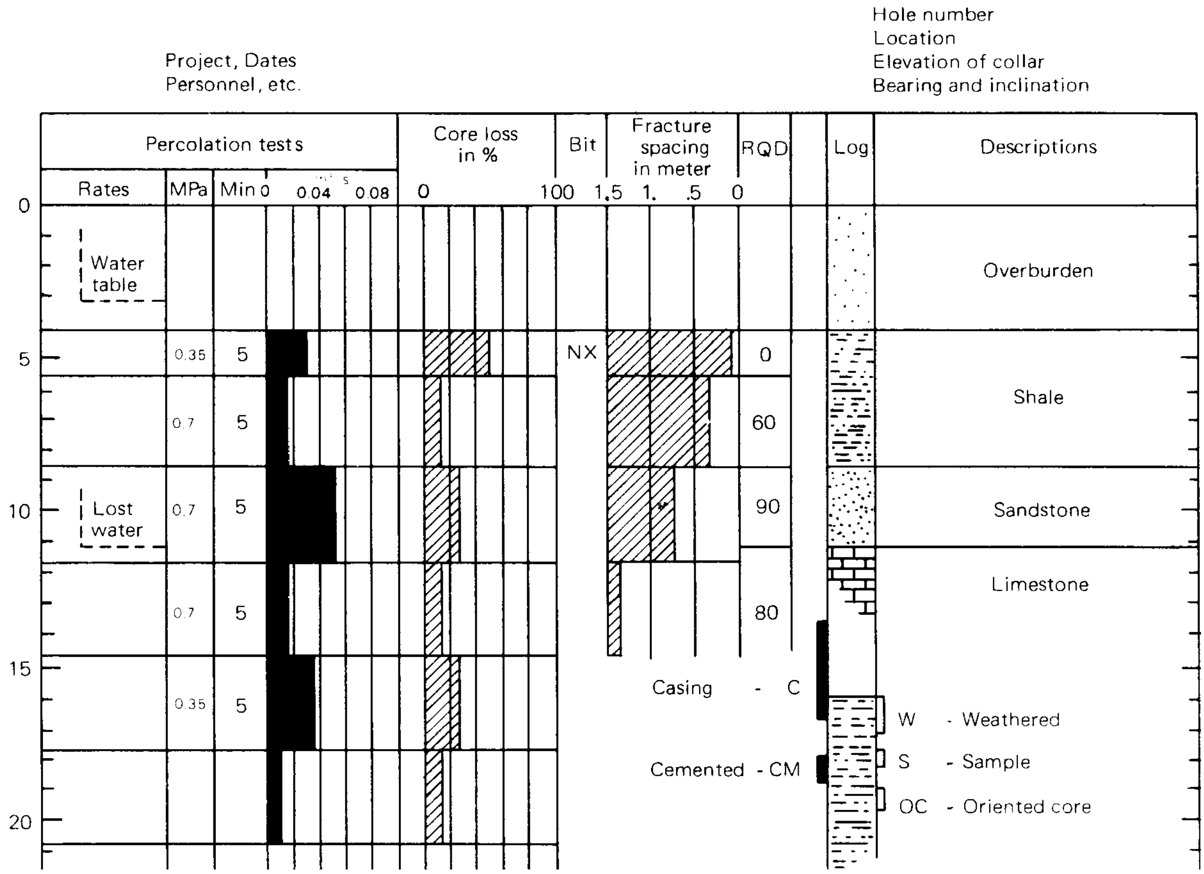
6.3.4.8 Graphical Presentation of Data

A graphical presentation shall be prepared. Apart from the geological log and description of rock type, this presentation shall include the following data, as far as relevant:

- core loss as a percentage (or core recovery as a percentage)
- type of core bit, and core bit size
- the Rock Quality Designation (RQD), which states the percentage of rock recovered as sound pieces which are 100 mm or more in length
- the Fracture Spacing Index (I_f), which refers to the average size of cored material within a recognizable geological unit
- results of percolation tests
- special notation for water table, lost drill water, casing, cemented intervals, weathered or altered rock, location of samples taken for analysis, and location of oriented cores.

A simplified and typical example of graphical presentation of a borehole log in rocky substratum is given in the table below.

TABLE 6.3.4.8 GRAPHICAL PRESENTATION OF A BOREHOLE LOG



The analysis and evaluation should include the following further information:

- mineral content
- strength anisotropy index (6.4.3.2)
- aggregate-durability index (6.4.3.3)

6.3.4.9 Type of Boring

For the extraction of rock core samples, rotary drilling with diameters larger than 45 mm, preferably 60 mm to 80 mm, shall be used. For each area of homogeneity being tested, a sufficient number of samples should be taken.

6.3.4.10 Insertion of Instruments

It has become normal practice to use certain diameters for the insertion of instruments (dilatometer, stress meter, photo-elastic tests), and for stress relief tests by means of overcoring.

For investigating strength characteristics, there are a number of instruments in general use which require a borehole diameter between 46 mm and 76 mm. For other instruments, a borehole diameter in the range 200 mm to 300 mm may be required.

When overcoring is necessary, it is usual to use an EX-standard bit of 38.1 mm (1.5 inches) diameter for the internal bore, and an NX-standard bit of 76.2 mm (3 inches) diameter for the overcoring.

For photo-elastic tests, borehole diameters larger than 76 mm are usually required.

If an electrical survey is to be carried out, the minimum borehole diameter shall be between 140 mm and 165 mm, with a maximum from 178 mm up to 508 mm diameter.

6.3.4.11 Permeability Tests

For permeability tests and for grouting tests, borehole diameters between 60 mm and 110 mm are normally used. For the former, borehole depth and direction will depend on the purpose of the test, and on local geology and rock mechanics.

Percolation tests, (e.g. for the determination of permeability), shall be adapted closely in line with local rock and geological conditions.

It is a requirement that instruments for measuring water leakage (loss of water) shall fit tightly against the wall of the borehole, and packers spaced 3-5 metres apart are used for this purpose. It follows also that the borehole walls should be as smooth as possible.

Special attention shall be given to permeability tests. It is essential to carry out the test under the right conditions. The following requirements shall be adhered to:

- the pressure shall apply to the test point, not to the top of the borehole
- the pressure of the water shall be kept uniform throughout the tests
- the packers used and the packer spacing adopted shall ensure a consistently tight fit between measuring instrument and borehole wall
- the infiltered flows and their respective pressures shall be presented graphically
- the accuracy of all measurements taken shall be of a sufficiently high order to give the right interpretation
- the flow of water shall be sufficient to prevent loss of water, etc., during test.

Groutability tests shall be performed when convenient (in relation to other tests) to obtain information on the volume of voids and cavities, to determine grout receptivity, or to determine what improvements need to be made.

All essential dates/time, grouting quantity, grouting pressure, etc., and events shall be recorded on standard forms, which together will comprise the documentation for each series of tests. Automatic recording of data is preferred.

6.3.4.12 Excavation of Trenches, Shafts and Galleries

The excavation of trenches, shafts and galleries is carried out mainly in order to obtain additional information which could be useful or is specifically needed in the design and construction of surface or underground structures at a site. In such cases it is necessary to determine those properties of the rock which will react to the imposition of structure loads, to the removal of overburden, or to the passage of fluids beneath them. It is also necessary to ascertain the extent and difficulty of excavation.

Trenches, shafts and galleries may be used also to furnish intending contractors with more information about the site substrata. Although much of the information required for bid purposes can be obtained quite satisfactorily from borings, excavations provide the means for a more thorough appraisal of site conditions in depth.

The main purposes of such excavations can be summarized as follows:

a) Investigating the rock mass structure:

- observation of system spacing, nature of joints, faults, shear zones, and the interface between the different types of rock.

b) Obtaining information on particular zones in the rock mass:

- observing and determining the area of deeply weathered or significantly altered zones
- tracing significant faults or fractured zones
- observation of permeable strata (particularly in volcanic areas), large open cracks, lava tunnels, and limestone caves or fissures
- ascertaining visually the effects of grouting, or testing a previously grouted area by means of a reagent.

c) Performing in-situ tests:

- shearing strength tests
- deformability tests
- permeability measurements
- stress state measurements
- geophysical exploration.

d) Obtaining samples for identification or laboratory testing.

e) Obtaining information for contractors:

- typical exposures of the type of rock that will be encountered
- an indication of how hard it will be to excavate
- basic information on support requirements.

The excavations can be further utilized by incorporating them into excavation for future construction.

6.3.4.13 Field Testing Methods

Field testing methods for engineering geological investigations are summarized in Table 6.3.4.13.

6.3.4.14 Summary of Engineering Geological Data

A summary of some engineering geological data/information is given in Appendix IV.

Table 6.3.4.13 ENGINEERING GEOLOGICAL METHODS

Method	Information provided	Main application
A. DRILLING & SAMPLING		
1. Blasthole, Rotary Percussion etc. Cutting Samples	1. By recording drilling rates these indicate major soil-rock boundaries and also boundaries between weaker and stronger rocks. Provide useful data on drillability of rock masses, drilling speeds, bit wear, etc. Cutting samples can be used to determine rock types, but are of limited value. Borehole can be used for other purposes - see B, C and D.	1. All projects where excavations are planned. Particularly useful for proposed quarries.
2. Core Drilling	2. Provides almost continuous core samples of rock and cohesive soils samples are used to develop geological picture - by logging and correlation with geological data from surface and other exposures. Also for tests of either substance or defects (see E and G). Oriented samples can be obtained. Boreholes can be used for other purposes - see B, C and D.	2. All projects.
3. Integral Sampling	3. Provides continuous sampling and gives attitudes and physical characteristics of the discontinuities of rock masses	3. To be used, together with 2 in projects where major geological problems may exist.
B. BOREHOLE PERISCOPE LOGGING, TELEVISION & PHOTOGRAPHY		
	4. Provide visual inspection of side of borehole, enabling measurements to be made of geometrical and physical characteristics of discontinuities and other defects.	4. Caverns, Special foundations, etc.
C. BOREHOLE PERMEABILITY TESTS		
	5. For most rock masses, these tests give permeabilities of individual sections of borehole. Pressure-leakage graphs for several cycles of increasing and decreasing pressures can be obtained.	5. Caverns, Underground constructions, some foundations, etc.
D. GROUTING TESTS		
	6. Provides information on volume voids and cavities, grout receptivity and convenient treatment or improvement. Usually follow C, and are followed by C again and G.	6. Underground works and Special foundations
E. BOREHOLE IN SITU DEFORMABILITY AND STRESS TESTS		
	7. Deformability and state of stress of rock masses.	7. Foundations and Rock Excavation works.
F. EXCAVATIONS - STRIPPING AREAS, TRENCHES, SHAFTS & GALLERIES.		
	8. Provide rock exposures where they do not naturally exist. These exposures may be mapped and used with other data to build up a geological picture.	8. All major projects. Stripping is useful for sites where rock exposure is not available. Shafts and galleries are usually limited to major constructions. Trenches are useful on any project where in situ rock can be exposed beneath shallow weathered or alluvial materials.
G. IN SITU ROCK TESTS IN EXCAVATIONS & GALLERIES		
1. Deformability tests	9. Deformability settlement, rheological behaviour and possible geometry of fabric of the rock masses.	9. Foundations and Rock excavation works.
2. Direct shear tests	10. Normal and shear stiffness and shear strength parameters for joints and seams, or for rock substance.	10. Underground constructions, tunnels, foundations for dams and other large structures, retaining walls, slope stability

		studies, etc.
3. Internal stress tests	11. Measurements of apparent stresses in different directions in rock in situ around the excavation, from which the probable original stress pattern can be calculated.	11. Underground constructions, tunnels, etc.
H. BLASTING TESTS	12. Conditions of excavation or exploration of rock masses. Tests of suitability of certain blasting techniques like "cayotte" method, etc.	12. Rock-fill works, large excavations, underground openings, quarries development, etc.

6.4 LABORATORY TESTING

6.4.1 Soil Mechanical Properties

Depending on the purpose of the investigation, the laboratory testing program shall include the following as a minimum:

1) Analysis of cohesionless soils:
   - visual classification, including sample description
   - wet and dry volume weight
   - grain size distribution, including silt content
   - chemical analysis of soil
   - organic content of silt samples
   - permeability tests.
2) Analysis of cohesive soils:
   - visual classification, including sample description
   - wet and dry volume weight, and water content
   - Atterberg limits (plasticity index)
   - chemical analysis of soil
   - organic content
   - angle of internal friction and cohesion, including stress/strain characteristics
   - consolidation coefficient (compressibility).

For reporting requirements, refer (6.2.9).

6.4.2 Chemical Analysis of Groundwater and Soils

The following analyses should be performed on groundwater and soil/rock samples in order to ascertain the aggressiveness of the groundwater and soil/rock towards concrete, steel and other buried items. For reporting requirements, refer (6.2.9).

6.4.2.1 Groundwater

The analysis shall include determination of the following:

1) pH value (ASTM D 1293).
2) Hardness: ($CaCO_3$) in mg/litre (ASTM D 1126)
   a) Total hardness.
   b) Carbonate hardness.
   c) Non-carbonate hardness.
3) a) Concentration of free carbon dioxide (CO_2) in mg/litre (ASTM D 513).
   b) Determination of aggressive CO_2 in accordance with the method attributed to Heyer, as described in DIN 4030: article 5.2.9.
4) Concentration of sulphates ($SO^{--}{}_4$) in mg/litre (ASTM D 516).
5) Concentration of chlorides (Cl^-) in mg/litre (ASTM D 512).
6) Concentration of magnesium (Mg^{++}) in mg/litre (ASTM D 511).
7) Concentration of sulphides (S^{--}) in mg/litre (DIN 4030).

8) Concentration of ammonium (NH^{+}_4) in mg/litre (ASTM D 1426).

9) Potassium permanganate consumption (ASTM D 2033).

10) Lime content (CaO) in mg/litre (ASTM D 511).

6.4.2.2 Soils (including weathered rock, etc.)

The analysis shall include determination of the following:

1) Acidity of soil expressed as a Bauman-Gully number (DIN 4030).

2) Sulphate content (SO^{--}_4) in mg/kg (DIN 4030).

3) Sulphide content (S^{--}) in mg/kg (DIN 4030).

4) Chloride content (Cl^{-}) in mg/kg.

5) Content of heavy metals and other polluting reagents in mud samples taken from harbour and estuarine areas.

6) Mineralogical composition of clay/silt samples, when applicable.

6.4.3 Testing of Rock Samples

6.4.3.1 General Properties

Depending on the purpose of the investigation, the laboratory testing program shall include the following as a minimum:

- density
- water content
- porosity
- permeability
- mineralogical and petrological composition
- solvability.

6.4.3.2 Strength Properties

Strength properties shall be determined by compression test, point load test or Brazilian tensile test. Another important property that shall be determined is the strength anisotropy index (I_a).

Relevant information on strength testing of rock samples and the determination of the strength anisotropy index (I_a) is given in Appendix V.

6.4.3.3 Weatherability

As an indication of the weatherability of the rock the aggregate durability index shall be determined.

It is expressed as a percentage and can vary from 0% for a rock which disintegrates completely, up to 100% for rock in which no disintegration occurs.

A description of this test is given in ASTM D 3744.

6.4.3.4 Other Properties

In addition to establishing the general properties, it may be necessary also to determine the following characteristics:

1) The strength characteristics of the rock in its various degrees of weathering just as it exists on the site (the relationship of the stress, cohesion, angle of internal friction, hardness and other characteristics of the rock to the mineralogical alteration degree is important to the understanding of the rock mass properties).
2) The rock deformability characteristics in its various degrees of weathering, including deformability characterization under short and long term loading.
3) The wave propagation velocity through the rock sample relative to the various degrees of weathering.
4) The anisotropy with regard to strength and deformability.

All tests shall be performed in accordance with the orientation of the rock layers or minerals.

6.4.3.5 Chemical Analysis

The chemical analysis of groundwater in rocky/cemented soil formations and of the rock/cemented soil samples shall be carried out as far as is relevant in accordance with the requirements of (6.4.2).

7. HYDROLOGICAL AND ENVIRONMENTAL DATA COLLECTION

7.1 DATA REQUIRED

The following information relating to the site shall be collected as a minimum:

- precipitation data
- evapotranspiration data
- temperature data
- humidity data
- wind data, including cyclonic data where relevant
- groundwater levels
- quality and variations in quality of groundwater
- surface run-off
- open wells, where relevant
- possible erosion due to surface run-off
- existing drainage systems (or lack of these)
- possible existence of water and soil pollution, and contaminated waste deposits.

The primary investigation into groundwater may be limited largely to determining its effect on construction methods. However, to the extent that unusual groundwater situations are indicated as a result of the examination, this may have an important effect on the design (and cost) of foundations. Important information with respect to groundwater can sometimes be obtained from the subsurface investigations into foundation conditions.

7.2 SOIL, WATER AND MUD SAMPLES

Soil and water samples collected onshore, and mud samples collected along the shore (at the proposed location of a berth/jetty), shall be analysed in accordance with (6.4.2).

7.3 HYDROLOGICAL INVESTIGATIONS

If the preliminary investigations have been relatively complete, the hydrological investigations included in them may be sufficient for design purposes, and no further detailed investigations will be necessary. However, where the study of a particular feature during the preliminary phase has been computed by approximation or without making full use of all available data, for example the incidence of maximum flooding, then these studies should be extended in detail before the design of the structure is undertaken.

8. HYDRAULIC SURVEY (RIVERS, CANALS, LAKES AND SEA)

8.1 FREE RUNNING WATER

If the proposed site is adjacent to any free running water, a hydraulic survey shall be carried out.

The primary study should begin with researching records and data relevant to the region. For some regions such information may be scarce or just not available, in which case (local) government or other native resources should be consulted, if possible. The information collected shall be supplemented by a field survey which should contain the following hydrographical data as a minimum:

1) For sea:
   - mean sea level datum (MSL)
   - mean high water springs (MHWS) and mean low water springs (MLWS)
   - lowest astronomical tide (LAT)
   - rise and range of tide with reference to Standard and Secondary Ports
   - tidal streams
   - the prevailing current speed and direction
   - predominant wave pattern and predictable variations thereto
   - general morphological data
   - quantity and pattern of siltation.
2) For rivers:
   - stream flow pattern and velocity
   - predictable variation in water level and discharge
   - indications of silting up
   - incidence of sediment and floating debris.
3) For canals:
   - stream flow pattern and velocity
   - predictable variation in water level.
4) For lakes:
   - predictable variation in water level
   - incidence of storms and high winds, and their effect on generating waves.

More especially for rivers, if a record is available which covers a period of 20 years or more, a satisfactory determination for purposes of design may be arrived at, both as to the maximum flood flow and as to somewhat smaller floods that may be expected to occur with any particular frequency. If such a record covers only a few years, it may not include within its limits any flood of great magnitude.

It will, however, permit an analysis of the larger floods shown, a determination of their relationship to the precipitation which produced them, and a determination of maximum flood flow through the application of this relationship to maximum expected storm precipitation.

8.2 FLOODING

The preliminary investigations shall always include an assessment of the risk of flooding, from whatever cause.

8.3 APPLICATION AND EXTENSION OF THE PRELIMINARY HYDRAULIC SURVEY

If the preliminary hydraulic survey has been relatively complete, it will generally be sufficient for site selection purposes. Once the site has been chosen, however, a more detailed investigation shall be carried out into some or all of the following items:

- determination of water temperatures and variations thereto
- chemical analysis of silt, and determination of chloride (Cl^-) content of the water
- investigation of the stability of the coast and/or river banks, with particular regard to erosion and future trends
- the need for shore and/or river bank protection work
- landing stages for the construction phase and for later operations
- incidence of typhoons and their likely effect
- subterranean water and its proximity to any proposed excavations or borings for foundations.

9. POLLUTION SURVEY

The degree to which locally generated pollution, from whatever cause, or effluent treatment facilities for the proposed project could be limiting factors in site selection, should be established at an early stage.

For example, water samples should be taken from watercourses below (local authority) sewage disposal systems and analysed, particularly if there is an outfall emptying into the stream. If the disposal system includes a by-pass, its effect should be evaluated. Similarly, the effect of other forms of pollution should also be evaluated.

Soil samples taken at suspected areas onshore, and mud samples taken offshore along the coast near to any outfall or discharge point at, or close to, the proposed location of a berth/jetty, shall be analysed for heavy metals and other polluting reagents, refer (6.4.2).

Effluent treatment facilities shall comply with, and shall be so sited as to meet local authority regulations.

10. REFERENCES

In this manual reference is made to the following publications:

Note: The latest issue of each publication shall be used together with any amendments/supplements/revisions to such publications, unless otherwise stated.

It is particularly important that the effect of revisions to international, national or other standards shall be considered when they are used in conjunction with DEP's, unless the standard referred to has been prescribed by date.

The use of SI units	DEP 00.00.20.10-Gen.

AMERICAN STANDARDS

Road and paving materials; Travelled surface characteristics	ASTM Volume 04.03
Natural Building Stones; Soil and Rock	ASTM Volume 04.08
Water (I)	ASTM Volume 11.01
Water (II)	ASTM Volume 11.02
Recommended practice for investigation and sampling soil and rock for engineering purposes	ASTM D 420
Test method for calcium and magnesium in water	ASTM D 511
Test method for chloride ion in water and waste	ASTM D 512
Test methods for carbon dioxide and biocarbonate and carbonate ions in water	ASTM D 513
Test method for sulphate ion in water	ASTM D 516
Definitions of terms and symbols relating to soil and rock mechanics	ASTM D 653
Test methods for hardness in water	ASTM D 1126
Test method for pH of water	ASTM D 1293
Test methods for ammonia nitrogen in water	ASTM D 1426
Practice for soil investigation and sampling by auger borings	ASTM D 1452
Thin-walled tube sampling of soils	ASTM D 1587
Test methods for particulate and dissolved matter in water	ASTM D 1888
Test method for consumption of potassium permanganate by impurities in deuterium oxide	ASTM D 2033
Classification of soils for engineering purposes	ASTM D 2487
Deep, quasi-static cone and friction cone penetration tests of soil	ASTM D 3441
Aggregate durability index	ASTM D 3744

Metric practice	ASTM E 380

Issued by:
American Society for Testing and Materials
1916 Race Street, Philadelphia,
Pa. 19103, USA

BRITISH STANDARDS

Code of practice for site investigation	BS 5930

Issued by
British Standards Institution,
2 Park Street, London W1A 2BS,
England

GERMAN STANDARDS

Evaluation of liquids, soils and gases agressive to concrete	DIN 4030

Issued by
Beuth Verlag GmbH,
Burggrafenstrasse 4-10,
D-1000 Berlin 30,
W. Germany

INTERNATIONAL STANDARDS

Report of the sub-committee on standardization of penetration testing in Europe

Issued by
The International Society for Soil Mechanics and Foundation Engineering.
(Presented at the 9th international conference on soil mechanics and foundation engineering in Tokio 1977)

11. APPENDICES

	Appendix
Methods for presenting substratum data derived from field measurements	I
Geophysical surveys	II
Borehole drilling	III
Summary of some engineering geological data/information	IV
Some data on strength testing and determination of anisotropy index of rock samples	V

APPENDIX I METHODS FOR PRESENTING SUBSTRATUM DATA DERIVED FROM FIELD MEASUREMENTS

Figure I-1: Result of a DCPT carried out using an electrical cone penetrometer with a friction sleeve providing continuous registration of cone resistance and local side friction (6.2.2).

Figure I-2: Result of a DCPT carried out using a simple (standard) cone penetration device, i.e. a mechanical cone without friction sleeve, providing only an intermittent or non-continuous registration of cone resistance (6.2.2)

Figure I-3: Comparison of the result of a DCPT with data obtained from a boring log (6.2.3, 6.2.6 and 6.3.4.7).

Figure I-4: Result of a combined measurement of cone penetration and pore water pressure (6.2.6).

Figure I-5: Results of DCPT and in-situ density measurement (6.2.6).

Figure I-6: Result of an SPT, (6.2.3, 6.2.6 and 6.2.7).

Figure I-7: Comparison of the result of a DCPT with the result of an SPT in soily substratum (6.2.3 and 6.2.6).

Figure I-8: Result of a Menard pressure meter test (6.2.6 and 6.2.7).

Figure I-1: RESULT OF A DCPT CARRIED OUT USING AN ELECTRICAL CONE PENETROMETER WITH A FRICTION SLEEVE PROVIDING CONTINUOUS REGISTRATION OF CONE RESISTANCE AND LOCAL SIDE FRICTION (6.2.2).

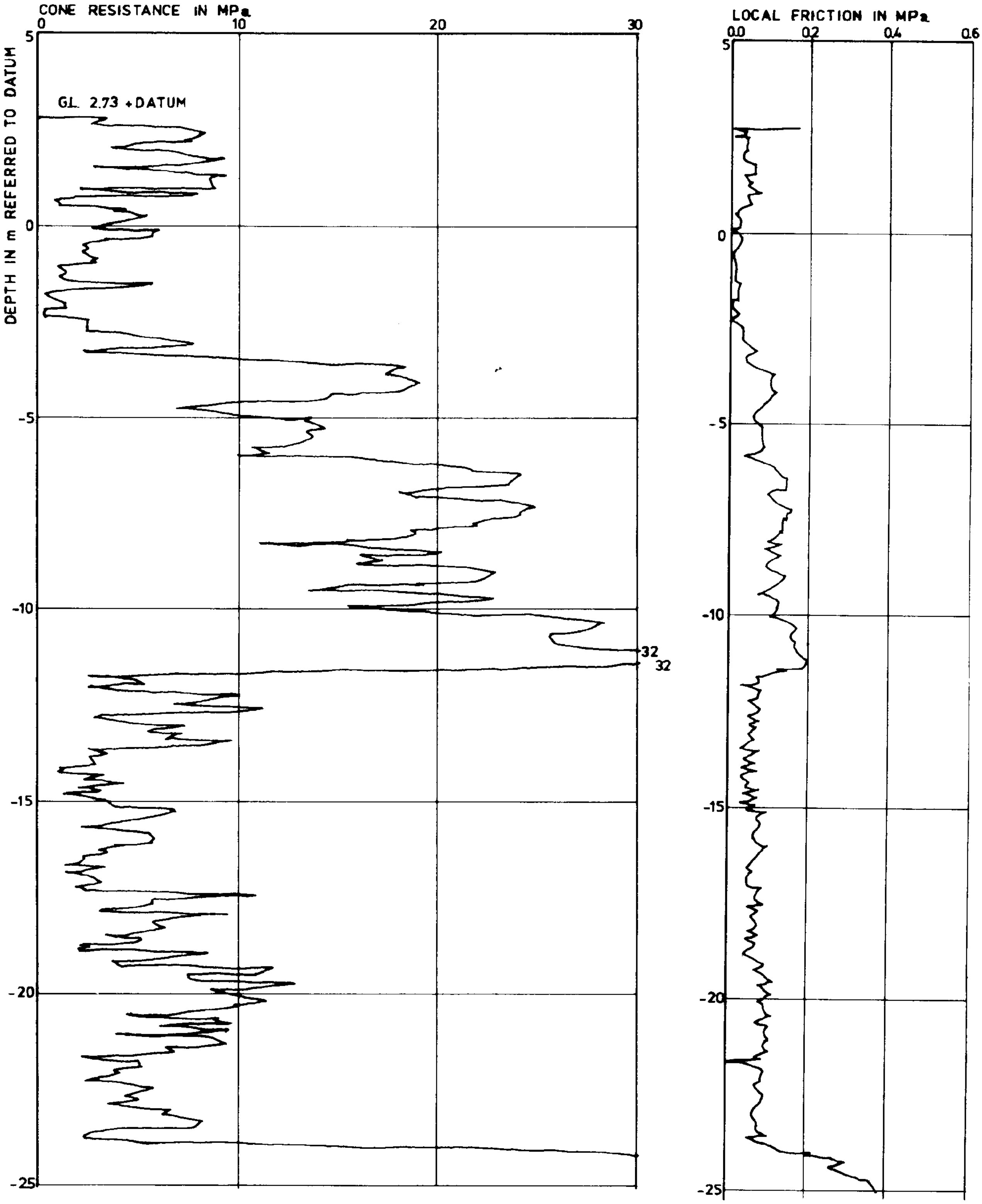


Figure I-2: RESULT OF A DCPT CARRIED OUT USING A SIMPLE (STANDARD) CONE PENETRATION DEVICE, i.e. A MECHANICAL CONE WITHOUT FRICTION SLEEVE, PROVIDING ONLY AN INTERMITTENT OR NON-CONTINUOUS REGISTRATION OF CONE RESISTANCE (6.2.2).

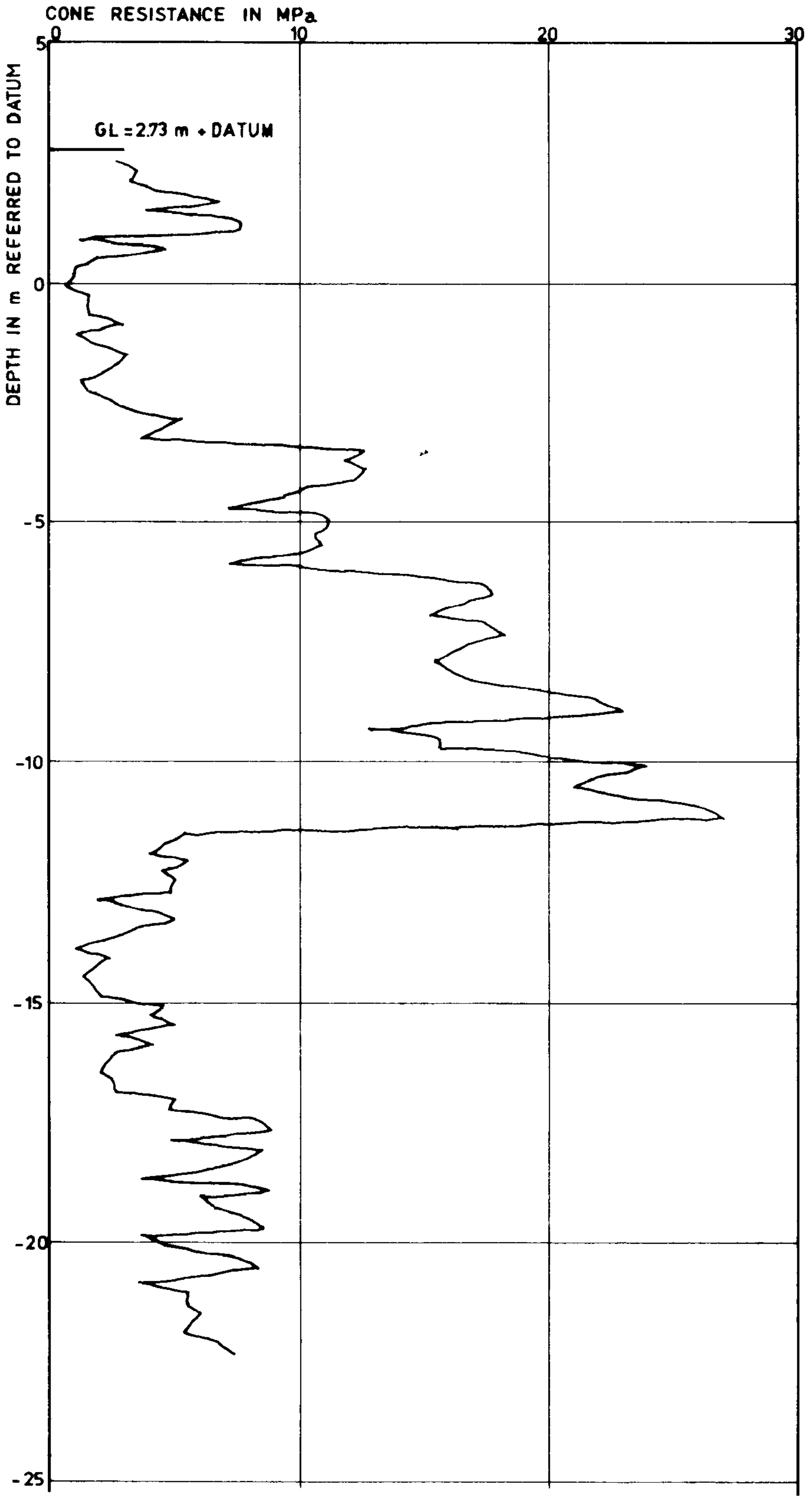


Figure I-3: COMPARISON OF THE RESULT OF A DCPT WITH DATA OBTAINED FROM A BORING LOG (6.2.3, 6.2.6 and 6.3.4.7).

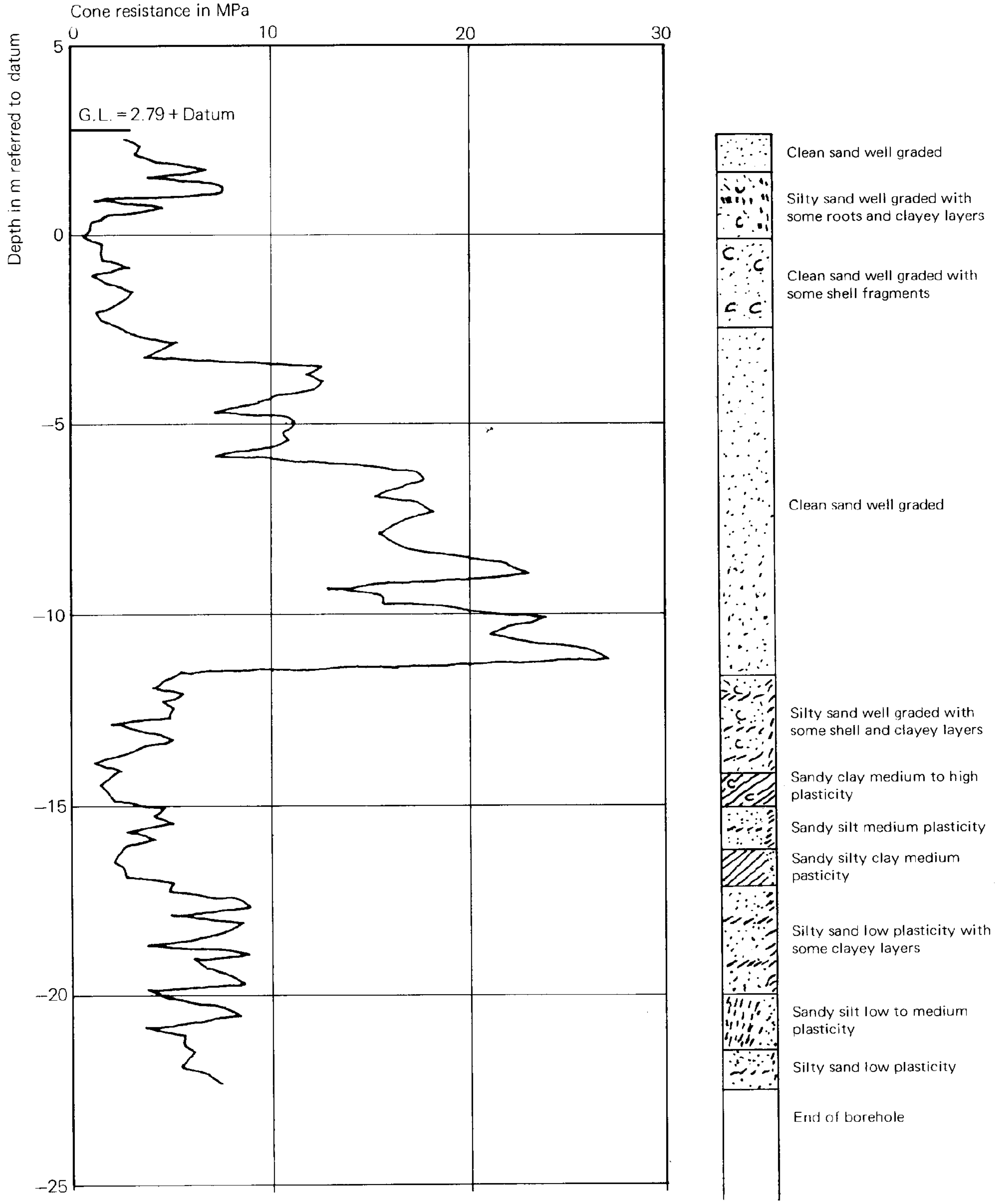


Figure I-4: RESULT OF A COMBINED MEASUREMENT OF CONE PENETRATION AND PORE WATER PRESSURE(6.2.6).

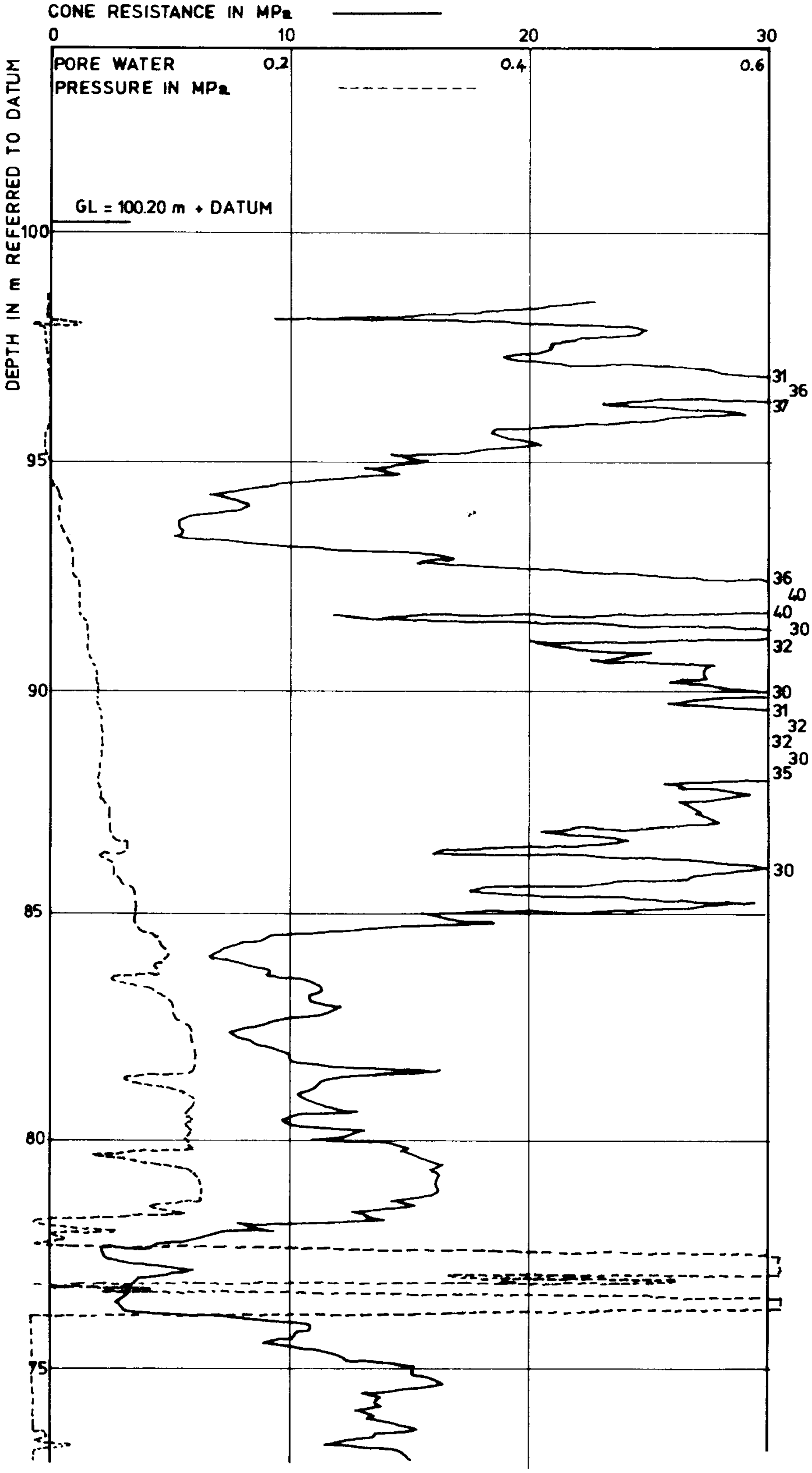


Figure I-5: RESULTS OF DCPT AND IN-SITU DENSITY MEASUREMENT(6.2.6).

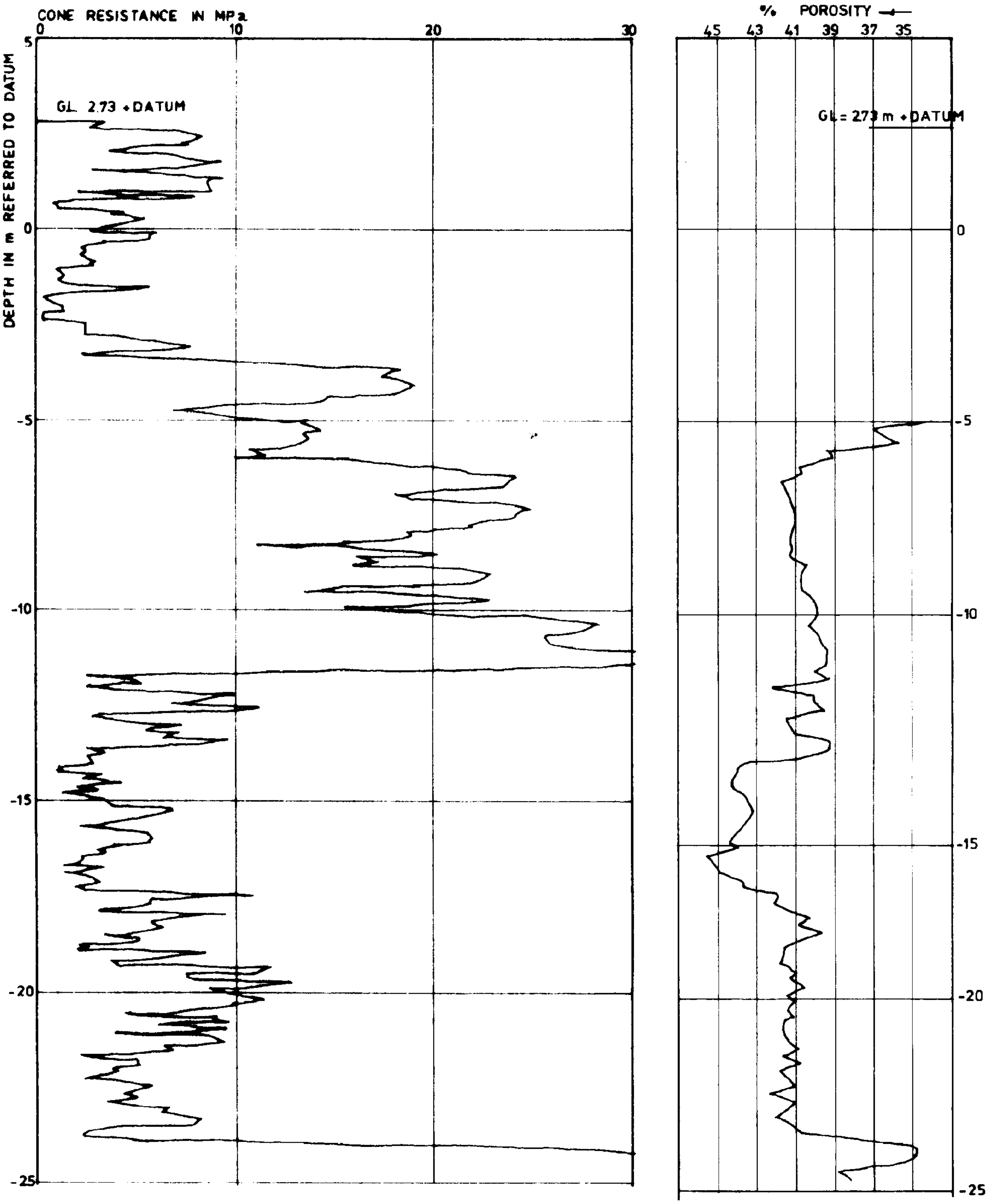


Figure I-6: RESULT OF A BOREHOLE WITH SPT.

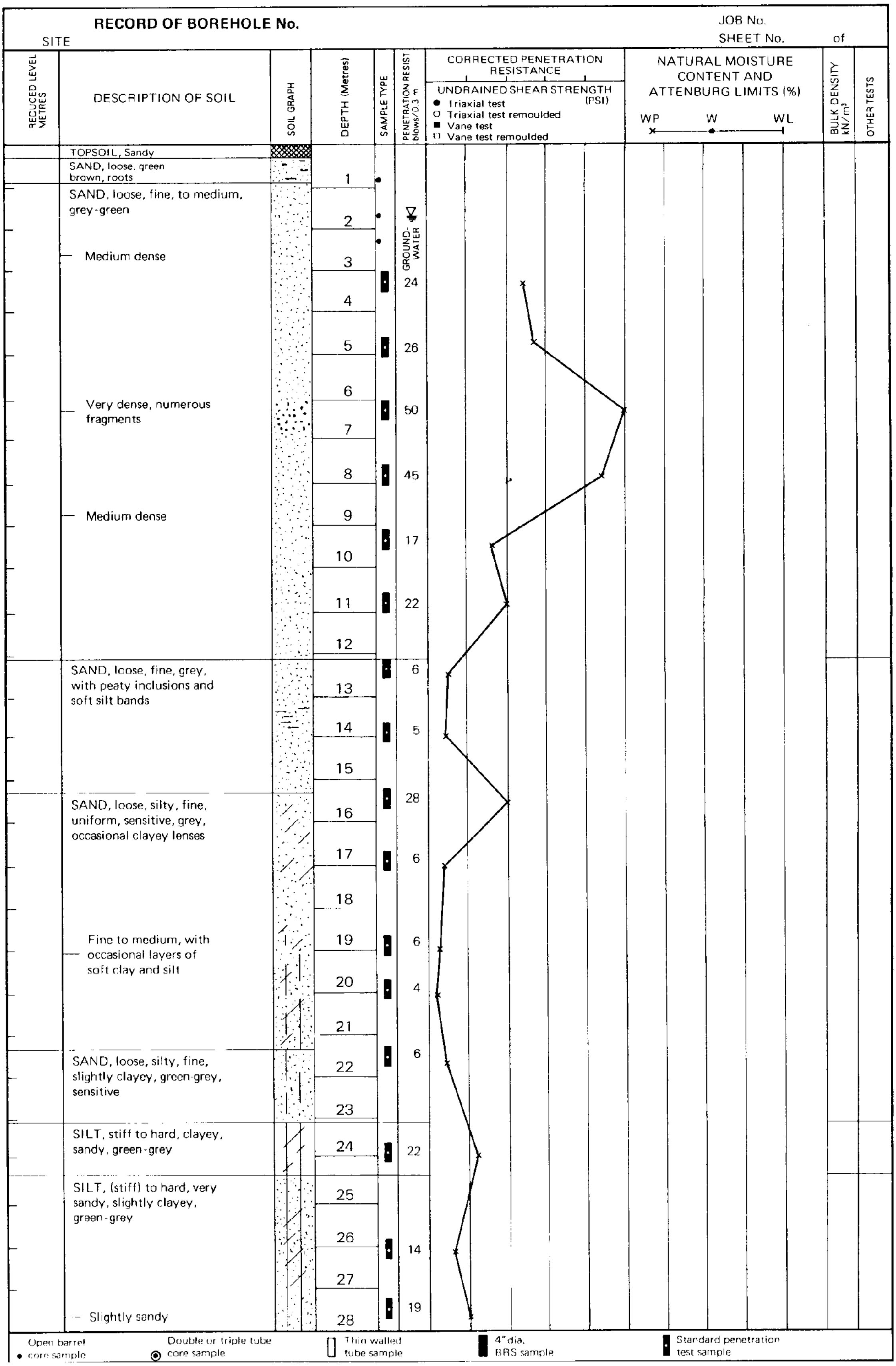


Figure I-7: COMPARISON OF THE RESULT OF A DCPT WITH THE RESULT OF AN SPT IN SOILY SUBSTRATUM (6.2.3 and 6.2.6).

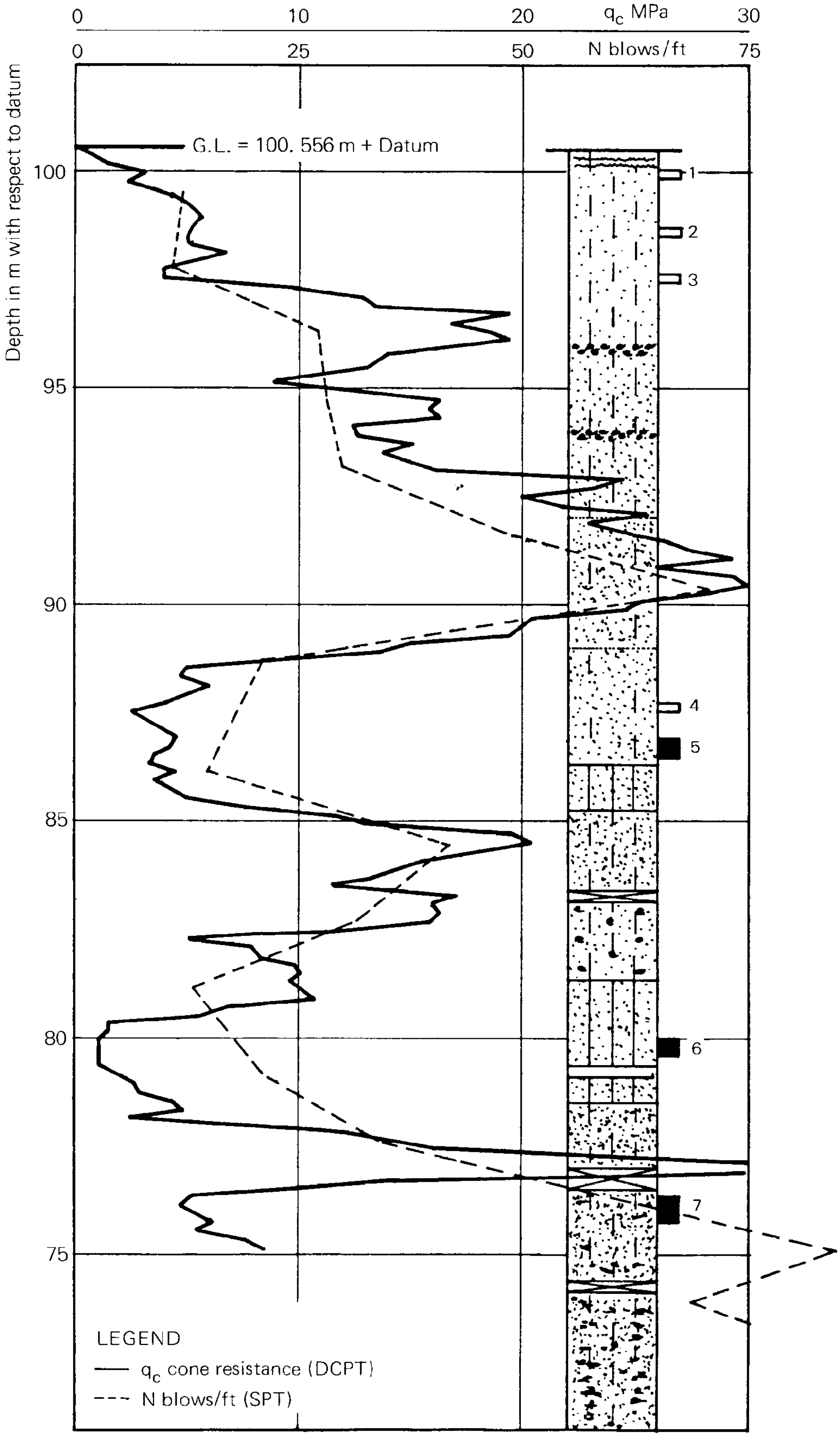
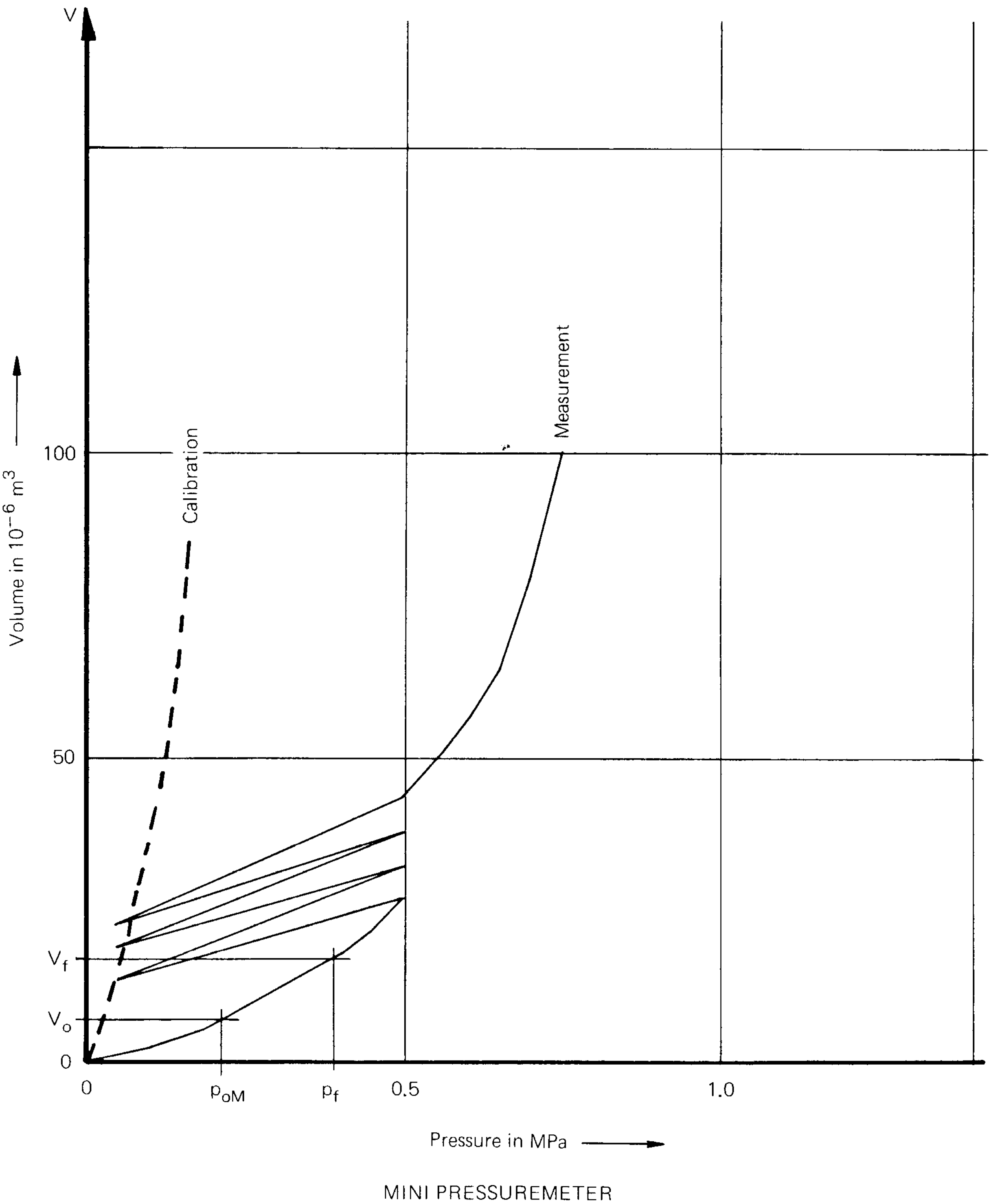


Figure I-8: RESULT OF A MENARD PRESSURE METER TEST.



NOTES TO FIGURE I-8

1. For a pressure meter test, a probe is inserted into a pocket below the bottom of a borehole or directly into a drilled hole of appropriate size and expanded laterally by compressed air or gas. The applied pressures and the resulting deformation (change of probe volume) are measured and used to determine the strength and deformation characteristics of the soil being investigated.

2. From the loading curve shown in figure I-8 the following parameters can be obtained:

   - Limit pressure p_f, which is related to the shearing resistance of the soil layer
   - Pressure meter modulus E_M

   As the pressure and volume changes are measured at ground level the measurements have to be corrected for deformations of the apparatus (tubes, etc.)by means of the calibration curve.

3. The modulus E_M is calculated with the following formula:

   (in MPa)

$$E_M = 2.66 * \left[V_c + \frac{V_f + V_0}{2} \right] * \left[\frac{p_f - p_{oM}}{V_f - V_0} \right]$$

   where:

V_c	=	initial volume measuring cell	(in m^3)
V_f	=	increase in volume of the measuring cell to reach the creep pressure	(in m^3)
V_o	=	difference between the volume of the cavity and the initial volume of the measuring cell	(in m^3)
p_f	=	creep pressure	(in MPa)
p_{oM}	=	pressure at the start of the straight line portion of the pressure meter test curve	(in MPa)

4. An extensive description of the pressure meter test is given by F. BAQUELIN in 'The Pressure Meter and Foundation Engineering'.

APPENDIX II GEOPHYSICAL SURVEYS

1. Engineering projects

A distinction must be drawn between geophysical exploration for engineering projects, and geophysical exploration for hydrocarbons.

Engineering geophysics investigates specific characteristics of subsurface materials, usually to depths of tens up to a maximum of a hundred metres. The investigation of layer thicknesses, properties of individual layers, interbeddings, locations and characteristics of faults, fractures, shear zones, and other aspects of engineering interest requires specific measuring techniques. The analysis of details of engineering interest requires instruments with a measuring accuracy that is sometimes close to technical limits.

For geophysical methods, the following classification is generally adopted:

a) seismic methods (propagation of elastic waves)
b) geoelectric methods (distribution of electric conductivity or dielectric constant)
c) radioactive methods (distribution of radioactivity)
d) geomagnetic methods (distribution of magnetic susceptibility)
e) geothermal methods (distribution of heat conductivity)
f) gravimetric methods (distribution of densities).

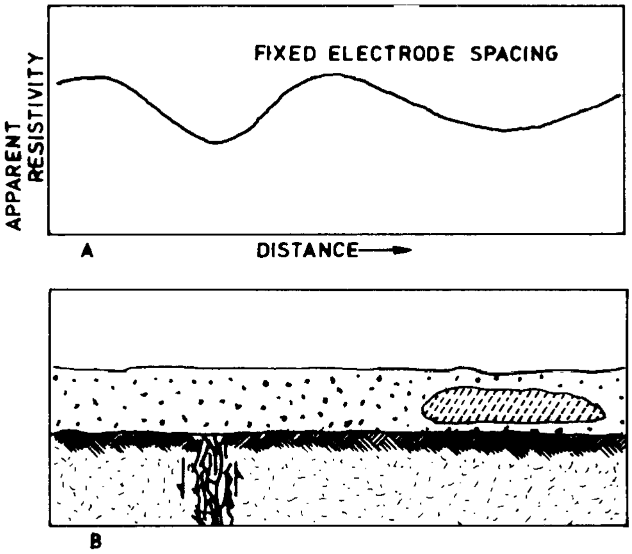
Features of the more commonly used methods and some geophysical properties are summarized in Tables II-1 A, B and C.

Table II-1.A GEOPHYSICAL METHODS

Method	Information provided	Main application
• Electrical Resistivity	1. Provides a measure of the "apparant resistivity" of the ground surface. Useful for locating the depth to bedrock beneath alluvium or weathered rock cover; also in the location of the water table, buried conductors or non-conductors, sheared zones, etc.	1. Most suited to projects requiring data at relatively shallow depths over large or elongated areas, e.g. construction materials, dam sites, roads, canal pipelines, etc.
• Seismic Refraction	2. Provides calculated values of the velocities of seismic waves in various layers of subsurface materials and calculated depths of the intersurfaces between the layers. The seismic velocity can also give an indication of whether or not a rock mass will require blasting for excavation and the dynamic modules of elasticity. 1. and 2. If carried out early can be used to obtain an initial indication of site conditions, to assist in the planning of direct exploration, it provides the basis for interpolation between the results of separate drill holes, and in some cases, extrapolation into the areas not covered by drill holes.	2. As above.
• Seismic Reflection	3. Provides measurements of the travel times of seismic waves reflected from interfaces between different rock or soil layers at depth.	3. Generally suited to submarine projects, dredging harbours, breakwaters.
• Geophysical and Nuclear and other methods of Bore-hole Logging	4. Provides measurements of the electrical, seismic and radio-active properties of the sub-surface materials, around boreholes.	4. Very useful occasionally to indicate the reason for core loss in diamond drilled holes, can show up cavities as distinct from weak seams and can provide information on hydrogeologic lithologic and tectonic conditions.

Table II-1.B RESISTIVITY OF SOME COMMON MATERIALS

Material	Resistivity (ohm.m)
Hard bedrock. Dry sand and gravel	26 000 and more
Slightly fractured bedrock. Sand and gravel with layers of silt	3300 - 29 500
Silty sand and gravel	3300 approx.
Fractured bedrock with water-filled cracks	1600 - 3300
Wet, silty clay	30 - 170
Saturated or moist clay	17 - 30



Hypothetical apparent resistivity curves obtained from a linear traverse with a fixed electrode spacing over a water-bearing fault beneath a gravel stratum and a clay lens in the gravel stratum.

Table II-1.C VELOCITIES OF COMPRESSION WAVES

	Vp m/s
Igneous rocks	
Basalt	5000 - 6400
Diabase	5800 - 6600
Gabbro	4000 - 6700
Granite	5500 - 6001
Metamorphic rocks	
Gneiss	3500 - 7000
Marble	3700 - 6900
Quartzite	5500 - 6001
Schist	3500 - 5500
Slate	3500 - 5300
Sedimentary rocks	
Dolostone (dolomite)	3500 - 6900
Gypsum	2000 - 3500
Limestone	2700 - 7000
Sandstone	1400 - 4400
Shale	2100 - 4400
Unconsolidated deposits	
Alluvium	300 - 600
Clay (wet)	1500 - 2000
Clay (sandy)	1800 - 2400
Water (25°C)	1500

The practical characteristics of the investigations can change rather rapidly according to the results obtained. Consistent with the needs of each particular problem, it is useful to modify the relative density of measurements which sometimes results in a change in the interpretation and a change, even, in the method itself: , for instance, from a refraction seismic method to a reflection seismic method or to a geoelectric method. In some cases it is necessary to change equipment, for instance, to increase the sensitivity of measurements.

2. Experience

The geophysical methods allow ascertainable relations, based on experience and empirical correlations between various quantities:, e.g. the absorption of elastic waves and the rheologic behaviour of solid and loose rocks, density, velocity of propagation of elastic waves, electrical resistivity, heat conductivity, permeability, porosity, internal stresses, water saturation, cementation, grain size, anisotropy, etc. A final clarification of these relations requires additional investigations that will help towards a closer correlation between geological and engineering facts about rock masses and structures and the results of physical measurements and the characteristics derived from them.

Radioactive determination of density and water content, and seismic and geoelectric exploration methods in boreholes for determining porosity, heavily jointed fabrics, faults and the dynamic moduli of elasticity are well proven geophysical methods of in-situ determination of soil and rock characteristics.

3. Long and shallow works

Investigations for long and shallow works like roads, channels, pipe trenches, usually begin with a profile along the axis with a medium or even a limited density of measurements. These are made as a part of the program for the geological investigation which also includes trenches, boreholes, seismic refraction, etc. Electrical resistivity methods are useful for combining two or more of these methods. Bore holes and other direct investigations are planned according to the results of the geophysical surveys.

Zones with special problems are usually studied in more detail after the preliminary investigation.

Before construction, it is useful to perform seismic refraction tests on locations of embankments and excavations that will be greater than 3 metres (approximately) in order to predict the methods of excavation, the time of construction, and the cost.

In zones with risk of subsidence by sinkholes or caves near the surface, investigations with a high density of measurements shall be used for defining the suspected points that must be tested by boreholes, pits or trenches.

4. Tunnels and galleries

Tunnels and galleries for water and deep storage facilities, whether under pressure or not, are among the type of works which have a long and deep axis that can be investigated by means of geophysical methods. Investigations are normally performed on an alignment defined by topographical and geological surface conditions. It is always convenient to study a zone with a certain width on both sides of the axis, to help the interpretation and to examine the possible alternatives in modifications of the alignment.

Very deep investigations present difficulties due to variations in shallow conditions near the alignment. For better separation of these effects from the results, lateral tests or 'partition' measurements are used (supplementary electrodes in resistivity, lateral shooting for seismic arrays). Access by adits or boreholes to the interior of the rock/soil mass may help for the geophysical work. Resistivity measurements as well as reflection-refraction seismic measurements can sometimes attain useful data.

5. Large works

For investigations of large and shallow works, e.g. tank farms, three types of geophysical programs can be considered for practical applications:

a) Parallel profiles rather closely spaced in order to form a grid and to provide enough data. They are usually combined with boreholes or shafts located after obtaining the results of the geophysical studies.

b) A few main profiles, in general one or two parallel to the longest direction and two or three perpendicular. After examination of the initial results, additional profiles as well as boreholes are drilled along the main profiles.

c) Perimeter profiles are followed by others when the first results of interpretation are completed. More detail may be required in later phases, according to the nature of the preliminary results.

The methods applied in these investigations are very often shallow seismic refraction and the different techniques of electrical resistivity.

Problems related to the type of work and the geological investigations conducted define the type of methods to be used.

If bearing capacity and deformability of the foundation are the problems to be studied, seismic refraction must be one of the methods used. It is important that measurements include both longitudinal ('P' wave) and transverse ('S' wave) velocity values for accurate moduli determinations. The use of two geophysical methods to confirm each other should be considered, since complete calculations need the knowledge of geometrical forms.

6. Cavities

Investigations for underground cavern storage or of large cavities in karstic rock masses call for investigations similar to those described above (III-5). In most cases, geophysical programs, types b) and c) are preferred, owing to their greater capacity for adapting to the needs for evaluating lateral influences.

Exploration in boreholes or using cross-hole methods are often used, taking advantage of boreholes drilled for direct investigation. These tests are accomplished by direct transmission of seismic waves and deep resistivity. Information obtained can be related at once to the results of borings and tests on the cores, and reliable interpretations can be achieved in a short time.

7. Rock masses with important joint and fracture systems

Rock masses with important joint and fracture systems, which is very often the case with hard sedimentary or sound crystalline rocks, can be effectively investigated as follows:

a) Seismic refraction and microseismic measurements are affected by joints and fractures, and their openings. Occasional drainage of interstitial water has an important effect if a developed fracturation exists. Seismic measurements reflect the elastic characteristics of the zones investigated, and permit the calculation of their dynamic values.

b) Electrical methods, based on conductivity (with different resistivity procedures), discover the shape and dimensions of the different zones. The influence of interstitial water and drainage is superimposed upon the conductivity of the rock itself, giving information about fracturation and permeability.

c) Some methods not so often used, such as controlled and coherent steady-state waves, geothermal and gravimetric methods, are useful in some instances in the exploration of fissured rock masses. Coherent values can help to indicate the surfaces or zones of transition. Geothermal measurements are useful for the analysis of phreatic water movements. Gravimetric or magnetic methods can detect faults, dykes and weak zones or inclusions.

8. Slightly jointed rock

In slightly jointed rock masses (i.e. relative absence of jointing), site investigations are easier because the differences between the localised measurements and the averages for a zone are less than in the case of intensely jointed rock masses. The density of measurements required for geophysical tests and for suitable definition of physical characteristics is less than that in the heavily fractured rock masses. The reliability of the results and the knowledge of the isotropy or anisotropy can become highly representative and useful in the case of slightly jointed rock masses.

Geophysical investigations are mainly used in these rock types to define the depth of weathering and the thickness of the overburden, the mapping of shear zones and fault areas, and the location of recommended points for boreholes, shafts or other investigating procedures. Elastic characteristics for dynamics problems are easily established.

9. Recent formations

Alluvial, volcanic or colluvial deposits (i.e. recent formations of low compaction), unconsolidated, consolidated and/or cemented soft or weak rocks have a high void ratio. Measurements of seismic velocities are of interest for evaluating the mechanical properties of such formations.

Investigations by resistivity methods allow the evaluation of the moisture changes and the water table position. In these formations, anomalous water tables can be found when the underground flow is distributed in alternating pervious and impervious levels.

10. Heterogeneous rock masses

In some cases rock formations are very heterogeneous, such as consolidated breccia, conglomerates, volcanic rocks (ash or vitreous tuffs), eruption materials with alternating lava flow and ash, hydraulic or volcanic tuffs, etc. Methods of investigation for these rock masses must consider the heterogeneous condition when deciding the density of measurements and the distribution of the points of measurements.

It is useful to begin the investigations with the minimum admissible density of measurements. This can be obtained with a first, single alignment. Initial results will usually indicate final density and distribution. It is desirable to obtain at least 3 different measurements for each zone and, if possible, an average of 10 or more. This condition is important for a good definition of transitions or boundaries.

Measurements carried out in heterogeneous media must be planned and interpreted in a different way to that adopted for uniform rock masses.

For the use of some methods (resistivity, electrical potential, seismic refraction, geomagnetic on a small scale), the density of measurements required can be from 4 to 10 times greater than the normal density needed for continuous and homogeneous rocks. For other methods, such as gravimetric, coherent waves or seismic reflection, many difficulties exist for heterogeneous formations and these methods can give a satisfactory subsurface picture if the quantity of measurements in the three dimensions is sufficient.

APPENDIX III BOREHOLE DRILLING

1. Percussion borehole drilling

Generally the ground is broken and penetrated by the percussion of repeatedly dropping a heavy bit of special steel suspended by a wire line or connected to the extremity of the sounding rod. The extraction of the cut samples is made by appropriate tools, referred to as 'bailers'. This is the most important moment of the percussive borehole drilling. The holes may require casing or not, depending on the looseness of the material bored. When necessary, water is introduced into the hole to make drilling easier and to help in recovery of drill cuttings. In soils or poorly consolidated rock, cuttings may be taken though they will always suffer a certain disturbance.

2. Rotary borehole drilling

A rotary boring is generally used for rock masses. The drilling is made by a special coring bit if it is desired to obtain a core. The debris resulting from the drilling is generally taken up to the surface by circulating water, or thin mud, injected through the rods. There are different types of core bits adapted to different types of rock masses and consolidated soils.

Table III-1: DIAMETERS COMMONLY USED IN BOREHOLE DRILLING

AMERICAN SERIES

Reference	Hole		Core	
	mm	in	mm	in
EX	38	1 1/2	22	7/8
AX	49	1 15/16	29	1 1/8
BX	60	2 3/8	41	1 5/8
NX	76	3 -	54	2 1/8
2 3/4 x 3 7/8	98	3 7/8	68	2 11/16
4 x 5 1/2	140	5 1/2	100	3 15/16
6 x 7 3/4	197	7 3/4	151	5 15/16

EUROPEAN SERIES

Reference	Hole	Core
Nominal diameter mm	mm	mm
45	46	24
55	56	34
65	66	38
75	76	48
85	86	58
100	101	72
115	116	86
130	131	101
145	146	116

APPENDIX IV SUMMARY OF CERTAIN ENGINEERING GEOLOGICAL DATA/INFORMATION

The information and data and the following tables and figures shall be applied in conjunction with the text of this manual as applicable.

Table IV-1: GRAIN SIZE CLASSIFICATION OF UNCONSOLIDATED DEPOSITS

Designation	Particle diameter (mm)
Cobbles, boulders, blocks	60
Coarse gravel	60 - 20
Medium gravel	20 - 6
Fine gravel	6 - 2
Coarse sand	2 - 0.6
Medium sand	0.6 - 0.2
Fine sand	0.2 - 0.06
Coarse silt	0.06 - 0.02
Medium silt	0.02 - 0.006
Fine silt	0.006 - 0.002
Clay	0.002

Table IV-2: LIST OF GRAPHIC SYMBOLS FOR PLOTTING LOGS OF UNCONSOLIDATED AND CONSOLIDATED (ROCK) MATERIALS

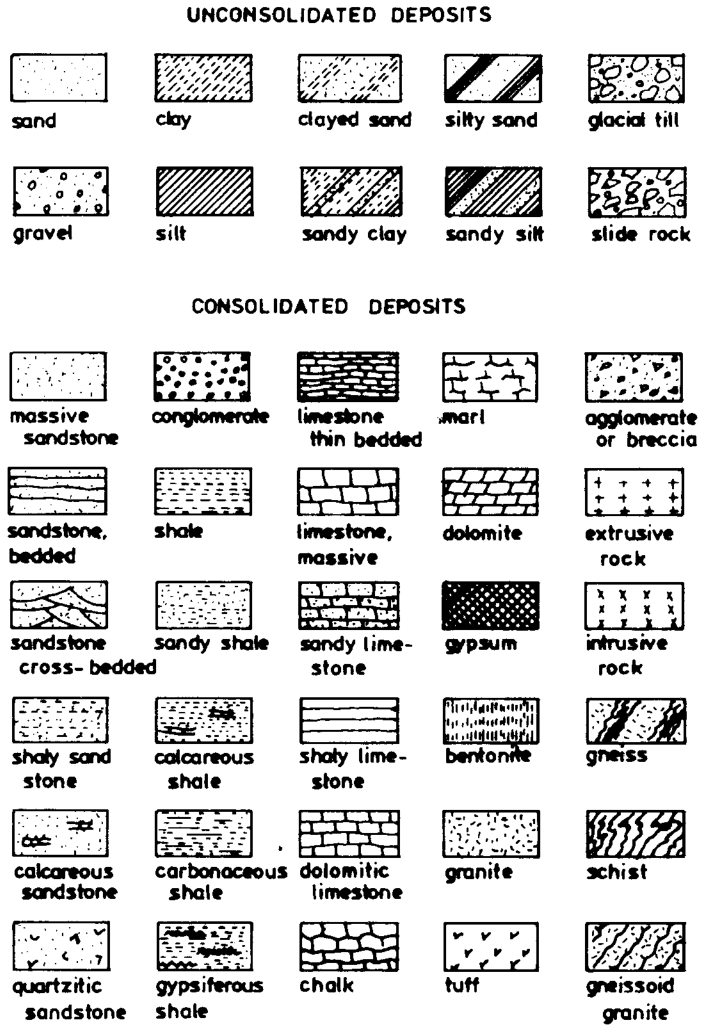


Table IV-3: RELATIVE PERMEABILITIES OF UNCONSOLIDATED MATERIALS

I.	Generally low permeablities A. Alluvial clay, mud, and silt accumulations B. Altered volcanic ash gravel with compact clay matirx C. Alluvial sand and gravel with compact clay matirx D. Glacial till with compact clay or rock flour matrix E. Buried mud flows F. Landslides, either consisting of clayey components, or of rock fragments in a continuous, compact clay matrix
II.	Generally with moderate permeabilities - sufficient to cause concern as to potential for seepage A. Alluvial sand or gravel, poorly sorted, and containing some clay matrix B. Very fine-grained sand C. Unaltered volcanic ash D. Glacial till with a low to moderate content of clay or rock flour E. Landslides consisting of rocky fragments with moderate amounts of clay-size matrix Some voids, not interconnecting, may be present F. Loess
III.	Generally with high permeabillities A. Well-washed and/or sorted alluvial sand or gravel B. Medium- to coarse-grained, angular pyroclastic deposits C. Glacial till with lenses or irregular bodies of steam-transported materials or glacial till in which piping has locally removed fine-grained matrix D. Buried sand dunes E. Landslides consisting of angular rock fragments with interconnecting interstitial voids

Table IV-4: ORDERS OF MAGNITUDE OF ORIGINAL PERMEABILITIES OF SOME NATURAL MATERIALS

	m/s
Unconsolidated sediments	
Gravel	10^{-2} - 1.0
Clean sand	10^{-5} - 10^{-2}
Clayey sand	10^{-8} - 10^{-5}
Clay	10^{-10} - 10^{-8}
Sedimentary rocks	
Sandstone	10^{-12} - 10^{-8}
Shale	10^{-12} - 10^{-10}
Limestone	10^{-11} - 10^{-8}
Crystalline, igneous and metamorphic rocks	10^{-12} - 10^{-10}

Table IV-5: RANGES OF UNCONFINED CRUSHING STRENGTHS OF SOME COMMON UNALTERED IGNEOUS AND METAMORPHIC ROCKS

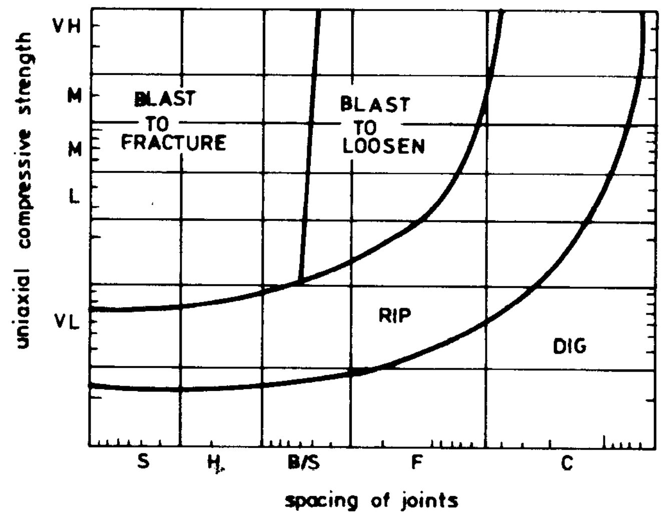
Rock	Crushing strength - MPa
Basalt	180 - 275
Diabase	150 - 320
Felsite and felsite porphyry	125 - 260
Gneiss	150 - 250
Granite	40 - 290
Marble	50 - 230
Phyllite (micaceous)	7 - 17
Quartzite	210 - 365
Schist, all varieties	8 - 140
Schist, mica-rich	8 - 50
Slate	100 - 325

Unconfined crushing strengths of some common clastic rocks

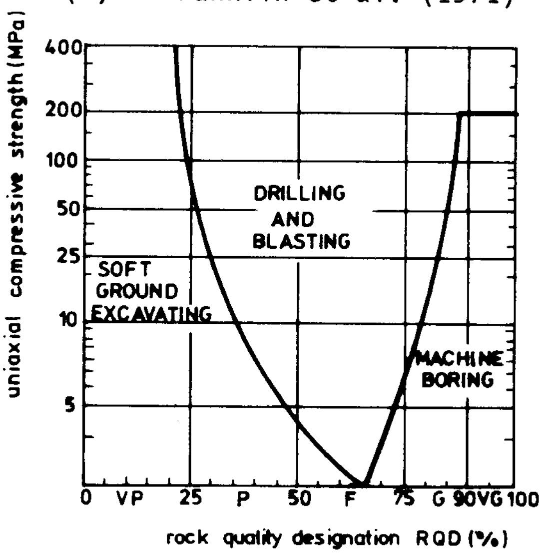
Rock	Crushing strength - MPa
Calcareous mudstone	55 - 190
Dolostone (dolomite)	60 - 350
Limestone	5 - 200
Sandstone	10 - 235
Shale	7 - 225
Siltstone	30 - 310

Figure IV-1: DIAGRAMS FOR THE WORKABILITY OF ROCK

Compiled from: (a) - Muir Wood (1972)



(b) - Franklin et al. (1971)

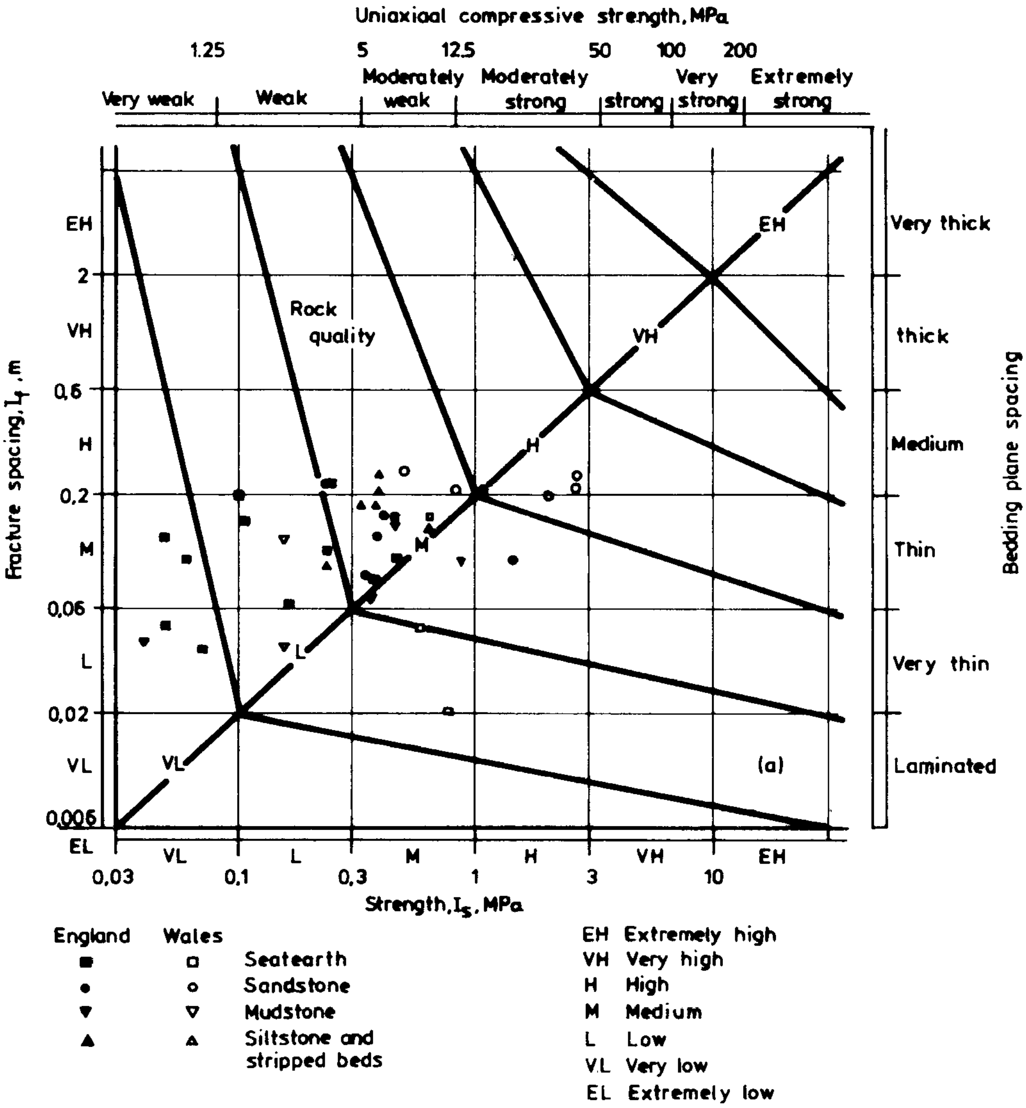


LEGEND:

Unixal compressive strength	Rock quality designation RQD (%)	Spacing of joints
VH-very high	VG-very good quality	S-solid(almost no joints)
H-high	G-good	M-massive
MH-medium	F-fair	B/S-blocky/seamy
L-low	P-poor	F-fractured
VL-very low	VP-very poor	C-crushed

Figure IV-2 ROCK QUALITY CLASSIFICATION DIAGRAMS.

General purpose classification is shown in (a) below, with an alternative method of subdivision (b) on page 8 of this appendix. The subdivision on the top and that on the right of the diagram (a) refer to suggestions by the Geological Society of London.

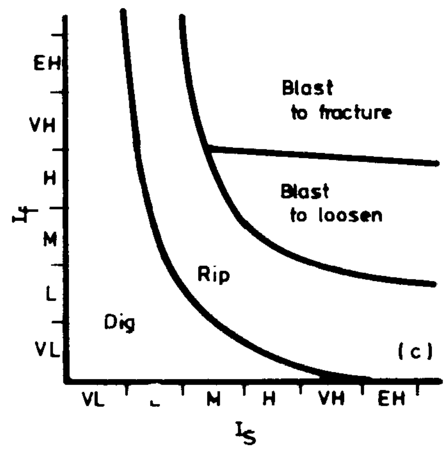


I_S = point load index (6.4.3.2 and Appendix V)

I_f = fracture spacing index (6.3.4.8)

Figure IV-2: ROCK QUALITY CLASSIFICATION DIAGRAMS - Cont'd

Alternative method of subdivision (b)



APPENDIX V DATA FOR THE STRENGTH TESTING AND DETERMINATION OF THE ANISOTROPY INDEX OF ROCK SAMPLES

PART 1

Figure V-1 DETAILS OF INDEX TESTS

(a) - point load tests
(b) - standard loading cone for point load tests
(c) - Brazilian disk test

Point Load Index, $I_S = \frac{P}{D^2}$

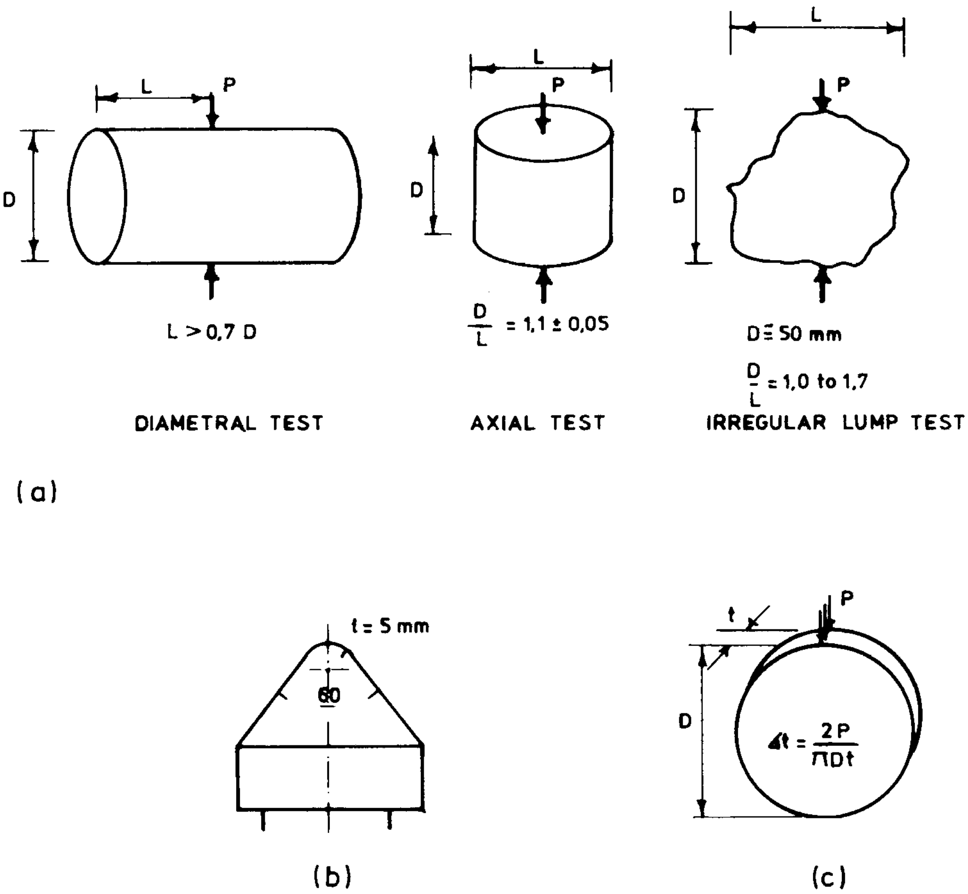


Table V-1: RESULTS OF POINT LOAD TESTING*

Rock material	Type of test	Specimens tested	Point load index		
			Mean (MPa)	Standard deviation	
				MPa	%
Sandstone	Diametral	30	2.34	0.37	15.7
	Axial	31	2.62	0.14	5.5
	Irregular lump	33	2.13	0.41	19.2
Belfast norite	Diametral	30	12.97	1.56	12.0
	Axial	32	14.59	1.88	12.9
	Irregular lump	33	16.08	4.12	25.6

* All the specimens tested were of comparable sizes, having dimension D = 54 mm as defined in Figure 1a.

Table V-2: COMPARISON OF THE RESULTS FROM UNIAXIAL COMPRESSIVE AND POINT LOAD TESTING

Rock material	Uniaxial compressive strength				Core size	Point load index in diametral test			
	No. of specimens	Mean (MPa)	Standard deviation			No. of specimens	Mean (MPa)	Standard deviation	
			MPa	%				MPa	%
Sandstone	40	55.1	3.02	5.5	NX	70	2.33	0.22	9.8
	20	56.4	4.07	7.2	BX	65	2.56	0.23	8.8
	25	56.1	3.58	6.4	EX	70	2.83	0.22	9.8
Quartzite	40	182.6	24.59	13.5	NX	45	8.30	1.35	16.2
	20	180.3	15.45	8.7	BX	40	9.47	2.10	22.4
	20	187.8	28.77	15.3	EX	40	10.37	1.82	17.5
Marikana norite	45	250.5	2.90	1.2	NX	40	10.84	1.57	14.5
	20	257.4	9.10	3.5	BX	20	11.16	2.19	19.6
	20	254.9	6.34	2.5	EX	20	13.05	1.16	8.9
Belfast norite	40	312.3	4.73	1.5	NX	70	13.13	1.21	9.2
	20	312.9	5.21	1.7	BX	35	13.77	2.10	15.2
	20	318.2	8.18	2.6	EX	40	15.92	0.86	5.4

Table V-3: STRENGTH CLASSIFICATION FOR ROCK MATERIALS

Description	Uniaxial compressive strength (MPa)	Point load index (MPa)
Very high strength	200	8
High strength	100-200	4-8
Medium strength	50-100	2-4
Low strength	25-50	1-2
Very low strength	25	1

Advantages of the point load test:

(1) Smaller forces are needed so that a small and portable testing machine may be used.
(2) Specimens in the form of core or irregular lumps are used and require no machining.
(3) More tests may be made for the same cost.
(4) Fragile or broken materials may be tested.
(5) Results show less scatter than those for the uniaxial compression test.
(6) Measurements of strength anisotropy are simplified.

Advantages of the uniaxial compression test:

(1) The testing procedure is better known and evaluated.
(2) Results are available for a wide variety of rock types, together with experience in linking these results of field performance.

PART 2 STRENGTH ANISOTROPY INDEX: I_a

The strength anisotropy index is defined as the ratio between the maximum strength index (i.e. the strength perpendicular to the planes of weakness in a point load test) and the minimum strength index (i.e. the strength diametrally along the planes of weakness in a point load test).

The lowest value for I_a is 1, and this is obtained when the rock is isotropic.

Possible size and shape effects in the point load test, and the directions of loading for maximum and minimum strength indices are shown in Figures V-2 and V-3.

Fig. V-2: SIZE AND SHAPE EFFECTS IN THE POINT LOAD TEST

(a) the diametral point load test

(b) the axial point load test

I_s = point load index (Part 1)

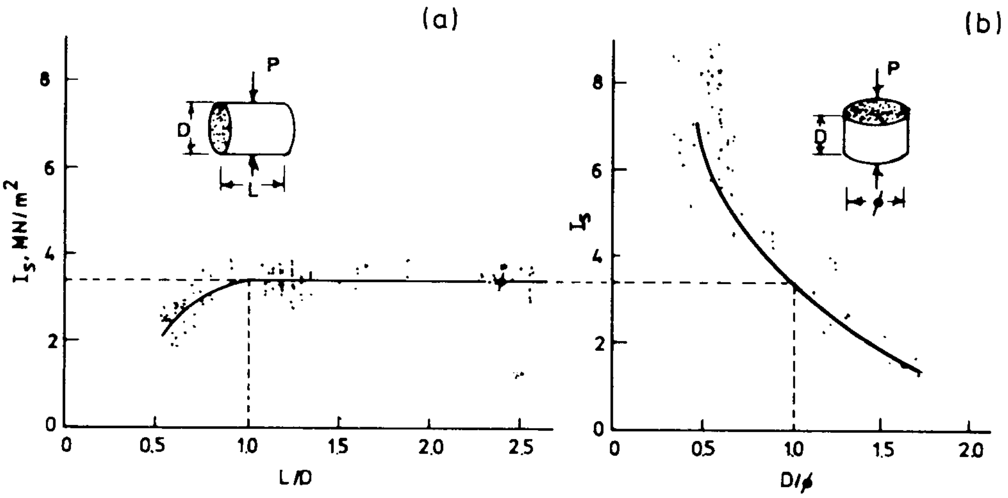


Fig. V-3: ANISOTROPY TESTING - DIRECTIONS OF LOADING

(a) maximum strength index

(b) minimum strength index