GUIDANCE NOTES
ON
GEOTECHNICAL INVESTIGATIONS
FOR
MARINE PIPELINES

Issue: OSIG Rev 03

Status: Final for Issue

Date: 17/09/04

Prepared by the Pipeline Working Group
of the
Offshore Soil Investigation Forum

Updated 2004 by The Society for Underwater Technology
Offshore Site Investigation and Geotechnics Committee

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FOREWORD

This document is aimed at offshore engineers, who are not geotechnical specialists, but may have the responsibility for assessing the appropriate level of geotechnical data required for successful pipeline design and construction and specifying a geotechnical investigation programme.

The document was originally produced by the Pipelines Working Group of the Offshore Soil Investigation Forum (OSIF) and subsequently updated in 2003 to reflect recent developments in industry, by the Society for Underwater Technology's Offshore Site Investigation and Geotechnics Committee (OSIG).

OSIF is an informal grouping of oil company geotechnical engineers, geotechnical contractors and consultants and geotechnical drilling vessel operators, which have been meeting annually since 1983.

OSIG forms part of the Society for Underwater Technology and provides representation for professionals with a particular interest in the geological and geotechnical aspects of subsea engineering.

The primary objectives of the two groups are similar and may be summarised as:

- To promote and encourage best practice in the use and integration of geophysical and geotechnical data.
- To provide a forum for exchange of experience and ideas
- To facilitate continuous improvement of all aspects of offshore site investigations, particularly those related to: Technical Quality, Health, Safety and the Environment.

1. INTRODUCTION

This document has been produced to provide guidance on acceptable good practice in the collection of geotechnical data for the purposes of design, installation and operation of marine pipelines. It is intended that it will provide a useful aid in the planning and specification of marine pipeline geotechnical surveys.

The principal contents of the document include:

- An indication of the relevant regulations and guidelines.
- Guidance regarding the planning and scope of work of geotechnical investigations.
- Information on the available methods of data acquisition such as corers, samplers and in situ testing systems, and their applicability.
- Guidance on which soil properties are of importance for particular aspects of design, installation and operation.
- Suggestions regarding the interpretation and presentation of geotechnical data for pipeline projects.

This document concentrates on the geotechnical aspects of survey operations, however it must be recognised that the collection and interpretation of geophysical data to identify and assess seabed features and subsea geological profiles is an essential part of any survey. Therefore, a brief description of appropriate techniques is included in this document for completeness. Further information on geophysical survey techniques can be obtained from the UKOOA document “Recommended Practice for Rig Site Surveys, Volumes 1 and 2”.

2. RELEVANT REGULATIONS & GUIDELINES

There are a number of published rules and guidelines relating to the design of offshore platforms and pipelines, and these include a discussion of the geotechnical aspects of design. However, there are very few standards that relate specifically to geotechnical investigations for marine pipelines. Those most applicable are:

American Petroleum Institute

- API Recommended Practice 1111, 3rd Edition, July 1999 Design, Construction, Operation And Maintenance Of Offshore Hydrocarbon Pipelines and Risers.
- API Recommended Practice 2A-WSD. 21st Edition, December 2000
  Planning, Designing and Construction Fixed Offshore Platforms.

Det Norske Veritas

- DNV, OC-F101, Rules for Submarine Pipeline Systems. (January 2000)
- DNV-RP-F107 Risk Assessment of Submarine Pipeline Protection (March 2001)
- DNV 30.4 Foundations (1995)

British Standards Institution

- British Standard; BS8010 Part 3, 1993
  Pipelines Subsea: Design, Construction and Installation.

International Standards Organisation

- ISO 13623 : Petroleum and Natural Gas Industries – Pipeline Transportation Systems

In addition to the above standards, there are a number of standards, which while not directly related to marine geotechnical investigations, do provide a general framework for the in situ testing, sampling and laboratory testing of soils. The most commonly used standards include:

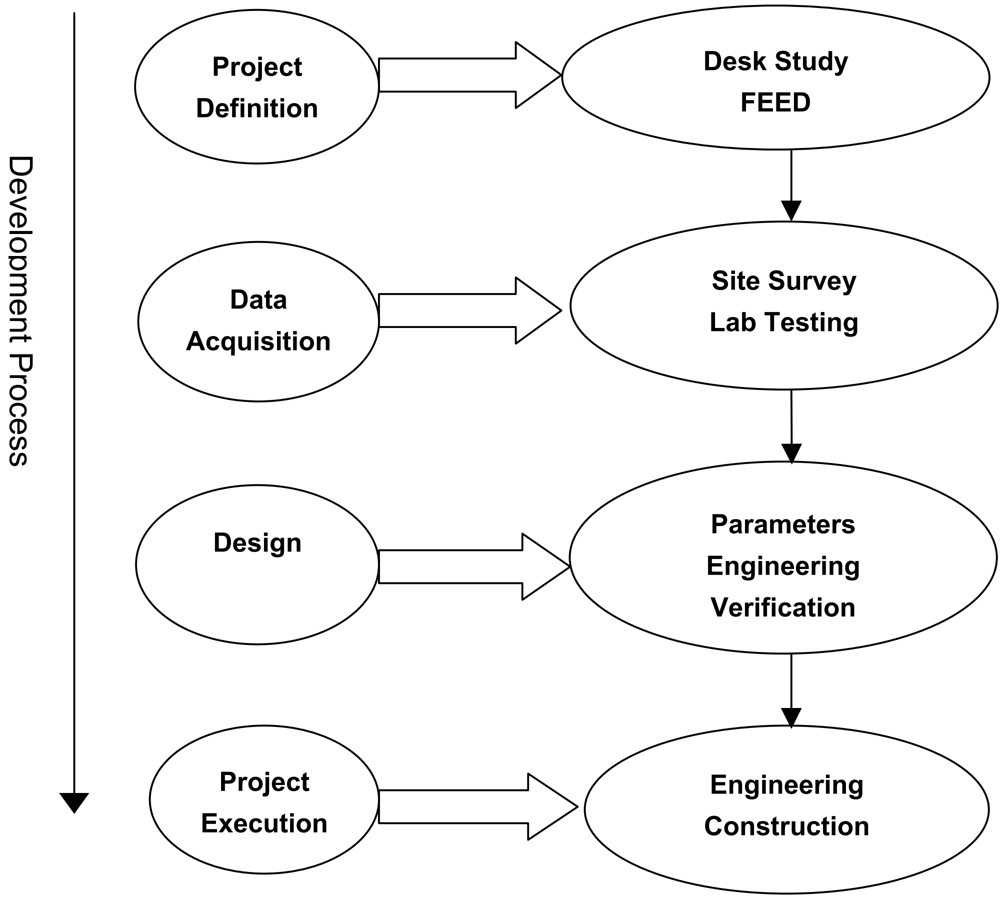
- British Standards Institution (1990) BS1377: Methods of tests for soil for civil engineering purposes.
- British Standards Institution (1999) BS5930: Code of Practice for Site Investigation.
- American Society of Testing and Materials, (2002) Volume 04.08, Soil and Rock (1) D420 – D5779. Annual Book of ASTM Standards
- EN1997, Eurocode 7, Geotechnical Design.
- International Standards Organisation: Geotechnical Investigation and Testing, Identification and Classification of Soil, Part 1: Identification and Description ISO 14688-1:2002.
- Norsk Standards 8000 to 8017. Series of standards for individual tests, eg:
  Norsk Standard, NS8005, Geotechnical testing. Laboratory methods. Grain size analysis of soil samples.

3. PLANNING AND SCOPE OF WORK

Objectives

The objective of the site investigation for a marine pipeline is to obtain sufficient reliable information to permit the safe and economic design of installation and permanent works. The investigation should be designed to verify and expand upon any information previously collected.

The various stages relating to site survey and geotechnical investigation are illustrated in Figure 3.1. At the initial stages of a project development, it is often adequate to assess geotechnical aspects from desk study information. As the project progresses, the level of detail required increases and additional costs are incurred in acquiring this information. The important factor to appreciate is that at all times expenditure on the site survey and geotechnical data should be commensurate with the level of detail required.



Planning and scheduling

At project conception, the data available should be sufficient to demonstrate the feasibility and suitability of the preferred pipeline design concepts and selected route corridors. This can often be achieved by a desk study to collate published data and information from previous investigations. However in areas where little information is available a preliminary investigation may be required. This can often be achieved by a geophysical survey, with simple sampling methods such as a grab sampler, or drop corer.

As the project progresses towards detailed design and construction, the data should be sufficiently detailed to provide input into pipeline design and to allow contractors to provide optimised pricing for supply and installation works.

The site investigation programme for a marine pipeline development should therefore be undertaken in progressive stages. Planning for each stage should be carried out based on the results from previous findings in order to optimise the extent of investigation work. Factors such as: vertical and horizontal uniformity of soil profiles, geological history and pipeline system size and concept, should be directly reflected in the extent of the site investigation. A full appraisal of the various geological factors at a site are often summarised in a geohazard study.

It is recommended that all stages of the planning and performance of a survey are directed by a suitably experienced person.

The sequence of the site investigation programme should be as follows:

Desk study

The desk study should incorporate a review of all appropriate sources of information and the collection and evaluation of all relevant available types of data for the area of interest. The various factors that should be investigated include, but are not limited to:

- Geological databases
- Bathymetric information
- Geophysical data
- Geotechnical data
- Metocean data (tides, currents etc)
- Seismicity
- Performance of existing pipelines
- Human activities (eg location of pipelines, cables wrecks, munitions disposal site, aggregate dredging,

The performance of a desk study alone is not normally sufficient for detailed engineering purposes. The desk study is the best way of obtaining some information, including location of existing subsea infrastructure (eg pipelines and cables) which may be required for the planning of both the survey and the construction works.

Geophysical survey

A geophysical survey will need to be performed along the proposed route of the marine pipeline to collect information on:

- Seabed topography – by echo-sounding or swathe bathymetry. The latter is particularly important in sand wave areas or other areas of generally uneven seabed.
- Seabed features and obstructions – by methods such as side scan sonar
- Profiling of uppermost 5m, or so, of seabed – usually by means of reflection seismic techniques (sub bottom profiling). Recent developments in towed resistivity and seismic refraction methods are providing useful complementary data. This is particularly the case in very shallow water where seismic reflection is not practical.
- Detection of existing cables, pipelines and other metallic obstructions – by means of a towed magnetometer, however, note is made that not all metallic objects may be detected, in particular small fibre optic cables.

As a general rule, the width of the survey corridor is between 500m and 1000m, centred on the proposed pipeline route. The actual width is influenced by factors such as water depth, seabed features and the need to provide a degree of flexibility in routing.

Shore approach corridors are more likely to be around 500 metres wide, whereas areas in deeper water incorporating seabed features such as pockmarks and iceberg scars may warrant survey corridors in excess of 1000 metres to allow re-routing based on detailed engineering, to minimise the number of potential free-spans for example. If the geotechnical survey is to be performed as a separate exercise (see below) it is still advisable and practical to collect some soil samples by grab or gravity core to aid the immediate interpretation of surface and sub-bottom profiling data. Survey tie-lines to nearby locations where soils information has previously been gathered will also aid this process.

The geotechnical investigation will normally be performed on completion of the geophysical survey, and after the route has been determined, either from the same vessel or as a completely separate operation from a different vessel. This allows for sample and test locations to be more effectively targeted to identify soil strata changes, clarify apparent anomalies or investigate specific seabed features. To accelerate interpretation and reporting on long route surveys, a “first pass” of sampling and testing can be made on completion of the route centre-line survey. Again, this may be performed from the geophysical survey vessel itself or from a separate vessel. In the latter case, the geotechnical vessel can be performing work along the centre line whilst the corridor “wing-lines” are being surveyed.

Using current satellite technology it is now feasible to transmit interpreted data between the geotechnical and geophysical vessels to facilitate onboard interpretation and programme modifications as appropriate.

The performance of the geophysical survey alone, or in addition to the desk study, is not normally sufficient for detailed engineering purposes, unless site geotechnical data are already available.

GeoBAS survey

The term ‘geoBAS’ (Geophysical Burial Assessment Survey) describes survey operations using geophysical methods operated from seabed sleds, and towed by the survey ship, to provide continuous quantitative information for the first few metres of soil below seabed. Available methods include seismic refraction and electrical resistivity systems. The use of these methods is often justified if trenching is difficult or the properties of the seabed are very variable. A more reliable continuous engineering assessment of the route can be made if geoBAS measurements are integrated with CPT and core sample data.

GeoBAS equipment is normally mounted on a sled, which is pulled by the survey vessel at speeds of between 1 and 4knots. It is essential to have some knowledge of seabed features and potential obstructions to reduce the risk of damage or loss of the equipment.

GeoBAS surveys may also be useful on the shore approach where deeper burial is required and sometimes rock is present near the surface. Towed systems can be pulled through the shallow water zone either towards or away from the beach. Technical issues relating to shallow water and surf noise should be addressed in a project specific manner.

Geotechnical survey

The geotechnical survey will typically encompass:

- Coring and sampling for material identification, description and subsequent laboratory testing.
- In situ testing for accurate stratification and determination of key engineering parameters.

There is a large range of available equipment for each method. They are described in Section 4.0 'Data Acquisition Methods', with additional detail presented in Appendix II.

The suitability of each tool for use in the geotechnical survey should be assessed by reference to Section 4.0. This should be carried out in conjunction with knowledge of the engineering objectives of the selected concept(s) and the results of the desk study and geophysical survey phases. Guidance on data acquisition requirements for specific pipeline engineering objectives are provided in Section 5.0, 'Soil Parameters for Engineering and Design Considerations'.

Suitable vessels and supervision

The geotechnical survey can be performed either from the geophysical survey vessel, provided it has the capabilities (e.g. craneage and station keeping) or from a suitable alternate vessel.

Pipeline landfalls present particular problems due to the shallow water depths, usually precluding use of normal offshore spreads. Trenching depths, and hence penetration requirements, may also be greater than for offshore sections of the pipeline. There may also be other factors to consider such as the presence of rock within the trench profile and a greater risk of sediment mobility. The use of land-based drilling and/or CPT equipment, deployed from suitable all-terrain or amphibious vehicles may be practical down to the low water mark. However, such methods usually leave a significant gap in data coverage, between their seaward limit and the landward limit of offshore spreads. In this situation, options include shallow-draft anchored pontoons or, more ideally, small jack-up drilling platforms may be used as a platform from which to drill, sample and test the seabed soil or rock, usually using an adapted onshore drilling system.

Data coverage

The spacing of soil sampling and soil testing locations along the route of the marine pipeline will depend on the lateral variability in ground conditions revealed by the desk study and geophysical survey phases. In selecting appropriate spacing, consideration should also be given to other project-specific factors such as:

- Trenching requirements including:
    - depth of trench
    - method of trenching
    - trench side stability
- Method of backfilling
- Geotechncal input to pipeline engineering including:
    - thermal insulation provided by trench backfill
    - upheaval buckling resistance of backfill soils
    - pipeline soil interface friction properties

- Surface features or obstructions for example sand waves, pockmarks, boulders or iceberg scars
- Size, purpose, location and foundation type of any seabed structures

Table 3.1 below gives some guidance on appropriate frequency and penetration of samples and tests. However each project should be reviewed separately and an appropriate sampling and testing programme determined by a competent geotechnical engineer.

Because of the exploratory nature of the geotechnical survey, it is probable that some modification to the scope of work will be required as data acquisition proceeds and results are reviewed. This is necessary to ensure that the objectives of the survey are being achieved in the most cost-effective and optimised manner, and specifiers of survey services should bear this in mind.

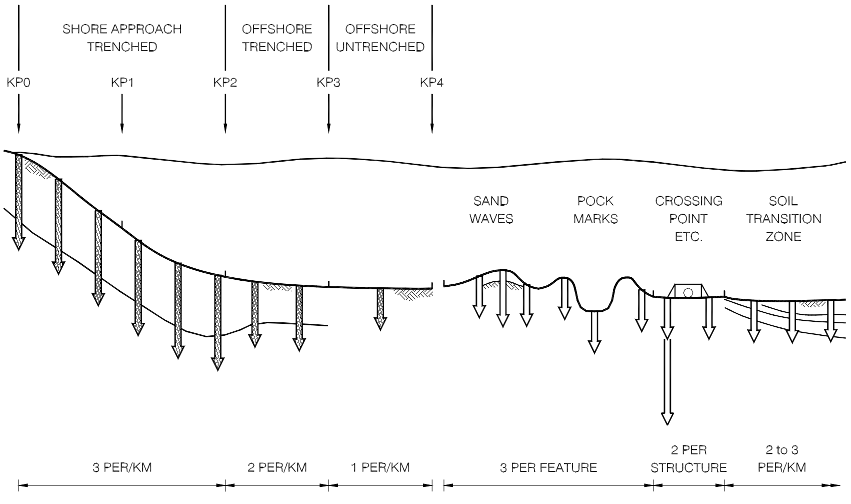
Table 3.1 Guidelines for Test/Sample Frequency and Penetration

Pipeline Route Sector	Average Spacing (km)	Penetration^1 (m)	Remarks
Untrenched sections	1 to 5^2	1 – 2	Increase frequency and penetration in areas of soft clay or potentially unstable slopes. Supplement with grab samples in areas of sand/gravel. Consider any particular requirements of project (eg pipeline soil interface friction).
Trenched sections (offshore)	0.5 to 1	Trench depth +1	Cores and CPTs should be located adjacent to each other for correlation purposes, at the spacing suggested
Trenched section (shore approach)	0.3 to 0.5	Trench depth +1	Ensure spacing nd sampling regime is adequate to identify any particular aspects for example rock outcrops, sediment mobility.
Soil transition zone	0.3 to 0.5	3 – 5	
Features Pockmarks, iceberg scars, sand banks	3 per feature	To maximum height/depth of feature	Representative features may need to be selected for investigation rather than all of them
Pipeline or cable crossing or subsea structure such as 'T's, valve cover etc.	min. 2 per structure	5	May need to be deeper for larger structures or piled structures
Anchor or support piles	min 1 per pile or pile group	10 – 20	Needs to be checked against required bearing capacity and soil type.

Notes

1 Typical penetration depth, each case should be reviewed separately and depth adjusted accordingly

2 Average spacing greater than 1km should only be considered in areas of consistent geology where geotechnical conditions are already well known



TEST/SAMPLE FREQUENCY AND PENETRATION

Figure 3.1 - Guidelines for Test/Sample Frequency and Penetration
(Graphical representation of Table 3.1)

4. DATA ACQUISITION

Introduction

The methods used in the acquisition of soils data for marine pipeline routes comprise geophysical, geoBAS and geotechnical techniques to determine the characteristics of the seabed topography and geology. The principal aspects of these techniques are described in the following sections, with a more detailed description of the geotechnical equipment presented in Appendix II.

Geophysical Equipment

The geophysical equipment used for pipeline route surveys should include as a minimum:

- Echo-sounder (single-beam or multi-beam)
- Sidescan sonar
- Sub-bottom profiler
- Magnetometer

The uses and suitability of the generic types of equipment are summarised in the Table 4.1.

Table 4.1 Geophysical Survey Methods

Survey Equipment	**Use of Data**	**Minimum Resolution Required**
Single beam echosounder	Determination of water depth below survey line and an estimate of seabed gradients	1% of maximum water depth
Multi-beam echosounder	Determination of water depth and seabed gradient across full survey corridor	1% of maximum water depth
Sidescan Sonar	Identification of the nature of the seabed (sediment type, rock outcrop, coral etc.), seabed features (bed forms e.g. sand waves, megaripples), and obstructions (cables, pipelines, boulders, wrecks)	Detect a nominal 0.1m^3 object or a 0.1m width linear object
Sub-bottom Profiler	Characterisation of shallow subseabed geology, which includes identifying vertical and lateral extent of sediments and the presence of any bedrock and other subsurface obstructions.	Vertical Resolution better than 0.5m down to a depth of 5m or depth of burial plus 3m whichever is greater
Magnetometer	Detection and location of pipelines, cables and any ferro-metallic debris, such as wrecks and munitions dumps.	1 nanoTesla or better

Geo BAS Equipment

The two methods normally used offshore are electrical resistivity and seismic refraction as described below:

- Electrical resistance of the seabed soils is determined by generation of an electrical potentiall (voltage) between two electrodes. Voltage is measured at intermediate points by further electrode, from which lines of equipotential can be determined. A mathematical model is then used to calculate the variation in resistance of the soil with depth. The method is particularly effective in identifying changes in the character of the soil because the resistivity is related to the soil porosity. Longitudinal profiles of resistivity (or Formation Factor which is the resistivity of the seabed soils normalised to that of the seawater) are prepared from the raw data.

- Seismic refraction requires generation of a compression wave, which is then sensed by an array of geophones at increasing distance from the source. The time taken for the compression wave to arrive at different geophones enables the depth of reflectors, and seismic velocity, to be determioned. The results are presented in the form of a profile of the compression wave velocity of the seabed strata, which can be correlated to soil strength properties. Seismic velocity is particularly useful for characterising weak rock formations for trenchability.

In general, systems are configured to penetrate to a depth of approximately 5m however, it is possible to achieve greater depths if required. Vertical resolution is typically in the region of 0.3m.

Both methods typically comprise a sled housing control and logging electronics, with a streamer of electrodes or geophones respectively. The sled is normally towed by the survey vessel with a combined tow wire / umbilical.

The primary application for both methods is in delineating significant changes in seabed soils and rock, and to aid extrapolation of soil parameters between CPT and/or core sample locations.

Geotechnical Equipment

The most commonly used tools for geotechnical investigation of pipelines are cone (or piezocone) penetration testing and vibrocore sampling. Where seabed soils are soft, gravity cores may be suitable in place of vibrocoring. These may be considered ‘primary’ methods, with a large number of ‘secondary’ methods such as box coring, and in situ vane testing. Brief details are presented below, with a more complete description presented in Appendix III.

Cone, or Piezocone, Penetration Testing equipment (CPT/PCPT or CPTU);

The cone penetration test comprises an instrumented probe, which is thrust into the ground from a seabed reaction frame. It records values of cone tip resistance (q_c), sleeve friction (f_s), and (in the case of piezocone) pore water pressure (u). These parameters in themselves do not indicate a particular soil type or property. However, geotechnical engineers can interpret these data to categorise soil type and geotechnical design parameters for most routine geotechnical analysis. A drawback of this test is that no physical sample is recovered to verify that the empirical correlations adopted are appropriate.

A development of the cone penetration tests is the ‘T’ bar, which as its name implies, comprises a closed horizontal tube mounted in place of the cone tip. This test is appropriate only appropriate in soft clays, but has the advantage of providing a more accurate assessment of undrained shear strength than a CPT, together with the potential to determine remoulded strength during extraction.

Vibrocore Sampling

A vibrocorer comprises simple a steel tube with an inner plastic liner which is vibrated into the seabed by the action of two counter rotating eccentric weights driven by an electric motor. Depth of penetration can be up to 8m in suitable soil conditions, with some sample being obtained in almost all soil types. The tube is pulled out of the seabed by the A frame orcrane used for deployment and the sample retained by a core catcher. Once recovered to deck, the plastic liner is removed and the sample described as far as practical and stored within the plastic liner for detailed description and laboratory testing onshore. Limitations to this equipment include sample disturbance in very soft or loose soils and limited penetration in hard seabed such as stiff clays and dense sands. The equipment is normally limited to water depths of approximately 800m.

Other equipment which is used less frequently, includes:

- **Gravity Corer**
  Similar to the vibrocorer in that a tube is lowered into the seabed, but with weights rather than vibration causing penetration. Sample quality is variable with simple gravity corers, however piston tye corers have the potential to recover good quality samples in very soft clay. Some of the larger piston corers (Jumbo corers) can recover good quality samples to depths of 20m.
- **Grab Sampler**
  A simple device, which recovers a sample of seabed soil. Depth of penetration is negligible, however it can be used on hard seabed where gravity cores may not recover any material or become damaged. A range of sizes are available, the size selected should be capable of recovering a representative volume of soil.
- **Box Corer**
  Box corers are suitable in soft clays, and are designed to recover an undisturbed block sample of the seabed soil.
- **Rock Corer**
  A seabed mounted rotary coring system. Seabed systems of the type normally used for pipeline routes are hydraulically powered from the surface and recover a single continuous core of between 3 and 6m. Good quality cores are difficult to achieve in many rock types. Note is also made of more advanced systems which are capable of much greater depths and are fully remotely operated.
- **In Situ Shear Vane Test**
  A more accurate method than PCPTs of determining shear strength in soft clay deposits.

> Particularly useful in deepwater environments and commonly used in the Gulf of Mexico and offshore West Africa.

More details on these tools are enclosed in Appendix II for information. It should be noted that many specialist testing and sampling methods exist in addition to those briefly described here. By their very nature these tools are designed for specialist tasks such as assessing thermal or electrical conductivity in situ, measuring soil temperature and gaining in situ estimates of density from nuclear density meters. It is recommended that if the requirements of a pipeline design dictate specialist soil parameters, experts are consulted.

5. SOIL PARAMETERS FOR ENGINEERING AND DESIGN

Pipeline design and installation engineering requires selection of geotechnical design parameters. These often cover a wide range of soil behaviour and design requirements. Examples include soil strength or density for embedment or on-bottom stability analysis, bearing pressures and settlement characteristics for stability of seabed structures, scour/sediment transport susceptibility, trenchability, and backfill properties of reconstituted soil after trenching.

It is important to ensure that the appropriate test methods are used to determine different soil parameters. The suitability of different techniques is summarised in Table 5.1, with suitability ranked on a scale of 1 (unsuitable / not appropriate) to 5 (ideal method for determination).

Table 5.1 Suitability of Test Methods

Soil Parameter	**In-Situ Testing**			**Laboratory Testing**		
	Type of Tests	**Applicability**		**Type of Tests**	**Applicability**	
		Sand	**Clay**		**Sand**	**Clay**
Interpolation of soil layering in between cores / borings / (P)CPTs	Seismic reflection, (sub-bottom) profiling	2	2	N/A	N/A	N/A
	geoBAS	4	4			
Soil classification	Seismic reflection	1	1	Grain size	5	5
	geoBAS	2	2	Water content	2	3
	CPT/PCPT	4	4	Atterberg limits	N/A	5
Soil density	CPT/PCPT	3 to 4	2	Unit weight and water content measurement	1 to 2	5
Soil strength	CPT/PCPT	1	3 to 4	Unconsolidated triaxial compression	N/A	3 to 4
	T Bar	N/A	5[1]	Consolidated triaxial compression	5	5
	In situ vane	N/A	4 to 5[2]	Fallcone, pocket penetrometer, Torvane, Labvane	N/A	4[2]
				Direct simple shear (DSS)	2	5
Friction angle	CPT/PCPT	3 to 4	1	Consolidated triaxial compression	5	5
				Direct Shear (Shear box)	4	1
Sensitivity	CPT/PCPT	N/A	2	Fall cone, labvane	N/A	5[2]
	In situ vane	N/A	4[2]			
Consolidation characteristics	*PCPT dissipation test*	1	3	Oedometer	2	5
Permeability	*PCPT dissipation test*	1	3	Laboratory permeability	4	5
Pipeline soil friction	N/A	N/A	N/A	Modified shear box	5	5
Upheaval buckling parameters	N/A	N/A	N/A	Centrifuge testing	5	5
Thermal conductivity	*Heat flow probe*	4	4	Thermal needle probe	4	4

Notes: N/A method or parameter is not appropriate in this soil type.

Test methods in *italics* may be classified as special tests and are not normally performed as part of a pipeline route survey.

[1] Very soft and soft clays only

[2] Very soft to firm clays only

As a minimum, the geotechnical investigation report for a pipeline should include the basic soil parameters listed in Table 5.2 below. These form the basis for most geotechnical design requirements.

Table 5.2 Basic Soil Parameters Required

Clay	Sand
Particle size distribution	Particle size distribution
Atterberg (plastic/liquid) limits	Relative density
Water content	Max / Min density
Bulk unit weight	Bulk unit weight
Undrained shear strength	Friction Angle

Experience has shown that additional soil information may be very useful and careful consideration should be given to acquiring soil parameters specific to the project. Table 5.3 may be used as a guide for selection of other geotechnical parameters that may be required on different projects. The advice of a suitable geotechnical specialist should also be obtained when defining the specific laboratory test programme, since some soil characteristics shown in Table 5.3 cannot be defined by individual tests.

It may also be appropriate to incorporate other testing within the geotechnical survey, for example to assess water quality or any environmental pollution which may have occurred.

Table 5.3 Additional Soil Parameters for Specific Applications

Application	**Pertinent soil parameters** **(Properties required for S=sand, C=clay, R=rock)**														
	Shear strength	**Friction angle**	**Relative density**	**Particle size distribution**	**Permeability**	**Compressibility**	**Sensitivity**	**Pipe-soil friction factors**	**Cyclic strength**	**Liquefaction resistance**	**Rock quality**	**Chemical analysis**	**Electrical Conductivity**	**Thermal conductivity**	**Backfill properties**
On bottom stability	C	S	S	S			C	C/S		S					
Scour / erosion	C	S	S	S											
Slope stability	C	S	S	S	S		C		C/S	S					
Liquefaction / flotation	C	S	S	S	S	S	C		C/S	S					
Settlements (rock berms)	C	S	S			C/S									
Upheaval buckling	C	S	S	S	S	C/S		C/S							
Free span assessments	C	S	S	S		S									
Dropped objects	C	S	S												
Shore approaches	C	S	S	S			C	C/S	C/S	S	R	C/S		C/S	C/S
Corrosion												C/S	C/S		
Thermal insulation														C/S	
Spool pieces / tie-in/PLEMs etc.	C	S	S				C	C/S	C/S	S					
Start-up piles	C	S	S	S											
Ploughing	C	S	S	S	S	S	C			S					C/S
Jetting	C	S	S	S	S	S	C			S					C/S
Self bury potential / natural backfill	C	S	S	S											
Sinkage	C	S	S				C			S					
Axial/lateral resistance	C	C/S	S	S				C/S							
Upheaval buckling	C	S	S	S			C			S				C/S	C/S

6. INTERPRETATION AND REPORTING

Introduction

To maximise the value of the survey it is essential that all field and laboratory data be:

- Evaluated critically
- Presented clearly
- Summarised succinctly

To achieve this it is important that a minimum standard of data presentation is achieved. The following sections describe good practice and recommend some minimum standards. All interpretation and reporting should be subject to Quality Assurance procedures to the standards of ISO 9000 or equivalent.

Core and sample logs

These should clearly show the soil type variation with depth and include as a minimum:

- A graphical soil symbol column
- A detailed written description of the soil type, its strength, constituent parts and any structure or inclusions and how these characteristics vary with depth. (Descriptions should adhere to terminology laid down in the selected national or international standard).

It is also eases understanding of the report if results of any testing on samples of the soil are presented on the core log. Results that may be presented on the core log include:

- Moisture content
- Atterberg (liquid and plastic) limits for clays
- Wet density test results
- Undrained shear strength measurements for clay
- Internal friction angle for sands

Examples of typical core log formats displaying most of these requirements are included in Appendix I.

CPT/PCPT results

Measured and derived parameters are normally presented graphically on a single sheet. Results that are normally presented include:

- Cone tip resistance ($q_{c)}$
- Sleeve friction (f_s)
- Excess pore pressure (u)
- Friction ratio (ratio of sleeve friction to cone resistance) (R_f)
- Pore pressure ratio (ratio of excess pore pressure to net cone resistance)
- Net cone tip resistance corrected for vertical effective stress and pore pressure (q_{net}).

In addition, an interpreted log of the CPT or PCPT should be presented in a format similar to a core log in order that it might be clearly understood by non-geotechnical engineers. The interpreted log should incorporate:

- A graphical soil symbol column
- A detailed description of the interpreted soil types (using the same standard terminology as the core logs).
- A graphical plot of interpreted shear strength for cohesive soils
- Estimated value of relative density for cohesionless soils.

Graphical representation of the results should be at an appropriate scale, typically 1cm per metre for depth, with cone parameters varied to suit the project. Examples of a typical PCPT result format are presented in Appendix II.

Special in situ test results

The results of non-standard tests should be presented in a clear and simple format, preferably including graphical representation, together with an explanation of the results and their implications.

Laboratory test results

Each individual laboratory test result should be presented graphically where appropriate, and in a format that complies with the relevant national or international standard. All results should also be summarised in tabular form.

Interpretation and design parameters

Competent geotechnical engineers should perform the interpretation and correlation of laboratory and in situ test data. The results should be presented as ranges of recommended geotechnical design parameters for each location or section of route.

Integration of results

It is essential that the results of the geophysical survey and the geotechnical testing are carefully integrated by suitably qualified personnel. In this way, the full value of these two components of the route assessment can be fully realised, and misleading interpolation between individual sample and test locations is avoided.

Report Formats

The format of a geotechnical report should be designed to be easily understood by engineers. The report should provide the following information as a minimum:

- The purpose for which the investigation was performed.
- A description of the equipment used and the work performed.
- Results of all in situ tests performed.
- Detailed descriptions of soils recovered by sampling.
- Results of any laboratory testing.
- All other information that may be of relevance.

Wherever possible the data should be summarised graphically in an “alignment sheet” format familiar to the offshore pipeline industry. Alignment sheets typically comprise a series of panels with the upper most presenting bathymetric results, followed by a panel showing seabed features, and a third panel presenting a cross section of seabed geology based on an interpretation of sub bottom profile data with results of the sampling and in situ testing. An example is presented in Appendix I. Additional panels should be included as appropriate, for example to present geoBAS results.

The data should be presented digitally on disk or by other electronic media. An example of a suitable format for transfer and storage of electronic data is the Association of Geotechnical Specialists format (AGS publication “Electronic Transfer Of Geotechnical Data From Ground Investigations (Edition 3)”).

The extent of interpretation required will be dependent on the particular project for which the report has been prepared. The various levels that may be considered include:

Factual Report: presents the survey information factually as described above, often with some identification of the primary soil units present.

Geotechnical Parameters Report: presents the factual information and additionally integrates the geophysical data to identify the soil and rock units present. Appropriate geotechnical design profiles are then developed based on the results of the geotechnical survey for the individual soil and rock units identified.

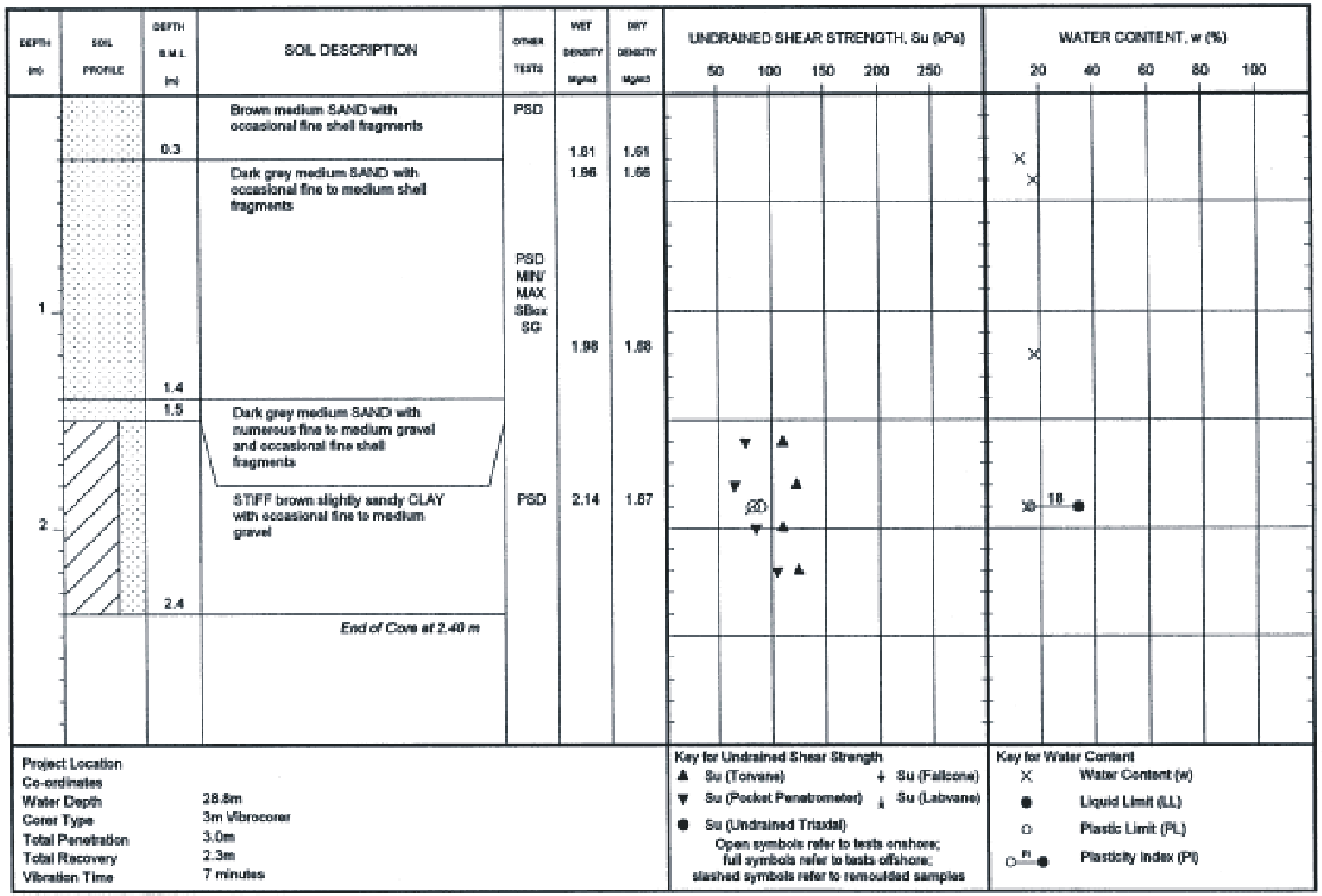
Engineering Report: This report summarises and integrates all the factual data (desk study, geohazard, geophysical, and geotechnical) and the assessment of geotechnical parameters. Based on this assessment, the suitability of different construction techniques, such as trenching methods and backfill requirements, are discussed and recommendations made for design factors such as upheaval buckling resistance parameters, pipeline soil interface frction and degree of thermal insulation.

APPENDIX I

PRESENTATION FORMATS

Approved By : DRM Date : 21/11/95
Checked By : DRM Date : 21/11/95

Logged By : ML Date Logged : 15/11/1995



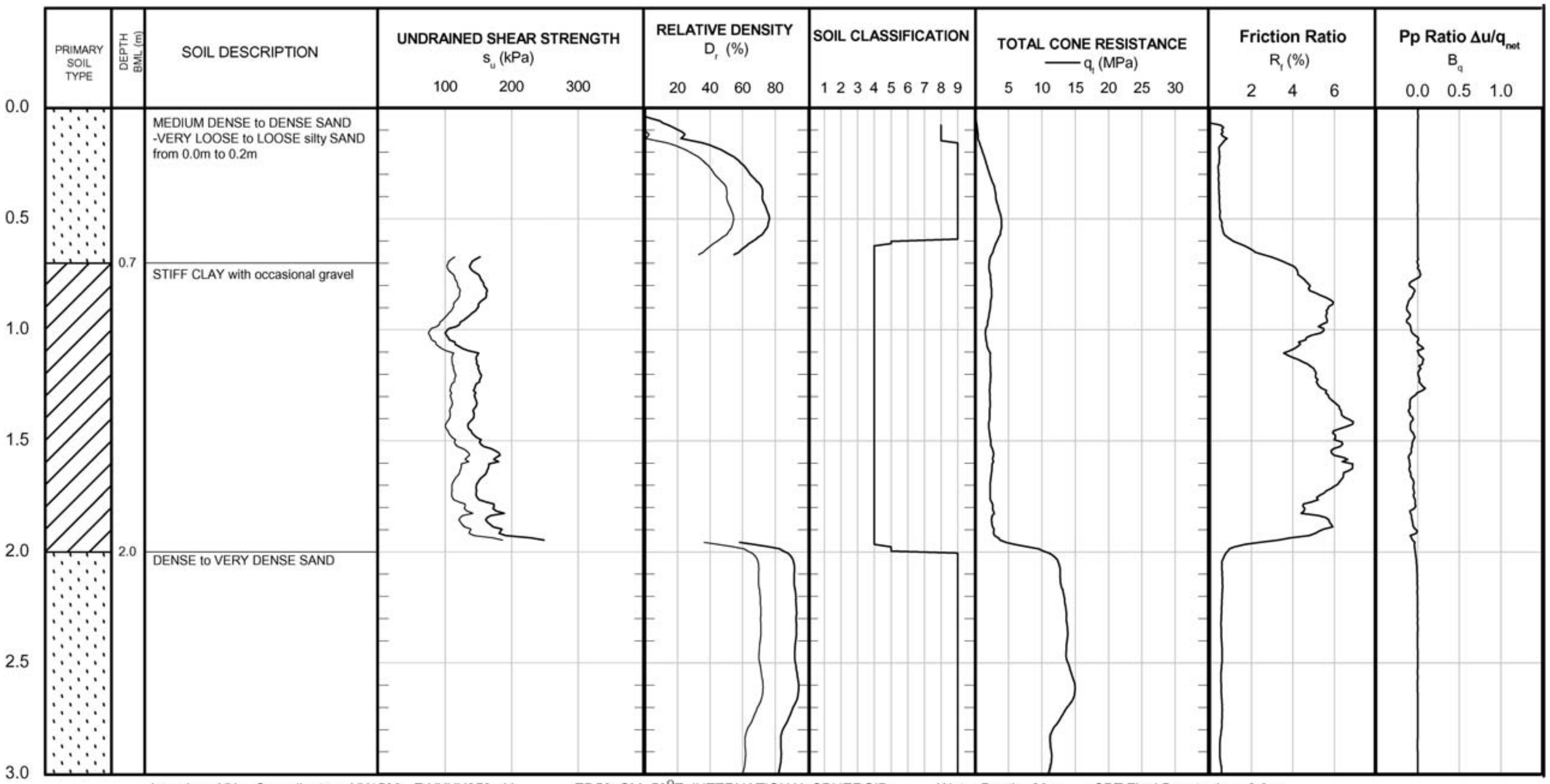
Project Location	
Co-ordinates	
Water Depth	28.8m
Corer Type	3m Vibrocorer
Total Penetration	3.0m
Total Recovery	2.3m
Vibration Time	7 minutes

Key for Undrained Shear Strength
- ▲ Su (Torvane)
- ▼ Su (Pocket Penetrometer)
- ● Su (Undrained Triaxial)
- Su (Fallcone)
- Su (Labvane)

Open symbols refer to tests onshore;
full symbols refer to tests offshore;
slashed symbols refer to remoulded samples

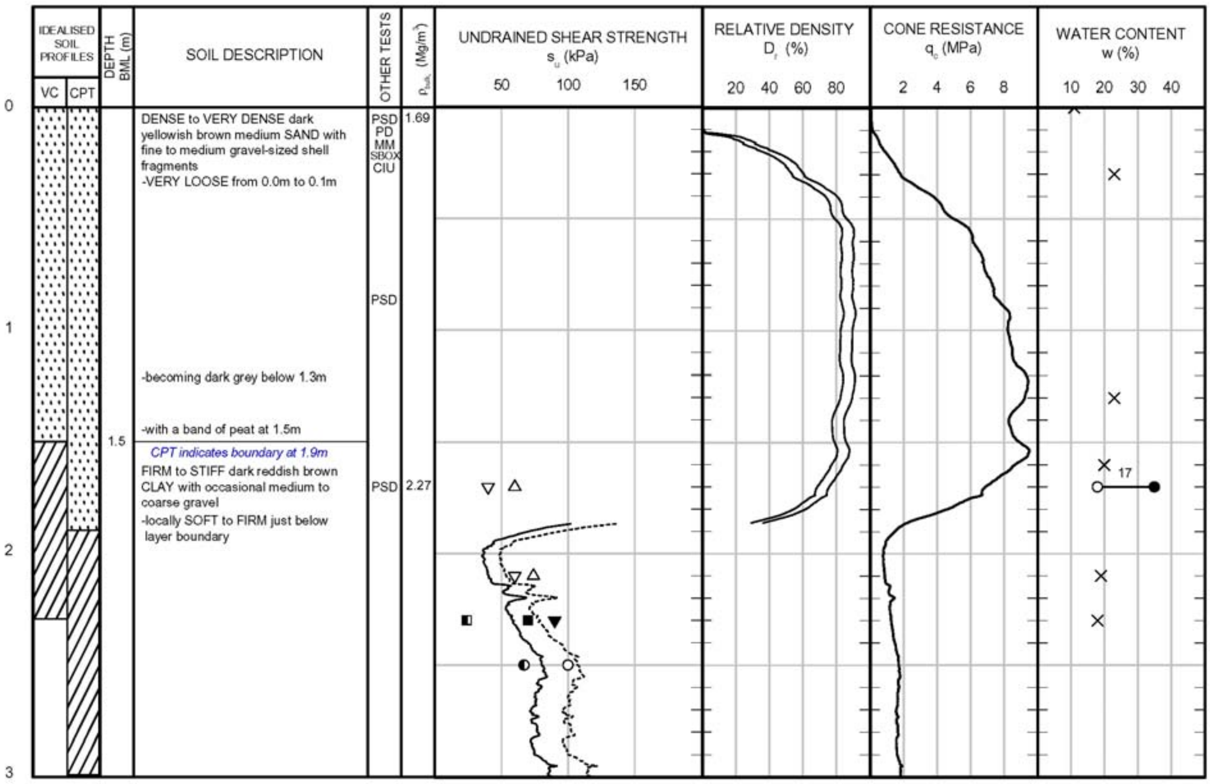
Key for Water Content
- × Water Content (w)
- ● Liquid Limit (LL)
- ○ Plastic Limit (PL)
- ○—PI—● Plasticity Index (PI)

LOG AND SOIL TEST RESULTS OF CORE VC2



Location : XX Co-ordinates : XX1580mE XXXX253mN ED50, CM=50°E, INTERNATIONAL SPHEROID Water Depth : 30m CPT Final Penetration : 3.0m

CPT LOG
CPT 01



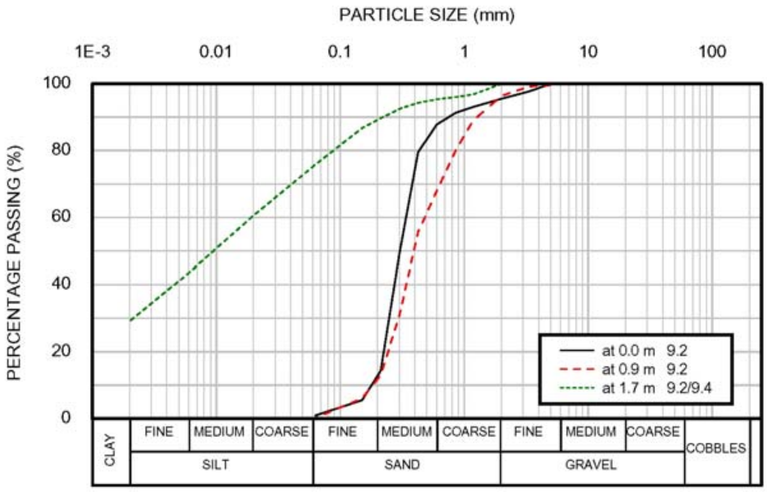
DENSE to VERY DENSE dark yellowish brown medium SAND with fine to medium gravel-sized shell fragments
-VERY LOOSE from 0.0m to 0.1m

-becoming dark grey below 1.3m

-with a band of peat at 1.5m

CPT indicates boundary at 1.9m

FIRM to STIFF dark reddish brown CLAY with occasional medium to coarse gravel
-locally SOFT to FIRM just below layer boundary



Key for Undrained Shear Strength

- ● s_u (UU) ▼ s_u (PP) ▲ s_u (TV)
- ◆ s_u (FC) ■ s_u (LV) ⊠ s_u (CAU)
- ◈ s_{ur} (FC - remoulded) ◧ s_{ur} (LV - remoulded)
- ------ s_u (Interpreted from CPT - Nkt = 15)
- —— s_u (Interpreted from CPT - Nkt = 20)

Open symbols refer to tests onshore;
Full symbols refer to tests offshore

Key for Relative Density

—— D_r (Range of Relative Density)

Key for Water Content

- × Water Content (w)
- ● Liquid Limit (LL)
- ○ Plastic Limit (PL)
- ○—● PI Plasticity Index (PI)

PSD Details

Tested in accordance with the following clauses of BS 1377 : Part 2 1990
- 9.2 Wet Sieve
- 9.3 Dry Sieve
- 9.4 Sedimentation by pipette
- 9.5 Sedimentation by hydrometer

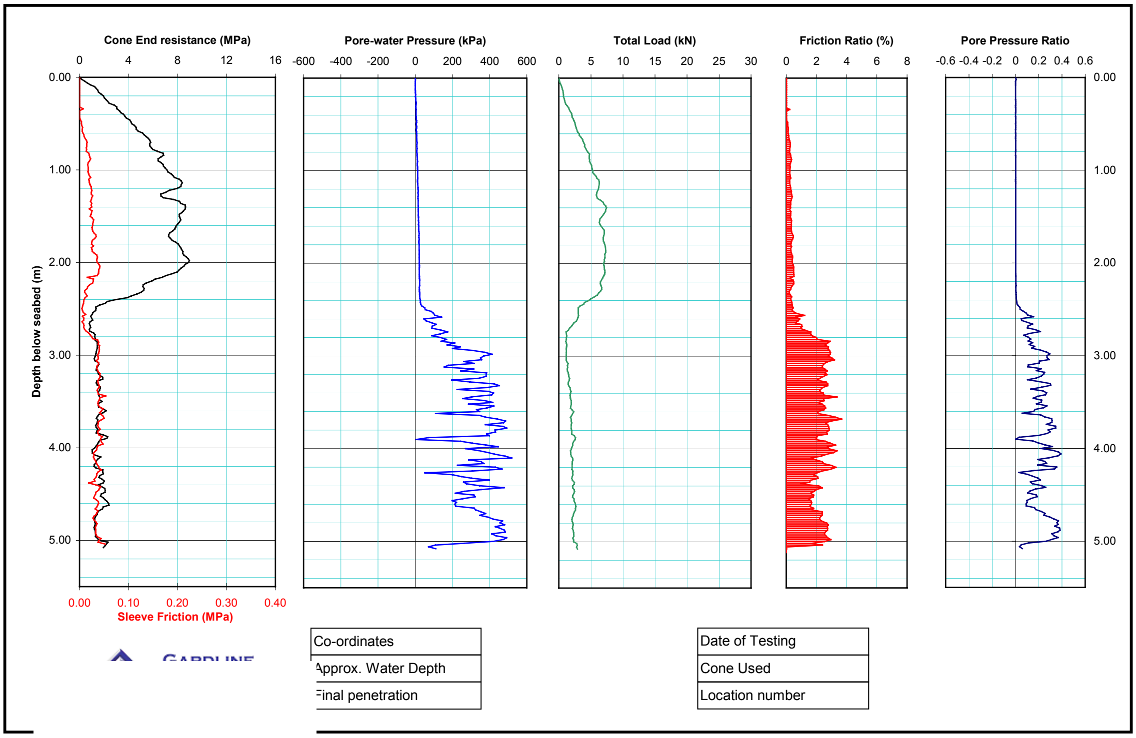
Log Details

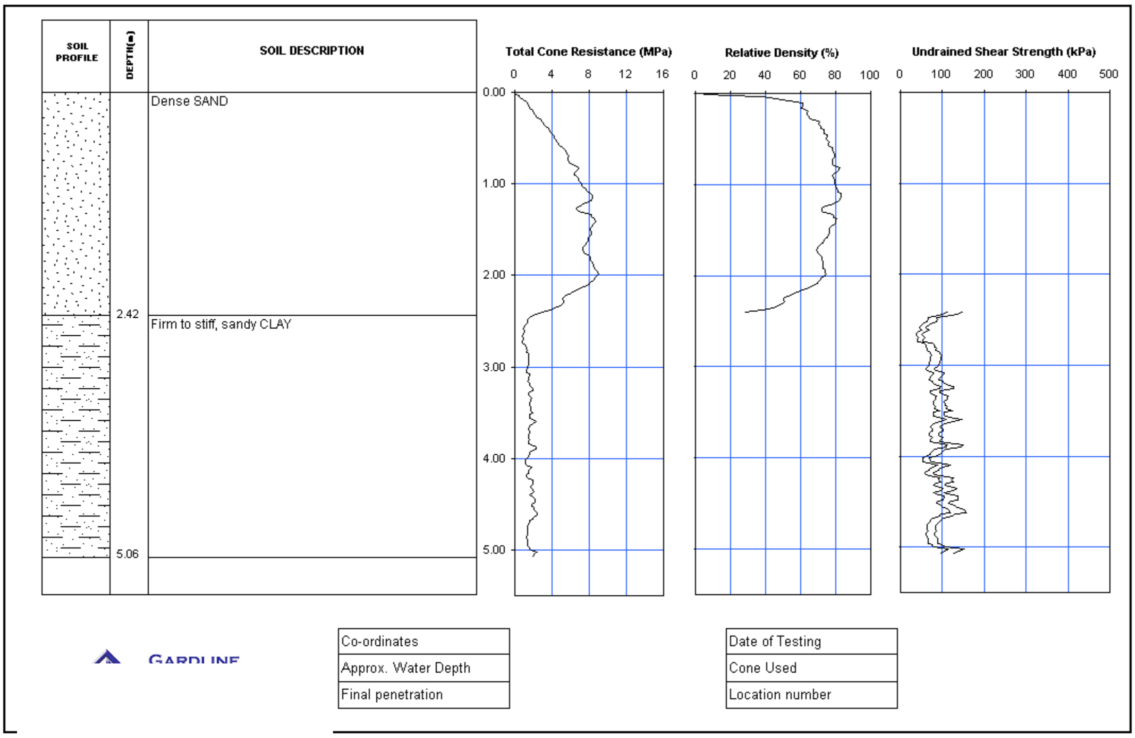
Location			Water Depth	51.0m
Co-ordinates	: CPT	431 580mE, 5 922 253mN	CPT Final Penetration	3.0m
ED50,CM:3°E	: VC	431 590mE, 5 922 255mN	VC Final Recovery	2.3m

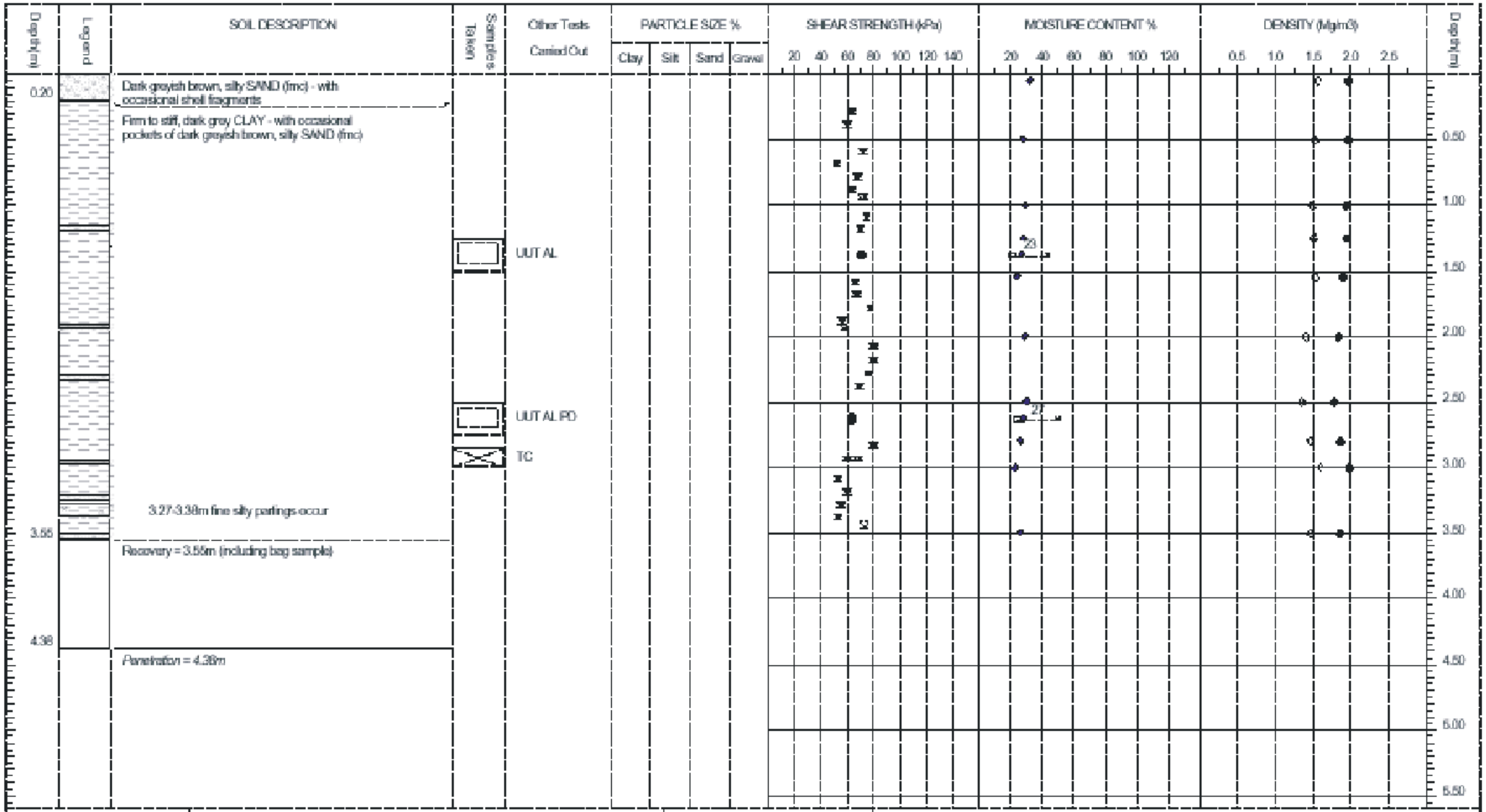
Notes:
(1) CPT layer boundaries are normally considered to be more reliable - see main text for more detail.
(2) Descriptions based on CPT data are shown in blue *Italics*.

COMBINED VIBROCORE / CPT LOG
LOCATION VC-01

EXAMPLE CONE PENETRATION TESTING RESULTS







CONTRACT NO.	6023	Core location	Comments Tulip Inverted
PROJECT TITLE	Northern Route-Dutch Sector		
CLIENT	BritNed Development Limited		
SITE TEST DATE	27 May 2003		
CO-ORDINATES	E 491045 N 5786136		
WATER DEPTH (m)	39.00 Uncorrected		

APPENDIX II

INFORMATION ON GEOTECHNICAL EQUIPMENT

APPENDIX II

INFORMATION ON GEOTECHNICAL EQUIPMENT

PRIMARY METHODS

Vibrocorers

a) Description

The vibrocorer, as the name suggests, is a method of driving a sample tube into the seabed by vibratory means. Typical systems comprise a steel core barrel of between 75mm and 100mm outside diameter and 3m to 8m in length. Inside the core barrel is a closely fitting plastic tube or "core liner", which is preferably transparent. This is held in place by a 'cutting shoe' at the end of the barrel, which also incorporates a sprung steel "core catcher" sample retention device. On top of the barrel is a vibratory motor, incorporating two contra-rotating asymmetrical weights, driven electrically or hydraulically. The motor and core barrel are usually encased in a tubular steel deployment frame with a tripod or oblong base to ensure stability and verticality.

The equipment is deployed on a single steel lifting cable with an associated electric or hydraulic umbilical cable. Once on the seabed the vibratory motor is activated, typically for between 5 and 10 minutes, and the barrel penetrates under the combination of the vibratory effect and the weight of the motor and core barrel.

On recovery to the surface the core barrel is removed and replaced by another ready for redeployment. The internal core liner is extruded and usually cut into sections for core description, testing and/or sealing for transport to an onshore laboratory.

System enhancements that are available include higher frequency motors to improve penetration in sands and percussion attachments, usually comprising a spring and reciprocating weight arrangement between the motor and core barrel, to improve penetration in stiff clay.

b) Advantages

The main advantages of this method are that the equipment is relatively simple, inexpensive and lightweight (around 0.75 tonnes to 1.25 tonnes in air typically, although lifting capacity must allow for barrel retraction forces and the self weight of cored soil) and can be a very cost effective method of recovering some material in most types of soil.

c) Disadvantages

The main disadvantages include :

i) Penetration may be limited in dense cohesionless strata or very stiff clays and thus fail to recover samples of critical strata that may, for example, give rise to trenching difficulties.

ii) Accurate definition of soil stratification may be impaired by plugging, compaction or core loss, causing sections of the soil profile to be missed or misinterpreted. In 'soft' soils for example the corer may penetrate say up to 0.5 metres before any material enters the barrel. During subsequent penetration the barrel may periodically plug and prevent the entry of soil and, on extraction of the core barrel, suction or gravity may pull part of the core from the barrel causing it to be left on or in the seabed. The net effect may then be that, despite achieving 3 metres penetration, the true stratification of the recovered material within the 3 metre section cannot accurately be determined.

iii) The vibratory method induces disturbance in the soil with the effect that subsequent laboratory tests for parameters such as shear strength and consolidation characteristics may produce unrepresentatively low values. This effect will be more predominant in softer soils, rendering the method unsuitable for accurate engineering evaluations in soft to very soft clay for example.

iv) On some vessels the equipment can prove cumbersome to handle, particularly for the longer barrelled models. For example, some “6 metre” vibrocorers have a total height of around 7.5 metres and a maximum base width of 5 metres.

Gravity corers

a) Description

The standard gravity corer normally comprises a core barrel, liner and cutting shoe, very similar to those used with vibrocorers; on top of which is a single large weight or a series of adjustable smaller weights usually totaling between 0.5 tonne and 1.0 tonne. They are deployed on a single steel lifting cable and penetration is achieved by allowing the unit to free fall the last 5 - 10 metres to the seabed.

The “stationary piston corer” (or Kullenberg-type corer) operates with a ‘trip-release’ mechanism and differs from a standard corer in having the core barrel closed at the bottom by a piston, which is connected to the main lift wire and remains approximately stationary as the core barrel penetrates the seabed. The presence of the piston can create a partial vacuum between it and the top of the soil core, thus resulting in improved recovery in some soil conditions.

b) Advantages

i) Relatively quick, inexpensive and simple to operate.

ii) Good quality samples possible in soft clays when using piston corers.

c) Disadvantages

i) Poor penetration in stiff clays and granular soils

ii) A “free fall” winch is required

or

iii) If a “trip-release” mechanism is used, this can be cumbersome to handle on deck and potentially dangerous because of the possibility of inadvertent triggering.

Grab sampler

a) Description

The grab sampler is, in simple terms, an articulated bucket, which closes when it comes into contact with the seabed and, in so doing, collects a sample of the surface deposits. These samplers can range in enclosed volume from a few litres to a cubic metre, with closure activated by a simple trip mechanism or by hydraulics in the case of some larger units. The samples obtained are suitable for description and ground truthing of geophysical interpretation, however they are not generally considered suitable for laboratory testing. When selecting a grab sampler, it is important that the size is sufficient to ensure a representative sample. Small ‘Shipek’ grabs are suitable in muds and sands, however where the seabed includes gravel, a large grab is required. Note is made that cobbles and boulders may be difficult to recover in representative numbers and that the result sample volume is likely to be very large volume.

b) Advantages

Usually relatively small, simple, inexpensive and easy to operate, with the larger hydraulic units being slightly more complex. However, the hydraulic units have the advantage of greater and more consistent recovery.

c) Disadvantage

i) Sample recovery tends to be hit and miss

ii) Very shallow penetration

iii) Highly disturbed sample

iv) Potential for wash-out of finer fraction of recovered sample, thus rendering particle size distribution analysis unreliable.

Cone/Piezo Cone Penetration Test (CPT/PCPT or CPTU)

a) Description

Cone Penetration Testing involves the measurement of the resistance to the controlled penetration into the ground of a steel rod with a conical tip. Standard electrical cone penetrometers incorporate internal load cells that measure resistance on the cone tip and side friction on a 'sleeve' behind the tip. The 'piezocone' version also measures excess pore water pressure in the ground generated by progress of the cone. This is achieved via a porous disc set in, or close to, the tip, which is connected to an internal pore pressure cell. Standard cones have a cross sectional area of 1000mm^2 or 1500mm^2 and are pushed into the seabed by a seabed frame with a drive mechanism. Normal depth of penetration is up to 5m, dependent on soil conditions.

Mini cones, with a cross sectional area of 100mm^2, 200mm^2 and 500mm^2 are also available. These units have the advantage of being much lighter and more compact than frames for full size cones, however penetration into harder soils is usually more limited. For the smaller cones, care is required in interpretation of geotechnical parameters.

A standard penetration rate of 20mm/sec is used for all cones and readings of tip resistance, sleeve friction, excess pore pressure and penetration distance are usually transmitted to the surface in real time via an umbilical cable at not less than 1 second intervals.

Parameters such as soil type, relative density, shear strength and stress history can be derived from the direct measurements and calculated ratios using empirical correlations.

Variations on cone penetration testing include fitting a T bar (a horizontal bar) in place of the cone tip. This is useful in soft clays where it may give an enhanced indication of soil strength and remoulded strength.

b) Advantages

The CPT/PCPT has many advantages over conventional coring techniques including :

i) Usually achieves greater penetration.
ii) Provides a complete stratigraphic profile (continuous measurement)
iii) Gives data in real time allowing almost immediate interpretation of ground conditions.
iv) Can reduce the amount of time-consuming laboratory testing.
v) Provides the only reliable method of determining the relative densities of cohesionless soils.
vi) Testing is very rapid and, depending on test spacing, the seabed unit may be left outboard between tests.

c) Disadvantages

The primary disadvantages have historically been :

i) Weight - typically 5 tonnes to 10 tonnes to ensure sufficient reaction force to achieve the desired penetration in dense sands/stiff clays.
ii) Cost - the technical complexity and precision engineering involved in many of the components inevitably makes it a more highly priced item of equipment and requires several highly trained personnel to operate.

d) T bar Testing

A variation of the CPT is the T bar test. For this test, the cone is replaced by a horizontal bar, typically of 40mm diameter and 200mm in length when used in conjuction with a 10cm^2 cone. This test method is appropriate in soft clay, and the clay flows around the bar as it is pushed into the ground.

The test has the advantage of providing a more accurate interpretation of undrained shear strength (as the N_k factor, used to calculate undrained shear strength, is better defined) and it is possible to estimate the remoulded strength of the soil as the T bar is retracted through the soil. A secondary advantage of the T bar is that the output of the load cell within the cone is magnified.

SECONDARY METHODS

The systems described below generally represent an addition to the primary spread of equipment and not a replacement for any of the main sampling and in situ testing techniques identified above.

However, they often have the advantage of providing more accurate and relevant data for the solution of a specific problem, reduce conservatism in design and hence deliver significant long term cost benefits.

Seabed rock corers

There are a variety of these available in the market place ranging in size from around 1 tonne to 13 tonnes and theoretically capable of taking cores with diameters ranging from 25mm to 150mm, to penetrations of up to 9 metres. Most incorporate a rotary drive mechanism and diamond or tungsten carbide impregnated drilling bits plus an inner core barrel. Their main advantage is to be able to take cores of rock outcropping at or near seabed without recourse to a floating or fixed drilling platform. Their primary disadvantage is the difficulty in obtaining high quality cores. Several systems allow remote control of drilling variables such as bit pressures, flushing fluid flow rates, rotation speeds and drive rates, however ‘feel’ is important in drilling, and this is reduced by remote operation.

Seabed drilling systems may also have difficulty drilling through and creating a stable hole through sands, gravel and cobbles, which may be present over rock head. Weathered, and heavy fractured, zones within the rock can also result in poor core recovery. The size and weight of some systems can also be a disadvantage.

Box corer

This is a relatively lightweight sampling system originally developed for oceanographic research purposes. It is designed to push a metal box about 0.5 metres into the seabed and, on retraction, seal in the sample by means of a blade-like door that closes beneath the box. Sample volumes are typically in the range 10 litres to 50 litres.

Its main application is in the retrieval of good quality block samples of soft clay in a manner that also permits inspection of a relatively undisturbed section of the seabed surface. This is particularly useful where the geotechnical parameters of seabed soils are required, for example, in deep water development where pipelines are surface laid and pipeline / soil friction is an important parameter. Its main disadvantage is its limited penetration capability.

In situ vane test

The in situ vane test is a very well established method, both onshore and offshore, for measuring the undrained shear strength of cohesive soils in situ. The test basically comprises the insertion of a cruciform vane into the soil (either directly from the seabed or within a borehole), and rotating it at a constant speed, whilst measuring torque and deflection, until the soil shears. The undrained shear strength of the soil can be directly back-figured since the area of the sheared cylindrical surface is known from the vane dimensions. Continued rotation can also provide a value for residual or remoulded shear strength.

Units are usually lightweight (less than 1 tonne) and relatively easy to handle.

The major advantage of such systems is the ability to measure in situ the undrained shear strength of soft to very soft soils at a high level of accuracy to penetrations of around 3m into the seabed. The main disadvantages are currently the speed of the operation - separate deployments are necessary for each penetration level at which tests are required - and that it is effectively a tool for investigating one soil type only, i.e. soft to very soft clay.

In situ model tests

As the description implies in situ model tests comprise equipment that attempt to reproduce the behaviour of a structure or component on or in the seabed by using a model of it and, by means of instrumentation, measure desired parameters as it is placed on, pushed into or pulled along the seabed. Examples include model instrumented pipeline ploughs which are designed to make a trenchability assessment of a pipeline route and a Model Pipe Settlement Tester which is designed to investigate the initial self embedment of surface laid pipelines with a view to improving the accuracy of axial and lateral stability analyses.

A variation of the Model Pipe Test is the Plate Load Test that is regularly performed onshore but less frequently offshore. It is essentially a bearing capacity test in which a circular or rectangular steel plate is placed horizontally on the ground or seabed or within an excavated pit and is loaded vertically until foundation "failure" occurs or deformation exceeds an acceptable limit. Load and deformation are constantly measured throughout the test and the results extrapolated to predict full size foundation behaviour.

The primary advantage of these tests is in providing direct indications of likely behaviour in situ and thus enabling reductions in design conservatism. Disadvantages can include size and cost of deployment for some systems and the fact that they are generally designed to provide information on one or two specific design parameters only.

Specialist in situ probes

There is a wide variety of probes available, mostly designed for use with conventional CPT/PCPT systems. Measurements that can be made include important design parameters such as thermal conductivity and electrical resistivity. The additional cost of adding such probes to a spread is usually insignificant.

The 'seismic' cone penetrometer incorporates one or more geophones within the cone and test rod. An energy source, at seabed or within the water column, generates one or more shockwaves and the sensors in the cone detect the arrival time of shear and/or compressional waves. From these measurements shear and compressional wave velocities can be measured and various dynamic moduli for the soil calculated. The additional equipment and time required for such testing is relatively small, and where specific risks exist, such as those posed by earthquakes or severe storm conditions, the data provided can be invaluable.

APPENDIX III

EXTRACTS FROM RELEVANT REGULATIONS AND GUIDELINES

APPENDIX III

EXTRACTS FROM RELEVANT REGULATIONS AND GUIDELINES

API RECOMMENDED PRACTICE 1111, 3rd Ed. July 1999 DESIGN, CONSTRUCTION, OPERATION AND MAINTENANCE OF OFFSHORE HYDROCARBON PIPELINES P.9

2.5 ROUTE SELECTION

2.5.1 Route of the Pipeline

The route of an offshore pipeline should be thoroughly analysed using the data from available charts, maps, other sources of relevant information, and a field hazards survey as described in 2.5.2. Whenever practical, the selected route should avoid anchorage areas; existing underwater objects such as sunken vessels and pilings; active faults; rock outcrops: and mud slide areas. The selection of route should take into account the installation methods applicable and should minimise the resulting installation stresses. The route of the pipeline should be shown on maps of an appropriate scale.

2.5.2 Preliminary Environmental, Bathymetric and Hydrographic Surveys

In selecting a satisfactory route for an offshore pipeline, a field hazards survey should be performed to identify potential hazards such as sunken vessels, piling, wells, geologic and manmade structures, and other pipelines. The bottom topographic and geologic features and soil characteristics should be determined. Data on normal and storm winds, waves and current, and marine activity in the area should be obtained where available. In areas where soil characteristics will be a factor in design and where previous operations or studies have not adequately defined the bottom soils, on-site samples should be acquired.

BRITISH STANDARD BS 8010 : PART 3 1993 SECTION 4

4.1.6 Routing

4.1.6.1 Survey

Data should be collected by hydrographic survey of the proposed route prior to final selection of the pipeline corridor.

This survey should include investigation of the following:

a) seabed geology and features
b) bathymetry
c) environmental and oceanographic data
d) wellheads, wrecks and debris

e) marine growth
f) landfall

4.1.6.2 Route selection

The following should be considered when selecting the route:

a) type and intensity of shipping and the presence of anchoring zones
b) type and intensity of fishing activity
c) presence of fishing grounds and other sensitive areas
d) presence of other pipelines, installations or wellheads
e) presence of wrecks or other obstructions
f) presence of regularly dredged areas and dumping grounds

B.1.9 Seabed soils

The following seabed soil information is typically required:

a) soil type;
b) grain size distribution;
c) presence and size of boulders;
d) shear strength, angle of internal friction and cohesion;
e) water content;
f) liquid and plastic limits;
g) bulk density;
h) oxygen content, salinity and organic content;
i) presence of hydrogen sulphide, producing bacteria;
j) electrical resistivity;
k) thermal conductivity;
l) historical records of bed movement and storm effects.

Seabed soil information is used to evaluate the following:

1) seabed friction;
2) seabed bearing capacity;
3) scour and spanning potential;
4) movement of sandwaves and other bedforms;
5) natural backfill potential;
6) self burial potential;
7) liquefaction;
8) flotation;
9) slope stability;
10) corrosion and cathodic protection;
11) heat loss from buried lines.

B.1.10 Seismic action

The possibility of seismic action on or near the pipeline system should be evaluated. The amplitude, velocity and acceleration of ground movement should be determined.

Seismically-induced shock pressure waves in the surrounding seawater and the possibility of soil liquefaction should also be evaluated.

DNV RULES FOR SUBMARINE PIPELINE SYSTEMS, DECEMBER 1996 Page 18 Sec. 3

E 400 Seabed properties

401 All the geotechnical properties which are necessary for evaluating the effects of relevant loading conditions are to be determined for the sea-bed deposits, including possible unstable deposits in the vicinity of the Pipeline, see Sec.5 D300. For guidance on soil investigation for Pipelines, see Classification Note No. 30.4 “Foundations”.

402 The geotechnical properties may be obtained from any available geological surveys and through a combination of seismic survey, coring, tests and borings with sampling. Supplementary information may be obtained from geological surveys, sea bottom topographical surveys, visual surveys, biological investigations, chemical examinations and laboratory testing on samples from borings.

403 In areas where the sea-bed material is subject to erosion, special studies of the current and wave conditions near the bottom including boundary layer effects may be required for the on-bottom stability calculations of Pipelines and the assessment of Pipeline spans.

404 Special investigation of the sea-bed material may be required to evaluate specific problems, as for example:

- problems with respect to excavation and burial operations
- possibilities of mud slides or liquefaction as the result of repeated loading
- implications on external corrosion
- possibilities of differences in frost heave due to different frost susceptibility from soil types surrounding the Pipeline.

DNV CLASSIFICATION NOTES – No. 30.4 "FOUNDATIONS"

1.6 SOIL INVESTIGATION FOR PIPELINES

1.6.1 General

1.6.1.1 The site investigation for a pipeline typically consists of a shallow seismic profiling survey of the wide lay barge anchoring corridor, a detailed bathymetric survey of the 100-150m wide construction corridor and finally a geotechnical investigation comprising cone penetration tests (CPT), push sampling, vibro coring, gravity coring etc. To define the various soil deposits along a proposed pipeline route, the emphasis is put on the shallow seismic profiling results. Testing and sampling should subsequently be performed for determination of the soil properties in these deposits.

1.6.2 Geophysical surveys

1.6.2.1 Total water depth is needed to determine external water pressure on the pipe and wave effects on the bottom sediments. The trenching, laying and burying methods will also be dependent on water depth. The seabed topography will influence the support conditions of the pipe, the formation of free spans and the stability of the seabed itself. Consequently, surveys with precise echosounders and sidescan sonar are usually required. The accuracy of such measurements will directly influence the degree of conservatism in the design of the pipeline itself.

1.6.2.2 Especially in areas of highly variable seabed topography, the limitations of the echosounder may necessitate more accurate mapping methods. Profiling with small submarines may improve the accuracy compared with that of surface vessels.

Seismic profiling is necessary to define the extent and variations of the various soils deposits along the pipeline route.

The equipment used should give good resolution for the shallow layers down to about 10m depth for definition of erodable material, applicability of trenching methods and stability of the pipeline itself. Deeper penetration should be recommended for identification of strata out-cropping at other locations along the route.

1.6.3 Geotechnical surveys

1.6.3.1 A sufficient number of samples should be secured from each major surface deposit to identify the soil or rock. Several types of shallow sampling techniques are now available for this purpose, see 1.2.5. In addition CPTs and/or vane shear tests should be performed.

1.6.3.2 A laboratory should be available onboard for the necessary soil classification and index testing, see 1.2.9.

1.6.3.3 In special cases the seabed conditions should be documented by use of TV or photos.

1.6.3.4 To complement the above surveys, measurements of seawater temperature and currents should be taken.

ACKNOWLEDGEMENTS

This document has been prepared by, or had input from, representatives of the following companies; however, it should be noted that any opinions and recommendations given within this document do not necessarily represent the views of those companies.

BP
Det Norske Veritas
Fugro
Gardline Geosurvey
Geocean
Exxon Mobil
Norsk Hydro
Norwegian Geotechnical Institute
RPS Hydrosearch
SEtech
Shell
Statoil
Stolt Offshore
Subsea 7
Technip Offshore
Thales Geosolutions
Total

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The latest version will always be available on the SUT website : **WWW.SUT.ORG.UK** ,
under Special Interest Groups / OSIG.
Comments and suggestions will be gratefully received and can be made to any of the following:

Offshore Site Investigation and Geotechnics Committee –
Pipeline Guidance Notes Sub-Committee Chairman
Peter Allan – SEtech
Tel: 44 (0) 191 2828000
Fax: 44 (0) 191 2828001
Email: peter.allan@setech-uk.com

Offshore Site Investigation and Geotechnics Committee – Chairman
Mick Cook – RPS Hydrosearch
Tel: 44 (0) 1483 746500
Fax: 44 (0) 1483 746505
Email: cookm@rpsplc.co.uk

Offshore Site Investigation and Geotechnics Committee – Secretary
Pat Power – Fugro Limited
Tel: 44 (0) 1442 240781
Fax: 44 (0) 1442 258961
Email: ptpower@fugro.co.uk