

Marine soil investigations

This NORSOK standard is developed with broad petroleum industry participation by interested parties in the Norwegian petroleum industry and is owned by the Norwegian petroleum industry represented by The Norwegian Oil Industry Association (OLF) and Federation of Norwegian Manufacturing Industries (TBL). Please note that whilst every effort has been made to ensure the accuracy of this NORSOK standard, neither OLF nor TBL or any of their members will assume liability for any use thereof. Standards Norway is responsible for the administration and publication of this NORSOK standard.

Standards Norway
Strandveien 18, P.O. Box 242
N-1326 Lysaker
NORWAY

Copyrights reserved

Telephone: + 47 67 83 86 00
Fax: + 47 67 83 86 01
Email: petroleum@standard.no
Website: www.standard.no/petroleum

Foreword	5
Introduction	5
1 Scope	6
2 Normative and informative references	6
2.1 Normative references	6
2.2 Informative references	7
3 Terms, definitions and abbreviations	9
3.1 Terms and definitions	9
3.2 Abbreviations	9
4 General objectives of investigations and need for planning	10
5 General requirements to execution of work	10
6 Drilling and logging	11
7 Sampling	11
8 In situ testing	11
9 Laboratory testing	12
10 Evaluation of data and reporting	12
10.1 Evaluation of data	12
10.2 Reporting of data	12
Annex A (Normative) Drilling and logging	13
A.1 Introduction	13
A.2 Drilling spread	13
A.3 Choice of drilling procedures depending on soil type	13
A.4 Logging of drilling parameters	14
A.5 Rotary core drilling	14
A.6 Geophysical borehole logging	14
A.7 Shallow gas	15
Annex B (Normative) Sampling	16
B.1 Background with definitions	16
B.2 Seabed sampling equipment and procedures	16
B.2.1 General	16
B.2.2 Grab	16
B.2.3 Gravity corer	16
B.2.4 Vibrocorer	17
B.2.5 Box corers	17
B.2.6 Other corers	17
B.3 Down-hole samplers	17
B.4 Choice of equipment according to expected soils	18
B.5 Sample handling and storage	18
B.5.1 General	18
B.5.2 Offshore handling	18
B.5.3 Offshore storage	19
B.5.4 Onshore transport, handling and storage	19
B.6 Sample log	19
B.7 Contaminated samples	20
Annex C (Normative) In situ testing	21
C.1 Deployment	21

C.1.1	Introduction	21
C.1.2	Seabed in situ testing (seabed mode)	21
C.1.3	Down-hole in situ testing (drilling mode)	21
C.2	Cone penetration test	21
C.2.1	Equipment requirements	21
C.2.2	Testing procedure	22
C.2.3	Data acquisition system	22
C.2.4	Calibration requirements	22
C.2.5	Required accuracy	23
C.2.6	Presentation of results	23
C.3	Seismic cone test	24
C.3.1	General	24
C.3.2	Geometry and configuration of equipment	24
C.3.3	Testing procedure	25
C.3.4	Data acquisition	25
C.3.5	Calibration	25
C.3.6	Presentation of results	25
C.4	Electrical conductivity cone	25
C.4.1	General	25
C.4.2	Geometry and configuration of equipment	25
C.4.3	Testing procedure	25
C.4.4	Data acquisition	26
C.4.5	Calibration	26
C.4.6	Presentation of results	26
C.5	Field vane test	26
C.5.1	Vane geometry	26
C.5.2	Testing procedure	26
C.5.3	Data acquisition	26
C.5.4	Calibration requirements	27
C.5.5	Accuracy	27
C.5.6	Presentation of results	27
C.6	BAT probe test/deep water gas probe (DGP)	27
C.6.1	General	27
C.6.2	Equipment	27
C.6.3	Test procedure	27
C.6.4	Calibration of sensors	28
C.6.5	Presentation of result	28
C.7	T-bar test	28
C.7.1	Equipment requirements	28
C.7.2	Testing procedure	28
C.7.3	Data acquisition system	28
C.7.4	Calibration requirements	29
C.7.5	Required accuracy	29
C.7.6	Presentation of results	29
C.8	Other in situ tests	29
C.8.1	General	29
C.8.2	Documentation requirements	30
Annex D (Normative)	Laboratory testing	31
D.1	Classification and index tests	31
D.1.1	General	31
D.1.2	Soil description and classification	31
D.1.3	Water content	31
D.1.4	Liquid and plastic limits	31
D.1.5	Bulk density of soil or soil unit weight	32
D.1.6	Specific gravity of soil	32
D.1.7	Maximum and minimum density	32
D.1.8	Grain size distribution	32

D.1.9	Angularity	33
D.1.10	Radiography	33
D.1.11	Index shear strength tests	33
D.1.12	Remoulded strength/sensitivity	34
D.2	Consolidation tests	35
D.2.1	General	35
D.2.2	Incremental load test	35
D.2.3	Continuous loading test	35
D.2.4	Measurement of permeability	35
D.2.5	Coefficient of consolidation	36
D.2.6	Measurements of horizontal stress	36
D.2.7	Calibration	36
D.2.8	Presentation of results	36
D.2.9	Evaluation of sample quality	37
D.3	Triaxial tests	37
D.3.1	General	37
D.3.2	Test apparatus	37
D.3.3	Preparation of test specimen	40
D.3.4	Consolidation stage prior to shearing	40
D.3.5	Static shearing	41
D.3.6	Cycling testing	42
D.3.7	Dismounting specimen	43
D.3.8	Presentation of results	43
D.3.9	Evaluation of sample quality	44
D.4	Direct simple shear tests	44
D.4.1	General	44
D.4.2	Test apparatus	44
D.4.3	Preparation of test specimen	47
D.4.4	Consolidation stage prior to shearing	47
D.4.5	Static shearing	47
D.4.6	Cyclic testing	48
D.4.7	Dismounting specimen	48
D.4.8	Presentation of results	48
D.4.9	Evaluation of sample quality	50
D.5	Ring shear tests	50
D.5.1	General	50
D.5.2	Sample preparation	50
D.5.3	Test procedure	50
D.5.4	Presentation of results	50
D.6	Resonant column tests	51
D.6.1	General	51
D.6.2	Sample preparation	51
D.6.3	Test procedure	51
D.6.4	Presentation of results	51
D.7	Piezoceramic bender element tests	51
D.7.1	General	52
D.7.2	Sample preparation	52
D.7.3	Test procedure	52
D.7.4	Presentation of results	52
D.8	Thixotropy tests	52
D.8.1	General	52
D.8.2	Sample preparation	52
D.8.3	Test procedure	52
D.8.4	Presentation of results	52
D.9	Heat conductivity test	53
D.9.1	General	53
D.9.2	Sample preparation	53
D.9.3	Test procedure	53

D.9.4	Presentation of results	53
D.10	Contaminated samples	54
D.11	Other relevant tests	54
D.11.1	General	54
D.11.2	Documentation requirements	54
D.12	Geological and geochemical tests	54
D.12.1	General	54
D.12.2	Visual description	55
D.12.3	Mineralogical analysis	55
D.12.4	Amino acid analysis	55
D.12.5	Stable oxygen isotope analysis	55
D.12.6	Analysis of gas in sediment samples	55
D.12.7	¹⁴ C dating (age determination)	56
D.12.8	Nanofossil and microfossil analysis	56
D.12.9	Organic and inorganic content	56
D.12.10	Analysis of parameters for determining corrosion risk	56
Annex E (Normative)	Reporting	57
E.1	Reporting according to type and level of investigation	57
E.2	Report structure	57
E.3	Report content	58
E.3.1	General	58
E.3.2	Executive summary	58
E.3.3	Part A: Soil parameters for design	58
E.3.4	Part B: Geotechnical data	63
E.3.5	Part C: Field operations	64
E.4	Reporting format	65
Bibliography		66

Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, NORSOK standards are, as far as possible, intended to replace oil company specifications and serve as references in the authorities' regulations.

The NORSOK standards are normally based on recognised international standards, adding the provisions deemed necessary to fill the broad needs of the Norwegian petroleum industry. Where relevant, NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of international standards, the relevant NORSOK standard will be withdrawn.

The NORSOK standards are developed according to the consensus principle generally applicable for most standards work and according to established procedures defined in NORSOK A-001.

The NORSOK standards are prepared and published with support by The Norwegian Oil Industry Association (OLF) and Federation of Norwegian Manufacturing Industries (TBL).

NORSOK standards are administered and published by Standards Norway.

Introduction

Revision 2 of this NORSOK standard is mainly an updated version to take into account the developments in the Offshore Soil Investigation Industry that have taken place since Revision 1 was issued in 1996.

According to the "Petroleum Activities Act" (1996), marine soil investigations are petroleum activities. The "Petroleum Activities Act" (1996) itself and the health, environment and safety (HES) regulations issued by the Petroleum Safety Authority (PSA) are therefore applicable for planning, documentation and execution of marine soil investigations. The HES regulations includes a number of requirements which have to be applied and documented before a marine soil investigation can commence, especially if a drilling vessel is used.

Type of soil investigation equipment to be used, extent of an investigation, laboratory testing programme and reporting requirements will be agreed as part of each contract. This will depend on type of structures involved (e.g. fixed platform, subsea structure, pipeline etc.), type of soil conditions and if it is a regional, site specific, preliminary or final soil investigation.

Use of this NORSOK standard will result in equal quality from the various soil investigations.

This NORSOK standard is published without marking of changes, compared to Rev. 1, as the modifications are considerable.

1 Scope

This NORSOK standard includes guidelines and requirements for equipment, testing procedures, interpretation and evaluation of test results and reporting for marine soil investigations. This NORSOK standard covers the most common equipment available today for sampling, in situ testing and laboratory testing.

This NORSOK standard is applicable both for marine soil investigations performed by specialised drilling vessels (drilling mode investigation with down-hole sampling and in situ testing) and for investigations performed by standard survey vessels (surface mode investigation). The detailed requirements in this NORSOK standard are only applicable for the equipment and methods specified by the user (client) in the scope of work for the actual field work.

2 Normative and informative references

The following standards include provisions and guidelines which, through reference in this text, constitute provisions and guidelines of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet or exceed the requirements and guidelines of the standards referenced below.

2.1 Normative references

API RP 2A-LRFD,	Planning, Designing and Constructing Fixed Offshore Platforms—Load and Resistance Factor Design. 1 st Edition, July 1, 1993.
API RP 2A-WSD,	Planning, Designing and Constructing Fixed Offshore Platforms—Working Stress Design. 21 st Edition, December 2000.
ASTM D422-63,	Standard Test Method for Particle-Size Analysis of Soils.
ASTM D854-02,	Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer.
ASTM D2166-00,	Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.
ASTM D2216-98,	Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.
ASTM D2435-03,	Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
ASTM D2573-01,	Standard Test Method for Field Vane Shear Test in Cohesive Soil.
ASTM D4015-92,	Standard Test Methods for Modulus and Damping of Soils by the Resonant-Column Method.
ASTM D4318-00,	Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.
ASTM D4452-85,	Standard Test Methods for X-Ray Radiography of Soil Samples.
ASTM D4648-00,	Standard Test Method for Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil.
ASTM D5334-00,	Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure.
ASTM D6528-00,	Standard Test Method for Consolidated Undrained Direct Simple Shear Testing of Cohesive Soils.
BS 1377-1:1990,	Methods of test for soil for civil engineering purposes. General requirements and sample preparation.
BS 1377-2:1990,	Methods of test for soil for civil engineering purposes. Classification tests.
BS 1377-3:1990,	Methods of test for soil for civil engineering purposes. Chemical and electro-chemical tests.
BS 1377-4:1990,	Methods of test for soil for civil engineering purposes. Compaction-related tests.
BS 1377-5:1990,	Methods of test for soil for civil engineering purposes. Compressibility, permeability and durability tests.
BS 1377-6:1990,	Methods of test for soil for civil engineering purposes. Consolidation and permeability tests in hydraulic cells and with pore pressure measurement.
BS 1377-7:1990,	Methods of test for soil for civil engineering purposes. Shear strength tests (total stress).

BS 1377-8:1990,	Methods of test for soil for civil engineering purposes. Shear strength tests (effective stress).
BS 1377-9:1990,	Methods of test for soil for civil engineering purposes. In-situ tests.
BS 5930:1999,	Code of practice for site investigations.
DNV Classification Note 30.4,	Foundations
IRTP (1999),	ISSMGE International Society of Soil Mechanics and Geotechnical Engineering (1999) International Reference Test Procedure for the Cone Penetration Test (CPT) and the Cone Penetration Test with Pore Pressure (CPTU). Report of the ISSMGE Technical Committee 16 on Ground Property Characterisation from In-situ Testing, Proceedings of the Twelfth European Conference on Soil Mechanics and Geotechnical Engineering, Amsterdam, Edited by Barends et al., Vol. 3, pp. 2195-2222. Balkema.
ISO 19901-4,	Petroleum and natural gas industries – Specific requirements for offshore structures – Part 4: Geotechnical and foundation design considerations.
ISO/DIS 19902,	Petroleum and natural gas industries - Fixed steel offshore structures
NS 3481	Soil investigations and geotechnical design of marine structures.
NS 8001,	Geotechnical testing - Laboratory methods - Percussion liquid limit.
NS 8002,	Geotechnical testing - Laboratory methods - Fall cone liquid limit.
NS 8003,	Geotechnical testing - Laboratory methods - Plastic limit.
NS 8005,	Geotechnical testing - Laboratory methods - Grain-size analysis of soil samples.
NS 8011,	Geotechnical testing - Laboratory methods - Density.
NS 8012,	Geotechnical testing - Laboratory methods - Density of solid particles.
NS 8013,	Geotechnical testing - Laboratory methods - Water content.
NS 8015,	Geotechnical testing - Laboratory methods - Determination of undrained shear strength by fall-cone testing.
NS 8016,	Geotechnical testing - Laboratory method - Determination of undrained shear strength by unconfined pressure testing.
NS 8017,	Geotechnical testing - Laboratory methods - Determination of one-dimensional consolidation properties by oedometer testing - Method using incremental loading.
NS 8018,	Geotechnical testing - Laboratory methods - Determination of one-dimensional consolidation properties by oedometer testing - Method using continuous loading.
Petroleum Activities Act (1996),	Lov om petroleumaktivitet. LOV 1996-11-29, sist endret LOV-2003-06-27-68. English translation: Act 29 November 1996 No. 72 relating to petroleum activities.

2.2 Informative references

ASTM D2487-00,	Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System).
ASTM D4253-00,	Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table.
ASTM D4254-00,	Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density.
ASTM D2850-03a,	Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils.
ASTM D6467-99,	Standard Test Method for Torsional Ring Shear Test to Determine Drained Residual Shear Strength of Cohesive Soils.
Bishop et al. (1971),	Bishop, A. W., G. E. Green, V. K. Garga, A. Andresen and J. D. Brown (1971): A new ring shear apparatus and its application to the measurement of residual strength. <i>Geotechnique</i> 21, 273-328.
Bromhead, E.N. (1979),	A simple ring shear apparatus. <i>Ground Engineering</i> , 12,40-44.

- Digby, A. (2002), Wireline logging for deepwater geohazard assessment. Proceedings of the SUT International Conference: "Offshore Site Investigation and Geotechnics", London, UK, 26-28 November 2002.
- Dyvik, R. and C. Madshus (1985), Lab measurements of G_{max} using bender elements. Proceedings of ASCE Annual convention. "Advances in Art of Testing Soils under Cyclic Conditions", Detroit, Michigan, October 1985. Soils under Cyclic Conditions", Detroit, Michigan, October 1985. Also published in NGI Publication No. 161.
- Dyvik, R. and T.S. Olsen (1989), G_{max} measured in oedometer and DSS tests using bender elements. NGI Publication No. 181.
- EN ISO 14688-1, Geotechnical investigation and testing – Identification and classification of soil – Part 1: Identification and description.
- ETC5 (1998), Recommendations of the ISSMGE For Geotechnical Laboratory Testing. Prepared by the European Regional Technical Committee ETC5 "Laboratory Testing".
- Jardine and Chow (1996) New design methods for offshore piles. MTD Publication 96/103, MTD (now CMPT) London.
- Norwegian Geotechnical Society, Guidelines and recommendations for presentation of geotechnical soil investigations, NGF, 1982.
- Norwegian Oil Industry Association (OLF), (2003), Guidelines for characterisation of offshore drill cuttings piles. Oljeindustriens Landsforening (OLF), Final report May 2003.
- Ladd, C.C. and R. Foott (1979), New design procedure for stability of soft clays. JGED, ASCE, Vol. 100, No. GT7, pp. 763-786.
- Lees, G. (1964), A new method for determining the angularity of particles. Sedimentology, Vol. 3, No. 1.
- Lunne et al. (1998), Lunne, T., T. Berre and S. Strandvik (1998). Sample disturbance effects in deepwater soil investigations. SUT Conference on Soil Investigations and Foundation Behaviour. London Sept. 1998. Proceedings pp. 199-220.
- Mokkelbost, K.H. and S. Strandvik (1999), Development of NGI's Deepwater Gas Probe, DGP. Proceedings International Conference on Offshore and Nearshore Geotechnical Engineering, Geoshore, Panvel, India, December, 1999. Pp. 107-112.
- NS 4737, Determination of sulphide content of waste water - Colorimetric method.
- Pettijohn, F.J. (1957), Sedimentary rocks. 2nd ed. New York, Harper & Brothers XVI, 718 pp.
- Rad, N.S. and T. Lunne (1994), Gas in Soils: Detection and η -profiling. Journal of Geotechnical Engineering, Vol. 120, No. 4, April, pp. 697-715.
- NGI/COFS (2004), Characterization of soft soils by in situ tests. Phase 2: Summary Report/Manual. NGI Report No. 20011026-8, dated 29.04.04.
- Ramsey et al. (1998), Ramsey, N., R. Jardine, B. Lehane and A. Ridley (1998) "A Review of Soil-Steel Interface Testing with the Ring Shear Apparatus", Proceedings SUT International Conference, Offshore Site Investigation and Geotechnics, London, November 1998.

Randolph et al. (1998),	Randolph, M.F., Hefer, P.A., Geise, J.M. and Watson, P.G. (1998) Improved seabed strength profiling using T-bar penetrometer. Proceedings of the SUT International Conference, Offshore Site Investigation and Foundation Behaviour 'New Frontiers', London 1998. Pp. 221-235.
SFT (1991),	Veiledning for miljøtekniske grunnundersøkelser. SFT-veiledning nr 91:01. Translated to English by NGI: "Guide to environmental soil investigation". NGI Report No. 537000-1, December 1992.
SUT-OSIG (2004),	"Guidance Notes on Geotechnical Investigations for Marine Pipelines", OSIG-Rev 03, 17 September 2004. Prepared by the Pipeline Working Group of the Offshore Soil Investigation Forum, OSIG. Updated 2004 by the Society for Underwater Technology.
Taylor, Donald W. (1948),	"Fundamentals of Soil Mechanics", New York, John Wiley & Sons Inc.
The Unified Soil Classification System (1953),	Waterways Exp. Station. Corps of Engineers, U.S. Army, Technical Memorandum No. 3-357, Vols. 1 to 3. Vicksburg, 1953.

3 Terms, definitions and abbreviations

For the purposes of this NORSOK standard, the following terms, definitions and abbreviations apply.

3.1 Terms and definitions

3.1.1

shall

verbal form used to indicate requirements strictly to be followed in order to conform to this NORSOK standard and from which no deviation is permitted, unless accepted by all involved parties

3.1.2

should

verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required

3.1.3

may

verbal form used to indicate a course of action permissible within the limits of this NORSOK standard

3.1.4

can

verbal form used for statements of possibility and capability, whether material, physical or casual

3.2 Abbreviations

BAT	commercial name of a gas sampler
CCV	consolidated constant volume
CPT	cone penetration test
CPTU	piezocone
CRS	constant rate of strain
CU	consolidated undrained
DGP	deepwater gas probe
DSS	direct simple shear
IRTP	International Reference Test Procedure
ISO	International Organization for Standardization
NGF	Norsk Geoteknisk Forening (Norwegian Geotechnical Society)
NGI	Norwegian Geotechnical Institute
NS	Norwegian Standard
OCR	overconsolidation ratio
RPM	rotations per minute

OSIG	Offshore Site Investigation and Geotechnical Committee
SFT	Statens Forurensningstilsyn (The Norwegian Pollution Control Authority)
SHANSEP	stress history and normalized soil engineering properties
SRB	sulphate reducing bacteria
SUT	The Society of Underwater Technology
UCT	unconfined compression test
UU	unconsolidated-undrained

4 General objectives of investigations and need for planning

The requirements given in ISO/DIS 19902, ISO 19901-4, NS 3481 and DNV Classification Note 3.4 shall be mandatory, unless otherwise documented. These standards are the basis for this NORSOK standard regarding planning and execution of marine soil investigations.

The level and extent of a soil investigation should be a function of several factors including, but not limited to, geology of the area, local soil conditions, project requirements, availability of previous investigations, accessibility, environmental conditions and any limitations related to budget and time available.

The detailed plans and specifications for the investigation should be based on a consideration of the following factors:

- type of investigation, regional or site specific;
- expected soil conditions, bathymetry and seabed features;
- active geological processes and possible geohazards;
- type of problem, soil structure interaction, slope stability etc.;
- required soil parameters;
- previous knowledge from the area, geological, geophysical and geotechnical;
- equipment that can be used;
- budgetary restraints;
- time schedules.

5 General requirements to execution of work

The requirements given in ISO/DIS 19902, ISO 19901-4, NS 3481 and DNV Classification Note 3.4 shall be mandatory, unless otherwise documented. These standards are the basis for this NORSOK standard regarding planning and execution of marine soil investigations.

Major equipment used during field work should as a minimum have a documentation consisting of the following:

- description with schematic drawings showing all significant dimensions (size and weight);
- operational procedures including safe job analyses;
- interface of various drilling and geotechnical tools;
- interface requirements to auxiliary equipment, power supply etc.;
- calibration charts for documentation of prescribed accuracy.

All lifting equipment including shackles and pad eyes shall be certified.

Sufficient number or amount of equipment and associated required consumables to perform the work shall be available on board.

The operators of the equipment shall have proper training and experience in the use of the equipment. Established routines shall be used for fault finding. This shall include personnel, equipment and spare parts to maintain and repair testing equipment breaking down during mobilisation or operation.

Soil borings shall be carried out in such a way that there is a minimum disturbance to the soil to be sampled or tested.

Continuous observations of the drilling progress shall be performed and checked against expected soil conditions, sample quality and results of in situ tests.

A continuous evaluation of results as the work proceeds shall be carried out. The investigation programme can thus be immediately revised in order to meet the objectives of the investigation.

The requirements regarding marine soil investigations shall be in accordance with ISO 19901-4.

6 Drilling and logging

The quality of down-hole samples and in situ tests depends very much on the equipment and procedures used for the drilling. Also performance rate and coverage of sampling and in situ testing depends on the drilling process. The drilling procedures should therefore be based on the aims of the project as detailed in Annex A. Attention should be given to drill bits, bit load, flow rate and mud type and their application to different soil types.

In many cases useful information can be obtained from the drilling parameters and these shall be logged as outlined in Annex A.

In some cases rotary core drilling may be the best solution, and if required this can be done according to Annex A.

7 Sampling

Basically sampling can be carried out in the following two modes:

- from the seabed without drilling (seabed mode);
- inside the drill string in the bottom of a borehole (drilling mode).

In most cases sampling and sample handling should be done in such a way as to cause minimum disturbance to the sample. In some cases it is most important to get as complete a coverage of the soil profile as possible or to get a large sample volume. In such cases other types of equipment may have to be used.

The choice of sampling equipment should be based on consideration of actual soil conditions, and the type of testing the soil samples are to be subjected to. A range of equipment is therefore normally required.

Generally the type of equipment to be used for sampling in drilling mode should be considered in the following priority:

- piston sampler, thin walled;
- push sampler, thin walled;
- push sampler, thick walled;
- hammer sampler;
- rotary core sampler.

In some cases, especially in very stiff or hard clays the use of rotary coring may give the best quality samples.

Further details are given in Annex B.

8 In situ testing

All in situ test equipment systems prescribed shall be checked for functionality during mobilisation of equipment on board the survey vessel. Such functionality checks shall include, but not be limited to

- signal response of sensors,
- data acquisition system,
- wet test of essential subsea equipment.

The in situ equipment with electronic transmission shall be designed to sustain the water pressures expected in the field.

During testing, zero readings of all sensors shall be recorded before and after each test.

The specifications for in situ test equipment and procedures in Annex C are made for the most used tests. For other in situ testing, equipment specifications and procedures shall be established prior to mobilisation.

Records of experience with the use of the equipment, routines and procedures for interpretation of measurements for assessment of soil parameters shall be documented and be made available on request.

9 Laboratory testing

Laboratory tests shall be carried out according to recognised standards or codes.

Detailed requirements to tests are given in Annex D, either as sole reference to standards and codes, or with additional guidance.

The laboratory should provide documentation upon sound working procedures and show that the relevant tests can be carried out as specified in Annex D.

Prior to the commencement of the testing the codes to be used and forms of presentation such as figures and plots should be agreed upon.

10 Evaluation of data and reporting

10.1 Evaluation of data

An evaluation of all test results shall be carried out. Commonly there will be some results less representative than others. These shall be identified and given less weight when establishing characteristic soil parameters.

The characteristic values shall in general be selected as conservative assessed mean values where the actual material property shall be selected so as to be on the conservative side.

The actual soil design parameters recommended shall depend on at least the following factors:

- soil investigation coverage;
- quality of data
- soil behaviour at failure (plastic, brittle, etc.);
- consequence of failure;
- spatial variability of material property within soil volume of interest;
- possibility of progressive failure.

10.2 Reporting of data

A standardised reporting structure will improve the access to the data and reduce laborious work. It is therefore required that reports are structured in levels and organised as outlined in Annex E.

The organization of the report shall depend on the type and extent of the investigation.

The reported data shall also be submitted in such a format that they can electronically be transformed to a geotechnical data base.

All reporting shall be in SI units.

Annex A (Normative) Drilling and logging

A.1 Introduction

The aim of this annex is to set focus on drilling procedures and how they may influence sample quality, performance rate and recovery. What the individual projects will focus on, will depend on the purpose of the investigation. For geotechnical work, sample quality will in most cases be most important. For geological investigations, sample coverage (recovery) may be more important than quality and for some projects (for instance hard layer detection) fast penetration in order to cover as large area as possible within the limit of the budget may be the most important. For some projects geophysical borehole logging may be a valuable supplement to sampling and in situ testing.

A.2 Drilling spread

The description shall, as a minimum, include

- weight capacity of drilling system under the power swivel (i.e. maximum weight of drill string including drill collars and BHA),
- description of system and procedures for depth accuracy (for instance hard-tie system),
- maximum stroke on heave compensation system and weather/current limitations,
- mud capacity including mixing capacity, number and volume of mud tanks and maximum pumping rate,
- drill string handling,
- geotechnical equipment handling,
- description of drill bits available onboard,
- crane and A-frame capacities,
- available free deck space for geotechnical equipment,
- laboratory facilities,
- office facilities.

A.3 Choice of drilling procedures depending on soil type

The drilling procedures shall be designed based on the aim of the project, i.e. sample quality, recovery or fast penetration. Emphasis shall be on sample disturbance minimisation, borehole stability, drill cutting removal and penetration rate.

Equipment and procedures to use in the following soil types shall be available:

- very soft to soft clays;
- stiff to hard clays;
- loose silty sand;
- dense sand;
- dense gravel;
- hard boulder clay with stones;
- soft rock (chalk).

For the various soil types and seabed conditions, the following variables shall be considered:

- type of drill bit;
- criteria for change of drill bit;
- type of mud and additives;
- mud pressure;
- mud flow rate;
- RPM;
- bit load;
- torque.

A.4 Logging of drilling parameters

Drilling parameters are useful for

- interpolation/extrapolation of soil data,
- to explain possible sample disturbance,
- detection of layering,
- rough assessment of soil conditions,
- assessment of drilling resistance for later wells and conductor setting,

If required by the client the following data should be logged in real time with a frequency of maximum 10 s and stored electronically:

- time;
- penetration;
- penetration rate;
- mud pressure;
- mud flow rate;
- RPM;
- bit load;
- torque.

A.5 Rotary core drilling

In some soil types and for certain purposes rotary drilling may be the best solution. In soft rock this is the case, but by experience rotary drilling may be a good alternative in hard boulder clay, especially if recovery is more important than sample quality. Standard geotechnical sample tools such as push and piston systems tend not to penetrate far in such soils. There are different systems in use. The most common are Christensen coring, various types of fast rotating piggyback diamond coring systems and Geobor S.

For hard boulder clay and soft rock the following variables shall be considered:

- type of drill bit;
- criteria for change of drill bit;
- type of mud and additives;
- mud pressure;
- mud flow rate;
- RPM;
- bit load.

A.6 Geophysical borehole logging

For some projects where enhanced geological and engineering details are required geophysical wireline logging can be considered. A number of tools are available, some for in-pipe measurements and some for open hole measurements as outlined by Digby, A. (2002). These tools include

- calliper tool,
Measures borehole diameter by a mechanical calliper.
- natural gamma radiation,
Measures concentration of radioactive isotopes. Gives information on soil type and variation in particle size distribution.
- neutron tool,
Uses a radioactive source to provide the porosity of the formation. Can also measure natural gamma radiation and formation resistivity.
- sonic tool,
Measures sound velocity. Gives indications on soil type and change of soil character.
- density tool.
Uses a radioactive source to measure the soil density. Can also measure natural gamma radiation and formation resistivity.

Operation of tools with radioactive sources shall comply with Norwegian safety requirements. A qualified "Radiation Protection Supervisor" shall on board, and procedures for use of the logging equipment, risk evaluation and contingency procedures have to be established.

A.7 Shallow gas

In areas with potential shallow gas, special procedures shall be available. Such shallow gas procedures shall evaluate and consider to include, but not be limited to, the following elements:

General precautions

- No hot work or smoking on deck.
- Heavy mud available.
- Gas detectors in the moon pool and in the derrick.
- Wind meter.
- Current meter.

In areas with risk of shallow gas

Consider to drill a dedicated pilot hole with a non-return valve in the lower part of the drill string and no running of down hole tools. When no shallow gas is encountered, a second boring close to pilot hole can be drilled and tested with geotechnical tools.

Precautions against gas through the drill string

Safety valve on top of the power swivel while using wire line operated down hole tools.

Precautions against gas outside the drill string

Offset between the vessel and the borehole. The direction of the offset is selected based on wind and current conditions.

In high risk areas additional precautions are recommended such as

- non return valve in the lower part of the drill string while drilling and pulling pipe,
- TV camera on the seabed frame,
- pull out sampler or in situ tool by lifting drill string while the down hole tool is latched into the bottom hole assembly,
- in situ gas measuring system in order to get an early warning before the gas charged layer is penetrated (BAT, DGP or similar).

Annex B (Normative) Sampling

B.1 Background with definitions

Samplers can in principle be deployed in the following two ways:

- penetration from the seabed and into the soil to a predetermined depth or until it cannot penetrate more (this is in the following called *seabed sampling*). This can be very short samples like for instance a grab sample (see B.2.2) or long seabed samples to more than 30 m in extreme cases;
- penetration from the bottom of a borehole and into the soil to a predetermined length of for instance 1 m, or until refusal (this is in the following called *down-hole sampling*).

The length of sample that can be obtained for both cases mentioned above will depend on several factors, e.g.:

- geometry, size and characteristics of the sampler;
- soil type;
- the available penetration force and how this is applied, e.g. by a steady pushing force, vibration or hammering/percussion.

If required the contractor shall, based on his experience, give documentation on what penetration can be expected for the different sampling methods he proposes and the expected soil conditions.

B.2 Seabed sampling equipment and procedures

B.2.1 General

The description shall, as a minimum, include the following:

- weight of equipment in air and in water;
- handling requirements:
 - deck space;
 - crane lifting force and arm length.
- manufacturer and name of equipment;
- any limitations as to water depth, soil type etc.

The retrieval from seabed and handling of seabed samples shall be done in such a way that the sampler is not subjected to significant shock or vibration that may cause disturbance to the sample.

B.2.2 Grab

For grab samplers the following information shall be given:

- maximum penetration below sea bed;
- maximum volume of sample;
- release mechanism;
- how wash out during retrieval of sample is prevented.

B.2.3 Gravity corer

For gravity corers the following information shall be given:

- geometry and dimensions of cutting shoe;
- inside and outside diameter of core barrel and liner;
- type of core catcher/retainer;
- whether a piston is used;
- weight and lengths available;

- any special handling requirements, including free fall mechanism, if relevant.

The gravity corers shall have a non-return valve at the top of the tube to avoid water ingress and sample washing out when pulling the sampler back to surface. Both penetration and recovery should be measured and reported. Limitations with penetration measurement system to be discussed.

For advanced long seabed samplers designed to give high recovery and a minimum of sample disturbance the following information is also required:

- precautions taken to reduce inside friction of liners;
- precautions taken to reduce outside friction of cutting shoe and core barrel;
- reference of piston position during sampling;
- method of measuring penetration.

B.2.4 Vibrocorer

For vibrocorers the following information shall be given:

- specifications of vibrator unit, power, frequency;
- geometry and weight of rig;
- umbilical required;
- geometry and dimensions of cutting shoe;
- inside and outside diameter of core barrel and liner;
- type of core catcher;
- sampling lengths available;
- any special handling requirements.

It is essential that recovery versus penetration is recorded and reported. It is therefore recommended that the vibrocorer is fitted with a device that measures continuously the progress of the sampler into the soil.

B.2.5 Box corers

For box corers the following information shall be given:

- dimensions of sample;
- weight and geometry;
- any special handling requirements;
- any other relevant information;
- how wash out during retrieval of sample is prevented.

B.2.6 Other corers

For other seabed corers the following information shall be given:

- description of driving mechanism;
- geometry and dimensions of sampler cutting shoe;
- inside and outside diameter of liner if applicable;
- type of core catcher/retainer;
- geometry and weight of sampling device;
- length(s) of sample available;
- any special handling requirements;
- any other relevant information.

B.3 Down-hole samplers

The drilling of a borehole should be carried out in such a way that the disturbance to the soil below the drill bit is minimised. Annex A gives detailed requirements to the geotechnical aspects of drilling. It is important that retrieval and handling of down-hole samplers are done in such a way that any shock or vibration is avoided with undue sample disturbance. In soil layers where shallow gas may be expected it is important that the sample cylinder is pulled out very slowly to avoid "swabbing" effects, see also Annex A.

To cover a wide range of possible soil types systems shall be available for taking hammer, push and piston samples. The following contains a description of the information needed in connection with drilling and sampling, depending on the scope of work:

- system for piston sampling including principle used as well as diameter and length of sample;
- system for push sampling including principle used as well as diameter, length of sample, available force and length of sample tube penetration;
- complete system for hammer sampling, including hammer weight. All vital data on the equipment including fall height of hammer and type of winch to be submitted;
- system for taking rotary core samples if applicable;
- drill pipe control (if applicable) including seabed rig and heave compensation system. Drill pipe heave compensation system connected to the seabed rig (e.g. hard tie system);
- sample tubes:
 - cutting shoe angle;
 - inside and outside diameter (inside clearance if applicable);
 - maximum sample length;
 - inside liners or stocking (if applicable);
 - core catching system (if applicable);
 - steel quality;
 - method of sealing sample tube if samples are not to be extruded offshore.

It is especially important that sample tubes shall not be reused without cleaning and a thorough check. Tubes with damaged tip shall be discarded. For push and piston sampling thin wall steel tubes shall preferably be used. A thin wall tube shall have a wall thickness not exceeding 2,0 mm. A 76,2 mm (3 in) thin wall sample tube will thus have outer and inner diameters of about $D_o = 76$ mm and $D_i = 72$ mm respectively. Inside clearance $C_i = (D_i - D_c)/D_c$, where D_c is internal diameter of cutting shoe, shall be in the range 0 % to 1 %. In soft clays where sample disturbance is of particular concern, some sample tubes with cutting shoe angle of 5 degrees should be available. Recovering of the sample on deck should be done in such a way as to cause a minimum of additional disturbance to the sample.

B.4 Choice of equipment according to expected soils

Equipment and procedures (with options if necessary) to use in the following soil types shall be available:

- very soft to soft clays;
- stiff to hard clays;
- loose silty sand;
- dense sand;
- dense gravel;
- hard boulder clay with stones;
- soft rock (chalk).

The aim is to have as undisturbed samples as possible and a satisfactory recovery. For soft soils the type of sampler should be considered in the following sequence:

- piston sampler, thin walled;
- push sampler, thin walled;
- push sampler, thick walled.

For very stiff to hard clay it is possible that carefully performed rotary coring may give the best quality sample.

B.5 Sample handling and storage

B.5.1 General

After retrieval of a soil sample (seabed or down-hole sample techniques) on board the survey vessel, the sample shall be handled with care.

B.5.2 Offshore handling

B.5.2.1 Down-hole steel tube samples

An end cap shall be mounted on the bottom of the cylinder (cutting edge side) immediately after retrieval in order to prevent soil and water escaping from the cylinder.

So-called "cuttings" and drill mud shall be removed from the top of the cylinder before the total length of sampled soil is measured. Each cylinder shall be labelled and marked uniquely, with location, borehole, cylinder number, depth to top of sample and date of sampling.

Depending on the subsequent testing (investigation) of the sampled soil, this shall now either be securely sealed in the cylinder or extruded in the offshore laboratory. Whether a sample part designated to be used for advanced onshore testing should be kept in the sample cylinder or extruded and sealed will depend on the strength and stiffness of the soil and the possible access to free water or mud. Generally for soft clays with undrained shear strength less than about 50 kPa, and with no suspicion of shallow gas, it is recommended to keep the soil in the sample cylinder to minimize the disturbance due to handling and transportation.

Extruded sample parts intended for subsequent testing in the onshore laboratory shall be securely wrapped in plastic and aluminium foil and then waxed and sealed, preferably in a cardboard cylinder. It is important that any mud or excess water be removed to avoid potential swelling of the sample. Each waxed sample part shall be uniquely marked including information on vertical orientation.

B.5.2.2 Seabed samples in plastic liner

The plastic liner with sample inside shall be carefully cut in 0,5 m or 1 m lengths. How much of the sample to split open or extrude and describe/test onboard will vary from project to project. Samples for transportation to onshore laboratory testing shall be clearly marked, with the vertical orientation the soil had in the ground, and properly sealed in each end by plastic cups and tape or similar.

B.5.3 Offshore storage

The sealed and marked sample cylinders and waxed samples shall be put in boxes or stacks suitable for transportation and stored, while on the board survey vessel, in a cool place with steady temperature. Rooms adjacent to heavy engines or generators, which generate excessive vibrations, shall be avoided. It is recommended that samples are stored vertically with the same orientation as the soil had in the ground.

B.5.4 Onshore transport, handling and storage

The boxes with sealed soil samples shall be transported to the onshore laboratory with caution and handled with care. Special precautions shall be made to prevent shock and impact loads to the soil samples during handling of the boxes. It is recommended that samples in tubes or liners are stored vertically, with the same orientation as the soil had in the ground, during transportation. Horizontal storing of samples may also be acceptable, especially for firm and stiff soils.

The soil samples shall not be exposed to temperatures below 0 °C.

Whether samples shall be air freighted or trucked to the onshore laboratory shall be decided in each case.

The sealed samples shall be stored in a humid room at about 7 °C in the onshore laboratory.

Each cylinder and waxed sample shall be registered and stored for convenient retrieval.

B.6 Sample log

Upon completion of the field work a sample log shall be prepared. For down-hole sampling in conjunction with drilling the log shall be complimentary to the drilling log.

The sample log shall include the following information:

- site area;
- borehole or core number;
- sample number;
- water depth;
- date of sampling;
- type of sampler;

- diameter of sampling tube;
- length of sample;
- whether sample is extruded on board or sealed in tube or liner;
- short description of soil type.

B.7 Contaminated samples

For samples that are suspected to consist of contaminated material special precautions should be taken as outlined in guidelines issued by The Norwegian Oil Industry Association, (OLF), (2003).

Annex C (Normative) In situ testing

C.1 Deployment

C.1.1 Introduction

An in situ tool can be inserted into the soils in the following two ways:

- from the seabed to either a pre-set depth or to refusal due to limitation in pushing force, capacity of load sensor(s) or other factors (this is called *seabed mode* in the following);
- from the bottom of the borehole to either a pre-set depth or to refusal due to limitation in pushing force, capacity of load sensor(s) or other factors (this is called *drilling mode* in the following).

C.1.2 Seabed in situ testing (seabed mode)

It is very important that the rig does not interact with the seabed soil in such a way that the result of the in situ test is influenced by its presence. Ideally the footprint and weight of the sea bottom rig should be such that the soil where the in situ test is carried out in the top most soil is not disturbed or influenced by stresses from the seabed rig. The effect of the seabed rig on the in situ test results may be reduced by careful consideration of whether

- the contact area (footprint) is ring or rectangle/square shaped with an open space where the in situ tool is pushed into sea bed,
- skirts are used on the periphery of the rig to transfer forces to stiffer soil,
- the weight of the rig is balanced so that it is no larger than what is required to provide sufficient reaction force.

In order to be able to evaluate any effects of the rig on the in situ measurements any penetration into the sea bottom should be monitored, e.g. by using a TV camera mounted on the rig.

Use of an remotely operated vehicle is a possible alternative in some cases for performing shallow testing, depending on soil type and required penetration depth.

C.1.3 Down-hole in situ testing (drilling mode)

The drilling of the borehole should be carried out in such a way that the disturbance to the soil below the drill bit is minimized. Annex A gives detailed requirements to the geotechnical aspects of drilling. In order to avoid any disturbed zone below the drill bit the in situ test tool should be penetrated at least 1 m if soil strength and density allows. The disturbed zone can be assessed from a continuous CPT/CPTU penetrated to say 3 m below the drill bit.

C.2 Cone penetration test

C.2.1 Equipment requirements

The geometry of the cone penetrometer with tip, sleeve and pore pressure filters shall follow IRTP (1999), from which the following is extracted:

- the penetrometer tip and adjoining rods shall have the same diameter for at least 400 mm behind the tip;
- the cone shall have a nominal cross section, A_c , of 1000 mm² with
$$35,3 \text{ mm} \leq d_c \leq 36,0 \text{ mm}$$
$$24,0 \text{ mm} \leq h_c \leq 31,2 \text{ mm}$$

where

d_c is the cone diameter

h_c is the height of the conical part

According to the IRTP (1999) cone penetrometers with a diameter between 25 mm ($A_c = 500 \text{ mm}^2$) and 50 mm ($A_c = 2000 \text{ mm}^2$) are permitted for special purposes, without the application of correction factors. The recommended geometry and tolerances given for the 1000 mm² cone penetrometer should be adjusted proportionally to the diameter.

C.2.2 Testing procedure

The testing procedure shall comply with the IRTP (1999) as follows:

- the nominal rate of penetration shall be 20 mm/s with an accuracy of $\pm 5 \text{ mm/s}$;
- the length of each stroke shall be as long as possible with due consideration of the mechanical and strength limitations of the equipment. Continuous penetration is preferred;
- readings of all channels shall be taken at least once per second (for every 20 mm of penetration);
- for quality control zero readings shall be recorded before and after each test, see also C.2.4.

For CPTU testing the filter stones shall be fully saturated and the pore pressure measurement system shall give an instantaneous response to changes in pressure. Documented procedure for saturation of filter stones shall be available.

Pore pressure dissipation tests should be carried out to at least 50 % consolidation (i.e. half way between pore pressure after stopping penetration of the cone and the assessed in situ pore pressure). In cases where this may imply long measurement periods, the client and the contractor should agree on the maximum test duration depending on the importance of the results.

The sampling rate during a dissipation test should at least be as follows:

During 1 st minute	2 times each second
Between 1 st minute and 10 th minute	1 time each second
Between 10 th and 100 th minute	1 time every 2 seconds
After 100 minutes	1 time every 5 seconds

C.2.3 Data acquisition system

The data acquisition system shall be such that the overall accuracy outlined in C.2.5 is maintained.

The resolution of the measured results shall be within 2 % of the measured value.

During actual testing with wire line tools, the data acquisition system shall allow for real-time inspection of the measured results both in digital and graphical form.

The measured results shall be stored digitally for subsequent processing.

C.2.4 Calibration requirements

For each cone penetrometer an accurate calibration shall be made of the area ratios of the cone (a) and the friction sleeve (b) as given in IRTP (1999). These values are characteristics for each cone penetrometer and should be documented in each field report as they are very important for data reduction. The (a) and (b) calibrations should be checked at least once a year.

Calibrations of each sensor shall be made prior to each project and at least every 3rd month or after about 100 soundings. If the load cells have been loaded close to maximum capacity, new calibrations shall be carried out.

During the field work regular function checks of the cone penetrometer and measuring system shall be carried out.

A calibration certificate for each cone penetrometer shall be presented before mobilisation.

For each cone or CPTU representative of each type (i.e. of the same load cell capacity) the following temperature calibration shall be documented to have been done at least once:

- variation of response to zero load for temperatures varying from 0 °C to 40 °C;
- calibration factor of each sensor at a temperature of + 5 °C; the method used to obtain the calibration factors shall be explained.

C.2.5 Required accuracy

The use of accuracy classes as required in the IRTP (1999) shall be adopted. Equipment and procedures to be used shall be selected according to the required accuracy class given in Table C.1.

Table C.1 - Accuracy classes

Class	Measured parameter	Minimum allowable accuracy	Maximum length between measurements mm
1	Cone resistance Sleeve friction Pore pressure Inclination Penetration length	50 kPa or 3 % 10 kPa or 10 % 5 kPa or 2 % 2 degrees 0,1 m or 1 %	20
2	Cone resistance Sleeve friction Pore pressure Inclination Penetration length	200 kPa or 3 % 25 kPa or 15 % 25 kPa or 3 % 2 degrees 0,2 m or 2 %	20
3	Cone resistance Sleeve friction Pore pressure Inclination Penetration length	400 kPa or 5 % 50 kPa or 15 % 50 kPa or 5 % 5 degrees 0,2 m or 2 %	50

If all possible sources of errors are added, the accuracy of the recordings shall be better than the largest of the values given in Table C.1. The relative or % accuracy applies to the measured value and not the measuring range or sensor capacity

Class 1 is meant for situations where the results will be used for precise evaluation of stratification and soil type as well as parameter interpretation in profiles including soft or loose soils. For Class 3 the results should only be used for stratification and for parameter evaluation in stiff or dense soils. Class 2 may be considered more appropriate for stiff clays and sands.

During the sounding, zero readings should be taken with the probe temperature as close as possible to the ground temperature, and all sensors and other electronic components in the data acquisition system should be temperature stabilised.

C.2.6 Presentation of results

C.2.6.1 General

The reporting of results from CPTs shall comply with the IRTP (1999).

For each cone test the following information shall be reported offshore after each test and in the field report (either in tabular form or on the CPT profiles):

- location;
- test number;
- coordinates of test location;
- date of performing test;
- cone serial number;
- cone geometry and dimensions with position and dimensions of filter stone;
- capacity of sensors (tip, pore pressure and sleeve friction);
- calibration factors used;
- zero readings of all sensors before and after each test, either at sea floor or bottom of borehole;
- observed wear or damage on tip or sleeve;
- penetration rate;
- any irregularities during testing;
- theoretical effective (net) area ratio of tip (α), see IRTP (1999);

- theoretical effective (net) friction sleeve (b), see IRTP (1999);
- water depth to sea floor during test;
- corrections due to tidal variations, if any;
- observed sinking in of the frame (optional);
- the inclination of the cone penetrometer to vertical axis, for a maximum penetration depth spacing of 1 m (for seabed type testing only).

The measured results in engineering units shall be presented in digital form, consisting of the following:

- depth of penetration in m;
- cone tip resistance in MPa;
- pore pressure(s) in MPa (if applicable);
- sleeve friction in kPa;
- total thrust during test in kN.

C.2.6.2 Graphical presentation

The results from CPTs in the field (offshore) shall be presented.

The depth scale shall be 1 m (field) = 1 cm (plot) if otherwise is not agreed upon.

The zero reference for seabed CPTs shall be the sea bottom and for down-hole CPT the bottom of the borehole. The scale for presenting the measured cone resistance, pore pressure and friction shall be selected to suit the soil conditions.

In addition to the measured CPT/CPTU values the following corrected/derived parameters shall be presented:

- corrected cone penetration resistance, $q_t = q_c + (1-a) u$ (with u measured behind the cone);
- corrected sleeve friction, f_t , only if pore pressures have been measured at both ends of the friction sleeve;
- friction ratio, $R_f = (f_s/q_t) \times 100 \%$ or if relevant $(f_t/q_t) \times 100 \%$, where f_t is the sleeve friction corrected for pore pressure effects (this requires measurement of the pore pressure at both ends of the friction sleeve);
- pore pressure ratio, $B_q = \frac{u - u_o}{q_t - \sigma_{vo}}$ with pore pressure recorded behind the cone,

where

σ_{vo} is total vertical stress with reference to sea bottom

u is the penetration pore pressure

u_o is in situ static pore water pressure.

For down-hole type tests it is important that the derived parameters are corrected to be referenced to sea bottom.

C.3 Seismic cone test

C.3.1 General

The seismic cone shall be able to measure the shear wave velocity generated from a source at the sea bottom and in addition be able to operate as a regular cone penetrometer. In some cases it may also be required to measure P-waves.

C.3.2 Geometry and configuration of equipment

The geometry and dimensions of the seismic cone shall be according to the requirements outlined in C.2.1. Seismographic sensors shall be placed behind the friction sleeve of the penetrometer within the shaft and shall not cause changes in the outside diameter of the shaft.

The seismic source shall be installed on the sea bottom in conjunction with the equipment used for other in situ testing, i.e. sea bed frame. A hydraulic hammer shear wave source type shall be used.

Signal transmission, including power and triggering signal from seismic source shall be through the umbilical of the seabed frame.

The seismic source shall be such that it generates shear waves with intensity strong enough to be clearly detected by the seismographic sensors down to about 80 m below seabed under favourable conditions.

C.3.3 Testing procedure

The test can be carried out in either seabed mode or drilling mode.

An event is defined as the generation of shear waves with corresponding monitoring of the seismographic sensors. Two events shall be made at each depth with opposite polarity. Additional events with same polarity may also be made to make use of the "stacking method".

After one set of events at one test depth has been performed, the CPTU shall be pushed at least 1 m further, where a new set of events shall be performed.

Soil samples should be taken adjacent to the seismic test depth levels and subsequently described and index tests performed.

For computation of maximum shear modulus, $G_{\max}$, it is necessary to have an accurate determination of soil density as a function of depth.

C.3.4 Data acquisition

The data acquisition system shall have a frequency response similar to the seismic sensors.

A triggering signal shall be generated at the time when the seismic source is activated, i.e. start of propagation of shear waves. The triggering signal and the measurements from the seismic sensors in the seismic cone shall be recorded versus time.

The system shall enable results from one event to be superimposed on another, e.g. two events with opposite polarity.

Analogue records of each test shall be stored for subsequent processing and evaluation.

C.3.5 Calibration

The seismic source and data acquisition system shall be calibrated such that the time when the shear waves start to penetrate into the seabed is recorded.

The overall accuracy of the measured velocity of the shear waves shall be within 10 % and 20 %.

C.3.6 Presentation of results

In addition to the requirements for presentation of standard CPT/CPTU results given in C.2.6 the following shall be presented:

- measured results from each set of events presented as sensor output versus time (millisecond);
- average shear wave velocity, V_s , over the depth intervals it has been measured;
- computed small strain shear modulus, G_o , over the intervals V_s has been measured.

C.4 Electrical conductivity cone

C.4.1 General

The electrical conductivity shall be measured between two electrodes placed on the cone penetrometer. This subclause only contains requirements related to the measurement of electric conductivity.

C.4.2 Geometry and configuration of equipment

The geometry of the electrical conductivity cone shall be according to the requirements outlined in C.2.1. The electrodes are normally placed behind the friction sleeve of the penetrometer within the shaft and shall not cause changes in the outside diameter of the shaft.

The cone penetrometer shall be able to measure at least the cone resistance and the sleeve friction together with the electrical conductivity of the soil.

C.4.3 Testing procedure

The testing procedure shall comply with IRTP (1999), particularly emphasising:

- the nominal rate of penetration shall be 20 mm/s with an accuracy of ± 5 mm/s;
- readings of all channels shall be taken at least once per second (for every 20 mm of penetration).

C.4.4 Data acquisition

The data acquisition system shall be such that the overall accuracy outlined in C.2.3 is maintained. During testing, the data acquisition system shall allow for real-time inspection of the measured results both in digital and graphical format.

C.4.5 Calibration

The general requirements given in C.2.4 shall apply for the electrical conductivity cone.

C.4.6 Presentation of results

In addition to the requirements for presentation of standard CPT/CPTU results given in C.2.6, the measured electrical conductivity shall be plotted versus depth either as separate plots or as composite plots together with the cone resistance and /or the sleeve friction. The figures shall contain information on the cone type and the configuration of the electrodes.

C.5 Field vane test

C.5.1 Vane geometry

Vane blades shall be rectangular as defined in ASTM D2573-01 or BS 5930:1999, according to expected shear strength are given in Table C.2.

Table C.2 - Vane blades

Measuring range of s_u kPa	Vane height mm	Vane width mm	Vane blade thickness mm
0 to 50	130	65	2
30 to 100	110	55	2
80 to 250	80	40	2

C.5.2 Testing procedure

The vane blade shall be pushed at least 0,5 m below the bottom of borehole before a vane test is started. The pushing rate shall not exceed 25 mm/s. The time from the instant when the desired test depth has been reached to the beginning of the test (waiting time) shall be 2 min to 5 min.

The rotation of the vane shall be smooth and for the initial test (undisturbed) be 6 degrees to 12 degrees per minute.

To measure remoulded shear strength the vane should be rotated at least 10 times at a rate ≥ 4 rev/min and until a constant torque over 45 degrees continuous rotation has been reached. At the end of the rapid rotations the remoulded shear strength shall be measured without delay with a rotation rate equal to that used for intact shear strength.

It is also possible to do vane tests in the seabed mode. The depth intervals between tests shall be at least 0,5 m.

The insertion method and test procedure to be used shall be described giving particular information about

- method for insertion and penetration of vanes below bottom of borehole,
- possible rotation rates available,
- method of providing torque and reaction.

C.5.3 Data acquisition

The data acquisition system shall be such that the overall accuracy outlined in C.5.5 is maintained.

The resolution of the measured result shall be within 2 % of the measured value.

During testing the data acquisition system shall allow for real-time inspection of measured results both in digital and graphical form.

C.5.4 Calibration requirements

The sensor for measuring the torque during vane testing shall be calibrated at least once a year and before each project. If the sensor is loaded close to its maximum or any damage is suspected it shall be checked and recalibrated.

Function checks shall be carried out in the field.

C.5.5 Accuracy

Taking into account all sources of error, including the data acquisition system, the uncertainty in the measured torque shall not exceed the smallest of the following values:

- 5 % of measured value;
- 2 % of the maximum value of the measured torque of the layer under consideration.

C.5.6 Presentation of results

For each vane test the following information shall be given:

- site area;
- date of test;
- operator;
- boring number/test identification;
- water depth at test location;
- dimensions of vane;
- depth below sea bottom to vane tip;
- depth below bottom of borehole to vane tip;
- rate of rotation;
- the complete curve of torque versus rotation (degrees);
- time to failure;
- any irregularities during testing;
- formula used to calculate the vane undrained shear strength, s_{uv} , including the assumption made for shear stress distribution on ends of the vane.

C.6 BAT probe test/deep water gas probe (DGP)

C.6.1 General

The BAT probe and the DGP are primarily used in drilling mode. The BAT probe is operated with electric power and signal transfer through a cable to deck. The DGP is powered by down-hole batteries and the operation is pre programmed. The measurements taken during the test are stored in a memory unit for downloading and processing when the probe is recovered on deck. A sample is taken of the pore water which may contain any gas. As outlined by Rad, N.S. and T. Lunne (1994) and Mokkelbost, K.H. and S. Strandvik (1999) the outcome of a BAT/DGP test can be

- coefficient of permeability in the soil adjacent to the filter of the probe,
- degree of pore water gas saturation.

C.6.2 Equipment

The geometry and dimensions of the tip of the probe can be varied, and each tip for the field work shall be described with special emphasis on the filter diameter and length. For permeability tests the filter material and rated porosity shall be given. The device shall be fitted with a pressure transducer to measure pressure changes as water flows into the evacuated container. Temperature during testing or on the obtained sample shall also be measured.

C.6.3 Test procedure

The BAT probe/DGP shall be pushed into the soil at a speed of 1 cm/s to 2 cm/s.

The top of the filter shall be pushed well into the undisturbed soil below the bottom of the borehole before stopping penetration and opening the communication between the low pressure container and the filter. The pressure in the container shall be recorded as a function of time. The test duration shall be sufficiently long to sample at least 15 ml in situ pore water plus the quantity of water used to saturate the filters (for short filters a smaller quantity of in situ pore water can be accepted). Normal testing time in clay is 60 min to 120 min while in sand 2 min to 5 min may be adequate.

Upon retrieval of the BAT probe/DGP on deck the probe should be dismantled so that pore water/gas can be sampled and tested immediately using a gas chromatograph.

C.6.4 Calibration of sensors

Before each job the pressure sensor, the temperature chip and the gas chromatograph should be calibrated.

C.6.5 Presentation of result

For each BAT/DGP test the following shall be reported:

- site area;
- borehole number;
- test number.
- coordinates of test location;
- water depth;
- depth below seabed;
- BAT/DGP sensors, serial number;
- temperature in probe during sampling of pore water;
- water gas saturation;
- type of gas (if any);
- permeability of the soil around the filter (if required).

C.7 T-bar test

C.7.1 Equipment requirements

The T-bar is a cylinder attached to a standard 10 cm² CPT rod (i.e. diameter of 36 mm) which is pushed into the soil in seabed mode using CPT deployment systems. The T-bar shall have a diameter of 40 mm and a length of 250 mm. The surface area of the T-bar should be lightly sandblasted. Normally the T-bar is mounted on a cone penetrometer so that the load cell used to measure cone resistance is used to measure T-bar penetration resistance.

C.7.2 Testing procedure

There is presently no official standard for the performance of a T-bar test. But the following procedures have been recommended by COFS (Centre of Offshore Foundation Systems, Perth, Australia) and NGI based on a recent research and development project NGI/COFS (2004):

- the T-bar resistance shall be measured both during penetration and during extraction;
- rate of penetration and retraction shall be 20 mm/s (± 5 mm/s);
- for tests deeper than 5 m inclination of the rod attached to the T-bar shall be measured;
- readings of all channels shall be taken at least once per second (for every 20 mm of penetration);
- if cyclic T-bar tests are carried out, these shall be done on T-bar extraction comprising cycles of $\pm 0,5$ m at a speed of 2 cm/s. At least six full cycles shall be carried out.

C.7.3 Data acquisition system

The data acquisition system should normally be the same as used for CPT/CPTU, with set up for measuring of resistance during extraction as well as during penetration. Reference is made to Randolph et al. (1998) and C.2.3.

The resolution of the measured results shall be within 2 % of the measured value.

During actual testing the data acquisition system shall allow for real-time inspection of the measured results both in digital and graphical form.

The measured results shall be stored digitally for subsequent processing.

C.7.4 Calibration requirements

The requirement for the load cell measuring T-bar resistance shall be the same as for the CPT/CPTU, see C.2.4.

C.7.5 Required accuracy

Taking into account all possible sources of error and using the complete field measurement system, the accuracy shall be better than the largest of the following values:

- 3 % of typical measurement (mean value) in the layer under consideration;
- 50 kPa.

Note: In order to achieve increased accuracy the use of sensors measuring differential pressures should be encouraged.

C.7.6 Presentation of results

C.7.6.1 General

For each T-bar test the following information shall be reported offshore after each test and in the field report (either in tabular form or on the T-bar profile plots):

- location;
- test number;
- date of performing test;
- load cell serial number;
- T-bar geometry and dimensions;
- capacity of sensor;
- calibration factor used;
- zero readings of sensor before and after each test at sea floor;
- observed wear or damage to the T-bar;
- penetration rate;
- any irregularities during testing;
- theoretical effective (net) area of tip (a), see IRTP (1999);
- water depth to sea floor during test;
- corrections due to tidal variations if any;
- observed sinking in of the frame.

The measured results in engineering units shall be presented in digital form, consisting of the following:

- depth of penetration in m;
- T-bar resistance during penetration and extraction in MPa or kPa;
- inclination if measured;
- total thrust during test in kN.

C.7.6.2 Graphical presentation

The results from T-bar tests in the field (offshore) shall be presented.

The depth scale shall be 1 m (field) = 1 cm (plot) if not agreed otherwise.

The zero reference for T-bar tests shall be the sea bottom. The scale for presenting the measured T-bar resistance during penetration and retraction shall be selected to suit the soil conditions.

The results of cyclic T-bar tests shall be included in the main plot as well as in an enlarged plot to show details.

C.8 Other in situ tests

C.8.1 General

In addition to the in situ tests specified in the previous clauses other appropriate tests may be needed for a complete soil investigation programme.

Such tests shall be specified separately.

Examples of such in situ tests which may be covered by this category are

- hydraulic fracture test,
- dilatometer test,
- permeability tests,
- pipeline trenching evaluation,
- pile-model testing,
- in situ density testing,
- pressure meter testing,
- pore water sampling,
- gas sampling,
- ambient pressure sampling.

C.8.2 Documentation requirements

All in situ test equipment shall have the following documentation:

- description of equipment and purpose of test;
- geometry of equipment;
- calibration of sensors with a statement on accuracy of measurements;
- data acquisition system, with statement on resolution of measured results;
- testing procedure;
- presentation of results.

Annex D (Normative) Laboratory testing

D.1 Classification and index tests

D.1.1 General

In the execution of a geotechnical laboratory soil investigation programme, routine tests shall be performed according to standardised procedures in order to give reproducible results.

The following requirements and specifications are given for classification and index testing of soils performed in geotechnical laboratories offshore and onshore.

D.1.2 Soil description and classification

The soil description and classification shall be made in accordance with a well established classification system, such as

- The Unified Soil Classification System (1953),
- BS 5930:1999,
- ASTM D2487,
- Norwegian Geotechnical Society (1982),
- EN ISO 14688-1.

Prior to start of laboratory testing, the classification system to be used shall be stated.

A detailed description of the soil in each sample cylinder retrieved shall be made for each boring.

The sample description should include the following:

- main soil type;
- secondary and minor soil components of importance to soil properties;
- strength (clay)/relative density and grading (sand);
- minor soil components;
- structure, texture or other relevant description;
- colour, including soil colour chart description (Munsell chart);
- photographs of typical samples from each discernible layer;
- miscellaneous, including special features e.g. presence of siliceous-calcareous ooze.

A simplified soil description and classification shall be presented as a boring log drawn to scale with depth. The sampled material shall be clearly marked on the log. The results from all the index tests shall be contained on the log, and a separate log shall be produced for each boring.

D.1.3 Water content

The natural water (moisture) content, w , shall be derived from test procedures as described in BS 1377-2:1990, BS 1377-3:1990, ASTM D2216-98 or NS 8013.

Water content shall be determined on all samples which are to be used for advanced tests, e.g. consolidation, triaxial, DSS. The water content shall be taken on the material before and after such tests. In addition water contents should be taken on selected samples to give a profile as continuous as possible of the natural water content in the soil borings.

D.1.4 Liquid and plastic limits

The liquid and plastic limits (Atterberg limits), w_L , and w_P , shall be derived from test procedures described by and referenced to one of the following standards:

Liquid limit:

- NS 8001
- NS 8002
- ASTM D4318-00
- BS 1377-2:1990

Liquid limits determined by the Casagrande method using the apparatus described in the BS 1377-2:1990, or in NS 8002, or using the apparatus described by ASTM D4318-00, produce slightly different results. The type of the liquid limit apparatus shall therefore be stated.

Plastic limit:

- NS 8003
- ASTM D4318-00
- BS 1377-2:1990

The description of the test procedure shall state whether the material was dried prior to the test, and if so, by what method (it is preferable not to dry the material before testing). It shall also be stated whether coarse material has been taken out prior to testing. If water has to be added, it should be distilled water even if the in situ pore water is salt.

The liquid and plastic limit determinations shall be presented on the boring logs and the results also presented in the form of plasticity charts.

D.1.5 Bulk density of soil or soil unit weight

The bulk density of soil, ρ , shall be determined according to BS 1377-2:1990 or NS 8011, and given in g/cm^3 . Density determinations should be performed on selected samples to provide a profile as detailed as possible of the boring and should also be compared with densities determined by other methods, i.e. in situ measurements or back calculation from measured water content and degree of saturation.

The measurements of soil volume and mass shall be measured to an accuracy of at least 1 % of the measured quantity. For boring profiles etc. the term "unit weight", γ , is generally used and given in kN/m^3 . The value for acceleration due to gravity g , shall be $9,81 \text{ m/s}^2$ when converting from units of mass to units of force.

D.1.6 Specific gravity of soil

Specific gravity of soil grains G , shall be determined according to BS 1377-2:1990, ASTM D854-02 or NS 8012.

The description of the test procedure shall state whether the material was dried prior to the test, and if so, by what method (it is preferable not to dry the material before testing). As an alternative to reporting specific gravity, unit weight of solid particles, γ_s , can be reported in kN/m^3 ($G = \gamma_s / \gamma_w$, where γ_w = unit weight of distilled water at + 4 °C).

D.1.7 Maximum and minimum density

The maximum and minimum porosities of a material are the densest and loosest states respectively (without crushing the soil grains) that can be produced in the laboratory. The maximum and minimum densities are usually determined for cohesion-less soils.

The different standards and methods available for the determination of the density give different results for the same material. A description of the method used shall be specified if required. Results from a test using this method on a reference sand should be documented together with results by using a recognised standard, e.g. ASTM D4253-00, ASTM D4254-00 and BS 1377-4:1990.

D.1.8 Grain size distribution

The grain (particle) size distribution of soils shall be derived according to procedures described in BS 1377-2:1990, ASTM D422-63 or NS 8005.

Particle size analysis should be performed on representative samples of all principal soil types in order to produce a complete soil description profile.

The referenced documents give specifications for different methods, i.e. dry or wet sieving for coarse grained soils and sedimentation methods (falling drop, pipette or hydrometer method) for fine grained soils. The actual method used shall be clearly stated for all grain size distributions.

The description of the test procedure shall state whether de-flocculation agents were used and whether the material was dried prior to testing, and if so, by what method. It is preferable not to dry the material before testing.

The grain size distribution shall be presented on a semi logarithmic plot with particle size (log) versus percentage by weight finer than the particle size.

D.1.9 Angularity

Angularity of sands should be determined either by the method described by Lees, G. (1964) or Pettijohn, F.J. (1957).

D.1.10 Radiography

Radiography of soil samples is a method to determine the quality of the soil samples, the layering of the soil and the presence/quantity of cobbles in the sample, as described in ASTM D4452-85.

Radiation safety policies should be established based on Norwegian requirements. Operators shall be provided with personal dosimeters. The operators of the X-ray equipment shall be trained in this specialised field. The interpretation of the radiographs should be done by a qualified engineer experienced in interpreting radiographs of soils.

Procedures for X-raying, photographing and describing the soil samples shall be submitted upon request. The previous experience with the interpretation of radiographs of soil samples should be documented upon request.

The reporting from radiography should include

- location and size of samples radiographed,
- description of X-ray set-up,
- descriptive interpretation of radiographs,
- example radiographs.

D.1.11 Index shear strength tests

D.1.11.1 General

Undrained shear strength estimates can be performed on cohesive soil samples. The shear strengths shall be given in kPa. The sample orientation (vertical or horizontal) shall be specified for the shear strength estimates.

D.1.11.2 Fall cone tests

Fall cone tests shall be performed according to test procedures described in NS 8015 and BS 1377-7:1990. A description of the fall cone test apparatus with specifications and calibration curves for the different cones shall be supplied upon request.

The cone apex shall be sharp and the cone surface smooth and clean. Routine checks of this should be made at frequent intervals.

At least three readings shall be done on each specimen, the average of which is taken as the actual reading. If one of the readings is substantially different from the others, more readings shall be taken. Operational procedures and references to the manufacturer of the equipment shall be supplied upon request.

D.1.11.3 Pocket penetrometer test

The undrained shear strength is derived from the force required to push a steel rod or an adaptor a given distance into the soil.

The calibration of the device should be checked before start of each laboratory programme and the accuracy shall be within 10 % of the original calibration. Adaptors with different diameter mounted on the steel rod can extend the use of the penetrometer for a wide variety of shear strengths. Each adaptor has a specified calibration factor. The depth of penetration of the rod or of the adaptor shall equal the rod diameter.

At least three readings shall be taken on each specimen and the average of these readings is taken as the actual reading. Care shall be taken such that the zone of influence from one penetration does not interfere with the other. If one of the readings is substantially different from the others a new reading shall be taken.

The operational procedures and references to the manufacturer of the equipment shall be supplied upon request.

D.1.11.4 Torvane test

The torvane can be used to measure the undrained shear strength on a flat surface of a cohesive soil sample according to test procedures described in BS 1377-7:1990. The area of the sample shall be at least twice the area of the torvane shear blades. The soil can be either confined in the sample cylinder or extruded.

The device shall indicate undrained shear strength directly from the rotation of the torsion spring. Adaptors of different sizes can be mounted on the original vane to accommodate a wider variety of shear strengths.

The calibrations of the torvane and the adaptors should be checked before start of each laboratory programme and the accuracy shall be within 4 % of the original calibration.

The operational procedures and references to the manufacturer of the equipment shall be supplied upon request.

D.1.11.5 Miniature vane test

The miniature vane (motor or hand operated) can be used to measure the undrained shear strength of cohesive soil confined in the sample tube, according to test procedures described in ASTM D4648-00 or BS 1377-7:1990.

The vane blades shall be pushed into the centre of the soil in the sampling tube until the vanes are fully embedded.

The operational procedures and references to the manufacturer of the equipment, and calibration curves shall be supplied upon request.

D.1.11.6 Unconfined compression test (UCT)

The UCT can be used to measure the undrained shear strength of cohesive soil. The test shall be performed according to ASTM D2166-00, BS 1377-7:1990 or NS 8016. The specifications of the equipment and accuracy of the measurements shall be supplied upon request.

The results shall be presented in the form of a shear stress versus axial strain curve. The shape of the failed sample should be sketched.

D.1.11.7 Unconsolidated-undrained (UU) triaxial test

The UU triaxial test can be performed according to ASTM D2850-95 or ETC5 (1998), E3.97. The equipment to be used, sample preparation and mounting of the specimen is as described in D.3. Normally, no pore pressure measurements are required, so filter stones and filter papers are not required.

After application of the confining stresses, the specimen shall be allowed to stabilise under undrained conditions for approximately 10 min before static shearing starts.

The results shall be presented in the form of a shear stress versus axial strain curve. The shape of the failed sample should be sketched.

D.1.12 Remoulded strength/sensitivity

Remoulded strength can be determined by one of several methods described in D.1.11 or in the ring shear apparatus, see D.5. The clay material shall thoroughly remoulded as described in e.g. NS 8015, without the material drying out. The remoulded strength should be reported in separate graphs.

Sensitivity, S_t , is the ratio of undrained shear strength of undisturbed material, s_u , to that of remoulded material, $s_{u, rem}$: $S_t = s_u / s_{u, rem}$. However, if the undisturbed strength was determined on material that had suffered from sampling disturbance, the undisturbed strength and the sensitivity are both likely to be on the low side.

D.2 Consolidation tests

D.2.1 General

One dimensional consolidation (oedometer) tests shall be performed to give the settlement characteristics of the soil and important input related to the stress history of the soil. The loading programme and unloading/reloading loops shall be carefully selected to meet these requirements.

Several types of consolidation tests can be performed such as the incremental loading test and the continuous loading test. An example of the continuous loading procedure is the CRS test.

The execution of consolidation tests shall be in accordance with the procedures outlined in NS 8017, NS 8018 and ASTM D2435-03.

D.2.2 Incremental load test

As a standard loading sequence, the load level shall be doubled at each load step according to NS 8017, i.e. $\Delta p/p = 1,0$. If determination of the preconsolidation stress, p'_c , is important, the stress increments should be smaller (i.e. $\Delta p/p = 0,5$) for stresses around the expected p'_c .

Any deviation from this procedure should be agreed upon prior to start of work.

The load duration shall allow the specimen to reach primary consolidation at every load step, as determined by "Taylor's method" as described by Taylor, Donald W. (1948).

The specimen shall be mounted with dry filter stones. Water (with the same ionic content as the specimen pore water) shall not be added to the stones before the vertical stress exceeds the swelling pressure. The compartment and tubings below the bottom filter and above the top filter stone shall be dry until the swelling pressure has been reached. The stress at the time of filter saturation shall be noted. Evaporation from the specimen in the period before saturation shall be effectively prevented.

D.2.3 Continuous loading test

There are several types of continuous loading tests. The cell configuration and specimen preparation etc. should be the same as for incremental load tests. Special requirements for the CRS test are given below.

For other types of continuous loading tests detailed information of the equipment and the test procedures shall be supplied upon request.

The loading for the CRS device shall be capable of compressing the soil sample at a constant rate of vertical strain, with a minimum of 0,2 % per hour and a maximum of 5 % per hour. These figures refer to a 20 mm high specimen with drainage only at one end.

The soil specimen shall be allowed to drain freely from the top only. The pore pressure shall be measured at the bottom of the specimen through a stiff pressure measuring device. The volume change of this device, when fully saturated, shall not exceed 2 mm³ when the pressure is increased from 70 kPa to 100 kPa.

The loading procedure should start with a vertical stress equal or less than 0,25 x p_o' (where p_o' is the effective overburden stress in situ) and the load should thereafter be applied at a CRS such that the pore pressure measured at the undrained bottom of the specimen never exceeds of the order of 10 % of the applied total vertical stress.

The requirements regarding filter stones specified in D.2.2 shall apply also for CRS tests.

D.2.4 Measurement of permeability

Permeability should be measured in constant head permeability tests under constant stress.

During the permeability test, the pore pressure shall always be increased (a decrease will lead to higher effective stress in specimen). The increase in pore pressure should at no stage of the test exceed 10 % of the total vertical stress acting on the specimen. The test should continue until steady state conditions have been obtained. Careful checks shall be made for each test to ensure that no leakage occurs in the equipment system.

D.2.5 Coefficient of consolidation

The coefficient of consolidation should be calculated either from the coefficient of permeability, k , and the tangent constrained modulus, M , of the stress-strain curve

$$c_v = \frac{M \cdot k}{\gamma_w}$$

or from the change in height versus time, using graphical methods. The method of calculating c_v shall be specifically noted when reporting the results.

D.2.6 Measurements of horizontal stress

Consolidation tests with measurements of horizontal stress for assessment of the coefficient of horizontal earth stress at rest, K_0 , should be performed according to the same procedures as a regular consolidation test.

Description of the consolidation cell with the horizontal stress measurement system and dimensions of soil sample shall, upon request, be supplied prior to start of laboratory testing.

D.2.7 Calibration

When force, deformation and pore pressure are measured with electronic devices, an accuracy check of the data acquisition system should be performed before each test to check that these parameters will be measured within an accuracy in accordance with standard references.

D.2.8 Presentation of results

The form of presentation of results required should be specified prior to start of the laboratory testing. The following shall be provided when appropriate:

Plots:

- vertical strain versus vertical effective stress;
- constrained modulus versus vertical effective stress;
- coefficient of permeability versus vertical strain;
- coefficient of consolidation versus vertical effective stress;
- ratio between excess pore pressure and total vertical stress versus vertical effective stress;
- vertical strain versus time;
- time resistance versus time;
- pore pressure versus time.

The vertical effective stress and/or the coefficient of permeability should be presented in both linear and semi-logarithmic scales. The linear plots shall have sufficient resolution at low stresses for accurate interpretation.

Sample data:

- location;
- specimen identification;
- depth;
- unit weight;
- initial and final water content;
- degree of saturation;
- specific gravity of soil solids (unit weight of solid particles);
- Atterberg limits;
- specimen dimensions;
- best estimate of the effective vertical stress in situ.

D.2.9 Evaluation of sample quality

The quality of an intact sample specimen tested can be evaluated based on the initial void ratio and the axial strain at p_o' , for instance by using the recommendations given by Lunne et al. (1998) and presented in Table D.1 .

Table D.1 - Evaluation of sample quality

OCR	$\Delta e/e_i$			
1 to 2	< 0,04	0,04 to 0,07	0,07 to 0,14	> 0,14
2 to 4	< 0,03	0,03 to 0,05	0,05 to 0,10	> 0,10
Quality:	1	2	3	4

Quality: 1 - very good to excellent, 2 - good to fair, 3 - poor, 4 - very poor

These recommendations are based on tests on soft clays that exhibit an apparent OCR due to aging. For stiff overconsolidated clays this sample quality description should be regarded as indicative only.

D.3 Triaxial tests

D.3.1 General

Triaxial tests shall be performed to provide shear strength characteristics and stress-strain relationships of the soil. For undrained tests with pore pressure measurements dilatancy parameters will also be provided.

The following subclauses describe general requirements for triaxial test equipment and test procedures and specification of detailed information. These shall be provided prior to start of laboratory test programme.

Detailed requirements for sample preparation, consolidation procedures and shearing stage for triaxial compression tests are found in ETC5 (1998), Chapter F1.97.

D.3.2 Test apparatus

D.3.2.1 Triaxial cell

The sealing bushing and piston guide shall be designed such that the piston runs smoothly and maintains alignment. If the axial force is measured outside the triaxial cell, the piston passing through the top of the cell and its sealing bushing shall be designed so that the friction between them never exceeds 2 % of the force applied on top of the piston. Requirements for internal load cells are specified in D.3.2.6.

For extension and cyclic tests, the piston connection to the top cap shall be able to take tensile forces, and be designed to give a minimum of false deformation.

The weight of the top cap should not exceed 5 % of the piston force at failure of specimen.

A detailed description of the triaxial cell and its load application system shall be provided upon request.

D.3.2.2 Rubber membrane

The thickness and material properties of the rubber membrane shall be such that the calculated correction to the axial and radial stresses due to membrane stiffness is lower than

- 15 % for $\tau_f < 12,5$ kPa,
- 10 % for $12,5 < \tau_f < 25$ kPa,
- 5 % for $\tau_f > 25$ kPa.

where

τ_f is the shear stress at failure.

The diameter of the membrane shall be between 95 % to 102 % of the initial specimen diameter. Each membrane shall be effectively checked for leakage before use.

The type of rubber membrane with dimensions and properties shall be provided upon request.

D.3.2.3 Filter discs and paper

Filter discs shall have plane and smooth surfaces facing the soil. Their compressibility shall be negligible compared to that of the specimen. Regular checks shall be made to ensure adequate permeability of the filter discs.

The types of filter discs presently acceptable are those with coefficient of permeability around 10 m/s to 5 m/s. To avoid sample swelling, the discs should be dry during specimen mounting and until the cell pressure reaches the swelling pressure.

The type of filters used, their specifications and mounting procedure shall be provided upon request.

D.3.2.4 Maintaining constant fluid pressure

The device for keeping the cell and the pore pressure constant during consolidation shall be accurate enough to keep the required difference between cell and pore pressure (the radial effective stress) constant within $\pm 2\%$. Differences below 25 kPa shall be kept constant with an accuracy of $\pm 0,5$ kPa.

Description of the pressure regulation system and its accuracy shall be provided upon request.

D.3.2.5 Loading press

Static loading

The loading press should be able to advance the piston with rates varying from at least 0,001 mm to 1 mm per minute. A minimum of ten different advance rates shall be obtainable. When the press is set to advance at a certain rate, the actual rate shall not deviate by more than $\pm 10\%$ from the required value for the high rates and $\pm 20\%$ for the low rates. The movement of the press shall be smooth without fluctuations or vibrations.

The stroke of the loading press should be at least 30 % of the specimen height.

A description of the loading press with capabilities and accuracies shall be provided upon request prior to start of the laboratory programme.

Cyclic loading

Unless otherwise agreed, the loading equipment commonly required shall be for load controlled cyclic triaxial tests.

It is required that the cyclic testing equipment shall be capable of maintaining a constant load wave form, amplitude, and frequency throughout the test within an accuracy of $\pm 2\%$ of the specified value.

Sinusoidal load wave forms should be imposed on the soil specimens. Other types of load wave forms can be accepted.

The specimen shall be subjected to stress reversals which are induced in the form of alternating cycles of vertical compression and extension loads about some ambient stress state, keeping the radial (cell) pressure constant within $\pm 1\%$.

The load rod to piston connection shall meet the following requirements:

- be easy to install;
- prevent any slip under load reversal or vibration;
- prevent application of torsion to the specimen;
- compensate for eccentricity between line of action of the loading equipment and the piston.

For cell pressures greater than 25 kPa the cell pressure during cyclic loading shall not differ by more than $\pm 1\%$ from the value of the initial cell pressure prior to start of cycling. For lower cell pressures the deviation shall be less than 0,25 kPa

The loading system for cyclic testing shall be described and contain information on

- type of system,
- capacities (load, displacement, frequency),
- accuracies,
- load-rod to piston connection.

This information shall be provided upon request.

D.3.2.6 Transducers

Force

The axial force applied to the specimen by the piston through the top of the triaxial cell shall be measured with an accuracy within ± 2 % of the peak force at failure. If the force is measured with a device installed inside the triaxial cell, the device shall be insensitive to horizontal forces and eccentricities in the axial force and not be influenced by the magnitude of cell pressure.

For cyclic loading the force transducer non-linearity and hysteresis shall not exceed 0,25 % of full scale range, and the repeatability shall be within 0,1 %.

Pressure

The pore pressure measurement system should be as rigid and stiff as possible, and the following requirement should apply as a guideline:

Static tests:

$$\frac{\Delta V_{ms}}{V \Delta u} = 0.5 \cdot 10^{-6} \text{ m}^2 / \text{kN}$$

where

ΔV_{ms} is the change in volume of pore pressure measurement system due to pore pressure change

Δu is the pore pressure change

V is the total volume of specimen.

Cyclic tests:

$$\frac{\Delta V_{ms}}{V \Delta u} = 0.1 \cdot 10^{-6} \text{ m}^2 / \text{kN}$$

Deformation

The deformation of the specimen should be measured with an accuracy better than $\pm 0,02$ % of the initial specimen height. Possible false deformation due to cell pressure change shall be accounted for.

For cyclic tests the deformation transducers should have a double amplitude strain range of at least 15 % of the sample height prior to start of the cyclic test.

Volume change

The amount of water and air going into or out of the specimen should be measured with an accuracy of $\pm 0,04$ % of the total volume of the specimen.

The type of transducers with capacities and characteristics shall be provided prior to start of laboratory testing.

Checks of the calibration of the transducers for load, deformation and pressure shall be made before each test, and documentation of this shall be available upon request. The response of the data acquisition system (including the transducers) should not deviate by more than ± 2 % from the applied reference values.

D.3.2.7 Data acquisition

The data acquisition system shall be able to accurately monitor the specimen performance during consolidation and loading.

For static tests readings of relevant parameters shall be taken at least at 100 points of the stress strain curve.

For cyclic tests the data acquisition system shall be able to record at least 50 sample-readings of all relevant variables per cycle. Representative cycles of a test shall be monitored.

Relevant parameters include

- axial force,
- axial displacement (cyclic and permanent),
- pore pressure.

D.3.3 Preparation of test specimen

Test specimens shall be cylindrical with diameter not less than 35 mm and specimen height from 1,85 times to 2,25 times the diameter.

The end surfaces shall be as plane and perpendicular to the longitudinal axis as possible.

Care shall be taken to maintain the in situ water content of the samples. Air circulation around the specimen shall be prevented. The relative humidity shall not be lower than 80 % in the specimen preparation room.

The specimen height and diameter (or circumference) shall be measured within $\pm 0,1$ mm and mass within $\pm 0,05$ % of the total mass of the specimen.

The following detailed sample preparation and mounting procedures shall be presented upon request:

- undisturbed specimens which can stand upright unsupported;
- undisturbed specimens which cannot stand upright;
- reconstituted specimens of silt and sand;
- remoulded specimens of clay and clayey material.

The procedures shall contain a list of equipment used for sample preparation.

A reduction in the sample height may be acceptable if end friction is reduced, e.g. by the use of smooth end platens. A description of the procedure and equipment for reducing the end friction shall be provided prior to start of laboratory testing upon request.

D.3.4 Consolidation stage prior to shearing

D.3.4.1 General

The method of predicting the K_0 value for the different soil layers shall be agreed upon.

D.3.4.2 Isotropic consolidation

The cell pressure should be increased in steps until the average effective stress reaches the required value in order to keep the piston in contact with the top cap. For softer material, smaller cell pressure steps should be used. Water shall be allowed to drain freely from the specimen.

Consolidation shall continue at least until end of primary consolidation, as determined from plots of volume change versus square root of time or checked by a mercury null-indicator.

Since pore pressure measurements are required, a stability check of the specimen shall be made. This is most conveniently done by a mercury null-indicator. The movement of the mercury in a 1 mm^2 bore null-indicator should be less than $+ 0,5$ mm over a period of 2 min. An alternative to the mercury null-indicator is a corresponding allowable change in differential pressure over the same time interval.

If stress-strain moduli and pore pressure parameters at small strains are not important, shearing may be started at the end of primary consolidation. However, if such parameters are important, shearing shall not be started before the stability check criteria are satisfied.

D.3.4.3 Anisotropic consolidation

The procedure to be used for anisotropic consolidation shall be agreed upon prior to start of laboratory testing.

The rate of volumetric strain before start of shearing shall satisfy the stability check criteria as outlined in D.3.4.1.

D.3.4.4 K_0 -consolidation

The procedure and requirements for control and adjustment of the confining stresses to be used for K_0 -consolidation shall be supplied upon request prior to start of the laboratory programme.

D.3.4.5 Other consolidation procedures

Other types of consolidation procedures exist, such as the SHANSEP-procedure described by Ladd and Foott (1979). Prior to start of the laboratory programme the type of consolidation procedure shall be presented.

D.3.4.6 Back pressure/saturation

Back pressure is to be used when the pore pressure shall be measured to improve the pore pressure response in the specimen.

For undrained tests with measurements of pore pressure, the back pressure shall be high enough to give a B-value of at least 0,95 for static tests and 0,98 for cyclic tests unless it is documented that a lower B-value gives satisfactory pore pressure response.

For drained tests, the back pressure shall be high enough to ensure that the difference between pore air pressure and pore water pressure becomes negligible.

A detailed description of method of back pressure application and measurement of B-value shall be provided upon request.

D.3.5 Static shearing

D.3.5.1 General

Before start of shearing, zero readings shall be taken on all the measuring devices.

During shearing, readings shall be taken on all measuring devices at strain intervals such that stress-strain curves and stress paths can be obtained from the readings.

Unless otherwise specified, the test can be stopped when the axial strain reaches 15 % or exceeds by 7,5 % the strain at peak principal stress difference, whichever occurs first.

In the following the most common triaxial shear tests are briefly specified. A detailed description with specification and accuracies for the tests shall be presented prior to start of laboratory testing.

D.3.5.2 Consolidated drained tests

Such tests shall be run slowly to ensure negligible pore pressure changes in the specimen during shearing.

For clay, the rate of axial displacement of the loading press, $(v_1)_{\max}$, shall not exceed:

$$(v_1)_{\max} = \frac{H \cdot \varepsilon_{af}}{15 \cdot t_{100}}$$

where

t_{100} is the time for primary consolidation

ε_{af} is the expected axial strain at failure

H is the height of specimen prior to shear (at end of consolidation).

The rate of axial strain for free draining materials (sand) shall not exceed 0,2 % per minute.

The following variables shall be recorded during the test:

- time;
- piston force;
- vertical displacement;
- volume change;
- frequent checks of the cell and back pressure.

D.3.5.3 Consolidated undrained (CU) tests

The pore pressure shall be measured during shear. When pore pressure is measured, the maximum allowable rate of axial displacement shall be 10 times the rate for drained tests.

The following variables shall be recorded during the test:

- time;
- piston force;
- vertical displacement;
- pore pressure (if required);
- frequent checks of the cell and back pressure.

D.3.5.4 Consolidated constant volume (CCV) tests

For CCV tests the pore pressure shall be constant during shear and the cell pressure adjusted so that no volume change takes place in the specimen.

The maximum rate of axial displacement shall be the same as for CU tests with pore pressure measurements.

The following variables shall be recorded during the test:

- time;
- piston force;
- vertical displacement;
- cell pressure;
- frequent checks of the pore pressure.

D.3.5.5 Extension tests

Extension tests can be run by keeping the total radial stress constant while decreasing the total axial stress or by increasing the total radial stress and keeping the total axial stress constant.

D.3.6 Cycling testing

Unless otherwise specified, the cyclic triaxial loading shall be performed as a load controlled test.

Before cycling, zero readings shall be taken on all the measuring devices.

The cyclic phase shall be undrained and the load frequency dependent on the problem to be investigated.

Prior to start of the laboratory programme the detailed cyclic test programme shall be defined.

Documentation for the cyclic tests shall include (but not be limited to) the following:

- definition of
 - cyclic stress level,
 - average stress level,

- cyclic "failure" strain/number of cycles to failure.
- number of tests to be performed;
- type of consolidation;
- specification of pre-shearing;
- form of presentation of results.

D.3.7 Dismounting specimen

After the cell pressure has been reduced to zero, the specimen should be carefully removed from the triaxial cell and weighed. A water content determination shall be made from the specimen.

D.3.8 Presentation of results

D.3.8.1 General

The results from triaxial testing shall be presented in the form of figures (plots) and tables with information on the most relevant parameters.

Stress paths should be given as shear stress versus effective average, octahedral, or radial stress

Mobilisation curves should be given as $\tan \rho$ versus γ or ε

Detailed data from specific tests shall be presented upon request.

The laboratory report shall contain a section with description of the test equipment, test procedures and symbol list.

D.3.8.2 Static shearing

The results from static tests should include the following:

Plots:

- deviator stress or shear stress versus axial strain;
- pore pressure versus axial strain (for CU tests with pore pressure measurements);
- volumetric strain versus axial strain (for drained tests);
- stress path (Shear stress versus effective octahedral stress or effective average stress or effective radial stress);
- stress paths shall have notation with agreed strain values;
- mobilisation curve: $\tan \rho$ versus γ ;
- shear stiffness curve: G versus $\tan \rho$ or γ .

The plots should contain information on

- project identification,
- location,
- boring,
- sample identification,
- test type identification,
- sample depth,
- initial water content.

In addition to the graphical plots of test results, the following information for each triaxial test should be given when appropriate in the form of tables:

- project identification/location;
- sample identification;
- depth;
- test type;
- initial water content;
- final water content;
- liquid limit, plastic limit, plasticity index;

- sand and clay fraction;
- shear strength estimate;
- sensitivity;
- unit weight of soil;
- degree of saturation;
- effective overburden pressure;
- laboratory OCR;
- observation during consolidation:
 - effective axial pressure (maximum and minimum if $OCR > 1,0$);
 - effective radial pressure (maximum and minimum if $OCR > 1,0$);
 - axial consolidation strain;
 - volumetric strain due to consolidation;
 - B-value.
- test interpretation:
 - undrained shear strength, s_u ;
 - pore pressure at s_u ;
 - strain at s_u .

D.3.8.3 Cyclic loading

The results from cyclic tests should include the following:

On plots:

- definition of symbols and average and cyclic stress and strain;
- maximum and minimum axial strain vs number of cycles;
- average pore pressure at zero axial load vs number of cycles;
- stress-path (maximum/minimum) vs number of cycles.

In addition to the information listed for static tests, the plots shall contain average and cyclic stress level.

The following should be presented in tabular form:

- average shear stress;
- cyclic shear stress;
- number of cycles to "failure";
- maximum and minimum axial strain of the "failure" cycle;
- pore pressure at zero axial load of the "failure" cycle;
- pore pressure when specimen has stabilised after cycling (if relevant);
- compressibility parameter due to consolidation after cycling (if appropriate).

D.3.9 Evaluation of sample quality

The quality of an intact sample specimen tested can be evaluated based on the initial void ratio and the axial strain at p_o' , for instance by using the recommendations given by Lunne et al. (1998) and presented in Table D.1.

D.4 Direct simple shear tests

D.4.1 General

In the simple shear test, a soil sample is consolidated under K_o -conditions and subjected to a horizontal shear stress. Both drained and CCV tests to simulate undrained conditions are performed in the conventional devices in use today. The simple shear test provides the shear strength and stress-strain characteristics of the soil in the horizontal direction.

The following subclauses describe general requirements for simple shear test equipment. Test procedures and specification of detailed information shall be supplied upon request. The execution of DSS tests shall be in general accordance with the procedures outlined in ASTM D6528-00.

D.4.2 Test apparatus

D.4.2.1 Horizontal support

The horizontal sample support shall be sufficiently rigid to ensure K_0 conditions during consolidation and constant cross-section dimensions of the sample during simple shear. Details of the method of sample support shall be provided prior to laboratory testing.

If a reinforced rubber membrane is used, the following details shall be submitted upon request:

- diameter, winding and yield stress of reinforcement;
- maximum allowable vertical consolidation stress.

The diameter of the membrane shall not differ more than 1/10 mm from the sample diameter after trimming.

The membrane reinforcement shall be such that a minimum of horizontal deformation of the soil specimen occurs under pure vertical load. Documentation shall be made available upon request.

D.4.2.2 Filter discs

Filter discs with plane and smooth surfaces shall be used. The compressibility of the filter shall be negligible compared to that of the specimen. Regular checks shall be made of possible clogging by clay or silt particles. The permeability of the filters shall be smaller or equal to the permeability of fine sand (around 10 m/s to 5 m/s).

To prevent horizontal sliding between the sample and the filter stone, the interface shall be reinforced. Examples of such reinforcement are short (1,5 mm) pins fastened to the filter stone, or epoxy covered end caps with small filters.

The filters shall be dry during mounting of the specimen. Saturation of the filters shall be done during consolidation at about half the maximum axial consolidation stress. If the sample at this stage starts to swell, additional axial load shall be applied to the sample.

Information on the filters used, especially with regards to type, interface, coefficient of permeability and air entry values shall be provided upon request.

D.4.2.3 Loading system

Static horizontal loading

The horizontal loading system shall be able to apply a linearly increasing movement or force to the specimen at variable speeds. The available range of rate of displacement shall be 0,001 mm to 2 mm per minute. The actual rate shall not deviate by more than $\pm 10\%$ from the required value.

The movement of the motor shall be smooth (without vibrations). The stroke of the horizontal loading device shall be at least 40 % of the specimen height.

Calibration curves for speed control as well as functional description, capabilities and accuracies shall be provided upon request.

Vertical loading

The vertical loading system shall be able to apply the required vertical consolidation stress as well as to control the vertical load during constant volume shearing when the apparatus does not allow for a fixed mechanical height control.

If the apparatus is equipped with an automatic mechanism for vertical load control, this mechanism shall be described in terms of accuracy and speed and basic operational features upon request.

During constant volume shear, the automatic vertical load control shall satisfy the following requirements:

- static tests, allowable height change : $\pm 0,0025$ mm;
- cyclic tests, allowable height change: $\pm 0,005$ mm;
- adjustable speed of relay height/vertical load.

For apparatus with fixed mechanical control of constant sample height, description and documentation on this equipment shall be supplied upon request prior to start of the laboratory testing.

Cyclic horizontal loading

The required loading equipment shall allow application of stress controlled cyclic loading unless otherwise agreed.

The loading system shall be capable of handling loading frequencies from 0,01 Hz to 0,5 Hz. It is further required that the cyclic testing equipment is capable of maintaining a constant load wave form, amplitude and frequency throughout the tests, and the loading system shall prevent any slip or vibration under load reversal.

Sinusoidal wave form loads shall be imposed on the soil specimens. The specimen shall be subjected to horizontal stress reversals which are induced in the form of alternating horizontal load cycles about an average stress value.

The loading system for cyclic testing should be described in terms of

- type of system,
- capacities (load, displacement, frequency),
- accuracies,
- load-rod to piston connection.

D.4.2.4 Transducers

Force

The horizontal force applied to the specimen by the piston through the horizontal loading rod shall be measured with an accuracy of at least ± 2 % of the peak force at failure.

For cyclic loading, the non-linearity and hysteresis of the horizontal force transducer shall not exceed 0,25 % of full scale range, and the non-repeatability shall not exceed 0,1 %.

Deformation

The vertical deformation of the specimen during consolidation shall be measured with an accuracy of at least $\pm 0,01$ % of the initial specimen height.

The shear strain of the specimen shall be measured with an accuracy of at least $\pm 0,01$ %. Possible false deformation shall be accounted for.

For cyclic tests the horizontal deformation transducers shall have a double amplitude deformation range to produce at least 20 % shear strain.

Specimen height measurement

To ensure a constant volume test, the height of the sample shall be kept constant with an accuracy of $+ 0,05$ % of the initial specimen height.

The type of transducers with capacities and characteristics or description of the height measurement device shall be provided upon request prior to start of the laboratory testing.

Checks of the calibration of the transducers for load and deformation shall be made for each test, and documentation of this shall be available upon request. If the response of the transducers deviates by more than $+ 2$ % (in the region around failure) from the specified value, a recalibration of the transducer shall be made.

D.4.2.5 Maintenance of apparatus

The devices for transferring vertical and horizontal load to the specimen shall be checked before each test. The internal friction in the load application system for both vertical and horizontal loading shall not exceed 1,5 N. The loading pistons shall run smoothly without vibration.

Correction curves for the false deformation of each apparatus shall be supplied upon request.

D.4.2.6 Data acquisition

The data acquisition system shall be able to accurately monitor the specimen performance during consolidation and loading.

For static tests, readings of relevant parameters shall be taken at least at 100 points of the stress strain curve.

For cyclic tests, the data acquisition system shall be able to record at least 50 sample readings of all relevant variables per cycle. Representative cycles of a test shall be monitored. Relevant parameters include

- horizontal force,
- horizontal displacement (cyclic and permanent),
- change in vertical load for constant volume tests,
- change in height during sample consolidation and during shearing for drained tests.

D.4.3 Preparation of test specimen

The sample shall have a cross-section in the range 20 cm² to 80 cm² and height 1,5 mm to 2,0 cm. The horizontal surfaces shall be plane and perpendicular to the vertical axis.

Care shall be taken to maintain the in situ water content of the samples. Air circulation around the specimen shall be prevented. The relative humidity shall not be lower than 40 % in the room where the specimen is prepared. The specimen shall be built in with dry filters to prevent swelling at low pressures.

The specimen height and diameter (or circumference) shall be measured within + 0,1 mm and the mass within + 0,05 % of the total mass of the specimen.

Detailed sample preparation and mounting procedures shall be supplied upon request for

- undisturbed specimens which can stand upright unsupported,
- undisturbed specimens which cannot stand upright unsupported,
- reconstituted specimens of silt and sand,
- remoulded specimens of clay and clayey material.

The procedures shall contain a list of equipment used for sample preparation. Specific sample preparation and mounting procedures may be required.

D.4.4 Consolidation stage prior to shearing

D.4.4.1 Consolidation procedure

The procedure to be used for consolidation shall be specified prior to start of laboratory programme.

Consolidation shall continue at least until end of primary consolidation. If stress-strain moduli at small strains are specified, shearing shall not be started before the rate of vertical strain is less than 0,05 % per hour.

D.4.4.2 Other consolidation procedures

Other types of consolidation procedures exist [such as the SHANSEP-procedure, see Ladd and Foott (1979)]. Prior to start of the laboratory testing the type of consolidation procedure shall be specified.

D.4.5 Static shearing

D.4.5.1 General

Before start of shearing, zero readings shall be taken on all the measuring devices.

During shearing, readings shall be taken as specified on all measuring devices.

The test can, unless otherwise specified, be stopped when the horizontal strain reaches 20 % or exceeds by 10 % the strain at peak horizontal stress, whichever occurs first. It shall be checked that no relative movement between the soil end surfaces and the end caps occurred.

Other procedures or techniques for testing may be required. These shall be agreed upon before start of laboratory testing.

D.4.5.2 Consolidated constant volume (CCV) shearing

For CCV tests the sample height shall be kept constant within the limits specified in D.4.2.3.

A horizontal strain rate appropriate to the soil type shall be used.

The following variables shall be recorded during the test:

- time,
- horizontal load,
- horizontal displacement,
- vertical load,
- strain rate.

D.4.5.3 Drained tests

Drained tests shall be performed with a horizontal deformation rate of one tenth (0,1) of the CCV test. The vertical load on the sample shall be constant during shear and the sample shall be free to drain.

The following variables shall be recorded during the test:

- time;
- horizontal force;
- horizontal displacement;
- vertical displacement;
- vertical load (at intervals).

D.4.6 Cyclic testing

The cyclic simple shear can be performed as a load-controlled or a strain-controlled test.

Before cycling, zero readings shall be taken on all the measuring devices.

The cyclic phase shall be undrained and the frequency dependent on the problem to be investigated.

Prior to start of the laboratory programme a cyclic test programme shall be defined and accepted. The cyclic test programme shall include, but need not be limited to, the following:

- definition of cyclic and average stress levels (in case of a load-controlled test: cyclic "failure" strain/ maximum number of cycles);
- definition of cyclic and average strain level (in case of a strain-controlled test: cyclic failure in terms of maximum number of cycles);
- frequency;
- number of tests to be performed;
- specification of pre-shearing;
- form of presentation of results.

D.4.7 Dismounting specimen

After the test is stopped and the horizontal and vertical stresses reduced to zero, the specimen should be carefully removed from the test apparatus as quickly as possible.

If other tests are to be performed after dismounting, water content determination shall be taken on only part of the specimen. Otherwise a water content determination should be made of the whole specimen.

D.4.8 Presentation of results

D.4.8.1 General

The results from a simple shear tests shall be presented in the form of plots and tables of the most relevant parameters measured during each test.

Detailed data from specific tests shall be presented upon request.

The laboratory report shall contain descriptions of the test equipment and test procedures and a list of the symbols and terms used.

D.4.8.2 Static shearing

Results from static tests shall be presented as:

On plots:

- shear stress versus shear strain;
- pore pressure (variation in vertical stress) versus shear strain;
- stress path as horizontal shear stress versus vertical stress;
- stress paths shall have notations with agreed shear strain values.

All plots should contain information on

- project identification,
- location,
- boring,
- sample identification,
- test type identification,
- sample depth,
- initial water content,
- consolidation stresses before testing.

In addition to the graphical plots of test results, the following information should be given where appropriate for each simple shear test in the form of tables:

- project identification/location;
- sample identification;
- depth;
- test type;
- initial and final water content;
- liquid and plastic limits, plasticity index;
- sand and clay fraction;
- shear strength estimate;
- sensitivity;
- initial unit weight of soil;
- effective overburden pressure;
- laboratory OCR;
- observation during consolidation:
 - effective vertical stress (maximum and minimum if $OCR > 1,0$);
 - vertical consolidation strain (maximum and minimum if $OCR > 1,0$).
- test interpretation:
 - horizontal undrained shear strength with corresponding pore pressure and shear strain.

D.4.8.3 Cyclic loading

The results from cyclic tests should include the following plots:

- definition of average and cyclic stress and strain;
- maximum and minimum horizontal strain vs number of cycles in case of a load-controlled test;
- maximum and minimum horizontal shear stress vs number of cycles in case of a strain-controlled test;
- representative pore pressure at zero horizontal load vs number of cycles.

In addition to the information specified for static tests, the plots should indicate the average and cyclic stress or strain level.

The following should be presented in tabular form from a cyclic test:

- average and cyclic shear stresses in case of a load-controlled test;

- average and cyclic shear strain in case of a strain-controlled test;
- stress or strength defining shear stress level;
- number of cycles to "failure";
- maximum and minimum shear strain and pore pressure at zero horizontal load in the "failure" cycle, in case of a load-controlled test.

D.4.9 Evaluation of sample quality

The quality of an intact sample specimen tested can be evaluated based on the initial void ratio and the axial strain at p_o' , for instance by using the recommendations given by Lunne et al., (1998) and presented in Table D.1.

D.5 Ring shear tests

D.5.1 General

The ring shear test is a method to investigate the development of shear stress within a soil sample or along the interface between soil and a structural element during large deformations and can be performed in accordance with ASTM D6467-99. The most common types of ring shear equipment are the Bishop device, Bishop et al. (1971) and the Bromhead device, see Bromhead, E.N. (1979). A test method for performing ring shear tests to provide data for MTD pile design has been presented by Ramsey et al. (1998).

D.5.2 Sample preparation

Preferably the specimen has a mean diameter of about 125 mm, about 20 mm wide and with a thickness of 20 mm. The specimen can be trimmed in one piece from intact material, or put together from a number of slices (or sectors) then trimmed to the circular form with the ring shear cutting device. Testing can also be performed on remoulded material.

D.5.3 Test procedure

Upon mounting, the specimens shall be loaded to the specified consolidation stresses. The test can be performed in fast rotation, simulating undrained conditions or in slow rotation simulating drained conditions.

The apparatus shall be able to provide a range of rate of horizontal displacement, at least covering 20 degrees/s to 0,002 degrees/s.

D.5.4 Presentation of results

The presentation of results from a ring shear test shall at least include a plot of shear stress versus displacement.

The plot should contain information on

- project identification,
- location,
- boring,
- sample identification,
- test type identification,
- sample depth,
- initial water content,
- consolidation stresses before testing,
- laboratory OCR,
- rate of shearing.

In addition to the graphical plots of test results, the following information should be given where relevant for each ring shear test in the form of tables:

- project identification/location;
- sample identification;
- depth;
- test type;
- initial and final water content;
- liquid and plastic limits, plasticity index;

- sand and clay fraction;
- shear strength estimate;
- sensitivity;
- initial unit weight of soil;
- effective overburden pressure;
- laboratory OCR;
- observation during consolidation:
 - effective vertical stress (maximum and minimum if $OCR > 1,0$);
 - vertical consolidation strain (maximum and minimum if $OCR > 1,0$).
- test interpretation.

D.6 Resonant column tests

D.6.1 General

The resonant column test method for determination of shear modulus and damping of soils at small strains shall be performed in accordance with ASTM D4015-92. The equipment used for these tests shall be specified. Unless otherwise agreed upon, equipment allowing for anisotropic consolidation shall be used.

D.6.2 Sample preparation

The preparation of soil samples shall be in accordance with the requirements specified for triaxial tests.

D.6.3 Test procedure

Resonant column test readings should be taken at times similar to that of a consolidation test (i.e. 1 min, 2 min, 4 min, 8 min, 15 min, 30 min, 60 min, 120 min. etc) and well into secondary consolidation.

The periodic resonant column measurements should be made at a constant shear strain level. A shear strain level of 10^{-3} % or lower, with an accuracy of + 10 % is suggested.

At the end of each consolidation phase, a series of resonant column test readings at increasing levels of shear strain starting at the lowest possible level shall be taken. Each measurement at shear strains larger than 10^{-3} % should be followed by a measurement at the lowest possible shear strain.

For a test series on samples in an over-consolidated state, the duration of the last confining stress level before unloading shall be specified and strictly maintained for all tests. This duration shall be similar to that used in any parallel triaxial testing programme.

The method for damping ratio determination shall be specified prior to start of the laboratory investigation.

D.6.4 Presentation of results

The presentation of results from a resonant column test shall be in the form of

- G_{max} versus log time,
- shear modulus versus shear strain,
- damping ratio versus log time,
- damping ratio versus shear strain.

The above shall be presented for each level of effective confining pressure tested.

In addition, sample data should be given, e.g.:

- sample location/identification;
- depth;
- bulk density/unit weight;
- initial and final water content;
- degree of saturation;
- density of soil particles;
- Atterberg limits (if applicable);
- specimen dimensions;
- best estimate of the effective vertical and horizontal stresses in situ.

D.7 Piezoceramic bender element tests

D.7.1 General

The result of a piezoceramic bender element test is the shear wave velocity, which can be used to compute the small strain shear modulus, $G_{\max}$, in a soil sample. The piezoceramic bender element technique can be used at any stage of a triaxial, DSS or consolidation test without interfering with the particular test. The test method is described by Dyvik, R. and C. Madhus (1985) and Dyvik, R. and T.S. Olsen (1989).

D.7.2 Sample preparation

The preparation of soil samples shall be in accordance with the requirements specified for oedometer, triaxial and DSS tests. Care shall be taken when inserting the piezoceramic bender element into the top and bottom of the specimen in order to obtain good soil contact and not do any damage to the electrical element. The protrusion of the piezoceramic element from the base pedestal as well as the height of the sample shall be determined accurately.

D.7.3 Test procedure

Once the piezoceramic elements are mounted, the shear wave velocity can be measured at any time during the consolidation and testing phases of the test. The two electrical elements act as generator and receiver, respectively, of the shear waves, and a test consists of measuring the travelling time of shear wave propagating from one end of the specimen to the other. The shear wave velocity can be calculated from the travelling time and length travelled. A proper oscilloscope capable of measuring the short travelling time of shear waves (especially for DSS and oedometer test specimens) shall be selected. The oscilloscope shall have the ability of storing the signals for processing and printing out on paper.

D.7.4 Presentation of results

The result shall be presented as shear wave velocity and calculated maximum shear modulus, $G_{\max}$. As documentation, the printout from the oscilloscope presenting the starting time and the arrival time of the shear wave shall be available, and can be presented in the report as additional information.

D.8 Thixotropy tests

D.8.1 General

The test provides data on increase in undrained shear strength with time of a remoulded sample, excluding the effect of consolidation.

D.8.2 Sample preparation

The soil sample is remoulded under in situ water content and a number of specimens are prepared in jars. At least ten different plexiglass jars should be prepared. The specimens are covered with plastic foil and stored in a cold and humid room.

D.8.3 Test procedure

Initial reading of undrained shear strength, s_u , using the fall cone is carried out, followed by subsequent readings with increasing time interval. Also the remoulded shear strength and the water content shall be measured at each time interval. Measurements should be performed on a cut surface in the jar to exclude any effects from a crust developing with time.

A detailed description of the methods used shall be available on request.

The time intervals for readings shall be at least 0,2 h, 8 h, 1 day, 2 days, 4 days, 8 days, 15 days, 30 days and 60 days.

D.8.4 Presentation of results

The presentation of results from a thixotropy test shall at least include a plot of

- remoulded-“undisturbed” shear strength versus time,
- remoulded- remoulded shear strength versus time,
- measured water content versus time.

The plot should contain information of

- project identification,

- location,
- boring,
- sample identification,
- test type identification,
- sample depth,
- initial water content.

In addition to the graphical plots of test results, the following information should be given where relevant for each thixotropy test in the form of tables:

- project identification/location;
- sample identification;
- depth;
- test type;
- liquid and plastic limits, plasticity index;
- sand and clay fraction;
- test interpretation.

D.9 Heat conductivity test

D.9.1 General

A laboratory method using the thermal needle probe can provide the thermal conductivity of an undisturbed or remoulded soil sample, as specified by ASTM5334-00. A long, small diameter needle is inserted into the specimen. The needle consists of both heating and temperature measuring elements. By applying a constant current to the heater, the rise in temperature is recorded as a function of time and the thermal conductivity is obtained from an analysis of the temperature-time curve.

D.9.2 Sample preparation

The needle is inserted into the undisturbed soil sample when it is still in the sample tube.

Remoulded soil is compacted into a metal or a plastic tube with the desired density and the needle is inserted.

D.9.3 Test procedure

The needle shall be calibrated before use (see ASTM5334-00), and the sample shall be in equilibrium with the room temperature. When the needle has been inserted, a known and constant current is applied and readings are taken at certain time intervals for a minimum of 100 s.

The thermal conductivity, λ , is computed from the linear portion of the temperature versus $\ln$ of time plot.

D.9.4 Presentation of results

The presentation of results from a thermal conductivity test shall at least include a plot of measured temperature versus $\ln$ of time.

The plot should contain information of

- project identification,
- location,
- boring,
- sample identification,
- test type identification,
- sample depth,
- initial water content,
- the computed thermal conductivity, λ (W/mK),
- the computed thermal resistivity, $\rho = 1/\lambda$ (mK/W).

In addition to the graphical plot of test results, the following information should, where relevant, be given for each test in the form of tables:

- project identification/location;
- sample identification;
- depth;
- test type;
- liquid and plastic limits, plasticity index;
- sand and clay fraction;
- test interpretation.

D.10 Contaminated samples

When sampling and testing contaminated soil care should be taken to obtain the correct amount of samples, and to seal and store them correctly with respect to the contamination and further analyses. The Norwegian Pollution Control Authority (SFT) has provided guidelines presenting standards and requirements for carrying out investigations of polluted ground, see SFT (1991). The guidelines mainly focus on investigation techniques to ensure the best possible basis for designing suitable remedial actions. They deal with both onshore and seabed sampling techniques and can thus be used for seabed and top soil sampling on the continental shelf.

If sampling of contaminated soils is included in the soil investigation programme, the procedures for sampling, storing and testing shall be discussed prior to the investigation.

D.11 Other relevant tests

D.11.1 General

In addition to the tests specified in the previous subclauses, other appropriate tests may be needed for a complete soil investigation programme.

Such tests should be specified prior to start of the laboratory testing.

Examples of typical tests which can be covered by this category are

- plane strain tests,
- high pressure tests (consolidation tests, triaxial tests),
- high or low temperature tests (consolidation tests, triaxial tests),
- laboratory model tests.

D.11.2 Documentation requirements

When specifying or proposing laboratory tests other than those specified in earlier subclauses, such tests should be described according to the following:

- purpose of tests;
- type of tests;
- apparatus/test equipment:
 - dimensions;
 - capacities;
 - accuracies;
 - data acquisition.
- sample preparation and mounting;
- test phase;
- dismounting;
- presentation of results.

D.12 Geological and geochemical tests

D.12.1 General

A geological investigation shall include both the local conditions at the site and a regional study.

The examination and analysis of undisturbed soil samples may give useful information about the geological origin and history of the sediments and should be performed by an experienced geologist.

A geological study should also include a re-interpretation of available shallow seismic data and well logs from the actual site if required. The aim of the re-interpretation is to correlate sedimentology and geotechnical properties of the soil with the seismic reflectors of the soil layers in the area.

For all the recommended tests which, unless otherwise specified, shall be performed by specialized laboratories, the following information shall be available prior to start of the laboratory programme:

- name of laboratory to perform the actual test;
- test procedures and possible national and international standards to be used.

The following subclauses contain specifications and requirements regarding geological and geochemical tests and analyses to be performed in connection with a soil investigation programme.

Possible additional or substitute tests or analyses should be suggested prior to the start of the laboratory testing programme.

D.12.2 Visual description

A detailed description shall be made on a fresh sample, if possible offshore. The description shall include the points listed in D.1.2.

Minor soil components should be collected for a more detailed onshore classification. Upon request, shell and shell fragments shall be described, if possible by name and the conditions under which they were living. The description of gravels and cobbles should include sizes (in mm), degree of roundness and classification of rock type.

The study of the structure of clay samples should be made on samples split halfway by a knife and broken on the other half. On such a surface both the sedimentary structure and macrocapit discontinuities (fissures) are best visible.

D.12.3 Mineralogical analysis

In addition to a visual description further analyses performed upon request may include

- visual description of the sand and coarser fractions, including degree of roundness and classification of mineral or rock type, determined visually or by low power magnifier (binocular microscope),
- thin section analysis of undisturbed soil samples. In addition to the classification of degree of roundness and a quantification of the identifiable minerals, a description of the structural formation (fabric) of the soil shall be made. Results from the analysis shall include a photograph.

Since the methods of quantification of minerals from X-ray diffraction may differ among different laboratories, the following information shall be supplied upon request:

- sample preparation procedure;
- original records from the X-ray diffractometer;
- instrument type and instrument parameters used.

Scanning electron microscope studies shall be performed if requested. A trained geologist shall take part in the inspection and selection of areas of samples to be photographed.

D.12.4 Amino acid analysis

Bulk samples of representative soil shall be sent to a laboratory specialising in amino acid chronology. Upon request, the method of analysis shall be described.

D.12.5 Stable oxygen isotope analysis

Representative soil samples shall be sent to a laboratory specialising in stable isotope analysis. Upon request, the method of analysis shall be described.

D.12.6 Analysis of gas in sediment samples

In the offshore laboratory, representative soil samples for shallow gas analyses shall be sealed as soon as possible. The samples shall be stored either in airtight tin cans or in plastic bags, and frozen immediately. If tins are used, the atmosphere in the tins shall be filled with nitrogen. If plastic bags are used, excess atmosphere shall be removed by squeezing the bags before closing. The ideal way of freezing is to use

either liquid nitrogen or dry ice (solid CO₂), and the samples shall be stored and transported to the laboratory in a frozen state.

The following types of gas analyses shall be performed if requested:

- headspace gas (can be measured only on samples stored in tins);
- occluded gas (gas dissolved in the pore water);
- adsorbed gas (gas adsorbed to the clay minerals);
- total gas (instead of differentiating between occluded and adsorbed);
- gas isotope analysis (carbon isotope ratios of methane, ethane and propane). The data can be used to identify the origin of the gas.

D.12.7 ¹⁴C dating (age determination)

When requested, dating of organic material or shells by the ¹⁴C dating method shall be performed if a sufficient amount of good quality soil is available. 5 g to 10 g of carbonate material is needed for conventional dating whereas a few milligrams is needed for accelerator mass spectrometer in ¹⁴C-analysis.

D.12.8 Nanofossil and microfossil analysis

Analysis shall be performed by personnel with experience in analyses of Quaternary sediments.

Standard preparation techniques shall be used.

Upon request preparation technique and results of raw data showing the percentages of different species shall be supplied.

D.12.9 Organic and inorganic content

The sample preparation method and test procedure for the determination of organic and inorganic content of soil shall be stated prior to the start of laboratory program, if requested. Such analyses shall be performed according to existing national standards or specified procedures.

D.12.10 Analysis of parameters for determining corrosion risk

If requested, the following soil corrosivity analyses shall be performed:

Offshore:

- sampling for SRB test and analysis of acid soluble sulphide: The samples shall be sealed with plastic foil in an airtight can under nitrogen atmosphere immediately after sampling. The can shall be stored cold (< 4 °C) in order to prevent biological and chemical changes;
- resistivity measurements shall be carried out on a naturally wet sample in a soil box with parallel electrodes and by a high frequency resistivity meter;
- pH measurements shall be carried out directly on a wet sample by a combined electrode and pH-meter;
- description of the soil sample especially with regard to colour and odour;
- sampling for sulphate, total sulphur, inorganic and organic carbon analysis shall be carried out by storing the undisturbed part of the soil sample close to previous sampling in an evacuated airtight plastic bag and stored cold (< 4 °C).

Onshore:

- SRBs: The sample shall be brought to the laboratory without delay;
- acid soluble sulphide should be measured on the same sealed sample as SRB and in accordance with NS 4737;
- sulphate: The reduced part of the bag sample or the rest of the SRBs shall be squeezed carefully for less than 1/5 of its porewater through a fine paper filter. The porewater shall be kept under N₂ atmosphere and analysed preferably by an ionchromatograph;
- total sulphur shall be analysed on dry powder. Inorganic and organic carbon shall be analysed on a dry powder as previously described. For analysis on a dry powder, 30 g to 40 g of the bag sample shall be dried and crushed fine in a mortar.

If the final test results regarding corrosivity depend on a certain evaluation scheme or evaluation procedure of the "raw data" from a laboratory test, the raw data shall be made available upon request.

Annex E (Normative) Reporting

E.1 Reporting according to type and level of investigation

The reporting structure should be chosen based on the type and level of the soil investigation. It is useful to distinguish between the following types:

- large site specific investigation for gravity base structure, piled jacket platform or similar;
- large investigation of regional character i.e. a geohazard study or first investigation for a new development;
- pipeline investigation;
- small investigation for small structure(s), e.g. templates.

For the most comprehensive investigations the report structure as described in E.2 will be required. For smaller investigations a simpler report scheme may be used as indicated below.

E.2 Report structure

The report structure should normally be presented in three levels and three main parts as shown in Table E.1. The number of volumes required will differ from a comprehensive to a simple investigation.

For a comprehensive investigation, level 1 may be in one volume. Part A, Part B and Part C with level 2 and level 3 are usually reported in three separate volumes or more.

For a less extensive investigation, the three levels and three parts are usually reported in one volume.

<u>Level 1</u>	An executive summary in terms of a short presentation of the project, the work scope and the results.
<u>Level 2 and level 3</u>	Consist normally of three parts with Part A covering soil parameters for design, Part B Geotechnical data and Part C Field operation. Level 2 should give a summary for each part, whereas level 3 will give all the details.

For each project, Table E.1 shall be included in the beginning of the report. Only the test types or evaluation included in the work scope shall be specified in the table.

Table E.1 - Reporting structure

Level 1:

Soil investigation XXXX Executive summary A short presentation of the project, the task and the results (Main points from Part A, Part B and Part C)	(Main
---	-------

Level 2:

Part A Soil parameters for design (Summary of Level 3)
--

Part B Geotechnical data (Summary of Level 3)

Part C Field operation (Summary of Level 3)

Level 3:

A.1	Summary of soil conditions
A.2	Basic soil parameters
A.3	Recommended soil parameters for foundation design
A.4	Interpretation and evaluation of geotechnical data
A.5	List of symbols and classification system used
A.6	References

B.1	Soil description and boring profiles
B.2	Classification tests
B.3	Consolidation and permeability tests
B.4	Triaxial tests
B.5	Direct simple shear tests
B.6	Piezoceramic bender element
B.7	Resonant column tests
B.8	Corrosion tests
B.9	Chemical tests
B.10	Geological tests
B.11	CPTU and seismic tests
B.12	BAT tests
B.13	T-bar tests
B.14	Field vane tests
B.15	Description of laboratory test procedures
B.16	List of symbols and classification system used
B.17	References

C.1	Log of activities
C.2	Drilling operations
C.3	Sampling
C.4	CPTU penetration testing
C.5	Seismic cone testing
C.6	T-bar
C.7	BAT
C.8	Water depth and tidal measurements
C.9	Field laboratory
C.10	List of reports
C.11	Positioning
C.12	References

Other in situ and laboratory tests may be added to Part B and Part C, if relevant.

For minor investigations it can be considered to have a simpler report structure to avoid unnecessary repetition. In some cases only a factual report is required such that Part A can be excluded.

E.3 Report content

E.3.1 General

All text, plots and scales shall be presented in easily readable format.

E.3.2 Executive summary

The executive summary should be written such that the reader shall be able to quickly appreciate the purpose of the soil investigation and the methods used. The main results of important geotechnical challenges or findings shall be included.

E.3.3 Part A: Soil parameters for design

The following sections:

- A.1: Summary of soil conditions;
- A.2: Basic soil parameters;
- A.3: Recommended soil parameters for foundation design;
- A.4: Interpretation and evaluation of geotechnical data;
- A.5: List of symbols and classification system used;
- A.6: References.

shall be included in all cases.

For most projects the geotechnical problems are known, but for others neither the final foundation solution nor the specific technical challenges are defined. In those cases, section A.3: Recommended soil parameters for foundation design, should include generic soil design parameters, or, as a minimum, a reference to section A.4.

Basic requirements for each of the different foundation solutions or geotechnical problems are included in the following sections.

Project specific requirements will come in addition with more details.

Section A.1: Summary of soil conditions

A general geologic description of the area investigated should be given. A general location plan showing the position of all borings and seabed in situ tests shall be given.

For each soil layer, the following key information shall be presented:

- soil description;
- depth below seabed or elevation with respect to mean sea level if specified (range if applicable);
- appropriate soil classification data, including, but not limited, to the following:
 - water content;
 - plastic and liquid limits and plasticity index;
 - grain size distribution characteristics;
 - soil unit weight;
 - unit weight of solid particles;
 - maximum and minimum porosity;
 - relative densities;
 - index shear strengths (pocket penetrometer, fall cone, torvane, laboratory/motor vane, UCT, UU);
 - remoulded shear strength and sensitivity, including interpretation of sleeve friction from CPTs.

Section A.2: Basic soil parameters

A number of basic soil parameters are independent of the type of structure to be installed or geotechnical problem that needs to be solved.

For each important layer where in situ tests and sampling/laboratory testing have been performed, recommended values of the following parameters shall be presented as functions of depth below seabed, or as elevation:

- effective overburden stress, p_o' or σ_{vo}' ;
- in situ pore water pressure, u_o , including any excess pore pressure, if relevant;
- preconsolidation stress, p_c' .
- OCR;
- coefficient of earth pressure at rest, K_o ;
- relative density, D_r , in sand layers.

Section A.3: Recommended soil parameters for foundation design: Example skirted and gravity base structures

The nature of the loading regarding composition and periods is different on a fixed offshore structure as compared to an anchored floating structure. The basic methods of analyses are, however, the same and so are several of the basic soil parameters required.

Subsection A.3.1: Deformation parameters for settlement calculations

The following deformation parameters should be given for the complete soil profile as applicable:

- undrained shear modulus, G_u ;
- drained Young's modulus, E_d , and the Poisson's ratio, ν ;
- constrained (one dimensional) modulus, M . When relevant, how this modulus varies with effective stress in terms of the modulus number, m .
- coefficient of consolidation in both vertical (c_v) and horizontal direction (c_h);
- coefficient of permeability in vertical and horizontal directions;
- creep parameters;
- parameters for computing settlement components due to cyclic loading.

An idealised stratigraphy with corresponding parameters shall be given along with distance between draining layers.

Subsection A.3.2: Deformation parameters for dynamic analysis (if applicable)

The following parameters should be given for the complete soil profile with relevant ranges of applicability:

- small strain shear modulus (G_{max});
- cyclic shear modulus as a function of strain;
- damping ratio as function of strain;
- data which enable the determination of cyclic shear modulus as a function of cyclic and average shear stress for various stress paths.

Subsection A.3.3: Shear strength parameters for stability calculations

Subsection A.3.3.1: Static strength parameters

Effective stress and undrained strength parameters needed for stability analysis should be presented.

The following undrained shear strength parameters shall be given for each layer:

- undrained shear strength, s_u :
 - consolidation to in situ stresses (p_o');
 - consolidation to stresses induced by installation ($p_o' + \Delta p$).

Whether both or one of these stress conditions apply will depend on the permeability of the foundation soil and the time duration that can be expected before the design load can be expected
- parameters required for calculation of s_u as a function of consolidation stresses;
- anisotropy effects shall be included by having separate s_u -profiles for the active, passive and direct shear zone of the potential sliding surface.

If SHANSEP consolidation [see Ladd and Foott (1979)] has been used the results shall be presented as normalized shear strength (s_u/σ_{vc}') as a function of OCR. This is so for both CAU triaxial and DSS tests.

The following effective stress parameters shall be given for each layer:

- friction ($\tan \phi'$);
- cohesion, c , or attraction, $a = (c \times \cotan \phi')$;
- pore pressure parameter, (D).

If relevant, parameters for evaluation of thixotropy shall be given.

Subsection A.3.3.2: Cyclic effects

Parameters to evaluate the effect of cyclic loading on platform stability should be given when appropriate.

The following contour diagrams shall be given, unless otherwise specified:

- contours of average and cyclic shear strain as a function of cyclic shear stress and number of cycles for relevant average shear stress;
- contours of average pore pressure as a function of cyclic shear stress and number of cycles for relevant average shear stress;
- contours of cyclic and average shear strain and average pore pressure as a function of cyclic and average shear stress for relevant numbers of cycles.

In addition the post cyclic shear strength may be given if required.

Subsection A.3.4: Contact stresses (soil reactions)

When required, parameters for computing expected base contact stresses shall be presented.

Such parameters are

- shear modulus versus strain (the dependency of modulus on effective stress shall be given),
- appropriate undrained shear strength profile,
- appropriate friction angle.

Subsection A.3.5: Skirt penetration resistance

When required, parameters should be given for computing both maximum expected and most probable skirt penetration resistance.

Where applicable unit skin friction and unit tip resistance may be recommended in terms of measured cone penetration resistance.

Parameters for bearing capacity calculations should be given in terms of effective stress and undrained shear strength parameters.

Section A.3: Recommended soil parameters for foundation design: Other aspects

Section A.3 should be tailor made according to purpose of the soil investigation.

The following subsections gives indications on how this may be done according to the type of structure or geotechnical problem that is being addressed by the investigation.

Subsection A.3.1: Piled structures

Unless otherwise specified soil parameters required for the pile design according to API RP 2A-WSD or API RP 2A-LRFD shall be given. Due to the empirical basis of the API rules the undrained shear strength profile shall mainly be based on UU triaxial tests.

If other approaches for establishing pile bearing capacity are to be included the soil parameters required in these methods shall be included in the report. An example is the Imperial College Pile design method which requires measured cone resistance profiles and results of ring shear interface tests, see Jardine and Chow (1996).

Parameters for mud mat stability and settlements will be similar to the parameters for gravity base or skirted structures as given above.

Subsection A.3.2: Jack up platforms

Parameters for stability calculations, punch through and settlements will be similar to the parameters for gravity base or skirted structures as given above.

Subsection A.3.3: Pipelines

Reporting of geotechnical investigations for pipelines should be done according to "Guidance Notes on Geotechnical Investigations for Marine Pipelines", SUT-OSIG (2004)

Table E.2 and Table E.3 are taken from the above guidance notes and show the types of soil parameters that may be required for design of pipelines.

Table E.2 - Basic soil parameters required for design considerations of pipelines

Clay	Sand
Grain size	Grain size
Plastic and liquid limits	Relative density
Water content	Maximum and minimum density
Total unit weight	Total unit weight
Undrained shear strength	Friction angle

Table E.3 - Additional soil parameters for specific pipeline problems

Application	Additional soil parameter
Ploughing	Strain rate effects, permeability (sand/silt)
Jetting	Strain rate effects, permeability (sand/silt), shell content, plasticity (see also liquefaction/flotation below)
Self-burying potential/natural backfill	Sensitivity (clays), permeability (sand/silt), strength of trenched material
On bottom stability	Sensitivity (clays), pipe-soil interface friction
Scour/erosion	Grain size, permeability (sand/silt)
Slope stability	Strain rate effects, cyclic behaviour of soil, permeability (sand/silt), strength anisotropy
Liquefaction/flotation	Properties of backfilled material (strength, unit weight, grain size), cyclic behaviour of soil, compressibility, relative density
Settlements (rock berms)	Constrained modulus and consolidation characteristics
Upheaval buckling	Properties of backfilled material (strength, unit weight, grain size, thermal conductivity) undrained friction angle in sand and clay
Free span assessment	Detailed mapping of outcropping clay, soil spring stiffness
Dropped objects	Strength (embedment), permeability (suction)
Shore approaches	Depth to bedrock, strength of rock, weak zones
Corrosion	Electrical resistivity, geochemical tests, bacteriological analyses
Thermal consideration/ frost	Thermal conductivity, heat capacity, salinity
Spool pieces/tie etc	Properties of backfilled material (strength, unit weight, grain size)
Start-up piles	Remoulded shear strength, elastic modulus

The project specific specification should list the parameters required in the report.

Subsection A.3.4: Geohazards

For slope stability calculations shear strength parameters as outlined in E.3.3 should be given. For earthquake analyses dynamic parameters as mentioned in E.3.3 should be reported.

Special attention should also be given to any effects of pore pressures in excess of hydrostatic and effects of gas on the soil properties.

Section A.4: Interpretation and evaluation of geotechnical data

All data treatment and interpretation of in situ and laboratory test results shall be described and documented. Relevant references to back up methodologies used shall be given. For each soil design parameter all data points from the relevant laboratory and in situ test shall be given on the same plot as the recommended profile. In case of large scatter or scarcity of data the assumptions made to arrive at the recommended parameter shall be discussed.

For effective stress strength parameters, a summary of stress paths in appropriate scale from triaxial tests in each defined layer shall be included. Strain levels shall be marked on the stress paths.

Wherever possible, the uncertainty related to the various recommended soil parameters shall be expressed. The total uncertainty reflects the combination of data scatter and possible systematic errors.

A best estimate is then calculated as an average (or mean) value, m_x , in a depth interval:

$$m_x = \frac{1}{n} \sum_{i=1}^n x_i \quad (\text{E.1})$$

where m_x is a function of depth, and the number of data points, n , shall be sufficient ($n > 5$).

The uncertainty about the best estimate is the standard deviation,

$$s_x = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - m_x)^2} \quad (\text{E.2})$$

where appropriate, m_x and $m_x \pm s_x$ should be plotted versus depth together with the actual data points for the different soil parameters presented.

Section A.5: List of symbols and classification system used.

A comprehensive list of symbols used in the report should be included in addition to a description of the soil classification system used.

Section A.6: References

Relevant references on methods used or experienced from similar soils should be included.

E.3.4 Part B: Geotechnical data

Table E.1 includes a large number of laboratory and in situ tests. For most projects not all these tests will be included and the non relevant sections shall be removed from the table.

Section B.1: Soil description and boring profiles

The section should contain a detailed description of the layering at the location with any lateral variation. The boring profiles shall contain (but may not be limited) to the following information and parameters plotted versus depth:

- description of the soil in each layer and sub layer;
- water content and plasticity parameters;
- soil unit weights;
- undrained shear strengths for various types of tests, both intact and remoulded.

Section B.2 to Section B.7: Various laboratory tests

Reporting should be made following the requirements listed in the laboratory testing specifications. Comments to the general quality of the tested samples and test results shall be given. Specific findings and test results which may be of relevance when interpreting the test results and developing design profiles for the various parameters, shall be addressed.

Section B.8 to Section B.14: Various in situ tests

Reporting should be made following the requirements listed in the in situ testing specifications. Comments to the quality of the test results shall be given. Specific findings and test results which may be of relevance when interpreting the test results and developing design profiles for the various parameters, shall be addressed (testing procedures and specifications and calibrations for the various tools shall be given in Part C of the report).

Section B.15: Description of laboratory test procedures

A detailed description of the test procedures for all laboratory test types included in the project shall be given. Reference to relevant standards shall be included, and any deviations from these standards shall be noted specifically.

Section B.16: List of symbols and classification system used.

A comprehensive list of symbols used in the report shall be included in addition to a description of the soil classification system used.

Section B.17: References

Relevant references on methods used or experience from similar soils that are used shall be included.

E.3.5 Part C: Field operations

Table E.1 includes a list of relevant in situ tests commonly used during an offshore soil investigation. For most projects not all these tests will be included and the non relevant sections shall therefore be deleted. In the following some relevant comments to the various sections in part C of the report are given.

According to this reporting scheme, given in Table E.1, Part C of the report will only contain descriptions of the field operations and procedures for the various in situ testing and sampling techniques used. The results from the in situ tests and the field laboratory tests will generally be reported in Part B of the report. Any deviations from this NORSOK standard (e.g. if the results obtained offshore shall be included in Part C) shall be agreed upon at least before the end of the offshore work.

Section C.1: Log of activities

The report shall include a detailed log on the activities performed during the entire soil investigation on a day to day basis. The log shall be the basis for statistical evaluations in terms of production, drilling rates, equipment break down and off hire and weather standby. Plots and graphs clarifying the above may be included. A list of the various parties with their main representatives involved in the offshore work shall be included.

Section C.2: Drilling operations

The report shall contain a detailed description of the drilling equipment used, including drill pipe and collars, bottom assembly and drill bits. The report should focus on the drilling conditions and the drilling rates obtained in the various soil types. Drilling parameters including bit load, type of drilling fluid type, mud pressure, flow rate, RPM as well as observed torque shall be reported. It is recommended to report such parameters as continuous profiles versus depth, however, representative values for each layer may be acceptable for standard investigations.

The correction procedure used for tidal variation (if any) shall be described.

Reference shall also be made to Annex A for further requirements.

Section C.3 to Section C.8: Sampling and in situ testing

Reporting shall follow the requirements listed in the sampling and in situ testing specifications, Annex B and Annex C.

Section C.9: Field laboratory

This section should contain a description of the various tests carried out in the field laboratory. Handling and storage of the samples as described in B.5.2 shall be included, as well as comments to the general sample quality and sample recovery.

Section C.10: List of reports

A list of reports planned and completed in the project up to date can be included here. Especially for large field developments it has been found useful to include reports written as part of other projects, dealing with the soil conditions at the present offshore field.

Section C.11: Positioning

Upon agreement either reference to the positioning report or the complete positioning report can be included here.

Section C.12: References

Relevant references on methods used in the field work and in the description of the field operations should be included.

E.4 Reporting format

The report shall be delivered in a paper format copy and a digital format copy. The digital copy could for example be in Adobe Portable Format (PDF).

Digital format functionality (e.g. linking, revision control, authenticity check, searchable text etc.) should be used for all parts of the report.

For each delivered CD-ROM, the digital document(s) should be made readable by including a reader version, e.g. Acrobat Reader. Also an ASCII text file should be included with the contents of the CD-ROM and explanation and instructions for opening the digital document(s).

Geotechnical data should be prepared to be included in a GIS system or equivalent according to the client's specifications.

Both during the offshore operations and during the onshore lab testing and reporting, reports and other data should be made available on a secure website.

Bibliography

Annual Book of ASTM Standards

Volume 04.08 Soil and Rock (I) and Volume 04.09 Soil and Rock (II); American Society for Testing and Materials. Yearly updates

Dahlberg, R and Ronold, K.O. (1993)

Limit state design of offshore foundations.

Proceedings of the International Symposium on "Limit state design in geotechnical engineering",
Copenhagen 26-28 May 1993

Norsk Geoteknisk Forening (1982)

Veiledning for symboler og definisjoner i geoteknikk. Presentasjon av geotekniske undersøkelser. Oslo, mars 1982.

Guidance to symbols and definitions in geotechnics. Presentation of geotechnical investigations. Oslo March 1992

Norsk Geoteknisk Forening (1989)

Veiledning for utførelse av vingebooring.

Guidance for vane testing.

Norsk Geoteknisk Forening (1994)

Veiledning for utførelse av trykksondering.

Guidance for penetration sounding.

SFT (1995)

Økoteknologisk testing av offshore kjemikalier og borevæsker dated 29.05.95

SPCA(1995) Ecological Testing of Offshore Chemicals and drilling Fluids dated 29.05.95

