

NORSOK STANDARD

COMMON REQUIREMENTS
MARINE SOIL INVESTIGATIONS

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1 FOREWORD

NORSOK (The competitive standing of the Norwegian offshore sector) is the industry initiative to add value, reduce cost and lead time and remove unnecessary activities in offshore field developments and operations.

The NORSOK standards are developed by the Norwegian petroleum industry as a part of the NORSOK initiative and are jointly issued by OLF (The Norwegian Oil Industry Association) and TBL (The Federation of Norwegian Engineering Industries). NORSOK standards are administered by NTS (Norwegian Technology Standards Institution).

The purpose of this industry standard is to replace the individual oil company specifications for use in existing and future petroleum industry developments, subject to the individual company's review and application.

The NORSOK standards make extensive references to international standards. Where relevant, the contents of this standard will be used to provide input to the international standardization process. Subject to implementation into international standards, this NORSOK standard will be withdrawn.

2 SCOPE

The intention with this standard is to as far as possible to standardise requirements to marine soil investigations.

The actual content of an investigation will depend upon types of structures/pipelines involved and the site specific conditions. This standard should not be considered as mandatory, and to which extent it should be used is to be agreed upon for each specific project.

However, by encouraging some working principles and establishing common requirements to equipment and testing, it is expected that both quality and compatibility are improved and hence, results from different investigations can be used to a greater extent.

The standard is divided into a general part and several annexes. The general part gives some common requirements for most investigations, while the annexes gives details to equipment and procedures to be considered for each investigation.

3 NORMATIVE REFERENCES

NS 3481	Soil Investigation and geotechnical design of marine structures.
NPD	Regulation for structural design of loadbearing structures.
DNV	Classification Note 30.4 Foundation

The references are to the latest edition.

Detailed references to standards and regulations are given in the relevant clauses.

4 DEFINITIONS AND ABBREVIATIONS

A comprehensive list containing all relevant definitions and abbreviations used in a soil investigation shall be included in the report for the investigation.

4.1 Definitions

Normative references	Shall mean normative in the application of NORSOK standards.
Informative references	Shall mean informative in the application of NORSOK standards.
Shall	Shall is an absolute requirement which shall be followed strictly in order to conform with the standard.
Should	Should is a recommendation. Alternative solutions having the same functionality and quality are acceptable.
May	May indicates a course of action that is permissible within the limits of the standard (a permission).
Can	Requirements are conditional and indicates a possibility open to the user of the standard.

4.2 Abbreviations

NPD	Norwegian Petroleum Directorate
NS	Norwegian Standard
DNV	Det norske Veritas

5 SAFETY

Safety procedures which will establish safe working practices and sound operating procedures shall be prepared.

The procedures shall give guidelines to general personnel safety as well as safety requirements to relevant working operations. The purpose of such procedures is to maintain safe working conditions throughout all work areas.

The procedures shall address possible occurrence of shallow gas.

Supervisors are responsible for employees who work under their direction to have knowledge of and to work in compliance with the instructions stated in the procedure. Each individual shall be encouraged to assume full responsibility for following the guidelines given, and they are expected to maintain an accurate and up-to-date knowledge of prevailing hazards.

All non-crew personnel shall have sufficient safety training, which should include a basic safety course and they shall understand the vessel's safety and emergency plans.

The safety procedures shall be submitted for acceptance.

6 GENERAL OBJECTIVES FOR THE INVESTIGATION

The required sophistication of the work is a function of project requirements and the need to characterise geological processes.

The party requiring an investigation should inform about the objectives for the work and his knowledge of the site. Possible vendors should advise upon investigation strategy, possible equipment, procedures, and tests to be carried out.

Typical topics could be:

- Type of investigation, regional or site specific
- Expected soil conditions, seabed features,
- Active geological processes, possible geo-hazards
- Type of installation, required soil parameters
- Previous experience from area, geotechnical and geophysical data
- Equipment to be used
- Preliminary programs
- Schedules

The results of such exchange of information will improve a mutual understanding of the work, relevant experience can be utilised, and proper technology applied.

7 OFFSHORE EQUIPMENT AND EXECUTION OF WORK

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.
- Interface requirements to auxiliary equipment, power supply etc.
- Calibration charts for documentation of prescribed accuracy.

Winches and equipment for lifting should be certified.

Sufficient number or amount of equipment and associated required consumable to perform the work should 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 normal anticipated 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 should be performed and checked against expected soil conditions, sample quality and results of in situ tests.

Attention should be given to drill bits and their application to different soil types.

A continuous evaluation of results as the work proceeds should be carried out. The investigation program may thus be immediately revised in order to meet the objectives of the investigation.

8 SAMPLING

Sampling may be carried out within a range of varieties from gravity or rotary coring at the seabed to down hole sampling or coring in a bore hole.

The actual sampling and subsequent handling shall be carried out with a minimum disturbance to the soil.

Occasionally maximum sample volume may have preference to the quality of the sample, and modification of equipment could become necessary.

The choice of sampler should reflect the actual soil conditions and the requirements to the use of the soil data. A variation in equipment should therefore be available.

Generally the type of sampling should be considered in the following sequence:

- Piston thin wall sampler
- Push thin wall sampler
- Push thick wall
- Hammer sampler
- Rotary coring

More details are given in Annex A, Soil Sampling.

8.1 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.

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 B, In Situ Testing are made for ordinary tests. For more special testing equipment procedures should be established.

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

9 LABORATORY TESTS

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

In Annex C detailed requirements to tests are given either as sole references 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 C. Laboratory Tests

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

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 out 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 interpretation of these requirement is that the characteristic soil property shall be taken as a value less than 50% in the estimated distribution of the mean, when a low value is conservative (e.g. foundation stability analyses), whereas the value shall be taken as a value higher than 50% when a high value is conservative (e.g. for prediction of penetration resistance).

The actual percentage must be judged for the problem in question, preferably by statistical methods and evaluation of factors such as:

- 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 recommended that reports are structured in levels and organised in a common way.

The reported data should also be submitted on such a format that they can electronically be transformed to a geotechnical data base. The format should satisfy Petroleum Open Software Corporation (POSC)

All reporting shall be in SI units.

Details upon reporting structure and content are given in Annex D, Reporting

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Veiledning for utførelse av vinge boring.

Guidance for vane testing.

Norsk Geotknisk Forening (1994)

Veiledning for utførelse av trykksondering.

Guidance for penetration sounding.

Norsk Standard, NS4737 (1976)

Determination of sulphide content of waste water.

Colorimetric method.

Norsk Standard, NS8001 (1982)

Geoteknisk prøving. Laboratoriemetoder. Støtflytegrensen.

Geotechnical testing. Laboratory methods. Percussion liquid limit.

Norsk Standard, NS8002(1982)

Geoteknisk prøving. Laboratoriemetoder. Konusflytegrensen.

Geotechnical testing. laboratory methods. Fall cone liquid limit.

Norsk Standard, NS8003 (1982)

Geoteknisk prøving. Laboatoriemetoder. Plastisitetsgrensen.

Geotechnical testing. Laboratory methods, Plastic limit.

Norsk Standard, NS8005 (1990)

Geoteknisk prøving. Laboratoriemetoder, Kornfordelingsanalyse av jordprøver. Geotechnical testing. Laboratory methods. Grain-size analysis if soil samples.

Norsk Standard, NS8011 (1982)

Geoteknisk prøving. Laboratoriemetoder. Densitet.

Geotechnical testing. Laboratory methods.

Norsk Standard, NS8012 (1982)

Geoteknisk prøving. Laboratoriemetoder. Korndensitet.

Geotechnical testing. Laboratory methods. Density of solid particles.

Norsk Standard, NS8013 (1982)

Geoteknisk prøving. Laboratoriemetoder. Vanninnhold.

Geotechnical testing. Laboratory methods. Water content.

Norsk Standard, NS8015 (1988)

Geoteknisk prøving. Laboratoriemetoder. Bestemmelse av udrenert skjærstyrke ved konusprøving.
Geotechnical testing. Laboratory methods. Determination of undrained shear strength by fall-cone testing.

Norsk Standard, NS8016 (1988)

Geoteknisk prøving. Laboratoriemetoder. Bestemmelse av udrenert skjærstyrke ved enaksial trykkprøving.
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Technical Memorandum No. 3-357, Vols. 1 to 3. Vicksburg, 1953.

ANNEX A SOIL SAMPLING

1 SAMPLING

1.1 Seabed sampling equipment and procedures

The description shall include as a minimum:

- 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.

1.1.1 *Grab*

For grab samplers the following information shall be given:

- Maximum penetration below sea bed.
- Maximum volume of sample.
- Release mechanism.

1.1.2 *Gravity corer*

For gravity corers the following information shall be given:

- Geometry and dimensions of tip.
- Inside and outside diameter of liner.
- Type of core catcher.
- Whether a piston is used.
- Weight and lengths available.
- Any special handling requirements.

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 shall be measured and recorded.

1.1.3 *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 tip.
- Inside and outside diameter of 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 preferable that the vibrocorer is fitted with a device that measures continuously the progress of the sampler into the soil.

1.1.4 Box corers

For box corers the following information shall be given:

- Dimension of sample.
- Weight and geometry.
- Any special handling requirements.
- Any other relevant information.

1.1.5 Other corers

For other seabed corers the following information shall be given:

- Description of driving mechanism.
- Geometry and dimension of sampler tip.
- Inside and outside diameter of liner if applicable.
- Type of core catcher.
- Geometry and weight of sampling device.
- Length(s) of sample available.
- Any special handling requirements.
- Any other relevant information.

1.2 Down hole samplers

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.
- System for ambient pressure sampling including sample volume, sealing system and pressure capacity (if applicable).
- 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 (example: Hard tie system).
- Sample tubes:
 - 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 of 1.5mm. A 3" thin wall sample tube will thus have outer and inner diameters of about $D_o = 76\text{mm}$ and $D_i = 73\text{mm}$ respectively. Inside clearance shall be in the range 1 to 3%.

1.3 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.

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

- Piston thin wall sample.
- Push thin wall.
- Push thick wall.
- Hammer.
- Rotary coring.

1.4 Sample handling and storage

1.4.1 General

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

1.4.2 Offshore handling

1.4.2.1 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 must 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 must now either be securely sealed in the cylinder or extruded in the offshore laboratory.

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. Each waxed sample part shall be uniquely marked.

1.4.2.2 Seabed samples in plastic liner

The plastic liner with sample inside must be carefully cut in 0.5m or 1m 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 must be clearly marked and properly sealed in each end by plastic cups and tape or similar.

1.4.3 Offshore storage

The sealed and marked sample cylinders and waxed samples shall be put in boxes suitable for transportation and stored, while on board survey vessel, in a cool place with steady temperature. Rooms adjacent to heavy engines or generators, which generate excessive vibrations, shall be avoided.

1.4.4 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.

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

Whether samples shall be airfreighted or trucked to the onshore laboratory must 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.

1.5 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

ANNEX B IN SITU TESTING

1 CONE PENETRATION TEST

1.1 Equipment requirements

The geometry of the cone penetrometer with tip, sleeve and pore pressure filters shall follow the International Reference Test Procedure for Cone Penetration Test (CPT) (1988), from which the following is extracted:

- The penetrometer tip and adjoining rods shall have the same diameter for at least 1000mm behind the tip.
- The cone shall have a nominal cross section of 10cm^2 with
$$38.4\text{mm} \leq d_c \leq 36.0\text{mm}$$
$$24.0\text{mm} \leq h_c \leq 31.2\text{mm}$$
Where d_c is the cone diameter and h_c is the height of the conical part.

An increase in crosssectional area of the cone to 15cm^2 is acceptable. The dimensions for diameter and height of conical part with corresponding tolerances as for 10cm^2 cone shall then be adjusted accordingly.

In some cases it may be advantageous to use cone penetrometers with diameter smaller than the standard 10cm^2 cone. In such cases experimental evidence shall be provided that the smaller cone gives very similar results compared to the standard diameter.

1.2 Testing procedure

The testing procedure shall comply with the International Reference Test Procedure (1988) and the Norwegian Geotechnical Society Guidelines for CPTs, NGF (1994), particularly emphasising:

- The nominal rate of penetration shall be 20mm/sec with an accuracy of $\pm 5\text{mm/sec}$.
- 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 20mm of penetration).

For piezocone 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 shall be carried out to at least 50% consolidation (i.e. half way between pore pressure after stopping penetration of the cone and the computed in situ pore pressure).

The sampling rate during a dissipation test shall be as follows:

During 1st minute	2 times each second
Between 1st and 10th minute	1 time each second
After 10 minutes	1 time each minute

1.3 Data acquisition system

The data acquisition system shall be such that the overall accuracy outlined in clause 12.1.4 is maintained.

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 on tape or disk for subsequent processing.

1.4 Calibration requirements

For each cone penetrometer an accurate calibration shall be made of the area ratios for the cone resistance (a) and the sleeve friction (b) as given in NGF (1994). These values are characteristics for each cone penetrometer and should be documented in each field report, 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 piezocone 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 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.

1.5 Required accuracy

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

- 2% of typical measurement (mean value) in the layer under consideration.
- 1% of the registered pore water pressure.

1.6 Presentation of results

The reporting of results from cone penetration testing shall comply with the International Reference Test procedure (1988) and the Norwegian Geotechnical Society Guideline for CPTs, NGF (1994).

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.

- 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 of tip, a and friction sleeve, b. Ref. NGF 94.
- 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 on tape or disk, consisting of the following:

- Depth of penetration (m).
- Cone tip resistance (MPa).
- Pore pressure(s) MPa (if applicable).
- Friction (kPa).
- Total thrust during test (kN).

1.6.1 **Graphical presentation**

The results from cone penetration tests in the field (offshore) shall be presented.

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

The zero reference for seabed CPTs shall be the sea bottom and for down-the-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 cone).
- Corrected sleeve friction f_t , only if pore pressures have been measured at both end of the friction sleeve.
- Friction ratio, $R_f = (f_s/q_t) \times 100\%$ or if relevant $(f_t/q_t) \times 100\%$.

Pore pressure ratio, $B_q = \frac{u - u_0}{q_t - \gamma \cdot Z}$ 1 with pore pressures recorded behind the cone.

2 **SEISMIC CONE TEST**

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.

2.1 Geometry and configuration of equipment

The geometry of the seismic cone shall be according to the requirements outlined in clause 8.2.1. 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 hammer shear wave source type shall be used. Polarization of the generated shear wave shall be possible.

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 an intensity strong enough to be clearly detected by the seismographic sensors down to about 80m below seabed.

2.2 Testing procedure

The test can be carried out in either seabed mode or down hole 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 piezocone shall be pushed at least one metre further, where a new set of events shall be performed.

Soil samples shall 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.

2.3 Data acquisition

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

2.4 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 depth to where the seismic sensors are located shall be measured within an accuracy of 0.1m.

The time for the shear wave to propagate from the source to the sensors shall be measured within an accuracy of 5%.

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

2.5 Presentation of results

For each set of events of seismic cone tests the following shall be reported offshore after each test location and in the field report.

- Site area.
- Test number.
- Cone/sensor serial number.
- Cone geometry and dimensions with position of sensors.
- Specification of sensors.
- Test depth.
- Type of seismic source.
- Zero reading of sensors.
- Any irregularity during testing.
- Measured results from each set of events presented as sensor output versus time (millisec.).
- 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.

In addition the cone penetration parameters shall be reported as outlined in 12.1.5.

3 ELECTRICAL CONDUCTIVITY CONE

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

3.1 Geometry and configuration of equipment

The geometry of the electrical conductivity cone shall be according to the requirements outlined in clause 12.1. 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

3.2 Testing procedure

The testing procedure shall comply with the International Reference Test Procedure (1988) and the Norwegian Geotechnical Society Guidelines for CPTs, NGF (1994), particularly emphasising:

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

3.3 Data acquisition

The data acquisition system shall be such that the overall accuracy outlined in clause 12.1.4 is maintained. During testing, the data acquisition system shall allow for real-time inspection of the measured results both in digital and graphical format.

3.4 Calibration

The general requirements given in 12.1.4 shall apply for the electrical conductivity cone.

3.5 Presentation of results

In addition to the requirements for presentation of standard CPT results given in clause 12.1.6, 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.

4 FIELD VANE TEST

4.1 Vane geometry

Vane blades shall be rectangular as defined in ASTM D2573 recommendations and given in the table below:

Table 1 Vane blades

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

4.2 Testing procedure

The vane blade shall be pushed at least 0.5m below the bottom of borehole before a vane test is started. The pushing rate shall not exceed 1m/60sec. The time from the instant when the desired test depth has been reached to the beginning of the test (waiting time) shall be 2-5min.

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

Testing procedure for remoulded shear strength tests shall be agreed upon. Preferably three full revolutions of the vane shall be made to remould the soil. The speed of rotation may be as high as one revolution per minute during the remoulding process. The speed of rotation for measuring remoulded strength shall be as for undisturbed test.

It is also possible to do vane tests in the seabed mode. The intervals between tests shall be at least 0.5m.

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.

4.3 Data acquisition

The data acquisition system shall be such that the overall accuracy outlined in clause 12.3.5 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.

4.4 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 must be carried out in the field.

4.5 Accuracy

The uncertainty in the depth determination shall not exceed 0.1m. 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.

4.6 Presentation of results

For each vane test the following information shall be given:

- Site area.
- Date of test.
- Operator.
- Boring number/test identification.
- 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.

5 DILATOMETER TEST

5.1 Geometry and dimensions

Only the geometries and dimensions of the standard Marchetti dilatometer (Marchetti, 1980) or the NGI offshore dilatometer (Lunne et al., 1987) shall be used.

The dilatometer shall be checked for straightness at regular intervals (see Schmertmann, 1986).

5.2 Test procedure

The tests shall comply with minimum requirements of the recommended procedure as presented by ASTM subcommittee D18.02 (Schmertmann, 1986). The main items are:

- A new membrane shall be exercised in air, sufficiently to ensure constant membrane resistance throughout a profile (100 expansion cycles may be required).
- Membrane stiffness correction values shall be recorded in air (or at seabed) before and after each test.
- Measure maximum thrust required during the last 10mm of penetration if correlation to sand (cohesionless material) is required.
- The dilatometer blade shall be penetrated at least 0.5m below bottom of borehole before the first membrane expansion is made.
- Minimum distance between each membrane expansion shall be 100mm (normal procedure is 200mm).
- The nominal rate of penetration shall be 20mm/sec with an accuracy of ± 10 mm/sec.
- The delay between stop of penetration and start of membrane expansion shall be less than 15sec.
- The membrane expansion rate shall be such that the lift off pressure (A) is reached within 15-30sec and the one mm expansion pressure (B) 15-30sec within the next.
- An additional reading can be the pressure against the membrane when it deflates and returns to its initial lift off position. This is called the C reading which when corrected for membrane stiffness becomes p_2 .
- When pore pressure is measured it shall be measured continuously during penetration of the dilatometer and during expansion of the membrane.

5.3 Data acquisition

If the Standard Marchetti dilatometer is used, the data acquisition system recommended by ASTM Subcommittee D.18.02 (Schmertmann, 1986) shall be used.

For the offshore dilatometer readings shall be obtained both digitally and if found appropriate also in a graphical form

The overall accuracy of the measurements shall not be reduced by the data acquisition system.

5.4 Calibration and required accuracy

The sensors of the dilatometer probes shall be calibrated before and after the field work found and if necessary, also during field work, to ensure that the following requirements are met:

- The overall accuracy of the measurements shall not be lower than the following, whichever is smaller:
 - 5% of the measured value.
 - 2% of the mean value of the layer in consideration.

- The membrane stiffness shall be recorded before and after each profile of tests.

6 BAT PROBE TEST

The BAT probe is primarily used in downhole mode. A sample is taken of the pore water which may contain any gas. As outlined by Rad and Lunne (1994) the outcome of a BAT test can be:

- Coefficient of permeability in the soil adjacent to the filter of the probe.
- Degree of pore water gas saturation.

6.1 Equipment

The geometry and dimensions of the tip of the probe can be varied, and each tip for the field work must be described with special emphasis on the filter diameter and length. For permeability tests the filter material and rated porosity must 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.

6.2 Test procedure

The BAT probe shall be pushed into the soil at a speed of 1-2cm/sec.

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 15ml 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 60-120min while in sand 2-5min may be adequate.

Upon retrieval of the BAT probe on deck the BAT body should be dismantled so that the container can be taken out. The content of the container shall be tested immediately using a gas chromatograph.

6.3 Calibration of sensors

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

6.4 Presentation of result

For each BAT test the following shall be reported:

- Site area.
- Borehole number.
- Test number.
- Water depth.
- Depth below seabed.
- BAT sensor, 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).

7 HYDRAULIC FRACTURE TEST

The testing method described herein is primarily meant to be used for assessing maximum allowable mud pressures for evaluating setting depth of the first conductor, i.e. usually in the depth interval 70-120m, but testing in more shallow depths may also be required.

Hydraulic fracture testing (HFT) is at present not a standardized and well documented in situ test technique. Special consideration shall be given to document equipment and procedures, reliability of the measured parameters and the evaluation of results for assessment of the hydraulic fracture pressure.

Limitations with regard to operation in different soil conditions and testing procedures shall be specifically covered.

7.1 Geometry and configuration of equipment

The volume to be pressure tested shall as much as is practically possible be representative of the conditions for which the assessed parameters from HFT are intended for (i.e. drilling below tip of first conductor).

The full borehole diameter should preferably be used for hydraulic fracture testing. Preferable the standard 4.5", API, drill string should be used - giving borehole diameter in the range 0.20-0.25m.

Alternatively, equipment suitable for piggy back drilling can be used with borehole diameter of about 0.09m.

The confinement (sealing) of the volume tested shall be adequate, such that pressurising fluid will not bypass the confinement. The equipment shall preferably allow inspection or control that the sealing is adequate.

The pressurising fluid shall be drilling mud or sea water.

The main pressure sensor for monitoring the applied pressure in the volume tested shall be located within or adjacent to the volume tested. A back up pressure sensor at deck level is highly desirable.

7.2 Testing procedure

The preferred procedure is to use the full diameter of the borehole and normally a test length of about 1-1.5m.

Sealing of the volume to be tested shall be checked.

The flow rate shall be controlled to produce 20-30% volumetric expansion. A constant flow rate of pressurising fluid shall be applied, while the pressure and total flow is monitored until the pressure reaches a constant level or suddenly decreases. Normally a constant flow rate in the range 2-20 litres/min shall be used; the actual value depending on the volume tested.

For a refracture test the pressure in the volume tested shall be allowed to decrease back to initial level.

An ideal test result (for clays) will be like shown in Figure 1 which includes measurement of the following pressures:

- Maximum fracture value ,i.e. the maximum fluid pressure which the formation can withstand before a fracture is formed.
- Steady state flow, i .e. the fluid pressure required to maintain and continuously widen a fracture.
- Close-up pressure , i.e. the fluid pressure that the formation can maintain after pumping of fluid into the formation has been stopped. It is then assumed that the fractures in the formation are closing and that the closing value is a measure of the least principal stress.
- Re-fracturing value, i.e. the maximum value for the second fracturing of the soil. This refracturing is carried out after the closing value has been registered and gives information about the consequences of formation strength having been previously exceeded.

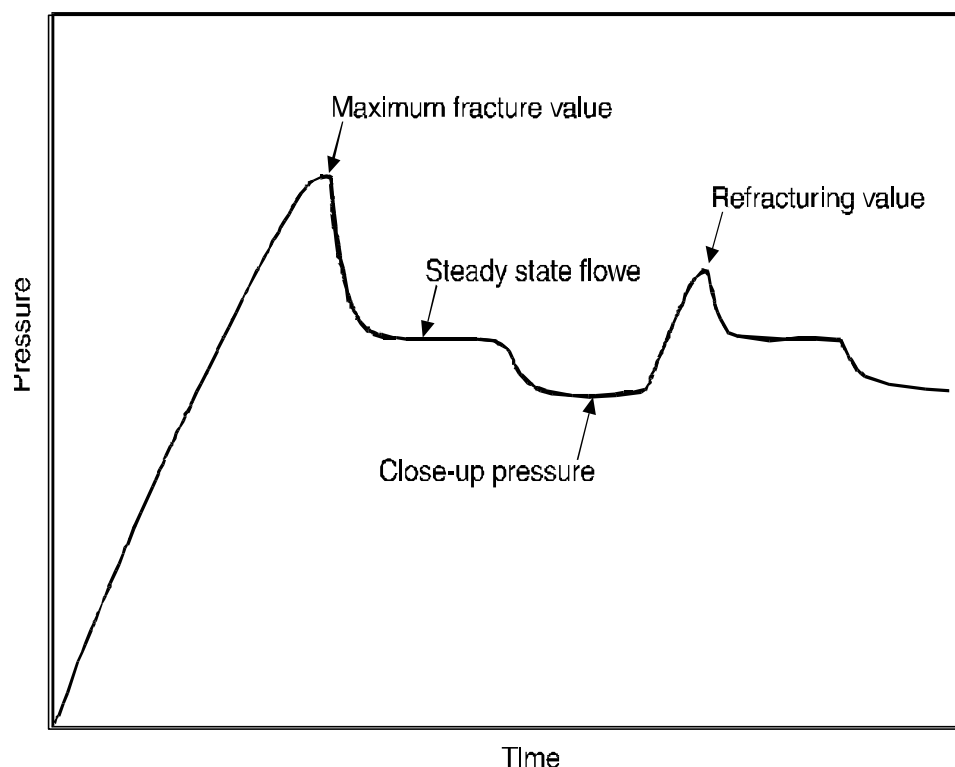


Figure 1 Development of an ideal HFT test

At least one soil sample shall be taken adjacent to or at the position of where the HFT is performed. The soil shall be described and classification tests performed. For clay soil undrained strength tests shall also be made. Alternatively, or in addition, a CPT can be carried out over the test length of the hydraulic fracture test.

7.3 Data acquisition system

The data acquisition system shall be able to monitor the pressure in the volume tested, flow rate and total flow of pressurising fluid during a HFT. The system shall allow for real-time inspection of the measured results both in digital and graphical form.

The measured results shall be stored on tape or disk for subsequent processing.

The data acquisition system shall be set up such that the overall accuracy outlined in clause 12.6.4 is maintained.

7.4 Calibration and required accuracy

The pressure shall be measured within an accuracy of 5% of the measured value.

Flow-rate and total volume shall be measured within an accuracy of 10%.

Calibration of all sensors for the HFT shall be made before and after field work. Documentation of this shall be available.

7.5 Presentation of results

For each set of HFT performed the following information shall be reported:

- Site area.
- Test number identification.
- Date of testing.
- Test depth.
- Description of soil at test depth.
- Inflation pressure in packer(s).
- Test volume (diameter and length of hole).
- Flow-rate.
- Zero reading (initial) of pressure in volume to be tested.
- Viscosity and density of pressurising fluid.
- Any irregularities during testing.
- Reference pressure.
- Plots of measured pressure (MPa) and flow-rate (litres/minute) versus time and/or total flow. (Linear scale). Before presentation of results the scales shall be approved.

8 OTHER IN SITU TESTS

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 program.

Such tests shall be specified separately.

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

- Permeability tests.
- Pipeline trenching evaluation.
- Pile-model testing.
- In situ density testing.
- Pressuremeter testing.
- Pore water sampling.
- Gas sampling.
- Ambient pressure sampling.

8.2 Documentation requirements

New 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 C LABORATORY TESTING

C.1 CLASSIFICATION AND INDEX TESTS

C.1.1 General

In the execution of a geotechnical laboratory soil investigation program, routine tests shall be performed according to standardized 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.

C.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: 41-42, British Standard, 1981.
- ASTM D 2487 2487-93, ASTM, 1995.
- Norwegian Geotechnical Society; guidelines and recommendations for presentation of geotechnical soil investigations NGF, 1982.

The latest version of the above documents shall be used. 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 shall 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.

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.

C.1.3 Water content (w)

The natural water (moisture) content shall be derived from test procedures as described in BS 13772-3, ASTM D 2216-92 or NS 8013.

Water content shall be determined on all samples which are to be used for advanced tests (consolidation, triaxial, simple shear). The water content shall be taken on the material before and

after such tests. In addition water contents shall be taken on selected samples to give a profile as continuous as possible of the natural water content in the soil borings.

C.1.4 Liquid and plastic limits (W_L , W_P)

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

Liquid limit:

- NS 8001 (Casagrande Method).
- NS 8002 (Fall Cone Method).
- ASTM D 4318-93 (Casagrande method).
- BS 1377:
 - 2-4.3 (Cone Penetrometer Method).
 - 2-4.4 (Casagrande Method).

Liquid limits determined by the Casagrande method using the apparatus described in the BS 1377, and using the apparatus described by ASTM D4318-93 produce slightly different results. The type of the liquid limit apparatus must therefore be stated.

Plastic limit:

- NS 8003.
- ASTM D 4318-93.
- BS 1377 - 2-5.

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.

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

C.1.5 Bulk density of soil (ρ) or soil unit weight (γ)

The bulk density of soil (ρ) shall be determined according to BS 13772-7 or NS 8011, and given in units of g/cm^3 or kg/m^3 . Density determinations shall 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" is generally used and given in units of KN/m^3 . The value for gravity, g , shall be 9.81 m/s^2 when converting from units of mass to units of force.

C.1.6 Specific gravity of soil (G)

Specific gravity of soil grains shall be determined according to BS 13772-8, ASTM D 854-92 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 (G_s) can be reported in KN/m^3 . $G = G_s / G_w$, where G_w = unit weight of the pore water of the soil.

C.1.7 Maximum and minimum porosity

The maximum and minimum porosities of a material are the loosest and densest states receptively, (without crushing the soil grains) that can be produced in the laboratory. The maximum and minimum porosities are usually determined for cohesionless soils.

The different standards and methods available for the determination of the porosity 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 shall be documented together with results of ASTM standard.(ASTM D 4253-93, ASTM D 4254-91), BS 1377 4-4).

C.1.8 Grain size distribution

The grain (particle) size distribution of soils shall be derived according to procedures described in BS 1377: 2-9, ASTM D 422-63 or NS 8005.

Particle size analysis shall 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 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 semilogarithmic plot with particle size (log) versus percentage by weight finer than the particle size.

C.1.9 Angularity

Angularity of sands shall be determined either by the method described by Lees, 1964 or Pettijohn, 1957.

C.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, described in ASTM D 4452-85.

The X-ray equipment shall have a minimum output voltage of 100kV. Peak currents of 5-15mA are needed. The X-ray set-up may be equipped with a monitor for immediate relay of the sample exposed and/or a camera for taking photographs.

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 specialized field. The interpretation of the radiographs shall 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 shall be documented upon request.

The reporting from radiography shall include:

- Location and size of samples radiographed.
- Type of equipment used, voltage, amperage and exposure time.
- Description of X-ray set-up, including distance of X-ray source to film surface
- Descriptive interpretation of radiographs.
- Example radiographs.

C.1.11 Index shear strength tests

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.

C.1.11.1 Fall Cone tests (FC)

Fall Cone tests shall be derived from test procedures described in NS 8015 and BS 1377. 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 shall be made of 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.

C.1.11.2 Pocket Penetrometer test (PP)

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

The calibration of the device shall be checked before start of each laboratory program and the accuracy shall be within 4% of the original calibration. Adapters with different diameter mounted on the steel rod can extend the use of the penetrometer for a wide variety of shear strengths. Separate calibration curves shall be presented upon request for each adapter. The depth of penetration of the rod or of the adapter 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.

C.1.11.3 *Torvane Test (TV) (BS 1377-7)*

The Torvane can be used to measure the undrained shear strength on a flat surface of a cohesive soil sample. 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. Adapters 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 adapters must be checked before start of each laboratory program 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.

C.1.11.4 *Miniature Vane test (MV) (ASTM D 4648-94 or BS 1377 7-3)*

The miniature vane (motor or hand operated) can be used to measure the undrained shear strength of cohesive soil confined in the sample tube.

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.

C.1.11.5 *Unconfined Compression Test (UCT)*

The unconfined compression test shall be performed according to ASTM D 2166-91, BS 1377 7-7 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 strain curve. The shape of the failed sample shall be sketched.

C.2 CONSOLIDATION TESTS

C.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 load test (IL) and continuous loading tests (CL). An example of the continuous loading procedure is the constante rate of strain test (CRS).

The execution of consolidation tests shall be in general accordance with the procedures outlined in NS 8017, NS8018, and ASTM D 2435-80.

C.2.2 Incremental load IL test

As a standard loading sequence, the load level shall be doubled at each load step according to NS 8017. (i.e. $D p/p = 0.5, 1.0$ etc.).

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

The load duration shall be equal at each load step, and allow the specimen to reach primary consolidation at every load step, as determined by "Taylor's method". If creep parameters are essential longer duration than normally shall be considered, preferably after pilot testing.

Except when high air entry value filter stones are used, 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 stress at the time of filter saturation shall be noted. Evaporation from the specimen in the period before saturation must be effectively prevented.

If high air entry value filter stones are used, these shall be fully saturated by water with same ionic content as specimen pore water.

The coefficient of permeability for the high air entry stones shall be at least 10 times higher than that of the specimen. The air entry value shall not be lower than 150kPa.

The compartment and tubings below the bottom stone and above the top filter stone shall be dry until the swelling pressure has been reached. The stress at the time of saturating the air trap shall be noted.

C.2.3 Continuous loading test

There are several types of continuous loading tests. The cell configuration and specimen preparation etc. shall be the same as for incremental load tests. Special requirements for the constant rate of strain (CL) 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 constant rate of strain 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 20mm high specimen with drainage only at one end.

The accuracy of the rate of deformation measured over 1% strain shall be within 10% of the required value.

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 2mm^3 when the pressure is increased from 70 to 100kPa.

The loading procedure shall start with a vertical stress of approximately $p_o'/4$ (p_o' is the effective overburden stress in situ) and the load shall thereafter be applied at a constant rate of strain such that

the pore pressure measured at the undrained bottom of the specimen never exceeds 10% of the applied total vertical stress.

The requirements regarding filter stones specified in clause 13.2.2 shall apply also for CRS tests.

C.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 shall at no stage of the test exceed 10% of the total vertical stress acting on the specimen. The test shall be continued 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.

C.2.5 Coefficient of consolidation

The coefficient of consolidation shall 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 the reporting of the results.

C.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 , shall 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.

C.2.7 Calibration

When force, deformation and pore pressure are measured with electronic devices, an accuracy check should be performed for each oedometer unit to check that these parameters have been measured within an accuracy of 2%.

Chapter 3.4 in the suggested international standard (Frydman and Calabresi, 1984) is amended by adding: "For a certain type of loading device it is sufficient to have one calibration curve for each assembled oedometer cell".

C.2.8 Presentation of results

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

Plots:

- Vertical strain vs vertical effective stress.
- Constrained modulus vs vertical effective stress.

- Coefficient of permeability vs vertical strain.
- Coefficient of consolidation vs vertical effective stress.
- Ratio between excess pore pressure and total.
- Vertical stress vs vertical effective stress.
- Vertical strain vs time.
- Time resistance (dt/de) vs time.
- Pore pressure vs time.

The vertical effective stress and/or the coefficient of permeability shall be presented in both linear and semilogarithmic 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.(Density of Solid Particles)
- Atterberg limits.
- Specimen dimensions.
- Best estimate of the effective vertical stress in situ.

C.3 TRIAXIAL TESTS

C.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 clauses 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 program.

Detailed requirements for sample preparation, consolidation procedures and shearing stage for triaxial compression tests are found in Berre, 1985.

C.3.2 Test apparatus

C.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 clause 13.3.2.6.

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 shall not exceed 5% of the piston force at failure of specimen.

When low air entry filters are used, both the top cap and the pedestal should have two drainage tubes to permit flushing of the filter system with water after mounting of the specimen.

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

C.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 $t_f < 12.5 \text{ kPa}$.
- 10% for $12.5 < t_f < 25 \text{ kPa}$.
- 5% for $t_f > 25 \text{ kPa}$.

where: t_f = shear stress at failure.

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

Corrections for membrane penetration may be used in granular material.

The type of rubber membrane with dimensions, properties and procedure for calculation of membrane correction shall be provided upon request.

C.3.2.3 Filter disks 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:

- Coarse discs with coefficient of permeability around 10^{-5} m/sec and air entry value less than 2 kPa. To avoid sample swelling, the discs shall be dry during specimen mounting and until the cell pressure reaches the swelling pressure.
- High air entry value discs with coefficient of permeability not lower than $2 \cdot 10^{-9} \text{ m/sec}$ and air entry value of at least 150 kPa. Such discs shall always be kept fully saturated.

Filter paper for side drain shall be of a type which does not soften in water, and with a coefficient of permeability not less than 10^{-7} m/sec for a normal pressure of 600 kPa.

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

C.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 +2%. Differences below 25kPa shall be kept constant with an accuracy of +0.5kPa.

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

C.3.2.5 Loading pres

Static loading

The loading press must be able to advance the piston with rates varying from at least 0.001 to 1mm per minute. A minimum of ten different advance rates shall be obtainable. When the press is set to advance at a certain rate higher than 0.005mm/min, the actual rate shall not deviate by more than +10% from the required value. For rates equal to and lower than 0.005mm/min, a deviation of +20% can be tolerated. The movement of the press shall be smooth without fluctuations or vibrations.

The stroke of the loading press shall 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 laboratory program.

Cyclic loading

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

It is further 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 +2% of the specified value.

Sinusoidal load wave forms shall 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 +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.
- Eliminate eccentricity between line of action of the loading equipment and the piston.

For cell pressures greater than 25kPa the cell pressure during cyclic loading shall not differ by more than +1% from the value of the initial cell pressure prior to start of cycling. For lower cell pressures the deviation shall be less than 0.25kPa

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

- Type of system.
- Capacities (load, frequency).
- Accuracies.
- Load-rod to piston connection.

This information shall be provided upon request.

C.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; 1) be insensitive to horizontal forces and eccentricities in the axial force and 2) 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 shall be as rigid and stiff as possible, and the following requirement shall apply:

Static tests:

$$\frac{\Delta V_{ms}}{V \cdot \Delta u} < 0.4 \cdot 10^{-6} \text{ m}^2/\text{kN}$$

where: ΔV_{ms} = change in volume of pore pressure measurement system due to pore pressure change.

Δu = pore pressure change

V = total volume of specimen.

Cyclic tests:

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

Deformation:

The deformation of the specimen shall be measured with an accuracy better than + 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 shall have a double amplitude strain range of at least 30% of the sample height prior to start of the cyclic test.

Volume change measurement:

The amount of water and air going into or out of the specimen shall be measured with an accuracy of +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 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.

C.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 for at least the following strains:

0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.75, 1.0, 1.25, 1.5, 2.0, 2.5, 3.0, 4, 5, 6, 10, 12.5 and 15%.

For cyclic tests the data acquisition system shall be able to record 20 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.

In addition to the digital storage of representative cycles an analogue record of all relevant parameters (axial force, pore pressure and axial deformation) shall be made of all cycles in a test.

The analogue record of a cyclic test shall be provided upon request.

C.3.3 Preparation of test specimen

Test specimens shall be cylindrical with diameter not less than 35mm and specimen height from 1.85 to 2.25 times the diameter.

The end surfaces shall be as plane and perpendicular to the longitudinal axis as possible. The angle between end surface and the longitudinal axis shall not deviate from a perpendicular angle by more than + 0.6 degrees.

Care must 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 specimen preparation room.

The specimen height and diameter (or circumference) shall be measured within +0.1mm and mass within +0.05% of the total mass of the specimen.

The following detailed sample preparation and mounting procedures for 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 one reduces end friction, for example 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.

C.3.4 Consolidation stage prior to shearing

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

C.3.4.1 Unconsolidated tests

After application of the confining stresses, the specimen shall be allowed to stabilise under undrained conditions before shearing is started.

When pore pressure measurements are not required, rapid undrained shearing may start approximately 10 minutes after the last cell pressure step.

When 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 1mm² bore null-indicator should be less than +0.5mm over a period of 2 minutes. An alternative to the mercury null-indicator is a corresponding allowable change in differential pressure over the same time interval.

C.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.

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 is satisfied.

C.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 clause 13.3.4.1.

C.3.4.4 Ko-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 program.

C.3.4.5 Other consolidation procedures

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

C.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.

C.3.5 Static shearing

C.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 20% 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.

C.3.5.2 Drained tests (CD)

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:

$$(V_{\text{sub}1})_{\max} = \frac{H - \epsilon_{\text{af}}}{15 - t_{100}} \quad 1$$

where: t_{100} = time for primary consolidation.

e_{af} = expected axial strain at failure.

H = 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.

C.3.5.3 Undrained tests (UU and CU)

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.

When pore pressure is not measured, the rate of strain during shear shall be such that the maximum deviator stress is reached after 15-20 minutes.

C.3.5.4 Constant volume tests (CCV)

For constant volume 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.

C.3.5.5 Extension tests (E)

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.

C.3.6 Cycling testing

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

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

The cyclic phase shall be undrained and the load frequency shall be 0.1Hz (period 10s), unless otherwise specified.

Prior to start of the laboratory program the detailed cyclic test program 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 preshearing.
- Form of presentation of results.

After cyclic loading, all specimens shall be subjected to static shearing unless the cycling caused severe deformation of the specimen, such that a static test is impossible or meaningless.

C.3.7 Dismounting specimen

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

C.3.8 Presentation of results

C.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 could be given as:

- shear stress vs. effective average, octahedral, or radial stress

Mobilization curves could be given as:

- $\tan \rho$ vs. 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.

C.3.8.2 Static shearing

The results from static tests shall include the following.

Plots:

- Deviator stress or shear stress vs axial strain.
- Pore pressure vs axial strain (for CU and UU tests with pore pressure measurements)
- Volumetric strain vs axial strain (for drained tests).

- Stress path (Shear stress vs effective octahedral or effective Average stress vs effective radial stress).
- Stress paths shall have notation with agreed strain values.
- Mobilisation curve: $\tan \phi$ vs σ .
- Shear stiffness curve: G vs $\tan \phi$ or σ .

The plots shall 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 shall 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 (max and min if $OCR > 1.0$).
 - Effective radial pressure (max and min 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 .

C.3.8.3 Cyclic loading

The results from cyclic tests shall include the following:

On plots:

- Definition of symbols and average and cyclic stress and strain.

- Maximum and minimum axial strain versus number of cycles.
- Average pore pressure versus number of cycles.
- Stress-path (max/min) versus number of cycles.

In addition to the information listed for static tests, the plots shall contain:

- Average and cyclic stress level.

The following shall be presented in tabular form:

- Average shear stress.
- Cyclic shear stress.
- Number of cycles to "failure".
- Maximum and minimum axial strain in "failure" cycle.
- Pore pressure in "failure" cycle.
- Compressibility parameter due to consolidation after cycling (if appropriate).

C.4 DIRECT SIMPLE SHEAR TESTS

C.4.1 General

In the simple shear test, a soil sample is consolidated under K_0 -conditions and subjected to a horizontal shear stress. Both drained and constant volume tests (CCV) 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 clauses describe general requirements for simple shear test equipment, test procedures and specification of detailed information shall be supplied upon request.

C.4.2 Test apparatus

C.4.2.1 Horizontal support

The horizontal sample support must 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 pressure cell is used, the requirements given for the triaxial cell shall be followed.

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.
- Membrane corrections for vertical stress and horizontal shear stress.

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

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

C.4.2.2 Filters

Filters 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 10-5m/sec).

To prevent horizontal sliding between the sample and the filter stone, the interface shall be reinforced. Examples of such reinforcement are short (1.5mm) 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.

C.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 0.002-0.2mm per minute. The actual rate shall not deviate by more than +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 must 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 automatic mechanism for vertical load control, this mechanism shall be described in terms of accuracy and speed and basic operational feature upon request.

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

Static tests, allowable height change : +0.0025mm

Cyclic tests, allowable height change: +0.005mm

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 to 0.2Hz. 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 must 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 shall be described in terms of:

- Type of system.
- Capacities (load, frequency).
- Accuracies.
- Load-rod to piston connection.

C.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.

If the simple shear device is placed in a pressure cell and the force is measured inside the cell, the measuring device shall not be influenced by the magnitude of the cell pressure.

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%.

Pressure

If a pressure cell is used, cell pressure and pore pressure must be measured such that the difference between them is obtained within +2%.

The pore pressure measurement system shall be as rigid and stiff as possible.

Deformation

The vertical deformation of the specimen during consolidation shall be measured with an accuracy of at least 0.01% of the initial specimen height.

The shear strain of the specimen shall be measured with an accuracy of at least 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, deformation and pressure 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.

C.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 1.5N. The loading pistons shall run smoothly without vibration.

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

C.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 for at least the following strains:

0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.75, 1.0, 1.25, 1.5, 2.0, 2.5, 3.0, 4, 5, 6, 10, 12.5 and 15%.

For cyclic tests, the data acquisition system shall be continuous (i.e. analogue record) and/or be able to record at least 20 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).
- Pore pressure for undrained tests/change in vertical load for constant volume tests.
- Change in height during sample consolidation and during shearing for drained tests.

The continuous record of a cyclic test shall be provided upon request.

C.4.3 Preparation of test specimen

The sample shall have a cross-section in the range 20-80cm² and height 1.5-2.0cm. The horizontal surfaces shall be plane and perpendicular to the vertical axis.

Care must be taken to maintain the in situ water content of the samples. Air circulation around 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 $\pm 0.1\text{mm}$ and the mass within $\pm 0.05\%$ 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.

C.4.4 Consolidation stage prior to shearing

C.4.4.1 Consolidation procedure

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

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.

C.4.4.2 Other consolidation procedures

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

C.4.4.3 Back pressure

If a pressure cell is used, back pressure shall be used to increase the degree of saturation to improve the pore pressure response in the specimen.

The back pressure shall be high enough to give a B-value of at least 0.95.

A detailed specification of the method of back pressure application and measurement of pore pressure parameter shall be provided prior to start of laboratory program.

C.4.5 Static shearing

C.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.

C.4.5.2 *Constant volume shearing (CCV)*

For constant volume tests the sample height shall be kept constant within the limits specified in clause 13.4.2.3.

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.

C.4.5.3 *Undrained tests*

Undrained tests shall be performed in a pressure chamber. The cell pressure shall be constant during the shearing and the rate of horizontal displacement shall be 3-5% per hour.

The pore pressure shall be measured during the test, and the following variables recorded:

- Time.
- Horizontal force.
- Horizontal displacement.
- Pore pressure.
- Cell pressure (at intervals).
- Vertical load (at intervals).

C.4.5.4 *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).

C.4.6 *Cyclic testing*

Unless otherwise specified, the cyclic simple shear loading shall be performed as a stress controlled test.

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

The cyclic phase shall be undrained and the load frequency shall be 0.1Hz (period 10s) unless otherwise stated.

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

- Definition of cyclic stress level:
 - Average stress level.
 - Cyclic "failure" strain/ maximum number of cycles.
- Number of tests to be performed.
- Specification of preshearing.
- Form of presentation of results.

After the cyclic phase is terminated, all specimens shall be subjected to static shearing to failure unless the cycling caused such severe displacement of the specimen that a static test will be impossible or meaningless.

C.4.7 Dismounting specimen

After the test is stopped and the horizontal and vertical stresses reduced to zero, the specimen shall 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 shall be made of the whole specimen.

C.4.8 Presentation of results

C.4.8.1 General

The results from 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.

C.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 horizontal shear stress versus effective vertical stress.
- Stress paths shall have notations with agreed shear strain values.

All plots shall 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 shall be given where appropriate for each simple shear test in the form of tables:

- Project identification/location.
- Sample identification.
- Depth.
- Test type.
- Initial water content.
- 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 (max and min if $OCR > 1.0$).
 - Effective horizontal stress if a pressure cell is used (max and min if $OCR > 1.0$).
 - Vertical consolidation strain (max and min if $OCR > 1.0$).
- Test interpretation:
 - Horizontal undrained shear strength with corresponding pore pressure and shear strain.

C.4.8.3 Cyclic loading

The results from cyclic tests shall include the following plots:

- Definition of average and cyclic stress and strain.
- Maximum and minimum horizontal strain versus number of cycles.
- Average pore pressure versus number of cycles.

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

In tabular form the following shall be presented from a cyclic test:

- Average shear stress.
- Cyclic shear stress.
- Stress or strength defining shear stress level.
- Number of cycles to "failure".
- Max and min shear strain in "failure" cycle.
- Pore pressure in "failure" cycle.

C.5 RESONANT COLUMN TESTING

C.5.1 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 D 4015-92 (ASTM, 1995). The equipment used for these tests shall be specified. Unless otherwise agreed upon, equipment allowing for anisotropic consolidation shall be used.

C.5.2 Sample preparation

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

C.5.3 Test procedure

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

The periodic resonant column measurements shall 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% shall be followed by a measurement at the lowest possible shear strain.

For a test series on samples in an overconsolidated 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 program.

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

C.5.4 Presentation of results

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

- Gmax vs log time.
- Shear modulus vs shear strain.
- Damping ratio vs log time.
- Damping ratio vs shear strain.

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

In addition, sample data shall be given; such as:

- 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.

C.6 PIEZOCERAMIC BENDER ELEMENT TEST

C.6.1 General

The piezoceramic bender element technique can be used at any stage of a triaxial, direct simple shear or oedometer test without interfering with the particular test. The result of a piezoceramic bender element test is the shear wave velocity, v_s , which can be used to compute the small strain shear modulus, G_0 , in the sample. The test method is described by Dyvik and Madshus (1985) and Dyvik and Olsen (1989).

C.6.2 Sample preparation

The preparation of soil samples shall be in accordance with the requirements specified for oedometer, triaxial and direct simple shear tests. Care must 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 elements from the base pedestals as well as the height of the sample must be determined accurately.

C.6.3 Test procedure

Once the piezoceramic element is mounted, the shear wave velocity can be measured at any time during the consolidation and testing phases of 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 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) must be selected. The oscilloscope must have the ability of storing the signals for processing and printing out on paper.

C.6.4 Presentation of results

The result shall be presented as shear wave velocity and calculated maximum shear modulus, G_{max} . As documentation, the outprint 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.

C.7 CONTAMINATED SAMPLES

C.7.1 General

When sampling and testing in 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 State Pollution Control Authority (SFT) has provided guidelines presenting standards and requirements for carrying out investigations of polluted ground, 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 are included in the soil investigation program, the procedures for sampling, storing and testing shall be discussed prior to the investigation.

C.8 OTHER RELEVANT TESTS

C.8.1 General

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

Such tests may be specified prior to start of laboratory testing.

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

- Plane strain tests.
- Ring shear tests.
- Hollow cylinder tests.
- Triaxial vane shear tests.
- Laboratory model tests.

C.8.2 Documentation requirements

When specifying or proposing laboratory tests other than those specified in earlier chapters, such tests shall 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.

C.9 GEOLOGICAL AND GEOCHEMICAL TESTS

C.9.1 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 shall be performed by an experienced geologist.

A geological study shall 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 program:

- Name of laboratory to perform actual test.
- Test procedures and possible national and international standards to be used.

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

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

C.9.2 Visual description

A detailed description shall be made on a fresh sample, if possible offshore. The description shall include the points listed in clause 13.1.2.

Minor soil components shall 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 shall include sizes (in mm), degree of roundness and classification of rock type.

The study of the structure of clay samples shall 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.

C.9.3 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.

A special procedure may need to be followed:

- SEM - 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.

C.9.4 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.

C.9.5 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.

C.9.6 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.

C.9.7 C14 dating (Age determination)

When requested, dating of organic material or shells by the C14 dating method shall be performed if sufficient amounts of good quality soil is available (5-10g of shells is needed).

C.9.8 Foraminiferal analysis

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

Sample preparation methods and techniques shall be similar to those described by Melgaard and Knudsen 1979.

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

C.9.9 Dinoflagellate cyst analyses

Samples shall be prepared according to standard palynological techniques which shall include:

- Weighing of dry sediment. (Specify if oven dried or air dried.).
- Acid treatment with HCl and HF.
- Wet sieving to obtain fraction >25mm.

C.9.10 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.

C.9.11 Analysis of parameters for determining corrosion risk

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

Offshore:

- Sampling for sulphate reducing bacteria 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 ($<4^{\circ}\text{C}$) 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 ($<4^{\circ}\text{C}$).

Onshore:

- Sulphate reducing bacteria (SRB): 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, NS 1976.
- Sulphate; The reduced part of the bag sample or the rest of the SRB shall be squeezed carefully for less than 1/5 of its porewater through a fine paper filter. The porewater shall be kept under N_2 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, 30-40g 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 D REPORTING

D.1 REPORT STRUCTURES

The report structure should be presented in three levels and three main parts as shown in table 14.1.

For less extensive investigations, the three levels and parts are likely to be within one volume. For more comprehensive investigations, level 1 may be in one volume, and Part A, B, and C with level 2 and 3 in three separate volumes or more.

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

For each project table 14.1 shall be included in the beginning of the report. Only the clauses included in the work scope shall be specified in the table.

Table 14.1 Reporting structure

Level 1:

Soil investigation 1995 Executive Summary A short presentation of the project, the task and the results (main points from Parts A, B and C)
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Level 2:

Part A Soil parameters for design *Summary Part A
--

Part B Geotechnical data *Summary Part B

Part C Field operation *Summary Part C

Level 3:

A1	Summary of soil conditions
A2	Basic soil parameters
A3	Recommended soil parameters for foundation design
A4	Interpretation and evaluation of geotechnical data
A5	List of symbols and classification system used
A6	References

B1	Soil description and boring profiles
B2	Classification tests
B3	Consolidation permeability tests
B4	Triaxial tests
B5	Direct simple shear tests
B6	Piezoceramic bender element
B7	Resonant column test
B8	HFT tests
B9	BAT tests
B10	DMT tests
B11	Corrosion tests
B12	Chemical tests
B13	Geological tests
B14	Piezocene and seismic tests
B15	Description of laboratory test procedures
B16	List of symbols and classification system used
B17	References

C1	Log of activities
C2	Drilling operations
C3	Sampling
C4	Piezocene penetration testing
C5	Seismic
C6	HFT
C7	BAT
C8	Water depth and tidal measurements
C9	Field laboratory
C10	List of reports
C11	Positioning
C12	References
:	

For minor investigations it can be considered to have a simpler report structure to avoid too much repetition.

D.2 REPORT CONTENT

D.2.1 Executive summary

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

D.2.2 Part A: Soil parameters for design

For most projects geotechnical problems are known, but for other projects the final foundation solution may not be known so that it will be required to prepare recommended soil design parameters for independent foundation solutions.

A1: Summary of soil conditions; A2: Basic soil parameters and A4: Interpretation and evaluation of geotechnical data should be included in all cases.

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

Project specific requirements will come in addition with more details.

A1: 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 as 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, UCT, UU).

A2: Basic soil parameters

A number of basic soil parameters are independent of the type of structure to be installed or geotechnical problem that need 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 .
- Preconsolidation stress, p_c' .
- Overconsolidation ratio, OCR.
- Coefficient of earth pressure at rest, K_o .
- Relative density, D_r , in sand layers.
- Soil sensitivity, S_t , in clay layers.

A3: Recommended soil parameters for foundation design

The nature of the loading between fixed and floating offshore structures, and foundation and anchors, with regard to direction and composition is quite different. Methods of analyses, however, are similar. The number and importance of certain laboratory tests will shift between categories. This is particularly true with regard to the developments of deformation parameters and cyclic properties in general which are more critical for fixed structures with foundations, or tension leg platforms with anchors.

A3.1: Deformation parameters for settlement calculations

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

- Undrained Young's modulus, E_u .
- Drained Young's modulus, E_d .
- Constrained (one dimensional) modulus, M . When appropriate, 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 (mainly limited to clays loaded above p_c').
- Parameters for computing settlement components due to cyclic loading.

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

A3.2: Deformation parameters for dynamic analysis (if applicable)

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

- Initial shear modulus (G_{max}).
- 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.

A3.3: Shear strength parameters for stability calculations

A3.3.1: 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 ($p_o' + \Delta p$).
- Parameters required for calculation of s_u during consolidation.
- Anisotropy effects shall be included by having separate s_u -profiles for the active, passive and direct shear zone of the potential sliding surface.

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

- Friction ($\tan \phi$).
- Cohesion, c , or attraction, $a = (c \times \cot \phi')$.
- Pore pressure parameter, (D) .

If relevant, parameters for both p_o' consolidation and $p_o' + \Delta p$ conditions shall be given. Anisotropy effects shall be included.

A3.3.2: 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 shall be given.

A3.4: Contact stresses (soil reactions)

When required, parameters for computing expected base contact stresses should 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.

A3.5: 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.

A4: Interpretation and evaluation of geotechnical data

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

For effective stress strength parameters, summary of stress path in appropriate scale from triaxial tests or 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:

$$m_x = \frac{1}{n} \sum_{i=1}^n x_i$$

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

The uncertainty about the best estimate is the standard deviation,

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

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.

A5: 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.

A6: References

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

D.2.3 Part B: Geotechnical data

Table 14.1 includes a large number of laboratory and in situ test. For most projects not all these tests will be included and the non relevant -sections shall be removed from the table.

B1: Soil description and boring profiles

The chapter 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 each layer and sublayers.
- Water content and plasticity parameters.
- Unit weights.
- Densities.
- Undrained shear strengths for various types of tests.

B2 to B7: Various laboratory tests

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

B8 to B14: Various in situ tests

Reporting should be made following the requirements listed in the laboratory testing specifications. Comments to the general quality of the testing and test results should be made. 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).

B15: Description of laboratory test procedures

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

B16: 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.

B17: References

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

D.2.4 Part C: Field operations

Table 14.1 includes a list of relevant in situ tests and in situ operations during an offshore soil investigation. For most projects not all these tests will be included and the non relevant sections shall therefore be excluded. In the following some relevant comments to the various chapters in part C of the report are given.

According to this reporting scheme, 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 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.

C1: Log of activities

The chapter should include a detailed log on the activities performed during the entire soil investigation on a day to day basis. The log shall for 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 presentation of the various companies with their main representatives involved in the offshore work should be included.

C2: Drilling operations

The chapter should contain a detailed description of the drilling equipment used, including drill pipe and collars, bottom assembly and drill bits. The chapter should focus on the drilling conditions and the drilling rates obtained in the various soil types, the mud type used with mud pressure and the bit load and torque used. Correction for tidal variation (if any) shall be described.

Reference shall also be made to “Geotechnical soil borings” for further requirements.

C3 to C8: Sampling and in situ testing

Reporting to be made following the requirements listed in the laboratory testing specifications, Chapters 7 and 8.

C9: Field laboratory

The chapter should contain a description of the various activities and tests performed in the field laboratory. Handling and storage of the samples as described in Chapter 7.4 should be included, as well as comments to the general sample quality and sample recovery.

C10: 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 under other projects, dealing with the soil conditions at the present offshore field.

C11: Positioning

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

C12: References

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