DRAFT FOR DEVELOPMENT

DD ENV 1997-2:2000

Eurocode 7: Geotechnical design —

Part 2: Design assisted by laboratory testing

ICS 91.010.30; 93.020

National foreword

This Draft for Development is the official English language version of ENV 1997-2:1999.

This publication is not to be regarded as a British Standard.

It is being issued in the Draft for Development series of publications and is of a provisional nature. It should be applied on this provisional basis so that information and experience of its practical application may be obtained. This document does not have a parallel British Standard and, therefore, it has been published for use in the United Kingdom (UK) without any National Application Document.

ENV 1997-2:1999 results from a programme of work sponsored by the European Commission to make available a common set of rules for the structural and geotechnical design of buildings and civil engineering works. The full range of codes covers the basis of design and actions, the design of structures in concrete, steel, composite construction, timber, masonry and aluminium alloy, and geotechnical and seismic design.

Comments arising from the use of this Draft for Development are requested so that the UK experience can be reported to the European organization responsible for its conversion into a European Standard. A review of this publication will be initiated 2 years after its publication by the European organization so that a decision can be taken on its status at the end of its three-year life. The commencement of the review period will be notified by an announcement in *Update Standards*.

According to the replies received by the end of the review period, the responsible BSI Committee will decide whether to support the conversion into a European Standard, to extend the life of the prestandard or to withdraw it. Comments should be sent in writing to the Secretary of BSI Subcommittee B/526/3, Soil tests, at 389 Chiswick High Road, London W4 4AL, giving the document reference and clause number and proposing, where possible, an appropriate revision of the text.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

Summary of pages

This document comprises a front cover, an inside front cover, the ENV title page, pages 2 to 107 and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

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EUROPEAN PRESTANDARD
PRÉNORME EUROPÉENNE
EUROPÄISCHE VORNORM

ENV 1997-2

April 1999

ICS 91.060.00; 91.120.20

English version

Eurocode 7: Geotechnical design - Part 2: Design assisted by laboratory testing

Eurocode 7: Calcul géotechnique - Partie 2: Calcul sur la base d'essais de laboratoire

Eurocode 7: Entwurf, Berechnung und Bemessung in der Geotechnik - Teil 2: Laborversuche für die geotechnische Bemessung

This European Prestandard (ENV) was approved by CEN on 30 August 1997 as a prospective standard for provisional application.

The period of validity of this ENV is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the ENV can be converted into a European Standard.

CEN members are required to announce the existence of this ENV in the same way as for an EN and to make the ENV available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the ENV) until the final decision about the possible conversion of the ENV into an EN is reached.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Central Secretariat: rue de Stassart, 36 B-1050 Brussels

Ref. No. ENV 1997-2:1999 E

FOREWORD

Objectives of the Eurocodes

(1) The structural Eurocodes comprise a group of standards for the structural and geotechnical design of buildings and civil engineering works.

(2) They are intended to serve as reference documents for the following purposes:

(a) As a means to prove compliance of building and civil engineering works with the essential requirements of the Construction Products Directive (CPD)
(b) As a framework for drawing up harmonised technical specifications for construction products.

(3) They cover execution and control only to the extent that is necessary to indicate the quality of the construction products, and the standard of the workmanship, needed to comply with the assumptions of the design rules.

(4) Until the necessary set of harmonised technical specifications for products and for methods of testing their performance is available, some of the Structural Eurocodes cover some of these aspects in informative annexes.

Background to the Eurocode programme

(5) The Commission of the European Communities (CEC) initiated the work of establishing a set of harmonised technical rules for the design of building and civil engineering works which would initially serve as an alternative to the different rules in force in the various Member States and would ultimately replace them. These technical rules became known as the "Structural Eurocodes".

(6) In 1990, after consulting their respective Member States, the CEC transferred work of further development, issue and updates of the Structural Eurocodes to CEN and the EFTA Secretariat agreed to support the CEN work.

(7) CEN Technical Committee CEN/TC 250 is responsible for all Structural Eurocodes.

Eurocode programme

(8) Work is in hand on the following Structural Eurocodes, each generally consisting of a number of parts:

EN 1990 Eurocode 0 Basis of design
EN 1991 Eurocode 1 Actions on structures
EN 1992 Eurocode 2 Design of concrete structures
EN 1993 Eurocode 3 Design of steel structures
EN 1994 Eurocode 4 Design of composite steel and concrete structures
EN 1995 Eurocode 5 Design of timber structures
EN 1996 Eurocode 6 Design of masonry structures
EN 1997 Eurocode 7 Geotechnical design
EN 1998 Eurocode 8 Design of structures for earthquake resistance.

EN 1999 Eurocode 9 Design of aluminium alloy structures

(9) Separate sub-committees have been formed by CEN/TC 250 for the various Eurocodes listed above.

(10) This part of the Structural Eurocode for Geotechnical design, is being issued by CEN as a European prestandard (ENV) with an initial life of three years.

(11) This prestandard is intended for experimental practical application in the design of the building and civil engineering works covered by the scope as given in 1.1.2 and for the submission of comments.

(12) After approximately two years CEN members will be invited to submit formal comments to be taken into account in determining future action.

(13) Meanwhile, feedback and comments on this prestandard should be sent to the Secretariat of sub-committee CEN/TC250/SC7 at the following address:

NNI
P.O.Box 5059
NL-2600 GB Delft
The Netherlands

or to a national standards organisation.

National application documents

(14) In view of the responsibilities of authorities in member countries for the safety, health and other matters covered by the essential requirements of the CPD, certain safety elements in this ENV have been assigned indicative values which are identified by [ ]. The authorities in each member country are expected to assign definitive values to these safety elements.

(16) Many of the supporting standards, including those giving values for actions to be taken into account and measures required for fire protection, will not be available by the time this prestandard is issued. It is therefore anticipated that a National Application Document giving definitive values for safety elements, referencing compatible supporting standards and giving national guidance on the application of this prestandard will be issued by each Member State or its Standards Organisation. This prestandard should be used in conjunction with the National Application Document valid in the country where the building and civil engineering works is to be constructed.

Matters specific to this prestandard

(16) This prestandard is intended to serve as a reference document for the use of laboratory tests for geotechnical design. It covers the execution and interpretation of the most commonly used laboratory tests. The prestandard aims at ensuring that adequate quality is reached in the execution of laboratory tests and their interpretation.

(17) Within the framework of European Standardisation, Eurocode 7 Part 1 on the design of geotechnical structures was established. The link between the design requirements in Part 1 and the results of laboratory tests run according to standards, codes and other accepted documents are covered by Part 2 «Geotechnical Design Assisted by Laboratory

Testing». Eurocode 7 Part 2 addresses in particular the requirements of Section 3 in Part 1, «Geotechnical data».

(18) ENV 1997-2 and ENV 1997-3 are complementary.

(19) No other standard covering to the extent of the present document the use of laboratory tests for geotechnical design has been published before. Some existing standards cover part of the material described in the present document. Various national standards on laboratory test procedures however have been published.

(20) CEN/TC 250/SC7 defined the scope for this part of Eurocode 7 in the following manner:

- the document should represent a prestandard for professional behaviour within the field of design assisted by laboratory testing.
- the requirements for the interpretation of the test results should include the «derived» values of the soil parameters and not the characteristic values.
- the document should only give those requirements that are essential to obtain reliable derived values of soil parameters; test procedures are to be presented elsewhere; the present document is a step towards a global set of standards including test procedures, interpretation and selection of characteristic values.

(21) Laboratory tests as such are not within the scope of this prestandard. This prestandard consists of a main text (Sections 1 to 15) and an informative annex (Sections A1 to A15). The main text contains the requirements and the aspects for each laboratory test method. The informative annex contains information which is useful for practical work, but which may not be as generally recognised in the member countries as the concepts in the main text.

(22) Section 2 contains general requirements applicable to all laboratory tests covered, section 3 covers calibration requirements. Sections 4 to 11 cover the requirements for laboratory testing of soils, with section 4 covering the preparation of soil specimens and sections 5 to 11 treating each laboratory test separately. Sections 12 to 15 cover the requirements for the laboratory testing of rocks, with section 12 covering the preparation of rock specimens for testing and sections 13 to 15 treating each laboratory test separately.

(23) The informative annex A with the same numeration system for the sections as the main text (Sections A.2 to A.15 correspond to Sections 2 to 15 in the main text) gives additional information on principles of measurement, testing procedures, minimum number of tests and reporting and interpretation.

(24) There are no European or ISO standards on laboratory testing procedures at the moment. Until standards on testing procedures have been completed, the informative annex contains a list of standards, prestandards and other publicly available documents that comply with the requirements of this prestandard.

In the annex, wherever possible, checklists and tables are provided to assist with planning, checking and interpretation of laboratory tests. The annex is by no means an exhaustive listing of all possible issues that may arise but points out important aspects to be considered.

1 GENERAL

1.1 Scope

1.1.1 Scope of Eurocode 7

(1)P Eurocode 7 applies to the geotechnical aspects of the design of buildings and civil engineering works. It is subdivided into various separate parts, (see 1.1.2).

(2)P Eurocode 7 is concerned with the requirements for strength, stability, serviceability and durability of structures. Other requirements, e.g. concerning thermal or sound insulation, are not considered.

(3)P Eurocode 7 shall be used in conjunction with ENV 1991-1 "Basis of Design" of Eurocode 1 "Basis of Design and Actions on Structures" which establishes the principles and requirements for safety and serviceability, describes the basis for design and verification and gives guidelines for related aspects of structural reliability.

(4)P Eurocode 7 gives the rules to calculate actions originating from the ground such as earth pressures. Numerical values of actions on buildings and civil engineering works to be taken into account in the design are provided in ENV 1991 Eurocode 1 "Basis of Design and Actions on Structures" applicable to the various types of construction.

(5)P In Eurocode 7 execution is covered to the extent that is necessary to indicate the quality of the construction materials and products which should be used and the standard of workmanship on site needed to comply with the assumptions of the design rules. Generally, the rules related to execution and workmanship are to be considered as minimum requirements which may have to be further developed for particular types of buildings or civil engineering works and methods of construction.

(6)P Eurocode 7 does not cover the special requirements of seismic design. Eurocode 8, "Design provisions for earthquake resistance of structures" provides additional rules for seismic design which complete or adapt the rules of Eurocode 7.

1.1.2 Scope of ENV 1997-2

(1)P This prestandard provides requirements for the execution, interpretation and use of geotechnical laboratory tests. The standard aims at providing assistance for the geotechnical design of structures. It does not replace national test standards on testing procedures.

(2) The provisions of this document are planned primarily for projects of Geotechnical Category 2, as defined in 2.1 of ENV 1997-1.

(3)P ENV 1997-2 shall be used in conjunction with ENV 1997-1.

(4) For each of the laboratory tests included, this prestandard presents the objective and the requirements of the test. The requirements are related to test programme, test apparatus and testing procedures, and the evaluation and presentation of the test results.

(4) Only commonly used geotechnical laboratory tests are covered in this prestandard. These were selected on the basis of their importance in geotechnical practice, availability in commercial geotechnical laboratories and existence of an accepted testing procedure in Europe. Tests less commonly used, especially more advanced tests, which may be essential for design of structures within Geotechnical Category 3, as defined in 2.1 of ENV 1997-1, are mentioned in connection with related tests. Unsaturated soils are not covered. The parameters needed for e.g. finite element calculations (Poisson's ratio, shear modulus and Young's modulus) are not dealt with either. It is expected that updates of the present prestandard will gradually include more advanced laboratory tests, unsaturated soils and deformation parameters.

(5) This document is meant for the person responsible for a geotechnical design.

1.2 References

(1)P This European prestandard incorporates by dated or undated reference, provisions from other standards. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this prestandard only when incorporated in it by amendment or revision.

ENV 1991-1:1994	Eurocode 1 Basis of design and actions on structures - Part 1 Basis of design
ENV 1997-1:1994	Eurocode 7 Geotechnical design - Part 1 General rules
ENV 1997-3:1998	Eurocode 7 Geotechnical design - Part 3 Design assisted by field testing

1.3 Distinction between Principles and Application Rules

(1)P Depending on the character of the individual paragraphs, distinction is made in this prestandard between Principles and Application Rules.

(2)P The Principles comprise:

- general statements and definitions for which there is no alternative, as well as;
- requirements and analytical models for which no alternative is permitted unless specifically stated.

(3)P The Principles are preceded by the letter P.

(4)P The Application Rules are examples of generally recognised rules which follow the Principles and satisfy their requirements.

(5)P It is permissible to use alternative rules different from the Application Rules given in this Eurocode, provided it is shown that the alternative rules accord with the relevant Principles.

1.4 Definitions

1.4.1 Terms common to all Eurocodes

(1)P The terms used in common for all Eurocodes are defined in ENV 1991-1 Basis of design.

1.4.2 Terms common to Eurocode 7

(1)P For terms, specific to Eurocode 7, reference is made to 1.5.2 of ENV 1997-1.

(2)P The following terms, used in this part of Eurocode 7, in addition to, or replacing the terms defined in 1.5.2 of ENV 1997-1, are defined here:

1.4.2.1 comparable experience: defined in 1.4 of ENV 1997-1. In addition three classes of comparable experience are defined:

- **none:** if no reliable results are available,
- **medium:** if data for similar soils are available or if data follow knowledge documented in geotechnical literature
- **extensive:** if statistical evaluations and/or published correlations, or if testresults for the same soil on a nearby location, exist

1.4.2.2 derived value: derived value of a geotechnical property is the value obtained by theory, correlation or empiricism from test results. Derived values form the basis for the selection of characteristic values of ground properties to be used for the design of geotechnical structures in accordance with 2.4.3 in ENV 1997-1.

1.4.2.3 disturbed sample: sample where the structure, water content and constituents of the soil have been changed during sampling.

1.4.2.4.element test: test on an element (specimen) of soil to determine a property, where the element is subjected to deformations, forces or percolation attempting to simulate the in situ conditions of a soil mass.

1.4.2.5 measured value: value is the value measured in a test.

1.4.2.6 normally consolidated soil: soil which state is on the virgin normal compression line.

1.4.2.7 overconsolidated soil: soil which state is below the virgin normal compression line.

1.4.2.8 quality class: classification by which the quality of a soil sample is assessed. For laboratory testing purposes, soil samples are classified in five Quality Classes, where Quality Class 1 represents an undisturbed sample, and Quality Class 5 a sample not suitable for representative testing.

1.4.2.9 remoulded specimen: fully disturbed specimen, at about natural water content.

1.4.2.10 re-compacted specimen: specimen forced into a mould with a rammer or under static pressure.

1.4.2.11 re-constituted specimen: specimen made into a slurry (at or above the liquid limit for clays) and then reconsolidated.

1.4.2.12 re-consolidated specimen: specimen compressed in a mould or cell under static pressure while allowing drainage to take place.

1.4.2.13 sample: portion of soil or rock recovered from the ground by sampling techniques.

1.4.2.14 specimen: part of a soil or rock sample used for a laboratory test.

1.4.2.15 strength index test: test of rather rudimentary nature that yields an indication of the shear strength, without necessarily giving a representative value. The results of such test is subject to considerable uncertainty.

1.4.2.16 swelling: expansion due to reduction of effective stress resulting from either reduction of total stress or absorption of water at constant total stress. Swelling includes the reverse of both compression and consolidation.

1.4.2.17 undisturbed sample: sample where no change in the soil characteristics of practical significance has occurred.

1.5 Symbols and units

1.5.1 Symbols common to all Eurocodes

(1)P The symbols used in common for all Eurocodes are defined in ENV 1991-1 "Basis of design".

1.5.2 Symbols used in Eurocode 7

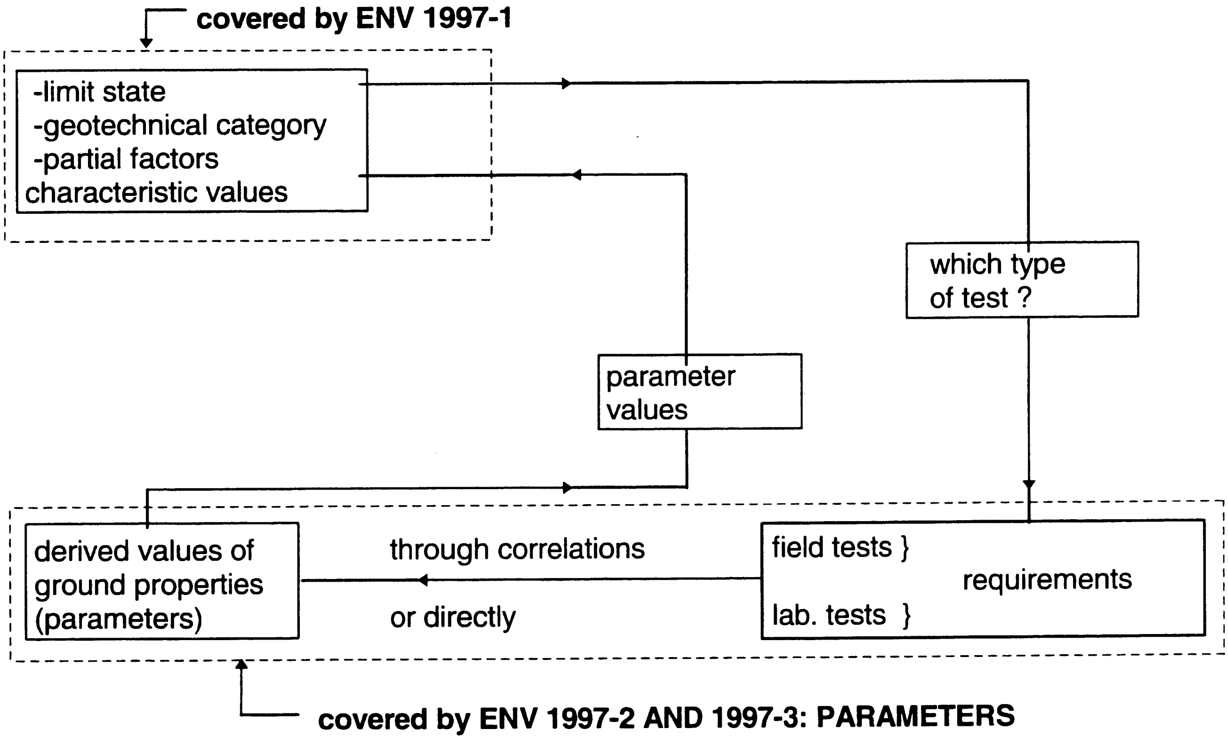
(1)P The symbols commonly used in Eurocode 7 are defined in 1.8 of ENV 1997-1. Symbols used in this prestandard are defined in the relevant texts.

1.5.3 Units

(1) For geotechnical calculations, the recommended units are defined in 1.6 of ENV 1997-1.

1.6 The link between ENV 1997-1 and ENV 1997-2

The flow chart shown below demonstrates the link between design and field and laboratory tests. The design part is covered by ENV 1997-1; the parameter values part is covered by ENV 1997-2 and -3.



2 REQUIREMENTS FOR ALL LABORATORY TESTS

2.1 General requirements

(1)P When designing with the help of laboratory tests, both the requirements in section 2 and the requirements for a specific test in sections 3 to 15 shall be satisfied.

(2)P The requirements for site investigations contained in section 2 of ENV1997-3 shall be followed.

(3)P The requirements contained in section 3 of ENV1997-1 shall be followed.

(4) The requirements given in this prestandard represent a minimum. Additional specifications, additional presentation requirements or additional interpretation, as appropriate for the ground conditions or geotechnical aspects of interest, may be required.

(5) Annex A2 presents in a schematic manner the different steps of a soil investigation, with special emphasise on laboratory tests.

2.2 Testing programme

(1)P The type of construction, the soil type and stratigraphy and the geotechnical aspects of the project shall be taken into account when setting up the laboratory testing programme.

(2)P The testing programme shall be set up to complete and expand on the information obtained from the field testing programme. Geotechnical design, field testing and laboratory tests shall form a whole where the test results are used as complementary and in combination during all stages of the work.

(3) Before any laboratory test is performed, all soil samples should be inspected visually such that a preliminary soil profile can be established. The visual inspection of the samples should be supported by simple manual tests to classify and identify the soil and to give a first impression of the consistency and the strength of the soil. The boring logs and existing investigation results should be evaluated and incorporated in the preliminary soil profile.

(4) Prior to setting up a test programme, the expected stratigraphy at the site should be established and the strata relevant for design selected to enable the specification of the type and number of tests in each stratum. Stratum identification should be a function of the geotechnical problem, its complexity, the local geology and the required parameters for design.

(5)P Samples for element tests shall be selected so as to cover the range of index properties of each relevant soil stratum.

(6)P The amount of testing shall be sufficient to meet the requirements given herein, also taking into consideration the safety requirements of the project, the cost benefit of the testing, the test methods selected and the available comparable experience.

(7)P The tests shall be run on specimens representative of the relevant strata.

(8)P The testing programme shall be adjusted as the results become available and the initial assumptions can be checked. In particular, the need for specifying additional testing to check whether the parameters obtained fit into a consistent behavioural pattern for soil or rock shall be considered.

(9)P The need for more advanced testing or additional field investigation as a function of the geotechnical aspects of the project, soil type, soil variability and computation model shall be considered.

2.3 Quality of soil samples

(1) Soil samples used for laboratory testing are classified in five Quality Classes with respect to the soil characteristics that remain unchanged during sampling or handling. The classes are described in Table 1.

Table 1 Quality Classes of soil samples for laboratory testing

Soil properties/Quality Class	1	2	3	4	5
Unchanged soil characteristics					
Particle size	x	x	x	x	
Water content	x	x	x		
Density, density index, permeability	x	x			
Compressibility, shear strength	x				
Properties that can be determined					
Sequence of layers	x	x	x	x	x
Boundaries of strata - broad	x	x	x	x	
Boundaries of strata - fine	x	x			
Atterberg limits, particle density, organic content	x	x	x	x	
Water content	x	x	x		
Density, density index, porosity, permeability	x	x			
Compressibility, shear strength	x				

(2)P Samples shall be tested as soon as possible after recovery. Transport and storage shall be done in such a manner that no change in the soil characteristics is likely to occur.

(3)P The effects of sample disturbance on the results of the laboratory tests shall be taken into account when planning the testing programme and when interpreting the test results.

(4) Soil samples, when recovered, are always disturbed to some degree.

(5) For the desciption of soil sampling methods and the quality of samples obtained by the different sampling methods, reference is made to ENV1997-3.

2.4 Equipment, procedures and presentation

(1)P The tests shall be carried out in accordance with procedures which comply with the requirements given in the paragraphs for each test.

(2)P The details of the tests required to determine the parameters that are needed for design shall be specified.

(3)P Accuracy checks shall be performed based on duplicate tests or comparisons with a database on comparable soil types.

(4)P Checks that the laboratory equipment used for testing is adequate and properly calibrated shall be made.

(5)P The test methods and procedures used shall be reported together with the test results. Any deviations from a standard test procedure shall be reported and justified.

(6) The test procedures may be reported by reference to documents that are recognised internationally by the geotechnical profession.

NOTE: no international or European standards for testing still exist

(7) Provided the requirements of this prestandard are met, alternative methods to present test results may be selected.

2.5 Evaluation of test results

(1)P The test results shall be evaluated as a whole, including the results of field and laboratory tests, comparing the results with existing experience for each derived value of a soil characteristic, giving special consideration to anomalous results for a given stratum and reconsidering the assumed stratum subdivision in light of the results obtained. The results shall be interpreted taking into account the ground water table, soil type, drilling method, sampling method, transport, handling and specimen preparation.

(2)P The evaluation of the laboratory test results shall take into account available comparisons of the results with existing experience, the results of other types of laboratory and field tests capable of measuring the same soil parameter, and correlations based on index properties of the soil.

(3)P When evaluating the test results, only relevant comparisons shall be made.

(4) As far as possible, the results should include a statement on limitations or constraints to which the use of a soil or rock parameter should be subjected.

(5) This prestandard applies to the most commonly encountered soils, such as sands, silts and clays. For other soils with different compositions and/or geology, additional or modified requirements may be needed. In particular, comparable experience should be used.

(6)P No substitution of strength and deformation tests with values selected from databases with comparable experience shall be done if the comparable experience is not well documented and the data and the estimates thereof have not been quality controlled.

(7) With natural soils, variations in measured properties may indicate significant variations in site conditions. It is very important that weak zones be identified, and that the uncertainty in laboratory test results be assessed. The use of statistics for determining derived values may mask the presence of a weaker zone. The statistical approach should be used with caution and generally combined with other methods.

(8)P As the test results are interpreted, the need for specifying further interpretation of the results to check whether each parameter obtained fits into a consistent behavioural pattern for soil or rock shall be considered.

2.6 Quality assurance and quality control

(1)P An appropriate quality assurance system shall be in place in the laboratory and engineering office, and quality control shall be exercised competently in all phases of the laboratory testing and interpretation of the test results.

3 CALIBRATION OF TEST EQUIPMENT

3.1 Objective

(1) The objective of calibration is to ensure that the uncertainties in any measurement, wherever practicable, can be quantified.

(2)P To achieve this, all measurements made in a testing laboratory shall be traceable back to national or international standards of measurement.

3.2 Requirements

3.2.1 Measuring instruments

(1)P All instruments used for the tests shall be calibrated, and records of calibration and re-calibration shall be maintained.

(2)P Each instrument used to calibrate or check the instruments shall be within its re-calibration interval.

(3)P Instruments used in connection with tests shall be subjected to frequent calibration checks and stability checks.

(4)P Electronic instruments shall be checked under the same conditions (electrical conditions, signal conditioning and logging equipment) that are used for testing.

(5)P Calibration shall be traceable to standards, where applicable, or the laboratory shall show other satisfactory evidence of calibration and accuracy of test results.

(6)P All measurements made in the course of the tests shall be within the limits of calibration of the instruments.

(7)P Standards and devices for in-house calibration of working instruments shall have valid certificates of calibration and shall be properly maintained and stored.

3.2.2 Test apparatus

(1)P Significant measurements (e.g. linear dimensions; masses) of each item of test apparatus shall be verified, and shall lie within the specified working tolerances.

(2)P Calibrations, measurements and checks required for particular test procedures shall be properly carried out and recorded.

(3)P Records of calibrations, measurements and checks shall be properly maintained by laboratory.

3.2.3 Malfunction of equipment

(1)P Any detected malfunction or change in calibration of test equipment shall be notified immediately to the recipients of test results, and all data produced since the preceding calibration or check shall be re-evaluated.

(2)P The item shall be re-calibrated before further use.

3.2.4 Environment

(1)P The relevant laboratory environmental conditions at the time of calibration shall be recorded.

4 PREPARATION OF SOIL SPECIMENS FOR TESTING

4.1 Objective

(1) The objective in the preparation of soil for laboratory tests is to provide test pecimens that are as representative as possible of the soil from which the samples are taken.

(2) For the purposes of preparation, test specimens fall into four categories, disturbed specimens, undisturbed specimens, re-compacted or remoulded specimens and re-constituted specimens

4.2 Requirements

4.2.1 Quantity of soil

(1)P The soil specimen used for testing shall be sufficiently large to take account of:
- the largest size of particle present in significant quantity,
- the natural features such as structure and soil fabric.

(2)P Undisturbed samples shall be prepared under conditions of a high relative humidity. If preparation is interrupted, the specimen shall be protected from drying out.

(3) Minimum masses of disturbed soil for classification tests and tests on re-compacted specimens are given in Annex A6. Masses of soil required for preparation of undisturbed specimens for strength and compressibility tests are also given in Annex A6.

4.2.2 Handling and processing

(1)P All samples shall be clearly and unambiguously labelled.

(2)P Soil samples shall be protected at all times against damage and deterioration, and excessive changes in temperature. The samples shall be protected from frost when stocked on site. Special care shall be taken with undisturbed samples to prevent distortion and loss of water during preparation of test specimens. The material from the sampling containers shall not react with the contained soil.

(3)P Soil shall not be allowed to dry before testing unless otherwise specified.

(4)P When disaggregation processes are aplied, breaking down of individual particles shall be avoided. If special treatment of bonded and cemented soils is required, this shall be specified.

(5)P Subdivision methods shall ensure that representative portions are obtained, avoiding segregation of large particles.

5 TESTS FOR CLASSIFICATION, IDENTIFICATION AND DESCRIPTION OF SOILS

5.1 General

(1) Until now there is no international or European standard for soil identification and description which can be referred to in this prestandard. National standards need to be used until a European standard on soil classification has been introduced.

(2) This prestandard deals with the following tests for identification and classification:

- water content,
- bulk density,
- particle density,
- particle size analysis,
- atterberg limits,
- density index test for granular soils,
- soil dispersibility,
- frost susceptibility.

(3) Annex A.5 provides more details on each classification test and its interpretation, and a guideline for the minimum number of samples and tests in one stratum.

5.2 Requirements for all classification tests

(1) The results of soil classification tests should be, as far as possible, presented together with the soil profile on a plot summarising the soil description and all classification results.

(2) If possible, the location of other laboratory tests (such as oedometer and triaxial tests) can be indicated on the same figure.

(3) For all classification tests, special caution should be exercised with the choice of the temperature for oven-drying, as too high temperatures can have detrimental effects on the quantity measured.

5.3 Water content

5.3.1 Objective

(1) The objective of the test is to determine the water content of a soil material.

5.3.2 Requirements

(1) The test specimens should be of at least Quality Class 3.

(2) If a sample contains only one type of soil, at least one test per sample should be used to determine the water content.

5.3.3 Evaluation of test results

(1)P The extent to which the water content measured in the laboratory on the soil 'as received' is representative of the 'in situ' value shall be checked. Effects such as sampling method, transport and handling, specimen preparation method and laboratory environment, need to be taken into account in this assessment.

(2)P The presence of significant amounts of halloysite, montmorillonite, or gypsum minerals, highly organic soils, materials in which the pore water contains dissolved solids and soils with closed pores filled with water, shall be reported.

(3) For the soils meant in 5.3.3 (2), a drying temperature of approximately 50°C may be more appropriate than the usually prescribed (105 ± 5) °C, but the results obtained should be considered with caution.

5.4 Bulk density

5.4.1 Objective

(1) The test is used to determine the bulk mass density of a soil. The bulk density is also used, in conjunction with the water content, to compute the density of dry soil.

5.4.2 Requirements

(1) The test specimens should be at least of Quality Class 2.

(2)P The test method to be used shall be specified.

5.4.3 Evaluation of test results

(1)P The densities shall be interpreted taking into consideration depth of the groundwater level, particle size distribution, mineralogy, maximum grain diameter of the sample and sample disturbance.

(2) Except in the case of special sampling methods such as freezing, the determined density of a coarse soil under the groundwater table is generally only very approximate.

5.5 Particle density

5.5.1 Objective

(1) The particle density is the mass of the particles divided by their volume. The particle density is necessary for the precise determination of a large number of geotechnical parameters.

5.5.2 Requirements

(1) The test should preferably be carried out according to the pycnometer method. However, other procedures are possible, such as the density bottle method or the gas jar method.

5.5.3 Evaluation of test results

(1)P If for a particular stratum the measured values do not fall within the normally expected range of 2500 to 2800 kg/m^3, the mineralogy of the soil, its organic matter and its geological origin shall be checked.

5.6 Particle size analysis

5.6.1 Objective

(1) Two methods, depending on the size of the particles, are used for the determination of particle size analysis:
- sieve method for particles > 63 μm (or closest sieve available),
- sedimentation method using a hydrometer, or pipette, for particles ≤ 63 μm (or closest sieve available).

5.6.2 Requirements

(1) Procedures for the removal of organics and carbonates prior to sieving and sedimentation or for corrections to account for the presence of carbonates and organic material should be used, if appropriate carbonates and organic matter can have a cementing or coagulating effect and influence the particle size distribution.

(2) Account should be taken that for some soils, f.i. chalky soils, treatment for carbonate removal is unsuitable.

(3) For low organic contents, caution should be exercised when removing organics.

(4) Prior to sedimentation, the specimen should not be dried. If drying is needed it should be dried at a temperature lower than 105°C.

5.6.3 Evaluation of test results

(1)P The report shall mention the following:

- ground water position corresponding to the specimens tested,
- drying method used,
- whether organics and carbonates have been removed and by which method,
- carbonate and/or organic content if relevant,
- whether the mass fractions are reported with respect to the total weight (including carbonate and organic matter).

5.7 Consistency limits

5.7.1 Objective

(1) The consistency limits comprise the liquid limit, plastic limit and shrinkage limit. The determination of the liquid limit and the plastic limit are covered only.

(2) The consistency limits are used to characterise the behaviour of clays and silty soils when the water content is changing. Classification of clays and silty soils is mainly based on the consistency limits.

5.7.2 Requirements

(1) The specimens tested should at least be of Quality Class 4.

(2)P For the liquid limit, the testing method to use (fall cone or Casagrande apparatus) shall be specified.

(3) In general, the fall cone method is preferred to the Casagrande method. Especially for low plasticity soils, the fall cone method gives more reliable results.

5.8 Density index test for granular soils

5.8.1 Objective

(1) The density index relates void ratio or dry density of a soil sample to reference values determined by standard laboratory procedures. The density index is used to characterise the shear strength and the compressibility of cohesionless soil under static and dynamic loading by relating the in situ void ratio to limiting dry densities, called the maximum and minimum dry densities. The density index test gives an indication of the state of compaction of a free draining granular soil.

5.8.2 Requirements

(1)P The following shall be specified or checked:

- quantity and quality of samples,
- type of testing procedure to be applied,
- method of preparation of each test specimen,
- testing procedure to be applied.

(2) The material used should contain less than 10% fines (particles passing the 63 μm sieve) and less than 10% of gravel (particles retained on the 6,3 mm sieve).

(3)P Density index test results shall be reported together with the available particle size analysis results, natural water content, density of solid particles, and percentage of oversize fraction (the latter if applicable). Any deviation with respect to 5.8.2 (2) shall be reported.

5.8.3 Evaluation of test results

(1) Values of maximum and minimum densities obtained in the laboratory do not necessarily represent limiting densities. It is also generally recognised that these methods give densities with a high degree of variability.

(2) The lower values of density index are usually considered for further decisions.

5.9 Soil dispersibility

5.9.1 Objective

(1) The objective of the tests is to identify the dispersive characteristics of clayey soils. Standard tests for classifying soils for engineering purposes do not identify the dispersive characteristics of a soil. Tests for dispersibility are carried out on clayey soils primarily in connection with earth embankments and other geotechnical structures in contact with water.

(2) Four test types are considered:
- **the pinhole test:** this test models the action of water flowing along a crack,
- **the double hydrometer test:** this test compares the dispersion of clay particles in plain water without mechanical stirring with that obtained using a dispersant solution and mechanical stirring,
- **the crumb test:** this test shows the behaviour of crumbs of soil placed in a dilute solution of sodium hydroxide,
- **the determination of soluble salts in the pore water:** this test allows the correlation of percent sodium to the total dissolved salts in saturation extract.

5.9.2 Requirements

(1)P The following shall be specified:
- storage of samples such that the samples are not allowed to dry before testing,
- the testing procedures to be applied,
- the specimen preparation method.

(2)P The results from the dispersibility tests shall be linked to the grain size distribution and consistency limits of the sample.

(3) For the pinhole test, the compaction conditions of the soil specimens, e.g. wet or dry of optimum, and the mixing water (e.g. distilled versus reservoir water) should be specified.

(4) For the double hydrometer test, a third hydrometer test may be specified if it appears necessary to study the effect of reservoir water on the soil in suspension.

(5) For the crumb test, the use of distilled water may be requested in addition to the sodium hydroxide solution.

5.10 Frost susceptibility

5.10.1 Objective

(1) The frost susceptibility of soil materials plays an essential role in the design of foundations placed above the freezing front in frost susceptible soils. Roads, airport runways, railways, buildings on spread foundations, buried pipelines, dams and other structures may be subject to frost heave due to freezing of a frost-susceptible soil having access to water. Frost-susceptible soils may be used in their natural state or as a constructed base for structures.

(2) The risk of frost heaving may be estimated from correlation with soil classification properties (particle size, height of capillary rise and/or fines content) or from laboratory tests on natural or reconstituted samples.

5.10.2 Requirements

(1) If the estimation of frost susceptibility based on classification properties of the soil does not clearly indicate the absence of risk of frost heaving, frost heaving test in the laboratory should be run. Examples of soil types indicating the need of laboratory tests in addition to correlations to classification properties include organic soils, peat, saline soils, artificial soils and coarse soils with a wide range of grain size.

(2) To determine the frost susceptibility of a soil in its natural state, natural samples should be tested. To estimate the frost susceptibility of a constructed fill, frost heave tests should be run on reconstituted specimens.

(3) The frost susceptibility test in the laboratory is a frost heave test. If the risk of thaw weakening is to be tested, a California Bearing Ratio test should be carried out after thawing of the specimen. The reconstituted specimen should be subjected to one or more freeze-thaw cycles before testing.

5.11 Evaluation of test results

(1) The results should be interpreted as a function of the type of construction work, the rules used in design and the available comparable experience, considering the consequence of the frost effects.

6 CHEMICAL TESTING OF SOILS AND GROUNDWATER

6.1 Requirements for all chemical tests

6.1.1 Scope

(1) Although the detailed chemical composition of soil is of little interest for civil engineering purposes, the presence of certain chemical constituents in soil may be very significant.

(2) Routine chemical testing in a soil laboratory is usually limited to organic content (loss on ignition, total organic content, organic matter), carbonate content, sulphate content, pH value (acidity or alkalinity) and chloride content. The standard deals with these five chemical test only.

(3) Annex A6 provides more detail on each chemical test and its interpretation, and some guidelines.

6.1.2 Objective

(1) The purpose of the chemical tests described herein is to classify the soil and to assess the detrimental effect of the soil and groundwater on concrete, steel and the soil itself. The tests are not intended for more environmentally related purposes.

6.1.3 Requirements

(1)P The following aspects shall be specified for all tests:

- samples which are to be tested,
- number of samples to be tested,
- test procedures to be applied,
- pre-treatments including treatment of oversize particles (i.e. $d > 2$ mm),
- number of tests per stratum and number of duplicate tests,
- number of separate tests for the determination of a mean value,
- format of reporting,
- required supplementary classification tests for each test or series of tests.

(2) Disturbed soil samples may be used for the chemical tests, but particle size and water content need to be representative of the field conditions (Quality Class 1 to 3)

(3) For the determination of organic content, the particle size only needs to be representative (Quality Class 4).

(3)P Test specimen shall be representative of the original sample and field conditions.

(4)P The proper procedures of mixing, riffling and quartering shall be strictly followed in order to avoid inconsistent results.

6.1.4 Evaluation of test results

(1)P The test results shall be reviewed together with the geological description and the prevailing environment.

(2)P Where appropriate, account shall be taken of recognised classifications in terms of the parameter measured.

6.2 Organic content

6.2.1 Objective

(1) The organic content test is used to classify the soil. The organic content is determined from the loss on ignition (often denoted LOI), which is determined by ignition of a prepared specimen at a controlled temperature. Other suitable tests may also be used. For example, organic content may be determined from the mass loss on treatment with hydrogen peroxide (H_2O_2), which provides a more specific measure of organics.

(2) The presence of organic content can have undesirable effects on the engineering behaviour of soils. For example, the bearing capacity is reduced, the compressibility is increased, swelling and shrinkage potential is increased due to organic content. Gas may lead to large immediate settlements, affect the consolidation coefficients derived from laboratory tests and give misleading shear strength in total stress tests. Organic matter is detrimental in soils used for stabilisation for roads and is usually associated with low pH and at times with presence of sulphates which may give detrimental effects on foundations.

6.2.2 Requirements

(1)P The following shall be specified for each test or series of tests, in addition to items listed in 8.1.3:
- the drying temperature,
- the ignition temperature,
- the required corrections for bound water, carbonates, etc.

(2) Non-homogeneous samples require larger specimens and the appropriate apparatus. Correspondingly larger crucibles should be used.

(3)P The LOI shall be reported as a percentage of original dry matter, giving also drying temperature, ignition temperature and drying and ignition times.

6.2.3 Evaluation of test results

(1) In clays and silty soils with moderate organic content, the errors involved in the correction for bound water or carbonates may be so large that special testing methods are necessary.

6.3 Carbonate content

6.3.1 Objective

(1) The determination of the carbonate content is used as an index to classify natural carbonate soils and rocks or as an index to indicate the degree of cementation.

(2) Measurement of the carbonate content depends on the reaction with hydrochloric acid (HCl) which liberates carbon dioxide. It is assumed that the only carbonate present is calcium carbonate (CaCO3). Carbonate content is measured from the mass loss on treatment with HCl.

6.3.2 Requirements

(1) Non-homogeneous samples call for large initial samples. These should be crushed and riffled.

(2) A visual assesment is needed before the selection of the appropriate pre-treatment.

(3)P The carbonate content shall be reported as a percentage of the original dry matter.

6.3.3 Evaluation of tests results

(1) Some carbonates, e.g. dolomite, may not dissolve using the standard solution of hydrochloric acid during the specified time. Special methods are necessary for soil or rock types containing such carbonates.

6.4 Sulphate content

6.4.1 Objective

(1) The objective of the test is to determine the sulphate content as an index for the possible detrimental effect of the soil on steel and concrete. All naturally occurring sulphates, with rare exceptions, are soluble in hydrochloric acid. Some are soluble in water.

(2) The acid-soluble sulphate content is referred to as the total sulphate content, as distinct from the water-soluble sulphate content. It is important to appreciate which value is relevant.

(3) Ground water containing dissolved sulphates, especially sodium and magnesium sulphates, can attack concrete and other materials placed in the ground or on the ground surface. Classification of soil and ground water in terms of sulphate content is therefore necessary so that suitable precautionary measures can be taken, if required.

6.4.2 Requirements

(1)P It shall be specified for each test or group of tests, whether acid- or water-soluble sulphate is required for the test, in addition to the items listed in 6.1.3.

(2) Non-homogeneous soils containing visible crystals of gypsum require large samples, which should be crushed, mixed and riffled to provide representative test specimens. A visual assesment is needed before selecting the appropriate specimen preparation method.

6.4.3 Evaluation of test results

(1)P SO_3 or SO_4, shall be reported, as a percentage of dry substance or in g/dm^3, relating to acid- or water- soluble sulphate.

6.5 pH value (acidity and alkalinity)

6.5.1 Objective

(1) The pH value of ground water or solution soil in water is used to assess the possibility of excessive acidity or alkalinity.

6.5.2 Requirements

(1)P The following shall be specified for each test or group of tests, in addition to the items listed in 6.1.3:
- whether or not the soil shall be dried,
- the ratio of soil to water.

(2)P Standard buffer solutions shall be used for calibration of the pH meter.

(3)P The pH value of the soil suspensions or the groundwater shall be reported. The test method shall be stated.

6.5.3 Evaluation of test results

(1) The evaluation should consider that, in some soils, the measured values may be influenced by oxidation.

6.6 Chloride content

6.6.1 Objective

(1) The objective of the test is the determination of the water-soluble or acid-soluble chloride content so that the salinity of the pore water or soil can be assessed. The results provide an index for the possible effect of the ground water towards concrete, steel, other materials and soils.

6.6.2 Requirements

(1)P The following shall be specified for each test or group of tests, in addition to the items listed in 6.1.3:

- whether water-soluble or acid-soluble chlorides shall be determined,
- whether or not the soil shall be dried.

(2)P After drying the soil shall be mixed thoroughly, to redistribute any salts which may have migrated to form a surface crust.

6.6.3 Evaluation of test results

(1)P The chloride content in g/dm^3 or as a percentage by dry mass of the soil shall be reported. The test procedures used shall state whether water-soluble or acid-soluble chlorides have been determined.

7 COMPRESSIBILITY TESTING OF SOILS

7.1 Objective

(1) This prestandard covers the requirements for the oedometer incremental compression and swelling tests and for evaluating the collapse potential of a soil. The cylindrical specimen is confined laterally, and is usually subjected to discrete increments of vertical axial loading or unloading and is allowed to drain axially.

(2) The objective of the oedometer incremental compression and swelling tests is to determine the compression, consolidation and swelling characteristics of soils.

(3) The objective of the collapse potential test is to establish compressibility parameters for the soil in its unsaturated state, and to evaluate the additional compression upon inundation due to structural collapse of the soil.

7.2 Requirements

(1) For the determination of the compressibility of a stratum of clay, silt or organic soils, undisturbed samples (Quality Class 1) should be used.

(2) If samples of Quality Class 2 are tested, the effects of the sample disturbance should be considered in the interpretation of the results.

(3)P For recompacted specimens, the composition, density and water content of the prepared specimens relevant for the in-situ conditions and the specimen preparation method shall be specified.

(4)P When planning the determination of compressibility characteristics of a soil stratum, the following items shall be taken into account:

a) in field investigation:
   - existing results of field investigations,
   - existing settlement measurements from neighbouring sites ,
   - number and quality of samples,
   - number and type of field tests.

b) in laboratory testing:
   - storage of samples,
   - special consideration for sensitive and cemented samples,
   - number of specimens,
   - specimen preparation,
   - orientation of the specimen,
   - need for additional classification tests.

(5)P For complex loading or unloading conditions and/or for difficult subsoil conditions, carrying out of more advanced tests than the incremental oedometer test, for example constant rate of strain tests, shall be considered.

(6)P The initial vertical stress shall not exceed the in-situ vertical effective stress.

(7) For strain-softening clays, an initial stress of one fourth the in situ vertical effective stress is an appropriate value.

(8) In a compression test, the highest vertical stress shall be well in excess of the maximum effective vertical stress likely to occur in-situ. In a swelling test, the range of decrements of vertical stress to be applied during the test shall include the range of stresses likely to be applied in-situ.

(9)P When testing collapse potential, the test specimens shall be selected with adequate consideration of existing knowledge on the behaviour of the soil when subjected to inundation. Account shall also be taken of the type of proposed structure and its tolerance to local settlements. The stress on the specimen at which inundation is applied shall be related to the range of vertical stresses likely to occur in-situ.

(10) Annex A.7 provides a guideline for the minimum number of samples and tests for one stratum, as well as additional information on the test and its evaluation.

7.3 Evaluation of test results

(1) The interpretation of the oedometer test results with respect to compressibility is usually more reliable than the interpretation with respect to the time-dependent behaviour.

(2) The oedometer test results are used to estimate the preconsolidation stress for clays and silty soils. The estimation of the preconsolidation stress can be greatly affected by sampling disturbance, and should account for these effects.

(3)P The option of running a constant rate of strain oedometer test shall be considered.

(4) The constant rate of strain testing method is often preferable to the incremental loading approach. The method can be used at any time in lieu of the incremental test.

8 STRENGTH INDEX TESTING OF SOILS

8.1 Objective

(1) The purpose of strength index tests is to determine in a rapid and simple manner the undrained shear strength of clays. The shear strength so determined is only an approximate estimate.

(2) This prestandard covers the following strength index tests:
- laboratory vane,
- pocket penetrometer,
- fall cone,
- unconfined compression
- unconsolidated undrained compression tests.

8.2 Requirements

(1) Annex A.8 presents information of each of the strength index tests considered and a checklist on the test procedures for each test.

(2) The test specimens should be undisturbed (Quality Class 1).

8.3 Evaluation of test results

(1) The results should preferably be presented together with the soil description and the other soil classification tests.

(2) In general, the unconsolidated undrained compression test gives more reliable results than the other strength index tests.

(3) In general, strength index tests can only be used for design where well documented comparable experience with similar soils exists.

9 STRENGTH TESTING OF SOILS

9.1 Objective and scope

(1) The objective of the tests is to establish the effective strength parameters, pore pressure parameters and/or undrained shear strength.

(2) The triaxial compression test and two types of direct shear tests, the box shear and the ring shear tests are covered. For the direct shear tests, the results apply to loading under drained conditions only.

(3) This method applies to saturated soils only.

9.2 Requirements

(1) For the determination of the shear strength of clay, silt and organic soils, undisturbed samples (Quality Class 1) should be used. For certain soils or special purposes, tests can be carried out on reconstituted or remoulded specimens.

(2) If samples of Quality Class 2 are tested, the effects of the sample disturbance should be considered in the interpretation of the results.

(3)P For clays, the test specimens shall be as representative as possible of the in situ conditions.

(4) For silts and sands, the test specimens may be re-compacted. Care should be taken to select a preparation method that reproduces as closely as possible the structure and density relevant for the design at hand.

(5)P For re-compacted specimens, the composition, density and water content of the prepared specimens relevant for the in situ conditions and the specimen preparation method shall be specified.

(6)P For a strength test, the following shall be evaluated or specified:

- number of tests required,
- selection of location of test specimens in samples recovered,
- required quality of sample,
- specimen preparation method,
- orientation of specimen,
- type of test,
- classification tests that need to be done,
- test conditions (e.g. consolidation stresses, end-of-consolidation),
- time for consolidation increments,
- shearing rate,
- failure criteria,
- strain at which the test shall be stopped,
- acceptability criteria (e.g. saturation, scatter),
- accuracy of measurements,
- format for presentation of test results,

– any procedure used in addition to those referenced in an accepted standard.

(7)P The shear strength and the Mohr failure envelope of a sample shall be determined by a set of three tests, or more, under different normal effective stresses.

(8)P When planning the determination of the shear strength of a soil stratum, the following shall be taken into account:

a) in field investigation:
   - existing field and laboratory results from neighbouring buildings,
   - number and quality of samples,
   - number and type of field tests.

b) in laboratory testing:
   - storage of samples,
   - type of shearing for shear strength determination,
   - number of specimens,
   - specimen preparation method,
   - need for additional classification tests.

(9)P The test conditions shall be selected to duplicate as closely as possible the field conditions.

(10) Annex A.9 provides a guideline for the minimum number of samples and tests for one stratum, as well as additional information on the test and its evaluation.

9.3 Evaluation of test results

(1) The triaxial compression and direct shear tests provide commonly accepted strength parameters which may be relevant to routine design methods, but which are not necessarily applicable to other analyses.

(2)P The presentation of the test results shall include, where applicable:
- the effective stress path(s),
- the stress-strain curves,
- the pore pressure-strain curves,
- the pore pressure parameter.

(3) Mohr's circle(s) may be provided in addition to the effective stress path(s). Linear extrapolation of the test results may give erroneous values of the strength of a soil as the Mohr failure envelope is generally not a straight line, especially at low normal stresses.

(4)P The stress range over which the strength parameters in terms of effective stresses have been determined shall be given.

(5) There are several methods to obtain the stress-strain and strength parameters of soils in the laboratory and in situ. The results available from these different tests should be compared when evaluating the test results.

(6) The results should be evaluated taking into account the strain rate used for testing.

9.4 Consolidated triaxial compression test

9.4.1 Requirements

(1)P For a triaxial compression test, the following shall be evaluated or specified:

- saturation method and saturation criterion,
- back-pressure required,
- any procedure used in addition to those referenced in an accepted standard (e.g. lubricated ends, local measurements of strains or pore pressure).

(2)P For consolidated undrained triaxial tests, the pore pressure response requirements and the total stress path for shearing shall be specified.

(3)P For consolidated drained tests, the volume change device requirements and the stress path for shearing shall be as specified.

(4)P The minimum classification tests that need to be done in connection with triaxial testing include water content before and after the test and bulk density before and after the test.

(5) One Atterberg limit determination and particle size distribution should be done per set of triaxial tests in one stratum.

(6)P The results shall state clearly the type of test that was carried out, and which strength parameters (e.g. peak deviator stress, peak stress ratio) are quoted and the shearing testing rate and the failure criterion used to select the shear strength.

(7)P Uncertainties in the saturation of the test specimen shall be given in the report. Deviations in the testing procedures or in the testing equipment relative to the reference standard shall be clearly indicated in the report and, where relevant, on key graphs.

(8)P The option of running more advanced tests shall be considered. More advanced strength laboratory tests include the triaxial extension test, simple shear test, plane strain compression and extension test, true triaxial tests, directional shear test, all with the possibility of anisotropic instead of isotropic consolidation.

9.4.2 Evaluation of test results

(1) The interpretation of the test results should take into account that undrained shear strength, pore pressure parameters and stress-strain relationships are affected by sample disturbance to a greater extent than the strength parameters.

(2) Reliable stress-strain modulus values can only be obtained from anisotropically consolidated tests unless the coefficient of earth pressure at rest in situ is equal to unity.

9.5 Consolidated box and ring direct shear tests

(1)P The location and orientation of the specimen shall be considered carefully so as to duplicate as closely as possible the in situ conditions. In the box and ring shear tests, failure is forced to occur on or near a horizontal plane in the middle of the test specimen.

(2)P Negative or positive pore water pressures due to shear shall be avoided during the test as they cannot be measured and accounted for in the interpretation of the test. The rate of shearing must be slow enough so that pore water pressures may dissipate.

10 COMPACTION TESTING OF SOILS

10.1 Scope

(1) This prestandard covers compaction tests and the California Bearing Ratio test.

(2) Annex A.10 provides a guideline for the minimum number of samples specified to be tested for one stratum, as well as additional information on the test and its evaluation.

10.2 Compaction tests

10.2.1 Objective

(1) Soil compaction tests may be used to determine the relationship between dry density and water content when a given compactive effort is applied. The tests yield the optimum water content which corresponds to the maximum dry density for a specified compaction effort. Laboratory compaction tests provide the basis for specifying field compaction requirements.

10.2.2 Requirements

(1)P The following shall be specified or checked:

- quantity and quality of samples,
- handling of soils with oversize fractions,
- treatment of stiff cohesive soils,
- testing procedures to be applied,
- rigidity of base on which mould is placed during compaction,
- specimen preparation and maturing,
- equipment (moulds and rammers) used are as specified in the standard(s),
- compaction energy.

(3)P The option of carrying out in situ tests instead of laboratory tests shall be considered for special types of soils.

10.2.3 Evaluation of test results

(1)P The compaction characteristics of soils shall be reported together with grain size distribution curves, natural water content, Atterberg limits, density of solid particles, and proportion of oversize material by dry mass with correction, if appropriate.

10.3 California Bearing ratio (CBR) test

10.3.1 Objective

(1) The objective of the test is to determine the California Bearing Ratio (CBR) of a compacted or undisturbed sample. The CBR test is used to evaluate the potential strength of subgrade, subbase, and base course materials (including recycled materials) for supporting road, railways and airfield pavements. The CBR value obtained from this test is the basic parameter for the design of flexible pavements.

(2) The principle of the test is to establish the relationship between force and penetration when a cylindrical plunger of a standard cross-sectional area is made to penetrate the surface of the material.

10.3.2 Requirements

(1)P The following shall be specified or checked:

- quantity and quality of samples,
- method of preparation of each test specimen,
- how many tests are to be run in a set of test specimens,
- handling of soils with oversize fractions,
- maturing of specimens,
- whether or not specimen is to be subjected to soaking,
- if soaking is used, whether swelling is to be measured,
- surcharge to be applied for soaking and for testing,
- water content at which compacted specimens are to be prepared,
- specimen dry density or compactive effort,
- equipment (moulds and rammers) used is as specified in standard,
- whether or not the test is to be carried out on one end or both ends of the specimen.

10.3.3 Evaluation of test results

(1)P The CBR test results shall be reported together with grain size distribution, natural water content, Atterberg limits, density of solid particles, and proportion of oversize material by dry mass, if relevant.

(2)P Selection of the CBR values shall be made on the basis of engineering judgement and the evaluation of all relevant data.

11 PERMEABILITY TESTING OF SOILS

11.1 Objective

(1) The objective of the test is to establish the coefficient of permeability and/or hydraulic conductivity for water flow through water-saturated soil. Annex A.10 lists some of the methods.

11.2 Requirements

(1) For permeability tests on clay, silt or organic soils, only soil specimens of Quality Class 1 or 2 should be used.

(2) For clays, if specimens of Quality Class 3 are used for testing, re-consolidation to minimise the effects of sample disturbance should be considered.

(3) For sand and gravel materials, specimens of Quality Class 3 and remoulded or re-compacted soil samples may be used.

(4)P The clay, silt and organic specimens tested shall not only the have same particle size, and the same void ratio as the soil in situ, but shall also have the same stratification and shall be tested at the relevant stresses.

(5)P When planning the determination of the coefficient of permeability of a soil stratum, the following items shall be considered:

a) for field investigation
   - existing results of field and laboratory investigations,
   - existing measurements from neighbouring sites,
   - number and quality of samples,
   - number and type of in situ tests.

b) for laboratory testing
   - storage of samples,
   - preferable test type for permeability determination,
   - number of specimens,
   - specimen preparation,
   - orientation of the specimen,
   - need for additional classification tests.

(6)P For the conditions for which the test results are to be used, the following parameters relevant for the test shall be specified:

a) in clay, silt and organic soils:
   - stress conditions under which specimen is to be tested,
   - degree of accuracy of steady-state flow condition,
   - direction of flow through specimen,

- hydraulic gradient under which specimen is to be tested,
- need for back-pressure and required degree of saturation.

b) in sand and gravel:
- density index to which specimen is to be prepared,
- hydraulic gradient under which specimen is to be tested,
- need for back-pressure and required degree of saturation.

(7)P When selecting the hydraulic gradient, it shall be checked that the gradient in the laboratory test and the gradient in situ lie within the domain of application of Darcy's law. The hydraulic gradient in the laboratory shall be close to that in the field.

(8) It should be checked that the volume changes due to the consolidation of the specimen shall only negligibly affect the measured permeability.

(9)P The report shall indicate any deviations in degree of saturation of the test specimens, testing procedures used, composition of the specimen and any other aspect from the preferred testing procedure mentioned in Annex A.11.

(9) Annex A.11 provides a guideline for the minimum number of samples and tests for one stratum, as well as additional information on the test and its evaluation.

11.3 Evaluation of test results

(1)P The evaluation shall assess:

- the extent to which the boundary conditions (degree of saturation, direction of flow, hydraulic gradient, stress conditions, density and layering, side leakage and head loss in filter and tubings) affect the test results,
- how well these conditions match the situation in the field.

(2) For non-saturated soils, much smaller values may be relevant than the values measured for a saturated soil.

(3) Due consideration should be given to whether a temperature correction should be applied.

12 PREPARATION OF SPECIMEN FOR TESTING OF ROCK MATERIAL

12.1 Objective

(1) The objective of preparing specimens for testing of rock is to provide specimens that are as representative as possible of a rock formation.

(2) Annex A.12 provides more detail on the preparation of rock specimens for testing and some guidelines.

12.2 Requirements

(1)P It shall be specified how a rock specimen shall be prepared. If these specifications cannot be met, the specimen shall be prepared as near to the specifications as possible and it shall be reported how the specimen has been prepared.

(2)P All instruments and assemblies for determining straightness, flatness and perpendicularity of end surfaces shall be controlled on a registered regular time basis having tolerances satisfying at least the requirements of the specific rock tests.

(3)P The following shall be specified:

- storage conditions for rock samples (short term and/or long term storage),
- moisture condition of the test specimens at the time of the test,
- method for preparing rock core specimens,
- method for determining dimension and shape tolerances.

(4)P Any change in water content shall be avoided. If a change in the natural water content should occur, its effect shall be counteracted as part of the preparation for testing.

(5)P The need for recoring to a specified dimension shall be defined with reference to laboratory coring method, coolant applied and the need for re-saturation of the test specimens

(6)P Together with the data and results for the particular test, the following shall be recorded and reported:

- source of test specimen, including depth/level and orientation in space,
- dates of specimen preparation and testing,
- Comment on representativeness of specimen(s) tested,
- all dimension and shape measurements, including conformance with requirements,
- water content of the sample/specimen (as received, during preparation, saturated),
- conditions for drying (air- or oven-drying, pressurised or partial vacuum).

(7) The cause and effect of any change in water content should be reported.

12.3 Evaluation of test results

(1)P The results shall be presented in tabulated form or on bore hole logs.

(2)P The following information shall be given for the interpretation of the test results:

- physical description of the specimen including rock type (such as sandstone, limestone, granite, etc.), location and orientation of inherent rock structural features and any discontinuities, and inclusions or inhomogeneities,
- sketch of the test specimen or a colour photograph for other than monotonous homogeneous rock types,
- core Recovery and Rock Quality Designation, where possible,
- data to substantiate the tolerance checks on straightness of elements on cylindrical surface, flatness of end bearing surfaces and perpendicularity of end surfaces with respect to axis of core.

13 CLASSIFICATION TESTING OF ROCK MATERIAL

13.1 General

13.1.1 Objective

(1) Among the classification tests for rocks, the following test are included in this standard:

- rock identification and description,
- water content,
- density and porosity.

(2) Classification relates to the division of identified rock into specific groups or categories defined for particular civil engineering purposes. The classification is related to mineralogical components, structure, induration, rock density, water content, porosity and rock strength.

(3) Annex A.13 provides more details and guidelines on the classification test.

13.1.2 Requirements

(1)P When reporting the classification test results, the results shall be reviewed together, compared with drilling logs and corresponding geophysical logs and comparable experience.

(2)P The engineering geological model supported by the soil and rock classification shall be compared with all other available information: drilling logs, geophysical logs, photographs of cores and other available geological background information. The use of available geological maps is essential for the classification of rock and rock masses.

(3) A consistent description may require second opinion evaluations and the use of typical examples with rock comparisons.

13.2 Rock identification and description

13.2.1 Objective

(1) The method provides an identification and description of rock material and mass on the basis of mineralogical composition, predominant grain size, genetic group, structure, weathering and other components. The description may be carried out on cores and other samples of natural rock and on rock masses in situ.

13.2.2 Requirements

(1)P The following shall be specified:

- rock classification system,
- need for advanced geological analyses,
- format of reporting.

(2)P Rock identification and description shall be carried out on all samples received in the laboratory, regardless of rock homogeneity, as the identification and description constitutes the framework for all testing and evaluations.

(3)P The report shall comply with the specified rock classification system.

13.3 Water content

13.3.1 Objective

(1) Water content of rock is determined by oven-drying at (105 ± 5)º C.

13.3.2 Requirements

(1)P Measures shall be specified to retain water during sampling and storage.

(2)P The following shall be specified:

- selection of test samples,
- storage in the laboratory before testing,
- possible re-saturation of desiccated samples using vacuum saturation technique,
- number of tests per strata,
- number of tests to be run in parallel with other tests from the same formation,
- number of accuracy checks to be run.

(3) Ideally, at least 10 pieces of broken core, each with a mass of at least 50 g and a minimum dimension of ten times the maximum grain size, should be used. However, for many purposes 50 to 100 g per piece will be sufficient.

(4)P The report shall state whether the water content corresponds to the in situ water content.

13.3.3 Evaluation of test results

(1) Plausibility checks may be performed by comparing the water content with the fully saturated water content as a function of the density (or porosity) of the test specimen. Anomalous results should be investigated by repeated testing.

(2)P Comparisons with available correlations of water content and rock type shall be made.

13.4 Density and porosity

13.4.1 Objective

(1) The test measures the bulk and dry density to obtain the porosity and related properties of a rock sample.

13.4.2 Requirements

(1)P The following shall be specified:

- selection of test samples,
- storage before testing,
- whether desiccated samples are to be re-saturated and by which technique,
- number of tests per formation required,
- whether parallel tests are to be run on the same formation.

(2) At least three test specimens each with a mass of at least 50 g and a minimum dimension of ten times the maximum grain size should be tested. However, for many purposes 50 to 100 g per piece may be sufficient to establish a representative test specimen.

14 SWELLING TESTING OF ROCK MATERIAL

14.1 General

14.1.1 Objective

(1) Some rock materials, notably those with high clay content, are prone to swelling, weakening and disintegration when exposed to wetting and drying or unloading in an aqueous environment. A number of index tests for classifying and comparing rock specimens has been developed, with the following measurements:

- swelling pressure index under conditions of zero volume change,
- swelling strain index for radially confined specimen with axial surcharge,
- swelling strain developed in unconfined rock specimen.

(2) The index tests provide an indication to estimate resistance to swelling under well controlled conditions.

(3) The tests are usually done on softer rock materials like claystone and shale. The tests may be used for the characterisation of harder rocks subjected to weathering. Rocks that disintegrate during the tests should be further classified using relevant soil classification tests such as the shrinkage, liquid and plastic limits, particle size distribution and the type and content of clay minerals.

(4) Annex A.14 provides more details on each of the swelling tests and their interpretation as well as some guidelines.

14.1.2 Requirements

(1) The specimens should conform closely to the practice recommended for right cylinders or for rectangular prisms in Annex A.16. The sample size shall allow for preparation of test specimens by recoring and/or machining in a lathe, with the axis for one direction of the swell measurement perpendicular to a bedding or foliation.

(2)P The following shall be specified:

- selection of test samples,
- test specimen preparation, orientation and dimensions,
- numbers of test per formation required,
- test method, equipment and calibrations,
- water to be used (natural or distilled water, water chemistry),
- recording period,
- need for curves of swell pressure or displacement as a function of time elapsed since flooding,
- selection of required additional parameters,
- reporting requirements.

14.1.3 Evaluation of test results

(1)P The results shall be reviewed in the light of the description, and classification parameters shall be established.

(2)P The value used in design shall be derived from field experience with comparable rock types under similar climatic, loading and wetting conditions, but may be supplemented by the results of swelling index tests, provided that these results shall only be used as a guide for the evaluation of the in-situ properties.

(3) The short and especially long term weathering processes of swelling, weakening or disintegration due to wetting and drying may only be partly mirrored by the laboratory tests, even for similar conditions of loading and water content, because of the influence of among others natural fissuring, stress, drainage and pore water chemistry.

14.2 Swelling pressure index under zero volume change

14.2.1 Objective

(1) The test is intended to measure the pressure necessary to constrain an undisturbed rock specimen at constant volume when immersed in water.

(2) The test may be used to estimate the swell pressure in situ by comparison to documented experience for the rock stratum.

14.2.2 Requirements

(1)P The applied force to maintain to condition of zero volume change shall be corrected for the deformation in the test cell system itself (ball bearings, bedding of filter stones and filter paper towards the end platens) and the rock specimen under the appropriate stress conditions.

14.3 Swelling strain index for radially confined specimen with axial surcharge

(1) The test is intended to measure the axial swelling strain developed against a constant axial surcharge, when a radially confined undisturbed rock specimen is immersed in water.

(2) The test may be used to estimate the swell potential in situ by comparison to documented experience for the rock stratum. Depending on the applied vertical stress, the test provides background for the evaluation of the vertical heave or the lateral deformation of a rock/structure interface.

14.4 Swelling strain developed in unconfined rock specimen

(1)P The test is intended to measure the swelling strain developed when an unconfined undisturbed rock specimen is immersed in water. The test shall only be applied to specimens that do not change their geometry appreciably. It is advised that slaking, less durable rocks are more adequately tested using a confined swelling test.

(2) The test may be used to estimate the swell potential in situ by comparison to documented experience for the rock stratum. The report shall clearly indicate that the specimen was *not* radially confined during the swelling test.

15 STRENGTH TESTING OF ROCK MATERIAL

15.1 General

15.1.1 Scope

(1) This prestandard includes five laboratory methods for determining the strength of rock:

- uniaxial compression and deformability test,
- point load test,
- direct shear test,
- brazil test,
- triaxial compression test.

(2) Annex A.15 provides more detail on each strength test and its interpretation.

15.1.2 Requirements

(1)P The following shall be specified:

- the samples that are to be tested,
- specimen preparation,
- number of tests per formation,
- any required additional parameters.

15.1.3 Evaluation of test results

(1)P In the interpretation of the strength test results, the report shall include:

- comparisons with recognised data bases to help screen the data for anomalous results, while accounting for the natural range in compressive strength and deformation parameters in rock,
- correlations with the results of classification tests,
- all test results shall be grouped and analysed with respect to the geological description. Statistical methods shall be used to obtain the parameters required for design.

15.2 Uniaxial Compressive Strength and Deformability

15.2.1 Objective

(1) The uniaxial compression test measures the compressive strength of cylindrical test specimens of rock. The test is intended for strength classification and characterisation of intact rock.

15.2.2 Requirements

(1)P The following shall be specified in addition to the requirements in 15.1.2:

- specimen orientation and dimensions,
- testing method,
- if relevant, definition of modulus (tangent, average or secant) and Poisson's ratio as a function of stress or strain

15.2.3 Evaluation of test results

(1) For the evaluation of test results reference is made to 15.1.3.

15.3 Point load test

15.3.1 Objective

(1) The Point Load Test is intended as an index test for the classification of rock materials. The test results may also be used for estimating the strength of a group of rocks of the same range of competence. The point load test is not a direct way to measure rock strength but an index test. The correlation between point load test results and strength needs to be documented in each case.

(2) The test measures the Point Load Strength Index of rock specimens, and their Strength Anisotropy Index, which is the ratio of the Point Load Strengths in directions which give the greatest and least values.

15.3.2 Requirements

(1)P In addition to the requirements in 15.1.2, the testing methods with reference to cores, blocks and irregular lumps shall be specified.

15.3.3 Evaluation of test results

(1)P From the test data consisting of at least 10 single tests, the two highest and two lowest values shall be deleted before calculating the mean from the remaining.

15.4 Direct shear test

15.4.1 Objective

(1) The direct shear test measures peak and residual direct shear strength as a function of the stress normal to the plane of shearing.

(2) This pre standard deals with the laboratory testing for the determination of the basic shear strength parameters and the surface characteristics of a discontinuity that controls the shear strength. In the latter case, an accurate description should be done, including type and roughness of the joint, type and thickness of fill material, and presence of water in the joint.

15.4.2 Requirements

(1)P The following shall be specified in addition to the requirements in 15.1.2:

- test specimen orientation and dimensions,
- specifications of the testing machine,
- rate of shear displacement during test,
- selection of normal stress to be maintained during the single shear tests.

15.4.3 Evaluation of test results

(1) For the evaluation of test results reference is made to 15.1.3.

15.5 Brazil test

15.5.1 Objective

(1) The Brazil test is intended to measure indirectly the uniaxial tensile strength of prepared rock specimens.

15.5.2 Requirements

(1)P The specimen orientation shall be known.

(2)P The following shall be specified in addition to the requirements in 15.1.2:

- test specimen orientation and dimensions,
- testing method.

(3)P The variability of the test method calls for a duplicate testing of test specimens cut in parallel.

15.5.3 Evaluation of test results

(1) For the evalaution of test results refereence is made to 15.1.3.

15.6 Triaxial compression test

15.6.1 Objective

(1) The triaxial compression test is intended to measure the strength of cylindrical rock specimens subjected to triaxial compression. A number of tests provide the values necessary to determine the strength envelope. From this envelope, the angle of shearing resistance and the cohesion intercept may be determined.

(2) No provisions are usually made for drainage of the pore water, nor for the measurement of pore water pressure. In certain rock types (e.g. shales and porous limestone and chalk) and under certain conditions, the pore water pressure may influence the results. For such rock types advanced triaxial test systems allowing for measuring pore water pressure and volumetric strains are necessary. Such testing may include similar measuring techniques as used for uniaxial compressive strength in 15.1.

15.6.2 Requirements

(1)P The following shall be specified in addition to the requirements in 15.1.2:

- test specimen orientation and dimensions,
- testing method.

15.6.3 Evaluation of test results

(1) For the evaluation of test results reference is made to 15.1.3.

ANNEX A
(INFORMATIVE)
DETAILED INFORMATION ON METHODS AND TESTS

A.1 GENERAL

A.1.1 Scope

(1) This informative annex provides additional information for most of the aspects treated in the main text.

(2) A.2 presents details on the requirements applicable to all laboratory tests.

(3) In Annex B a bibliography is presented giving a list of standards that give examples of each laboratory test. The following list gives an overview of the subsection numbers and the tests treated in this annex. Annex A and Annex B have the same numeration system as the main text:

A.3 Calibration

A.4 Preparation of soil specimens for testing

A.5 Tests for classification, identification and description of soils
- A5.1 Water content
- A.5.2 Bulk density
- A.5.3 Particle density
- A.5.4 Particle size analysis
- A.5.5 Atterberg limits
- A.5.6 Density index test of granular soils
- A.5.7 Soil dispersibility
- A.5.8 Frost susceptibility

A.6 Chemical tests on soils and ground water
- A.6.1 Organic content
- A.6.2 Carbonate content
- A.6.3 Sulphate content
- A.6.4 pH (acidity and alkalinity)
- A.6.5 Chloride content

A.7 Compressibility testing of soils
- A.7.1 Incremental oedometer test
- A.7.2 Swelling test in oedometer
- A.7.3 Collapse test in oedometer

A.8 Strength index tests in soils
- A.8.1 Laboratory (hand) vane test
- A.8.2 Pocket penetrometer test
- A.8.3 Fall cone test
- A.8.4 Unconfined compression test
- A.8.5 Unconsolidated undrained compression test

A.9 Strength testing of soils
- A.9.1 Consolidated triaxial compression test
- A.9.2 Consolidated box and ring shear test

A.1.2 Abbreviations and notations

(1) The following notations have been used in this annex:

ASTM	American Society for Testing and Materials,
DGF	Dansk Geoteknisk Forening (Danish Geotechnical Society),
ETC	European Technical Committee,
LOI	Loss on ignition,
ISRM	International Society of Rock Mechanics,
ISSMFE	International Society of Soil Mechanics and Foundation Engineering.

A.2 REQUIREMENTS FOR ALL LABORATORY TESTS

A.2.1 General requirements

(1) Figure A.2.1 presents schematically the different steps of soil investigations, including laboratory and field work and the process of evaluating soil and rock parameters. The steps in figure A.2.1 are elaborated upon in the next paragraphs.

A.2.2 Testing programme

(1) Depending on the local ground conditions, the geology, the type and size of the structure and the geotechnical aspects of importance, one or more alternative ground profiles may be set up, to account for all relevant strata. The least favourable geometry should be considered.

(2) Strata in which soil and load parameters differ only slightly may be considered as one stratum. A sequence of fine layers with greatly differing composition and/or mechanical properties may be considered as one stratum if the overall behaviour is relevant, and the behaviour can be adequately represented by soil parameters selected for the stratum (DGF, 1995).

(3) The selection of samples to be used for preparing test specimens should be done carefully, based on an examination of available samples, the general nature of the soil and the site and the requirements of the project.

(4) The representativeness of the samples and test specimens should be established on the basis of classification tests.

(5) The laboratory testing programme depends in part on whether comparable experience exists. The extent and quality of comparable experience for the specific soil or for comparable soils should be established. Soil classification tests should be used to determine how well the soils compare. Geology should be considered to establish the expected non-homogeneity within comparable soils. The results of field observations on neighbouring structures, when available, should also be used.

(6) Whenever possible, allowances should be made for additional test specimens the case of difficult soils, damaged specimens and other factors.

A.2.3 Quality of soil samples

(1) For element tests on clays, silts and organic soils, the quality of soil samples to be used depends on the property to be determined and the test procedures used.

(2) For a fill or a stratum of sand or gravel, reconstituted specimens may in general be tested. Reconstituted specimens should have approximately the same composition, density and water content as in situ.

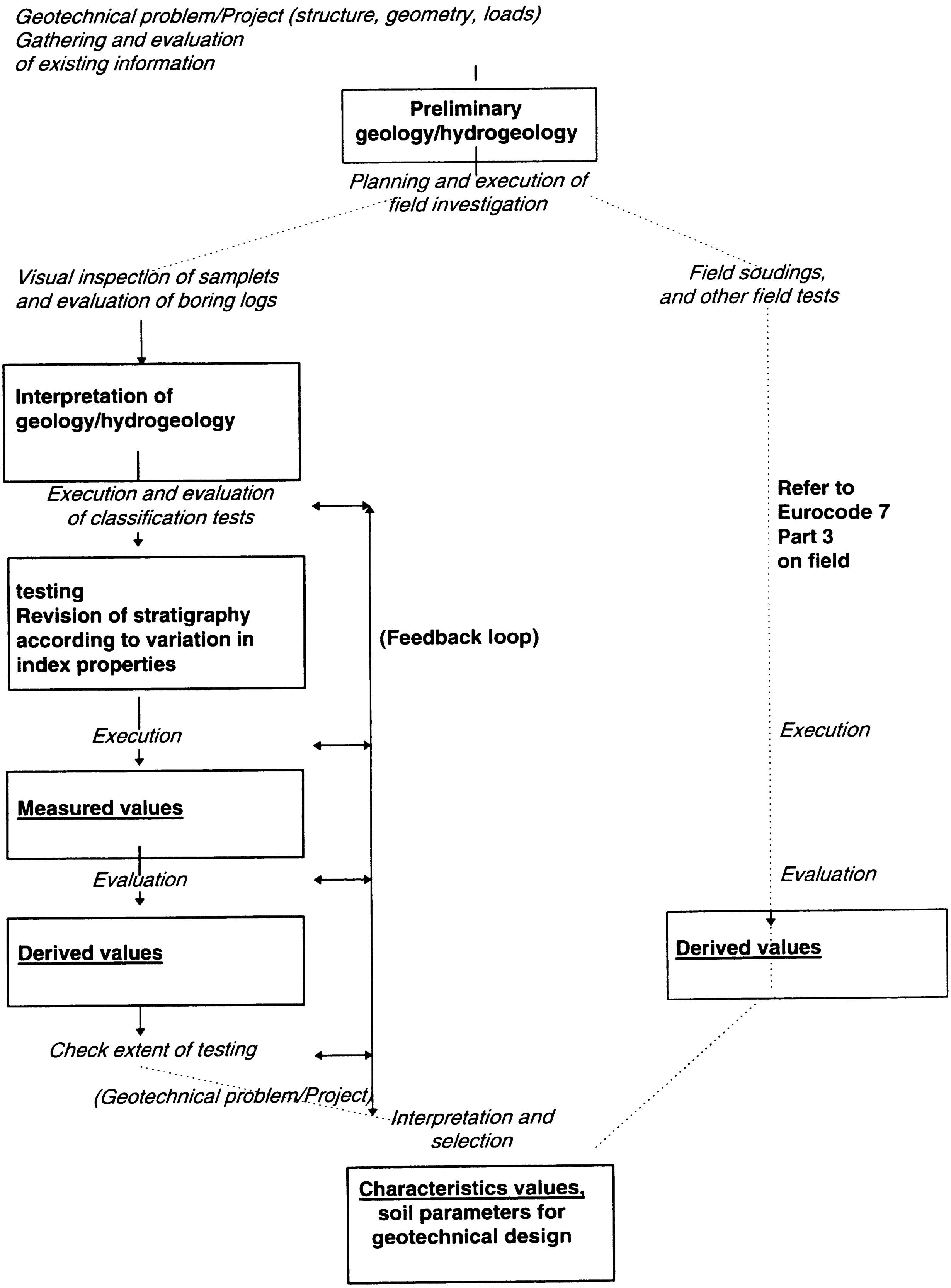


Figure A.2.1 Steps from soil investigation to selection of characteristic value, for given project, structure, geometry and loads.

A.2.3.1 Classification testing

(1) Soil classification tests should be run to determine the composition and the index properties in each soil stratum. The samples for the classification tests should be selected in such a way that the tests are approximately equally distributed over the complete area and the full depth of the strata relevant for design.

(2) If distinct and significant differences in the index properties between different portions of one stratum are found, the preliminary soil profile should be further subdivided.

(3) The results of the classification tests should be used to check if the extent of the investigations was sufficient or if a second investigation stage is needed (Fig. A.2.1).

(4) Classification tests should be used to check the representativeness of a specimen.

A.2.3.2 Test specifications

(1) When tests are to be carried out on undisturbed samples, the size of speimens to be prepared for testing should be specified, taking into account size of available samples, type of test equipment available, largest particles size present in the soil, presence of soil 'fabric' (especially discontinuities) and number of test specimens to be prepared.

(2) The details of the tests required to determine the relevant parameters needed for design should be specified.

(3) Each type of analysis requires particular parameters and it is not possible to provide parameters applicable to all types of geotechnical problems.

A.2.3.3 Number of tests

(1) The necessary number of specimens to be tested depends on the homogeneity of the soil, the quality and amount of comparable experience with the soil and the geotechnical category of the problem.

(2) The number of tests should be sufficient to give a reliable average value for design.

(3) Annex A.7 to A.17 suggest a minimum number of tests for each test type for projects of Geotechnical Category 2. This minimum number of element tests for a stratum supposes that the variability of the stratum has been investigated by a sufficient number of classification tests.

(4) The minimum required number of tests suggested in A.7 to A.17 may be reduced if the geotechnical design is not to be optimised and is done with conservative values of the soil parameters. The tables should be used to check whether the extent of the testing was sufficient.

A.2.4 Evaluation of test results

(1) The results of all tests (laboratory, field, descriptive records during boring) should be assembled and presented together. The data points representing the individual measurements of a test shall clearly refer to the testing method used.

(2) The results should be considered regarding plausibility. The measured values should be checked with values found in the literature, correlations with index properties and comparable experience.

(3) The characteristic value (see 2.4.3 of ENV 1997-1) is the result of the evaluation and interpretation of the test results, incorporating other laboratory tests, correlations, the results of field tests, knowledge of the geology and any other comparable experience with respect to the geometry of the problem and the type of loading (see Fig. A.2.1).

A.3 CALIBRATION OF TEST EQUIPMENT

A.3.1 General

(1) All measurements necessary for the performance of tests should be traceable, to standards of measurement through an unbroken chain of calibrations. The number of links in the chain of calibrations should be no greater than is necessary to achieve the required accuracy.

(2) Measuring instruments and test equipment should be calibrated or re-calibrated either by a national accredited external organisation, or in-house by the laboratory's own staff using calibrated reference standards.

(3) Annex B gives an overview of publicly available literature of the subject

A.3.2 Calibration of measuring instruments

(1) All calibrations should be carried out only by properly trained personnel. In the case of in-house calibrations they should be performed only by persons who have been authorised to undertake this work, and in accordance with written procedures.

(2) Reference standards and instruments used for calibration of working devices for performing tests should be of an accuracy greater than that of the working device so that the desired accuracy of test measurements can be achieved.

(3) The records of calibration should include the following points:

- name of the item,
- manufacturer's name, type and serial number,
- date received and date placed in service,
- condition when received (e.g. new; used; reconditioned),
- current location (where appropriate),
- date of each calibration, and by whom, with reference to calibration records,
- details of maintenance, modification, malfunction, misuse, damage or repair.

(4) Traceability of calibration should be established by means of a certificate of calibration for the relevant item, including the following information:

- name of the calibrating organisation,
- name and location of the organisation for whom calibrated,
- description and identification number of the instrument calibrated,
- method of calibration,
- equipment used for the calibration,
- calibration certificate number of the reference device,
- calibration temperature,

- calibration data and results,
- date of calibration,
- name and signature of the person carrying out the calibration,

(5) Routine re-calibration of measuring instruments should be carried out at intervals that are based on usage and on the analysis of calibration data, to ensure that the required accuracy is not lost between calibrations. The maximum intervals between re-calibrations should not exceed those given in Table A.3.1, regardless of usage and previous calibration history. The laboratory quality assurance system should give the calibration practice.

Table A.3.1 Maximum intervals between re-calibrations of measuring instruments

Physical quantity	Type of instrument	Maximum interval between re-calibrations
Mechanical instruments		
Mass	Balances Loose weights	6 months; daily check 1 year
Length	Steel rules Vernier calipers Micrometers	2 years 1 year 1 year
Displacement	Dial gauges	1 year
Volume	Volumetric glassware Volume-change indicators	1 year 2 years
Density	Soil hydrometers	Initial calibration only
Temperature	Thermometers Thermocouples	5 years 6 months
Time	Clocks and timers	1 year
Force	Load rings Hanger weights	1 year 2 years
Pressure	Pressure gauges	6 months
Electronic instruments		
Displacement Volume change Force Pressure	Electronic transducers	6 months, and function check before every test
Electrical noise, drift	Data acquisition systems	6 months
Processing and calculations	Computer-controlled systems	12 months

(6) Whenever a change of accuracy of an instrument is suspected, or when an instrument has been mishandled, repaired, dismantled, adjusted or overhauled, it should be re-calibrated before further use.

(7) Results of pre-use of interim checks (such as daily balance checks) should be taken into account when deciding the need to re-calibrate or increase re-calibration frequencies.

(8) Electronic devices should be calibrated together with the same read-out unit as is used for test measurements.

(9) Calibrations and checks should take into account the following:

- Checks for electrical noise and drift over periods corresponding to the duration of a typical test,
- Initial checks at the start of each test against mechanical measurements to ensure that transducers are functioning correctly,
- Verification that computer-controlled processes and calculations are done correctly.

A.3.3 Calibration and checking of test equipment

(1) Specifications for test equipment given in standards normally include permissible manufacturing tolerances on critical dimensions (such as linear measurement; mass). Working tolerances normally make allowance for changes in these dimensions as a result of wear in use. Unless stated otherwise, the maximum permissible working tolerances are twice the specified manufacturing tolerances. When the variation from a specified dimension exceeds this value, the equipment is no longer deemed to comply with standards and should be withdrawn from service.

(2) Checking and calibration requirements for test apparatus are summarised in Table A.3.2, which also includes the maximum intervals between re-calibrations or re-checks.

(3) Pressure systems and sample drainage systems (including volume change indicators) should be checked for leakage before starting each test. In addition, long-term pressure checks over periods equivalent to the duration of typical test stages should be carried out at intervals not exceeding 12 months.

(4) Calibration records should include the following points:

- name of the item,
- manufacturer's name, type and serial number,
- date received and date placed in service,
- condition when received (e.g. new; used; reconditioned),
- current location (where appropriate),
- details of any maintenance carried out,
- details of any adjustment, modification, malfunction, misuse, damage or repair,
- details of calibration checks, including dates,
- signature of the person making records.

Table A.3.2 Maximum calibration and checking intervals for test apparatus

Item	Calibration of checking operation	Maximum intervals between checks
Drying ovens	Calibrate temperature control Check temperature Verify temperature profile	1 year Daily Initially
Constant temperature bath	Calibrate temperature Check temperature	1 year Daily
Test sieves – perforated plate – woven wire	 Measure apertures Check against master set	 6 months* 3 months*
Fall cone	Check cone angle Check falling mass Point sharpness Freedom of movement Calibrate penetration gauge	Initially 1 year Every use Every use 1 year
Casagrande liquid limit device	Check drop Check grooving tool Check bearings for wear	Every use 1 week 3 months
Compaction moulds	Check dimensions	1 year*
Compaction rammers	Check mass and drop	1 year*
Vibrating hammers	Frequency and performance	1 year
Specimen moulds and formers	Check dimensions	1 year*
Cutting rings	Check condition Check dimensions and mass	Every use 1 month*
Shakers, stirrers	Inspect Check frequency	Every use 1 year
Oedometer press	Deformation under load	Initially, then 2 years
De-ionised water	Check indicated conductance Check pH and TDS	Every use 3 months
* Or after 400 uses, whichever occurs first		

A.3.4 In-house calibration

(1) For those working instruments that are to be calibrated in-house, the laboratory should hold suitable reference standards or instruments which are used solely for calibration and for no other purpose.

(2) Reference standards and instruments against which laboratory working instruments are calibrated should have certification of calibration provided by a suitably accredited organisation or a competent national body. Examples of instruments and other items that may be used as laboratory reference standards are summarised in Table A.3.3.

(3) Reference standards and instruments should be of an accuracy greater than that of the working device being calibrated. They should be re-calibrated by an accredited organisation at intervals not greater than those specified in Table A.3.3.

Table A.3.3 Examples of instruments used as reference standards

Physical quantity	Instruments	Maximum intervals between re-calibrations
Mass	Reference weights	2 years
Length and displacement	Gauge blocks Gauge bars	5 years
Temperature	Mercury-in-glass thermometer Thermocouple Platinum-resistance thermometer	5 years
Time	(Ref. to national telephone clock, or radio time signals)	- -
Force	Proving ring Electrical force transducer Hydraulic press using dead-weights	1 year
Pressure	Test grade pressure gauge Dead-weight tester	1 year
Grain size	Reference sieves	1 year

A.4 PREPARATION OF SOIL SPECIMENS FOR TESTING

A.4.1 Procedure

(1) Detailed procedures are being worked on by the Technical Committee 5 "Laboratory Testing" (ETC5) of the Regional European Society of Soil Mechanics and Foundations. Only part of the main points are reproduced herein.

A.4.2 Preparation of disturbed soil for testing

A.4.2.1 Drying of soil

(1) Soil should normally not be dried before testing, unless otherwise specified, but should be used in its natural state. When drying of soil is necessary, one of the following methods should be used:

- oven drying to constant mass in ventilated oven at a temperature of (105 ± 5) °C,
- partial oven drying in ventilated oven at a specified temperature less than 100 °C,
- air drying (partial) by exposure to air at room temperature, with or without a fan.

A.4.2.2 Disaggregation

(1) The extent of disaggregation to be applied, and the treatment of any remaining cementing material, should be related to the specific requirements and conditions, and should be specified. In particular, the disaggregation and the treatment should be done at the natural water content of the soil.

(2) Aggregations of particles should be broken down in such a way as to avoid crushing of individual particles. The action should be no more severe than that applied by a rubber-headed pestle. Special care is necessary when the soil particles are friable. If a large quantity of soil is to be prepared, disaggregation should be done in batches.

A.4.2.3 Subdividing

(1) Disaggregated soil should be mixed thoroughly before subdividing. The subdivision process should be repeated until representative samples of the specified minimum masses are obtained for use as test specimens.

A.4.2.4 Mass of disturbed soil for testing

(1) The minimum masses of disturbed soil required for testing are summarised in Table A.4.1. Where the minimum mass depends on the size of the largest particles present in significant quantity, this is related to the minimum mass required for sieving (denoted by (MMS) which is given below Table A.4.1.

(2) The required mass listed in Table A.4.1 allows for the preparation of one test specimen, with some allowance for wastage but not for the inclusion of over-size particles. When only the fine fraction of soil is required for testing, the prepared sample of the original soil shall be large enough to provide the specified mass of the desired fraction.

(3) When it is necessary to remove large particles from the initial sample in order to prepare test specimens, the size range and the proportion by dry mass of the oversize material removed should be recorded.

A.4.2.5 Preparation of soil for compaction

(1) Soil that is to be used for compaction-related tests should not be allowed to dry. If it is necessary to reduce the water content of the soil, this should be done by air drying.

(2) The upper limit of allowable particle sizes depends upon the size of the mould to be used. Particles larger than the sizes stated below should be removed before preparing the soil for testing (see Table A.4.3).

A.4.3 Preparation of undisturbed specimens

(1) The method of preparation of test specimens from undisturbed samples of soil depends on the type of sample and the type of specimen to be prepared.

(2) The approximate mass of soil required for typical laboratory test specimens is given in Table A.4.4 The stated mass is sufficient for one test specimen with some allowance for wastage due to trimming.

Table A.4.1 Mass of soil required for tests on disturbed samples

Test	Initial mass required	Minimum mass of prepared test specimen			
		Clay & silt	**Sands D <2 mm)**	**Gravelly soils (D = 2-10 mm)**	**Gravelly soils (D >10 mm)**
Water content	(at least twice specimen mass)	30 g	100 g	(MMS)	(0,3 x MMS) (500 g min.)
Particle density	100 g	10 g (particle size < 4 mm)			
Grain size					
Sieving	2 g·(MMS)	(MMS)			
Sedimentation		**Clay & silt**	**Sandy soils**		
- hydrometer	250 g	50 g	100 g		
- pipette	100 g	12 g	30 g		
Atterberg limits	500 g	300 g (particle size < 0.4 mm)			
Density index	8 kg	*			
Dispersibility	400 g	*			
Compaction	S / NS				
- "Proctor" mould	25 kg / 10 kg	*			
- "CBR" mould	80 kg / 50 kg	*			
CBR	6 kg	*			
Permeability**		*			
Diameter 100 mm	4 kg				
75 mm	3 kg				
50 mm	500 g				
38 mm	250 g				

notation:
- D — Largest particle diameter in significant proportion (10% or more by dry mass)
- S — Soil particles susceptible to crushing during compaction
- MMS — Minimum mass to be taken for sieving: see table A.4.2
- NS — Soil particles not susceptible to crushing
- * — Mass of specimen depends on soil behaviour during test
- ** — Permeability specimens with height equal to twice the diameter

Table A.4.2 Minimum mass for sieving

Largest particle diameter D [mm]	Minimum mass for sieving (MMS)
75	120 kg
63	70 kg
45	25 kg
37,5	15 kg
31,5	10 kg
22,4	4 kg
20	2 kg
16	1,5 kg
11,2	600 g
10	500 g
8	400 g
5,6	250 g
4	200 g
2,8	150 g
≤ 2	100 g

Table A.4.3 Allowable size of particles for compaction tests

Type of test		Maximum size of particle
Compaction	- in one-litre mould	20 mm
	- in CBR mould	37,5 mm
CBR determination		20 mm

Table A.4.4 Mass of soil required for tests on undisturbed samples

Type of test	Specimen dimensions		Minimum mass required [g])
	diameter [mm]	height [mm]	
Oedometer	50	20	90
	75	20	200
	100	20	350
Compression	35	70	150
-Unconfined	38	76	200
-Unconsolidated-undrained	50	100	450
-Triaxial	70	140	1200
	100	200	3500
	150	300	12000
Shear box	**Planar size**		
	60×60	20	150
	100×100	20	450
	300×300	150	30000
Density	**Largest particle size**		
(D = largest particle size*)	D = 5,6 mm		125
	D = 8 mm		300
	D = 10 mm		500
	D > 10 mm		1,4 (MMS)**

Notation: * D= Largest particle diameter in significant proportion (10% or more by mass).
** MMS = Minimum mass to be taken for sieving, as specified in Table A.4.1.

A.4.4 Preparation of recompacted specimens

A.4.4.1 General requirements

(1) Disturbed soil may be recompacted to form test specimens in accordance with either of the following criteria.

- Compaction using a specified compactive effort at a specified water content,
- Achieving a specified dry density at a specified water content.

(2) Clay soil that is to be recompacted to form test specimens should not be allowed to dry. If it is necessary to reduce the water content of the soil, this should be done by air drying. If it is necessary to add water in order to increase the water content, the water should be well mixed in and the soil should be allowed to stand in a sealed container for at least 24 hours before use.

(3) The soil should be broken down before recompaction as described in A.4.3.2.

(4) The upper limit of allowable particle sizes depends upon the size of the test specimen to be formed. Particles larger than the sizes stated below shall be removed before preparing the soil for recompaction (Table A.4.5).

(5) The particle size distribution of a recompacted specimen should be checked before and after compaction.

Table A.4.5 Allowable particle size as a function of size of test specimen

Type of test specimen	Maximum size of particle
Oedometer consolidation	H/5
Direct shear (shear box)	H/10
Compressive strength (cylindrical specimen with H/d of about 2)	d/5
Permeability	d/12
where H = height of specimen, d = diameter of specimen	

A.4.4.2 Recompacted sample larger than test specimen

(1) When preparing specimens for oedometer consolidation, direct shear or compressive strength tests, the soil should normally be compacted in the specified manner into a suitable mould that is of a larger size than the desired test specimen. The compacted sample should then be extruded from the mould and the test specimen should be prepared using the procedures described for undisturbed samples.

(2) Specimens for permeability tests may be compacted directly into the mould or container in which the test is performed.

(3) For compaction using a specified effort, the compactive effort applied should normally correspond to that used in one of the two types of compaction tests specified for the Compaction test (section 10 and A.10). Compaction should be applied in layers, and the top of each layer should be lightly scarified before adding the next.

(4) To obtain a specified density, the soil may be either compacted dynamically or compressed under a static load. Check weighings and volume measurements should be made after placing each layer to ensure that the desired density will be achieved. Preliminary trials may be desirable to establish the appropriate method.

(5) If clay is present in the soil the compacted sample should be sealed and stored for a curing period of at least 24 hours before extrusion to form test specimens.

A.4.4.3 Recompaction of test specimen

(1) For the preparation of small test specimens for direct shear, oedometer or compressive strength, the soil should be tamped, kneaded or compacted into the appropriate mould, ring or tube. A suitable hand rammer, or the Harvard compaction apparatus, or a kneading action, may be used. Care should be taken to avoid the formation of cavities within the specimen. The exact procedure required to obtain the desired density or compactive effort should first be determined by trial. Details should be recorded so that the procedure can be repeated to provide a number of specimens of consistent properties.

(2) Compaction of cylindrical test specimens of 100 mm diameter or more may be carried out using a compaction rammer. The number of layers and number of blows per layer should be specified.

(3) If clay is present in the soil, the compacted specimen should be sealed and tored for a curing period of at least 24 hours before use, to allow for dissipation of excess pore water pressures.

A.4.4.4 Re-saturation

(1) A re-compacted specimen will invariably be initially unsaturated. Re-saturation will normally be required before testing, and this shall be carried out by using one of the recognised saturation methods given in the test procedures for shear strength or compressibility tests. Full saturation should be confirmed by checking the B value.

A.4.4.5 Remoulded test specimen

(1) Remoulding can be achieved by sealing the soil in a plastic bag where it is squeezed and kneaded with the fingers for several minutes. A remoulded test specimen is formed by working the soil into the appropriate mould, e.g. by using a tamping rod. This operation should be carried out as quickly as possible to avoid change of water content, and without entrapping air. The specimen should then be extruded and trimmed by the appropriate method given in A.4.3.

A.4.5 Preparation of reconstituted specimens

A.4.5.1 Preparation of slurry

(1) The soil should be thoroughly mixed with water to form a homogeneous slurry of a water content above the liquid limit. Preparing the slurry should preferably start from the natural water content without drying of the soil. Drying of the soil and grinding it to a powder is however also an option. If necessary, coarser particles can be removed by wet sieving using an appropriate sieve. The mixing water may be either distilled or de-ionised, or of the appropriate chemistry. The slurry should be fluid enough to be poured; a water content about twice the liquid limit is usually satisfactory.

A.4.5.2 Consolidation

(1) The cell in which the sample is consolidated should be large enough to provide a test specimen, or a sample for trimming, of the required size after consolidation. Provision should be made for drainage of the sample, without allowing escape of soil particles.

(2) After pouring the slurry into the mould, initial consolidation should be applied under the weight of the top plate only, until the specimen ends are stiffened enough to prevent loss of material under further loading. The vertical stress applied for consolidation should be sufficient to enable the sample to be handled when consolidated, and should be maintained for long enough to ensure that consolidation is substantially complete.

A.4.5.3 Specimen preparation

(1) The consolidated sample should be extruded from the cell and trimmed as necessary for the preparation of a test specimen or specimens, using one of the methods described in A.4 for undisturbed samples.

(2) If one-dimensional consolidation tests are to be performed on the re-constituted soil, they may be carried out in the cell in which it has been consolidated from slurry.

A.5 TESTS FOR CLASSIFICATION, IDENTIFICATION AND DESCRIPTION OF SOILS

A.5.1 General

(1) Examples of how to perform tests for classification, identification and description of soils are given in the documents listed in Annex B.5.

A.5.2 Checklists for classification testing

(1) The number of specimens to be tested depends on the variability of the soil and the amount of experience with the soil and to a lesser extent than other soil tests on the geotechnical problem. Table A.5.1 gives guidance on the number of classification tests.

(2) Table A.5.2 presents a checklist for each of soil classification tests included in the document.

Table A.5.1 Suggested minimum number of samples to be tested in one soil stratum Classification tests for projects of Geotechnical Category 2

Classification test	Comparable experience	
	no	**yes**
Particle size distribution	4-6	2-4
Water content	All samples of Quality Class 1 to 3	
Strength index test	All samples of Quality Class 1	
Atterberg limits	3-5	1-3
Loss on ignition (for organic and clay soils)	3-5	1-3
Bulk density	Every element test	
Density index	As appropriate	
Particle density	2	1
Carbonate content	As appropriate	
Sulphate content	As appropriate	
pH	As appropriate	
Chloride content	As appropriate	
Soil dispersibility	As appropriate	
Frost susceptibility	As appropriate	

Table A.5.2 Checklist for soil classification tests

Classification test	Checklist
Water content	Check storage method of samples Co-ordinate testing programme with other classification tests Standard oven-drying method not appropriate for halloysite, montmorillonite, gypsum, organic soils; precautions may be needed Report presence of halloysite, montmorillonite, gypsum, organic soils For coarse soils, correction of measured water content may be needed Correction needed for saline soils
Bulk density	Test method needs to be selected Check sampling and handling methods used For large earthwork projects, method may need to be adapted, or use field method For sands and gravels, correction of measured density may be needed; use also field methods
Particle density	Sample preparation (oven-drying vs moist specimen) can influence results Check whether material can have enclosed pores; for such material, special techniques might be appropriate Report if material has enclosed pores If results fall outside the range of typical values, consider additional determinations; mineralogy and organic content will affect result
Particle size analysis	Selection of test method depends on particle size and gradation Carbonates and organic matter influence test results; for such materials, remove carbonates or organic matter if appropriate, or adapt testing method Check that correct quartering is used (particle size and sample representativeness)
Atterberg limits	Selection of test method for liquid limit; several methods are acceptable, but fall cone method is recommended as the preferable one Check storage method of samples Check specimen preparation, especially homogenisation and mixing Check whether drying has been used Drying can influence results dramatically, and should be avoided in oven Soils that oxidise should be tested quickly Results are not reliable for thixotropic soils
Density index for granular soils	Check storage method of samples Select test type to be used Results are very dependent on procedure used, and variability is high for sands with less than 10 % by weight fines Prepared specimens have high degree of non-uniformity
Soil dispersibility	Need to consider specifying different compaction conditions for specimens Avoid drying of the specimen before testing Need to select test procedures to use Need to run classification tests in addition
Frost susceptibility	---

A.5.3 Water content

A.5.3.1 Test procedures

(1) Examples of how to perform tests for classification, identification and description of soils are given in the documents listed in Annex B.5.

A.5.3.2 Evaluation of test results

(1) If the water in the soil is saline, the dissolved salts will remain in the soil after drying and may give an incorrect water content result. A more appropriate value is the «fluid content» i.e. the mass of fluid (water plus salts) per unit mass of dry soil.

(2) For a coarse soil, the water content obtained in the laboratory on a sample for which the maximum grain diameter is limited by the sample size, may differ from the in place water content. In such a case, the water content should be corrected as a function of the percentage of grains that are larger than the maximum grain diameter.

A.5.4 Bulk density

A.5.4.1 Test procedures

(1) Examples of how to perform tests for the bulk density of soils are given in the documents listed in Annex B.5.

(2) The linear measurement method is appropriate for cohesive soils only. For coarse-grained soils, density can normally be determined with sufficient accuracy from in situ tests, and more accurately from measurements on a frozen "undisturbed" sample.

(3) Table A.5.3 presents a guideline for the minimum number of tests required for one stratum of clay or silty soils. In the table, a specification of only one test represents a verification of the existing knowledge.

A.5.4.2 Evaluation of test results

(1) The test results should be checked by calculating the degree of saturation, which should not exceed 100%.

(2) For a coarse soil, the density of dry soil obtained in the laboratory on a sample for which the maximum grain diameter is limited by the sample size, may differ from the in place density of dry soil. In such a case, the density of dry soil should be corrected as a function of the percentage of grains that are larger than the maximum grain diameter.

Table A.5.3 Minimum number of soil specimens to be tested for one soil stratum Density tests for projects of Geotechnical Category 2

Variability in measured density	Comparable experience		
	None	Medium	Extensive
Range of measured density $> \approx 0{,}02$ g/cm^3	4	3	2
Range of measured density $< \approx 0{,}02$ g/cm^3	3	2	1

A.5.5 Particle density

(1) Examples of how to perform tests for the particle density of soils are given in the documents listed in Annex B.5.

(2) The volume of material necessary for the determination of soil particle density is very small (minimum of 10 g with particle size less than 4 mm). The specimen is usually extracted from a specimen used for another laboratory test.

(3) In porous materials with enclosed pores, the particles only have an apparent density. The density of solid particles should then be measured in the laboratory using a special technique.

(4) In the case of soil with organic materials, the laboratory testing should follow special procedures. Otherwise, the measured values should be used with caution.

(5) Modern methods such as the He-pycnometer may be applied. The methods should be calibrated against one of the methods more commonly used, for example the methods described in the documents listed in B.5.5.

A.5.6 Particle size analysis

(1) Examples of how to perform tests for the particle size analysis of soils are given in the documents listed in Annex B.5.

(2) For coarse-grained cohesionless soils (predominantly gravel and/or sand sizes), the particle size distribution of soils of this category is determined by sieving after washing, and sedimentation is not usually necessary. For fine-grained soils (predominantly silt and/or clay sizes), the sedimentation procedure is used, including sieving of any sand-sized particles. For mixed soils (containing all size ranges), both sieving and sedimentation procedures are used.

(3) In mixed-graded materials such as moraines, it is sometime difficult to obtain the necessary mass for particle size analysis in an exploration borehole. It is preferable to carry out the particle size analysis for masses slightly less than those given in A.3 rather than mixing non-contiguous samples from the same layer.

(4) Special care should be taken for tests on clays and organic soils. For example clay particles may have a cementing effect which can become irreversible during drying at 105 °C, organic matter becomes partly oxidised during drying at 105 °C.

(5) Modern methods that incorporate detection systems using X-rays, laser beams, density measurements, and particle counters may also be applied. They should be calibrated against the methods suggested in this subsection.

A.5.7 Consistency limits

(1) Examples of how to perform tests for the testing of consistency of soils are given in the documents listed in Annex B.5.

A.5.8 Density index test of granular soils

(1) Examples of how to perform tests for the testing of the density index of granular soils are given in the documents listed in Annex B.5.

(2) The recommended minimum number of soil specimens to be tested for one soil stratum for projects of Geotechnical Category 2 is 2 for the determination of the maximum density and 3 for the determination of the minimum density.

A.5.9 Soil dispersibility

A.5.9.1 General

(1) Some natural clayey soils disperse rapidly in slow moving water by colloidal erosion along cracks or other flow channels. Such soils are highly susceptible to erosion and piping. The tendency for dispersive erosion in a soil depends upon the mineralogy and chemistry of the clay, and the dissolved salts in the soil pore water and the eroding water. Dispersive clays are usually high sodium content soils.

A.5.9.2 Test procedures for all tests

(1) Examples of how to perform tests for the testing of soil dispersibility of soils are given in the documents listed in Annex B.5.

(2) Dispersibility tests are not applicable to soils with clay content of less than 10 % and with a plasticity index less than or equal to 4 %.

(3) The recommended minimum number of soil specimens to be tested for one soil stratum for projects of Geotechnical Category 2 is 2 for the pinhole test, 2 for the double hydrometer test, 2 for the soluble salts in pore water test and 3 for the crumb test. The specification of number of tests to be carried out should be based on engineering judgement.

A.5.9.3 Pinhole test

(1) Examples of how to perform tests for the Pinhole test can be found in the documents listed in Annex B. In case these examples are followed, the following points sould be considered.
It is recommended to follow the literature listed in Annex B, except that:
- the specimen should be compacted in a Harvard miniature mould at a water content close to the plastic limit,

- five layers should be used for the total specimen height of (38 ± 2) mm,
- a constant compaction effort on each layer should be applied such that the resulting dry density of the sample is equal to 95% of the maximum dry density determined in the laboratory from standard compaction test(s).

(2) The presentation of the results should include:

- results of classification tests,
- density of tested specimen,
- water heads used and testing time under each head,
- flow rates through specimen,
- cloudiness of flowing fluid at end of test
- hole size and shape after test,
- classification of soil according to standard reference.

A.5.9.4 Double hydrometer test

(1) The presentation of the results should include the grain size curves obtained with and without a dispersant solution and mechanical shaking/stirring, and the percentage dispersion.

A.5.9.5 Crumb test

(1) Presentation of the results should include the soil classification as dispersive or non-dispersive and details on the reagent used. Examples of such classifications are given in the documents listed in Annex B.5.

A.5.9.6 Sodium and dissolved salts in saturation extract

(1) Examples of test procedures for the determination of soluble salts in the pore water, are given in the documents listed in Annex B.5.

(2) The report should present the exchangeable sodium percentage obtained.

A.5.10 Frost susceptibility

A.5.10.1 Test procedures

(1) Examples of test procedures for the determination of frost susceptibility of soils are given in the documents listed in Annex B.5.

(2) A sample in its natural state can be obtained unfrozen in soft clayey and silty soil or frozen in clay, silt and sand (without gravel). If the sample size is not directly suitable for testing, the sample can be reshaped, doing this carefully.

(3) The sample that will be recompacted can be strongly remoulded as long as the grain size distribution is not modified by the sampling operation.

(4) The diameter of a specimen in its natural state should be at least five times the maximum grain size, and no less than 75 mm. For a reconstituted specimen, a minimum size of 150 mm should be used.

(5) Both a natural specimen and a reconstituted specimen may be saturated with back-pressure prior to the frost heave test.

(6) If a CBR test is needed, the test should be carried out on a specimen compacted at a water content close to the optimum water content, as determined from the compaction curve of a compaction test (see 12.2). The specimen should be compacted in a mould in successive layers, or in a gyratory compression device.

(7) Generally one CBR test is carried out per sample. However, several tests should be carried out to assess the influence of for example water content variations and compactive force.

A.5.10.2 Evaluation of test results

(1) A soil is deemed to be frost-susceptible if it exhibits segregational heaving in the frost heave test in the laboratory.

(2) The degree of frost action in clayey soils with low permeability is affected by the length of the winter season, i.e., the altitude and the latitude of the site considered. For these soils, the longer the winter, the more severe the frost action. This should be taken into account in northern and alpine countries.

A.6 CHEMICAL TESTING OF SOILS AND GROUNDWATER

A.6.1 General

A.6.1.1 Test procedures

(1) Examples of test procedures for the five chemical tests are given in the documents listed in Annex B.6. Equivalent methods also exist in other national standards and in textbooks.

(2) The above routine chemical tests utilise traditional testing methods which are within the capability of many geotechnical laboratories. Chemical tests for the presence of other substances should normally be performed by a specialist chemical laboratory.

(3) One hundred grams of dry soil is sufficient for most chemical testing. Usually a much larger sample of dried soil will be required at the outset, but a very small sample of dried soil is required for the specific testing. Thorough mixing of the initial sample, and correct sub-dividing procedures, are essential.

(4) Storage temperature before testing may influence the biological degradation of organic matter. Whenever possible, the sample material for chemical tests should be kept at a temperature of 5 to 10°C.

(5) Most test methods include a calibration routine using "blind" samples and reference samples. Electrochemical methods like pH have well defined calibration schemes with a number of solutions with known pH.

(6) Special requirements may call for deviations from the standard procedures, including specimen preparation. Any procedural deviations should be clearly reported, including the reasons for the deviations.

A.6.1.2 Number of tests

(1) The number of tests specified should take into account the fact that the organic content, carbonate content, sulphate content, pH value and chloride content can vary widely even within a geological stratum. Multiple tests on closely-spaced samples may be necessary to define the local variability.

A.6.2 Organic content

A.6.2.1 Test procedures

(1) Examples of test procedures for the determination of organic content are given in the documents listed in Annex B.6.

(2) The loss on ignition is normally determined on a representative sample of the soil finer than 2 mm as the mass lost by ignition of a prepared specimen at the specified temperature. The organic content is calculated on the assumption that the organic mass is totally burned by the ignition, and that the mass loss is only due to the ignition of the organic matter.

(3) The loss on ignition generally relates to the organic content of soils containing little or no clay and carbonates. For soils with higher percentage of clay and/or carbonate, factors unrelated to organic content could be responsible for the major proportion of the ignition loss.

(4) A drying temperature lower than the usual (105 ± 5) °C is necessary to avoid oxidation of some organic matter during drying. The example mentioned in A.6.2.1(1) specifies a drying temperature of (50 ± 2,5) °C, which might not remove all water. Check tests may be necessary to establish a suitable drying temperature.

(5) The ignition temperature specified in the example in A.6.2.1(1) is (440 ± 25) °C, but other standards specify temperatures up to 750 °C. Caution should be exercised when specifying ignition temperature, taking into account the following:

- some clay minerals can begin to disintegrate at temperatures of about 550 °C,
- chemically bound water may vanish at lower test temperatures; for example in some clay minerals, this can start at 200 °C, and gypsum disintegrates at from about 65 °C,
- sulphides may oxidise, and carbonates disintegrate, in the range 650 °C to 900 °C.

For most purposes, an ignition temperature of 500 °C or 520 °C would be appropriate.

(7) The drying and ignition periods should be sufficient to ensure that equilibrium has been achieved. If the period of ignition is less than three hours, the report should document that constant mass was confirmed by repeated weighing.

A.6.2.2 Evaluation of test results

(1) The quantity of organic carbon and organic matter can be related to loss on ignition, if the latter is corrected for other expelled constituents.

A.6.3 Carbonate content

A.6.3.1 Test Procedures

(1) Examples of test procedures for the determination of carbonate content are given in the documents listed in Annex B.6. This document contains two alternative procedures. For the purpose of this prestandard, the rapid titration method is the preferred procedure. This method should give results that are accurate enough for soils, provided that care is taken to ensure that the dissolution process is finalised, and that sufficient duplicate tests are performed.

(2) The documents listed in Annex B also give a gravimetric method[1)]. The rapid titration method for soils should give sufficient accuracy for soils, provided that care is taken for the dissolution process to be finalised, and that a large number of duplicate tests is performed.

(3) Other examples given in the documents listed in Annex B, determine the carbonate content by measuring the liberated carbon dioxide (CO_2) in a gasometer under controlled temperature and atmospheric pressure.

A.6.3.2 Evaluation of test results

(1) The carbonate content in percentage carbonate in the sample is expressed as the amount of CO_2. This is formally correct but impractical for design. The results may be given in equivalent calcium carbonate $CaCO_3$, i.e. the carbonate composition for most soil types. The amount of equivalent $CaCO_3$ is obtained from the amount of CO_2 by the

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1) similar to BS 1881: part 124 for hardened concrete

equation: $CaCO_3 = 2{,}273 \cdot CO_2$.

where: - $CaCO_3$ is the $CaCO_3$ content as percentage of dry weight,
- CO_2 is the CO_2 content as percentage of dry weight.

A.6.4 Sulphate content

A.6.4.1 Test Procedures

(1) Examples of test procedures for the determination of sulphate content are given in the documents listed in Annex B. The gravimetric method for analysis of acid or water extract or ground water, mentioned here is suggested as the preferred one, unless it can be shown by parallel analysis that an alternative method has equal or better accuracy.

(2) The crystalline form of calcium sulphate, gypsum ($CaSO_4 \cdot 2H_2O$), begins to lose its water of crystallisation at temperatures higher than about 65 °C, which can give rise to erroneously high measured water contents. Lower drying temperatures than normal should be specified for determination of water content.

(3) The relationship between SO_3 and SO_4 is given by $SO_4 = 1.2 \cdot SO_3$, with SO_3 and SO_4 contents expressed as a percentage.

A.6.4.2 Evaluation of test results

(1) The interpretation should consider that the solubility of calcium sulphate in water is low, but that in geological time, appreciable quantities can be dissolved, as occurs for example in karstic formations. Particular care is needed when results are marginal with respect to classification categories.

(2) Gypsum bearing samples ($CaSO_4 \cdot 2H_2O$) should be dried out at a temperature of 50 °C. At higher temperatures, partial dehydration of chemical bound water may cause erroneous results.

(3) The presence of certain other substances (notably sulphides and sesqioxides) can affect the chemical reactions, which then influence the test results. Sulphides in soil can oxidise in the long term to produce additional sulphates.

A.6.5 pH value (acidity and alkalinity)

A.6.5.1 Test Procedures

(1) Examples of test procedure for the determination of the pH value are given in the documents listed in Annex B.6. Several methods are available for determining values of pH. Of these, the electrometric method, which gives a direct reading of pH either in a prepared suspension of soil or in groundwater, is recommended as the definitive method.

A.6.5.2 Evaluation of test results

(1) Erroneous test results can be caused by:

- omitting or wrong calibration of the pH meter before and after each set of tests,
- inadequate protection of electrodes when the instrument is not in use,
- failure to allow the pH meter to reach a stable condition before taking pH readings,
- contamination due to inadequate washing of containers for sampling ground water.

A.6.6 Chloride content

A.6.6.1 Test Procedures

(1) Procedures for determination of chloride content include:

- Mohr's method for water-soluble chlorides,
- Volhard's method for acid-soluble or water-soluble chlorides,
- electrochemical procedures.

(2) The first two methods make use of the exchange reaction between the chlorides and silver nitrate, but different methods of analysis are used. Both methods require careful observation and weighing. The third method is based on the measurement of conductivity in dilutions of the sample with known water content.

(3) The presence of chlorides can be confirmed from a quick qualitative test: take about 5 ml of filtered groundwater, or of 1:1 soil-water extract, in a test-tube. If this is highly alkaline (pH 12-14), add a few drops of nitric acid to acidify it. Add a few drops of 1% silver nitrate solution. Appreciable turbidity indicates that chlorides are present in a measurable quantity, which can be determined from one of the test procedures.

(4) Volhard's method is the basis of the tests given in British standard BS 1377:Part 3[2] subclause 7.2 (water-soluble chlorides) and subclause 7.3 (acid-soluble chlorides), and of the method given in BS 812: Part 118 for mineral aggregates. In principle, an excess of silver nitrate solution is added to the acidified chloride solution and the unreacted portion is back-titrated with potassium thiocyanate, with ferric aluminum used as an indicator.

(5) In Mohr's method, the test solution and a blank for comparison are each titrated with 0,02 N silver nitrate solution, potassium chromate being used as an indicator. This method is preferable for determining chlorides in ground water.

A.6.6.1 Evaluation of test results

(1) The theoretical relationship between salinity expressed as sodium chloride content and chloride content may not hold due to the very mobile nature of the chloride anion.

A.7 COMPRESSIBILITY TESTING OF SOILS

A.7.1 Test procedures

(1) Examples of test procedure for the testing of compressibility of soils are given in the documents listed in Annex B.7.

(2) For undisturbed samples of normally or lightly overconsolidated cohesive soils, one loading-unloading cycle is normally sufficient to determine the compressibility. With more heavily overconsolidated soils which have been affected by sample disturbance, a preloading cycle should be done to reduce deformations due to sample disturbance, bedding effects and horizontal stresses less than in situ.

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2) see Annex B Bibliography

A.7.2 Number of tests

(1) For a soil stratum which contributes significantly to the settlement of a structure. Table A.7.1 gives a guideline for the minimum number of tests required as a function of the variability of the soil and the existing comparable experience with the type of soil.

(2) The number of specimens tested should be increased if the structure is very sensitive to settlements. In Table A.7.1, a specification of only one test represents a verification of the existing knowledge. If the new test results do not agree with the existing data, additional tests should be run.

Table A.7.1 Minimum number of soil specimens to be tested for one soil stratum Incremental oedometer test for projects of Geotechnical Category 2

Variability in oedometer modulus E_{oed} in relevant stress range	**Comparable experience**		
	None	**Medium**	**Extensive**
Range of values of E_{oed} > ≈50%	4	3	2
≈20% < Range of values of E_{oed} < ≈50%	3	2	2
Range of values of E_{oed} < ≈20%	2	2	1*
*One oedometer test and classification test are sufficient to verify compatibility with comparable knowledge			

A.7.3 Evaluation of compressibility characteristics

(1) There are four widely used methods to determine the compressibility of a soil:

- back-calculations of measured settlements,
- empirical evaluation of indirect in situ tests such as soundings,
- direct measurements by in situ tests, such as plate load and pressuremeter tests,
- compression tests with soil samples in the laboratory.

The evaluation of the coefficient of permeability can be optimised by a combination of these methods.

(2) The most reliable method to assess the compressibility characteristics of a soil is the back-calculation from measured settlements under comparable stresses. For foundations on sand and gravel, field tests such as soundings are often used: these are interpreted empirically, most often based on comparable experience. In cases where sands, coarser soils, silts and clays are expected, a combination of field and laboratory methods is desirable.

A.8 STRENGTH INDEX TESTING OF SOILS

(1) Examples of test procedures for the following strength index tests:

- laboratory vane,
- pocket penetrometer,
- fall cone, unconfined compression test,
- unconsolidated undrained compression test.

are given in the documents listed in Annex B.8.

(2) Table A.8.1 suggests a summary checklist on the test procedures for the engineer for each of strength index tests included for soils included in this prestandard.

(3) The tests are applicable to clayey soils only.

Table A.8.1 Checklist for strength index tests on clayey soils

Strength index test	Checklist
All strength index tests	Tests provide approximate index of shear strength There is a large uncertainty in the measurements Use results cautiously for non-homogeneous and jointed/slickensided soils All results are affected by the applied testing rate Test repeatability needs to be checked
Laboratory vane	Test provides in addition a measure of sensitivity and remoulded shear strength Check mode of rotation (hand-operated vs motorised) Tests can be performed on extruded samples or in sampling tube
Pocket penetrometer	Test specimen should be stripped of weathered dried zones Push loading piston slowly, perpendicularly and at constant speed Do as many test repetitions as possible Check that zone tested is representative by checking material under piston imprint
Fall cone	Test can be performed on extruded samples or in sampling tube Provides in addition a measure of sensitivity on remoulded specimen Check wear on tip of cone Check tip cone angle
Unconfined compression	Unconfined compression strength is twice the undrained shear strength Avoid delays between trimming and testing to prevent drying out of specimen Use only soft clays samples that maintain water content and with sufficient capillarity to keep internal effective stresses constant
Unconsolidated-undrained compression	Soil specimen should not be given access to water; pore pressures should not be measured as this would expose the specimen to water

A.9 STRENGTH TESTING OF SOILS

A.9.1 Consolidated triaxial compression test

A.9.1.1 Test procedures

(1) An example of a test procedure for the consolidated teaxial compression test is given in the document listed in Annex B.9. Other documents with description of procedure exist.

(2) Multistage tests can be run only if lubricated ends or large height to diameter ratios are used. Multistage tests are generally not recommended.

A.9.1.2 Number of tests

(1) Table A.9.1 gives guidelines for the minimum number of tests required as a function of the variability of the soil and existing comparable experience with the type of soil. If only one test set is required, the test is run to provide a verification of existing knowledge. If the new test results do not agree with the existing data, more tests should be run.

(2) The number of tests may be reduced if shear stress data are available from other testing methods, for example, field tests.

A.9.1.3 Evaluation of test results

(1) In addition to a factual evaluation, the engineer should include the undrained shear strength characteristics and correlations as a function of soil type, plasticity index, etc. The undrained shear strength evaluations should be related to the type of test that produced the results.

(2) The angle of shearing resistance should be checked against correlations as a function of for example soil type and density index in the case of sands. Comparisons of the angle of shearing resistance measured and the in situ stress conditions (e.g. axi-symmetrical vs plane strain conditions) should be carefully considered and in relevant cases, the angle of shearing resistance should be adjusted. Relations with for example the results of cone penetration tests and existing correlations with angle of shearing resistance should also be included.

Table A.9.1 Minimum number of soil specimens to be tested for one soil stratum Triaxial compression tests for projects of Geotechnical Category 2
(one recommended test means set of 3 individual tests)

Tests to determine effective friction angle

Variability in strength envelope	Comparable experience		
Coefficient of correlation *r* on regression curve	None	Medium	Extensive
$r \leq 0{,}95$	4	3	2
$0{,}95 < r \leq 0{,}98$	3	2	1
r 0,98	2	1	1

Tests to determine undrained shear strength

Variability in undrained shear strength	Comparable experience		
(for same consolidation stress)	None	Medium	Extensive
Ratio max/min values > 2	6	4	3
1,25 < Ratio max/min value ≤ 2	4	3	2
Ratio max/min value ≤ 1,25	3	2	1

A.9.2 Consolidated box and ring direct shear tests

A.9.2.1 Test procedures

(1) Examples of procedures for direct shear testing are given in documents listed in Annex B.9

(2) For the shear box test, a testing device where the two halves of the shear box move exactly in parallel should be used to prevent tilting. Only shear boxes that control parallelism will give a correct simulation of the in situ shearing in shear bands. Non-parallel plates can lead to effective friction angles as much as 4° higher in clay soils, and as much as 6° lower in sands (see Wernick, 1979).

A.9.2.2 Planning of the test programme

(1) The direct shear (box or ring shear) test is run preferably for soils and stability conditions where a distinct rupture plane is expected to develop or when the strength characteristics of an interface are to be determined.

(2) Comparative studies show that the test results of direct box and ring shear tests are in good agreement. In the shear box test, the preparation of the specimen is easier. In the ring shear test, the stresses are more homogeneous, but the strains are not uniform. It is easier to produce large strains and thus determine the residual strength of a soil in the ring shear apparatus than in the shear box apparatus.

(3) Twice as much material as needed for the number of specimens tested should be taken from the stratum.

A.9.2.3 Number of tests

(1) Table A.9.2 gives a guideline for the minimum number of tests required as a function of the variability of the soil and existing comparable experience with the type of soil. The recommendation applies to the case when direct shear tests are used alone to determine the shear strength of a soil stratum.

Table A.9.2 Minimum number of soil specimens to be tested for one soil stratum Direct shear tests for projects of Geotechnical Category 2
(one recommended test means set of 3 individual tests)

Variability in strength envelope Coefficient of correlation on regression curve	**Comparable experience**		
	None	**Medium**	**Extensive**
Coefficient of correlation < 0,95	4	3	2
0,95 ≤ Coefficient of correlation < 0,98	3	2	2
Coefficient of correlation ≥ 0,98	2	2	1*
*A single test and classification tests are sufficient to verify compatibility with comparable experience			

A.10 COMPACTION TESTING OF SOILS

A.10.1 Test procedures applicable to both test types

(1) Exaples of test procedures for compaction testing of soils ear given in the documents listed in Annex B.10

(2) The minimum number of soil specimens to be tested for one soil stratum for projects of Geotechnical Category 2 is 3. The number of tests specified should be based on engineering judgement.

(3) The number of tests to be carried out should be selected considering the variation of the particle size distribution, the Atterberg limits and the quantity of material to be compacted. For dams, road construction etc., in standards the number of tests to be run for different specific situations may be found.

A.10.2 Requirements specific to compaction tests

(1) The most frequently used compaction tests are the Standard and the Modified Compaction Tests.

(2) Some highly permeable soils such as clean gravels, uniformly graded and coarse clean sands do not yield a well defined maximum density. Therefore an optimum water content might be difficult to obtain.

(3) For stiff cohesive soils which need to be shredded, or chopped into small lumps, suggested methods are to shred the soil so that it can pass through a 5 mm test sieve, or to chop it into pieces to pass a 20 mm test sieve.

(4) For stiff cohesive soils which need to be shredded or chopped into small lumps, the results of a compaction test depends on the size of the resulting pieces. The densities obtained from the test will not necessarily be directly related to densities obtained in-situ.

(5) For soils not susceptible to crushing, only one sample may be used for testing. The sample can be used several times after increasing progressively the amount of water. The departure from the common procedure should be mentioned in the report.

(6) For soils containing particles that are susceptible to crushing, separate batches at different water contents should be prepared.

A.10.3 Requirements specific to California Bearing Ratio (CBR) test

(1) In situ tests may be carried out, but the laboratory test is the definitive procedure.

(2) Tests may be carried out on either undisturbed or recompacted material.

(3) The moisture content of the soil should be chosen to represent the design conditions for which the test results are required.

(4) The CBR test should be carried out on material passing the 20 mm test sieve. If the soil contains particles retained on the 20 mm sieve, these particles should be removed and weighed before preparing the test specimen. If the fraction retained on the 20 mm sieve is greater than 25 % by mass of the fraction passing the 20 mm sieve, the CBR test is not applicable.

(5) Where a range of water contents is to be investigated, water should be added to or removed from the natural soil after disaggregation. The sample should not be allowed to become dry.

A.11 PERMEABILITY TESTING OF SOILS

A.11.1 Test procedures

(1) Examples of procedures for testing of permeability of soils are given in the documents listed in Annex B.11.

(2) Twice as much material as needed for the number of specimens to be tested should be taken from the stratum.

(3) The specimens to be tested should be selected to represent the extremes in relevant soil properties, i.e. composition, density index, void ratio, etc.

(4) As a guideline, the hydraulic gradient in clays and silts should be less than 30 and less than 10 in sand.

(5) Depending on soil type and required accuracy of coefficient of permeability, the required degree of saturation in the permeability test should be considered.

A.11.2 Number of tests

(1) Table A.11.1 gives a guideline for the minimum number of tests required as function of the variability of the soil and existing comparable experience with the type of soil.

Table A.11.1 Minimum number of soil specimens to be tested for one soil stratum Permeability tests for projects of Geotechnical Category 2

Variability in measured coefficient of permeability [*k*]	Comparable experience		
	None	Medium	Extensive
$k_{max}/k_{min} > 100$	5	4	3
$10 < k_{max}/k_{min} \leq 100$	5	3	2
$k_{max}/k_{min} \leq 10$	3	2	1*

*A single test and classification tests are sufficient to verify compatibility with existing knowledge.

(2) In Table A.11.1, a specification of only one test represents a verification of the existing knowledge. If the new test results do not agree with the existing data, additional tests should be run.

A.11.3 Evaluation of test results

(1) There are four widely used methods to determine the coefficient of permeability (hydraulic conductivity):

- field tests, such as pumping and borehole permeability tests,
- empirical correlations with grain size distribution,
- evaluation from an oedometer test,
- permeability tests on soil specimens in the laboratory.

The evaluation of the coefficient of permeability can be optimised by a combination of these methods.

(2) Even in a homogeneous soil stratum, there can be a large variation in the coefficient of permeability due to small changes in stresses, void ratio, structure, particle size and bedding. The most reliable method to obtain a value of the coefficient of permeability is a field testing method.

(3) Even in a homogeneous soil stratum, the coefficient of permeability of a soil layer should be described by upper and lower limit values.

(4) For silts and clays, the derivation of the coefficient of permeability from incremental oedometer test results only gives an approximate estimate.

(5) In homogeneous sand, the coefficient of permeability may be assessed in a reasonably accurate manner from correlations with the grain size distribution.

(6) For clay, silt and organic soils where undisturbed samples of high quality can be obtained, laboratory tests may give reliable test results. The representativeness of the specimens tested should be carefully checked.

(7) For some types of soil, the degree of saturation may influence the coefficient of permeability up to as much as three orders of magnitude.

A.12 PREPARATION OF SPECIMEN FOR TESTING ON ROCK MATERIAL

(1) The ISRM Suggested Methods for Rock Characterisation, Testing and Monitoring do not contain a specific requirement for preparation of rock specimens. However, most of the test methods contain a section on preparation of samples, with requirements on sample volume, sample quality, preparation method, specific dimensions and tolerance checks on dimensions and shape.

(2) Examples of the common practice for preparing rock core specimens and determining dimensional and shape tolerances are given in the document listed in Annex B.12. In the following, extracts of, and comments on these documents are given.

(3) It is not always possible to obtain or prepare rock core specimens which satisfy the desirable criteria given in the ISRM suggested methods, for example for weaker, more porous, and poorly cemented rock types and rock types containing structural features.

(4) All instruments and assemblies for determining straightness, flatness and perpendicularity of end surfaces shall be controlled on a registered regular time basis having tolerances satisfying at least the requirements of the specific rock tests.

(5) Most unfractured cores taken by single tube, double tube or triple tube core barrel using rotary drilling techniques can be used with or without recoring after a trimming of the end bearing surfaces. Blocks collected directly from a rock formation may also be used, if the orientation of the block is clearly indicated on the sample that will be used for recoring the test specimens.

(6) The required sample volume depends on the test programme. For many purposes, samples 300 mm to 1000 mm long with a diameter greater than 50 mm should be sufficient for preparing rock specimens for a group of classification, strength and deformation tests.

(7) The required quantity of cores depends highly on the natural and induced fissuring of the rock material. The initial description of the core should include an evaluation of the degree of fissuring and homogeneity. This description should be used when selecting the core sections for testing.

(8) Selection of test specimens from zones of the core without fractures may lead to non-representativeness of the test specimens for the formation. This should be taken into account in the reporting.

(9) For weaker rocks (sedimentary rocks), the sample treatment is extremely important for deformability, strength and swelling tests. The rock samples for such tests should be packed in the field as soon as obtained from the core barrel. Even a short exposure may change the water content and the inherent properties of the rock.

A.13 CLASSIFICATION TESTING OF ROCK MATERIAL

A.13.1 General

(1) Examples of tests for the classification of rock are given in the documents listed in Annex B.13.

(2) Nationally and internationally recognised classification systems exist for different purposes. Rock mass classification systems, based on semi-numerical methods, exist for engineering purposes as summarised by Bieniawski (1989) «Engineering Rock Mass Classification».

(3) The classification of the rock mass based on cores calls for the highest possible core recovery to identify discontinuities and possible cavities. The disturbance of the core from the drilling process should be minimised since most rock quality designations relate to the fractures found in the cores.

(4) Most classification systems relate to cores and rotary drilling samples with a sample diameter of at least 50 mm. For most tests, a non-fractured core length of 50 mm to 200 mm long is sufficient for element testing.

A.13.2 Rock identification and description

(1) Examples of test procedures are given in the documents listed in Annex B.13.

(2) Any published and locally approved classification system may be used, provided the report gives a traceable reference.

A.13.3 Water content

A.13.3.1 Test procedures

(1) The test procedures may follow the examples given in the documents listed in Annex B.13.

(2) If specified, accuracy checks should be carried out by comparing results on specimens taken in parallel within the same formation.

A.13.3.2 Number of tests

(1) In general, the water content should be taken at least one per metre of core.

A.13.4 Density and porosity

A.13.4.1 Test procedures

(1) The test procedure may follow the examples given in the documents listed in Annex B.13.

(2) The determination of the porosity (or void ratio) calls for a determination of the density of solid particles (or an estimate of it based on local experience with similar rock type).

(3) The existence of closed pores may influence the porosity. Determination of the total pore volume may be based on the density of solids of a powdered sample, however the determination of the amount of open and closed pores calls for specialised analysis.

(4) Methods using mercury displacement should be avoided.

A.13.4.2 Number of tests

(1) The density and porosity shall be determined once at least every two metres, and at least once for each differentiated rock type unit, regardless of the rock homogeneity. The density/porosity parameters represent part of the framework for most evaluations of rock strength and deformation properties.

A.14 SWELLING TESTING OF ROCK MATERIAL

A.14.1 General

(1) Examples of tests for swelling of rocks are given in the documents listed in Annex B.14.

(2) Undisturbed rock specimens should preferably be tested where possible, since rock fabric has an important effect on swelling characteristics. Where the sample is too weak or too broken to allow preparation, such as joint fill material, the swelling index tests may be carried out on remoulded and recompacted specimens. The procedures used should then be described in the report.

(2) Table A.14.1 gives a guideline for the minimum number of swelling tests required for different specimen dimensions. The suggestions apply for sites with a limited risk of occurrence of swelling rock types. For sites with rock types more likely to be subject to swelling, the number of tests should be increased to at least the double of the numbers given in the table. Other advanced tests may be better suited to determine the in situ swelling performance.

A.14.2 Swelling pressure index under zero volume change

(1) Examples of tests for the swelling pressure index under zero volumechange are given in the documents listed in Annex B.14.

(2) The testing apparatus may often be an ordinary oedometer cell for soil consolidation.

A.14.3 Swelling strain index for radially confined specimen with axial surcharge

(1) Examples of tests for swelling strain developed in an unconfined rock specimen are given in the documents listed in Annex B.14.

(2) The example specifies a loading device capable of applying a sustained pressure of 5 kPa to the specimen under water flooding. However, more appropriate to represent the field, may be specified. The report and any evaluation should include description of any such procedural deviations.

A.14.4 Swelling strain developed in unconfined rock specimen

(1) Examples of tests for swelling strain developed in an unconfined rock specimen are given in the documents listed in Annex B.14

Table A.14.1 Minimum number of rock specimens to be tested in one formation Swelling tests on rocks for projects of Geotechnical Category 2

Test type	Minimum thickness	Minimum diameter	Minimum number of test specimens	Notes
(1) Swelling pressure index under zero volume change	15 mm and/or 10 times max particle size	2,5 times thickness	3	Specimen shall fit closely in the ring
(2) Swelling strain index for radially confined speci-men with axial surcharge	15 mm and/or 10 times max particle size	4 times thickness	3 + duplicate specimens for water content	Specimen shall fit closely in the ring
(3) Swelling strain developed in unconfined rock specimen	15 mm and/or 10 times max particle size	15 mm and/or 10 times max particle size	3 + duplicate specimens for water content	---

A.15 STRENGTH TESTING OF ROCK MATERIAL

A.15.1 General

(1) Examples of tests for determination of the strength of rock material are given in the documents listed in Annex B.15.

A.15.2 Uniaxial Compressive Strength and Deformability

A.15.2.1 Test procedures

(1) The test procedure should follow the example in Annex B.15.2 for uniaxial compressive strength testing and deformability testing. In addition the modifications prescribed in this prepresent standard should be used.

(2) The test procedure described in ISRM contains two levels of testing:

- Part 1. Method for determining the uniaxial compressive strength of rock materials
- Part 2. Method for determining deformability of the rock materials in compression

(3) The first method provides the compressive strength, the second method gives in addition the axial deformation modulus (Young's modulus) and Poisson's ratio. The second method is preferred.

(4) The procedures suggested by the reference ISRM are rather exacting and extremely difficult to conform to, especially with respect to sample preparation and geometrical tolerances. The practice recommended in this prestandard is less strict. Although the procedures recommended by ISRM are desirable, a set of minimum requirements is given herein. It is considered more important to run a greater number of tests than fewer tests on higher quality specimens.

(5) The following amendments should be made to the ISRM procedure:

- The diameter of the platens should be between D and $D + 10$ mm, where D is the diameter of the sample. Provided it can be ensured that the stiffness of the plate is sufficient, the platen diameter may be greater than $D + 10$ mm. Special provisions are required to centre the specimen properly.

- At least one of the two end platens should incorporate a spherical seat.

- Test specimens should be right circular cylinders having a height to diameter ratio between 2 and 3 and a diameter not less than 50 mm. The diameter of the specimen related to the largest grain in the rock may in case of weak rock be as low as 6:1; however a ratio of 10:1 is preferred.

- The ends of the specimen should be flat within 0,02% of the specimen diameter and should not depart from perpendicularity to the axis of the specimen by more than 0,1 degrees.

- The use of capping materials or end surface treatments other than machining is not permitted except when testing soft rocks, where the mechanical characteristics of the capping materials should be better than the rock to be tested.

- The diameter and the height of the test specimen should be determined to the nearest 0,1 mm or 0,2%, whichever is the greatest.

- Regarding strain gauge measurements of radial and axial strains, the length of the gauges should be at least ten times the grain size. Strain gauges, dial micrometers or LVDT's should generally not intrude within one-third of the height of the specimen ends. Measurement of vertical strain over the whole specimen height is allowed if it can be shown that practically the same result is obtained as when the strain is measured over the middle third of the specimen height.

- The load should be applied on the specimen at a constant stress rate or constant strain rate such that failure occurs within 5 min to 15 min. If cycles of loading and unloading are performed to define better deformation parameters, the time for such should be excluded from the before-mentioned time period.

- The machine to be used for applying and measuring axial load to the specimen should be of sufficient capacity and capable of applying load at constant rate. The parallelism of the machine platens should be checked.

(6) Initial deformations may include bedding of the specimen ends to the compression machine and/or closure or micro-cracks in the test specimen. Measurement of the total vertical deformations by using only the distance between the two steel platens of the machine may lead to false deformation properties.

A.15.2.2 Number of tests

(1) The characteristics of rock may vary greatly as function of lithology, diagenesis or induration, stress history, weathering, and other natural processes, even within a geological stratum. Table A.15.1 gives a guideline for the minimum number of uniaxial compressive tests as a function of the variability of the rock and existing comparable experience.

Table A15.1 Minimum number of test specimens to be tested for one formation Uniaxial compression tests, Brazil tests and triaxial tests for projects of Geotechnical Category 2

Standard deviation of measured strength [*s*]	Comparable experience		
	None	**Medium**	**Extensive**
$s > \approx 50\%$ of mean	6	4	2
$\approx 20\%$ of mean $< s < \approx 50\%$ of mean	3	2	1
$s < \approx 20\%$ of mean	2	1	0*
* Only valid for very homogeneous rock types with extensive experience from nearby locations			

A.15.3 Point load test

A.15.3.1 Test procedures

(1) For the recommended method to be used see Annex B.15.3.

(2) The test can be run with portable equipment or using a laboratory testing machine, and may be conducted either in the field or in the laboratory.

(3) Rock specimens in the form of either core (the *diametrical* and *axial* tests), cut blocks (the *block* test), or irregular lumps (the *irregular lump* test) may be used for testing provided the reference (e.g. ISRM) specifications of shape and dimensions are followed.

A.15.3.2 Number of tests

(1) The mean value of the Point Load Strength Index is used to classify samples or strata. To get a representative mean value, the minimum number of single tests should be 5.

(2) For rock characterisation and predictions of other strength parameters, a higher number of tests than specified in A.15.2.2, is necessary. Generally, at least 10 separate tests per stratum should be carried out.

A.15.4 Direct shear test

A.15.4.1 Test procedures

(1) The example listed in Annex B.15 should be followed. Some amendments have been introduced based on the recommendations of the SPRINT Rpt 216 project Quality Assurance in Geotechnical Testing.

(2) The following amendments should be made to the ISRM procedure:

- The testing machine should have a travel greater than the amount of dilatation or consolidation expected, and should be able of maintaining normal load to within 2% of a selected value throughout the test. Dilation should be measured during the test with the same accuracy as the shear displacements.

- The rate of shear displacement should be less than 0,1 mm/min in the 10 min. period before taking a set of readings. If automatic data logging is used, there may be no need for a reduction of the rate of shear displacements to 0,1 mm/min.

- The specimen should be reconsolidated under each new normal stress, and shearing continued according to criteria given in ISRM. If sample surfaces are cleaned before beginning a new testing phase, or the samples are unloaded before repositioning, this should be noted in the test report. The appearance of the material removed by cleaning should be described.

(3) The direct shear strength may also be determined by field tests. This requires a detailed assessment of the field characteristics of the discontinuities.

(4) The results are utilised in, for example, equilibrium analysis of slope stability problems or for the stability analysis of dam foundations, tunnels and underground openings.

(5) Rock specimens in the form of either cores or cut blocks may be used. The test plane should preferably have a minimum area of 2500 mm^2. In case of unfilled joints, the diameter or the edge (in case of a square cross-section) of test specimens should preferably be related to the size of the largest grain in the rock by a ratio of at least 10:1. The ratio between joint length and shear box size is recommended not to be less than about 0,5 to avoid possible instability problems of the shear apparatus.

(6) Equipment for cutting the specimen, for example a large-diameter core drill or rock saw should be used. Percussive drills, hammers and chisels should be avoided as the samples have to be as undisturbed as possible.

(7) The inclination of the test specimen with respect to the rock mass, and its direction of mounting in the testing machine are usually selected so that the sheared plane coincides with a plane of weakness in the rock, for example a joint, plane of bedding, schistosity or cleavage, or with the interface between soil and rock or concrete and rock.

A.15.4.2 Number of tests

(1) A shear strength determination should preferably comprise at least five tests on the same test horizon or from the same joint family, with each specimen tested at a different but constant normal stress in the applicable stress range.

A.15.5 Brazil test

A.15.5.1 Test procedures

(1) The example listed in Annex B.15 should be used.

(2) Test specimens should be cut with specimen diameters not less than the NX core size, (about 54 mm), with a thickness of approximately equal to the specimen radius. The cylindrical surface should be free from obvious tool marks. Any irregularities across the thickness of the specimen should not exceed 0,025 mm. End faces shall be flat within 0,25 mm and parallel to within 0,25°.

(3) For shale and other anisotropic rock it is recommended to cut test specimens parallel to and perpendicular to the bedding. For specimens cut parallel to the direction of the bedding, the direction of the load should also be specified.

A.15.5.2 Number of tests

(1) Table A.15.1 gives a guideline for the minimum number of Brazil tests as a function of the variability of the rock and existing comparable experience. For rock characterisation and predictions of other strength parameters a higher number of tests is necessary.

A.15.6 Triaxial compression test

A.15.6.1 Test procedures

(1) The example listed in Annex B.15 should be followed.

(2) Test specimens should be cut with specimen diameter D not less than the NX core size, (approximately 54 mm), and the height equal to 2 to 3 times the diameter as defined in Section 13 and with the specifications in accordance with 15.1.

A.15.6.2 Number of tests

(1) Table A.15.1 gives a guideline for the minimum number of triaxial compression tests as a function of the variability of the rock and existing comparable experience. For rock characterisation and predictions of other strength parameters a higher number of tests is necessary.

Annex B
(informative)
BIBLIOGRAPHY

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