

Eurocode 7: Geotechnical design —

Part 3: Design assisted by fieldtesting

ICS 91.010.30; 93.020

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National foreword

This Draft for Development is the official English language version of ENV 1997-3:1999.

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 1997-3:1999 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 146, an inside back cover and a back cover.

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Eurocode 7: Geotechnical design - Part 3: Design assisted by fieldtesting

Eurocode 7: Calcul géotechnique - Partie 3: Calcul sur la base d'essais en place

Eurocode 7: Entwurf, Berechnung und Bemessung in der Geotechnik - Teil 3: Felduntersuchungen für die geotechnische Bemessung

This European Prestandard (ENV) was approved by CEN on 30 July 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.

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

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

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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 1991 Eurocode 1 Basis of design and 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.

(15) 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 Standard 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. It is intended that this Prestandard is used in conjunction with the NAD valid in the country where the building or civil engineering works are located.

Matters specific to this prestandard

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

(17) In the framework of European Standardization, Eurocode 7 Part 1 on design of geotechnical structures has been established. The link between the general requirements for the design such as stated in ENV 1997-1 and the existing standards, codes and other types of generally accepted documents for operating field investigations is covered by Eurocode 7 Part 3: "Geotechnical design assisted by field tests". Eurocode 7 Part 3 in particular addresses some of the requirements of ENV 1997 - Part 1, especially section 3: "Geotechnical data".

(18) ENV 1997-3 does not replace standards for equipment and performance of different test methods, but provides basic requirements for such standards.

(19) Section 2 of ENV 1997-3 gives general requirements with respect to planning of field and laboratory investigations. This section serves as a common section of both Eurocode 7 Parts 2 and 3.

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 the 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 Eurocode 1 "Basis of Design and Actions on Structures". Part 1: "Basis of Design", 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 this prestandard.

1.1.2 Scope of ENV 1997-3

(1)P In addition to ENV 1997-1 the scope of ENV 1997-3 is to provide for a number of commonly used field tests:

- a) requirements for the equipment and test procedures;
- b) requirements for the reporting and the presentation of test results;
- c) interpretation of test results.

(2)P Part 3 shall serve as a link between the design requirements of Part 1 and the results of a number of field tests. Therefore part of the scope is to give:

- d) examples on how to derive values of geotechnical parameters from the test results.

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

1.1.3 Limitations

(1)P The derivation of parameter values is dedicated primarily to the design of pile and spread foundations as elaborated in the annexes B, C, D, and E of ENV 1997-1.

(2)P The scope of ENV 1997-3 does not cover the following:

- the assessment of characteristic values;
- environmental geotechnics, chemical investigations or the environmental impact of structures;
- geohydrological tests e.g. pumping tests.

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 constructs Part 1 Basis of design
ENV 1997-1:1994	Eurocode 7 Geotechnical design Part 1 General rules
ENV 1997-2:1998	Eurocode 7 Geotechnical design Part 2 Design assisted by laboratory testing
ISO 3898:1997	Basis for design of structures. Notations. General symbols

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 Definitions common to all Eurocodes

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

1.4.2 Definitions used in Eurocode 7

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

1.4.3 Definitions used in ENV 1997-3

(1) In sections 3 to 14 specific definitions relating to that section are given.

(2) For the purpose of this prestandard the following terms apply:

1.4.3.1 derived value: value of a geotechnical parameter 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 of ENV 1997-1.

1.4.3.1.1 Concept of derived values

(1) The concept of 'derived values' is elaborated as a way to link test results to geotechnical parameters. From the test results the values for geotechnical parameters for the use in analytical methods and coefficients for the use in semi-empirical or direct methods may be arrived at through:

— results of field tests	-----> through correlations -->	<u>to geotechnical parameter values</u>
	----->	<u>to coefficients in direct methods</u>
— results of lab. tests	----->	<u>to geotechnical parameter values</u>
	-----> through correlations with other tests ----->	<u>to geotechnical parameter values</u>

These values of the geotechnical parameters and/or coefficients, arrived at through, for example correlations, are called 'derived values'.

(2) ENV 1997-3 provides a set of examples of derived values for geotechnical parameters. From this the characteristic and the design values according to the requirements of ENV 1997-1 have to be established.

(3) The concept of 'derived values' is as follows: assume a homogeneous zone of ground governing the behaviour of a geotechnical structure. Assume that two types of field tests are carried out (see Fig. 1.1): five Cone Penetration Tests (CPT) and five pressuremeter tests (gives P_{LM}), and assume five laboratory tests to establish the undrained shear strength. From the five (over the depth of the layer averaged) CPT values and P_{LM} values from pressuremeter tests, the following sets of derived values are established through certain correlations with the undrained shear strength:

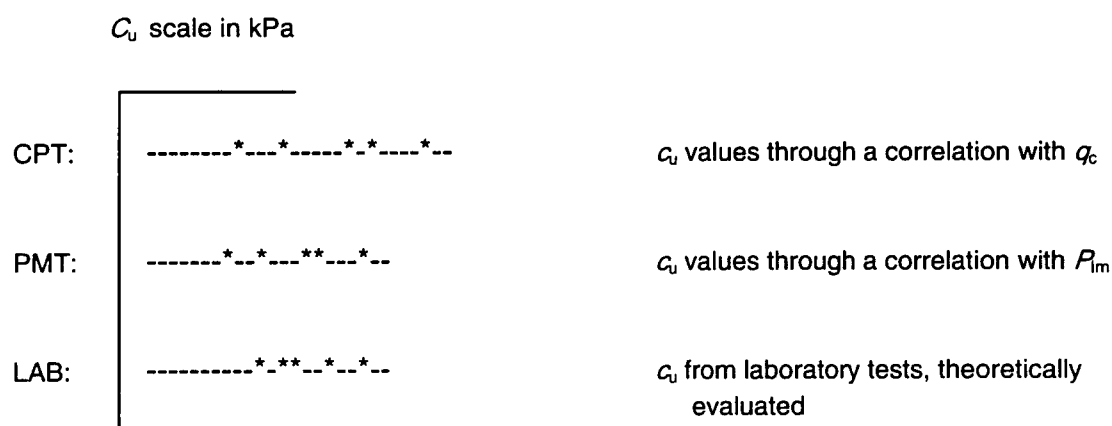


Figure 1.1 Concept of derived values

(4) From these three sets of derived values for the undrained shear strength of a homogeneous soil mass, the characteristic value to be used in the design has to be assessed.

1.4.3.1.2 Correlations

(1) The examples in the annexes, to subclauses #.7 of this prestandard, are based on various correlations obtained from the literature. These correlations may correlate a geotechnical parameter derived value either with a measured value, for example the q_c -value of a CPT, or with a corrected value, for example the q_t -value of a CPTU being the q_c -value corrected for the measured excess pore pressure.

(2) Apart from this, the correlation may connect a geotechnical parameter derived value either with the mean value of the measured/corrected value or a conservative estimate of the measured/corrected value (see Fig 1.2).

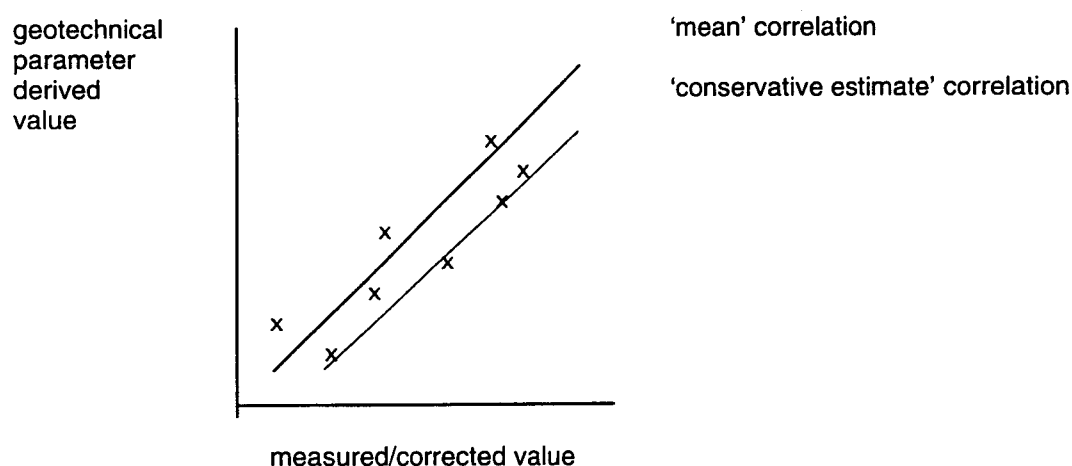


Figure 1.2 Types of correlation

(3) Each subclause #.7 of the tests covered by ENV 1997-3 gives examples on how to derive values of geotechnical parameters or coefficients in direct methods. In the examples in the annexes, the subclauses #.7 of ENV 1997-3 refer to, either 'mean' or 'conservative' correlations are used.

Sometimes the correlation can even be meant as a correlation of a geotechnical parameter and the characteristic value of the measured/corrected value. Normally the type of correlation is unknown. Also the theory used to determine a soil parameter value may differ between references and are not always presented in the references. In evaluating the examples in the annexes this should be kept in mind. If the type of correlation is known, this is indicated in the annexes.

1.4.3.2 excess pore pressure: the pore water pressure over and above the equilibrium pore pressure at the end of the consolidation

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 and units used in Eurocode 7

(1)P The symbols commonly used in ENV 1997-3 are defined in each section. Other symbols are defined where they are used locally in the text.

(2)P The units recommended for geotechnical calculations are defined in 1.6 of ENV 1997-1.

(3) The symbols follow the rules given in ISO 3898.

1.6 The link between ENV 1997-1 and ENV 1997-3

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

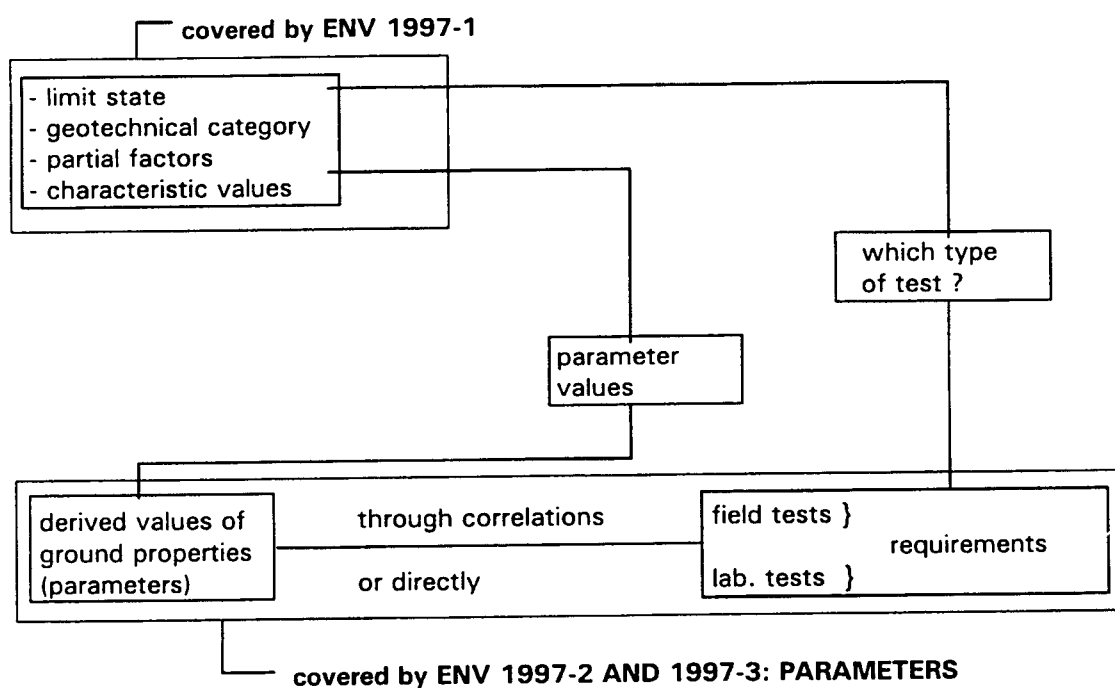


Figure 1.3 Flowchart geotechnical design

2 PLANNING OF SITE INVESTIGATIONS

2.1 General

(1)P Site investigations consist of desk studies, field and laboratory investigations and all other investigations performed in order to establish knowledge of the ground; soil, rock and groundwater conditions, and to determine the properties of the soil and rock. Site investigations may also include appraisal of existing constructions, tunnels, embankments and slopes and the environmental impact of the project.

(2) Ground investigations are normally performed in phases depending on the questions raised during planning, design and construction of the actual project, see 3.2.1 of ENV 1997-1. The following phases are treated separately in this section:

- preliminary investigations for positioning and preliminary design of the structure, see 2.3;
- investigations for design and construction, see 2.4;
- control investigations, see 2.5.

(3) The provisions in this document are planned primarily for geotechnical category 2 projects (see 2.1 of ENV 1997-1) and based on the fact that the results from investigations recommended in one phase are available before the next phase is started. In cases where all investigations are performed at the same time, both 2.3 and 2.4 should be considered simultaneously.

(4) The ground investigation requirements for category 1 projects are normally limited as the verifications often will be based on local experience. For category 3 projects the amount of investigations required will normally be at least the same as indicated for category 2 projects in the following sections. In addition complementary investigations related to the circumstances that place the project in category 3 may apply.

(5)P The composition and the extent of each phase of the investigations shall be based on the following:

- the topographical, geological and hydrogeological conditions on the site and pertinent available information about them;
- the type and design of the construction, e.g. type of foundation, improvement method or retaining structure, location and depth of the construction;
- the local experience and climate conditions.

(6)P When composing the investigation programme both for field and laboratory tests, the knowledge from desk studies of the following documents, if available, and the results of a site examination shall be accounted for (see 3.2.3 of ENV 1997-1):

- topographical maps;
- old city maps describing the previous use of the site;
- geological maps and descriptions;
- engineering geological maps;
- geohydrological maps and descriptions;
- geotechnical maps;
- aerial photos and previous photo interpretations;
- aerogeophysical investigations;
- previous investigations at the site and in the surroundings;
- previous experiences from the area;

(7)P the use of preliminary investigations shall be considered.

(8) The extent of direct field investigations and sampling with subsequent classification and laboratory testing depends on the geology, type of structure and the local experience.

(9)P The preliminary investigations shall be planned in such a way that adequate data are obtained, when applicable, concerning:

- the overall stability of the area;
- suitable positioning of the structure;
- possible foundation methods and ground improvements;
- possible effects to neighbouring buildings;
- preliminary costs for foundations and ground improvements;
- preliminary costs for provisional constructions;
- proposals for design investigation.

For planning and execution of preliminary investigations reference is made to 2.3.

(10)P Investigations for the design and construction phase shall provide sufficient information to the following questions, when applicable:

- location of construction;
- foundation methods and levels;
- erosion protection;
- protection against swelling and shrinkage;
- ground improvements or other stabilizing measures;
- foundation design;
- design of temporary constructions;
- excavatability;
- driveability for piles;
- drainages and filters;
- frost susceptibility;
- methods and order of construction/operations;
- requirements for the selection of filling material;
- slope inclination;
- existing hindrance such as old constructions and service pipes and cables;
- durability of construction material in the ground.

For planning and execution of investigations for design and construction reference is made to 2.4.

(11) Annex A provides a flow chart which can be used for the selection of a proper field investigation method for the various soil investigation stages.

(12)P Where construction elements are applied in the geotechnical structures of which the durability may be affected by the surrounding soil and groundwater, the aggressiveness of the soil and groundwater shall be determined, to enable provisions when applicable, (see 2.3 of ENV 1997-1).

(13) To determine the aggressiveness of the ground and groundwater a selection of chemical analyses often should be undertaken and the results compared to available experience on the aggressiveness to various construction materials and protection techniques. Chemical analyses often require groundwater sampling and thus special provisions in the borehole.

(14)P The results of the desk studies and the site inspection shall be considered, when locating the various investigation points. Investigations shall be targeted at points representing the variation in ground conditions for soil, rock and groundwater.

(15)P In cases where more than one type of investigation shall be made at a certain location (e.g. CPT-test and piston sampling), the boreholes shall be placed at least 2 m apart.

(16)P The depth of investigation shall include all relevant layers for the actual geotechnical design.

(17)P The selection of the location of boreholes and test pits shall take account of possible adverse effects on the integrity of the construction to be built and neighbouring structures and shall minimize the probability of harmful environmental effects.

(18)P The class and number of samples shall be based on the aim and status of the soil investigations, on the geology of the site and on the complexity of the geotechnical structure and of the construction to be designed.

(19)P Sampling shall be done in accordance with sections 12 and 13.

(20) Where lamination or fine stratification of the subsoil can influence the geotechnical design, consideration should be given to the use of continuous boring with open tube sampler or core drilling. Additional samples may be taken with e.g. a short open tube sampler, a fixed piston sampler or a block sampler.

(21) In case there is no stratification or no influence from stratification, in coarse soils, samples from auger or bailer may be sufficient. In clays and organic soils high quality samples should be taken with special equipment.

(22) Laboratory investigations for classification purposes and determination of the properties of the soil or rock should be performed as relevant for the project as a part of the total ground investigation programme. Guidance on the choice of investigation methods in order to obtain various properties of soil and rock may be found in paragraphs (23) to (26).

(23) Suitable routine classification for soil samples with various degrees of disturbance is presented in table 2.1. The routine tests are generally performed in both the preparatory and the design investigation phases. However, in the preparatory phase a limited number of samples may often be investigated.

Table 2.1: Routine soil classification tests

Soil type	Clayey soils			Silty soils			Sandy, gravelly soils	
Sample quality	Undis- turbed	Dis- turbed	Re- moul- ded	Undis- turbed	Dis- turbed	Re- moul- ded	Dis- turbed	Re- moul- ded
Parameters								
Soil class	X	X	X	X	X	X	X	X
Water content, (w)	X	(X)	(X)	X	(X)	(X)	(X)	(X)
Density, (D)	X	(X)	-	X	(X)	-	-	-
(D_{max}), (D_{min})	-	-	-	(X)	(X)	(X)	X	X
Atterberg limits	X	X	X	X	X	X	-	-
Grain size distribution	(X)	(X)	(X)	X	X	X	X	X
Undrained shear strength, (c_u)		-		(X)	-	-	-	-
Sensitivity, (S_t)	X	-	-	-	-	-	-	-
	X							
X = normal to determine; (X) = possible to determine; - = not applicable.								

(24) In addition to these routine tests for soils other classification tests for certain cases may be performed e.g. activity, density of grain material and organic content.

(25) Laboratory tests to determine various geotechnical parameters for design purposes are indicated in table 2.2.

Table 2.2: Laboratory tests for the determination of certain geotechnical parameters

Geotechnical parameter	Type of soil					
	Gravel	Sand	Silt	NC clay	OC clay	Peat organic clay
Oedometer modulus (E_{oed})	OED ^{*)}	OED ^{*)}	OED	OED ^{*)}	OED	OED ^{*)}
Effective shear strength (c'), (ϕ')	TX, DSS, (DST)	TX, DSS, (DST)	TX, DSS, (DST)	TX, DSS, (DST)	TX, DSS, (DST)	TX, DSS, (DST)
Undrained shear strength (c_u)	-	-	TX, SIT, DSS, (DST)	TX, SIT ^{*)} , DSS, (DST)	TX, SIT ^{*)} , DSS, (DST)	TX, SIT ^{*)} , DSS, (DST)
Permeability (k)	PT(C), SV	PT(C), SV	PT(C), PT(F)	PT(F)	PT(F)	PT(F)
^{*)} Indicate investigations normally performed in the preliminary phase, at least to some extent. ^{**)} Requires special device.						

Abbreviations of laboratory tests:

OED	Oedometer test
TX(	Triaxial test
PT(F)	Permeability test (falling head)
PT(C)	Permeability test (constant head)
DST	Direct shear test
SIT	Strength index tests
SV	Sieving
DSS	Direct simple shear test

(26) Suitable routine laboratory tests for rock samples are presented in table 2.3. These tests normally give the necessary basis for the description of the rock material.

Table 2.3: Routine rock tests

Type of test	Type of rock ^{***)}			
	1	2	3	4
Geological classification	X	X	X	X
Unit weight, (γ)	X	X	X	X
Water content, (w)	X	X	X	X
Porosity, (n)	X	X	X	X
Uniaxial compressive strength test	X	X	X	X
Point load test	x	X	X	X
Compressibility, (E)	X	X	X	X
***) Group according to ENV 1997-1, Annex E, Table E.1.				

(27) The classification of core samples will normally comprise a geological description, the core recovery, the Rock Quality Designation (RQD), the degrees of induration, weathering and fissuring. For weathering classification see annex L. In addition to the routine tests in table 2.3 for rocks other tests may be selected for different purposes, e.g. density of grains, wave velocity, Brazilian tests, shear strength of rock and joints, slake durability tests, swelling tests and abrasion tests.

(28) The properties of the rock mass including the layering and fissuring normally may indirectly be investigated by compression and shear strength tests along joints. In weak rocks complementary tests in the field or with large scale laboratory tests on block samples may be made.

2.2 Definitions

(1)P dynamic sounding or probing: driving a penetrometer into the ground with a hammer or a percussion drilling machine while measuring the resistance in e.g. blows or seconds for a certain amount of penetration.

(2)P field investigations for geotechnical purposes: geophysical investigations, penetration tests, in situ testing, soil sampling, rock sampling, groundwater measurements, large scale tests and monitoring.

(3) Examples of the various types of field investigations are:

- geophysical investigations (e.g. seismic profiling, ground penetrating radar, resistivity measurements and borehole logging);
- penetration testing (e.g. CPT, SPT, static soundings and dynamic probings);
- in situ testing (e.g. pressuremeter tests, dilatometer tests, plate load tests, field vane tests and permeability tests);
- soil and rock sampling for description of the soil or rock and laboratory tests;
- groundwater measurements to determine the groundwater table or the pore pressure profile and their fluctuations;

- large scale tests in order to determine e.g. the bearing capacity and behaviour of elements directly;
- monitoring of the behaviour of different constructions e.g. movement of anchored retaining structures, settlement of foundations, pore water dissipation beneath embankments etc.

(4)P investigation point: the co-ordinates (x,y,z) where one or a number of different tests or a sampling is performed.

(5)P large scale tests: tests to determine directly the bearing capacity and behaviour of plates, piles, ground anchors or the transmissivity of the ground by pumping tests.

(6)P measuring While Drilling (MWD): technique of measuring a number of boring parameters during soil-rock sounding. Both manual and automatic recording exists.

(7) During drilling for example the penetration rate, rate of rotation, bit force, torsional moment, flush pressure and volume of flushing agent can be measured.

(8)P penetration test: all different tests where a rod provided with a tip is pushed or driven into the ground while the resistance to penetration is recorded.

(9) Penetration tests thus include both static and dynamic penetration tests and sounding methods such as CPT, WST, SPT, DP and soil-rock sounding (SR) in accordance with definitions in the following sections.

(10)P preliminary investigation: investigations performed before designing and specifying an investigation programme, including desk studies and site inspection.

(11)P soil or rock layer: layer of normally uniform material with similar properties, extending over a certain area in the ground.

(12)P soil-Rock Sounding: dynamic probing through possible soil into the rock with a percussion drilling machine and normal rock drilling tools and possibly MWD-technique.

(13)P static sounding: pushing or rotating a statically loaded penetrometer through the soil while the resistance is measured in e.g. kN or for the weight sounding test in halfturns per 0,2 m of penetration.

2.3 Preliminary investigations for positioning of a structure and preliminary design

(1)P A preliminary soils investigation for positioning of the structure and preliminary design shall supply estimates of soil data concerning:

- type of soil or rock and their stratification;
- thickness and relative density or strength of the soil;
- groundwater table or pore pressure profile;
- preliminary strength and deformation properties for soils and rock;
- the occurrence of contaminated ground or groundwater that might be hazardous to health or the durability of construction material.

(2)P In cases where the overall stability of the site may be of concern, a preliminary investigation shall be made.

(3) The slope stability investigation should be performed in the assumed most unfavourable section and the surrounding area where previous failure may have occurred. The volume to be investigated should cover at least a depth down to 5 m below potential slip surfaces.

(4) A slope stability investigation in soil should comprise: surveying, penetration tests, sampling, in situ tests, groundwater measurements and laboratory testing.

(5) Rock slope investigations in addition should comprise a site inspection with mapping of discontinuities and determination of the strength of joints.

(6)P In the preliminary investigation phase the investigation points shall be distributed over the area, in such a way that an adequate picture is derived of the variability of the site with regard to the stratification and quality of the ground and of the groundwater situation.

(7)P When parts of the soil and/or the structure are particularly complex the preliminary investigation shall be focussed on the concerned part of the building site.

(8) The influence on or effect of surrounding constructions shall be considered when defining the preliminary investigation programme.

(9) The extend of the preliminary soils investigation should as a minimum contain three investigation verticals equally distributed in a respective cross-section of the building site. This investigation may comprise penetration tests, in situ testing, boring for sampling (in the weakest soil) and ground water measurements where the most unfavourable groundwater level may be expected.

2.4 Investigations for design and construction

(1)P When planning investigations for design and construction account shall be taken of 3.2.3 of ENV 1997-1. The investigations for design and construction shall provide the necessary information for the construction works, the ground and groundwater conditions. The investigations shall be established for the ground below and around the construction site as far as the behaviour of the ground may adversely affect the construction works.

(2)P In cases where the preliminary investigations have not clearly shown that the overall stability is satisfactory, complementary investigations shall be performed during the design investigation phase.

(3)P The design investigations for the overall stability shall have such a composition and amount of investigation points that necessary stability analyses may be made and stabilization measures may be designed.

(4)P The composition of the ground investigation programme and location of the investigation points shall consider the size of the area, the topography, the geology, the groundwater conditions, the type and design of the construction and the type and location of neighbouring structures.

(5) The investigated area should extend into the neighbouring area for a distance of at least 1,5 times the expected excavation depth or depth of the soil layer that can generate settlements in the neighbouring area.

(6) When applicable, investigations in the design phase should comprise penetration tests, borings and/or test pits for sampling, in situ tests and groundwater measurements.

(7) The number of investigation points should be extended if it is deemed necessary to obtain an accurate insight in the complexity and the variability of the ground at the building site. Where ground conditions are relatively uniform, a wider spacing or less investigation points may be sufficient. In either case this choice should be justified.

(8)P For identification and classification of soils, at least one boring with sampling shall be available. Samples shall be obtained from every separate soil layer influencing the behaviour of the actual structure.

(9) In cases of inhomogeneous soil layers, organic soils or when high quality samples are required, samples should be taken at least every 1 m in one boring.

(10) The depth of investigations should be extended to all strata that will be affected by the project. For dams, weirs, excavations below groundwater level, and where dewatering work is involved, the depth of exploration should also be selected as a function of the hydrogeological conditions. Slopes and steps in the terrain should be explored to depths below any potential slip surface.

(11) The groundwater pressure should be measured to a depth of at least 3 m below anticipated foundation level both in high and low points of the area or equal to the expected height of the phreatic surface above the foundation level.

2.5 Control Investigations

(1)P In order to check that the ground conditions, the delivered construction materials and the construction works correspond to those presumed or ordered a number of checks and additional tests shall be made during construction and execution of the project, when relevant.

(2) The following general control measures may apply:

- inspection of excavations;
- complementary site investigations;
- check of ground profile and properties;
- measurements of groundwater level or pore pressure and their fluctuations;
- measurements of the behaviour of neighbouring constructions, services or civil engineering works;
- measurements of the behaviour of the actual construction.

(3)P The results of the control measures shall be compiled, reported and checked against the design requirements. Decisions shall be taken based on the checks.

2.6 Reporting of site investigations

(1)P The results of a geotechnical investigation shall be reported and evaluated according to 3.4 of ENV 1997-1.

(2)P All site investigations shall be reported in such a way that the results may be checked and re-evaluated.

(3)P For identification and quality assurance purposes all investigation records, logs, samples and presentations shall contain the following information:

- name of company executing the test;
- identification of the actual site or area;
- identification number of the job or commission;
- borehole number;
- type of test.

(4)P In addition the following information shall be given on the field and laboratory investigation records in combination with the information required for each specific investigation method as indicated in sections 3 to 14:

- date of investigation;
- ground level;
- method of boring and borehole diameter;

- type of test methods used with reference to actual standards;
- calibration data for the actual measuring equipment;
- any deviations from the requirements of this prestandard, other relevant standards or recommendations;
- the signature of the operator in charge, or the field manager.

(5)P The ground investigation report shall include data indicating the basis for the survey of the site.

(6)P The factual ground investigation results shall be compiled in a report, with plans, in such a way that the total amount of basic information can be used in the evaluation of the results. The location of all investigation points shall be clearly indicated.

(7)P The evaluation of geotechnical information according to 3.4.2 of ENV 1997-1 shall be based on all relevant basic information available at the actual phase of the investigation.

(8)P Proposals for complementary investigations shall aim at clarifying the ground conditions in all the areas involved for the actual project and surrounding structures which are influenced by the project.

(9) Such proposals should account for the variations in the soil layer sequence, the variations in groundwater level or pore pressure and variations in the ground properties obtained from the investigations performed.

2.7 Evaluation of site investigations

2.7.1 Evaluation of the preliminary investigations

(1)P The evaluation of the ground conditions in the preliminary investigation phase for positioning of the structure and the preliminary design shall make use of all relevant information from the desk study and the investigations performed at the site, related to the actual project.

(2) Geological maps and descriptions of the site, penetration test results, in situ test results, classification of soil and rock samples, laboratory test results and groundwater measurements should be used to identify and describe the soil layers, the rock mass and the groundwater conditions of the total area involved in the project.

(3) The evaluation should be summarized in the report, presenting the factual investigation data according to paragraph 2.6(6)P.

(4) A preliminary derivation of ground parameter values for a preliminary design can be made for identified layers and can, for example, be expressed in terms of density, water content, penetration resistance, strength and deformation properties and pore pressures.

2.7.2 Evaluation of investigations for design and construction

(1)P The evaluation of the ground conditions in a design and construction phase shall

make use of all relevant information from the actual and earlier phases to describe the situation in relation to the actual project.

(2)P The influence from or on surrounding structures, services or civil engineering works shall be considered in the evaluation so that all necessary data are obtained.

(3) When deriving the boundary between different soil layers, soil and rock and the groundwater level a rectilinear interpolation between the investigation points may normally be sufficiently accurate, unless there is substantial heterogeneity.

(4) Evaluation of the unit weight may be based on density measurements on undisturbed soil samples or core samples in rock. In cases where only disturbed samples have been obtained the unit weight may be estimated from in situ density tests or from compiled local experiences especially considering the degree of saturation, the content of coarse material and the natural scatter in density.

(5) The unit weight may also be estimated from local classification charts on the basis of results from CPT or dilatometer tests. In rock, and soils within a casing the density may be estimated from calibrated geophysical loggings as an alternative.

(6)P When deriving ground parameter values for design purposes from site investigations the type of ground, the type of construction, the total and local experiences from similar design cases as well as the scatter of the test results shall be considered.

(7) When deriving ground parameter values, the profile of the ground should be schematised into a representative sequence of layers of soil and rock on the basis of a geotechnical identification and classification and fieldtests. Within the distinguished layers the strength and deformation properties should not vary considerably.

(8) For the assessment of the strength and deformation properties of the distinguished layers in the schematised profile of the soil or rock, the following should be taken into consideration:

- direct measurement of the properties from field vane tests, plate load tests or pile load tests;
- laboratory measurements of certain parameters at certain stress conditions, e.g. triaxial tests, direct shear tests or oedometer tests;
- transformation of measured data to soil properties by using compiled correlations with different parameters, e.g. angle of shearing resistance, modulus of elasticity, relative density from e.g. cone penetration tests, dynamic probing tests, SPT-tests, dilatometer tests or pressuremeter tests. Since correlations of this kind normally are limited to only one investigation method and one type of experiment it is not recommended to use them for cross correlations e.g. to transform N_{60} to q_c and then to N' or E_m ;
- direct use of measured parameter values in a design method based on compiled experiences, e.g. calculating the bearing capacity and settlements from pressuremeter tests, cone penetration tests or standard penetration tests.

3 CONE PENETRATION AND PIEZECONE TESTS - CPT(U)

3.1 General

(1)P The cone penetration test (CPT) consists of pushing vertically into the soil, at a relatively slow and constant rate, a penetrometer which comprises a series of rods terminated by a penetrometer tip comprising a cone and a cylindrical shaft and measuring the penetration resistance of the cone as well as, possibly, the local friction on a sleeve located in the cylindrical shaft.

(2)P The piezocone test (CPTU) is a CPT which includes the measurement of the pore water pressure during penetration at the level of the base of the cone.

(3)P This section covers mainly electric penetrometers.

(4)P The tests shall be carried out in accordance with a method that complies with the essential requirements given in this section.

(5)P The test method used shall be reported in detail with the test results.

(6) The test method may be reported by reference to a standard.

(7)P Any deviation from the requirements given below shall be justified and in particular its influence on the results shall be commented upon.

(8) Experience of deviations exists with respect to:

- size of the cone;
- use of mechanical or hydraulic penetrometers.

3.2 Definitions

For the purpose of this prestandard the following definitions related to CPT and CPTU apply:

(1)P **penetrometer tip**: The main parts of the penetrometer tip are defined in figure 3.1.

(2)P **cone resistance (q_c)**: the measured axial force Q_c acting on the cone divided by the total area of the base of the cone A_c ;

(3)P **local unit side friction (f_s)**: the measured frictional force Q_s acting on the sleeve divided by its area

(4)P **friction ratio (R_f)**: f_s/q_c where q_c and f_s are determined at the same depth, expressed as a percentage

(5)P **friction index (I_f)**: q_c/f_s where q_c and f_s are determined at the same depth.

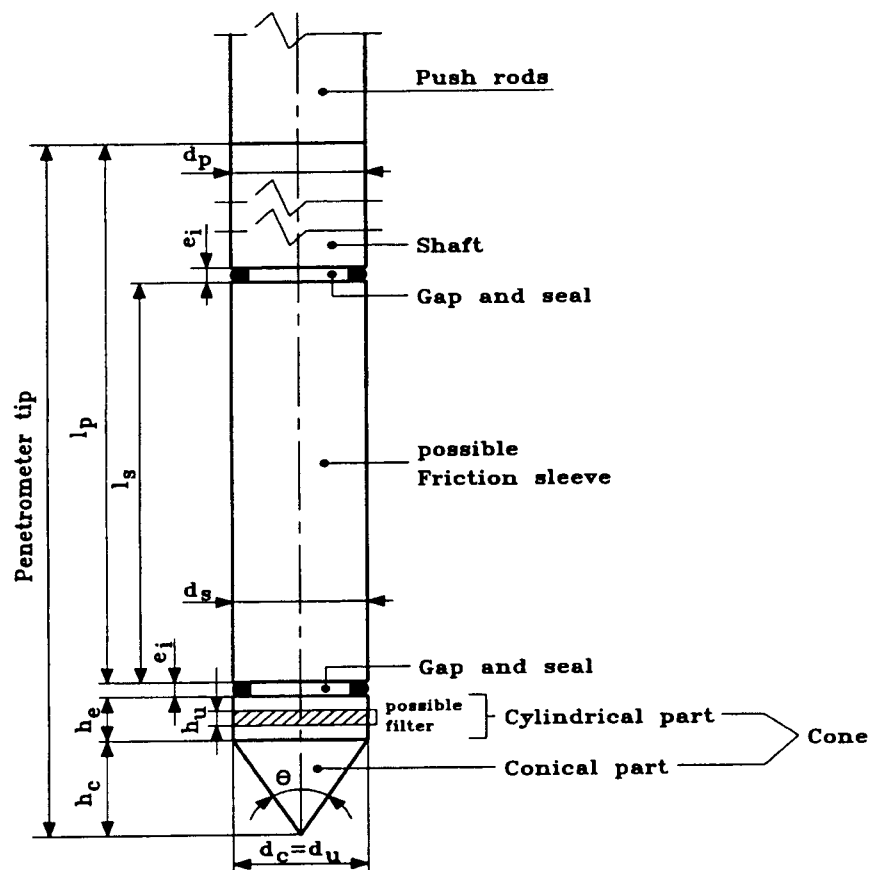


Figure 3.1: Scheme of an electric penetrometer tip

(6)P For CPTU the following additional parameters are defined.

(7)P cone area factor (a): A_N/A_c , where A_N is the net area of the cone (see figure 3.2)

(8)P penetration pore pressure (u): the pore pressure measured during penetration on the cylindrical part of the cone, just above the conical part of the cone (see figure 3.1)

(9)P generated pore pressure (Δu): $u - u_0$, where u_0 is the pore pressure existing in the ground before the penetration test at the level of the cone;

(10)P total (corrected) cone resistance (q_t): $q_c + u(1-a)$

(11)P pore pressure ratio B_q : $\Delta u / (q_t - F_{v0})$, where F_{v0} is the total vertical stress existing in the ground before the penetration test at the level of the cone.

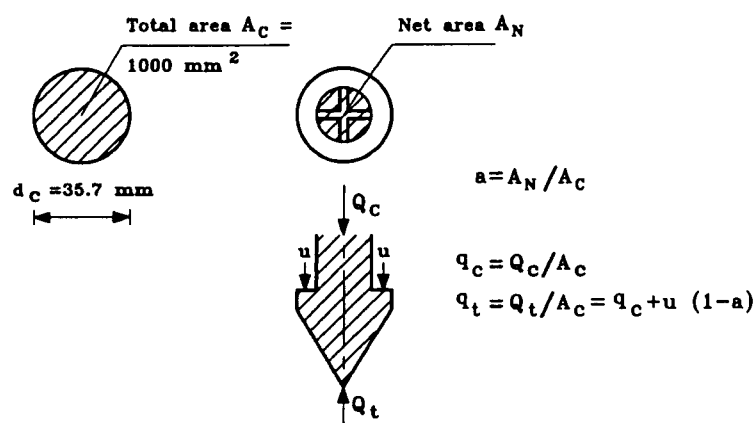


Figure 3.2: Definitions for a piezocone test (CPTU)

3.3 Equipment

3.3.1 Apparatus

(1)P The apparatus shall comprise:

- thrust machine;
- push rods;
- penetrometer tip;
- measuring/recording equipment.

(2)P The thrust machine shall push the rods into the soil at a constant rate of penetration. It shall be stabilised in such a way that it does not move significantly during the pushing action.

(3)P The push rods shall be assembled tightly in order to form a rigid-jointed series with a continuous straight axis.

(4) In order to prevent buckling, guides and/or casings should be provided for the free part of the push rods above the soil, in very soft layers situated above a highly resistant layer and for the part of the push rods in water.

(5) Before loading, push rods should be straight so that the maximum deflection of a point on a 1 m push rod, from a straight line through the ends, does not exceed 1 mm for the 5 lowest push rods and 2 mm for the remainder.

(6)P The penetrometer tip terminates the series of rods. It shall have a cone and shaft with the same axis as the series of push rods.

(7)P When the penetrometer tip includes a friction sleeve, it shall have the same axis and shall be located immediately above the cone.

(8)P The apex angle of the cone θ shall be 60° .

(9) The assessment of the derived values in 3.7 is based on the nominal total area of the base $A_c = 1000 \text{ mm}^2$.

(10) When cones having a base A_c different from 1000 mm^2 are used, careful attention should be given to size effects.

(11) In Annex M documents have been listed that give examples of the description of the geometry, tolerances and surface roughness of the cone, friction sleeve and shaft, as well as the geometry of gaps, geometry and deformability of seals. It is recommended that these should be used.

(12)P For CPTU a filter element for pore water pressure measurement is incorporated into the cylindrical part of the cone. Its diameter shall not be less than the diameter of the cylindrical part of the cone and not more than the diameter of the friction sleeve, if applied.

(13) The use of additional filter elements placed at other locations is not in contradiction with the minimum requirements given in this section.

(14) For CPTU the geometry of the cone should be such that:

- the height h_e of the cylindrical part including the height h_u of the filter element is: $7,0 \text{ mm} \leq h_e \leq 10,0 \text{ mm}$,
- the diameter d_u of the filter element is: $d_c \leq d_u \leq d_c + 0,2 \text{ mm}$

where:

d_c is the diameter of the cylindrical part of the cone

and the seal in the gap should be such that the remaining area A_i (see figure 3.3) is as small as possible.

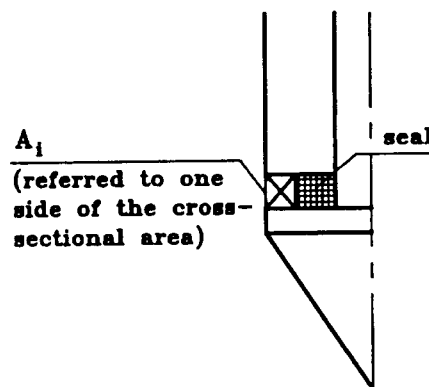


Figure 3.3: Remaining area A_i for a piezocone test CPTU

3.3.2 Measuring equipment

(1)P The apparatus for CPT or CPTU shall include suitable measuring devices with suitable data transmission and data recording systems. The recorded data shall always be accessible on the site.

(2) Devices for measuring the following quantities should be used, when relevant:

- total penetration force Q_t ;
- axial force Q_c , acting on the cone, linked to the cone;
- frictional force Q_s , acting on the friction sleeve, linked to the friction sleeve (alternatively, sum of the forces $Q_c + Q_s$, acting on the cone and on the friction sleeve, linked to the cone and friction sleeve);
- inclination and penetration rate of the cone;
- in a CPTU penetration pore pressure u relative to a known pressure, linked to the filter element in the cone.

(3) If electric measuring devices are built into the tip, they should be temperature compensated.

(4) The sensing devices for measuring cone resistance and local side friction should be designed in such a way that eccentricity of the load does not affect the readings.

(5)P The inaccuracy of the measurements shall not exceed 5 % of the measured value.

3.4 Test procedure

3.4.1 Calibration and checks

- (1)**P** All measuring devices shall provide reliable and accurate measurements.
- (2) All measuring devices should be calibrated every 3000 m of CPT sounding or at least every 6 months or after repair.
- (3)**P** For a CPTU the filter, its sensing device and all fluid spaces shall be filled with a deaired fluid before each test and precautions shall be taken to ensure full saturation of the whole system.
- (4) The wear of the cone and of the friction sleeve should be checked regularly to ensure that they satisfy the tolerances. Examples of tolerances are given in the documents listed in Annex M.
- (5) The seals should be checked for the presence of soil particles and be cleaned.
- (6) If a friction reducer is used, it should be located at a sufficient distance above the penetrometer tip so as not to influence the measurements.

3.4.2 Performing the test

- (1)**P** The penetration shall be performed with no rotation, no vibrations, nor blows, and the direction of the thrust shall be vertical.
- (2) The axis of the push rods should at the surface not deviate, more than 2 % from vertical.
- (3)**P** The rate of penetration shall be (20 ± 5) mm/s.
- (4)**P** The penetration depth of the cone shall be measured with an inaccuracy not exceeding 0,2 m and the depth interval between the readings shall not exceed 0,1 m.

3.5 Interpretation of the results

- (1) Results of CPT and CPTU may be used for determining stratification, classifying soils and determining properties of a wide range of soils and soft rocks, provided penetration is possible.
- (2) In a CPTU the total (corrected) cone resistance q_t and pore pressure ratio B_q should be determined with q_c and u measured at the same level.
- (3) For interpretation of the results of a CPTU the pore pressure u_0 and the total vertical stress σ_{v0} existing in the ground before the test should be used. u_0 is the equilibrium pore pressure; σ_{v0} may be determined from the unit weights of the ground layers.
- (4) When CPT results are used for classifying soils, the classification should be based at least on cone resistance, local unit side friction and friction ratio (or friction index). A better classification is obtained by performing CPTU and using total (corrected) cone resistance q_t , generated pore pressure u and pore pressure ratio B_q (and/or local unit side friction and friction ratio or index, if relevant).

3.6 Reporting of the results

(1)P In addition to the requirements given in 2.6 the test report shall include the following information:

- apparatus used, type of tip used;
- date of calibrations;
- zero readings of measuring devices;
- system of measurement (electric, mechanical or hydraulic);
- the depth over which a friction reducer or push rods with a reduced diameter have been used;
- the depth of the start of the test;
- the depth of water in the hole or of the water table when available;
- graphs of the following results, with depth, on an arithmetic scale:
 - cone resistance: q_c ;
 - local unit side friction: f_s , when relevant;
 - total side friction resistance Q_{st} , when relevant;
 - friction ratio: R_f or friction index: I_f , when relevant;
 - observations of the operator such as incidents, procedure details not included in the test method which might have an influence on the tests results.

(2)P For a CPTU the report shall also include:

- cone area factor: α ;
- graphs of the following results, with depth, on an arithmetic scale:
 - penetration pore water pressure: u ;
 - total (corrected) cone resistance: q_t (replacing q_c);
 - pore pressure ratio: B_q .

3.7 Derived values of geotechnical parameters

3.7.1 Derived values for calculations of bearing capacity and settlement of spread foundations

(1)P When the bearing capacity or the settlement of a spread foundation is evaluated from CPT results, either a semi-empirical method or an analytical method shall be used.

(2)P When a semi-empirical method is used, all the features of the method shall be taken into account.

(3) When the sample analytical method for bearing capacity of annex B in ENV 1997-1 is used, the undrained shear strength of cohesive soils c_u may be determined from the following relation:

$$c_u = \frac{q_c \cdot \sigma_{v,0}}{N_k}$$

or, in the case of CPTU, preferably by:

$$c_u = \frac{q_t \cdot \sigma_{v,0}}{N_{k,t}}$$

with N_k or $N_{k,t}$ estimated from local experience.

(4) When the sample analytical method for bearing capacity of annex B of ENV 1997-1 is used, the angle of shearing resistance ϕ' may be determined from the cone resistance q_c , on the basis of local experience, taking into account depth effects, when relevant.

An example of sample values for quartz and feldspar sands is given in annex B.1 to estimate a value of ϕ' from q_c , for the bearing capacity of spread foundations, when depth effects do not need to be taken into account.

(5) More elaborated methods may also be used for determining ϕ' from q_c , taking into account the effective vertical stress, the compressibility, and the overconsolidation ratio.

(6) When the adjusted elasticity method of annex D of ENV 1997-1 is used for calculating settlements of spread foundations from CPT results, the correlation between cone resistance q_c and the drained (long term) Young's modulus E_m depends on the nature of the method; the semi-empirical elasticity method, or the theoretical elastic method.

(7) An example of a semi-empirical method for calculating settlements in cohesionless soils is given in annex B.2.

(8) When a theoretical elastic method is used, the drained (long term) Young's modulus E_m may be determined from cone resistance q_c , on the basis of local experience. An example of sample values for quartz and feldspar sands is given in annex B.1 to estimate a value of E_m from q_c .

(9) Correlations between the oedometer modulus E_{oed} and the cone resistance q_c may also be used when calculating settlements of spread foundations.

The following relation between the oedometer modulus E_{oed} and q_c is then often adopted:

$$E_{oed} = \alpha \times q_c$$

where:

α is a correlation factor estimated on the basis of local experience

An example of a correlation is given in annex B.3.

3.7.2 Pile foundations

(1)P When the ultimate bearing resistance of piles is evaluated from CPT results according to 7.6.3.3(4)P of ENV 1997-1, calculation rules based on established correlations between the results of static load tests and CPT results shall be used.

(2) In annex B.4 an example is given for the assessment of the bearing resistance of a single pile on the basis of q_c -values from a CPT.

4 PRESSUREMETER TEST (PMT)

4.1 General

(1)**P** The pressuremeter test covers the measurement in situ of the deformation of soils and weak rocks to the expansion of a cylindrical flexible membrane under pressure.

(2)**P** Four different types of apparatus are specified:

- Ménard pressuremeter (MPM),
- prebored pressuremeters (PBP),
- self-boring pressuremeter (SBP)
- full displacement pressuremeter (FDP).

(3) The PBP and the MPM are lowered into a test hole created specifically for the pressuremeter test.

(4) The SBP is drilled into the ground using an integral cutting head at its lower end such that the probe replaces the material it removes thereby creating its own test hole.

(5) The FDP is usually jacked into the ground with an integral cone at its lower end, thereby creating its own test hole. The MPM may in some instances be jacked or driven into the ground.

(6) PBP, SBP and FDP probes may take a number of forms, therefore descriptions are given in accordance with the type of installation and measuring systems.

(7) Two different basic test procedures are specified: a procedure to obtain a pressuremeter modulus, E_M , and limit pressure, p_{LM} , that may be used in design procedures formulated for the Ménard pressuremeter; and a procedure to obtain other stiffness and strength parameters.

(8)**P** The tests shall be carried out in accordance with a test method that complies with the requirements given in this section.

(9)**P** The test method used shall be reported in detail together with the test results.

(10) The test method may be reported by reference to a standard.

(11)**P** Any deviations from the requirements given below shall be justified and in particular their influence on the results shall be commented upon.

4.2 Definitions

(1)**P pressuremeter**: cylindrical device, designed to apply a uniform pressure to the walls of a cavity by means of a flexible membrane. The main components of a pressuremeter are shown in fig. 4.1.

(2)**P probe**: cylindrical part of the pressuremeter that is inflated and thereby transmits the pressure to the cavity walls. The probe may be lowered into a prebored hole, be bored, jacked or driven into the ground (see fig. 4.1)

(3)**P expanding section**: part of the probe fitted with the flexible membrane. The expanding section may be subdivided in one or three cells (see fig. 4.1).

(4)**P test hole**: length of borehole, specifically created for pressuremeter testing. It can be of the same diameter or smaller than the borehole and is created below the base of the borehole.

(5)**P cavity**: portion of a test hole that is subjected to pressure by the expanding membrane. At the start of a test the diameter of the cavity is the same diameter as the test hole.

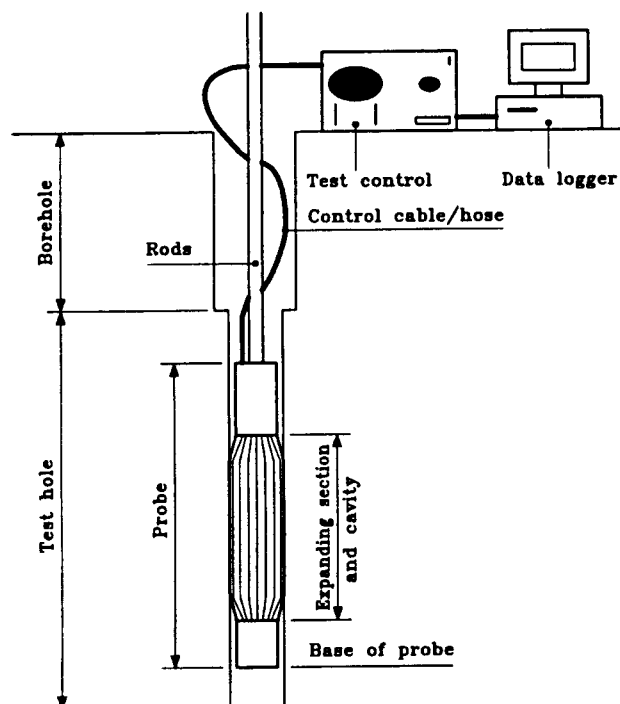


Figure 4.1: Key features of a pressuremeter

(6)P monocell probe: pressuremeter with a single expanding cell.

(7)P tricell probe: pressuremeter with three expanding cells, one of which, the central cell, is the measuring cell.

(8)P volume displacement type pressuremeter: pressuremeter fitted with a volume change gauge to measure the change in volume of the expanding section.

(9)P radial displacement type pressuremeter: pressuremeter fitted with displacement transducers to measure the change in radius or diameter of the expanding section.

(10)P membrane stiffness: pressure required to inflate the membrane in air.

(11)P membrane compression: change in thickness of the membrane as the pressure is increased.

(12)P system expansion: change in volume of the pressuremeter system, excluding the volume change of the probe, as a result of a pressure change.

(13)P applied pressure: is the pressure applied by the pressuremeter to the walls of the cavity in the soil or rock.

(14)P volume change: change in volume of the expanding cavity.

(15)P volumetric strain: change in volume of the cavity with respect to the original volume of either the cavity or the expanding section of the probe.

(16)P cavity strain: change in radius of the cavity with respect to the original radius of the cavity.

(17)P pressuremeter test curve: plot of the variation of the applied pressure with either the cavity strain or volume change or the volumetric strain.

(18) The basic curve can have one of the following forms, shown in figure 4.2. For the MPM test the axes are usually transposed.

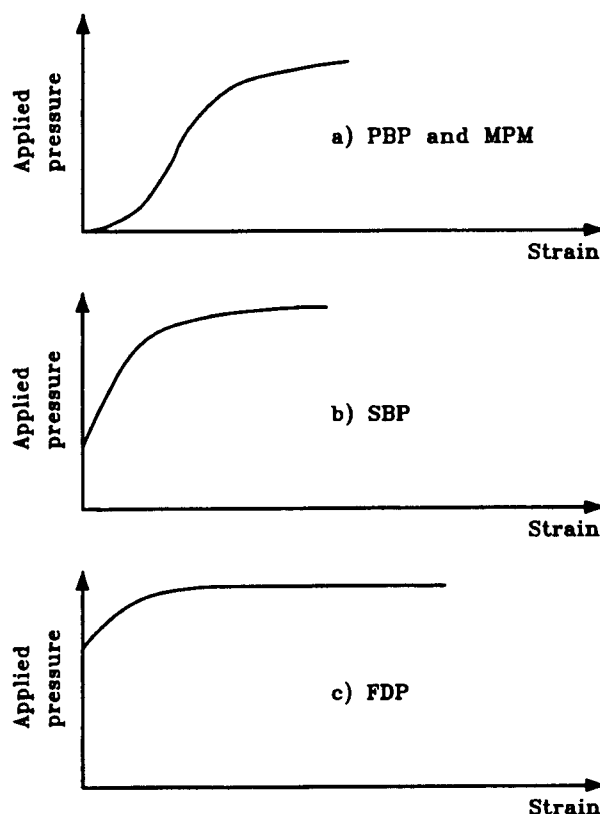


Figure 4.2: Forms of pressuremeter curves

4.3 Equipment

4.3.1 Apparatus

(1)**P** The expanding section of a pressuremeter, defined in 4.2, shall have a length to diameter ratio greater than 5.

(2)**P** The diameter of the flexible membrane shall be capable of expansion without bursting by:

- 50 % if the Ménard method is required;
- 50 % if an FDP is required;
- 25 % if a PBP is required;
- 15 % if an SBP is required in soils;
- 10 % if an SBP is required in weak rocks.

(3)**P** If a volume displacement type probe is used, volume changes shall be measured either in the control unit, at the surface, or in the probe.

(4)**P** If a radial displacement type probe is used, displacements shall be measured directly on the membrane circumference, at three or more equidistant points in the plane perpendicular to the axis through the centre of the probe.

(5)**P** The thrust machine and push rods used to jack an FDP into the ground shall comply with the specification for cone penetration tests.

4.3.2 Measuring equipment

(1)P Volume measuring gauges shall be capable of measuring changes in volume equal to 100 % or 50 % of the initial volume of the expanding section of the probe depending on the test method specified (100 % for the Ménard method).

(2)P The applied pressure shall be measured either in the control unit at the surface or in the probe and the gauge or transducer shall have a sensitivity compatible with the pressure range required for the ground being tested.

(3)P The working range of a pressure transducer or gauge shall be suitable for the ground to be tested.

(4)P The resolution of all electrical measuring devices and any associated data acquisition systems shall be within 0,1 % of their full working range. The resolution of all other measuring devices shall be within 1% of their full working range.

4.4 Test procedure

4.4.1 Calibrations

(1)P Calibrations for all probes shall be reliable, repeatable, accurate and traceable to standards.

(2)P Results of all calibrations shall be available on site for inspection.

(3)P The following calibrations shall be required:

- volume displacement type probes:
 - pressure transducers or gauges;
 - volume displacement gauges;
 - system expansion;
 - membrane stiffness;
 - membrane compression (if testing rock);
- radial displacement type probes:
 - pressure transducers;
 - displacement transducers;
 - membrane stiffness;
 - membrane compression (if testing rock).

(4)P Transducers and gauges shall be calibrated prior to the start and following the completion of the testing programme. For MPM testing this only applies if no calibration has been performed within the last 6 months.

(5)P Calibration of membrane stiffness shall be carried out prior to the start of testing on site and after the completion of every borehole. A new membrane shall be calibrated before use.

(6)P The displacement and pressure transducers shall be re calibrated following any repair of the transducers readout/control unit and connecting cables.

4.4.2 Installation

(1)P The probe shall be installed in such a manner that the disturbance to the surrounding ground is kept to a minimum for the type of probe.

(2)P Boring to form a test hole below the base of a borehole for the insertion of an MPM or PBP shall be carried out using equipment, techniques and a flushing medium consistent with achieving minimum disturbance. For any particular test hole sampling requirements shall be specified.

(3)P The boring techniques and flushing medium used with a SBP shall be consistent with achieving minimum disturbance to the ground surrounding the probe.

(4)P The initial volume of a deflated volume displacement type probe shall be determined at the surface before it is lowered into the borehole.

(5) The orientation of the probe may be recorded prior to the start of insertion into the borehole and before it is removed, particularly when radial displacement probes are used.

4.4.2.1 Ménard and other prebored pressuremeters

(1)P The diameter of the test hole shall be kept close to the diameter of the deflated probe, but shall not be less than the diameter of the deflated probe.

(2)P If a test hole is to be used for one test only, then the probe shall be inserted into the test hole within 60 min after completion of drilling the test hole, provided the depth to the test hole does not exceed 30 m. For holes below that, more time may be used.

(3)P If the borehole is of a larger diameter than the test hole then the distance between the top of the expanding section of a probe and the base of the borehole shall be at least half the length of the expanding section.

(4)P For a long test hole in which a number of tests will be carried out, all boring and testing shall be completed within one working shift.

4.4.2.2 Self-boring pressuremeter

(1)P The SBP shall be bored continuously from the ground surface or from the base of a borehole. It shall be bored a sufficient distance beyond a previous test position or beyond the base of a borehole into ground that is unaffected by either the previous test or the drilling of the borehole.

(2)P The minimum distance between test locations shall be equal to twice the distance between the centre of the expanding section and the base of the probe. If a length greater than that distance is required, then the length to be self-bored shall be specified.

(3)P During self-boring of a SBP the setting, type and rotational speed of the cutter, type and characteristics of drilling fluid, the drilling fluid pressure, rate of advance and ram pressure shall all be adjusted to ensure minimum disturbance without causing undue risk of damage to the equipment.

(4)P In free draining soils an expansion test shall be started as soon as practically possible following the completion of self-drilling. In all remaining soils and weak rocks there shall be a minimum of 30 minutes and a maximum of one hour between completion of self-boring and the start of the expansion test.

4.4.2.3 Full displacement pressuremeters

(1)P When a FDP incorporates an electrical cone, it shall be jacked into the soil between test levels at (20 ± 5) mm/s either from the base of a borehole or from the surface.

(2)P An expansion test shall be started as soon as practically possible following the completion of jacking.

4.4.3 Testing procedure

(1)P The expanding section of the pressuremeter shall be pressurised until the specified diameter as defined in 4.3.1(2)P is reached. The maximum pressure capacity of the probe shall be consistent with the pressure required to inflate the expanding section in the particular ground conditions as stated in 4.3.(2)P. For safety reasons the expansion may be terminated if either the maximum pressure capacity of the probe is reached or if any of the displacement transducers has reached its full working range or the maximum safe expanded volume is reached.

(2) The pressuremeter may be unloaded to produce an unload-reload cycle. The rates of unloading and reloading should be specified.

(3) Prior to unloading there can be a period during which the pressure or displacement is held constant.

(4) The reduction in stress during any unload-reload cycle should be specified.

(5) The strain at the start of any additional unload-reload cycles may be specified.

(6)P The output from the transducers shall be recorded at a minimum frequency of 10 s. intervals throughout the test if automatic recording is used, or 30 s. if manual readings are taken or shall be specified.

(7) For MPM tests recordings or readings are conventionally taken at 15 s, 30 s and 60 s after pressure application is completed.

4.4.3.1 Stress controlled tests - Ménard method

(1)P With the Ménard stress controlled method tests shall be carried out at a constant rate of pressure increase. The increments shall be adjusted to ensure that there are at least seven increases in pressure throughout the loading stage, however ten increases are preferred.

(2)P Each pressure increment shall be held constant for 1 min.

4.4.3.2 Other stress controlled tests

(1)P Incremental stress controlled tests shall be carried out at a constant rate of pressure increase.

(2) One unload-reload cycle, if required, can be included in the loading sequence when either the cavity has increased in diameter by between 1 % and 3 %, or when the pressure has reached 10 MPa, whichever occurs first.

(3)P The increments shall be no greater than 5 % of the maximum capacity of the probe and shall be adjusted to ensure that there are at least fifteen increases in pressure throughout the loading stage (excluding any unload-reload cycles).

(4) The size of the pressure increments may be adjusted during the early stage of the test to ensure that a sufficient number of readings can be taken to accurately define when the membrane comes in contact with the side of the hole and shall be no greater than 0,2 MPa.

(5)P Each pressure increment shall be held constant for 1 min.

4.4.3.3 Strain controlled tests

(1)P Strain controlled tests undertaken with a PBP shall be carried out using constant increments of volumetric or cavity strain. The increments shall be adjusted to ensure that there are at least twenty increases in volume throughout the loading stage.

(2)P Each increment shall be maintained for 1 min.

(3)P Strain controlled tests undertaken with an SBP shall be carried out at a constant rate of stress increase during the early stage of the test. Once expansion starts, a constant rate of strain of 1 % per minute shall be used.

(4)P Strain controlled tests undertaken with an FDP shall be carried out at a constant rate of stress increase during the early stage of the test. Once expansion starts, a constant rate of strain shall be used.

(5)P A sufficient number of readings shall be taken to define accurately the pressure at which expansion starts.

(6) An unload-reload cycle, if required in a PBP test, should be carried out when either the hole has increased in diameter by between 1 % and 3 % or when the pressure has reached 10 MPa, whichever occurs first.

(7) An unload-reload cycle, if required in an SBP test, should be carried out when the hole has increased in diameter by between 1 % and 3 %.

(8) An unload-reload cycle, if required in an FDP test, may be carried out once constant pressure conditions are approximately achieved.

4.5 Interpretation

4.5.1 Data reduction of pressuremeter tests

(1)P The applied pressure, corrected for membrane stiffness if necessary, shall be converted to stress.

(2)P If a radial displacement type pressuremeter is used, the displacement readings shall be converted to cavity strain and, if testing weak rock, corrected for membrane compression and thinning.

(3)P If a volume displacement type pressuremeter is used (e.g. Ménard) then the volume reading shall be corrected for system expansion.

4.5.2 Interpretation of the Ménard test

(1)P A plot of corrected volume change against corrected applied pressure expressed in stress shall be produced.

(2)P The Ménard pressuremeter modulus E_m and limit pressure p_{LM} shall be determined using the method illustrated in figure 4.3.

(3)P p_{LM} is defined as the pressure required to double the total volume of the cavity from the point (p_r, V_r) (see fig. 4.3). The pressure p_r is the pressure where $d(\Delta V)/dp$ is a minimum and V_r is the corresponding value of the injected volume. V_c is the deflated volume of the probe.

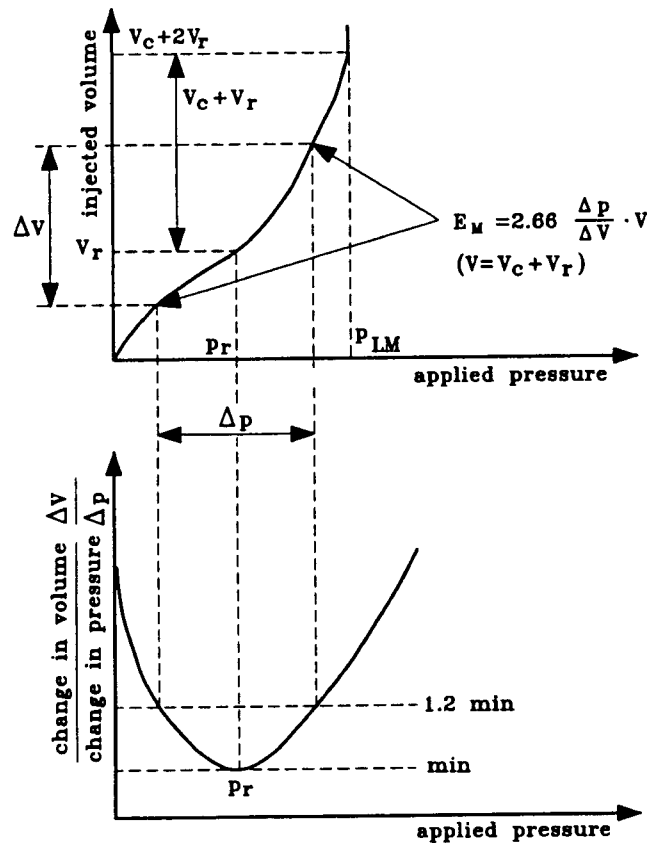


Figure 4.3: Interpretation of E_M and p_{LM} for an MPM test

4.6 Reporting the results

(1)P The following information shall be submitted prior to starting site work:

- full details of the pressuremeter and testing equipment;
- details of the proposed drilling equipment and flushing medium to be used for drilling boreholes;
- description of the methods of carrying out all the drilling operations for forming test holes;
- typical test data sheets and forms for presenting final results;
- reference description of the methods for carrying out the tests.

(2)P In addition to the requirements given in 2.6 the report shall include the following information to be submitted for each test on request:

- depth of the top and bottom of the test hole, and depth of the displacement measurement axes;
- details of bored, drilling (and self-drilling if applicable), including date and time of start and finish of all drilling, description and estimate of any drilling fluid returns and depth and size of casing used, if any;
- the output of the transducers recorded prior to and during installation and on removal from the borehole for any PBP;
- tabulated output of the transducers during a test, if required, time of start and finish of test and rates of stress and/or strain on magnetic media;
- the calibration results used to convert the test data to engineering units;
- tabulated calibrated test data on magnetic media on request if applicable;
- a plot of applied pressure against the volumetric or average cavity strain expressed as a percentage.

(3)P All information shall be presented. All graphical plots shall be presented on a scale which sensibly fills the entire page.

(4)P Values of E_M and ρ_{LM} if a Ménard test is carried out shall be submitted.

(5) In table 4.1 a list of additional plots is given.

Table 4.1: A list of additional plots

Probe	Ground type	Abscissa	Ordinate
radial displacement type			
self-bored, pushed in	all	cavity strain for each arm	applied pressure
prebored	all	cavity strain for each pair of arms	applied pressure
self bored	all	initial cavity strain for each arm	applied pressure
all	all	cavity strain for unload- reload cycle for each arm	applied pressure
all	clay	logarithm of cavity strain for each arm	applied pressure
all	sands	natural logarithm of current cavity strain for each arm	natural logarithm of effective applied pressure
volume displacement type (except MPM) ¹⁾			
prebored	all	volume change	applied pressure
prebored	all	rate of change of volume	applied pressure
¹⁾ For MPM tests the pressure is plotted as abscissa and the volume change as ordinate.			

4.7 Derived values of geotechnical parameters

(1)P When an indirect or analytical method is used the geotechnical parameters of shear strength and shear modulus shall be derived from the pressuremeter curve.

(2)P When a direct or semi-empirical method is used all the features of the method shall be taken into account.

4.7.1 Derived values for the calculation of bearing capacity resistance of spread foundations

(1) When the sample semi-empirical method of annex C in ENV 1997-1 is used the specification for the Ménard pressuremeter may be followed.

(2) An example of the calculation of the bearing resistance is given in annex C.1.

(3) When the sample analytical method of annex B in ENV 1997-1 is used, the strength of the soil may be determined using empirical and theoretical methods but only on the basis of local experience.

(4) The angle of shearing resistance, ϕ , may be determined from an SBP test in non cohesive soils by theoretical methods and from FDP and PBP tests using empirical correlations but only on the basis of local experience.

4.7.2 Derived values for the calculation of settlement of spread foundations

(1) The settlement of spread foundations may be determined from stress controlled tests (Ménard method, see 4.4.3.1) using a semi-empirical method.

(2) An example of the calculation of the settlement of a spread foundation is given in annex C.2.

(3) When the sample analytical methods of annex D in ENV 1997-1 are used, the stiffness of the soil may be determined using theoretical methods but only on the basis of local experience.

4.7.3 Pile foundations

(1) The ultimate bearing resistance of piles may be evaluated directly from stress controlled tests (Ménard method, see 4.4.3.1).

(2) An example of the calculation of the ultimate bearing resistance is given in annex C.3.

(3) When the ultimate bearing resistance of a pile is evaluated indirectly from pressuremeter test results an analytical method may be applied to derive values of base and shaft resistance based on local experience.

5 STANDARD PENETRATION TEST (SPT)

5.1 General

(1)P This method covers the determination of the resistance of soils at the base of a borehole to the dynamic penetration of a split barrel sampler and the obtaining of disturbed samples for identification purposes.

(2)P The basis of the test consists in driving a sampler by dropping a hammer of 63,5 kg mass on to an anvil or drive head from a height of 760 mm. The number of blows (N) necessary to achieve a penetration of the sampler of 300 mm (after its penetration under gravity and below a seating drive) is the penetration resistance.

(3) The test is used mainly for the determination of the strength and deformation properties of cohesionless soils, but some valuable data may also be obtained in other types of soils.

(4)P The tests shall be carried out in accordance with a method that complies with the requirements given in this section.

(5)P The test method used shall be reported in detail with the test results.

(6) The test method may be reported by reference to a standard.

(7)P Any deviation from the requirements given below shall be justified and in particular its influence on the results of the test shall be commented upon.

(8) Experience of deviations exists with respect to the following points:

- use of a solid 60° cone instead of the standard shoe when dealing with gravelly materials;
- use of a barrel with an internal diameter larger than that of the shoe, in order to place an inside liner flush with the shoe where the sample is recovered;
- an encased hammer assembly operating directly on top of the sampler in the bottom of the borehole.

5.2 Definitions

(1)P drive-weight assembly: a device consisting of the hammer, hammer fall guide, the anvil, and the hammer drop system.

(2)P anvil or drive head: that portion of the drive-weight assembly which the hammer strikes and through which the hammer energy passes into the drive rods.

(3)P drive rods: rods that connect the drive-weight assembly to the sampler.

(4)P Energy ratio-ER: ratio between the actual energy delivered into the drive rod, immediately below the anvil, and the theoretical free fall energy of the hammer, expressed in percentage.

(5)P hammer: that portion of the drive-weight assembly consisting of the 63,5 kg impact weight which is successively lifted and dropped to provide the energy that accomplishes the sampling and penetration.

(6)P N-value: the number of blows required to drive the sampler. The N-value, reported in blows per 300 mm, equals the sum of the number of blows required to drive the sampler over the depth interval of 150 mm to 450 mm from the base of the borehole (and after its eventual penetration under gravity).