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Geotechnical investigation and testing - Field testing - Part 2: Dynamic probing (ISO 22476-2:2005)

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Geotechnische Erkundung und Untersuchung - Felduntersuchungen - Teil 2: Rammsondierungen (ISO 22476-2:2005)

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Foreword

This document (EN ISO 22476-2:2005) has been prepared by Technical Committee CEN/TC 341 “Geotechnical investigation and testing”, the secretariat of which is held by DIN, in collaboration with Technical Committee ISO/TC 182 “Geotechnics”.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2005, and conflicting national standards shall be withdrawn at the latest by July 2005.

EN ISO 22476 *Geotechnical investigation and testing - Field testing* has the following parts:

— *Part 1: Electrical cone and piezocone penetration tests*

— *Part 2: Dynamic probing*

— *Part 3: Standard penetration test*

— *Part 4: Ménard pressuremeter test*

— *Part 5: Flexible dilatometer test*

— *Part 6: Self-boring pressuremeter test*

— *Part 7: Borehole jack test*

— *Part 8: Full displacement pressuremeter test*

— *Part 9: Field vane test*

— *Part 10: Weight sounding test*

— *Part 11: Flat dilatometer test*

— *Part 12: Mechanical cone penetration test*

— *Part 13: Plate loading test*

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1 Scope

This document specifies requirements for indirect investigations of soil by dynamic probing as part of geotechnical investigation and testing according to EN 1997-1 and EN 1997-2.

This document covers the determination of the resistance of soils and soft rocks in situ to the dynamic penetration of a cone. A hammer of a given mass and given height of fall is used to drive the cone. The penetration resistance is defined as the number of blows required to drive the cone over a defined distance. A continuous record is provided with respect to depth but no samples are recovered.

Four procedures are included, covering a wide range of specific work per blow:

— dynamic probing light (DPL): test representing the lower end of the mass range of dynamic equipment;

— dynamic probing medium (DPM): test representing the medium mass range of dynamic equipment;

— dynamic probing heavy (DPH): test representing the medium to very heavy mass range of dynamic equipment;

— dynamic probing super heavy (DPSH): test representing the upper end of the mass range of dynamic equipment.

The test results of this document are specially suited for the qualitative determination of a soil profile together with direct investigations (e.g. sampling according to prEN ISO 22475-1) or as a relative comparison of other in situ tests. They may also be used for the determination of the strength and deformation properties of soils, generally of the cohesionless type but also possibly in fine-grained soils, through appropriate correlations. The results can also be used to determine the depth to very dense ground layers e.g. to determine the length of end bearing piles, and to detect very loose, voided, back-filled or infilled ground.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 10204, *Metallic products — Types of inspection documents*

prEN ISO 22475-1, *Geotechnical investigation and testing — Sampling by drilling and excavation methods and groundwater measurements — Part 1: Technical principles for execution (ISO/DIS 22475-1:2004)*

3 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

3.1
dynamic penetrometer
cone and drive rods

3.2
dynamic probing equipment
penetrometer and all equipment necessary to drive the penetrometer

3.3
anvil or drive head
portion of the drive-weight assembly that the hammer strikes and through which the hammer energy passes into the drive rods

3.4
cushion; damper
placed upon the anvil to minimise damage to the equipment

3.5
hammer
portion of the drive-weight assembly which is successively lifted and dropped to provide the energy that accomplishes the penetration of the cone

3.6
height of fall
free fall of the hammer after being released

3.7
drive-weight assembly
device consisting of the hammer, the hammer fall guide, the anvil and the drop system

3.8
drive rods
rods that connect the drive-weight assembly to the cone

3.9
cone
pointed probe of standard dimensions used to measure the resistance to penetration (see Figure 1)

3.10
actual energy; driving energy
E_{meas}
energy delivered by the drive-weight assembly into the drive rod immediately below the anvil, as measured

3.11
theoretical energy
E_{theor}
energy as calculated for the drive weight assembly,

$$E_{\text{theor}} = m \times g \times h$$

where

m is the mass of the hammer;

g is the acceleration due to gravity;

h is the falling height of the hammer.

3.12
energy ratio
E_{r}
ratio of the actual energy E_{meas} and the theoretical energy E_{theor} of the hammer expressed in percentage

3.13
N_{xy}-value
number of blows required to drive the penetrometer over a defined distance x (expressed in centimetres) by the penetrometer y

3.14
specific work per blow
$\boldsymbol{E_n}$
value calculated by

$$E_n = m \times g \times h/A = E_{theor}/A$$

where

m is the mass of the hammer;

g is the acceleration due to gravity;

h is the falling height of the hammer;

A is the nominal base area (calculated using the base diameter D);

E_{theor} is the theoretical energy.

4 Equipment

4.1 Driving device

Dimensions and masses of the components of the driving device are given in Table 1. The following requirements shall be fulfilled:

a) hammer shall be conveniently guided to ensure minimal resistance during the fall;

b) automatic release mechanism shall ensure a constant free fall, with a negligible speed of the hammer when released and no induced parasitic movements in the drive rods;

c) steel drive head or anvil should be rigidly connected to the top of the drive rods. A loose connection can be chosen;

d) guide to provide verticality and lateral support for that part of the string of rods protruding above the ground should be part of the driving device.

If a pneumatic system for lifting a hammer is used, it shall be supplied with inspection documents as stipulated by EN 10204 because the driving energy is not always ensured.

4.2 Anvil

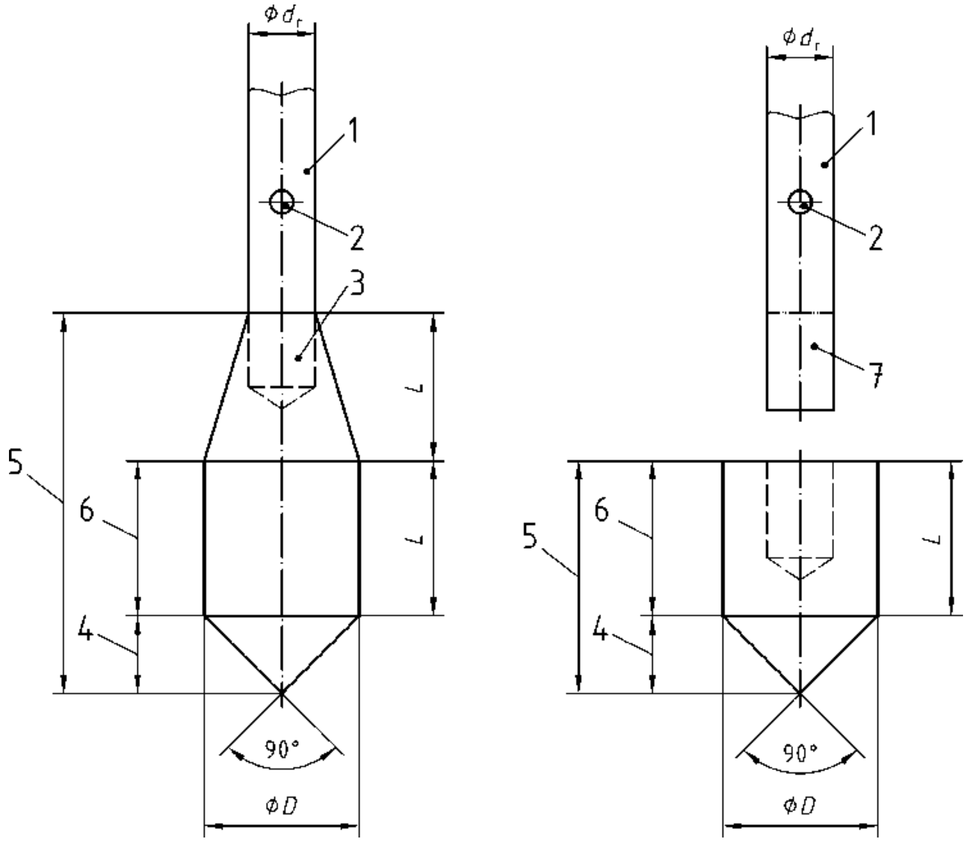
The anvil shall be made of high strength steel. A damper or cushion may be fitted between the hammer and anvil.

4.3 Cone

The cone of steel shall have an apex angle of 90° and an upper cylindrical extension mantle and transition to the extension rods as shown in Figure 1 and with the dimensions and tolerances given in Table 1. The cone may be either retained (fixed) for recovery or disposable (lost). When using a disposable cone the end of the drive rod shall fit tightly into the cone. Alternative specifications for the cones are given in Figure 1.

Key

1 Extension rod
2 Injection hole (optional)
3 Thread mounting
4 Cone tip
5 Cone
6 Mantle
7 Point mounting
L Mantle length
D Base diameter
d_r Rod diameter



a) Cone Type 1 shown as retained (fixed)

b) Cone Type 2 shown as disposable (lost)

Figure 1 – Alternative forms of cones for dynamic probing (for *L*, *D* and d_r see Table 1)

4.4 Drive rods

The rod material shall be of a high-strength steel with the appropriate characteristics for the work to be performed without excessive deformations and wear. The rods shall be flush jointed, shall be straight and may have spanner flats. Deformations shall be capable of being corrected. The deflection at the mid point of an extension rod measured from a straight line through the ends shall not exceed 1 in 1 000, i.e. 1 mm in 1 m. Dimensions and masses of the drive rods are given in Table 1.

Hollow rods should be used.

4.5 Torque measuring device

The torque necessary to turn the driving rods is measured by means of a torque wrench or similar measuring device. The apparatus shall be able to measure a torque of at least 200 Nm and be graduated to read at least in 5 Nm increments.

A sensor for recording the torque may be used.

The spanner flat in the drive rods can be used to fix the torque wrench or measuring device.

4.6 Optional equipment

4.6.1 Blow counter

A device to count the number of blows of the hammer by measuring mechanical or electric impulses can be placed on the system.

4.6.2 Penetration length measuring device

The penetration length is measured either by counting on a scale on the rods or by recording sensors. In this latter case, resolution shall be better than 1/100 of the measure length.

4.6.3 Injection system

The injection system includes:

— hollow rods;

— solid end of the lowest when using disposable (lost) cone;

— pump with mud connected to a device fixed under the anvil and intended to ensure the filling of the annular space between the ground and the drive rods created by the enlarged cone.

The flow of the pump is such that it will always ensure that the annular space between the ground and the drive rods is filled.

NOTE 1 Mud, for example, can be a mixture of bentonite and water with a mass ratio of dry particles and water of 5 % to 10 %.

NOTE 2 The mud circulation towards the surface is not obligatory. The pressure of injection is that corresponding, after deduction of the head losses, to the hydrostatic pressure due to mud on the level of the cone.

A manual pump may be used.

4.6.4 Apparatus for measuring the dimensions of the cone

The measurement of the diameter and length of the cone is made by means of a slide calliper to the 1/10 of mm or by an equivalent system.

4.6.5 Device to control rod string deviation from the vertical

A system or guide for supporting the protruding part of the rods should be in place to ensure and check that the drive rods are maintained in a vertical alignment.

Table 1 — Dimensions and masses for the four types of dynamic probing apparatus

Dynamic Probing Apparatus	Sym-bol	Unit	DPL (light)	DPM (medium)	DPH (heavy)	DPSH (super heavy)	
						DPSH-A	DPSH-B
Driving device							
hammer mass, new	m	kg	10 ± 0,1	30 ± 0,3	50 ± 0,5	63,5 ± 0,5	63,5 ± 0,5
height of fall	h	mm	500 ± 10	500 ± 10	500 ± 10	500 ± 10	750 ± 20
Anvil							
diameter	d	mm	$50<d<D_h$ [a]	$50<d<D_h$ [a]	$50<d<0,5\ D_h$ [a]	$50<d<0,5\ D_h$	$50<d<0,5\ D_h$ [a]
mass (max.)	m	kg	6	18	18	18	30
(guide rod included)							
90° Cone							
nominal base area	A	cm^2	10	15	15	16	20
base diameter, new	D	mm	35,7 ± 0,3	43,7 ± 0,3	43,7 ± 0,3	45,0± 0,3	50,5 ± 0,5
base diameter, worn (min.)		mm	34	42	42	43	49
mantle length (mm)	L	mm	35,7 ± 1	43,7 ± 1	43,7 ± 1	90,0 ± 2 [b]	51 ± 2
length of cone tip		mm	17,9 ± 0,1	21,9 ± 0,1	21,9 ± 0,1	22,5 ± 0,1	25,3 ± 0,4
tip max. permissible wear		mm	3	4	4	5	5
Drive rods [c]							
mass (max)	m	kg/m	3	6	6	6	8
diameter OD (max)	d_r	mm	22	32	32	32	35
rod deviation [d]:							
lowermost 5 m		%	0,1	0,1	0,1	0,1	0,1
remainder		%	0,2	0,2	0,2	0,2	0,2
Specific work per blow	mgh/A E_n	kJ/m^2	50	100	167	194	238

[a] D_h diameter of the hammer, in case of rectangular shape, the smaller dimension is assumed to be equivalent to the diameter.

[b] disposable cone only

[c] maximum rod length shall not exceed 2 m

[d] rod deviation from the vertical

NOTE Tolerances given are manufacturing tolerances.

5 Test procedure

5.1 Equipment checks and calibrations

Prior to each test, a check of dimensions shall be made to ensure that they are within the values given in Table 1. The straightness of the rods shall be checked once on each new site and at least every 20 penetration tests at that site. After each test, a visual check of the straightness of the rods shall be made.

At the test site, the rate of blows, the height of fall, the friction free fall of the hammer, the proper condition of the anvil and the mechanical release devices shall be checked for satisfactory operation which is to be ensured for the whole test series. In addition, the proper functioning of the recording device has to be checked in case automatic recording equipment is used.

The precision of the measuring instruments – if applicable – shall be checked after any damage, overloading or repair and at least once every six months, unless the manufacturer's manual requires shorter inspection intervals. Faulty parts shall be replaced. Calibration records shall be kept together with the equipment.

To check pneumatic dynamic penetrometers, the driving energy per impact (actual energy E_{meas}) shall be measured directly. When divided by the area of the cone then this shall not deviate from the theoretical value of specific work per blow as specified in Table 1 by more than 3 %. The driving energy per impact shall be checked every six months.

Energy losses occur e.g. due to friction at the hammer (velocity loss compared to the free fall) or due to energy losses during the hammer impact on the anvil. Therefore, for each new driving device the actual energy transmitted to the drive rods should be determined.

NOTE A recommended method to determine the actual energy is given in Annex C.

5.2 Test preparation

In general, dynamic probing is performed from the ground surface.

Dynamic probing test equipment shall be set up with the penetrometer vertical, and in such a way that there will be no displacement during testing. The inclination of the driving mechanism and the driving rod projecting from the ground shall not deviate by more than 2 % from the vertical. If this is not the case, the dynamic probing test shall be stopped. In difficult ground conditions deviations up to 5 % may be allowed and shall be reported.

Trailer-mounted dynamic probing test equipment shall be supported in such a way that the suspension travel of the support trailer cannot influence the test.

The equipment shall be set up with appropriate clearance from structures, piles, boreholes etc., in order to be certain that they will not influence the result of the dynamic probing test.

When carrying out dynamic probing in situations where the rods are free to move laterally, for instance over water or in boreholes, the rods shall be restrained by low-friction supports spaced not greater than 2,0 m apart in order to prevent bending during driving.

5.3 Test execution

The drive rods and the cone shall be driven vertically and without undue bending of the protruding part of the extension rods above the ground.

No load shall be applied to anvil and rods during lifting of the hammer.

The penetrometer shall be continuously driven into the ground. The driving rate shall be kept between 15 and 30 blows per minute. All interruptions longer than 5 minutes shall be recorded.

The rods shall be rotated 1½ turns or until maximum torque is reached at least every 1,0 m penetration. The maximum torque required to turn the rods shall be measured using a torque measuring wrench or an equivalent device and shall be recorded.

During heavy driving, the rods shall be rotated 1½ turns after every 50 blows to tighten the rod connections.

To decrease skin friction, drilling mud or water may be injected through horizontal or upwards holes in the hollow rods near the cone. A casing may be sometimes used with the same purpose.

The number of blows shall be recorded every 100 mm penetration for the DPL, DPM and DPH and every 100 mm or 200 mm penetration for the DPSH-A and DPSH-B.

The normal operating range of blows should be between N_{10} = 3 and 50 for DPL, DPM and DPH and between N_{20} = 5 and 100 for DPSH-A and DPSH-B. For specific purposes, these ranges may be exceeded. In cases beyond these ranges, when the penetration resistance is low, e.g. in soft clays, the penetration depth per blow may be recorded. In hard soils or soft rocks, where the penetration resistance is very high or exceeding the normal range of blows, the penetration for a certain number of blows may be recorded as an alternative to the N -values.

In general, the test should be stopped, if either the number of blows exceeds twice the maximum values given above or the maximum value is exceeded continuously for 1 m penetration.

5.4 Influencing factors

Geotechnical or equipment related factors can influence the selection and operation of the equipment and the results of the tests.

NOTE Examples are given in Annex D.

5.5 Safety requirements

National safety regulations shall be followed; e.g. regulations for:

— personal health- and safety equipment;

— clean air, if working in confined spaces;

— ensuring the safety of the equipment.

6 Test results

The test results shall be reported and interpreted based on values of N_{10} for DPL, DPM, DPH and N_{10} or N_{20} for DPSH-A and DPSH-B.

Another possibility for the interpretation of test results is the use of the dynamic point resistance (see Annex E).

Consideration shall be given to the influence on recorded N_{xy}-values such as rod friction due to soil adhesion or bending (see e.g. Annex D).

Because of hammer fall energy losses, it is recommended to know by calibration the actual energy E_{meas} transmitted to the drive rods when this test is used for quantitative evaluation purposes.

7 Reporting

7.1 Field report

7.1.1 General

At the project site, a field report shall be completed. This field report shall consist of the following, if applicable:

a) summary log, e.g. according to Annex A;

b) record of measured values and test results.

All field investigations shall be reported such that third persons are able to check and understand the results.

7.1.2 Record of measured values and test results

At the project site, the following information shall be recorded for each test:

a) general information:

1) name of the client;

2) name of the contractor;

3) job or project number;

4) name and location of the project;

5) name and signature of the test equipment operator in charge;

b) information on the location of the test:

1) date and number of test;

2) field sketch (to scale or not to scale) including direct investigations (e.g. boreholes);

3) place within or which is nearest to the location of the penetration test;

4) ground elevation referred to a fixed point;

5) x, y, z co-ordinates of the location of the penetration test;

6) operation on land or water;

c) information on the used test equipment:

1) type of dynamic probing (DPL, DPM, DPH, DPSH-A or DPSH-B);

2) manufacturer, model and number of the test equipment;

3) type of cone (disposable or fixed);

4) type of anvil (fixed or loose);

5) use of dampers or cushions;

d) information on the test procedure:

1) weather condition;

2) documentation of the equipment check and calibration conducted in accordance with 5.1;

3) test record with:

— N_{10}/N_{20}-values at each measured depth of the tip of the cone;

— maximum torque at each measured depth;

4) separate precautions against rod friction (e.g. use of casing, drilling mud or water);

5) pre-drilling, if used;

6) blow count frequency when operating the equipment;

7) groundwater level, artesian conditions, if known;

8) all unusual events or observations during the operation (e.g. low blow count, penetration without blows, temporary obstructions, malfunction of the equipment);

9) observations on the recovered cone and/or rods;

10) all interruptions during the work, with time duration and change of rod;

11) reasons for early end of the test;

12) back-filling of penetration hole, if required.

NOTE Annexes A and B give examples of field report documents.

7.2 Test report

For checking the quality of the data, the test report shall include the following in addition to the information given in 7.1:

a) field report (in original and/or computerised form);

b) graphical representation with respect to depth of the following data:

- recorded number of blows to drive the cone 100 mm for the DPL, DPM and DPH or 100 mm or 200 mm for the DPSH-A and DPSH-B, as step diagram with the number of blows on the horizontal axis and the depth on the vertical axis;

- maximum torque required to rotate the penetrometer at each test level (in Nm);

- all interruptions during the work, longer than 5 minutes;

c) any corrections in the presented data;

d) any limitations of the data (e.g. irrelevant, insufficient, inaccurate or adverse test results);

e) name and signature of the field manager.

The test results shall be reported about in such a fashion that third persons are able to check and understand the results.

Annex A
(informative)

Summary log for dynamic probing

Place within which or which is nearest to*) location of penetration test: ______________________

x, y, z-coordinates: ______________________

Client/job number: ______________________

Name and location of project: ______________________

Contractor: ______________________ Equipment operator: ______________________

Date of test: ______________________

Type of dynamic probing *): DPL, DPM, DPH, DPSH-A, DPSH-B: ______________________

Equipment checked and in accordance with EN ISO 22476-2, 5.1; Yes/No*) on: ______________________

Field sketch (scale 1 :_______/not to scale) *) **with direct geotechnical investigations (e.g. boreholes) entered:**							

Other relevant data: ______________________

Signature: ______________________

Name of the operator in charge:

____

*) Delete as applicable.

Annex B
(informative)

Record of measured values and test results for dynamic probing

Contractor:				**Job number:**				**Enclosure:**	
Client/name of project:									
Dynamic probing test No:				Date:					
Type of dynamic probing test*): DPL, DPM, DPH, DPSH-A, DPSH-B or:									
Lost/fixed cone *)				Fixed/loose anvil *)					
x, y, z-coordinates									
Depth; add 10, 20 or 30 m (as depth > 10 m): +				m					
Depth	N_{10}/N_{20}*)	Depth	N_{10}/N_{20}*)	Depth	N_{10}/N_{20}*)	Depth	N_{10}/N_{20}*)	Depth	N_{10}/N_{20}*)
0,10		2,10		4,10		6,10		8,10	
0,20		2,20		4,20		6,20		8,20	
0,30		2,30		4,30		6,30		8,30	
0,40		2,40		4,40		6,40		8,40	
0,50		2,50		4,50		6,50		8,50	
0,60		2,60		4,60		6,60		8,60	
0,70		2,70		4,70		6,70		8,70	
0,80		2,80		4,80		6,80		8,80	
0,90		2,90		4,90		6,90		8,90	
1,00		3,00		5,00		7,00		9,00	
**)	Nm		Nm	**)	Nm	**)	Nm	**)	Nm
1,10		3,10		5,10		7,10		9,10	
1,20		3,20		5,20		7,20		9,20	
1,30		3,30		5,30		7,30		9,30	
1,40		3,40		5,40		7,40		9,40	
1,50		3,50		5,50		7,50		9,50	
1,60		3,60		5,60		7,60		9,60	
1,70		3,70		5,70		7,70		9,70	
1,80		3,80		5,80		7,80		9,80	
1,90		3,90		5,90		7,90		9,90	
2,00		4,00		6,00		8,00		10,00	
**)		**)		**)		**)		**)	
*) delete as applicable. **) measured torque									
Other data Groundwater: .... m below starting point Name and signature of the operator in charge:									

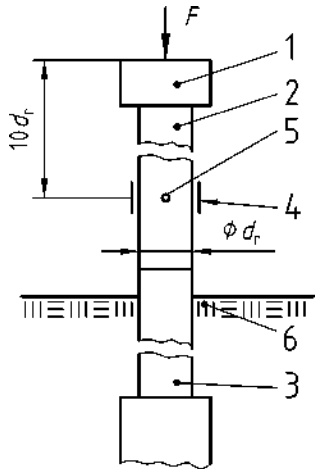
Annex C
(informative)

Recommended method to measure the actual energy

C.1 Principle

The measurement of the energy transmitted to the drive rods can be made by means of an instrumented section of rod positioned at a distance greater than 10 times the rod diameter below the point of hammer impact on the anvil (see Figure C.1).

For additional information see [1] to [6] of the bibliography.



Key

1 Anvil

2 Part of instrumented rod

3 Drive Rod

4 Strain gauge (measuring transducer)

5 Accelerometer

6 Ground

F Force

d_r Diameter of the rod

Figure C.1 — Instrumented rod (example)

C.2 Equipment

The measuring device consists of a removable instrumented rod fixed between the anvil and the head of rods. It includes:

— system for measurement of vertical acceleration having a linear response up to 5 000 g;

— system for measurement giving the axial deformation induced in the rod;

— apparatus, with a resolution better than 1×10^{-5}s, for viewing, recording and pre-treatment of the signals;

— data processing system (data logger and computer).

When strain gauges are used for the measurement of the axial deformation, they should be uniformly distributed around the instrumented rod, preferably in two orthogonal pairs.

C.3 Measurements

At each impact, check the correct operation of the measuring equipment and the sensors by displaying the results of measurements.

It should be verified that the signals from the accelerometers and of the gauges are null before and after the impact.

For the measurement of the acceleration and deformation, the precision should be better than 2 % of the measured value.

C.4 Calculation

C.4.1 The force F transmitted to the rods is calculated as follow:

$$F(t) = A_{\text{a}} \times E_{\text{a}} \times \varepsilon_{\text{m}}(t) \quad \text{(C.1)}$$

where

$\varepsilon_{\text{m}}(t)$ is the measured axial deformations of the instrumented rod at time t;

A_{a} is the cross-sectional area of the instrumented rod;

E_{a} is the Young's modulus of the instrumented rod.

C.4.2 The particle velocity $v(t)$ of the measurement section is calculated by integration of the acceleration $a(t)$ with time t.

C.4.3 The basic equation for the energy E which passes into the drive rods is:

$$E(t') = \int_0^{t'} F(t) v(t) dt \quad \text{(C.2)}$$

where

$E(t')$ is the driving energy which passes into the drive rod up to time t' after the impact.

NOTE Various methods for developing the above equation and additional information can be found in the Bibliography.

C.4.4 The hammer energy to take into account is the mean value obtained from at least five measures:

$$E_{\text{meas}} = \frac{1}{n} \sum_{1}^{n} E \quad \text{(C.3)}$$

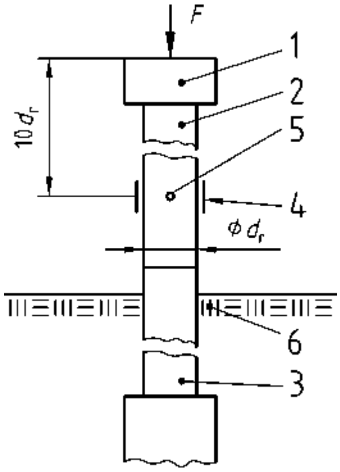
C.4.5 The hammer energy ratio which characterises each dynamic penetrometer is given by:

$$E_{\text{r}} = \frac{E_{\text{meas}}}{E_{\text{theor}}} \leq 1 \quad \text{(C.4)}$$

where

$E_{\text{theor}} = m \times g \times h$;

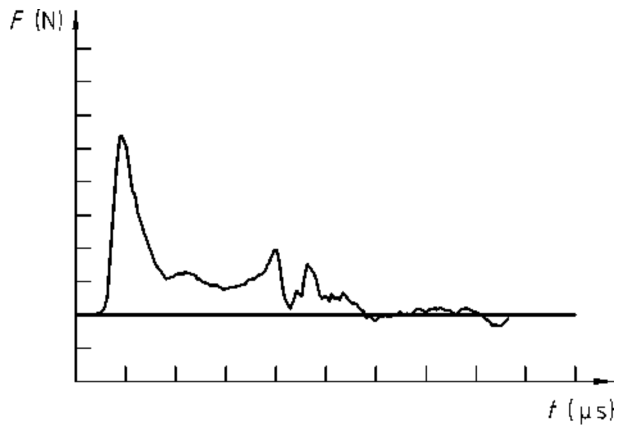
h is the falling height of the hammer;
m is the mass of the hammer;
g is the acceleration due to gravity.



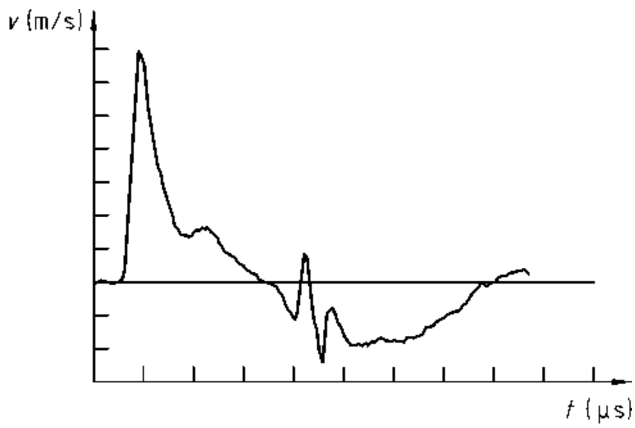
(Key see Figure C.1)

Hammer Energy Measurement Report	
Type of dynamic probing	
Job number	
Date of the test	
Mass of the hammer m	
Falling height h	
$E_{theor} = m \times g \times h$	
Characteristics of the instrumented rod	
Diameter d_r	
Length of the instrumented rod l_a	
Area A_a	
Modulus E_a	

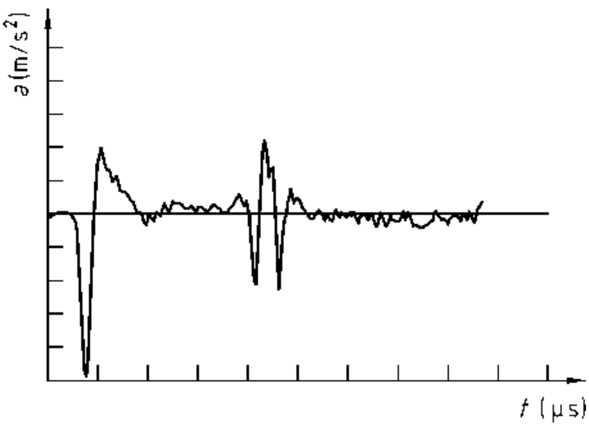
Force



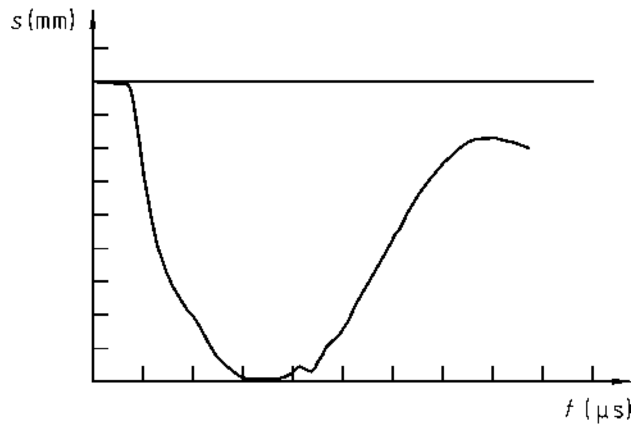
Particle velocity



Acceleration



Axial deformation



Observations:		Date
E_{meas}=	E_{theor}=	Name and signature of the operator in charge

Figure C.2 — Example of a hammer energy measurement report

Annex D
(informative)

Geotechnical and equipment influences on the dynamic probing results

D.1 Introduction

D.1.1 General

The following factors can affect the results:

- geotechnical influences due to the dependence of the penetration resistance on the shear strength of the soil and the stress level at the depth of penetration;
- equipment influences.

In selecting and operating the equipment and in order to avoid misinterpretation of the dynamic probing results, these factors should be considered; also findings from direct investigations (e.g. sampling according prEN ISO 22475-1) should be available.

D.1.2 Geotechnical influences

D.1.2.1 Influence of soil type, soil group and soil characteristics

For coarse-grained soils, apart from density, the grain structure, the grain size distribution, the grain shape and grain roughness, the mineral type, the degree of cementation and the strain condition in the soil can affect the results.

Examples of the influences of soil type, soil group and soil characteristics are given in D.2 to D.4.

An example of the influence of the boundary depth is given in D.5.

For fine grained soils, rod friction can have a significant influence on the recorded blow count. The use of drilling mud and water can reduce this effect (see D.3).

D.1.2.2 Influence of the groundwater

Under otherwise equal soil conditions in coarse grained soils, the number of blows is lower below the groundwater level; this is particularly marked for low penetration resistances. Examples of the influence of the groundwater are given in D.6.

Under otherwise equal soil conditions, the number of blows in silty soils may be equal or higher below the groundwater level.

D.1.3 Equipment influences

The following are to be considered as equipment influences on the penetration resistance:

- cone diameter;
- rod length;
- rod deviation;

— energy losses within the drive systems.

Examples of some of the equipment influences are given in D.7.

D.2 Examples for results of dynamic probing in coarse-grained soils

Other conditions remaining the same, the following applies:

a) the penetration resistance increases more than linearly with increasing density index of the soil; thus a change in density index, for example as a result of deep compaction, can be detected by dynamic probing;

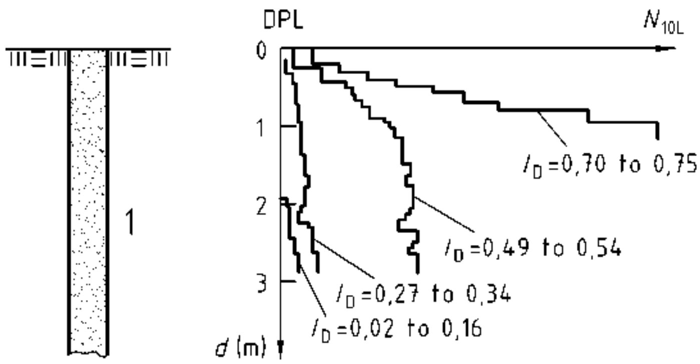
b) soils with sharp-edged or rough particles possess a higher penetration resistance than soils with round and smooth particles;

c) cobbles and boulders can significantly increase the penetration resistance;

d) particle size distribution (uniformity coefficient and grading curve) influence the penetration resistance;

e) penetration resistance is considerably increased by cementation.

Figure D.1 shows the results of a light dynamic probing test (DPL) in backfilled soil.



Key

1 Medium and coarse sand

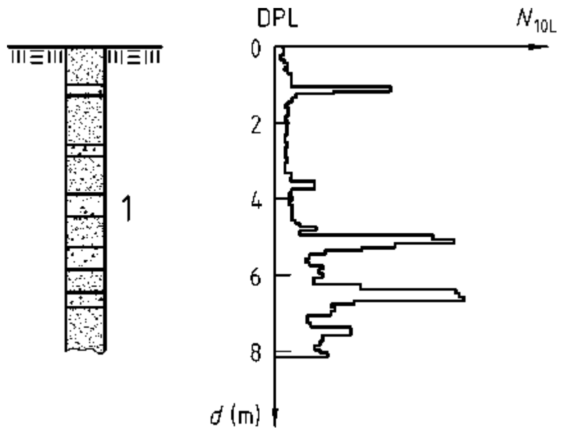
I_D Density index

d Depth

Figure D.1 — Change in penetration resistance with density index I_D in a homogeneous backfilled soil

The tests were made in a test pit in which medium and coarse sand had been placed in layers of different relative densities. The penetration resistance increases sharply with increasing density index of the soil; the indication thus becomes more sensitive.

Figure D.2 shows the increase in penetration resistance when there are thin layers with embedded cobbles. Locally occurring peaks of penetration resistance do not represent a measure of the bearing capacity of the whole layer.



Key

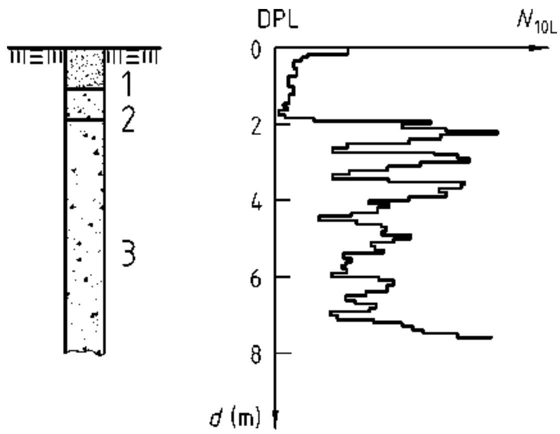
1 Coarse silt, fine-sandy with layers of stones

d Depth

Figure D.2 — Increase in penetration resistance due to embedded cobbles

Figure D.3 shows that penetration resistance fluctuates more sharply in coarse-grained soils than in fine grained soils. The range of variation is more pronounced in gravels than in sands.

The absolute variations in penetration resistance obtained with a light dynamic penetrometer (DPL) do not result only from differing relative densities but also from the larger penetration resistance due to displacing or breaking up of embedded larger particles.



Key

1 Silt, sandy

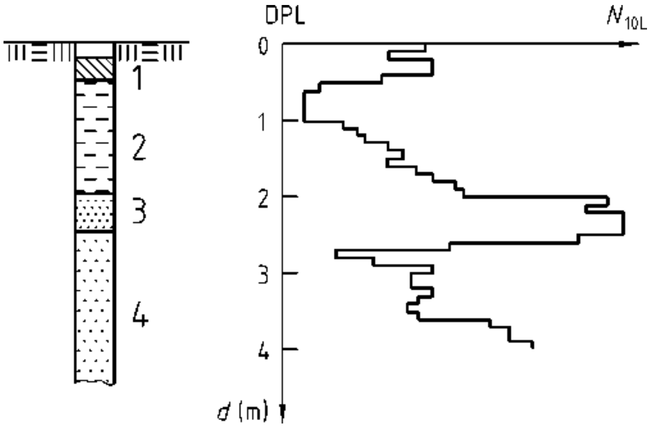
2 Silt

3 Gravel

d Depth

Figure D.3 — Variations in penetration resistance in fine-grained and coarse-grained soils

Figure D.4 shows the effect of cementing of the particles of a sand layer on the penetration resistance to a light dynamic penetrometer (DPL). This type of cementing may remain undetected with borings. The cementing was observed in trial pits.



Key

1 Loam

2 Clay

3 Medium sand, cemented

4 Medium sand

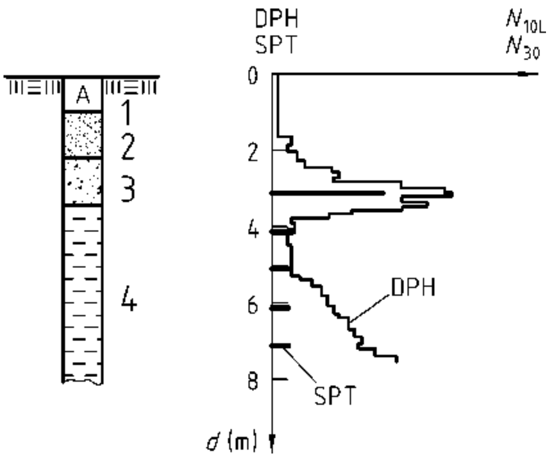
d Depth

Figure D.4 — Increase in penetration resistance in a cemented medium sand

D.3 Examples for results from dynamic probing in fine-grained soils

In soft soil types the skin friction along the rod has considerable influence on the penetration resistance. This may mean, for example, that cavities in the subsoil are not recognised as such.

Figure D.5 shows that the standard penetration test (SPT), unlike the result produced by the heavy dynamic penetrometer (DPH), shows virtually the same penetration resistances in clay because here the skin friction along the rod has been eliminated by performing the SPT in a borehole.



Key

1 Fill

2 Silt, sandy, gravely

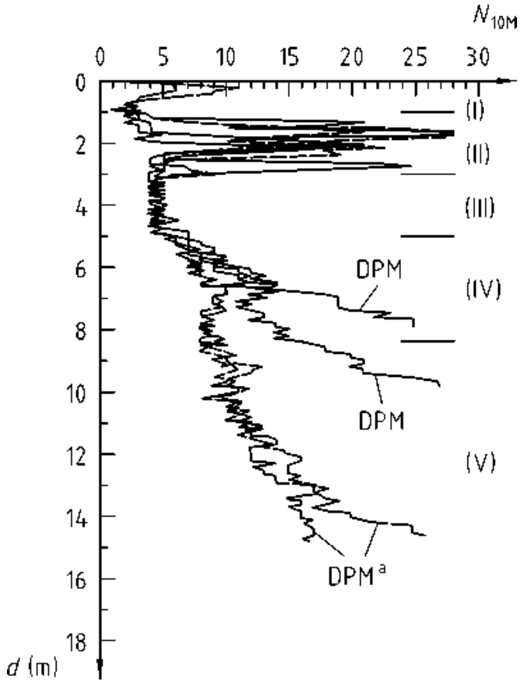
3 Gravel, sandy

4 Clay

d Depth

Figure D.5 — Increase in penetration resistance as a result of skin friction along the rod using a heavy dynamic penetrometer (DPH) compared with the standard penetration test (SPT)

Figure D.6 shows DPM profiles driven with and without the aid of drilling mud. The drilling mud reduces the friction on the drive rods allowing penetration to greater depth. This data has not been corrected for friction using the torque measurements.



Key

DPM Dynamic probing medium without drilling mud

DPM [a] Dynamic probing medium with drilling mud

I Crust

II Gravel

III Reworked weathered clay

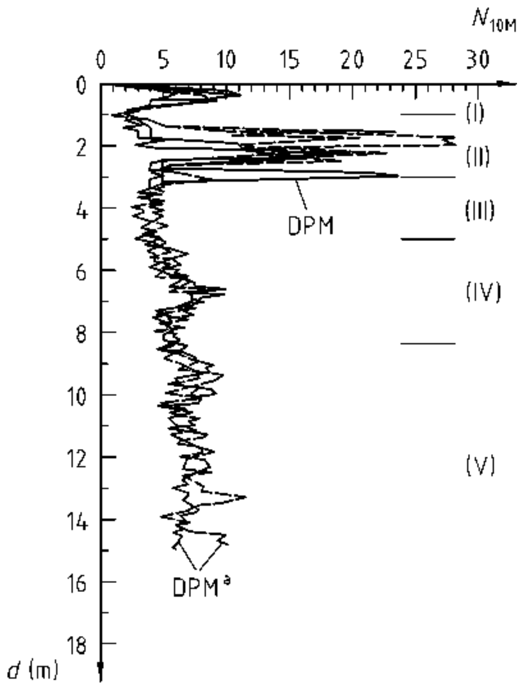
IV Weathered clay

V Unweathered clay

d Depth

Figure D.6 — Reduction of skin friction due to drilling mud

Figure D.7 shows the DPM data from Figure D.6 corrected using the torque readings to correct for the effect of friction on the rods. The correction reduces the N_{10M} values at the deeper depths and presents a reproducible depth profile both with and without the drilling mud. All data fall into one band.



Key

DPM Dynamic probing medium without drilling mud

DPM [a] Dynamic probing medium with drilling mud

I Crust

II Gravel

III Reworked weathered clay

IV Weathered clay

V Unweathered clay

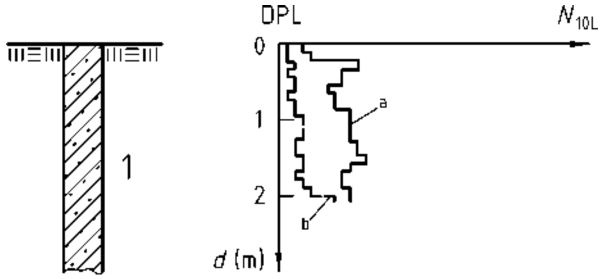
d Depth

Figure D.7 — Example for the effect of torque measurement correction in a fine-grained soil

Figure D.8 shows the result of a dynamic probing using the light dynamic penetrometer (DPL) in relation to structural changes in a soil in:

a) natural silt and

b) filled, only slightly compacted silt.



Key

a Natural silt

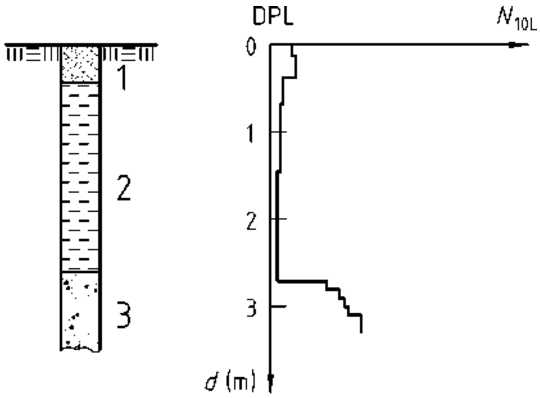
b Filled, only slightly compacted silt

1 Medium silt, slightly clayey (loess loam)

d Depth

Figure D.8 — Penetration resistance in natural silt and in filled, only slightly compacted silt of nearly the same density

Figure D.9 shows that a decomposed peat has a very low penetration resistance.



Key

1 Silty clay

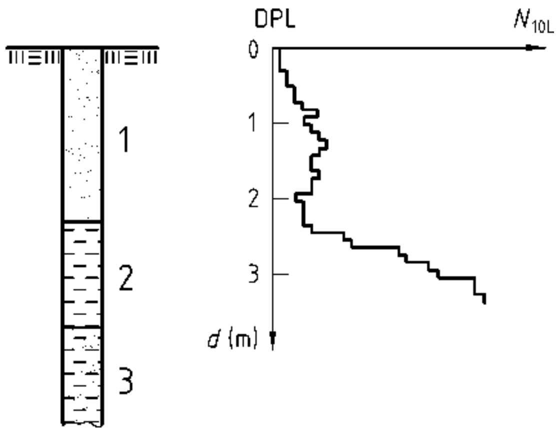
2 Peat, decomposed

3 Clay, sandy, very silty

d Depth

Figure D.9 — Dynamic probing in decomposed peat

Figure D.10 shows that a fibrous, barely decomposed peat shows high levels of penetration resistance, including skin friction. Similiar effects can be observed in highly organic clays and silts.



Key

1 Gravel and sand

2 Peat, fibrous

3 Fine sand and silt, slightly clayey

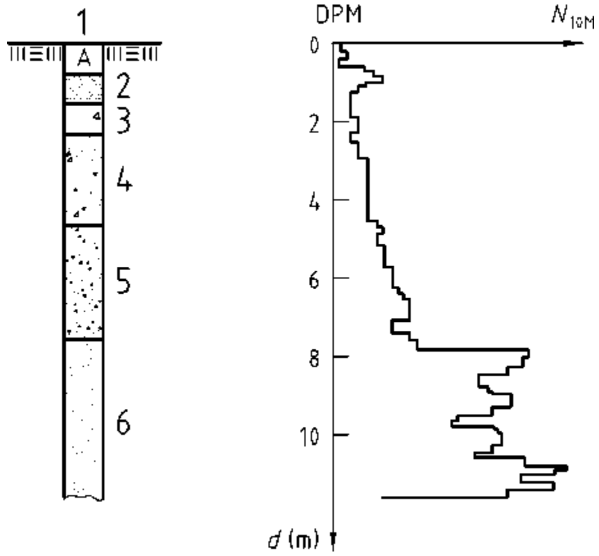
d Depth

Figure D.10 — Dynamic probing in fibrous, barely decomposed peat

D.4 Example for results of dynamic probing in mixed-grained soils

Since the above influences can overlap in mixed-grained soils, the possibility of an incorrect interpretation is relatively great.

Figure D.11 shows the fluctuations in penetration resistance using a medium dynamic penetrometer (DPM) in various types of soil. The fluctuations are greater in soils with mixed grain sizes (e.g. silty coarse sand) owing to the higher proportion of coarse grains, than in fine-grained soils with organic admixtures (e.g. lake marl).



Key

1 Fill
2 Clayey sand, gravel, silty
3 Peat
4 Lake marl with remnants of plants
5 Clayey lake marl
6 Silty coarse sand with fine gravel
d Depth

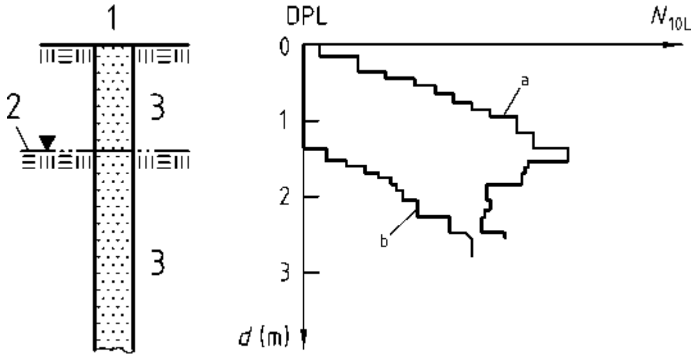
Figure D.11 — Variations in penetration resistance in various soils

D.5 Example for penetration resistance results in shallow depths

In coarse-grained soils, the boundary or critical depth (1 m to 2 m below the ground surface) increases with density index and cone diameter. In addition, the penetration resistance increases sharply until the boundary depth is reached. Below the boundary depth, the penetration resistance remains nearly constant under otherwise equal conditions.

The overburden of the layer investigated (e.g. by back-fill) or any additional loading of the subsoil (e.g. foundation loads) may increase the penetration resistance.

Figure D.12 shows two results of dynamic probing with a light dynamic penetrometer in a test pit in which a coarse to medium sand of the same density throughout the depth has been laid. The test carried out from the surface of the back-fill showed initially an increase in penetration resistance with depth and then a virtually constant value. After removing a 1,30 m thick layer, a second test was carried out. This showed, starting from the new surface, initially a lower penetration resistance in the zones near the surface compared with the first test, but after a sharp increase in penetration resistance it gave the same values at greater depths as the first test, i.e. from the surface of the back-fill.



Key

a Test from the surface of the back-fill

b Test from the bottom of the pit

1 Surface of back-fill

2 Bottom of pit

3 Coarse medium sand, dense

d Depth

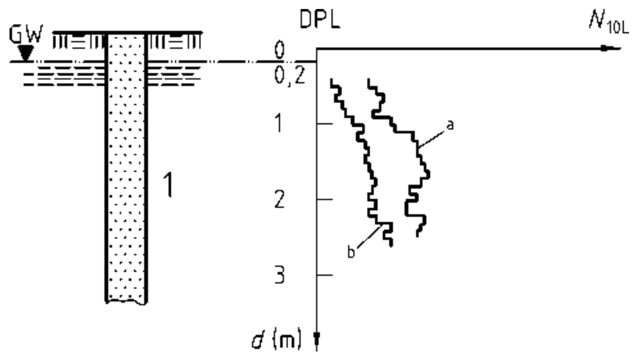
Figure D.12 — Low penetration resistance in the zone near the surface of a dense medium sand

D.6 Example for the influence of groundwater

In coarse-grained soils, other conditions being the same, the penetration resistance in groundwater is lower than above the groundwater due to the lower effective vertical stress.

In fine-grained soils, owing to the capillary effect, the penetration resistance may be equal or higher. The penetration test results may be also influenced by pore water pressures and groundwater flow.

The results shown in Figure D.13 show the influence of groundwater in coarse-grained soils. Where there is groundwater, lower penetration resistances are measured even if the density index is the same.



Key

a No groundwater

b Groundwater at 0,2 m below the surface of the terrain

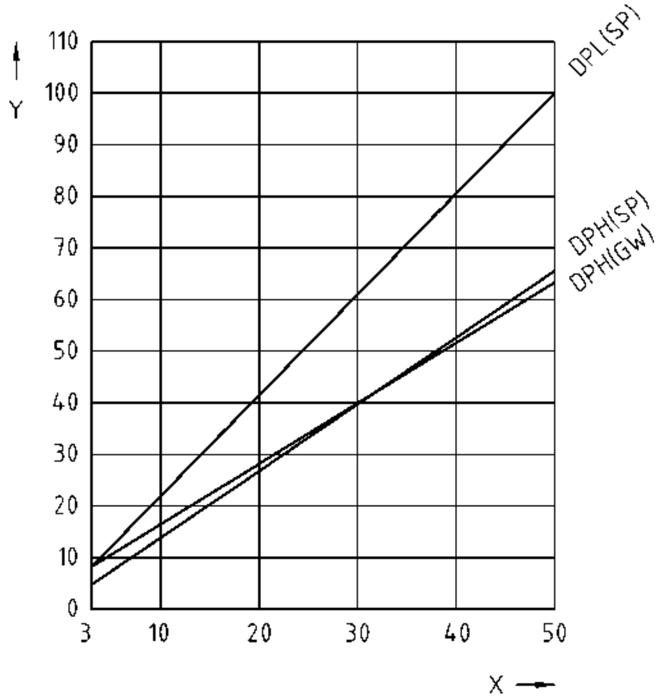
1 Fine and medium sand

d Depth

Figure D.13 — Change in the penetration resistance of a fine and medium sand as a result of groundwater

The following is an example of quantifying the influence of groundwater on dynamic probing test results in cohesionless soils. Comparative tests were conducted with DPL and DPH in a poorly graded sand (SP) and with DPH in a well graded sand-gravel mixture (GW) under controlled conditions above and below groundwater level. Figure D.14 shows the corresponding relationship of the number of blows N_{10L} and N_{10H} above to number of blows N'_{10L} and N'_{10H} below groundwater. The relationships have the general form:

$N_{10} = a_1 N'_{10} + a_2$; they are of deterministic nature and conservative estimates.



Soil classification	Uniformity coefficient	Coefficients			
		DPL		DPH	
	$U_c = d_{60}/d_{10}$	a_1	a_2	a_1	a_2
SP	≤ 3	2,0	2,0	1,3	2,0
GW	≥ 6	-	-	1,2	4,5

Key

X Number of blows N'_{10L} and N'_{10H} below groundwater

Y Number of blows N_{10L} and N_{10H} above groundwater

SP Poorly graded sand

GW Well graded sand-gravel mixture

Figure D.14 — Examples of the influence of groundwater on dynamic probing results

D.7 Examples for equipment influences

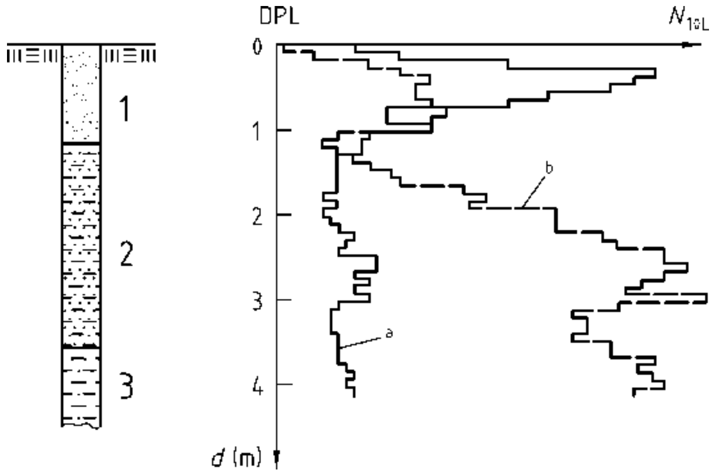
In dynamic probing, penetration resistance increases with increasing cross-section of the penetrometer cone. Penetration resistance is influenced to an extent that depends on how the ratio of cone diameter to rod diameter affects skin friction along the rod. This influence also depends on the type of soil, the sequence of layers and the depth of penetration.

In fine-grained soils, when the ratio of cone cross-section to rod diameter is small the skin friction along the rod can increase rapidly.

Figure D.15 shows, that in layers near the surface the penetration resistance is generally greater with a larger penetrometer cone diameter than with the smaller cone diameter at constant rod diameter. In deeper layers, the change in penetration resistance depends on the type and condition of the soil. Thus with dynamic probing in silt layers, the penetration resistance of a smaller cone diameter is greater compared with a larger cone diameter due to skin friction.

With the smaller cone diameter, the skin friction along the rod has a very substantial effect because the cone is only slightly wider than the rod.

With dynamic probing, other conditions remaining the same, a larger number of blows is necessary as the length of the rod increases, because the efficiency decreases.

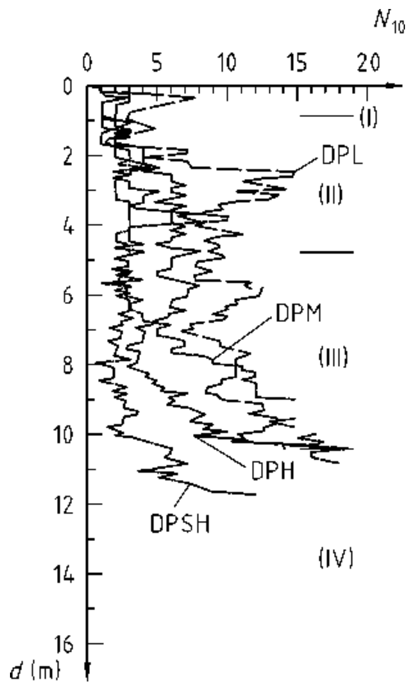


Key

a Larger cone diameter
b Smaller cone diameter
1 Gravel, sandy
2 Silt, sandy, slightly clayey (stiff)
3 Silt, clayey (soft)
d Depth

Figure D.15 — Influence of the cross section of the cone on the results of dynamic probing

Figure D.16 shows N_{10} data from four different configurations of dynamic probing equipment. The sensitivity of the lighter weight configurations show greater variations within each soil layer and the heavier configurations give N_{10} values close to or lower than the recommended minimum acceptable value. Drilling mud was used to reduce the friction on the drive rods for all but the DPSH probing significantly reducing penetration depth.



Key

I Crust
II Weathered till
III Unweathered till
IV Silty sand
d Depth

Figure D.16 — Comparison of different dynamic probing equipment configurations

Annex E
(informative)

Interpretation of test results by using the dynamic point resistance

The results from dynamic probing are usually presented as blows per 10 cm penetration (N_{10}) against depth as a straight field record and should be within the standard range of values (typically 3 to 50). The N_{10} values can be interpreted to give the unit point resistance r_d and the dynamic point resistance q_d. The value of r_d is an assessment of the driving work done in penetrating the ground. Further calculation, to produce q_d, modifies the r_d value to take account of the inertia of the driving rods and hammer after impact with the anvil. The calculation of r_d includes the different hammer weights, the height of fall and the different cone sizes. The different sizes and number of extension rods are included in the calculation of q_d, and so this should allow comparison of different equipment configurations.

Typically the equations used are:

$$r_d = \frac{E_{theor}}{A \times e} \qquad \text{(E.1)}$$

or

$$r_d = \frac{E_{meas}}{A \times e} \qquad \text{(E.2)}$$

and

$$q_d = \left(\frac{m}{m + m'}\right) r_d \qquad \text{(E.3)}$$

where

r_d and q_d resistance values in Pa;

m mass of the hammer in kg;

g acceleration due to gravity in m/s^2;

h height of fall of the hammer in m;

A area at the base of the cone in m$^{2'}$;

e average penetration in m per blow
(0,1/N_{10} from DPL, DPM, DPM, and DPH, and 0,1/N_{10} and 0,2/N_{20} from DPSH);

N_{10} number of blows per 100 mm;

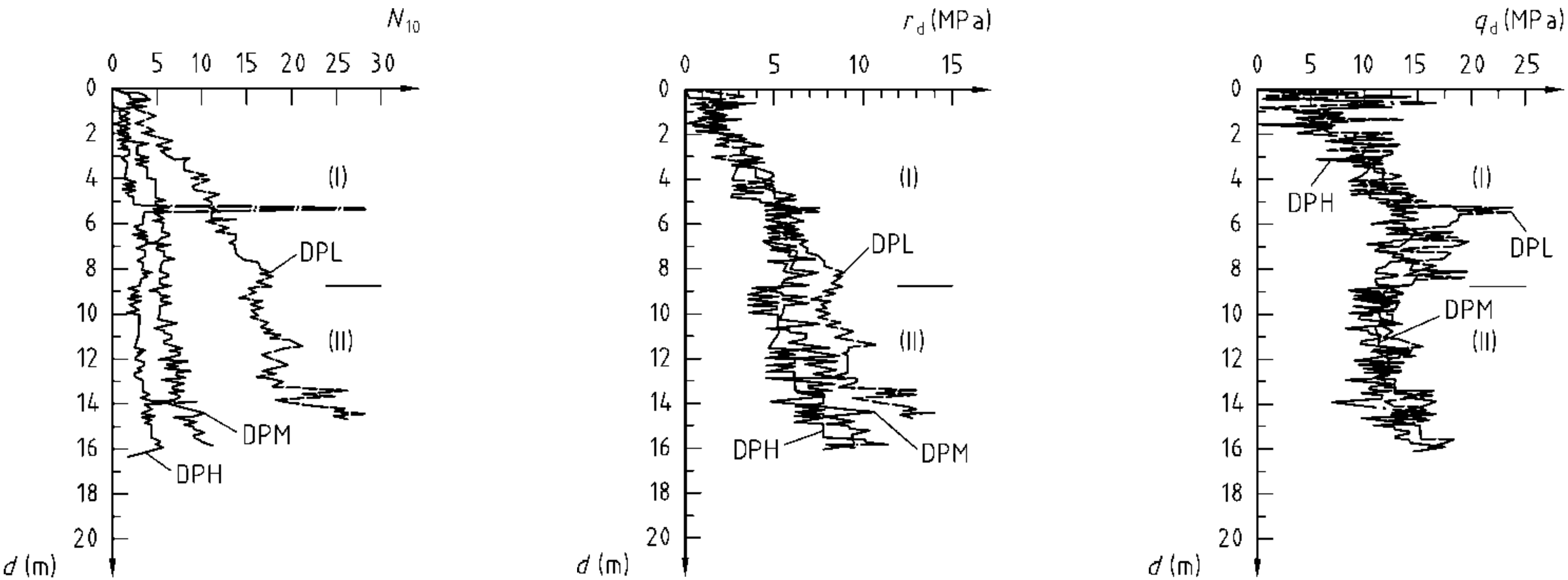
N_{20} number of blows per 200 mm;

m' total mass of the extension rods, the anvil and the guiding rods at the length under consideration, in kg.

Figure E.1 gives data from DPL, DPM ands DPH for a stiff over-consolidated clay site. While each configuration of test equipment gives a different value of N_{10} the calculation of r_d brings the DPM and DPH closer and the calculation of q_d shows all three configurations giving very similar profiles.

Figure E.2 shows data from an over-consolidated glacial till and includes data from DPL, DPM, DPH and DPSH. Here again the r_d values bring the profiles closer but calculation of q_d gives very similar profiles.

The use of q_d has the potential to allow the configuration of equipment to be varied down a profile as the blow counts fall too low (reduce the hammer mass) or rise too high (increase the hammer mass).



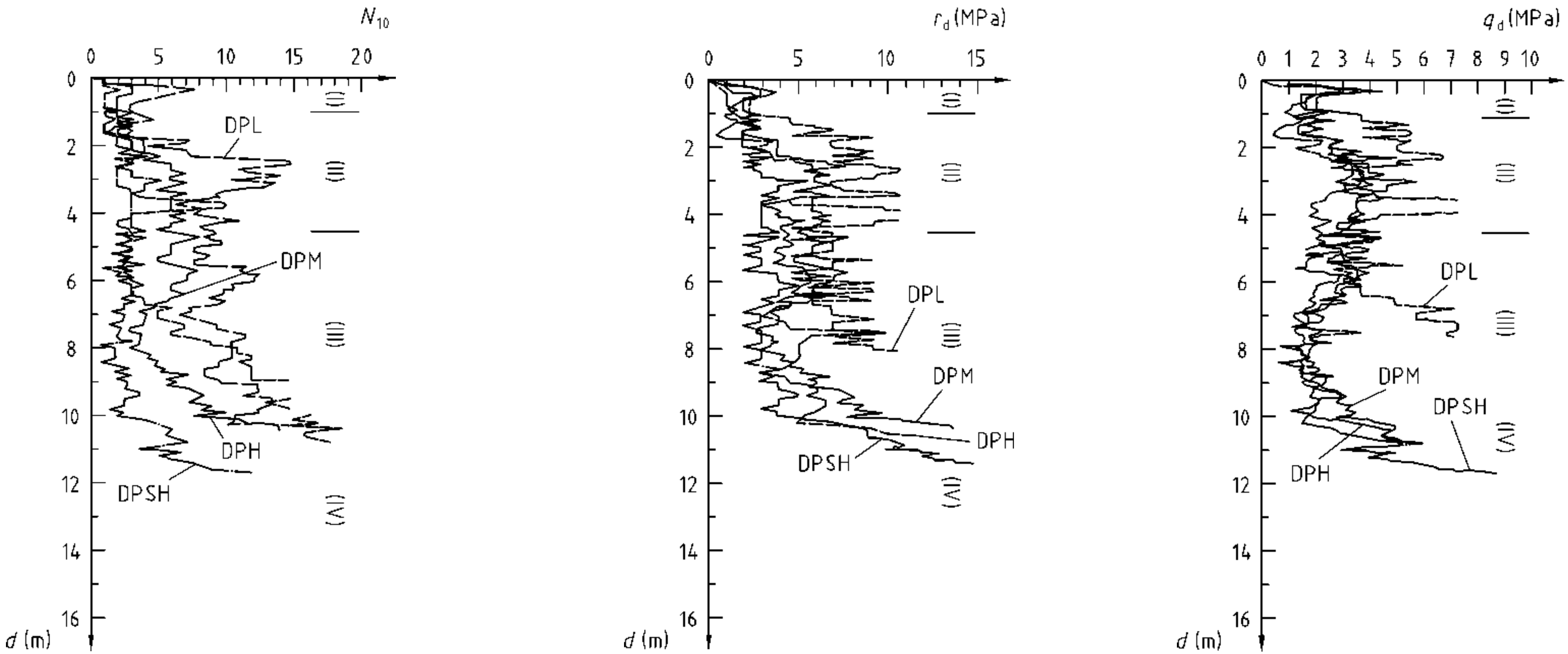
Key

I Weathered London Clay

II Unweathered London Clay

d Depth

Figure E.1 — Data from DPL, DPM and DPH for a stiff overconsolidated clay site



Key

I Crust

II Weathered till

III Unweathered till

IV Silty sand

d Depth

Figure E.2 — Data from DPL, DPM, DPH and DPSH for an overconsolidated glacial till

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