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Geotechnical investigation and testing — Field testing —

Part 15: **Measuring while drilling**

Reconnaissance et essais — Essais de sol —

Partie 15: Enregistrement des paramètre de forages

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

ISO 22476-15 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO/TC 182, *Geotechnics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 22476 series, published under the general title *Geotechnical investigation and testing — Field testing*, can be found on the ISO website.

Introduction

The measuring-while-drilling (MWD) method deals with the recording of the machine parameters during the drilling process. This can be done manually or with the use of computerized systems which monitor a series of sensors installed on rotary and/or percussive drilling equipment. These sensors continuously and automatically collect data on all aspects of drilling, in real time, without interfering with the drilling progress. The data are displayed in real time and are also recorded for further analysis. Examples for interpretation of the results are presented in Annex A.

The borehole can be used for other applications such as installation of monitoring equipment, geophysical logging or realization of expansion tests. The interpretation of the MWD results can be done in relation with the information provided by sampling.

It should be noted that measured and calculated drilling parameters are relative and dependant of the test conditions, procedures and equipment.

Geotechnical investigation and testing — Field testing —

Part 15: **Measuring while drilling**

1 Scope

This part of ISO 22476 specifies the technical principles for measuring equipment requirements, the execution and reporting on the parameters of the investigation drilling process for geotechnical purposes.

It is applicable to top-driven, destructive drilling methods performed by a fully hydraulically powered drill rig and driving device. It is commonly used with destructive drilling techniques but can also be used with core drilling.

The recording of the drilling parameters during soil grouting, drilling of nails, anchors or piles are beyond the scope of this part of ISO 22476.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 14688-1, *Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description*

ISO 14689-1, *Geotechnical investigation and testing — Identification and classification of rock — Part 1: Identification and description*

ISO 22475-1, *Geotechnical investigation and testing — Sampling methods and ground water measurements — Part 1: Technical principles for execution*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22475-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
drilling parameters
parameters measured and recorded on the drill rig during drilling (mainly hydraulic pressures, depth, penetration rate, rotation speed, fluid pressure and flow, etc.)

3.2
compound parameters
parameters derived from the combination of a number of the drilling parameters

3.3
reflected vibration
acceleration due to elastic rebound of rods compressed by hammer impact

3.4
penetration length
length measured along the axis of the borehole between ground level and the drilling tool

3.5
penetration rate
rate of penetration of drilling tool into the ground

3.6
down thrust pressure
thrust pressure applied to drilling tool

3.7
holdback pressure
pressure limiting penetration rate due to safety requirements

3.8
flushing medium pressure
pressure at the level of the drilling tool

3.9
torque
drill head rotational torque

3.10
rotation speed
drill head rotational speed

3.11
flushing medium circulation rate
rate of output of drilling tool down the hole

4 Symbols

Symbol	Name	Unit
a	measured penetration length	m
α	efficiency coefficient of down-thrust work	—
β	efficiency coefficient of torque work	—
γ	efficiency coefficient of hammering work	—
C_R	measured drill head torque	kN·m
$C_{R\,max}$	maximum measured drill head torque	kN·m
d_o	external diameter of drill bit	mm
E	calculated drilling energy	J
E_S	calculated specific energy	J
E_R	measured reflected vibrations	J
f	hammer frequency	Hz
F_{max}	maximum down thrust force	kN
H_{max}	maximum hold back force	kN
I_A	calculated alteration index	—
N	quantity of rods	—
p	measured hydraulic pressure in feed motor or cylinder	MPa

Symbol	Name	Unit
p_{CR}	measured hydraulic pressure in torque motor	MPa
p_{CRO}	unloaded torque motor pressure	MPa
$p_{CR\,max}$	maximum measured hydraulic pressure in torque motor	MPa
p_H	measured hold back pressure	MPa
p_I	calculated flushing medium pressure at output of the drilling tool	MPa
p_E	calculated net down-thrust (or feed thrust) applied on drilling tool	MPa
p_F	measured flushing medium pressure at output of the pump	MPa
p_M	measured hammering pressure	MPa
p_{max}	maximum measured down-thrust pressure	MPa
p_O	raw down-thrust (or feed thrust) applied on drilling tool	MPa
p_{HC}	calculated holdback pressure	MPa
$p_{H\,max}$	maximum measured holdback pressure	MPa
P_R	penetration resistance	s/0,2 m
Q_I	measured borehole drilling fluid inflow	l/min
Q_O	measured borehole drilling fluid outflow	l/min
R_{SR}	calculated soil-rock resistance	MPa m^{-1} s^{-1}
S_d	calculated Somerton index	—
s_O	measured area removed by drill bit (= drilling tool surface)	m^2
t	measured time	s
v_A	penetration rate	m/h
v_R	measured drill head rotational speed	r/min
W_H	weight of rotary head	kN
W_R	weight of drill rod	kN
Z	measured depth	m
r_w	measured ground water table depth	m

5 Equipment

5.1 General

Drilling parameters can be considered as being in one of three categories.

— Parameters imposed by the method (type of drilling tool and diameter, nature of the fluid medium, limits of machine performance and injection system) and unmanaged scalable parameters (tools wear, changes in the composition of the fluid).

— Parameters set by the operator (p_O down-thrust, v_R drill head rotational speed, Q_I flushing medium circulation rate in the case of an incompressible or water based drilling fluid, p_I injection pressure in the case of a compressible air based fluid),

— Parameters depending on the response of the ground (v_A penetration rate, C_R torque, p_I injection pressure in the case of an incompressible or water based fluid, Q_I flushing medium circulation rate in the case of a compressible air-based fluid),

These parameters may be measured directly or calculated using calibration relations. Further compound parameters may be derived by combining a number of drilling parameters (see A.2.)

5.2 Drilling equipment

Drilling machines with appropriate stability, power and equipment such as drilling rods and bits shall be selected in order to achieve the required depth and stability of the borehole. The drilling equipment shall be of the appropriate size and type in order to produce the required quality of MWD test. The drilling rig and equipment shall allow all drilling functions to be adjusted accurately.

The drill rig shall be chosen based on the project objectives with sufficient capacity to penetrate the various geologic layers and equipped with the appropriate drilling tools.

Drill head and feed mechanism shall be hydraulically operated to allow drilling parameter monitoring.

Only top hammer drilling shall be used. The equipment shall be loaded or anchored to limit movements of the drilling machine relative to ground level while the penetration occurs.

The drilling flow pump shall comply with the following characteristics:

— provide a constant flow independent of the pressure, pumps creating pulsation shall be avoided (e.g. single piston pump);

— achieve a minimum pressure of 3 MPa (unless otherwise noted);

— have a sensitive and calibrated pressure gauge mounted directly on the pump outflow;

— allow a 0,8 m/s to 1 m/s cutting return (depending on fluid viscosity).

Prior to each use, the straightness of rods shall be checked visually. The deviation of the linearity of the rods shall not exceed 5 mm from the centreline for 3 m long rod. The straightness of the push rods shall be determined at regular intervals.

The drilling tool used for MWD method shall be drill bit type acting in rotary or rotary percussion drilling. The use for other drilling technique shall be avoided.

5.3 Measuring system

5.3.1 General

The automatic measurement system shall include

— a data recorder incorporating a data display,

— a data acquisition system including a signal converter (sometime part of data recorder), and

— transducers set on the machine.

Depending upon the MWD application class (see 5.4), the influence of the positioning of sensors on the recorded measurements shall be minimized.

The manual measurement shall include

— depth according to time or time for a penetration of 0,2 m, and

— parameters read by the operator on gauges.

The measuring system shall give a real-time display of the readings to allow adjustments to the drilling process according to the observed progress of the test.

The measuring equipment shall be checked and/or calibrated regularly according to the manufacturers' specification. The results of the checking and/or calibration shall be reported (see Clause 7). If any part of the system is repaired or exchanged, calibration shall be verified.

Calibration of all sensors shall be performed at the following interval:

— yearly, if certifications are made by third-party control (for instance, manufacturer) at regular interval;

— at least every six months by internal control.

A calibration report should be generated and a copy of the report should be kept with the maintenance log. A copy of the latest calibration test report shall be available at the job site.

5.3.2 Sensors for hydraulic pressures

The following pressures shall be measured:

a) down-thrust pressure p and torque pressure p_{CR};

b) holdback pressure p_H (complementary to the down-thrust, this pressure p_H shall be measured to calculate the net down-thrust applied on the bit; holdback pressure is the hydraulic pressure prevailing in the return line);

NOTE 1 Differential pressure transducer can be used to measure the net down thrust directly.

NOTE 2 Down-thrust force can be directly measured by load sensor.

c) flushing medium pressure p_F.

Measurement of this pressure shall be performed in the manual procedure on pressure gauges and in the automatic procedure using transducers placed on the flush line.

5.3.3 Measuring system for penetration length

Measurement of drilling tool penetration length shall be performed between the top of the mast and the drill rod.

The penetration length shall be determined through the following methods:

— automatic, using a rotary encoder fitted on the feed motor axis, a chain/cable attached between the fixed mast and moving drill-head, a wheel fitted the drill head and running against the mast or other suitable method;

— manual, using a tape.

5.3.4 Measuring system for flushing medium flow

Flow shall be measured using a flow meter. Its accuracy and calibration shall be documented as part of the report.

NOTE The measurement of the drilling fluid return flow (outflow), Q_O, at the exit of the borehole can provide an estimation of the volume of fluid exchanged (absorbed or provided from confined aquifer) within the ground.

5.3.5 Measuring system for rotational speed

Rotational speed (v_R) measurement shall be done through the following methods:

— manual procedure using a tachometer;

— automatic procedure using a rotation or proximity sensor that counts the passage of a metallic element.

5.3.6 Measuring of hammering energy

Hammering energy shall be measured using a pressure transducer to measure the pressure p_M used to activate the hammer and the blow frequency, f (alternatively determined by a flow meter).

5.3.7 Reflected vibrations

Vibration due to percussive reflected waves generated when the hammer hits the anvil (E_R) which descends and ascends after reflection in the end of the rods may be measured with an accelerometer. This signal is disturbed by stray reflections to each new stem, natural attenuation of the signal, and so on.

5.3.8 Time

Measuring the time, t, shall be performed using the following methods:

— manual procedure using a stop watch;

— automatic procedure using the internal clock of the data acquisition system and corresponds to a detection time of a new depth step.

5.4 Selection of measured parameters

Depending on the number of parameters measured while drilling, three quality classes of MWD measurements are defined (see Table 1):

— quality class 1, where six or more parameters are measured;

— quality class 2, where four or five parameters are measured;

— quality class 3, where at least two parameters are measured.

The following drill parameters may be measured:

— penetration length;

— down-thrust pressure in feed motor or cylinder;

— holdback pressure;

— torque pressure in motor;

— flushing medium pressure;

— drill head rotational speed;

— flushing medium circulation rate.

The fluid flow, as well as the total drilling fluid volume for each boring, should be recorded.

In the case of rotary percussion, reflected vibrations, E_R may be measured.

Instead of penetration length, a, the operator can use penetration rate, v_A, given by the measuring system to control the machine (see 5.3).

For all quality classes, the parameters measured shall always include the measured penetration length, a, and the down-thrust pressure, p, in feed motor or cylinder except for Quality Class 3 manual recording when p shall be replaced by penetration resistance, p_R. Additional parameters shall be selected to meet the particular requirements of the investigation.

Table 1 — Quality class

Quality class	Recording	Examples of measured drill parameters	Allowable minimum accuracy of measured values[a]
1	Automatic	penetration length (a)	5 mm or 0,1 %
		down-thrust pressure (p)	1 %
		holdback pressure (p_H)	1 %
		flushing medium pressure (p_F)	1 %
		drillhead rotational speed (v_R)	1 %
		flushing medium circulation rate (Q_I)	1 l/min
		torque pressure (p_{CR})	1 %
2	Automatic	penetration length (a)	1 %
		down-thrust pressure (p)	2 %
		holdback pressure (p_H)	2 %
		flushing medium pressure (p_F)	2 l/min
		torque pressure (p_{CR})	2 %
3	Automatic or manual	penetration length (a)	0,2 m or 2 %
		penetration resistance (P_R)	1 s/0,2m

a The allowable minimum accuracy of the measured parameter is the larger value of the two values quoted.

5.5 Factors influencing MWD results

5.5.1 Tool influence

The type of tool determines the effectiveness of the chosen drilling method for the geological conditions at site.

For this reason, the type of tool shall be recorded. The same type tool shall be kept during the drilling in order to interpret the recording.

Tool wear or change shall be documented in the field report before and after MWD (see Clause 8).

5.5.2 Drilling rig influence

As the characteristics of the drilling rig such as its capability and its hydraulic design have an influence on the MWD results, care shall be taken comparing MWD results obtained by different types of drill rigs at the same site. Therefore the characteristics of the drill rig shall be reported.

5.5.3 Operator influence

The operator should be familiar with MWD method and should be clearly and completely instructed regarding the investigation requirements. This should ensure that results are consistent where it is desired to interpret a series of tests taken using one or more different drill rigs. A change of driller should be avoided if possible but if this is unavoidable, the change of operator shall be noted.

6 Test procedures

6.1 General

The measured, calculated and derived drilling parameters (e.g. depth, advancement rate, pull-down pressure, torque, rotation rate, flush fluid pressure, flush fluid flow, vibration, penetration resistance, soil-rock resistance) can produce useful data about the lithology of the layers for a reliable geotechnical model, their density or weathering, the localization of voids or faults in the ground, the depth to rock and other properties like permeability.

The MWD test can be used in soil, rock and manmade ground, either on land or off-shore.

After the MWD test, the borehole can be used for other purpose such as installation of monitoring equipment, etc.

Before using new drilling equipment or when changes of the drilling equipment have occurred, a calibration drilling should be performed. That calibration drilling should be performed before the start of each major project. Before performing the calibration drilling, calibration of equipment should be performed.

6.2 Position and level of drill rig

The distance between the test location and the location of previous investigation points should be sufficient to prevent interaction effects.

There shall be a distance of at least 2 m between MWD tests. There shall be a distance from a previous borehole of at least 20 times the borehole diameter. Some borehole techniques, such as air flush drilling, may require larger distances. Nearby excavations should be avoided.

The drill rig shall push the drilling rods so that the axis of the pushing force is as close to vertical or the desired axis of inclination as possible. The deviation from the intended axis should be less than 2° or 35 mm per metre. The axis of the drilling tool shall correspond to the loading axis at the start of the penetration.

6.3 Preparation of the measurement

The drill rig shall be checked for suitable performance.

Selection and preparation of an appropriate flushing medium shall be made using information provided from previous site investigation or relevant geological or hydrogeological data. The flushing channels of drilling bit and rods shall be checked to ensure that they are open.

In a first step, manual adjustment of machine parameters such as maximum flushing pressure, thrust pressure and minimum penetration rate shall be made at pre-set values proposed by the responsible expert or the user.

Then calibration drilling shall be performed in homogeneous rock or soil mass with a warmed-up machine in order to set the thrust pressure, rotational speed and other drilling parameters so that the chosen leading parameter becomes a constant value. The settings of drilling parameters from the calibration drilling shall then be kept at any subsequent test.

Selecting values that are too high will negatively affect the quality of the measurements. The drill rig and the associated tools shall be operated well below their maximum capacity to help in conducting a successful investigation.

6.4 Drilling procedure

To validate a drilling procedure, the drilling program planning should include a few borings for calibrating the results. During this reference drilling test, the “selected driving parameter(s)” shall fall within certain limits defined jointly by the responsible expert and the user of the test results. This shall be achieved by adjusting the machine parameters and the type and the size of the drill bit. The holdback pressure should be set such that it can detect variations between two geologic zones of different consistency.

At a minimum, the results of the first drilling should ideally be used to check the selected driving parameters.

To avoid additional calibration the same drill rig, drilling tool configuration and type of flushing medium should be kept unchanged for the duration of each project.

Hammering should be only used in hard layers.

If changes occur or tools are repaired or replaced, such information shall be noted in the field report and accounted for in the interpretation of the recorded parameters. The drilling shall be terminated when one of the following events occur.

— The required penetration length or penetration depth has been reached. For example, a minimum of 3 m of penetration into a solid layer is usually required.

— The agreed maximum down-thrust or maximum capacity of the drill rig or measuring systems is reached.

— There is a possibility that the equipment will be damaged.

During the MWD test, any event which can affect the results of the measurement and the corresponding penetration length shall be recorded and reported.

6.5 Frequency of logging parameters

Recording shall be done based on penetration depth.

The methodology for determining values recorded from the measured values shall be indicated in the operating manual accompanying the recorder.

The logging interval for the various measured values can also be chosen depending on the detail required in the profile, e.g. detection of thin layers. Usually, the same reading interval is used for registration of all parameters.

6.6 Registration of penetration length

The level of the drilling tool shall be determined relative to the ground level or another fixed reference system (not the thrust machine). The penetration length shall be checked and recorded at the end of the test.

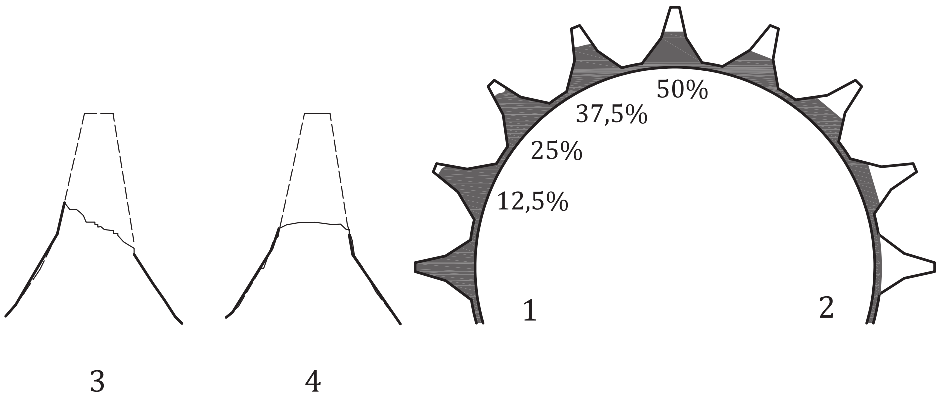
6.7 Test completion

At completion of the test, rods shall be counted when retrieved and the result compared to the penetration length achieved.

After completion of the test and cleaning of the equipment and tools, the drilling tool shall be inspected and if clogging and any excessive wear or damage has occurred during the MWD test, it shall be noted.

The reference readings of the measured parameters of Quality Class 1 shall be recorded after extraction of the drill rods from the ground and, if necessary, after cleaning of the drill rig. If the zero drift of the measured parameters is larger than the permitted minimum accuracy according to Table 1, then the results should be discounted, or the test may be put into a lower class.

To identify the influence of tool wear on measured drilling parameters, the status of the initial and final wear of the tool shall be checked and reported. For this purpose, the percentage wear of the cutting bits at the beginning and end of drilling shall be estimated and reported in accordance with Figure 1. The change or replacement of any equipment shall be reported as well.



Key

1 new wear = 0 %

2 fully worn = 100 %

3 bit wear self-sharpening

4 bit wear flat edge

Figure 1 — Example of bit wear for a rolling bit

6.8 Equipment checks and calibrations

The requirements regarding checks and calibration by the manufacturer shall be fulfilled.

7 Test results

7.1 General

The raw data shall be saved. The data output format shall be in an open format.

7.2 Calculated parameters

7.2.1 General

The measured raw data shall be converted to drilling parameters.

7.2.2 Penetration rate

The penetration rate, v_A, shall be obtained from the measurement of the penetration length, a, and the time interval, dt, between measures.

$$v_A = \frac{a_{t+dt} - a_t}{dt} \tag{1}$$

NOTE v_A represents an average value of the speed over the depth range considered, instant speed can be much higher and especially in rotary percussion. The maximum speed which can be attained by the machine is v_{max}.

7.2.3 Down-thrust pressure

Measurement of down-thrust pressure, p_O, corresponds to the hydraulic pressure measured close to the cylinder piston or hydraulic motor, p. This measure is scaled with maximum down-thrust force, F_{max}, evaluated during calibration with head at lower mechanical stop and adding the rotary head weight, W_H, and the number of rods n of unit weight, W_R. The use of reeving systems shall be reported and taken into account if added to the hydraulic cylinder.

$$S_o \cdot P_o = \frac{p}{p_{max}} F_{max} + W_H + n.W_R \tag{2}$$

NOTE For deep boreholes, buoyancy applied on drill rods can be taken into account.

7.2.4 Net down-thrust pressure

Net down-thrust pressure, p_E, is a function of down-thrust and holdback, weights of drill rods and of rotation head.

$$p_E = p_o - p_H \tag{3}$$

p_H shall be evaluated from calibration by loading the head to H_{max} until movement show that holdback pressure is overpassed.

$$S_o \cdot P_H = \frac{p_H}{p_{H\,max}} H_{max} \tag{4}$$

NOTE In some systems, pressure differential or force transducer is used allowing direct measurement of net down-thrust pressure.

7.2.5 Flushing medium pressure

The measured value of the flushing medium pressure, p_F, may be corrected with the height of the drilling fluid medium (density γ_M) present in the drilling rods reduced by the height of the ground water level measured from the bit.

The fluid pressure, p_I, at the output of drilling bit may be calculated using the estimated or measured value of the water table level, z_W:

$$p_l = p_F + z_w . \gamma_M \tag{5}$$

NOTE For most purposes, it is sufficient to consider $p_I = p_F$.

7.2.6 Drill head rotational torque

The drill head rotational torque, C_R, applied on the drilling tool is proportional to the hydraulic pressure, p_{CR}, which the motor receives and maximum torque, C_{Rmax}, evaluated during the calibration process.

$$C_R = \frac{p_{CR} - p_{CR\,0}}{p_{CR\,max}} C_{R\,max} \tag{6}$$

It may be useful in the case of fine measurement to measure the unloaded torque motor pressure, p_{CRo}.

For an accurate measurement, measures of flow and pressure at hydraulic motor output are needed.

NOTE 1 In some systems, differential pressure transducers are used.

Where gear ratios are manually varied to change the relationship between the engine speed and the rotation speed of the rotary head, this will affect the torque. To allow the possibility of calculating the drill head rotational torque from the hydraulic pressure, it is necessary to know which gear ratio is being used, and therefore, this must be recorded. Where the hydraulic characteristics of the rotation system are varied automatically, the torque will be varied without the possibility of recording when changes occur. In this case, the use of such a system shall be reported.

8 Reporting

8.1 General

At the project site, a field report shall be completed. The field report shall consist of the following information:

a) summary log according to ISO 22475-1;

b) record of measured values and test results;

c) information according to 8.2.

The test report shall include the following information:

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

b) graphical presentation of the test results (plot);

c) information according to 8.2.

The test results shall be reported in such a way that third parties are able to check and understand the results.

Test results shall be transferred using an open digital format.

8.2 Reporting of test results

NOTE Where appropriate, information can be reported on the associated summary log according to ISO 22475-1.

8.2.1 General information	**Field report**	**Test report**	**Every plot**
1.a. Reference to this standard		x	x
1.b. Company executing the test		x	x
1.c. Name of the operator	x		
1.d. Name and signature of the field manager		x	
1.e. Groundwater level (if recorded) and date and time of recording	x	x	x
1.f. Depth of predrilling or excavation	x	x	x
1.g. Any observations during the drilling concerning the ground conditions	x	x	x
1.h. Any observations during the drilling concerning the conditions of the drill rig and tools	x	x	
1.i. Depth and possible causes of any stops in the penetration	x	x	
1.j. Stop criteria applied, i.e. target depth, maximum down-thrust force, inclination, etc.	x	x	

8.2.2 Location of the test	**Field report**	**Test report**	**Every plot**
2.a. Identification of the test	x	x	x
2.b. Elevation of the MWD test		x	x
2.c. Local or general coordinates		x	x

8.2.3 Test equipment	**Field report**	**Test report**	**Every plot**
3.a. Drilling tool type	x	x	x
3.b. Geometry, dimensions and characteristics of the tools used	x	x	x
3.c. Type of drilling machine used, thrust capacity, feed stroke	x	x	
3.d. Type of MWD data acquisition system used	x		
3.e. Serial number of the MWD data acquisition system	x		
3.f. Measuring ranges of the transducers (recommended)		x	
3.g. Date of last calibration of sensors		x	

8.2.4 Test procedure	**Field report**	**Test report**	**Every plot**
4.a. Quality Class	x	x	
4.b. Date of the test	x	x	x
4.c. Starting time of the test (if relevant)	x	x	
4.d. Depth of the start of penetration		x	x
4.e. Type of drilling fluid	x	x	
4.f. Use of the hammer	x	x	x
4.g. Tool wear before test	x		
4.h. Tool wear after test	x		

8.2.5 Measured parameters	**Field report**	**Test report**	**Every plot**
5.a. Zero and/or reference readings of drilling parameters before and after the test and zero drift (in engineering units).	x	x	
5.b. Drilling parameters readings according to Quality Class	x	x	x
5.c. Time during the test	x		
5.d. Corrections applied during data processing		x	

If time during the test is not available from the MWD system, the start and end times of the test should be reported, together with the penetration rate, v_A, throughout the test.

The test reports shall include a copy of the signed MWD log.

The graphical presentation of test results shall be uniform for a specific project.

Preliminary identification and description of the soil and rock based on the visual examination of cuttings collected during drilling shall be done according to ISO 14688-1 and ISO 14689-1. This information shall be reported (without correction deduced from MWD) on a summary log and shall be included in the field report.

An example field report on the drilling parameter recording is given in Annex B.

Annex A
(informative)

Application of drilling parameters

A.1 Interpretation of drilling parameters

A.1.1 General

The recorded drilling parameters can be used to identify transitions between soil and rock layers and variations in ground conditions to improve the geotechnical model in combination with other site investigation and sampling methods.

A.1.2 Penetration rate

The penetration rate, v_A, is related to the mechanical strength of drilled formation.

Penetration rate will increase in softer ground. Effective change in the characteristics of the ground can be further studied by comparing simultaneously with other drilling parameters like torque and net down-thrust.

If the down-thrust is kept constant, instant feed rate is lower in dense materials and highest in loose materials. This rate is linked to the equipment used (e.g. drilling tool or hammer characteristic), the hardness of the formation and its susceptibility to shocks and jetting.

A.1.3 Net down-thrust

Net down-thrust parameter gives information on the ground condition such as

— the transition between different layers, and

— voids and cavities.

A.1.4 Flushing medium pressure

Flushing medium pressure, p_F, measurement gives indication on the conditions of the circulation of the fluid medium in the borehole. It is affected by fine particles content of the ground that may clog the tool. Therefore, it may be an indication of the content of fines in the formation. In weathered rock, it may be an indication of the presence of fractures.

A.1.5 Torque

The torque depends on the selected drilling tool and provides information on the variations of the ground conditions.

A.1.6 Conclusion

Table A.1 indicates the variation of drilling parameters in different ground conditions without hammering; Table A.2 with hammering.

Table A.1 — Variation range of drilling parameters in different ground conditions without hammering

Ground	Parameters												Observations
	Penetration rate (v_A)			Down thrust (p_E)			Fluid medium pressure (p_F)			Torque (C_R)			
	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	
sludge and soft clay, soft clayey soil			+++	++	o			++		+	+		linear profile limited variation of C_R
clay, stiff clay marl	o	++	+	++	++	o			+++			++	variation of v_A and p_E with density, high values of C_R and p_I indicating plugging
sandy soils	o	+	++	++	++	o	++	+		+	+	o	variation of v_A and p_E with density and of p_R with content of fines, limited variation of C_R
gravels	+	+	o		++		++	+			+	++	variation of v_A and p_E with density and of p_R with content of fines, limited variation of C_R
cobbles	+	+			+	++	+				+		very irregular profiles of v_A, p_E and C_R
weathered and solid rocks	+++					+++	+			+			increase of v_A and decrease of p_E in weathered and fractured zone, except if very clayey, limited variation of C_R

Key

+++ most significant

++ significant

\+ least significant

o possible

Table A.2 — Variation range of drilling parameters in different ground conditions with hammering

Ground	Parameters												Observations
	Penetration rate (v_A)			Down thrust (p_E)			Fluid medium pressure (p_F)			Torque (C_R)			
	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	
clay, stiff clay marl	o	++	+++	+++	++	o			+++			++	variation of v_A and p_E with density, high values of C_R and p_I indicating plugging
sandy soils	o	+	+++	+++	++	o	++	+		+	+	o	variation of v_A and p_E with density and of p_R with content of fines, limited variation of C_R
gravels	o	+	++	++	++	o	++	+		+	+	o	variation of v_A and p_E with density and of p_R with content of fines, limited variation of C_R
cobbles	+++	+			+	++	++				+		very irregular profiles of v_A, p_E and C_R
weathered and soft rocks	++					+++	+			+			increase of v_A and decrease of p_E in weathered and fractured zone, except if very clayey, limited variation of C_R
hard and solid rocks	+++					+++	+			+			limited variation of C_R

Key

+++ most significant
++ significant
+ least significant
o possible

NOTE Where calculated values are not available, similar variations of drilling parameters may be observed using measured pressures, e.g. p_{CR} instead of C_R, p and p_H instead of p_E.

A.2 Compound parameters

A.2.1 General

Compound parameters are those which may be derived from the combination of various drilling parameters. Their use can assist in the understanding and characterization of the ground conditions and any variations therein.

A.2.2 Penetration resistance

The penetration resistance is the time measured in seconds for 0,2 m of penetration[1].

$$p_R = (t)_{z=0,2\,m} \qquad \text{(A.1)}$$

The penetration resistance parameter is used to determine the depth of the rock surface, the relative strength of the rock and its fracturing.

A.2.3 Soil-rock resistance

Soil-rock resistance is calculated as follows:

$$R_{SR} = \frac{p_E}{v_A} \qquad \text{(A.2)}$$

The use of this parameter is recommended when down-thrust is measured. The use of hammering shall be reported.

A.2.4 Somerton Index

The Somerton index, S_d, based on experimental results obtained in the laboratory[2] is calculated as follows:

$$S_d = W_{net}\sqrt{\frac{w_d}{v_d}} \qquad \text{(A.4)}$$

where

W_{net} is the effective weight on the bit (thrust pressure and rods and bit weight);

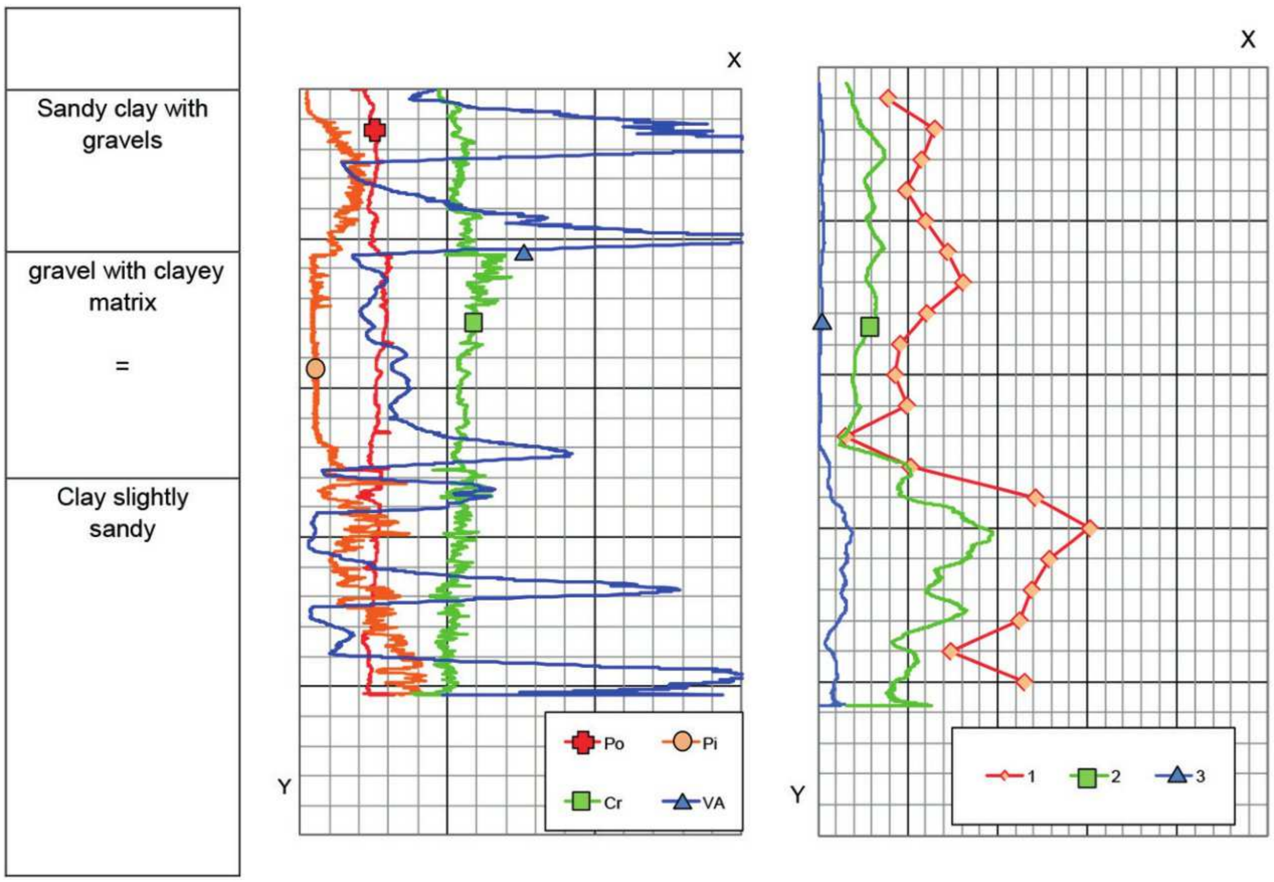
w_d is the rotation rates;

v_d is the advance rate.

For a constant rotation speed, the Somerton index can be simplified to

$$S_d \approx \frac{p_E}{\sqrt{v_A}} \qquad \text{(A.5)}$$

An example of results is compared with the Ménard limit pressure in Figure A.1.



Key

1 Ménard limit pressure

2 Somerton index, S_d

3 soil-rock resistance, R_{SR}

X calculated drilling parameter or compound parameter

Y depth

Figure A.1 — Comparison of Somerton index, Soil-rock resistance profiles versus stratigraphy

A.2.5 Energy

Estimation of energy used to drill a hole for a specific tool can be obtained using Formula (A.6)[3]:

$$E = \frac{\alpha . p_E . v_A + \beta . C_R . 2 . \pi . v_R + \gamma . p_M . f}{v_A} \quad \text{(A.6)}$$

where

α, β, γ are the efficiency coefficient of drilling which need to be estimated.

For shallow boreholes, a specific energy compound parameter simplification of drilling energy can be used which combines energy and drilling depth[4,5]:

$$E_S \approx p_E + C_R \cdot \frac{v_R}{v_A} \tag{A.7}$$

The term p_E is often neglected which reduces to using work produced by the rotation torque, C_R. The torque energy per unit of penetration results in:

$$E_R = \frac{C_R . v_R}{v_A} \tag{A.8}$$

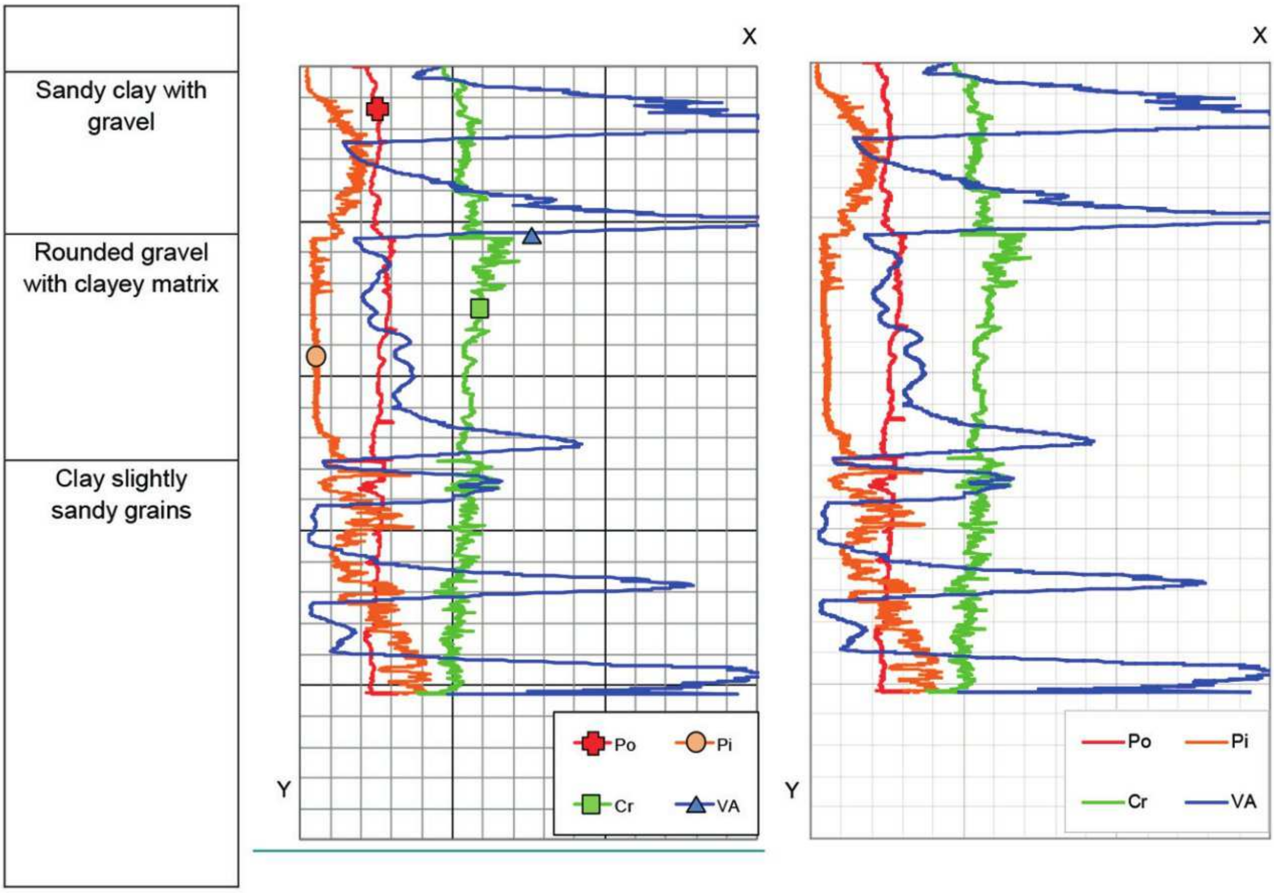


Figure A.2 — Example of specific energy

These parameters when used in non-cemented materials allow the identification of layers of varying consistencies (Figure A.2).

Annex B
(informative)

Graphical presentation of drilling parameters

The test results shall be presented as continuous profiles as a function of the penetration depth or penetration length. Examples which are presented against penetration length or depth are given below.

According to Quality Class Class 1

— p, Hydraulic pressure in thrust system (MPa)

— p_H, Hold back pressure (MPa)

— p_F, Flushing medium pressure (MPa)

— v_R, Drill Head Rotational Speed (r/min)

— p_{CR} Hydraulic pressure in Torque Motor (MPa)

— Q_I, Measured Borehole Drilling Fluid Inflow (l/min)

According to Quality Class 2

— p, Hydraulic pressure in thrust system (MPa)

— p_F, Flushing medium pressure (MPa)

— $p_{CR,}$ Hydraulic pressure in Torque Motor (MPa)

— v_R, Drill Head Rotational Speed (r/min)

According to Quality Class 3

— v_A, Penetration Rate (m/h)

— p, Hydraulic pressure in thrust system (MPa)

Units in kPa can be used depending on scale of measured parameters.

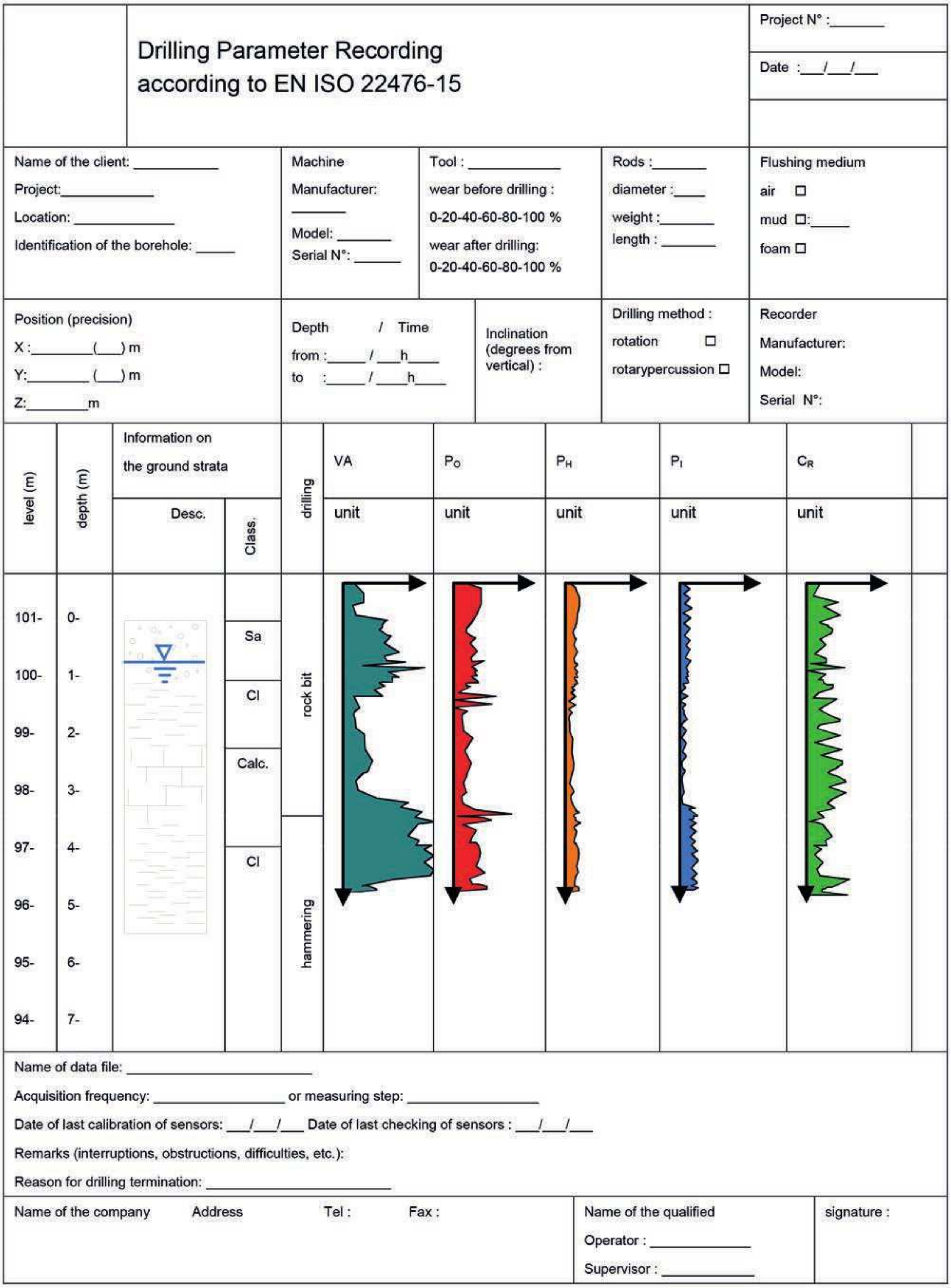


Figure B.1 — Example of field report of Drilling Parameter Recording

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