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Geotechnical investigation and testing — Field testing —

Part 3:
Standard penetration test

Reconnaissance et essais géotechniques — Essais en place —

Partie 3: Essai de pénétration au carottier

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Foreword

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ISO 22476-3 was prepared by the European Committee for Standardization (CEN) in collaboration with Technical Committee ISO/TC 182, *Geotechnics*, Subcommittee SC 1, *Geotechnical investigation and testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

ISO 22476 consists of the following parts, under the general title *Geotechnical investigation and testing — Field testing*:

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

— *Part 2: Dynamic probing*

— *Part 3: Standard penetration test*

— *Part 4: Menard 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: Lefranc permeability test*

— *Part 13: Water pressure test in rock*

— *Part 14: Pumping tests*

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Foreword

This document (EN ISO 22476-3:2005) 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of an identical text or by endorsement, at the latest by July 2005, and conflicting national standards shall be withdrawn at the latest by July 2005.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:

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— *Part 12: Lefranc permeability test*

— *Part 13: Water pressure tests in rock*

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard : Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

1 Scope

This document specifies requirements for indirect investigations of soil by standard penetration test as part of geotechnical investigation and testing according to EN 1997-1 and EN 1997-2 to compliment direct investigations (e.g. sampling according to prEN ISO 22475-1).

The standard penetration test aims to determine the resistance of soils at the base of a borehole to the dynamic penetration of a split barrel sampler and the recovering of disturbed samples for identification purposes (SPT). In gravelly soils and in soft rocks a solid cone is also be used (SPT(C)).

The standard penetration test is used mainly to assess the strength and deformation parameters of cohesionless soils, but some valuable data may also be obtained in other soil types.

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.

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.

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 purposes of this document, the following terms and definitions apply.

3.1
anvil or drive head
that portion of the drive-weight assembly that the hammer strikes and through which the hammer energy passes into the drive rods

3.2
hammer
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 penetration and sampling

3.3
height of fall
free fall of the hammer after being released

3.4
drive-weight assembly
device consisting of the hammer, the hammer fall guide, the anvil and the drop system

3.5
drive rods
rods that connect the drive-weight assembly to the sampler

3.6
actual energy
E_{meas}
energy delivered by the drive-weight assembly into the drive rod, immediately below the anvil, as measured

3.7
theoretical energy
E_{theor}
energy as calculated for the drive weight assembly:

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

where

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

3.8
energy ratio
E_r
ratio of the actual energy E_{meas} and the theoretical energy E_{theor} of the hammer expressed in percentage

3.9
***N*-value**
number of blows required to drive the sampler for a test drive of 300 mm following the seating drive

4 Equipment

4.1 Drilling equipment

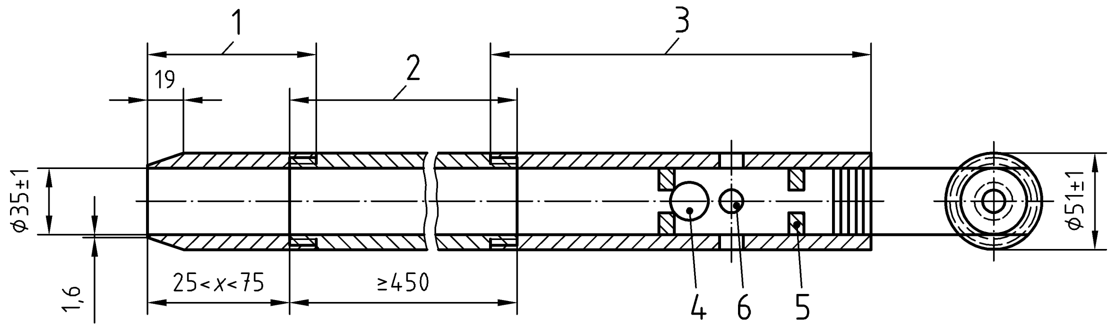
The drilling equipment shall be capable of providing a clean hole to ensure that the penetration test is performed on essentially undisturbed soil.

The area that is exposed in the base of the borehole prior to testing can influence the results and consequently the borehole diameter shall always be reported. A significant effect on the result can begin to occur when the diameter is 150 mm or more.

4.2 Sampler

The steel split barrel sampler shall have the dimensions indicated in Figure 1 and shall be provided with a non-return valve with sufficient clearance to permit the free flow of water or mud during driving.

The inner diameter of the sampler can be up to 3 mm larger than that of the shoe to allow for a liner. In gravelly sand, a solid 60° cone instead of the standard shoe can be used. In this case the test shall be noted as SPT(C).



Key

1 Drive shoe

2 Split barrel

3 Coupling

4 Non return valve (ball diameter: recommended 25 mm; ball seating: recommended 22 mm)

5 Ball retaining pins

6 Four vent holes (min diameter 12 mm)

x Length of the drive shoe

Figure 1 — Longitudinal cross section of an SPT sampler without a provision for a liner (dimensions in mm)

4.3 Drive rods

The drive rods shall have a stiffness that prevents buckling during driving. Rods with a mass of more than 10,0 kg/m shall not be used. Only straight rods shall be used and periodic checks shall be made on site, including connections between consecutive rods. When measured over the whole length of each rod the relative deflection shall not be greater than 1 in 1 200.

4.4 Drive weight assembly

The drive weight assembly, of an overall mass not exceeding 115 kg, shall comprise:

— a steel hammer of 63,5 kg ± 0,5 kg conveniently guided to ensure minimal resistance during the drop;

— an automatic release mechanism which will ensure a constant free fall of (760 ± 10) mm, a negligible speed of the hammer when released, and no induced parasitic movements in the drive rods;

— a steel drive head or anvil rigidly connected to the top of the drive rods. It may be an internal part of the assembly, as with safety hammers.

4.5 Optional equipment

4.5.1 Blow counter

A device to measure mechanical or electric impulses can be placed on the system in order to count the number of the blows of hammer.

4.5.2 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 less than 1/100 of the measured length.

5 Test Procedure

5.1 Equipment checks and calibration

Prior to each test series, the sampler shall be checked to ensure that it is in proper condition (dimensions). 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 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 shall be checked when automatic recording equipment is used.

The precision of the measuring instruments – if applicable – shall be checked after any damage, overloading or repair but 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.

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, the energy ratio E_r of the equipment used has to be known if the N-values are going to be used for the quantitative evaluation of foundations or for the comparisons of results. A certificate of calibration of the E_r-value immediately below the driving head or anvil shall be available.

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

5.2 Preparation of the borehole

The borehole shall be prepared for the specified test depth. The base of the borehole shall be clean and essentially undisturbed at the test elevation and without an upward water pressure gradient.

When drilling bits are used, they shall be provided with side discharge and not with bottom discharge, from a safe distance of the test elevation.

When testing below the groundwater table, particular care shall be taken to avoid any entry of water through the bottom of the borehole, as this will tend to loosen the soil or even lead to piping. For this purpose, the level of the water or drilling fluid in the borehole shall be maintained at a sufficient level above the groundwater level in the layer with the highest pressure (potential) at all times, even during withdrawal of the boring tools. Withdrawal shall be performed slowly and with drilling tools providing enough clearance to prevent suction effects at the bottom.

When a casing is used, it shall not be driven below the level at which the test will start.

5.3 Test execution

The sampler and the drive rods shall be lowered to the bottom of the borehole and then the hammer assembly added. The initial penetration shall be recorded. The sampler shall be penetrated over an initial or seating drive of 150 mm applying the 63,5 kg hammer free falling 760 mm and the number of blows N_0 shall be recorded. Then the sampler in the same manner shall be driven over a test drive of 300 mm in at least 2 increments of 150 mm. The number of blows needed, shall be recorded during each of these increments (N_n). If a total of 50 blows for the test drive is reached, the test may be finished (N = 50); in soft rocks it can be increased to 100 blows (N = 100). The total number of blows required for the 300 mm penetration after the seating drive is termed the penetration resistance of that soil layer ($N = N_n + N_{n+1}$).

In hard soils or in soft rocks where the penetration resistance is very high, the penetration for a certain number of blows may be recorded.

If the sampler advances below the bottom of the borehole under the static weight of the drive rods and hammer assembly on top, the corresponding penetration shall not be included, as seating drive and this information should be reported. In no case shall any material reach the level of the non return valve.

Samples recovered shall be recorded and handled in accordance with prEN ISO 22475-1.

5.4 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 as N or the test drive blow.

The N-values can vary with test equipment and mode operation as well as geotechnical conditions (see Annex A). The corrections of Annex A shall be considered.

7 Reporting

7.1 Field report

7.1.1 General

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

a) summary log according to prEN ISO 22475-1;

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 test the equipment operator in charge;

b) information on the location of the test:

1) borehole number;

2) field sketch (to scale or not to scale);

3) ground elevation referred to a fixed point;

4) x, y, z-co-ordinates of the borehole;

5) operation on land or water;

c) information on the used test equipment:

1) method of drilling and borehole diameter at the test level;

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

3) type and size of drive rod;

4) type and size of hammer and release mechanism and weight of the drive head;

5) split-spoon sampler with or without liner;

6) solid cone (SPT(C)), if used;

7) the energy ratio E_r and the calibration report;

d) information on the test procedure:

1) date and number of test;

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

3) test record with:

— the uncorrected N-value for each test, the corresponding depth interval;

— N_n, N_{n-1}, if required;

— the corresponding penetration, if the drive is terminated at 50 blows (or 100 in soft rocks);

— penetration per blow in difficult ground conditions, if required;

— penetration of the sampler under static weight;

4) record on recovered samples;

5) groundwater or artesian conditions, if known;

6) level of water or flushing medium during the preparation and execution of each test;

7) depth of test and casing;

8) weather conditions;

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

10) observations on the recovered sampler and/or rods;

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

12) reasons for early end of the test;

13) back-filling of penetration hole according to prEN 22475-1, if required.

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 presentation of the test results;

c) corrections applied, if any, and the corrected N-value;

d) graphical representation with respect to depth of N and corrected N, if applicable;

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

f) 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)

Correction factors

A.1 Energy delivered to the drive rods

Energy losses are induced by the hammer assembly due to frictional and other parasitic effects, which cause the hammer velocity at impact to be less than the free fall velocity. Further losses of energy are originated by the impact on the anvil, depending on its mass and other characteristics. The type of machine, skill of the operator and other factors can also influence the energy delivered to the drive rods.

The value of the blow count, N, in sands is inversely proportional to the energy ratio E_r so that:

$$N_a \times E_{r,a} = N_b \times E_{r,b} \qquad \text{(A.1)}$$

For general design and comparison purposes in sands, the N-values should be adjusted to a reference energy ratio of 60 %, by the following equation:

$$N_{60} = \frac{E_r}{60} N \qquad \text{(A.2)}$$

where

N is the blow count;

E_r is the energy ratio of the specific test equipment.

If a design method for sands has been elaborated for a value of E_r different from 60 %, the corresponding corrected N-value should be determined based on equation A.1.

A.2 Energy losses due to the length of rods

If the length of rods is less than 10 m, the correction factors shown in Table A.1 may be applied to the blow count for sands; for rod lengths greater than 10 m, no correction should be applied.

Table A.1 —Correction factors in sands due to rod length

Rod length below the anvil m	Correction factor λ
>10	1,0
6 to 10	0,95
4 to 6	0,85
3 to 4	0,75

A.3 Other correction factors

If the inner diameter of the sampler is 3,0 mm larger than that of the shoe, as mentioned in 4.2 no correction is necessary if a liner of appropriate thickness is used, such that the inside of the whole sampler is practically flush to a uniform diameter of 35 mm. Nevertheless, attention should be paid to the eventual damage of the liner during driving and its influence on the corresponding blow count. If the liner is omitted, the additional clearance of the inside of the barrel with reference to the shoe leads to N-values between 10 % and 20 % lower in sands.

A.4 Effect of overburden pressure in sands

The effect of the overburden pressure in the N-value in sands may be taken into account, for example, by applying to the measured N-value the correction factor C_N given in Table A.2 with reference to the type of consolidation and the density index I_D.

Table A.2 — Correction factors C_N for vertical stress σ_v' due to overburden of the soil in sands

Type of consolidation	Density Index I_D %	Correction factor C_N
Normally consolidated	40 to 60	$\frac{200}{100+\sigma'_v}$
	60 to 80	$\frac{300}{200+\sigma'_v}$
Overconsolidated	—	$\frac{170}{70+\sigma'_v}$
(σ_v' in kPa)		

Another example of the correction for normally consolidated sand is the use C_N given in the following equation:

$$C_N = \sqrt{\frac{98}{\sigma'_v}} \tag{A.3}$$

Values of the correction factor C_N larger than 2,0 and preferably 1,5 should not be applied.

The number of blows corrected to an energy ratio E_r of 60 % and normalised for an effective vertical stress σ_v = 100 kPa is then:

$$(N_1)_{60} = \frac{E_r \times N \times C_N}{60} \tag{A.4}$$

A.5 Use of the correction factors

Several correction factors have been mentioned in the previous paragraphs. As the existing design methods of foundations based on the SPT are of an empirical nature, only the corresponding correction factors should be used, unless duly justified.

If all the correction factors corresponding to this test procedure are applied for a design method based on an energy ratio of 60 %, the following value for the final blow count would be obtained (without including the one mentioned in A.3):

$$N_{60} = \frac{E_r}{60} \times \lambda \times C_N \times N \tag{A.5}$$

where

λ is the correction factor for energy losses due to the rod length in sand;

C_N is the correction factor for vertical stress due to overburden of the soil in sand.

Annex B
(informative)

Recommended method to measure the actual energy

B.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 B.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

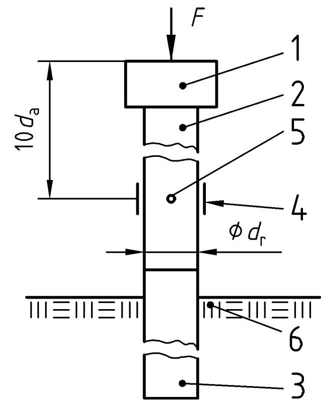


Figure B.1 — Instrumented rod (example)

B.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.

B.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.

B.4 Calculation

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

$$F(t) = A_a \times E_a \times \varepsilon_m(t) \quad \text{(B.1)}$$

where

$\varepsilon_m(t)$ is the measured axial strain 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.

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

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

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

where

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

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

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

$$E_{meas} = \frac{1}{n}\sum_1^n E \quad \text{(B.3)}$$

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

$$E_r = \frac{E_{meas}}{E_{theor}} \le 1 \quad \text{(B.4)}$$

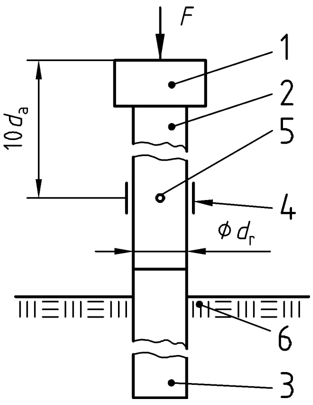
where

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

h is the falling height of the hammer;

m is the mass of the hammer;

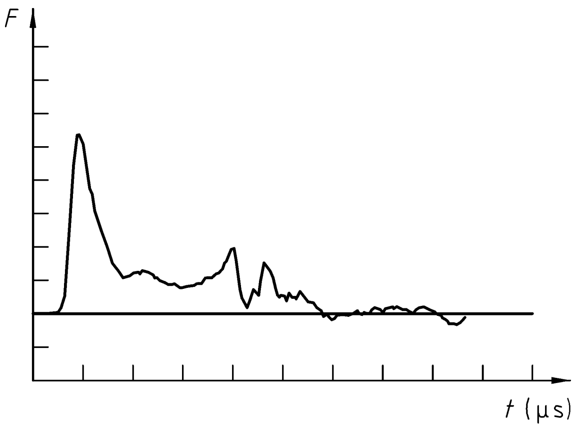
g is the acceleration due to gravity.



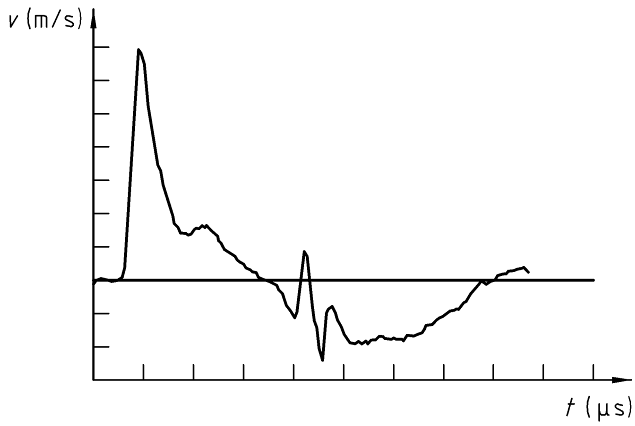
(Key see Figure B.1)

Hammer Energy Measurement Report	
Type of dynamic probing	SPT
Job number	
Date of the test	
Mass of the hammer m	63,5 kg
Falling height h	0,76 m
$E_{theor} = m \times g \times h$	473 J
Characteristics of the instrumented rod	
Diameter d_r	
Length of the instrumented rod	
Area A	
Modulus E_a	

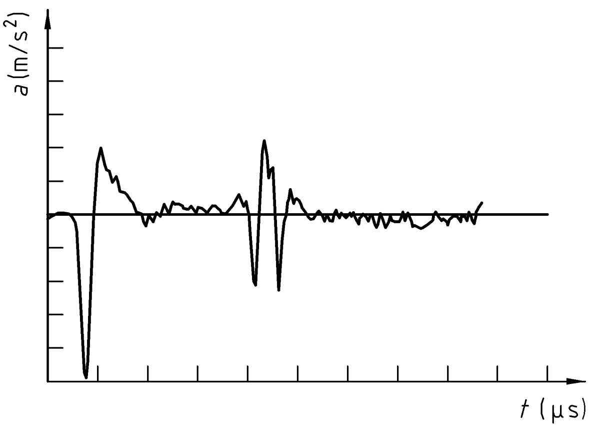
Force



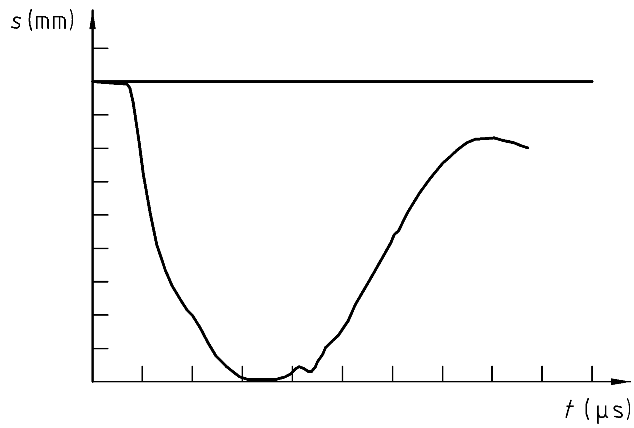
Particle velocity



Acceleration



Axial deformation



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

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

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