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Geotechnical investigation and testing — Laboratory testing of soil —

Part 12:
Determination of Atterberg limits

Reconnaissance et essais géotechniques — Essais de sol au laboratoire —

Partie 12: Détermination des limites d'Atterberg

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Throughout the text of this document, read "...this European pre-Standard..." to mean "...this Technical Specification...".

ISO 17892 consists of the following parts, under the general title *Geotechnical investigation and testing — Laboratory testing of soil*:

— *Part 1: Determination of water content*

— *Part 2: Determination of density of fine-grained soil*

— *Part 3: Determination of particle density — Pycnometer method*

— *Part 4: Determination of particle size distribution*

— *Part 5: Incremental loading oedometer test*

— *Part 6: Fall cone test*

- *Part 7: Unconfined compression test on fine-grained soil*
- *Part 8: Unconsolidated undrained triaxial test*
- *Part 9: Consolidated triaxial compression tests on water-saturated soil*
- *Part 10: Direct shear tests*
- *Part 11: Determination of permeability by constant and falling head*
- *Part 12: Determination of the Atterberg limits*

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Foreword

This document (CEN ISO/TS 17892-12:2004) 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”.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this Technical Specification: 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.

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- *Part 12: Determination of Atterberg limits*

Introduction

This document covers areas in the international field of geotechnical engineering never previously standardised. It is intended that this document presents broad good practice throughout the world and significant differences with national documents is not anticipated. It is based on international practice (see [1]).

1 Scope

This document specifies methods of test for the determination of the Atterberg limits of a soil. The Atterberg limits comprise the liquid limit, plastic limit and shrinkage limit. These limits are also called consistency limits. This document covers the determination of the liquid limit and the plastic limit only.

The liquid limit is the water content at which a soil changes from a liquid to a plastic state. This document describes the determination of the liquid limit of a specimen of natural soil, or of a specimen of soil from which material retained on a 0,4 mm or nearest sieve has been removed, using the fall-cone method. This standard has adopted both the 60 g/60° cone and the 80 g/30° cone as it has been shown that both cones give essentially the same value of the liquid limit. Other cone devices may be adopted provided they can be shown to give results equal to those obtained from the tests described herein.

NOTE The Casagrande method is an alternative method for the determination of the liquid limit. Experience has shown that the results are subject to the performance and judgement of the operator. Moreover, the Casagrande type apparatus and test method have undergone many small but significant variations since it was first proposed by Casagrande in 1932. These variations give rise to differences in the values of the liquid limit determined from the test. The fall-cone method is the preferred method of determining the liquid limit of a soil.

The plastic limit of a soil is the lowest water content at which the soil is plastic. The determination of the plastic limit is normally made in conjunction with the determination of the liquid limit. It is recognised that the results of the test are subject to the judgement of the operator, and that some variability in results will occur.

The Atterberg limits are influenced by oxidation or other changes in the specimen, resulting from storing it too long or otherwise by treating it in an unsuitable way. This applies especially to quick clays, sulphide clays and organic soils.

2 Normative references

The following referenced document is 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.

CEN ISO/TS 17892-1, *Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content (ISO/TS 17892-1:2004)*.

3 Terms and definitions

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

3.1
liquid limit
w_L
empirically established water content at which a soil passes from a liquid state to a plastic state

3.2
plastic limit
w_P
empirically established water content at which a soil becomes too dry to be plastic

3.3
plasticity index
I_P
numerical difference between the liquid limit and the plastic limit of a soil

NOTE A soil which has a plasticity index of zero or one for which the plastic limit cannot be determined is called non-plastic. The term consistency in this context refers to the relative ease with which a soil can be deformed. A characteristic of a cohesive soil is that, with decreasing water content, its consistency changes from that of a liquid (ability to flow under its own mass) to a plastic material that is mouldable and keeps its general form after deformation, to a solid (non-plastic with a brittle rupture occurring at small deformations). There is also an intermediate state between a solid and a plastic consistency where the soil behaves as a semi-solid. The Atterberg limits are empirically established water content limits which represent these changes in behaviour.

3.4
liquidity index

I_L

ratio of the difference between water content and the plastic limit of a soil, to the plasticity index

NOTE The liquidity index is a measure of the consistency of the soil in the remoulded state at the natural water content, and is also used as an indication of the sensitivity of a soil.

3.5
consistency index

I_C

ratio of the difference between the liquid limit and the water content, to the plasticity index

NOTE The consistency index is, like the liquidity index, a measure of the consistency of the soil in the remoulded state. The consistency index and the liquidity index are related by the following relationship:

$$I_C = 1 - I_L$$

3.6
activity index

I_a

ratio of the plasticity index to the clay size fraction of the soil

NOTE The activity index can be an indication of the colloidal properties of a clay, and is principally dependent on the amount and the type of clay minerals and organic colloids present as well as on the electrolyte content of the pore water.

3.7
clay size fraction

CF

dry mass of particles having an equivalent diameter of less than 0,002 mm divided by the total dry mass of the specimen (or of the dry mass after removal of the coarse fraction)

3.8
coarse fraction

particles that are retained on the 0,4 mm

4 Apparatus

4.1 General

The following items are necessary to determine Atterberg limits:

a) spatulas;

b) spray bottle (preferably of plastic) with distilled water;

The addition of distilled water dilutes the pore fluid, which may affect the measured liquid limit. Consideration should be given to using water taken in-situ should the effect on the liquid limit be significant.

c) evaporating dish;

d) a corrosion resistant airtight container;

e) balance (accuracy 0,03 g, readable to 0,01 g);

f) apparatus for determination of water content according to CEN ISO/TS 17892-1;

g) stopclock or stopwatch, readable to 1 s;

h) mortar with rubber-covered pestle (when required, for the preparation of mixed grained soil);

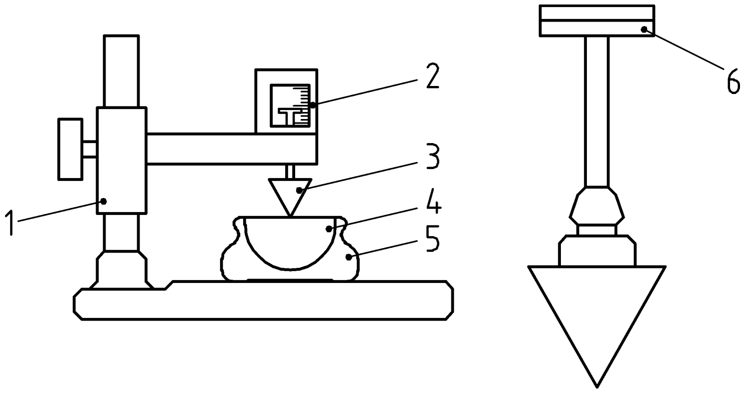
i) sieves; for preparation of mixed-grained soils, sieves with apertures of 2 mm and 0,4 mm or nearest shall be used;

j) a flat mixing plate (alternatively, a mixing tray may be used).

4.2 Liquid limit equipment

4.2.1 General

4.2.1.1 The cone apparatus shall permit the cone to be held firmly initially and to be released instantaneously to fall freely in a vertical direction into the soil (see Figure 1).



Key

1 adjustable stand arm
2 plexiglass with graded scale
3 fall cone
4 specimen
5 mixing cup
6 index line

Figure 1 — Example of fall cone equipment

4.2.1.2 The cone apparatus shall have a mechanism which allows the cone to be brought into contact with the surface of the specimen prior to its release.

4.2.1.3 The apparatus shall include a method of measuring the penetration of the cone into the specimen after release to a resolution of ± 0,1 mm within a range of 5 mm to 20 mm if the 60 g/60° cone is used, or within the range of 10 mm to 30 mm if the 80 g/30° cone is used.

4.2.2 Cone

4.2.2.1 The cone shall be made of stainless steel or duralumin material of 60 g mass with an apex angle of 60°, or of 80 g mass with an apex angle of 30°.

4.2.2.2 The height of the conical section of the cone shall be 20 mm or greater.

4.2.2.3 The surface roughness of the cone shall be less than 0,8 µm.

4.2.2.4 The mass of the cone, together with its shaft, shall be within 1 % of the nominal mass.

4.2.2.5 The tip angles shall be within ± 0,2° of the nominal angles. The deviation from the geometric tip at manufacture α, shall be less than 0,1 mm. The maximum wear, b, shall be less than 0,3 mm for the 60 g/60° cone and less than 1 mm for the 80 g/30° cone (see Figure 2A).

To ensure that the point remains sufficiently sharp for the purposes of the test, the cone should be replaced if the point can no longer be felt when brushed lightly with the tip of the finger when the tip is pushed through a hole 1,50 ± 0,02 in diameter, bored through a metal plate 1,75 mm ± 0,1 mm thick for the 80 g/30° cone or a 1,0 mm thick metal plate for the 60 g/60° cone (see Figure 2B).

NOTE The effect of surface roughness of the cone has more significance than variations in the cone angle or bluntness of the tip.

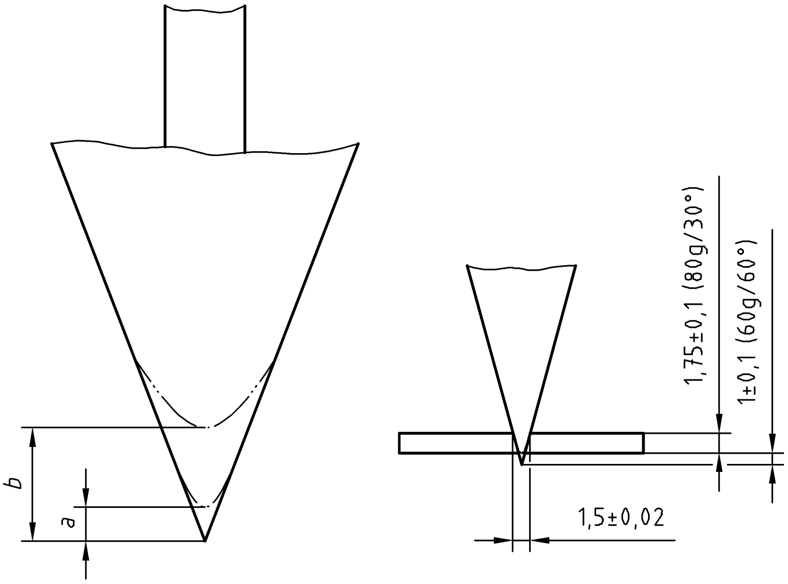


Figure 2 — Fall cone

4.2.3 Mixing cups

The cups shall be made of steel, porcelain or plastic, of cylindrical or semi-spherical shape, with a diameter greater than 55 mm and depth of 30 mm if the 60 g/60° cone is used and a depth of 40 mm if the 80 g/30° cone is used.

4.2.4 Straightedge

A metal straightedge about 100 mm long on a straight-bladed spatula.

4.3 Plastic limit equipment

4.3.1 Mixing plate

The plate shall be flat, clean, smooth and free from scratches. A convenient size of plate is about 10 mm thick and 300 mm square.

NOTE The condition of the surface of the glass plate affects the behaviour of the rolled threads. Mixing of soil containing silica particles inevitably scratches a glass surface. Use of a separate unscratched glass plate for the rolling operation will reduce discrepancies due to this effect.

4.3.2 Two palette knives or spatulas

4.3.3 Rod

The rod shall be 3 mm in diameter and 100 mm long.

5 Test method

5.1 Specimen preparation

5.1.1 Whenever possible the tests shall be carried out on soil from its natural state.

5.1.2 The specimen to be tested shall not be allowed to dry below the water content at which it is to be tested (see 5.1.6.7 and 5.2.1).

5.1.3 About 200 g of the natural soil passing the 0,4 mm or nearest sieves or 300 g of the soil prepared using the 'wet method' is required for the determination of the liquid limit.

5.1.4 Where fine-grained soils and organic soils contain coarse material, this shall, if possible, be excluded from the specimen tested. The presence of such coarse material shall be noted along with comments on whether or not these were removed when the specimen was being remoulded.

5.1.5 Where possible the coarse fraction shall be removed by hand rather than by wet sieving in order to avoid possible changes in the soil material by the addition of water different to that of the pore fluid.

5.1.6 If the coarse fraction cannot be removed by hand, the particles shall be removed using the wet method as follows:

5.1.6.1 A representative specimen of undried soil that will give at least 300 g of soil passing a 0,4 mm or nearest sieve shall be taken and weighed to the nearest 0,01 g (m_1).

5.1.6.2 Another specimen representative of the sample shall be taken and the water content w shall be determined.

5.1.6.3 The weighed specimen shall be placed in a container and just enough distilled water (without dispersant) shall be added to cover it. It shall be stirred until it forms a slurry.

5.1.6.4 The slurry shall be poured through a 2 mm sieve nested on a 0,4 mm or nearest sieve. The minimum amount of distilled water shall be used to wash clean the particles retained on the sieves until the water passing the 0,4 mm or nearest sieve is virtually clear. All the washings shall be collected.

5.1.6.5 The material retained on the 2 mm and 0,4 mm or nearest sieves shall be dried at 105 °C and weighed to the nearest 0,01 g (m_2).

5.1.6.6 The collected washing shall be allowed to settle for a suitable time, and any clear water shall be poured off.

5.1.6.7 The suspension shall partially dry in a current of warm air or in an oven at not more than 50 °C or by filtration until it becomes a firm paste. Local drying shall be prevented at the surface or edges by repeated stirring. The paste should be of a consistency corresponding to a penetration of about 7 mm for the 60 g/60° cone or 15 mm for the 80 g/30° cone.

5.1.6.8 When remoulding a soft, originally natural specimen, a breakdown of the structure of the soil skeleton takes place. The rate of breakdown depends on the remoulding effort, on the type of soil, on the natural water content of the specimen (the breakdown increases with increasing water content) and on the electrolytic content of the pore fluid. The remoulding is normally carried out by hand using a spatula and should be continued until the consistency of the specimen ceases to change. It should be carried out in such a way as to avoid air bubbles being mixed into the specimen.

5.1.6.9 After remoulding, a thixotropic strength increase generally takes place. The thixotropic strength increase has a considerable significance on the Atterberg limits determined in tests, particularly for montmorillonite and quick clays. Determination of Atterberg limits should therefore be made directly after remoulding.

5.2 Determination of liquid limit by fall-cone method

5.2.1 The prepared paste shall be mixed thoroughly. If necessary distilled water may be added so that the first cone penetrometer reading is as indicated in Table 1.

Table 1 — Cone penetration requirements

Cone penetration requirements	80 g/30°	60 g/60°
initial penetration	about 15 mm	about 7 mm
penetration range	15 to 25 mm	7 to 15 mm
maximum difference between two successive tests	0,5 mm	0,4 mm
w_L determined from penetration of:	20 mm	10 mm

NOTE The liquid limit is influenced by admixture of air bubbles when remoulding the specimen, or insufficient remoulding.

NOTE Some soils (e.g. clays of high plasticity; residual soils) may require up to 40 minutes of continuous mixing immediately before testing to obtain reliable results

If in doubt, comparative tests should be carried out.

5.2.2 A portion of the mixed soil shall be placed into a clean and dry cup with a palette knife, taking care not to trap air. Excess soil shall be struck off with the straight edge to give a smooth level surface.

5.2.3 With the penetration cone locked in the raised position, the supporting assembly shall be lowered so that the tip of the cone just touches the surface of the soil. When the cone is in the correct position a slight movement of the cup will just mark the soil surface.

5.2.4 The cone shall be locked in position and, if required for the particular apparatus, the initial position of the cone shaft shall be recorded to the nearest 0,1 mm.

5.2.5 The cone shall be released for a period of 5 s ± 1 s. If the apparatus is not fitted with an automatic release and locking device, care shall be taken not to jerk the apparatus during this operation.

NOTE Especially in cone tests on silty soils, a post-sinking of the cone takes place due to the influence of dilatancy and water migration in the specimen. After a certain penetration, the cone momentarily stops, and then continues to sink slowly until it finally stops.

If post-sinking occurs, this should be observed and noted in the record.

5.2.6 The cone shall be locked in position if required by the particular apparatus.

5.2.7 The final position of the cone shaft shall be recorded to the nearest 0,1 mm.

5.2.8 The penetration of the cone shall be calculated as the difference between the initial and final position of the cone shaft, to the nearest 0,1 mm.

5.2.9 The cone shall be lifted out and cleaned carefully to avoid scratching.

5.2.10 A little more wet soil shall be added to the cup, taking care not to trap air, and the surface shall be made smooth as in 5.2.2.

5.2.11 5.2.3 to 5.2.9 shall be repeated until the difference between two subsequent penetrations is no more than indicated in Table 1.The average of the last two penetrations shall be calculated.

5.2.12 A specimen (± 10 g) from the zone penetrated by the cone shall be taken and the water content shall be determined according to CEN ISO/TS 17892-1.

For soils with a very high liquid limit such as organic clays, and amorphous peat, the water content should be determined on at least 20 g of the soil to give an accurate determination.

5.2.13 5.2.2 to 5.2.11 shall be repeated at least three more times using the same specimen of soil but at different water contents. The amount of water subtracted/added shall be such that a range of penetration values in accordance with Table 1 is covered by the four or more test runs, and that readings are evenly distributed.

NOTE It is normally more practicable to carry out the test going from the drier condition to the wetter condition in continuously increasing water contents although going from the wetter to the drier condition is also acceptable.

5.2.14 The water content of the specimen should not be alternately increased and reduced but either increased or reduced in stages.

5.2.15 When increasing the water content of the specimen, distilled water shall be added and then carefully mixed in with the spatula.

5.2.16 When reducing the water content, the whole specimen shall be spread on a plate or evaporating dish. The specimen shall then be moved to a clean mixing cup or flat plate and carefully remoulded with the spatula.

5.2.17 If at any time during the above procedure the soil has to be left for a while it shall be covered with the evaporating dish or a damp cloth to prevent it from drying out.

NOTE For soils which are easily affected by oxidation e.g. clays containing sulphides, it is of important that the duration of the test is not excessively long.

5.3 Determination of plastic limit

5.3.1 A specimen of about 20 g shall be taken from the soil paste prepared according to 5.1, and it shall be placed on the mixing plate.

NOTE It is often convenient to carry out the test on a portion of the material prepared for one of the liquid limit tests procedures.

5.3.2 The soil shall be allowed to partially dry on the plate until it becomes plastic enough to be shaped into a ball.

5.3.3 The ball of soil shall be moulded between the fingers and rolled between the palms of the hands until the heat of the hands has dried the soil sufficiently for slight cracks to appear on its surface. This specimen shall be divided into two sub-specimens of about 10 g each and a separate determination shall be carried out on each portion.

5.3.4 Each sub-specimen shall be divided into four equal parts and each part shall be treated according to 5.3.5 to 5.3.8.

5.3.5 The soil shall be moulded between the fingers to equalise the distribution of moisture and subsequently the soil shall be moulded into a thread about 6 mm diameter between the first finger and thumb of each hand.

5.3.6 The thread shall be rolled between the fingers of one hand, from finger-tip to the second joint, on the surface of the mixing plate or the surface of the rolling plate. Enough pressure shall be used to reduce the diameter of the thread to about 3 mm in 5 to 10 complete forward and back movements of the hand at a rate of about 1 complete movement per second. Some highly plastic clays will require 10 to 15 movements when the soil is near the plastic limit because the soil hardens at this stage. It is important to maintain a uniform rolling pressure; the pressure may not be reduced as the thread diameter approaches 3 mm.

NOTE Gradual drying of the soil is effected by alternately rolling and moulding, not by continual rolling, either as a ball or as threads, which produces a dried crust. It may be particularly difficult to knead a high plasticity clay homogeneously when the water content approaches the plastic limit. In this case, when rolling again, the specimen splits in parts which have not been sufficiently kneaded together. By performing rolling tests on these parts, it can be determined whether the plastic limit has been reached.

5.3.7 5.3.5 and 5.3.6 shall be repeated until the thread shears both longitudinally and transversely when it has been rolled to about 3 mm diameter, as gauged by the rod. The pieces of soil may not gather together after they have crumbled in order to reform a thread and to continue rolling; the first crumbling point is the plastic limit.

NOTE With soils that are marginally plastic it is often difficult to assess the precise crumbling condition.

5.3.8 The portions of the crumbled soil thread assessed to have been at their plastic limit shall be gathered together and shall be transferred to a suitable container and the lid shall be replaced immediately.

5.3.9 5.3.5 to 5.3.8 shall be repeated on the other three portions of soil, placing them all in the same container. The water content of the soil in the container shall be determined.

5.3.10 5.3.4 to 5.3.9 shall be repeated on the duplicate specimen formed in 5.3.3 above, placing the crumbled specimens in a second container.

6 Test results

6.1 Initial dry mass

When the coarse fraction of the soil is removed by sieving, the initial dry mass shall be calculated according to equation (1):

$$m_\mathrm{d} = \frac{100 \times m_1}{100 + w} \tag{1}$$

where

m_d is the mass of dry soil,

m_1 is the mass of undried soil;

w is the water content [%].

6.2 Dry mass retained on 0,4 mm (or nearest) sieve

When the coarse fraction of the soil is removed by sieving, the percentage by dry mass retained on the 0,4 mm or nearest sieve shall be calculated according equation (2):

$$p_\mathrm{a} = \frac{m_2}{m_\mathrm{d}} \times 100\% \tag{2}$$

where

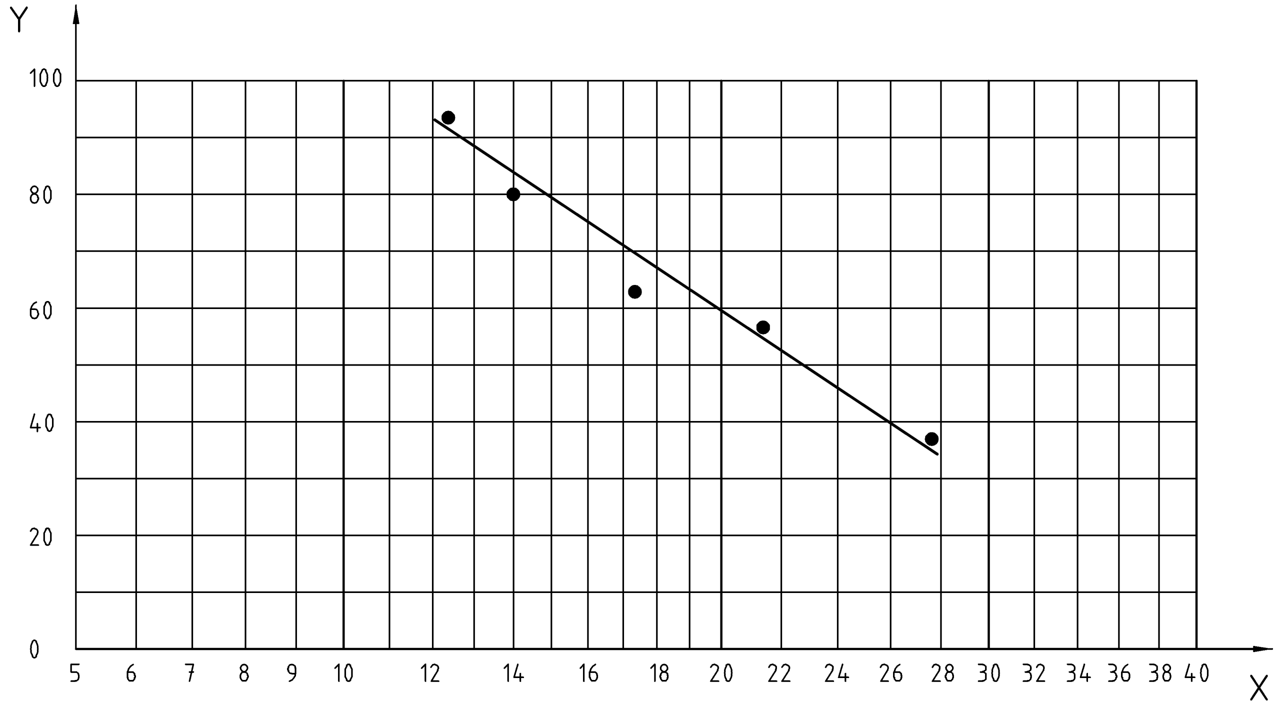
p_a is the fraction retained on 0,4 mm (or nearest) sieve;

m_2 is the mass of dried washings retained on sieves.

6.3 Liquid limit

The relationship between water content (%) and the cone penetration shall be plotted on a semi-log scale with the water content on a linear scale as abscissa and the cone penetrations on a log scale as ordinates (see Figure 3). The best straight line fitting the plotted points shall be drawn. From the graph, the water content corresponding to a cone penetration of 10 mm shall be read off for the 60 g/60° fallcone method or the water content corresponding to 20 mm cone penetration for the 80 g/30° fall-cone method.

The semi-log scale can be replaced by linear scales for both the water contents and the cone penetrations if the 80 g/30° cone is used.



Key

x cone penetration (mm)

y water content (%)

Figure 3 — Example or report

6.4 Plastic limit

The water content (%) of both specimens tested shall be calculated and the results shall be expressed to the first decimal. If the two results differ by more than 0,5 % water content, the whole test shall be repeated. The average of the two water content values shall be calculated and the value shall be expressed to the nearest whole percent and report as the plastic limit w_P.

6.5 Plastic index

The plasticity index I_P, when required, shall be calculated according to equation (3):

$$I_P = w_L - w_P \tag{3}$$

6.6 Liquidity index

The liquidity index I_L, when required, shall be calculated according to equation (4):

$$I_L = \frac{w - w_P}{w_L - w_P} \tag{4}$$

6.7 Consistency index

The consistency index I_C, when required, shall be calculated according to equation (5)

$$I_C = \frac{w_L - w}{w_L - w_P} \tag{5}$$

For soils containing a significant amount of coarse particles, it may be more relevant to calculate the liquidity index and the consistency index from the water content of the fraction passing the 0,4 mm (or nearest) sieve, instead of the natural water content w.

7 Test report

The test report shall affirm that the test was carried out in accordance with this document, and shall contain the following information:

a) identification of the sample (material) being tested, e.g. by boring number, sample number, test number, etc.;

b) value of the liquid limit to two significant digits, when determined. The method of obtaining the liquid limit and the type of cone used shall also be reported. If post sinking occurs during the fall cone test, this shall be reported;

c) plastic limit of the soil to two significant digits, when determined. If the test was carried out using absorbing paper, this shall be reported. If it was not possible to determine the plastic limit, this fact shall also be reported;

d) plasticity index, when determined;

e) percentage of material passing the 0,4 mm or nearest sieve, when determined;

f) history of the sample, e.g. whether tested in the natural state or after wet sieving or after any other process;

g) liquidity index, when determined.

Bibliography

[1] DIN, ISSMGE (Eds.) (1998): Recommendations of the ISSMGE for geotechnical laboratory testing; (in English, German and French); Berlin, Wien, Zürich (Beuth Verlag).

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