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Geotechnical investigation and testing — Laboratory testing of soil —

Part 5: Incremental loading oedometer test

Reconnaissance et essais géotechniques — Essais de sol au laboratoire —

Partie 5: Essai à l'oedomètre sur sol saturé

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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*

Contents

Page

Foreword

This document (CEN ISO/TS 17892-5:2004) 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 the 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 is intended for determination of the compression, swelling and consolidation properties of soils. The cylindrical test specimen is confined laterally, is subjected to discrete increments of vertical axial loading or unloading and is allowed to drain axially from the top and bottom surfaces.

The main parameters derived from the oedometer test relate to the compressibility and rate of primary consolidation of the soil. Estimates of preconsolidation pressure, rate of secondary compression, and swelling characteristics are sometimes also obtainable.

The main parameters which can be derived from the oedometer test carried out on undisturbed samples are:

1) compressibility parameters;

2) coefficient of consolidation;

3) apparent preconsolidation pressure or yield stress;

4) coefficient of secondary compression;

5) swelling parameters.

The fundamentals of the incremental loading oedometer test include:

— stress path corresponds to one-dimensional straining;

— drainage is one-dimensional and axial.

The stress paths and drainage conditions in foundations are generally three dimensional and differences can occur in the calculated values of both the magnitude and the rate of settlement.

The small size of the specimen generally does not adequately represent the fabric features present in natural soils.

Analysis of consolidation tests is generally based on the assumption that the soil is saturated. In case of unsaturated soils, some of the derived parameters may have no physical meaning.

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 1997-2, *Eurocode 7 - Geotechnical design — Part 2: Ground investigation and testing.*

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

CEN ISO/TS 17892-2, *Geotechnical investigation and testing — Laboratory testing of soil — Part 2: Determination of density of fine grained soil (ISO/TS 17892-2:2004).*

3 Terms and definitions

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

3.1
excess pore pressure
pore water pressure over and above the equilibrium pore pressure at the end of consolidation

3.2
primary consolidation
process whereby soil compresses as a result of an increase (or decrease) in effective stress due to dissipation of excess pore pressure under constant total applied stress accompanied by drainage of water from the voids

3.3
secondary consolidation
process in which compression occurs after full excess pore pressure dissipation

3.4
swelling
expansion due to reduction of effective stress

NOTE Swelling includes both the reverse of compression and the reverse of consolidation.

3.5
undisturbed sample
normally a sample of quality class 1 according to prEN 1997-2

4 Symbols

For the purposes of this document, the following symbols apply.

A Cross-sectional area of specimen.

e Void ratio, i.e. volume of pores relative to volume of solid particles.

e_0 Original void ratio, i.e. void ratio of the specimen at the start of the test.

e_f Void ratio of the specimen at the end of an increment: this is the void ratio of the specimen at the start of the next increment.

D Diameter of the oedometer ring.

H Height of the specimen.

H_0 Original height, i.e. height of the specimen at the start of the test: this is normally taken as the depth of the oedometer ring.

H_i Initial height, i.e. height of the specimen at the start of an increment: this is the height of the specimen at the end of the previous increment.

H_f Height of the specimen at the end of an increment: this is the height of the specimen at the start of the next increment.

H_s Equivalent height of solids.

m_d Dry mass of specimen.

ε_v Vertical strain.

ρ Initial density of specimen.

ρ_d Initial dry density of specimen.

ρ_s Particle density.

σ'_s Swelling pressure, i.e. the pressure required to maintain constant volume (i.e. to prevent swelling) when a soil is flooded with water.

σ_v Total vertical stress, i.e. the vertically applied force divided by the horizontal cross-sectional area.

σ'_v Effective vertical stress, i.e. the difference between the total vertical stress and the pore water pressure.

5 Equipment

5.1 Requirements

5.1.1 Oedometer ring

5.1.1.1 The oedometer ring shall be indelibly marked with a unique identification number. The cutting edge shall not be damaged.

5.1.1.2 The internal dimensions shall conform to the following:

— diameter: minimum 35 mm;

— height (H): not less than 12 mm;

— ratio (D/H): not less than 2,5.

5.1.1.3 The ring shall either be laterally confined to restrict expansion under load, or have sufficient stiffness to prevent the internal diameter expanding by more than 0,05 % when subjected to the maximum horizontal stress resulting from the test.

5.1.1.4 The ring shall be made of corrosion-resistant metal or other suitable material and shall have a sharp cutting edge. The internal surface shall be smooth, and shall be lubricated with a thin film of silicone grease, petroleum jelly, or other suitable lubricant.

5.1.2 Porous plates

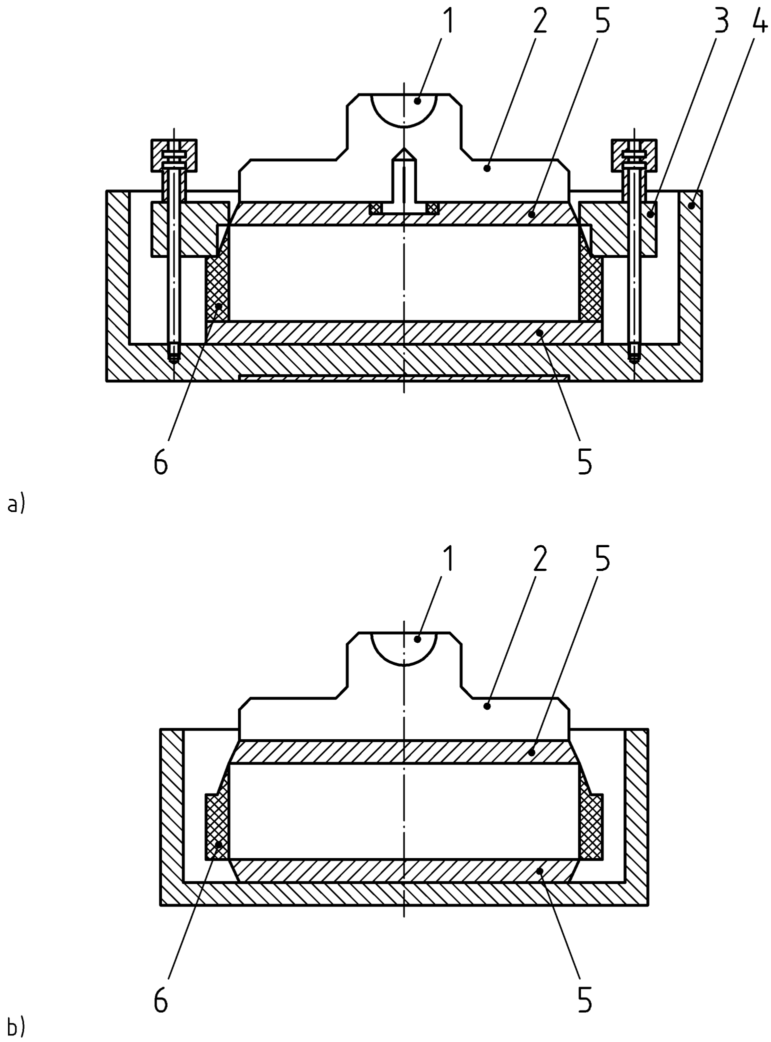
5.1.2.1 The top and bottom porous plates shall be of corrosion-resistant material and shall allow free drainage of water, while preventing intrusion of soil particles into their pores. The upper and lower surfaces shall be plane, clean and undamaged. The material shall be of negligible compressibility under the maximum stress likely to be applied during the test and shall be thick enough to prevent breakage under load.

5.1.2.2 If necessary, a filter paper may be used to prevent intrusion of the soil into the porous stones. However, the permeability of the stones and the filter paper shall be sufficiently high to prevent retardation of the drainage of the specimen.

5.1.2.3 The diameter of the top porous plate shall be about 0,5 mm less than the internal diameter of the oedometer ring, and may be tapered towards the upper face to minimize the risk of binding due to tilt.

5.1.2.4 In a fixed-ring cell the bottom porous plate shall be large enough to support the oedometer ring.

5.1.2.5 In a floating-ring cell the diameter of the bottom porous plate shall be about 0,5 mm less than the internal diameter of the ring. The bottom porous plate shall be similar to the top plate, but tapered towards the lower face (see Figure 1).



Key

a) Fixed ring oedometer
b) Floating ring oedometer
1 Seating
2 Loading cap
3 Lateral restraint for ring
4 Cell body
5 Porous plates
6 Oedometer ring

Figure 1 — General arrangements of typical oedometer cells

5.1.2.6 Before use, new porous plates shall be saturated by boiling in distilled or de-ionised water for at least 20 min. They shall then be kept immersed in distilled water until required for use.

5.1.2.7 The surface of the porous plates which have previously been used shall be cleaned with a natural bristle or nylon brush, followed by a check that the plates are readily permeable to water and that the pores are not clogged by soil particles. They shall then be saturated by boiling as described above.

In soft soils the difference between the diameter of the porous plate and the internal diameter of the ring may need to be reduced to 0,2 mm to avoid extrusion of soil.

5.1.3 Cell body

5.1.3.1 The cell body shall be of suitable corrosion-resistant metal or other suitable material.

5.1.3.2 A fixed-ring cell (see Figure 1a) shall accept the oedometer ring with a push fit and shall be rigid enough to prevent significant lateral deformation of the ring when under load.

5.1.3.3 A floating-ring cell (see Figure 1b) shall provide adequate clearance around the outside of the ring.

5.1.3.4 The assembled cell (see Figure 1) shall be watertight and shall hold water to a level which submerges the upper porous plate.

5.1.3.5 All components shall be made of materials which are not corrodible by electro-chemical reaction with each other, or the soil and the pore water.

5.1.4 Loading cap

5.1.4.1 The loading cap shall be rigid enough to ensure negligible deformation under load.

5.1.4.2 It shall be fitted with a central load seating and shall be mounted centrally in the consolidation cell.

5.1.4.3 If porous disks with a thickness of less than 6 mm are used, then the loading cap shall have perforations or grooves to allow the free drainage of pore water.

5.1.5 Deformation gauge

5.1.5.1 The deformation gauge may be either a dial gauge or an electrical displacement transducer, rigidly supported for measuring the vertical deformation of the specimen during the test.

5.1.5.2 The gauge shall have a travel of at least 10 mm with a resolution and accuracy of 0,002 mm. When a travel exceeding 10 mm is required (e.g. for highly compressible soil) an accuracy and resolution of 0,01 mm is acceptable.

If non-conventional equipment is used the reference system used for the measurements should be clearly defined in order to clarify which components of the apparatus contribute to the compliance of the measuring system.

5.1.6 Loading frame

5.1.6.1 The loading frame shall have a rigid bed on which the cell body is supported.

5.1.6.2 The loading frame shall allow the application of vertical stresses acting centrally on the loading cap only.

5.1.6.3 The vertical stress applied to the specimen shall be accurate to better than 1 % or 1 kPa. The stress shall remain constant within these limits throughout the duration of a loading increment. The mechanism shall allow the application of a given load increment within a period of 2 s without significant impact.

5.1.6.4 Adequate arrangements shall be made to ensure stability of the load frame, or a group of load frames, when fully loaded.

5.1.7 Ancillary apparatus

The ancillary apparatus consists of:

- balance, accuracy 0,03 g, readable to 0,01 g or better;
- timer readable to 1 s;
- maximum/minimum thermometer readable to 1 °C;
- metal disk with flat, smooth and parallel end faces. The diameter shall be about 1 mm less than the internal diameter of the oedometer ring and the height shall be the same as that of the ring;
- apparatus for determination of water content;
- apparatus for determination of particle density;
- vernier callipers reading to 0,05 mm.

5.1.8 Apparatus for specimen preparation

The apparatus for the specimen preparation consists of:

- cutting and trimming tools (e.g. cheese-wire, wire-saw, sharp knife, scalpel);
- spatulas;
- straight-edge trimmer;
- reference straight-edge (e.g. engineer's steel rule);
- steel try-square;
- flat glass plate;
- extrusion equipment and clamping jig (for preparing and trimming specimens from a tube sample).

5.1.9 Water

The water added to the cell to submerge the sample shall not influence the test results. For marine clays and for soils from off-shore sites sea-water should be used.

Normally ground water from the site at which the sample was taken, or similar natural or prepared water shall be used if distilled water is likely to influence the test results. Soils from certain regions may require water with salinity even higher than that of normal sea-water.

5.2 Calibration

5.2.1 Oedometer ring

5.2.1.1 The internal diameter of the oedometer ring shall be measured in two perpendicular directions to the nearest 0,05 mm. The mean diameter D (mm) and the area A (mm^2) shall be calculated.

5.2.1.2 The height of the ring at four equally spaced points shall be measured to the nearest 0,05 mm. The mean height H_0 (mm) and the contained volume V_0 (ml) shall be calculated.

5.2.1.3 The ring shall be weighed to the nearest 0,01 g.

5.2.2 Deformation of apparatus

5.2.2.1 The oedometer apparatus shall be assembled by using the metal disc in place of the specimen. The porous stones shall be moistened. If filter papers are to be used during the actual test, they should be moistened during calibration and sufficient time should be allowed during the calibration process for the water to be squeezed from them.

5.2.2.2 Increments of load shall be applied similar to those applied in a test and the reading of the deformation gauge corresponding to each increment shall be recorded. It is advisable, before a calibration loading test, first to load and unload the metal disc without taking any reading in order to avoid small movements, strains, inequalities etc., and then start the calibration loading as above.

5.2.2.3 Unloading shall be performed in similar decrements and the deformation shall be recorded.

5.2.2.4 The deformations shall be tabulated as cumulative deformations against the applied loads or plotted as a graph of cumulative deformation against the applied load. In the calibration report it should be clearly noted whether filter papers were used during the calibration process and, if so, what type of filter paper was used.

5.2.2.5 Re-calibration of the equipment is necessary at regular intervals (at least once a year) and when essential parts are changed or replaced.

5.2.2.6 The appropriate value of the apparatus deformation is deducted from the measured deformation in a test to give the cumulative deformation of the specimen itself under the given load. This correction is likely to be significant only for relatively stiff soils.

5.2.2.7 In extremely stiff soils, tested at high stress levels, the lateral deformability of the ring may also affect the results. To avoid lateral deformation of the specimen, special very stiff oedometer rings should be used.

5.3 Environment

5.3.1 Test specimens shall be prepared in an environment which avoids significant loss or gain of soil water. If the preparation process is interrupted the specimen shall be protected by wrapping in thin plastic sheet or clingfilm.

5.3.2 The area in which the test is carried out shall be free from significant vibrations and mechanical disturbance. The apparatus shall be protected against sunlight, local sources of heat and draughts.

5.3.3 The temperature of the test location shall be maintained constant to within ± 2 °C. Maximum and minimum temperatures shall be recorded daily.

6 Test procedure

6.1 General requirements

6.1.1 This test is applicable to saturated homogeneous specimens. The test should be carried out on undisturbed samples.

6.1.2 The mean diameter of the largest particle within a specimen shall not normally exceed one-fifth of the height of the ring.

6.2 Specimen preparation

6.2.1 Selection of preparation method

Test specimens may be prepared by the following methods depending on the type of sample available:

- extrusion from a sample tube of the same diameter as the oedometer ring (when trimming would cause significant disturbance);
- extrusion from a sample tube of a diameter larger than that of the ring (homogeneous soils with few coarse particles or other features likely to cause disturbance);
- trimming from an undisturbed block sample (taken by hand or removed from a tube);
- trimming from an undisturbed sample obtained by continuous sampling methods;
- artificial compaction of disturbed soil (when undisturbed samples cannot be obtained).

6.2.2 Extrusion from tube of diameter equal to ring

6.2.2.1 The sampling tube shall be mounted in the extrusion device and the oedometer ring shall be securely clamped in position with its axis in line with the axis of the tube.

6.2.2.2 Any disturbed soil shall be extruded from the end of the tube and the surface of the soil remaining in the tube shall be trimmed flat.

6.2.2.3 The sample shall be extruded until the ring is filled, with some excess soil at either end. The direction of extrusion shall be recorded.

6.2.2.4 The extruded soil shall be cut off with a wire saw.

6.2.2.5 Portions of the soil trimmings shall be used for a preliminary determination of water content, a test for particle density and other classification properties, if required (see note).

6.2.2.6 Each end of the specimen shall be trimmed in turn, using a sharp knife or scalpel to cut away excess soil a little at a time. The ends shall be checked to be flat and flush with each edge of ring. Leaving smeared surfaces shall be avoided.

NOTE The water content determined at this stage enables preliminary values of void ratio to be calculated while the test proceeds, before the final dry mass is available.

6.2.3 Extrusion from tube of larger diameter

6.2.3.1 The procedure described in 6.2.2 shall be followed. Additionally, it should be checked that excess soil that is cut off by the ring can be removed easily and does not impede the extrusion process.

6.2.4 Trimming from block sample or continuous sample

6.2.4.1 A horizontal flat surface shall be prepared on the sample of a size larger than the diameter of the oedometer ring.

6.2.4.2 The sample shall be placed on to the trimming apparatus, the ring shall be fitted into its holder and the cutting edge shall be lowered on to the prepared surface.

6.2.4.3 The ring shall be steadily forced into the sample until it is filled with soil with an excess protruding from the top. Soil cuttings shall be removed so that advance of the ring is not impeded.

6.2.4.4 With stiff soils the sample shall be trimmed in advance of the ring to about 1 mm or 2 mm larger than the internal ring diameter so that the cutting edge removes the remaining thin layer.

6.2.4.5 The sample shall be cut off underneath the ring to remove the ring and contained soil.

6.2.4.6 Soil trimmings shall be used and the trimming of the specimen shall be completed, as described in 6.2.2.5 and 6.2.2.6.

6.2.5 Recompacted specimens

6.2.5.1 Disturbed samples shall be prepared by compacting the soil into a suitable mould (e.g. a compaction mould) either at the required water content and under the application of the appropriate compaction effort, or to achieve the specified dry density.

6.2.5.2 The sample shall be extruded from the mould and the test specimen shall be prepared by one of the methods described above (6.2.2, 6.2.3, or 6.2.4). With friable soils it may be necessary to compact the soil directly into the oedometer ring. Trials should be made to ascertain the degree of controlled compaction required to achieve the desired density.

6.3 Measurement and protection

6.3.1 Immediately after preparation the soil and ring shall be placed on a previously weighed container and weighed to the nearest 0,01 g, and the mass of the specimen shall be calculated.

6.3.2 The diameter, height and volume of the specimen may be assumed to be equal to the corresponding internal dimensions of the ring.

6.3.3 The test should be started immediately after the specimen has been prepared but, if a short delay is unavoidable, the specimen shall be protected by wrapping in thin plastic film or clingfilm until ready for testing.

6.4 Preparation of apparatus

6.4.1 Assembly of cell

6.4.1.1 The bottom porous plate, the specimen in its oedometer ring and the top porous plate shall be placed in the correct alignment in the consolidation cell (see Figure 1). If required, filter papers may be placed between the specimen and the porous plates. In this case they shall also be used during calibration procedures (see 5.2) and their use shall be reported on the test results. Place the loading cap centrally on the top porous plate.

6.4.1.2 For saturated soils, or soils which do not have a high affinity for water, free water shall be allowed to drain from the surface of the porous plates before placing. The pores shall remain saturated.

6.4.1.3 For soils that readily absorb water (e.g. stiff clays) the porous plates shall be air dry before placing.

6.4.2 Assembly in load frame

6.4.2.1 The consolidation cell shall be placed in position on the apparatus.

6.4.2.2 A small seating pressure shall be applied to the specimen not exceeding 3 kPa including the weight of the top cap and porous plate.

6.4.2.3 The deformation gauge shall be secured in position and the initial reading corresponding to zero deformation shall be recorded.

6.4.2.4 The timer to zero shall be set to zero.

6.4.2.5 If a system with counter-balanced beams is used, the initial inclination of the beam upwards should be about equal to the inclination downwards under the maximum loading to be applied, so that the mean position during the test is horizontal. For many types of apparatus the inclination of the beam is not critical.

6.5 Loading

6.5.1 Loading sequence

6.5.1.1 The vertical stresses applied to the specimen shall be chosen. In soft soils applied stresses would typically be smaller than in stiff soils.

6.5.1.2 Typically four to six increments of loading are usually sufficient. In the normal procedure each stress shall be double the previous stress (increment ratio = 1). If the apparent preconsolidation pressure σ'_p is to be determined, the load increment ratio may be decreased near the expected value and this shall be reported.

6.5.1.3 For soils with a swelling tendency the next stress in the suggested sequence above the swelling pressure should be applied as the first increment. Alternatively the specimen may not be submerged until the vertical stress exceeds the swelling pressure.

Table 1 — Suggested initial pressure

Soil consistency	Initial pressure
Stiff	Equal to σ'_0 or the next higher recommended pressure above σ'_0 if σ'_0 is less than σ'_s.
Firm	Somewhat less than σ'_0, preferably using the next lower recommended pressure.
Soft	Appreciably less than σ'_0, usually 25 kPa or less.
Very soft	Very low, typically 6 kPa or 12 kPa. Initial consolidation under small load will give added strength to prevent squeezing out under next load increment.

6.5.1.4 The largest vertical stress should be well in excess of the maximum vertical stress likely to occur in-situ. For overconsolidated clay where the apparent preconsolidation pressure σ'_p is to be determined, loading should extend to at least two load increments above σ'_p. For some soils this may require very large stresses in excess of those which can be achieved in conventional equipment.

NOTE A suggested stress sequence is: 6, 12, 25, 50, 100, 200, 400, 800, 1600, 3200 kPa.

6.5.1.5 Reducing the load increment ratio may affect the time-settlement plots and make interpretation of c_v more difficult.

The initial vertical stress to be applied depends on the type of soil; Table 1 suggests some initial values.

6.5.1.6 Consideration may be given to include, as a special test condition, one or more unload/reload cycles to assess and reduce the effects of sample disturbance, and to assess and reduce the effects of system compliance.

6.5.1.7 When testing soft soils, the initial stress should be restricted in order to avoid yielding.

6.5.2 Application of loads

6.5.2.1 The deformation gauge reading shall be recorded as the initial reading for the load increment stage (d_i).

6.5.2.2 The required load shall be carefully applied, without jolting, within a period of 2 s. (Alternatively, a jacking system shall be used to support the lever arm while weights are added to the hanger.) At the same instant the timer shall be started and the small seating load shall be removed.

6.5.2.3 The consolidation cell shall be filled with water to the top of the upper porous plate. If the specimen begins to swell this shall be prevented either by applying the next higher vertical stress in the sequence and re-starting the timer or by determining the swelling pressure, as described in 6.5.3.

6.5.2.4 The deformation gauge readings shall be recorded at intervals of time to enable the graphs referred to in 7.3.5 to be plotted. If an automatic data-logger is used the timings should at least conform to those used for manual recording. These times give a regular spacing of points when plotted, but more frequent readings may be needed for soils which consolidate very rapidly. Readings may be taken at other time intervals so long as they enable the time-compression curve to be plotted with sufficient accuracy. If determination of c_v is not required, such frequent readings may not be necessary.

6.5.2.5 Deformation gauge readings shall be plotted against the logarithm of time and/or square-root of time (see Figures A.3 and A.4). The vertical stress shall be maintained until the plotted readings indicate that primary consolidation has been completed. If the coefficient of secondary compression C_α is required for a given pressure increment, the duration of the increment should be sufficient to enable the linear portion of the log time/settlement plot to be established.

6.5.2.6 The deformation gauge reading d_f shall be recorded at the termination of the load increment stage. This reading becomes the initial reading d_i for the next stage.

6.5.2.7 The vertical stress shall be increased to the next value in the sequence, as in 6.5.2.2 above, and repeat 6.5.2.4 to 6.5.2.6.

6.5.2.8 The specification of 6.5.2.7 shall be repeated for each subsequent vertical stress in the selected sequence.

6.5.2.9 Under no circumstances should the specimen be allowed to swell. If desired the swelling pressure (σ'_s), which can be important in soils that have a swelling capability when allowed access to water, may be determined as described in 6.5.3.

6.5.2.10 The following reading intervals are suggested: 0, 10, 20, 30, 40, 50 s, 1, 2, 4, 8, 15, 30 min, 1, 2, 4, 8, 24 h. Subsequent readings, if necessary, should be recorded at the start, middle and end of each working day.

6.5.2.11 A period of 24 h is normal but this should be verified. Periods longer or shorter than 24 h might be appropriate, depending on the type of soil, in which case the duration shall be reported.

6.5.2.12 The consolidation period should normally be about the same for each load increment whether for determination of primary consolidation or secondary compression.

6.5.3 Determination of swelling pressure

6.5.3.1 After completing the operations described in 6.5.2.2, water at room temperature shall be added and the timer shall be started.

6.5.3.2 The vertical load shall be increased as necessary to maintain the deformation gauge reading within 0,01 mm of the corrected zero reading. The cumulative magnitude of each vertical stress shall be recorded on the specimen and the corresponding elapsed time.

6.5.3.3 When equilibrium is established, the vertical stress σ'_s applied to the specimen shall be calculated and the value shall be recorded as the swelling pressure. The approach of equilibrium can be seen by plotting a graph of the vertical stress on the specimen against the square-root of elapsed time at which each load adjustment was made.

6.5.3.4 The test as described in 6.5.2.4 shall be proceeded by recording the deformation gauge reading and applying the next higher vertical stress in the loading sequence. The deformation gauge shall not be reset.

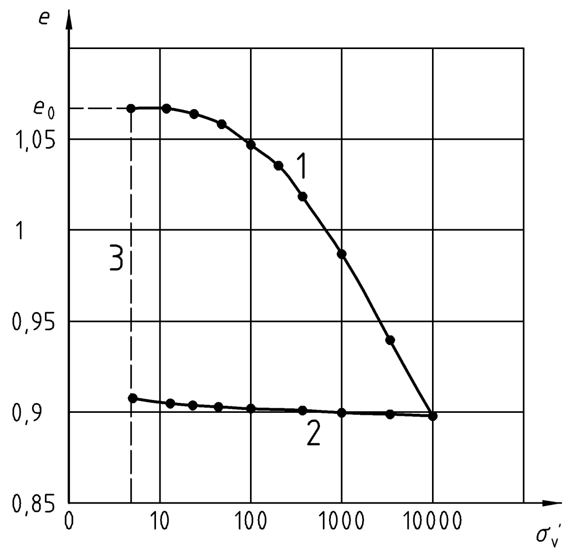
NOTE The corrected zero reading is the initial gauge reading adjusted by the correction necessary to allow for deformation of the apparatus, using the data derived as described in 6.2.

6.6 Unloading

6.6.1 Unloading sequence

6.6.1.1 The unloading portion of the log pressure/void ratio curve is sometimes required (e.g. for estimating preconsolidation pressure) but taking readings during unloading is optional. Normally the number of unloading stages should be at least two; however, more may be used to provide curves with reasonably equally spaced points on the plotted graph. A second or subsequent load/unload cycle may be applied if required.

6.6.1.2 For a soil with swelling capability, the lowest vertical stress should not be less than the swelling pressure, unless provision has been made for allowing the specimen to swell (see Figure 2).



Key

1 Loading
2 Unloading
3 Swelling pressure

Figure 2 — Typical plot of void ratio against vertical effective stress

6.6.2 Load decrements

6.6.2.1 The deformation gauge reading shall be recorded at the end of the last loading stage. This becomes the initial reading for the decrement stage.

6.6.2.2 The vertical stress shall be reduced on the specimen carefully to the selected value. At the same instant the clock shall be started.

6.6.2.3 Deformation gauge readings shall be recorded at suitable intervals of time such as those given in 6.5.2.10, until swelling is virtually completed.

6.6.2.4 The final reading of the deformation gauge shall be recorded.

6.6.2.5 6.6.2.2 to 6.6.2.4 shall be repeated for each unloading stage, finishing with the swelling pressure, if appropriate, or the initial applied stress.

6.7 Further loading and unloading cycles

If required, one or more additional cycles of loading and unloading may be applied following a sequence of changes of vertical stress. Each sequence of reloading and unloading shall be carried out as described in 6.5.2 and 6.6.2 respectively.

6.8 Dismantling

6.8.1 When equilibrium under the final vertical stress is indicated, the water shall be drained from the cell and about 15 min shall be allowed for free water to drain from the porous plates. Any excess water shall be removed from within the cell with an absorbent tissue.

6.8.2 The vertical stress shall be removed from the specimen, the cell shall be removed and dismantled.

6.8.3 The density and water content shall be determined from the whole specimen. Any soil adhering to the porous plates or the filter papers, if used, shall be included.

7 Test results

7.1 General

The following clauses describe calculations and plots which are mandatory for reporting. Examples and suggestions for further reporting are given in Annex A.

7.2 Initial values

7.2.1 General

The measurements of initial mass and volume and the water contents of the trimmings may be used to calculate values for the voids ratios during the test. Reported values shall be based on measurements on the whole specimen.

7.2.2 Initial water content

The initial water content w_0 [%] shall be determined in accordance with CEN ISO/TS 17892-1.

7.2.3 Initial bulk and dry density

The initial bulk and dry density ρ and ρ_d [Mg/m^3] shall be determined in accordance with CEN ISO/TS 17892-2.

7.3 Compressibility characteristics

7.3.1 General

The compressibility characteristics may be illustrated by plotting a measure of the compression of the specimen as ordinate against the corresponding applied pressure σ'_v (kPa) as abscissa on a logarithmic and/or linear scale. Alternative measures of specimen compression include:

— dial gauge readings (mm);

— settlement (mm);

— actual thickness of the specimen (mm);

— strain expressed as the percentage reduction in thickness referred to the initial height of the specimen;

— void ratio or specific volume;

— natural strain or natural logarithm of specific volume.

It may be useful to depict several ordinate scales of different measures of compression adjacent to each other.

7.3.2 Specimen height

7.3.2.1 The heights of the specimen H_f [mm] at the end of each loading or unloading stage are calculated from the dial gauge readings corrected for any compliance in the apparatus.

7.3.2.2 If load increment duration is not constant throughout the test, or if load increment duration is appreciably longer than 24 h, consideration may be given to calculating the heights of the specimen after 24 h from the start of each load increment.

7.3.3 Vertical strain

If compression results are to be plotted in terms of vertical strain, the vertical strain shall be calculated according to equation (1):

$$\varepsilon_v = \frac{H_0 - H_f}{H_0} \quad (1)$$

7.3.4 Void ratio, e[–]

7.3.4.1 If compression results are to be plotted in terms of void ratio, void ratios shall be calculated from the final mass and water content measured at the end of the test as indicated in 7.3.4.2 and 7.3.4.3.

7.3.4.2 The equivalent height of solid particles, H_s (mm) shall be calculated according to equation (2) or (3):

$$H_s = \frac{m_d}{\rho_s \times A} \quad (2)$$

$$H_s = \frac{H_0}{1 + e_0} \quad (3)$$

$$e_0 = \frac{\rho_s}{\rho_d} - 1 \quad (4)$$

In organic soils and peats, the density of solid particles often exhibits strong spatial variation, and this value should then be measured, preferably on a specimen of material dried after the test. Alternatively, use may be made of well-established correlations of the density of solid particles with index properties.

7.3.4.3 The voids ratio e_f corresponding to the heights calculated in 7.3.4.2 shall be calculated according to equation (5):

$$e_f = \frac{H_f - H_s}{H_s} \tag{5}$$

7.3.5 Compression-stress diagram

7.3.5.1 Values of the chosen measure of compression shall be plotted as ordinate against applied pressure on a logarithmic scale as abscissa. The values should all relate to the same time from the start of the increment.

7.3.5.2 Smooth curves shall be drawn through the points for both the loading and the unloading proportions, or alternatively, these points shall be connected by straight lines. If the swelling pressure was measured, curves will start and terminate at the swelling pressure.

7.3.5.3 The initial value of the chosen measure of compression shall be indicated on the vertical axis.

NOTE For some applications it is useful to choose a linear scale of applied pressure as abscissa.

8 Test report

8.1 Mandatory reporting

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

a) identification of the sample (material) being tested, e.g. origin, geographical location, sample number, depth or level etc.;

b) description of the sample;

c) depth, location and orientation of the test specimen within the sample;

d) identification of apparatus: fixed or floating ring, double or single drainage, use of filter paper, lubrication of oedometer ring, compliance calibration;

e) initial dimensions of the specimen;

f) initial water content, bulk density and dry density;

g) swelling pressure (to the nearest load step), if observed;

h) compression-stress plot, i.e. a plot of the chosen measure of compression (voids ratio, strain or displacement) against the applied pressure to a logarithmic and/or linear scale for the complete test, including any extra unload-reload loops;

i) the laboratory temperature at which the test was performed.

8.2 Optional reporting

The following additional information may be required (see Annex A):

a) comments on sample condition, disturbance, soil fabric and other features such as sample storage conditions;

b) method of preparation of test specimen;

c) original voids ratio, and degree of saturation if determined;

d) density of solid particles (specific gravity), and statement of method of determination (or that the value has been assumed);

e) plots of compression against time (logarithm of time or square root time, or both as appropriate) for each load increment;

f) compressibility and swelling parameters as specified by the engineer, together with method of calculation;

g) coefficient of consolidation c_{v} [m^2/s or m^2/year], and the method used to determine this parameter;

h) where appropriate, the field temperature to which the coefficient of consolidation has been corrected;

i) coefficient of secondary compression for each load increment, together with the method of evaluation;

j) apparent preconsolidation pressure σ'_{p}.

Annex A
(informative)

Additional calculations

A.1 Additional symbols

C_c Compressibility index, i.e. the gradient of the linear portion of the e versus log (σ'_v) curve for normal compression (if evident).

C_s Swelling index, i.e. the gradient of the linear portion of the e versus log (σ'_v) swelling curve.

c_v Coefficient of consolidation, i.e. parameter which relates the degree of consolidation to time from the start of consolidation.

C_α Coefficient of secondary compression, i.e. the ratio of the change in height to the initial height over one log cycle of time during the secondary compression phase.

NOTE 1 For highly compressible materials, such as peat, it can be desirable to relate secondary compression to H_i; the method used should be stated.

E_{oed} Oedometer modulus.

NOTE 2 The symbol M is often used.

f_T Temperature correction factor (see Figure A.5).

L Length of drainage path, allowing for change of specimen height.

NOTE 3 For an oedometer test specimen with drainage at both ends $L = {}^1/_2\ H$.

m_v Coefficient of volume compressibility.

S_c Compression stiffness index.

S_r Degree of saturation.

S_s Swelling stiffness index.

t_{50} Time to 50 % consolidation.

t_{90} Time to 90 % consolidation.

w_0 Initial water content.

σ'_0 In situ vertical effective stress.

σ'_p Apparent pre-consolidation pressure, i.e. the vertical effective stress at the intersection of the current recompression line with the normal compression line.

NOTE 4 This may not be the maximum effective stress to which the soil has been subjected during its past history of loading.

A.2 Soil condition

A.2.1 Degree of saturation, S_r [%]

The degree of saturation of the specimen before testing is calculated from:

$$S_r = \frac{w_0 \rho_s}{e_0 \rho_w} \quad \text{(A.1)}$$

A.3 Compressibility parameters

A.3.1 Coefficient of volume compressibility, m_v [MPa^{-1}]

The coefficient of volume compressibility for each load increment is calculated from:

$$m_v = \frac{H_i - H_f}{H_i} \times \frac{1000}{\sigma'_{v2} - \sigma'_{v1}} \quad \text{(A.2)}$$

where

σ'_{v1} the pressure applied to the specimen in the previous load increment (kPa).

σ'_{v2} the pressure applied to the specimen in the load increment being considered (kPa).

A.3.2 Oedometer modulus, E_{oed} [MPa or kPa]

The oedometer modulus for each load increment is calculated from:

$$E_{oed} = \frac{\delta \sigma'_v}{\delta \varepsilon_v} \quad \text{(A.3)}$$

NOTE 1 This definition of E_{oed} yields a secant modulus.

NOTE 2 The oedometer modulus is often plotted versus the effective vertical stress. Formulations exist which relate E_{oed} to σ'_v.

A.3.3 Compression stiffness index, S_c [–]

The compression stiffness index from the linear portion of the compression curve as shown in Figure A.1 is calculated from:

$$S_c = \frac{\delta \ln \sigma'_v}{\delta \varepsilon_v} \quad \text{(A.4)}$$

where:

$\delta \varepsilon_v$ the change in vertical strain along the chosen linear section of the compression curve.

$\delta \ln \sigma'_v$ the change in natural logarithm of applied stress along the chosen linear section of the compression curve.

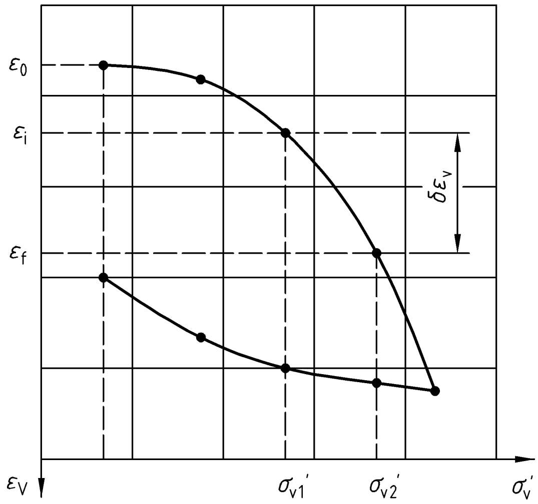


Figure A.1 — Change of effective stress and vertical strain for incremental loading and unloading

A.3.4 Compression index, C_c [–]

The compression index from the linear portion of the compression curve as shown in Figure A.2 is calculated from:

$$C_c = \frac{-\delta e}{\delta \log \sigma'_v} \tag{A.5}$$

where:

δe the change in void ratio along the chosen linear section of the compression curve.

$\delta \log \sigma'_v$ the change in logarithm of applied stress along the chosen linear section of the compression curve.

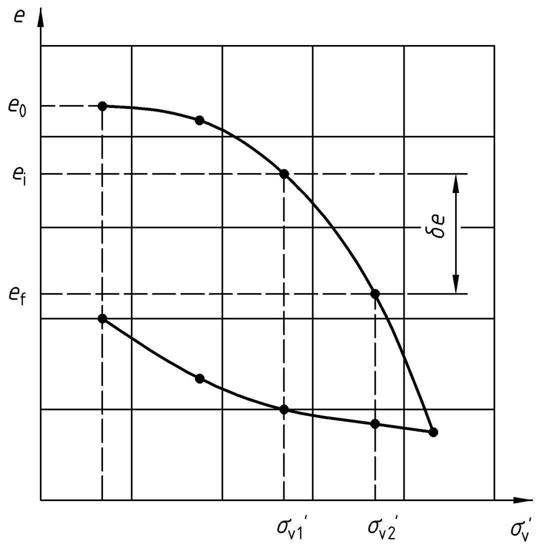


Figure A.2 — Change of effective stress and void ratio for incremental loading and unloading

A.4 Swelling parameters

A.4.1 Swelling stiffness index, S_s [–]

The swelling stiffness index from the unloading portion of the curve is calculated from:

$$S_S = \frac{-\Delta \ln \sigma'_v}{-\Delta \varepsilon_v} \quad \text{(A.6)}$$

A.4.2 Swelling index, C_s [–]

The swelling index from the unloading portion of the curve is calculated from:

$$C_S = \frac{-\delta e}{\delta \log \sigma'_v} \quad \text{(A.7)}$$

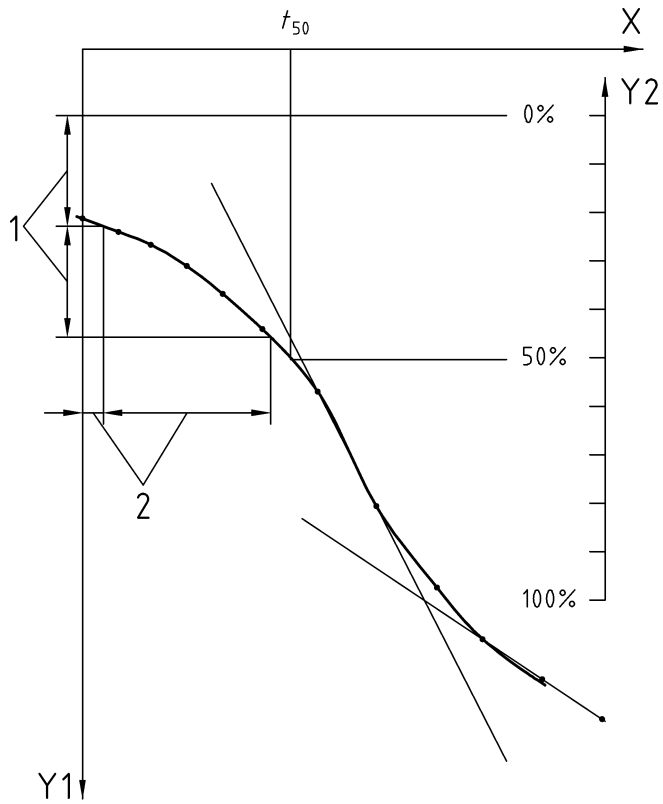
A.5 Consolidation parameters

A.5.1 Coefficient of consolidation

A.5.1.1 General

Either the logarithm-of-time curve-fitting method or the square root time curve-fitting method can be used for evaluating the coefficient of consolidation c_v during each load increment.

A.5.1.2 Log time curve-fitting (see Figure A.3)



Key

1 ratio 1:1

2 ratio 1:4

3 theoretical consolidation

x time

y compression

Figure A.3 — Laboratory consolidation curve: example of log time fitting method

A.5.1.2.1 The corrected zero point is located by marking off the difference in ordinates between any two points on the initial (convex) portion of the curve having times in the ratio 1 : 4, and laying off an equal distance above the upper point. This operation is repeated using two other pairs of points having times in the same ratio, and the average of the compression readings so determined is taken as the corrected zero compression point, denoted by d_0 (see note 1 in A.5.1.2.5).

A.5.1.2.2 The tangents to the two linear portions of the laboratory curve are drawn and extended, i.e. at the point of inflection, and the secondary compression portion. Their intersection gives the compression corresponding to theoretical 100 % primary compression, denoted by d_{100}.

A.5.1.2.3 From the zero and 100 % points, the 50 % primary compression point d_{50} is located on the laboratory curve and its time, t_{50} (in seconds) is obtained.

A.5.1.2.4 The coefficient of consolidation c_v (m²/s), for the load increment under consideration is calculated from:

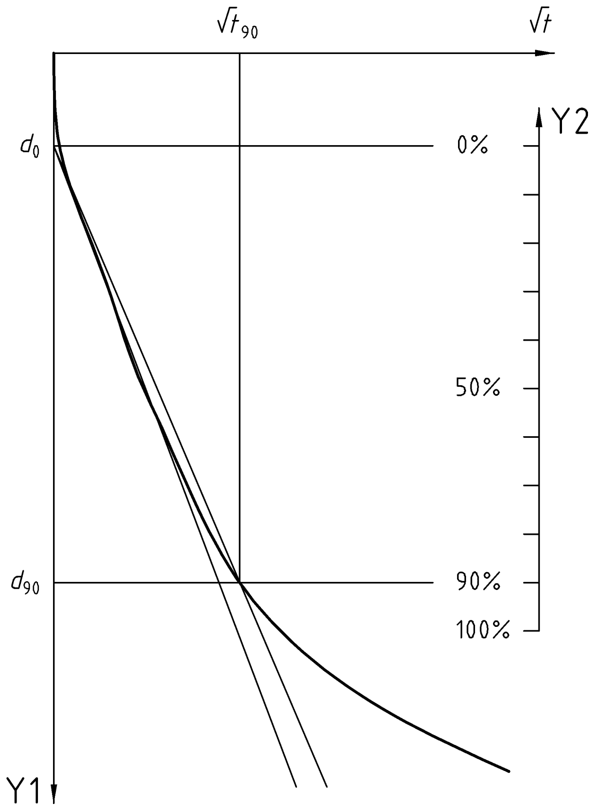
$$c_v = \frac{0{,}197 L^2}{t_{50}} \times f_T \qquad \text{(A.8)}$$

A.5.1.2.5 The above is repeated for each load increment applied to the specimen.

NOTE 1 This construction is based on the early part of the curve being parabolic when plotted on linear scales.

NOTE 2 The coefficient of consolidation can also be reported in units of m^2/year. This latter yields values without large negative exponents, which are therefore more easy to comprehend.

A.5.1.3 Square root time curve-fitting method (see Figure A.4).



Key
1 compression
2 theoretical consolidation

Figure A.4 — Laboratory consolidation curve: example of square root of time fitting method

A.5.1.3.1 The straight line of best fit to the early portion of the curve (usually within the first 50 % of compression) is drawn and is extended to intersect the ordinate of zero time. This intersection represents the corrected zero point, denoted by d_0.

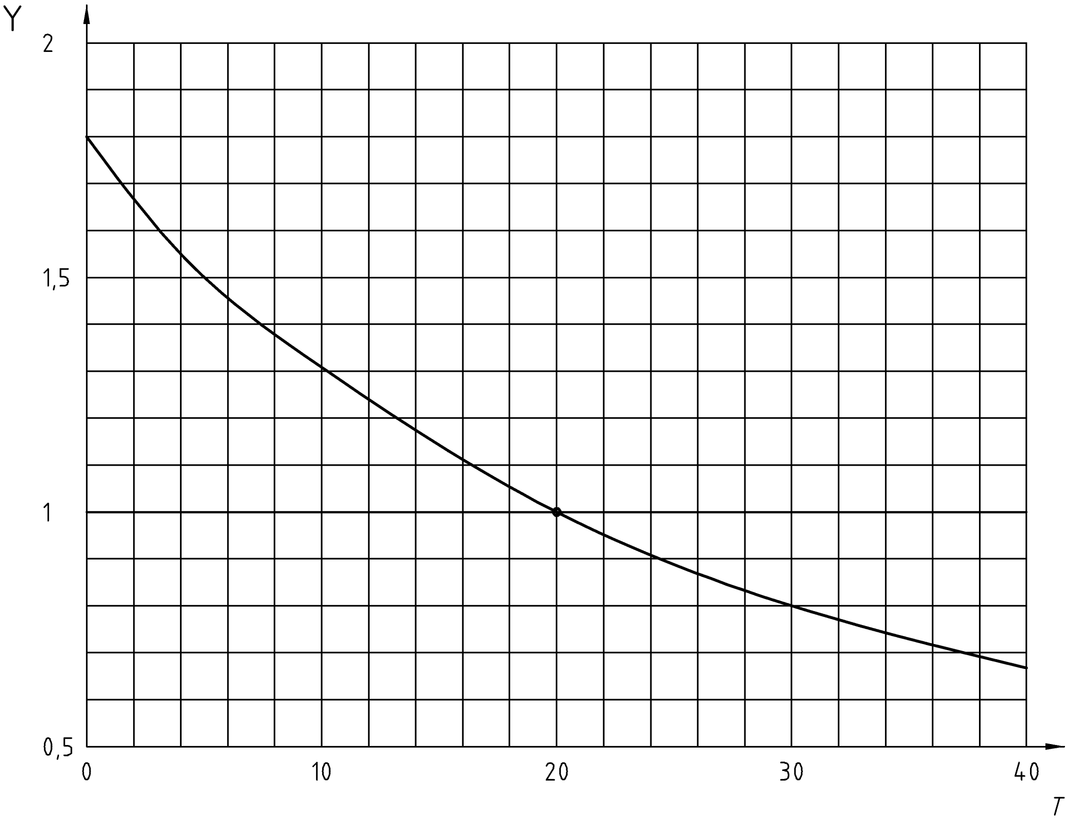
A.5.1.3.2 The straight line is drawn through the d_0 point and which at all its points has abscissae 1,15 times as great as those on the best fit line drawn in the first step, above. The intersection of this line with the laboratory curve gives the 90 % compression point, d_{90}.

A.5.1.3.3 The value of $\sqrt{t_{90}}$ is read off from the laboratory curve corresponding to the d_{90} point and the value of c_v (m^2/s) is calculated from:

$$c_v = \frac{0{,}848 L^2}{t_{90}} \times f_T \tag{A.9}$$

A.5.2 Temperature correction

A.5.2.1 If the laboratory temperature is significantly different from 20 °C the temperature correction factor f_T given in Figure A.5 is used to correct the results to 20 °C.



Key

x laboratory temperature

y correction factor

Figure A.5 — Temperature correction curve for coefficient of consolidation

A.5.2.2 If conversion to another temperature is required, the correction factor can be obtained by:

$$f_{\mathrm{T}} = \frac{f_{\mathrm{T;\,20}}}{f_{\mathrm{T;\,ref}}} \tag{A.10}$$

where:

$f_{\mathrm{T;\,20}}$ temperature correction factor to convert from laboratory temperature to 20 °C.

$f_{\mathrm{T;\,ref}}$ temperature correction factor to convert from the required temperature to 20 °C.

NOTE The temperature correction is necessary because of the dependence upon temperature of the viscosity of water. Ground temperatures at some depth below ground surface are often more or less constant year-round, and it is then useful to take an accepted value of field temperature for large regions. This varies from 7 °C in Nordic countries, through 10 °C in moderate climates, to 20 °C in Mediterranean climates.

A.5.3 Coefficient of secondary compression, C_α [–]

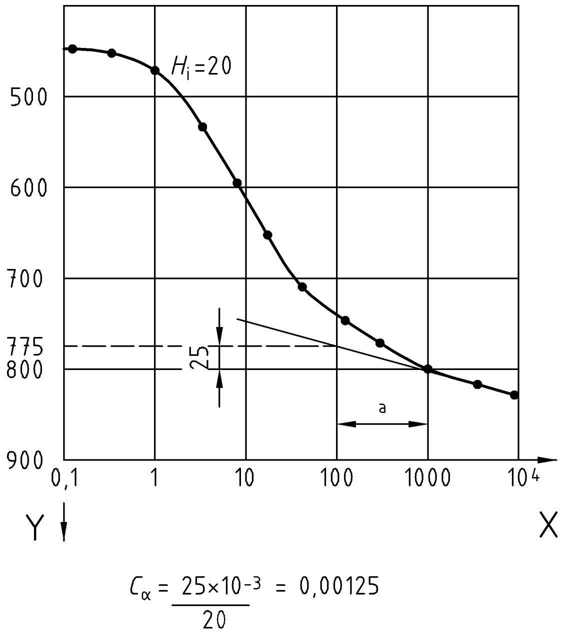
The coefficient of secondary compression from the linear portion of the secondary compression-time curve as shown in Figure A.6 is calculated from:

$$C_\alpha = \frac{\delta H}{H_\mathrm{i}} \times \frac{1}{\delta \log t} \tag{A.11}$$

where:

δH the change in specimen height along the chosen linear section of the compression-time curve.

$\delta \log t$ the change in logarithm of time along the chosen linear section of the compression-time curve.



Key

a one log cycle

x time (min)

y settlement gauge reading (mm × 10^{-3})

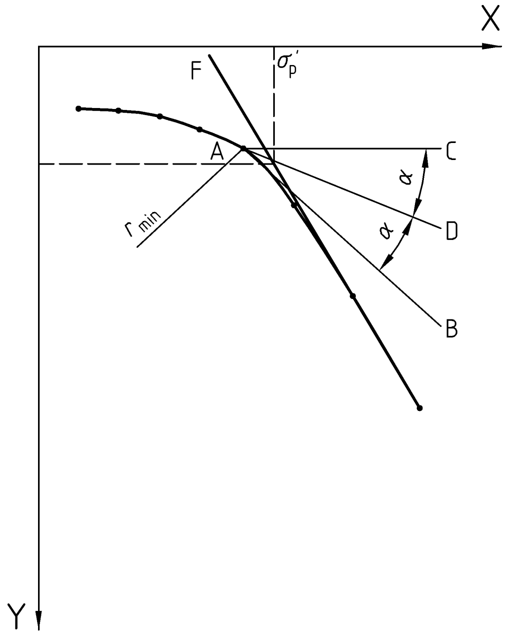
Figure A.6 — Derivation of coefficient of secondary compression C_α

A.6 Apparent preconsolidation pressure, σ'_p [kPa]

In soils which are not heavily overconsolidated, the apparent preconsolidation pressure σ'_p can be determined by moderate loading, but very heavy loading can be required in stiff soils.

There are a number of different methods for estimating σ'_p from oedometer test results. The most well-known method is due to Casagrande, and this is described here.

In the curve of void ratio or vertical strain versus logarithm of effective vertical stress, see Figure A.7, the point of maximum curvature (point A) is determined. The line AB is drawn through A tangent to the curve. The line AC is drawn horizontally through A. The angle ∠BAC is designated as 2α. Line AD is drawn as the bisectrix of 2α. The straight portion of the virgin part of the curve is produced backwards to obtain line EF and EF is intersected with AD. The stress at the intersection is taken as the apparent preconsolidation pressure σ'_p.



Key

x load

y compression

Figure A.7 — Determination of the apparent preconsolidation pressure σ'_p

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