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Geotechnical investigation and testing — Laboratory testing of soil —

Part 5: Incremental loading oedometer test

Reconnaissance et essais géotechniques — Essais de laboratoire sur les sols —

Partie 5: Essai de chargement par palier à l'oedométre

Reference number
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Foreword

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

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

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

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

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

ISO 17892-5 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical investigation and testing*, in collaboration with ISO Technical Committee ISO/TC 182, *Geotechnics*, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This first edition cancels and replaces ISO/TS 17892-5:2004, which has been technically revised. It also incorporates the Technical Corrigendum ISO/TS 17892-5:2004/Cor 1:2006.

A list of all parts in the ISO 17892 series can be found on the ISO website.

Introduction

This document covers areas in the international field of geotechnical engineering never previously standardized internationally. 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 practices (see Reference [1]).

Geotechnical investigation and testing — Laboratory testing of soil —

Part 5:
Incremental loading oedometer test

1 Scope

This document specifies methods for the determination of the compressibility characteristics of soils by incremental loading in an oedometer.

This document is applicable to the laboratory determination of the compression and deformation characteristics of soil within the scope of geotechnical investigations.

The oedometer test is carried out on a cylindrical test specimen that is confined laterally by a rigid ring. The specimen is subjected to discrete increments of vertical axial loading or unloading and is allowed to drain axially from the top and bottom surfaces. Tests may be carried out on undisturbed, remoulded, recompacted or reconstituted specimens.

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 not be appropriate

NOTE This document fulfils the requirements of the determination of the compressibility characteristics of soils in the oedometer for geotechnical investigation and testing in accordance with EN 1997–1 and EN 1997–2.

2 Normative references

The following documents are referred to in text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 17892-1, *Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content*

ISO 17892-2, *Geotechnical investigation and testing — Laboratory testing of soil — Part 2: Determination of bulk density*

ISO 17892-3, *Geotechnical investigation and testing — Laboratory testing of soil — Part 3: Determination of particle density*

3 Terms and definitions

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

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

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

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

3.1
excess pore pressure
difference between the pore water pressure and the equilibrium pore pressure at the end of consolidation

3.2
primary consolidation
process whereby the void ratio of a specimen decreases as a result of an increase in the effective stress due to a decrease in the *excess pore pressure* (3.1) under constant total applied load

Note 1 to entry: Time dependent volume change during primary consolidation is primarily controlled by drainage conditions.

3.3
secondary compression
process in which compression occurs independent from *excess pore pressure* (3.1) dissipation

Note 1 to entry: Time dependant volume change during secondary compression is controlled by factors other than drainage conditions.

3.4
swelling
expansion due to reduction of stress or due to increase in water content

3.5
swelling pressure
pressure required to maintain constant volume (i.e. to prevent absorption of water) when a soil is flooded with water.

4 Symbols

A cross-sectional area of the specimen (mm²)

D mean diameter of the oedometer ring (mm)

d_f deformation gauge reading at the end of a load increment

d_i deformation gauge reading at the start of a load increment

e_f void ratio of the specimen at the end of a load increment

e_0 initial void ratio of the specimen at the start of the test

H mean height of the oedometer ring (mm)

H_f height of the specimen at the end of a load increment (mm)

H_i height of the specimen at the start of a load increment (mm)

H_s equivalent height of solids (mm)

H_0 initial height of the specimen at the start of the test (mm)

m_d dry mass of the specimen (g)

w_0 initial water content of the specimen (%)

$\varepsilon_{v,f}$ vertical strain at the end of an increment, compression being defined as positive strain (%)

ρ initial bulk density of the specimen (Mg/m^3)

ρ_d initial dry density of the specimen (Mg/m^3)

ρ_s particle density (Mg/m^3)

σ'_v vertical effective stress (kPa)

5 Equipment

See Annex A for calibration requirements for the equipment in this clause.

5.1 Oedometer ring

The ring shall be made of corrosion-resistant material and shall have a sharp cutting edge. A ring mounted with a temporary sharp cutting edge may be used.

Internal dimensions should conform to the following:

— diameter (D): not less than 35 mm;

— height (H): not less than 12 mm;

— ratio (D/H): not less than 2,5.

The internal surface of the ring shall be smooth and may be lubricated with a thin film of silicone grease, petroleum jelly, or other suitable lubricant.

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.

5.2 Porous discs

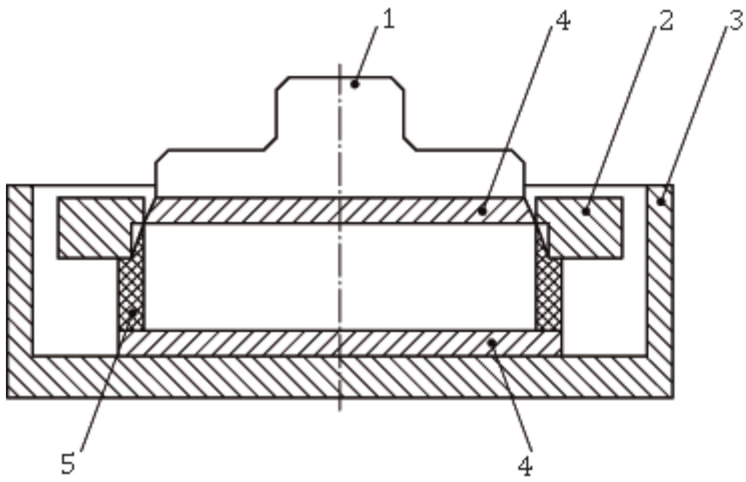
The top and bottom porous discs shall be of corrosion-resistant material and shall allow free drainage of water, while preventing intrusion of soil particles into their pores. The upper and lower surfaces shall be plain, clean and undamaged. The material shall be of negligible compressibility under the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

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

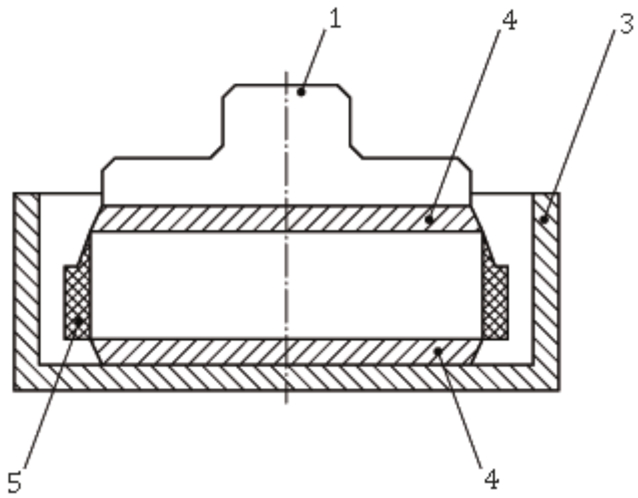
The diameter of the top porous disc shall be smaller than the ring by 0,2 mm to 0,5 mm in order to prevent binding to the ring and to prevent extrusion of the sample, and shall be larger than 85 % of the diameter of the loading cap. The top porous disc may be tapered towards the upper face to minimize the risk of binding due to tilt.

In a fixed-ring cell [see Figure 1 a)], the bottom porous disc shall be large enough to support the oedometer ring.

In a floating-ring cell [see Figure 1 b)], the diameter of the bottom porous disc shall meet the same requirements as the top disc, but tapered towards the lower face.



a) Fixed-ring cell oedometer



b) Floating-ring cell oedometer

Key

1 loading cap

2 lateral restraint for ring

3 cell body

4 porous discs

5 oedometer ring

Figure 1 — General arrangements of typical oedometer cells

Before use, new porous discs shall be saturated by boiling in distilled water for at least 20 min, and allowed to cool before use.

The surface of the porous discs which have previously been used shall be cleaned, for example using a natural bristle or nylon brush, followed by a check that the porous discs are readily permeable to water and that the pores are not clogged by soil particles.

Porous discs shall be kept immersed in water until required for use. For soils that readily absorb water (e.g. stiff clays), the porous discs should be air-dried immediately before use.

5.3 Cell body

The cell body shall be made of a suitable corrosion-resistant material.

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

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

The assembled cell shall be watertight and shall hold water to a level which submerges the upper porous disc.

5.4 Loading cap

The loading cap shall be rigid enough to ensure negligible deformation under load. It shall be fitted with a central load seating and shall be mounted centrally in the oedometer ring.

The loading cap shall have perforations or grooves to allow the free drainage of pore water.

5.5 Deformation measurement

The deformation measuring device shall have a resolution of at least 0,01 % and accuracy of at least 0,1 % of the initial specimen height.

The measurement of deformation of the soil to be tested shall use a device suitable for measuring and displaying/recording as mentioned above, e.g. a dial gauge or electrical displacement transducer.

5.6 Loading frame

The loading frame shall allow the application of vertical stresses acting centrally on the loading cap only. The frame may apply load either by addition of physical weights, or by other mechanical, hydraulic, pneumatic or electromechanical means.

The vertical stress applied to the specimen shall be accurate to at least 1 % of the intended stress or 1 kPa whichever is the greater. The stress shall remain constant within these limits throughout the duration of a loading increment. The mechanism should allow the application of a given load increment within a period of 2 s.

Adequate arrangements shall be made to ensure stability of the load frame, or a group of load frames, when fully loaded. This can be achieved by bolting the load frame or group of load frames to the floor. The load frame shall be free of vibration.

5.7 Ancillary apparatus

The ancillary apparatus consists of:

— balance, accurate up to 0,01 g or 0,1 % of the weighed mass, whichever value is greater;

— timer, readable to 1 s;

— thermometer, readable to 1°C maximum/minimum;

— metal disc 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 or digital callipers, reading to 0,05 mm.

5.8 Apparatus for specimen preparation

The apparatus for specimen preparation consists of:

— cutting and trimming tools, e.g. cheese-wire, wire-saw, sharp knife, scalpel;

— spatulas;

— straight-edge trimmer;

— straight edge;

— steel try-square;

— flat glass plate;

— extrusion equipment and clamping jig, for preparing and trimming specimens from a tube sample.

5.9 Water

Water of a similar chemistry to the pore water should be used if the soil is susceptible to the chemistry of the water. If the chemistry of the pore water is unknown, tap water should be used as its chemistry is more likely to be similar to ground water than distilled water would be.

6 Test procedure

6.1 General

The mean diameter of the largest particle within a specimen should be less than one-fifth of the height of the ring.

The initial water content (w_0) should be determined according to ISO 17892-1 on soil trimmings.

6.2 Specimen preparation

6.2.1 Selection of preparation method

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

— trimming from an undisturbed sample extruded from its sampling tube, or from a block sample;

— extrusion directly into an oedometer ring from a sample tube of a larger diameter than that of the ring;

— recompaction, remoulding, reconstitution or reconsolidation of disturbed soil.

6.2.1.2 The cutting edge and condition of the oedometer ring shall be visually checked to be free from damage prior to each use.

6.2.2 Trimming from extruded or block sample

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

6.2.2.2 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. The ring should be centred on the sample, unless visible discontinuities or disturbance suggests that a better quality specimen can be cut off-centre.

6.2.2.3 The ring shall be steadily pushed 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.

6.2.2.4 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.

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

6.2.2.6 Each end of the specimen shall be trimmed in turn, using appropriate tools to cut away excess soil a little at a time. The ends shall be checked to be flat and flush with the ring.

6.2.3 Extrusion from tube of diameter larger than the oedometer ring

6.2.3.1 The sampling tube shall be mounted in the extrusion device and secured.

6.2.3.2 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.

6.2.3.3 The sample shall be extruded through the oedometer ring while checking that the excess soil can be removed easily and does not impede the extrusion process.

6.2.3.4 Each end of the specimen shall be trimmed in turn using appropriate tools 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.

6.2.4 Recompacted specimens

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

6.2.4.2 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 or 6.2.3). 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

6.3.1 Immediately after preparation, the soil and ring shall be 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. If a short delay is unavoidable, the sample should be wrapped to prevent the specimen from air drying.

6.4 Preparation of apparatus

6.4.1 Assembly of cell

6.4.1.1 If wet porous discs are used, free water shall be allowed to drain from them and excess surface water removed before placing in the oedometer cell.

6.4.1.2 The bottom porous disc, the specimen in its oedometer ring and the top porous disc shall be placed in the correct alignment in the oedometer cell (see Figure 1). Filter papers may be placed between the specimen and the porous discs. Place the loading cap centrally on the top porous disc.

6.4.2 Assembly in load frame

6.4.2.1 The oedometer 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 (in addition to the stress due to the weight of the top cap and porous disc) to ensure proper contact between the loading system and the soil. Care shall be taken to assemble the top cap and load frame such that the load is applied axially without imposing tilt of the top cap.

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

6.4.2.4 Take and record the initial time reading.

6.4.2.5 If a system with counter-balanced beams is used, the beam shall be balanced prior to the test. 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 sequence of stresses to be applied to the specimen should be defined, taking into account the nature of the soil, the presumed *in situ* stress history and the parameters that are required from the test.

6.5.1.2 A minimum of seven load stages should be applied, although additional increments or decrements of loading may be required to fully define the potential range of consolidation parameters including the pre-consolidation pressure or yield stress.

6.5.1.3 For soils with a swelling tendency, if the chosen initial vertical stress is less than the swelling pressure, care will be required when water is introduced to the specimen (see 6.5.2).

6.5.1.4 Loading sequences typically increase the vertical stress by a factor of two for each additional stage in the load sequence, although other factors including variable factors may be used.

NOTE A doubling of each load in the sequence gives an even distribution of data points on a logarithmic plot of stress.

6.5.1.5 The largest vertical stress to be applied should be in excess of the maximum vertical stress likely to occur *in situ*. If the apparent pre-consolidation pressure is to be determined (B.6), loading should extend to determine the slope of the virgin compression line on a logarithmic plot of stress. For some soils this may require very large stresses.

6.5.1.6 It is recommended to include one or more unload/reload loops in the loading sequence. Normally, the number of unloading stages during each unloading should be at least two. If an unload/reload loop is required in order to assess and reduce the effects of sample disturbance and system compliance, it should be included before the apparent pre-consolidation pressure is reached. If the swelling index is to be determined (B.4.2), an unload/reload loop should be included after the apparent pre-consolidation pressure is reached.

6.5.2 Application of loads

6.5.2.1 The deformation gauge reading before application of each load shall be recorded as the initial reading for that load increment stage (d_i).

6.5.2.2 The required load shall be applied carefully without jolting, and should be fully applied within a period of 2 s. A jacking system may be used to support the lever arm while weights are added to the hanger. The timer shall be started without delay.

6.5.2.3 Water shall be introduced to the specimen to a level at which the top porous disc is submerged. However, if it is suspected that the sample may swell under the applied stress, water may be added at a load increment subsequent to the first. Furthermore, water shall be added during the test to replace any lost by evaporation, in order to keep the top porous disc submerged.

6.5.2.4 If the specimen begins to swell after adding water, swelling shall be prevented by immediately increasing the vertical stress to the next load in the sequence. If the chosen initial vertical stress was low, and the swelling pressure significantly higher, this may need repeating two or more times.

6.5.2.5 The deformation gauge readings shall be recorded at suitable intervals of time to enable the graphs referred to in Annex B to be plotted in sufficient detail for them to be interpreted. For each increment, the following reading intervals are suggested: 0 s, 10 s, 20 s, 30 s, 40s, 50 s, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min, 1 h, 2 h, 4 h, 8 h, 24 h. Subsequent readings, if necessary, should be recorded at least at the start, middle and end of each working day. If determination of the coefficient of consolidation (Annex B) is not required, such frequent readings may not be necessary.

6.5.2.6 The vertical stress shall be maintained until the deformation gauge readings indicate that primary consolidation has been completed. If the coefficient of secondary compression (B.5.3) 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.

NOTE While it is normal to apply load increments for a period of 24 h each, completion of primary consolidation might be achieved in longer or shorter periods, depending on the type of soil.

6.5.2.7 The deformation gauge reading, d_f, shall be recorded at the termination of the load increment stage.

6.5.2.8 The vertical stress shall be increased (or decreased) to the next value in the sequence, as in 6.5.2.2, and then repeat 6.5.2.5 to 6.5.2.7.

6.6 Dismantling

6.6.1 At completion of the test, the water shall be drained from the cell and the porous discs. Any excess water shall be removed from within the cell, for example with an absorbent tissue.

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

6.6.3 Determine the dry mass of the specimen, either by

— drying the whole specimen in accordance with ISO 17892-1, or

— weighing the specimen in the equipment (e.g. the oedometer ring), and subtracting the mass of the equipment, and determining the final water content by drying a representative portion in accordance with ISO 17892-1.

6.6.4 Cut the specimen open to allow any internal structure or inhomogeneities to be identified and recorded.

7 Test results

7.1 General

The following subclauses describe calculations and plots which are mandatory for reporting. Examples and suggestions for optional reporting are given in Annex B.

7.2 Initial values

7.2.1 General

Reported values should ideally be based on measurements on the whole specimen.

7.2.2 Initial water content

The initial water content, w_0 (%), should be determined from the initial wet mass of the specimen and the final dry mass of the specimen. The final mass of the dry specimen may be measured directly or calculated from the final wet mass and final water content. The initial water content derived from trimmings may be used as an alternate.

If the pore water contains dissolved minerals, correction for the loss of these during consolidation may be required.

7.2.3 Initial bulk and dry density

The initial bulk and dry density, ρ and ρ_d (Mg/m^3), shall be determined by linear measurement in accordance with ISO 17892-2.

7.3 Compressibility characteristics

7.3.1 General

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

— vertical strain expressed as the percentage change in height referred to the initial height of the specimen;

— void ratio.

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 deformation gauge readings, if necessary corrected for any apparatus deformation under load (see Annex A).

7.3.2.2 If the 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. In this case the new value is used as H_f.

7.3.3 Vertical strain

If compression results are to be plotted in terms of vertical strain, the vertical strain at the end of each increment, $\varepsilon_{v,f}$, shall be calculated according to Formula (1):

$$\varepsilon_{v,f} = \frac{H_0 - H_f}{H_0} \tag{1}$$

7.3.4 Void ratio

7.3.4.1 If compression results are to be plotted in terms of void ratio, void ratios shall be calculated.

7.3.4.2 The initial void ratio, e_0, is calculated from the initial dry density and a measured or assumed particle density calculated according to Formula (2):

$$e_0 = \frac{\rho_s}{\rho_d} - 1 \tag{2}$$

7.3.4.3 The void ratio, e_f, corresponding to the heights at the end of each loading stage shall be calculated according to Formula (3):

$$e_f = \frac{H_f - H_s}{H_s} \tag{3}$$

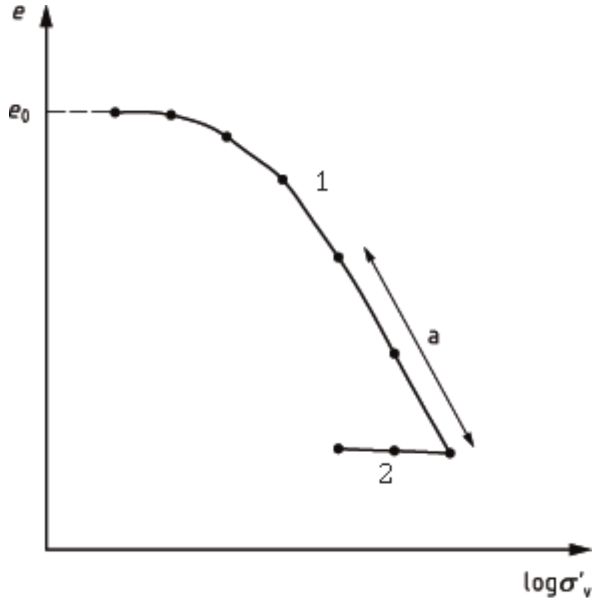
Where H_s is the equivalent height of solids and is calculated from either Formula (4) or Formula (5):

$$H_s = \frac{1\,000 m_d}{\rho_s \cdot A} \tag{4}$$

$$H_s = \frac{H_0}{1 + e_0} \tag{5}$$

7.3.5 Compression-stress diagram

7.3.5.1 Values of the chosen measure of compression shall be plotted as ordinate against vertical effective stress on a logarithmic or linear scale as abscissa. An example plot is shown in Figure 2.



Key

1 loading

2 unloading

a near-linear portion

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

7.3.5.2 The plotted points may be connected by smooth curves or straight lines for presentation.

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

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 information:

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

b) visual description of the specimen, including any observed features noted after testing, following the principles in ISO 14688-1;

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

d) method of preparation of the test specimen;

e) initial dimensions of the specimen;

f) initial water content and a statement that it has been based on the specimen trimmings if appropriate;

g) initial bulk density and dry density;

h) compression-stress plot, i.e. a plot of the chosen measure of compression against the applied stress to a logarithmic and/or linear scale for the complete test;

i) average laboratory temperature at which the test was performed;

j) whether the results have been corrected for equipment deformation;

k) deviations from the test method.

8.2 Optional reporting

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

a) particle density used, and whether it has been measured according to ISO 17892-3 or has been assumed;

b) initial and final void ratio;

c) degree of saturation;

d) final water content;

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

f) additional tables of results and/or parameters calculated from the test data and where applicable whether these have been corrected for temperature, some examples of which are given in Annex B.

Annex A
(normative)

Calibration, maintenance and checks

A.1 General requirements

All measurement equipment used in this document shall be calibrated periodically, its performance shall be checked where required at intervals, and it shall be operated in a controlled environment if so specified in this annex. This annex defines these requirements for this method.

If calibration of measurement equipment is carried out by a third party, it shall be carried out by an accredited calibration laboratory. The certification shall show traceability to recognized national or international standards of measurement.

Where calibration of test measuring equipment is carried out in-house, the laboratory shall hold appropriate reference standards or instruments that are used solely for calibration purposes. These should be calibrated by an accredited calibration laboratory with certification requirements as above. When not in use, reference measurement equipment should be retained securely in a suitable environment separate from working standards or instruments. Reference standards and instruments shall be at least as accurate as the working device so that the desired accuracy of test measurement is achieved.

In-house calibration procedures shall be documented and only performed by approved persons. Records of such calibrations and of performance checks shall be retained on file.

Notwithstanding the required calibration or check intervals in this annex, whenever any item of reference equipment or test measurement equipment has been mishandled, repaired, dismantled, adjusted or overhauled, it shall be recalibrated before further use.

All calibrated equipment shall be used only within the range for which it has been calibrated.

A.2 Environmental conditions

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 from changes to its water content.

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.

The temperature of the test location shall be maintained within ±3 °C during the test and shall be verified by measurement and records kept. The recording of daily minimum and maximum temperatures of the test location shall be acceptable.

A.3 Equipment

A.3.1 Ovens

The set temperature close to the mid-point of the usable oven space of an empty oven shall be checked by means of a calibrated temperature measuring device at least once a year.

The temperature distribution of an empty oven shall be checked before first use and after any major repair or replacement of heater elements and/or thermostat. If any of the individual temperature points is found to be outside the specified range of the set temperature, remedial action shall be taken.

A.3.2 Thermometers

Reference thermometers shall be calibrated or replaced at intervals not exceeding five years. All other liquid-in-glass thermometers shall be calibrated before first use and shall be recalibrated or replaced at intervals not exceeding five years.

An ice point or another appropriate single-point check of working thermometers shall be carried out six months after first being brought into use, then annually in addition to the five year calibration interval requirement.

If thermocouples are used for verifying oven temperatures, they shall be calibrated against a reference thermocouple, reference platinum resistance thermometer or reference liquid-in-glass thermometer before first use and thereafter at least once a year.

A.3.3 Balances

Balances shall be calibrated over their working range, using certified reference weights, at least once a year in the location in which they are used. Reference weights shall be appropriate to the category of balance being calibrated, and shall have a tolerance (maximum permissible error) better than the resolution of the balance to be calibrated. Reference weights shall be calibrated when first brought into use and thereafter at least every two years.

Balances shall be checked on each day of use to confirm the zero point and to confirm the mass of a test item of known mass. The test item should not corrode or otherwise change mass with time, and should have a mass within the range of 50 % to 80 % of the working range of the balance. The results of these checks shall be recorded. If the balance cannot be zeroed or the mass of the test weight is found to be outside the tolerance specified in 5.7, the balance shall be taken out of service until remedial action is complete.

A.3.4 Oedometer ring

The dimensions of the oedometer ring and mass shall be verified at least once per year as follows:

— the internal diameter of the oedometer ring shall be measured in at least two perpendicular directions to the nearest 0,05 mm, and the mean diameter (D) and the cross sectional area shall be calculated;

— the height of the ring at four equally spaced points shall be measured to the nearest 0,05 mm, the mean height (H) shall be calculated and the ring shall be weighed to the nearest 0,01 g.

A.3.5 Deformation apparatus

In some circumstances, the deformation of the oedometer equipment may significantly affect the measured deformation of the sample during the test. This effect increases with increasing applied load and specimen stiffness, particularly if filter papers are used.

The need for a correction to be made to the measured data should be determined, taking account of the maximum load to be used in the test.

The following procedure may be used to obtain a correction.

— The oedometer apparatus for use in the test is assembled by using the metal disc in place of the specimen. The porous discs 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.

— It is advisable before a calibration loading test to first load and unload the metal disc without taking any readings in order to avoid small movements, strains, inequalities, etc., and then start the calibration loading.

— Increments or decrements of load are applied similar to those applied in a test and the reading of the deformation gauge corresponding to each increment shall be recorded.

— The deformations should 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.

The calibration obtained from the above procedures should be used to correct the deformation gauge readings during oedometer testing. The appropriate value of the apparatus deformation should be 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.

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.

The most accurate correction may be obtained by following the actual load sequence and duration of the test immediately before or after the test of the specimen using the same equipment.

A.3.6 Oedometer weights

Oedometer weights (if used) shall be checked at least every five years to show that their mass is within 1 g or 0,1 % of their declared mass, whichever is greater.

Other means of applying load (if used), and any electronic force measurement devices such as load cells (if used), shall be calibrated at least once per year to achieve the accuracy required in 5.6.

A.3.7 Dimensional measurement devices

The devices used to measure the specimen dimensions and deformations during the test shall be calibrated against reference gauge blocks or other reference device at least every year. Reference gauge blocks and other reference devices shall be calibrated at least every five years.

A.3.8 Time measuring devices

Timing devices, such as clocks and stop watches, shall be calibrated at least once per year to an accuracy of ±1 s in a 10 min period.

Annex B
(informative)

Additional calculations

B.1 Additional symbols

C_c compression index, i.e. the gradient of the linear portion of the void ratio versus the logarithm of vertical effective stress curve beyond the pressure of pre-consolidation

C_s swelling index, i.e. the gradient of the linear portion of the void ratio versus the logarithm of vertical effective stress swelling curve

c_v coefficient of vertical consolidation, i.e. parameter which relates the degree of consolidation to time from the start of consolidation (m^2/s or m^2/year)

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

E_{oed} oedometer modulus, i.e. the ratio between the vertical effective stress and strain. The symbol M may be used alternatively (MPa or kPa)

f_T temperature correction factor (see Figure B.5)

L length of drainage path, allowing for change of the specimen height, and is equal to half the specimen height for drainage from both ends (m)

m_v coefficient of volume compressibility (MPa^{-1})

S_c compression stiffness index

S_r degree of saturation (%)

S_s swelling stiffness index

T temperature (°C)

t_{50} time to 50 % primary consolidation (s)

t_{90} time to 90 % primary consolidation (s)

σ'_p apparent pre-consolidation pressure or yield stress (kPa)

ρ_w density of water at the test temperature (Mg/m^3)

B.2 Soil condition

B.2.1 Degree of saturation

The degree of saturation, S_r (%), of the specimen before testing is calculated from Formula (B.1):

$$S_r = \frac{w_0 \cdot \rho_s}{e_0 \cdot \rho_w} \tag{B.1}$$

B.3 Compressibility parameters

B.3.1 Coefficient of volume compressibility

The coefficient of volume compressibility, m_v (MPa^{-1}), for each load increment is calculated from Formula (B.2):

$$m_v = \frac{H_i - H_f}{H_i} \cdot \frac{1\,000}{\sigma'_{v2} - \sigma'_{v1}} \quad \text{(B.2)}$$

where

σ'_{v1} is the pressure applied to the specimen in the previous load increment, in kPa;

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

B.3.2 Oedometer modulus

The oedometer modulus, E_{oed} (MPa or kPa), also known as the secant modulus, for each load increment is calculated either from Formula (B.3) or Formula (B.4):

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

$$E_{oed} = \frac{\delta\sigma'_v}{\delta e}(1 + e_0) \quad \text{(B.4)}$$

where

$\delta\sigma'_v$ is the change in stress between the last load stage and this one;

$\delta\varepsilon_v$ is the change in vertical strain during the load stage, relative to the specimen height at the start of the load stage;

δe is the change in void ratio during the load stage.

B.3.3 Compression stiffness index

The compression stiffness index, S_c, from the linear portion of the compression curve as shown in Figure B.1 is calculated from Formula (B.5):

$$S_c = \frac{\delta \log\sigma'_v}{\delta\varepsilon_v} \quad \text{(B.5)}$$

where

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

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

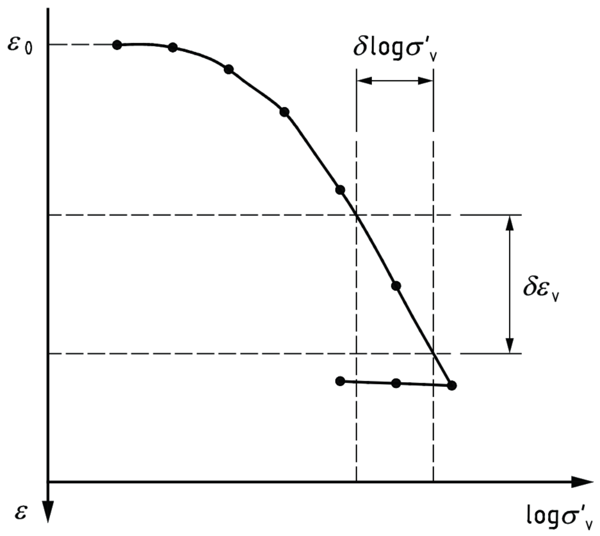


Figure B.1 — Change of effective stress and vertical strain for incremental loading and unloading

B.3.4 Compression index

The compression index, C_c, from the near-linear portion of the compression curve as shown in Figure B.2 is calculated from Formula (B.6):

$$C_c = \frac{-\delta e}{\delta \log \sigma'_v} \quad \text{(B.6)}$$

where

$\delta\varepsilon$ is the change in void ratio along the chosen linear section of the compression curve;

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

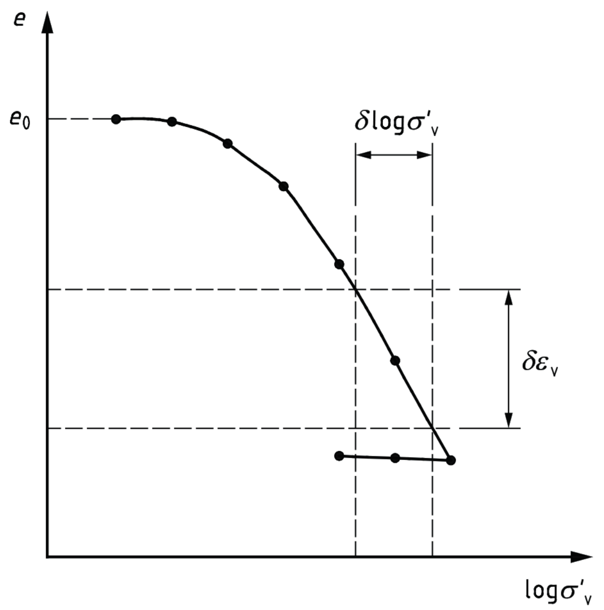


Figure B.2 — Change of effective stress and void ratio for incremental loading and unloading

B.4 Swelling parameters

B.4.1 Swelling stiffness index

The swelling stiffness index, S_s, from the unloading portion of the curve is calculated from Formula (B.7):

$$S_s = \frac{\delta \log \sigma'_v}{\delta \varepsilon_v} \tag{B.7}$$

B.4.2 Swelling index

The swelling index, C_s, from the unload/reload portion of the curve is calculated from Formula (B.8):

$$C_s = \frac{\delta e}{-\delta \log \sigma'_v} \tag{B.8}$$

B.5 Consolidation parameters

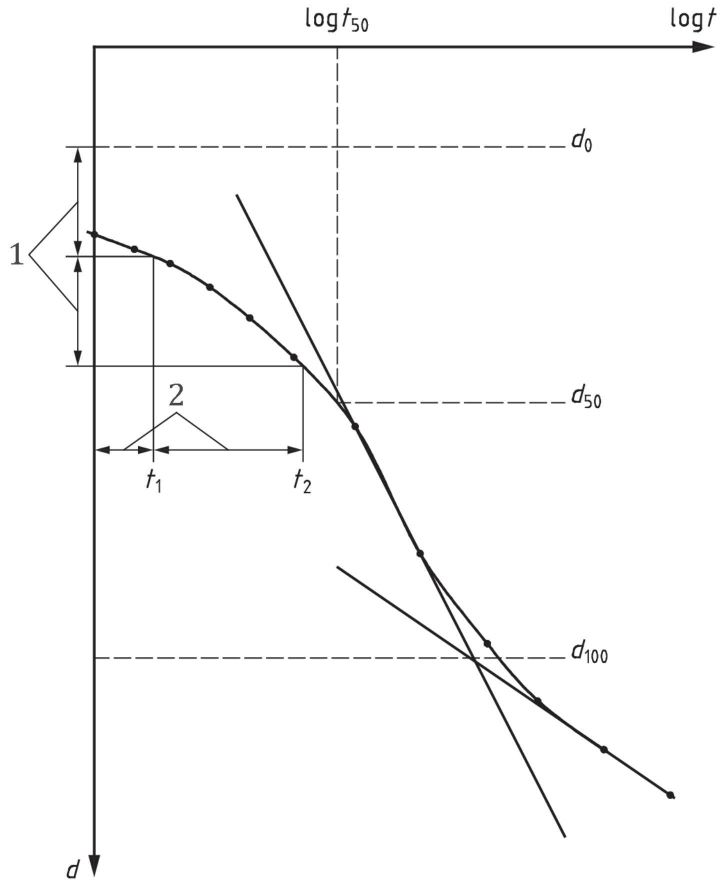
B.5.1 Coefficient of consolidation

B.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. Alternatively, a combination of these methods may be used. The following examples represent idealized data. Real sample data may not allow either curve fitting method to be used with confidence and thus, a value of c_v may not be determinable.

B.5.1.2 Log time method

For each stage, plot the height or change of height of the specimen as ordinate against the logarithm of time as abscissa (see Figure B.3).



Key

1 ratio 1:1

2 ratio 1:4

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

B.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 t_1 and t_2, where t_2 is four times t_1, and laying off an equal distance above the upper point. This operation may be repeated using other pairs of points having times in the same ratio, and the average of the compression readings taken. The value determined is taken as the corrected zero compression point, denoted by d_0.

B.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}.

B.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.

B.5.1.2.4 The coefficient of consolidation, c_v (m²/s), is calculated for each stage for which a value is required from Formula (B.9):

$$c_v = \frac{0,197 \cdot L^2}{t_{50}} \cdot f_T \qquad (B.9)$$

The value of c_v may be reported in m²/year as an alternative.

B.5.1.3 Square root time method.

For each stage, plot the change of height of the specimen (d) as ordinate against the square root of time as abscissa (see Figure B.4).

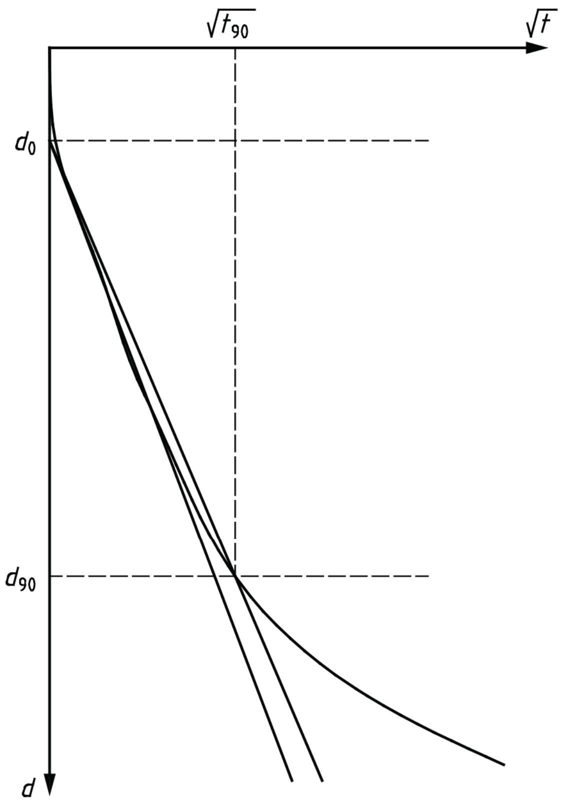


Figure B.4 — Laboratory consolidation curve: example of square root of time fitting method

B.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.

B.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 B.5.1.3.1. The intersection of this line with the laboratory curve gives the 90 % compression point, d_{90}.

B.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 Formula (B.10):

$$c_v = \frac{0,848 \cdot L^2}{t_{90}} \cdot f_T \tag{B.10}$$

The value of c_v may be reported in m^2/year as an alternative.

B.5.2 Temperature correction for coefficient of consolidation

B.5.2.1 If the average laboratory temperature during the test is significantly different from 20 °C and correction for temperature is to be done, then the temperature correction factor, f_T, given in Figure B.5 or equivalent may be used to correct the results to 20 °C.

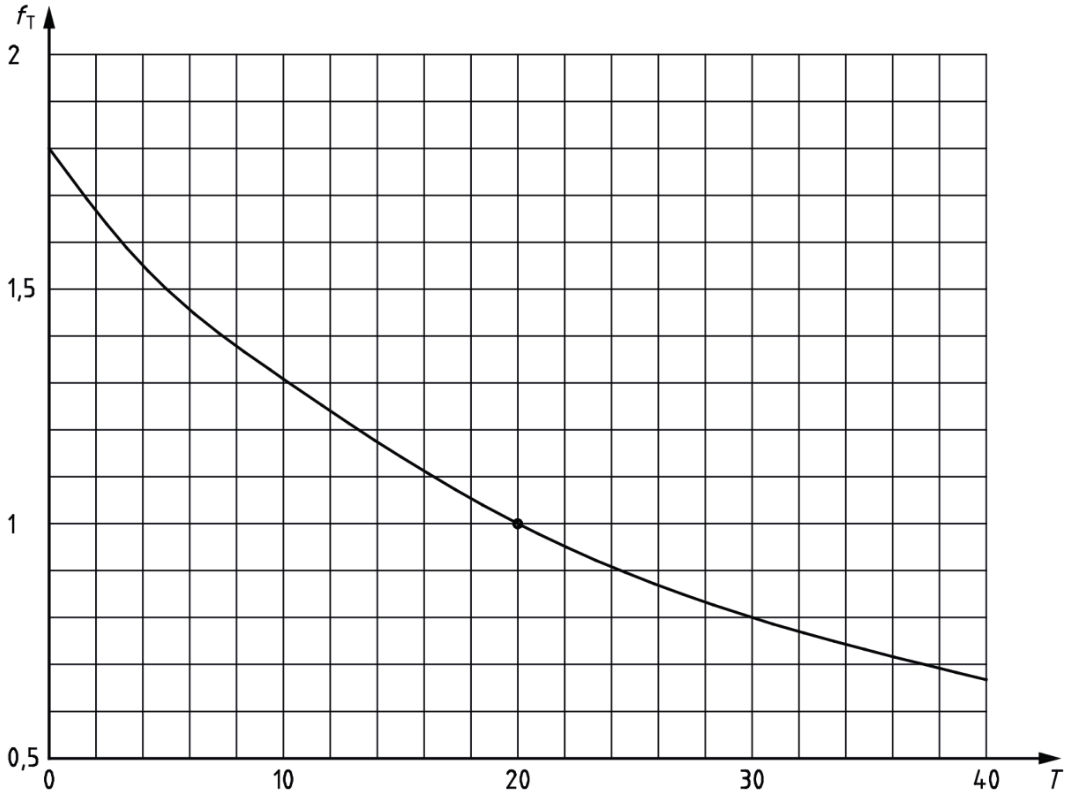


Figure B.5 — Temperature correction curve for coefficient of consolidation

B.5.2.2 If conversion to another temperature is required, the correction factor can be obtained by Formula (B.11):

$$f_T = \frac{f_{T;lab}}{f_{T;ref}} \tag{B.11}$$

where

$f_{T;lab}$ temperature correction factor to convert from laboratory temperature to 20 °C;

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

NOTE If the test temperature is significantly different from the temperature in the ground, the viscosity of water in the test will be significantly different to the viscosity of the ground water. Ground temperatures at some depth below ground surface are often more or less constant year-round.

B.5.3 Coefficient of secondary compression

Plot the height, or change of height, of the specimen against the logarithm of time. The coefficient of secondary compression, C_α, is obtained from the linear portion of the secondary compression-time curve as shown in Figure B.6 and calculated from Formula (B.12):

$$C_\alpha = \frac{\delta H}{H_\mathrm{i}} \cdot \frac{1}{\delta \mathrm{log}t} \quad \text{(B.12)}$$

where

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

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

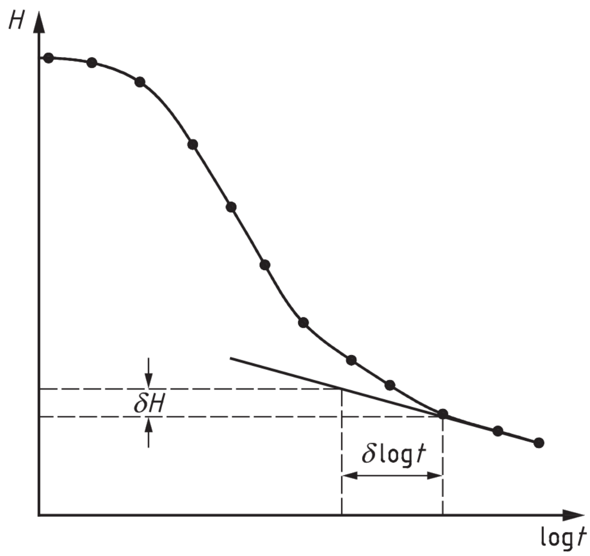


Figure B.6 — Derivation of coefficient of secondary compression

B.6 Pre-consolidation pressure

There are a number of different methods that may be used for estimating the pre-consolidation pressure (also known as yield stress) from oedometer test results. An example is the original method by Casagrande, and this is described in Figure B.7. There are other methods in common use and these are equally acceptable.

In heavily over-consolidated soils, very high loads may be required to determine the pre-consolidation pressure.

NOTE The pre-consolidation pressure determined from these constructions may not represent the actual load history of the specimen but may be due to other processes; hence, it is sometimes referred to as the apparent pre-consolidation pressure.

The estimation of the pre-consolidation pressure is as follows:

— determine the point of maximum curvature (Point A) in the curve of void ratio or vertical strain versus logarithm of vertical effective stress (see Figure B.7);

— draw line AB as the tangent to the curve at A;

— draw line AC horizontally through A;

— draw line AD as the bisectrix of the angle ∠BAC;

— draw line EF as the straight portion of the curve at high vertical effective stress, projected backwards until it crosses AD;

— the stress at the intersection of lines AD and EF is taken as the pre-consolidation pressure σ'_p, in kPa.

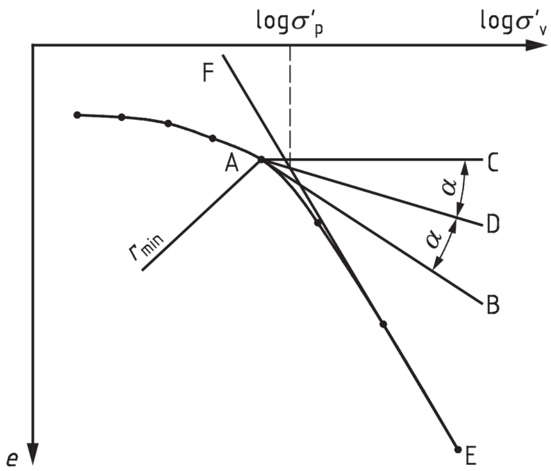


Figure B.7 — Estimation of the pre-consolidation pressure by the Casagrande method

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