AS 1289.6.6.1:2020

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Australian STANDARD®

Methods of testing soils for engineering purposes

Method 6.6.1: Soil strength and consolidation tests — Determination of the one-dimensional consolidation properties of a soil — Standard method

STANDARDS Australia

AS 1289.6.6.1:2020

This Australian Standard® was prepared by CE-009, Testing Of Soils For Engineering Purposes. It was approved on behalf of the Council of Standards Australia on 5 June 2020.

This Standard was published on 26 June 2020.

This Standard was issued in draft form for comment as DR AS 1289.6.6.1:2019.

ISBN 978 1 76072 875 5

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Originated as AS A89.19A—1966.
Previous edition AS 1289.F6.1—1977.
Revised and redesignated as AS 1289.6.6.1—1998.
Second edition 2020.

Preface

This Method was prepared by the Standards Australia Committee CE-009, Testing of Soils for Engineering Purposes, to supersede AS 1289.6.6.1—1998, *Methods of testing soils for engineering purposes, Method 6.6.1: Soil strength and consolidation tests—Determination of the one-dimensional consolidation properties of a soil—Standard method.*

A list of all test methods in the AS 1289 series can be found in the Standards Australia online catalogue.

The objective of this Standard is to determine the rate and magnitude of consolidation of soil when it is restrained laterally and loaded and drained axially, using either manual loading or automated equipment. The Method is most reliable when used on saturated clay soils. For these soils, the rate of consolidation is sufficiently slow for results to be correctly interpreted following the procedures set out in this Standard.

The major change in this edition is allowing for the use of automated apparatus in the performance of the test.

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Australian Standard®

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Method 6.6.1: Soil strength and consolidation tests — Determination of the one-dimensional consolidation properties of a soil — Standard method

1 Scope

This Method describes a procedure for determining the rate and magnitude of consolidation of soil when it is restrained laterally and loaded and drained axially, using either manual loading or automated equipment. The Method gives the most reliable results when used on saturated clay soils, which the consolidation theory applies.

NOTE The result of any test reached in accordance with this procedure requires interpretation in relation to the nature of the soil and the way in which the specimen was obtained and prepared.

2 Normative references

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

NOTE Documents referenced for informative purposes are listed in the Bibliography.

AS 1289.2.1.1, *Methods of testing soils for engineering purposes, Method 2.1.1: Soil moisture content tests — Determination of the moisture content of a soil — Oven drying method (standard method)*

AS 1289.3.5.1, *Methods of testing soils for engineering purposes, Method 3.5.1: Soil classification tests — Determination of the soil particle density of a soil — Standard method*

3 Terms and definitions

No terms and definitions are listed in this document.

4 Apparatus

The following apparatus shall be used:

(a) *Load device* — suitable for applying vertical loads to the specimen. The device shall be capable of maintaining specified loads for long periods of time with an accuracy of ± 2 % of the applied load, and permit application of a given load increment within a period of 10 s without impact. In any increment, if the time to apply the load exceeds 10 s the time it took shall be reported.

NOTE 1 Some automated devices may require adjustment of the rate of load application to ensure the load increment is applied within the 10 s limit.

(b) *Consolidation cell* — a device to hold the specimen in a ring which is either fixed (to the base of the consolidation cell) or floating (supported by friction on the periphery of the specimen) with porous plates on each face of the specimen. The consolidation cell shall also provide means for inundating the specimen with water, for transmitting the vertical load, and for measuring the change in thickness of the specimen. The consolidation ring shall meet the following requirements:

(i) The ring shall be metallic with a cutting edge to aid in specimen preparation having a minimum wall thickness of 3 mm and be corrosion resistant in relation to the soil to be tested. The inner surface of the ring shall be smooth.

NOTE 2 Suitable grease — Silicone or “PTFE” (Polytetrafluoroethylene).

(ii) Minimum ring diameter, 50 mm; minimum ring height, 15 mm.

NOTE 3 Specimens containing inert materials with particle sizes greater than 10 times the diameter may influence the results and should be noted in the reporting.

(iii) Minimum internal ring diameter: height ratio is 3:1.

(c) Two porous plates of silicon carbide, aluminium oxide, or metal which is not attacked by the soil or soil moisture. The porous plate shall have a permeability not less than 20 times the permeability of the soil. The following requirements shall be met:

(i) Plates shall be a minimum of 0.3 mm and no more than 0.5 mm smaller in diameter than the ring to minimize extrusion of soil between the inner face of the ring and the plate.

(ii) Top plate shall be loaded through a corrosion-resistant loading cap of sufficient rigidity to prevent breakage of the plate.

(d) Dial gauge or transducer (LVDT) with a travel of at least 5 mm and readable to at least 0.002 mm.

(e) Trimming knife or wire saw.

(f) Filter paper.

(g) Oven — designed for soil engineering purposes and capable of drying a sample of soil to a constant mass.

5 Calibration of consolidation apparatus

The calibration shall be as follows:

(a) Moisten the porous plates. Assemble the consolidation cell with a metal disc of about the same thickness as the specimen and approximately 1 mm smaller in diameter than the ring in place of the specimen. Place filter paper layers in position as if they are to be used in the test.

(b) Load and unload the consolidation cell as in the test and measure the deformation for each load applied for a set period of 30 min per load or unload.

(c) Table corrections to be applied to the deformation at the end of each cycle.

6 Preparation of specimens

Preparation of specimens shall be carried out in the following manner:

(a) Prepare a specimen, using one of the following methods:

NOTE 1 Care of the specimen: Precautions should be taken to minimize disturbance of the soil during preparation. Vibration, distortion, and compression should be particularly avoided.

(i) From a thin-walled sample tube, extrude a length of soil for trimming to the required test specimen dimensions using a trimming knife or wire saw.

(ii) From a block sample, trim a soil cylinder larger than the required test specimen dimensions using a trimming knife or wire saw.

NOTE 2 The laboratory test should compress the soil in the same vertical direction as the applied vertical load in the field.

(iii) From a disturbed sample, compact a specimen to the desired moisture/density condition in a mould or former.

(b) Measure and record the internal diameter and height of the ring (H_0). Lightly grease the ring (see Clause 4(b)(i) Note 2) and determine the mass of the ring and grease $\left(m_o\right)$.

(c) Using the lightly greased cell ring, gradually trim the specimen obtained in Step (a) into the ring using light force, while trimming the soil to fit the size of the ring with a trimming knife or wire saw.

(d) Trim the ends of the specimen flush with the ends of the cell ring, wiping all residue soil from the outside of the ring, and determine the mass of the ring plus specimen $\left(m_1\right)$. Subtract the mass of the ring to determine the initial wet mass of the specimen $\left(m_1 = m_i - m_o\right)$.

(e) Using the trimmings of the specimen, measure the moisture content in accordance with AS 1289 2.1.1 and record as the initial moisture content.

(f) Determine the apparent density of the soil particles $\left(\rho s\right)$ as described in AS 1289.3.5.1 (fine fraction only). For batches of tests on the same project and of the same geological origin, a reduced number of tests may be completed, and the value assumed to be the same.

7 Procedure

The procedure shall be conducted as follows:

(a) Dampen the porous plates as necessary to minimize any tendency to absorb water from the specimen. Assemble the consolidation cell with ring, specimen, filter paper on either side of the specimen and porous plates. Position the loading plate on top of the specimen.

(b) Place the consolidation cell in the loading device, set the dial gauge, record the reading, and then apply a small seating pressure.

NOTE 1 A seating pressure of 6.25 kPa ± 1 kPa is recommended for typical apparatus and soil. For very soft soils a seating pressure of 3 kPa or less may be used.

(c) Inundate the specimen with water.

NOTE 2 Inundation procedures vary depending on the soil consistency and moisture content. Inundate the specimen at the start of the test unless otherwise specified by the client. Specimens may be inundated at times or loads other than at the beginning of the test. Any resulting effects, such as expansion or increased settlement, should be noted in the test report.

In the case of unsaturated soils, inundation may not be necessary, and the test would be carried out under conditions that minimize the loss of moisture by evaporation from within and around the specimen.

(d) Apply the first loading pressure and record the change in thickness of the specimen at the following time intervals: 7.5, 15, and 30 s; 1, 2, 4, 8, 16 and 32 min; 1, 2, 4, 8, and 24 h. The following loading pressure increments shall be used as the normal test range unless otherwise specified:

(i) Loading pressure increments: 6.25, 12.5, 25, 50, 100, 200, 400, and 800 (kPa).

(ii) Unloading pressure increments: 200 and 50 (kPa).

NOTE 3 Swelling of specimen: If the specimen swells on inundation, increase the pressure to the next higher value in the series. If swelling continues, increase the pressure to the next applied pressure increment until the sample begins to consolidate.

(e) Continue the readings until the slope of the characteristic linear secondary portion of the thickness versus log-of-time plot is obvious, see Clause 8.1 and Figure 1. For soils that have slow primary consolidation, loads shall act for the same periods of time and for a minimum of 24 h. In extreme cases, or where secondary consolidation is evaluated, loads will need to be applied for a longer period. Where the coefficient of secondary compression is to be determined, plot the time-settlement curve for the loading stage as the test progresses on a log time basis to ensure the rate of secondary compression can be defined. Then apply the next load increment.

(f) When the thickness versus square-root-of-time method is used, the time intervals may be adjusted to times that have easily obtainable square roots, e.g. 0.09, 0.25, 0.49, 1 min, 4 min, and 9 min, see Clause 8.1.3.

NOTE 4 Progressive plotting: Some advantage may be gained in determining when the next load increment may be applied by plotting the deformation versus square-root-of-time for the initial stages of consolidation in conjunction with a plot against log-of-time for the whole of the consolidation in the pressure increment. In some soils, 100 % consolidation can be achieved in less than 24 hrs and the next load increment may be applied prior to reaching 24 hrs.

(g) On completion of the deflection readings, unload the specimen to the load increments as detailed in Steps 7(d) (i) and (ii). The unloading of the specimen shall occur for a minimum of 30 min per stage. Lower pressure increments may result in the soils swelling, in which case the test shall be stopped.

(h) On completion of the test, remove the specimen from the consolidation cell, record the mass of the ring and soil (mf). Extrude the soil out of the ring and cut the specimen with a trimming knife or break open for examination. Record the description of the cut or broken surfaces and the presence of layering, stones, calcareous matter and other irregularities. Determine the moisture content of the soil in accordance with AS 1289 2.1.1 and record as final moisture content.

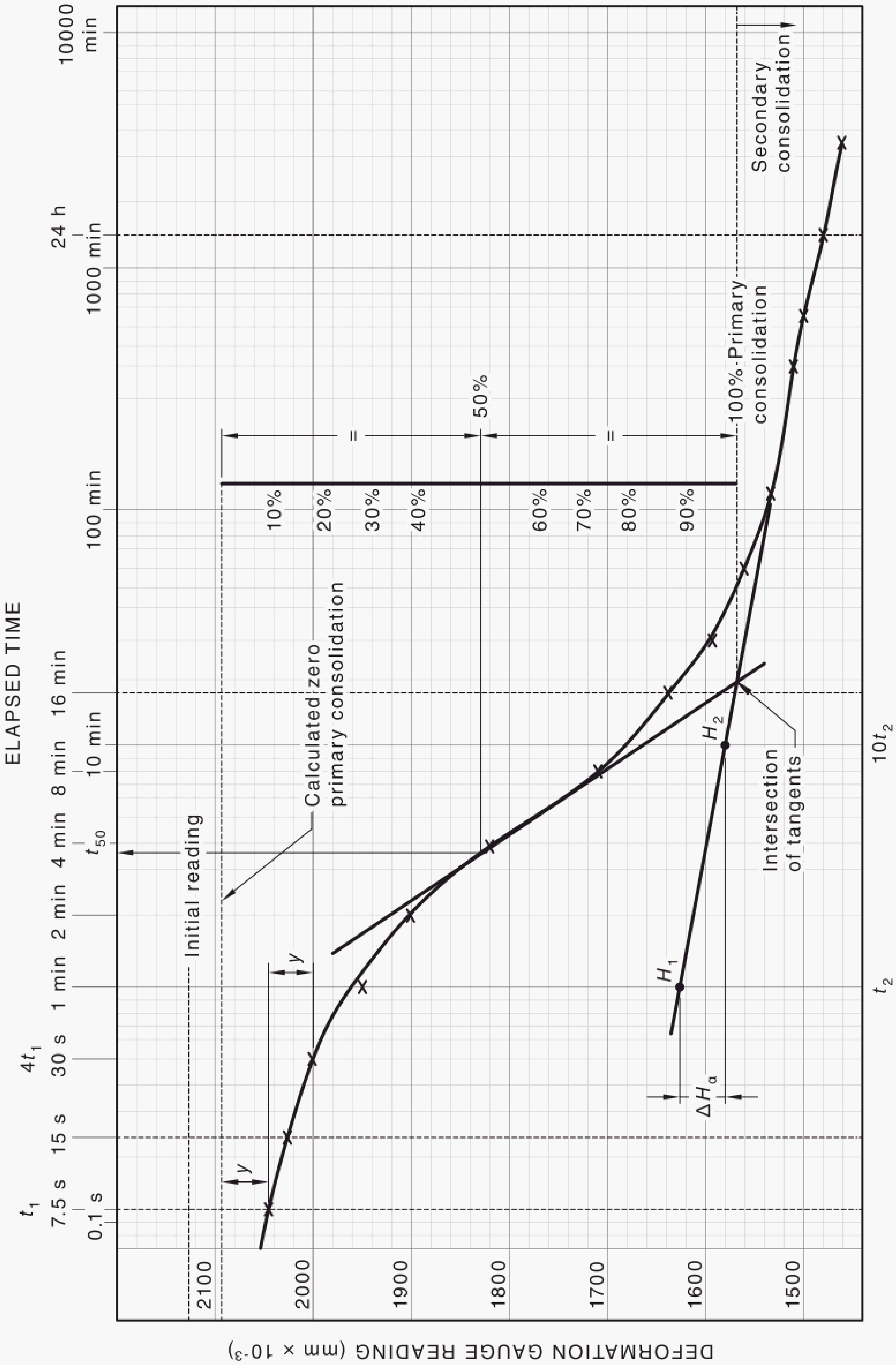

Figure 1 — Typical compression versus time (log scale)

8 Calculations

8.1 Deformation/time properties

8.1.1 General

The primary consolidation deformation/time properties shall be calculated in accordance with either the log/time method or the square-root/time method. For the secondary consolidation properties, the log/time method shall be used.

8.1.2 Log/time method

The procedure shall be as follows:

(a) Plot the deformation gauge readings versus the log-of-time in minutes for each increment of load or pressure as the test progresses.

(b) In order to find the deformation representing 100 % consolidation for each load increment, draw a straight line through the points representing the final readings that lie on a straight line. Draw a tangent to the steepest part of the deformation curve. The intersection represents the deformation corresponding to 100 % primary consolidation, see Figure 1.

NOTE The interpretation of any plot made in accordance with this procedure requires interpretation in relation to the shape of the curve and the tangent point selected.

(c) Find the deformation representing 0 % consolidation by selecting the deformations at any two times that do not exceed t_{50} and that have a ratio of 1:4 (e.g. 7.5s and 30s, 4s and 16s, 5s and 20s) so the change in deformation from the starting time of that load increment to the longer time is less than half the total deformation of the load increment. The deformation corresponding to 0 % primary consolidation is equal to the deformation corresponding to the shorter time interval less the difference in the deformations for the two selected times (see *y* in Figure 1).

(d) The deformation corresponding to 50 % primary consolidation for each load increment is equal to the average of the deformations corresponding to the 0 and 100 % deformations. The time required for 50 % consolidation is interpreted graphically from the deformation time curve for the load increment.

(e) For each load increment the coefficient of consolidation $\left(c_{\mathrm{v}}\right)$ for the double drainage condition in square metres per year can be calculated from Equation 8.1:

$$c_{\mathrm{v}} = \frac{0.026\overline{H}^{2}}{t_{50}} \qquad 8.1$$

where

c_{v} = coefficient of consolidation, in square metres per year

$\overline{H}$ = average thickness of specimen for the load increment, in millimetres

t_{50} = time for 50 % primary consolidation, in minutes

(f) Where the coefficient of secondary compression (c_{α}) is required, determine the specimen height change (ΔH_{α}) over one complete log cycle from the straight line drawn through the data points after the completion of primary consolidation, see Figure 1.

The coefficient of secondary compression is calculated from Equation 8.2:

$$c_\alpha = \Delta H_\alpha / H_o \quad 8.2$$

where

c_α = coefficient of secondary compression

ΔH_α = specimen height change, in millimetres, over one log cycle of time

H_o = initial height of specimen, in millimetres

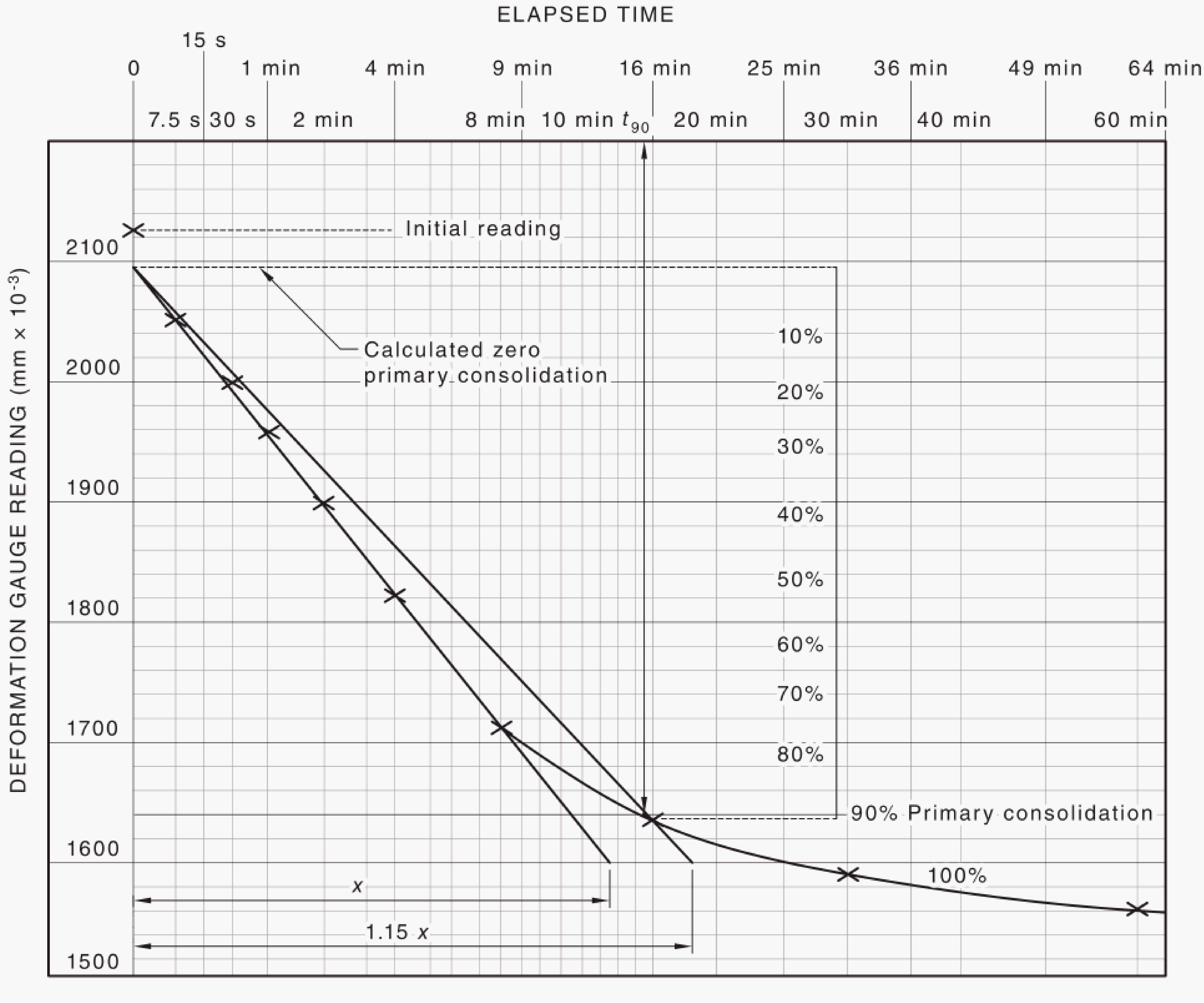

Figure 2 — Typical compression versus time (square root scale)

8.1.3 Square root/time method

The procedure shall be as follows:

(a) Plot deformation gauge readings *vs* the square-root-of-time in minutes (see Figure 2) for each increment of load or pressure as the test progresses.

(b) Approximate the initial part of the curve by a straight line and extrapolate back to $t = 0$. The corresponding deformation represents 0 % primary consolidation. A second straight line is drawn through this point so that the abscissae of the lines are 1.15 times the abscissa of the straight-line approximation of the initial part of the curve. The intersection of the new line with the deformation/square-root-of-time curve corresponds to 90 % primary or hydrodynamic consolidation. The deformation at 100 % primary consolidation is one-ninth more than the difference in deformations between 0 % and 90 % consolidation. The coefficient of consolidation $\left(c_{\mathrm{v}}\right)$ for the double drainage condition in square metres per year can be calculated from the time of 90 % consolidation from Equation 8.3:

$$c_{\mathrm{v}} = \frac{0.112\,\overline{H}^{2}}{t_{90}} \qquad 8.3$$

where

c_{v} = coefficient of consolidation, in square metres per year

$\overline{H}$ = average thickness of specimen for the load increment, in millimetres

t_{90} = time for 90 % primary consolidation, in minutes

8.2 Deformation/load properties

Where determination of the deformation and/or load properties are required, these may be calculated in accordance with the following procedure:

(a) Calculate the equivalent height of the solid particles (H_{s}) from Equation 8.4:

$$H_{\mathrm{s}} = \frac{m_2 \times 1000}{\rho_{\mathrm{s}} \times A} \qquad 8.4$$

where

H_{s} = equivalent height of solid particles, in millimetres

m_2 = dry mass of the specimen, in grams

ρ_{s} = soil particle density, in grams per cubic centimetre

A = area of the specimen, in square millimetres

(b) Calculate the initial void ratio $\left(e_{\mathrm{o}}\right)$ and degree of saturation $\left(S_{\mathrm{r}}\right)$, as follows:

(i) The void ratio $\left(e_{\mathrm{o}}\right)$ is given by Equation 8.5:

$$e_{\mathrm{o}} = \frac{H_{\mathrm{o}} - H_{\mathrm{s}}}{H_{\mathrm{s}}} \qquad 8.5$$

where

e_{o} = initial void ratio

H_{o} = initial height of the specimen, in millimetres

H_{s} = equivalent height of solid particles, in millimetres

(ii) The initial degree of saturation $\left(S_{\mathrm{r}}\right)$, is given by Equation 8.6:

$$S_{\mathrm{r}} = \frac{m_1 - m_2}{A \times \rho_{\mathrm{w}}\left(H - H_{\mathrm{s}}\right)} \times 10^5 \qquad 8.6$$

where

S_r = degree of saturation, in percent

m_2 = dry mass of the specimen, in grams

m_1 = initial wet mass of the specimen, in grams

A = area of the specimen, in square millimetres

ρ_w = density of water, in grams per cubic centimetre

H_0 = initial height of specimen in millimetres

H_s = equivalent height of solid particles, in millimetres

(c) Calculate the void ratio or percent settlement at the end of each loading increment and correct for the overall compression of apparatus as determined by the difference of the initial reading and the calculated zero reading for each increment.

Plot the void ratio or percentage settlement versus log-of-consolidation pressure.

The void ratio at the end of a loading increment (e) is given by Equation 8.7:

$$e = \frac{H - H_s}{H_s} \qquad 8.7$$

where

e = void ratio at the end of a loading increment

H = corrected height of specimen at end of loading increment, in millimetres

H_s = equivalent height of solid particles, in millimetres

(d) Calculate the coefficient of volume compressibility (m_v), in square metres per kilonewton, for every pressure increment.

NOTE Field versus laboratory behaviour: The method presented assumes that the laboratory relationship between void ratio and pressure also applies in the field. It is sometimes necessary to modify the laboratory curve to give expected field behaviour. For further information, refer to Terzaghi, Peck and Mesri (1996).

The coefficient of compressibility shall be calculated from Equation 8.8:

$$m_v = \frac{\Delta H}{\Delta p} \times \frac{1}{H} = \frac{\Delta e}{\Delta p} \times \frac{1}{1 + e} \qquad 8.8$$

where

m_v = coefficient of volume compressibility, in square metres per kilonewton

ΔH = change in height of the laboratory specimen, in millimetres

Δp = increase in pressure, above the present overburden pressure, in kilopascals

H_0 = height of the laboratory specimen, in millimetres

Δe = change in void ratio of the laboratory specimen

e = void ratio of the laboratory specimen

(e) The Compression Index for each load increment (C) shall be calculated from Equation 8.9:

$$C = \frac{\Delta e}{\Delta(\log_{10} p)} \quad 8.9$$

where

C = compression index

Δe = change in void ratio

p = change in log pressure, in kPa

9 Test report

The report shall include the following:

(a) Plot of either the void ratio versus log-of-pressure or percent settlement versus log-of-pressure.

(b) Plot of either deformation versus log-of-time or deformation versus the square-root-of-time.

NOTE Progressive plotting: Some advantage may be gained by plotting the deformation versus square-root-of-time for the initial stages of consolidation in conjunction with a plot against log-of-time for the whole of the consolidation in the pressure increment.

(c) Tabulation or plot of the coefficient of consolidation for relevant pressure ranges.

(d) Value of the coefficient of volume compressibility for each load increment or as otherwise requested.

(e) Coefficient of secondary compression, if required.

(f) Coefficient index for each load increment.

(g) Identification and description of the specimen, stating whether the soil is undisturbed, remoulded or otherwise prepared. Describe any observations of the specimen post-test indicating the presence of layering, stones, calcareous matter and other irregularities.

(h) Initial dry density, in tonnes per cubic metre.

(i) Initial height and final height in millimetres and initial moisture content and final moisture content as a percentage.

(j) Soil particle density as described in AS 1289.3.5.1, in tonnes per cubic metre, noting if the value was determined as a part of a batch.

(k) Initial degree of saturation, as a percentage.

(l) Conditions of the test, e.g. natural moisture or inundated, and load at inundation.

(m) Departure from the procedure described, including special loading sequences.

(n) Date of sampling and date of testing.

(o) Any other data or information as requested.

(p) Reference to this Australian Standard, i.e. AS 1289.6.6.1.

Bibliography

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For information regarding the development of Standards contact:
Standards Australia Limited
GPO Box 476
Sydney NSW 2001
Phone: 02 9237 6000
Email: mail@standards.org.au
www.standards.org.au

ISBN 978 1 76072 875 5