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

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. The Method is primarily intended for application to saturated soils to which the consolidation theory applies, but it may be adapted for application to unsaturated soils (see Note 1).

2 REFERENCED DOCUMENTS The following documents are referred to in this Standard:

AS

1289	Methods of testing soils for engineering purposes
1289.2.1.1	Method 2.1.1: Determination of the moisture content of a soil—Oven drying method (standard method)
1289.3.5.1	Method 3.5.1: Soil classification tests—Determination of the soil particle density of a soil—Standard method

3 APPARATUS The following apparatus shall be used:

(a) A load device suitable for applying vertical loads to the specimen (see Note 2). The device shall be capable of maintaining specified loads for long periods of time with an accuracy of ±2 percent of the applied load and shall permit application of a given load increment within a period of 2 s without impact.

(b) A consolidation cell, i.e. 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 submerging the specimen, for transmitting the vertical load, and for measuring the change in thickness of the specimen. The consolidation ring shall conform to the following requirements:

   (i) Preferred minimum specimen diameter — 50 mm.

   (ii) Minimum specimen thickness —15 mm, but not less than 10 times the maximum grain diameter.

   (iii) Minimum specimen diameter-to-thickness ratio —3:1.

   (iv) Thickness of the ring, such that, under assumed hydrostatic stress conditions in the specimen, the change in diameter of the ring does not exceed 0.04 percent under an applied pressure of 1600 kPa.

(v) The ring shall be made from material that is corrosion resistant in relation to the soil to be tested. The inner surface of the ring shall be smooth and shall be smeared with grease (see Note 3) to minimize edge disturbance. A ring with the cutting edge attached provides the most accurate fit in most soils.

(c) Porous plates of silicon carbide, aluminium oxide, or metal which is not attacked by the soil or soil moisture. The plate shall be sufficiently fine so that the soil will not extrude into the pores, but be sufficiently coarse so that it has a permeability not less than 20 times the permeability of the soil. It is often convenient to place filter paper at the interface between the soil and the porous plate. The following requirements shall be complied with:

(i) Plates shall be 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. The preferred difference in diameter is 0.3 mm.

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

(d) A trimmer, or cylindrical cutter, for reducing samples with a minimum of disturbance to the inside diameter of the cell ring. The cell ring may itself have a cutting edge, thereby eliminating additional disturbance to the soil caused by transfer from the cutting ring to the cell ring.

(e) Apparatus for determination of moisture content as described in AS 1289.2.1.1.

(f) Dial gauge with a travel of at least 5 mm and readable to 0.002 mm, or LVDT of equivalent readability.

(g) Miscellaneous equipment for use in preparing specimens, e.g. spatulas, knives, wire saws and grease.

4 CALIBRATION OF CONSOLIDATION CELL 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 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.

(c) Plot loads *vs* the resulting corrections to be applied to the deformation at the end of each cycle.

5 PREPARATION OF SPECIMENS The preparation of specimens shall be carried out in the following manner:

(a) Taking extreme care to minimize loss of moisture (see Note 4), obtain from a sample a subsample, as follows:

(i) From a thin-walled sample tube, extrude a sufficient length for trimming to the required test specimen dimensions.

(ii) From a block sample, trim a soil cylinder slightly larger than the required test specimen dimensions.

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

(b) Trim the subsample obtained in Step (a) directly in the cell ring, provided that the cell ring has a cutting edge. Alternatively, trim the subsample obtained in Step (a) with a suitable cutter and transfer to the cell ring. The laboratory test should normally compress the soil in the same direction relative to the soil stratum as the applied load in the field.

(c) Trim the ends of the specimen flush with the ends of the cell ring and determine the mass of the ring plus specimen (see Note 5). Subtract the mass of the ring to determine the initial wet mass of the specimen (m_1).

(d) If accurate void ratios are required determine the apparent density of the soil particles (ϱ_s) as described in AS 1289.3.5.1. Otherwise assume a value of particle density.

6 PROCEDURE The procedure shall be 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 and porous plates.

(b) Place the consolidation cell in the loading device and apply a seating pressure of about 6 kPa. For very soft soils a seating pressure of 3 kPa or less is desirable. Adjust the position of the dial gauge to allow for a small amount of swelling of the specimen, the remainder of the range of travel being taken to allow for compression. Record the initial reading and time and then inundate the specimen (see Note 6).

(c) Apply pressure increments such as to double the previous pressure. If the test is associated with an actual field loading, the range of pressure in the test should generally cover from one-half or less of the lowest field stress on the sample to four times the highest field stress. The following values, in kilopascals, are suggested as a normal test range:

6, 12.5, 25, 50, 100, 200, 400, 800, 1600, 3200 (see Note 7).

(d) Record the thickness or change in thickness of the specimen before each load increment is applied and at preferred times of 7.5, 15 and 30 s; 1, 2, 4, 8, 16 and 32 min; 1, 2, 4, 8, and the like, hours; measured from the time of the load application (see Notes 8 and 9). Continue the readings at least until the slope of the characteristic linear secondary portion of the thickness *vs* log of time plot is apparent (see Clause 7.1 and Figure 1). For soils that have slow primary consolidation, loads shall act for approximately equal periods of time, and for at least 24 h; in extreme cases, or where secondary consolidation is evaluated, loads will be required 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.

(e) If thickness *vs* square root of time plots are to be made, the time intervals may be adjusted to times that have easily obtainable square roots, i.e. 0.09, 0.25, 0.49, 1 min, 4 min, 9 min, etc, if special recording sheets are not available (see Clause 7.1 and Note 9).

(f) On completion of the deflection readings, unload the specimen to almost zero pressure and record the change in thickness. Where rebound or unloading characteristics are required, unload by stages using every second pressure from the loading sequence, e.g. 1600, 400, 100, 25 kPa. Record at time intervals as suggested above in Step (d) or (e)).

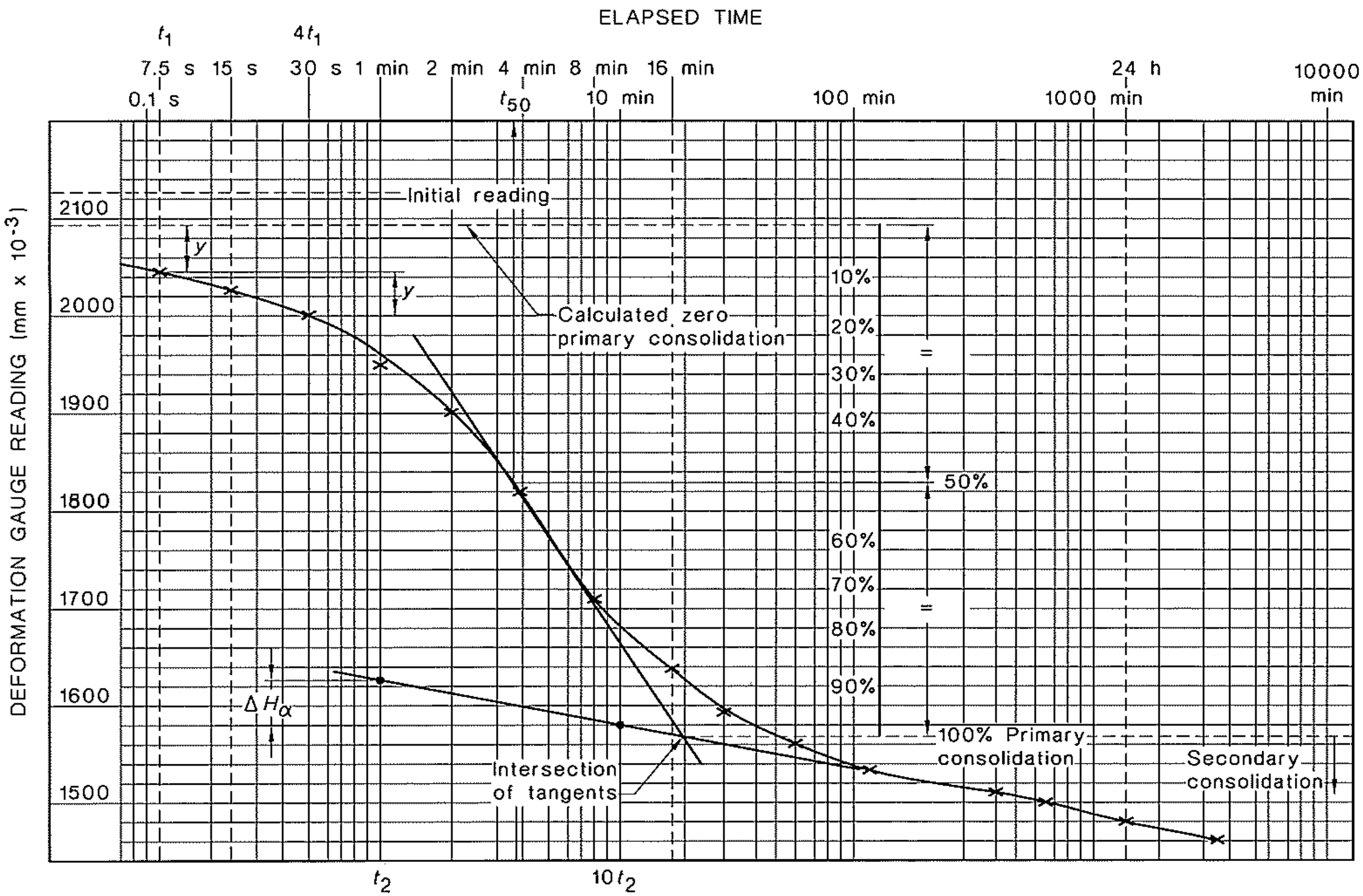

FIGURE 1 TYPICAL COMPRESSION vs TIME (LOG SCALE)

(g) On completion of the deflection readings, remove the entire specimen from the consolidation cell and determine its mass. Cut the specimen with a wire saw or break open for examination. Record the description of the cut or broken surfaces (see Clause 8(f)) and the presence of layering, stones, calcareous matter and other irregularities. Oven-dry and determine the dry mass of the specimen (m_2) to obtain the mass of solids.

7 CALCULATIONS

7.1 Deformation/time properties The primary consolidation deformation/time properties shall be calculated in accordance with either of the following procedures, and for the secondary consolidation properties the log/time method shall be used:

(a) *Log/time method (see Figure 1)* This shall be as follows:

(i) Plot the deformation gauge readings *vs* the log of time (in minutes) for each increment of load or pressure as the test progresses.

(ii) In order to find the deformation representing 100 percent 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 percent primary consolidation (see Figure 1).

(iii) Find the deformation, representing 0 percent consolidation, by selecting the deformations at any two early times that have a ratio of 1:4 (e.g. 7.5 s and 30 s) so that the approximate 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 percent primary consolidation, is equal to the deformation corresponding to the shorter time interval less the difference in the deformations for the two selected times (y in Figure 1).

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

(v) For each load increment the coefficient of consolidation (c_v), in square metres per year, for the double drainage condition can be calculated from the following equation:

$$c_v = \frac{0.026\bar{H}^2}{t_{50}} \qquad \ldots 7(1)$$

where

c_v = coefficient of consolidation, in square metres per year

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

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

(vi) 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 the following equation:

$$C_\alpha = \Delta H_\alpha / H_o \qquad \ldots 7(2)$$

where

C_α = coefficient of secondary compression

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

H_o = initial height of specimen, in millimetres.

(b) *Square-root/time method (see Figure 2)* This shall be as follows:

(i) Plot of deformation gauge readings *vs* the square root of time in minutes for each increment of load or pressure as the test progresses (see Note 9).

(ii) Approximate the initial part of the curve by a straight line and extrapolate back to $t = 0$. The corresponding deformation represents 0 percent 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 percent primary or hydrodynamic consolidation. The deformation at 100 percent primary consolidation is one-ninth more than the difference in deformations between 0 and 90 percent consolidation. The coefficient of consolidation (c_v), in square metres per year, for the double drainage condition can be calculated from the time of 90 percent consolidation by the following equation:

$$c_v = \frac{0.112\ \bar{H}^2}{t_{90}} \qquad \ldots 7(3)$$

where

c_v = coefficient of consolidation, in square metres per year

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

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

7.2 Deformation/load properties If the determination of the deformation/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 the following equation:

$$H_s = \frac{m_2 \times 1000}{\varrho_s \times A} \qquad \ldots 7(4)$$

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 (e_0) and degree of saturation (S_r), as follows:

(i) The void ratio is given by the following equation:

$$e_0 = \frac{H_o - H_s}{H_s} \qquad \ldots 7(5)$$

where

e_0 = initial void ratio

H_o = initial height of the specimen, in millimetres

H_s = equivalent height of solid particles, in millimetres.

(ii) The degree of saturation (S_r), is given by the following equation:

$$S_r = \frac{(m_1 - m_2)}{A \times \rho_w (H - H_s)} \times 10^5 \qquad \ldots 7(6)$$

where

S_r = degree of saturation, in percent

m_1 = initial wet mass of the specimen, in grams

m_2 = dry 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 = corrected height of specimen at end of loading increment, in millimetres

H_s = equivalent height of solid particles, in millimetres.

(c) Compute the void ratio or percent settlement at the end of each loading increment and correct for the overall compression of apparatus as determined in accordance with Clause 4 (see Note 10). Plot void ratio, or percent settlement *vs* log of consolidation pressure.

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

$$e = \frac{H - H_s}{H_s} \qquad \ldots 7(7)$$

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) Compute the coefficient of volume compressibility (m_v), in square metres per kilonewton, for the pressure increment of 100 kPa in excess of the present effective overburden pressure or, if required, compute other values of the coefficient of compressibility (see Note 11).

The coefficient of compressibility shall be computed from the following equation:

$$m_v = \frac{\Delta H}{\Delta p} \times \frac{1}{H} = \frac{\Delta e}{\Delta p} \times \frac{1}{1 + e} \quad \ldots 7(8)$$

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, in kilopascals, above the present overburden pressure

H = height of the laboratory specimen, in millimetres

Δe = change in void ratio of the laboratory specimen

e = void ratio of the laboratory specimen.

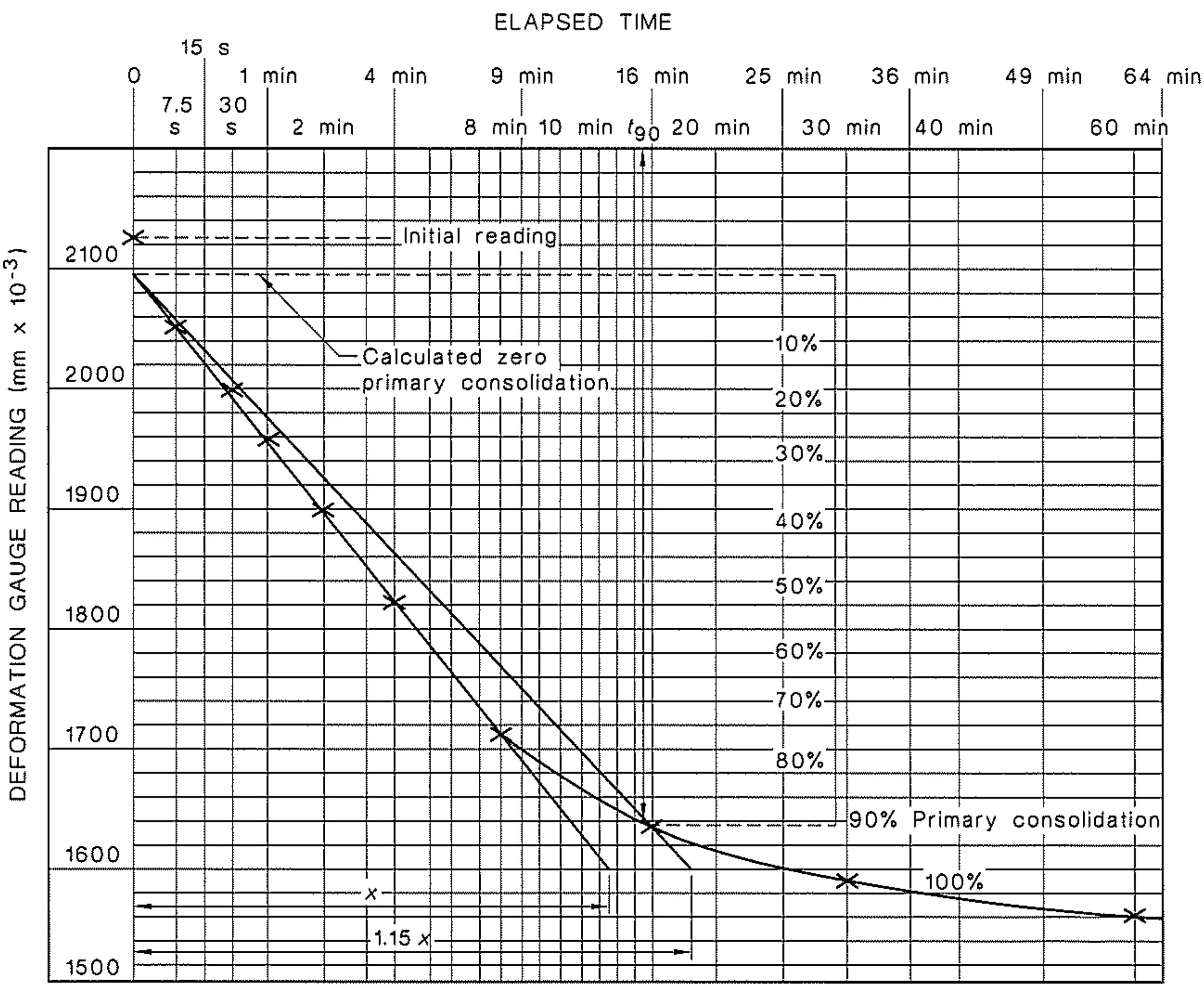

FIGURE 2 TYPICAL COMPRESSION vs TIME (SQUARE ROOT SCALE)

8 REPORTING OF RESULTS Report the following:

(a) Plot of either the void ratio *vs* log of pressure or percent settlement *vs* log of pressure.

(b) Plot of either deformation *vs* log of time or deformation *vs* the square root of time (see Note 9).

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

(d) The value of the coefficient of volume compressibility in the range of 100 kPa in excess of the effective overburden pressure or as otherwise requested.

(e) The coefficient of secondary compression if required.

(f) The identification and description of the specimen stating whether the soil is undisturbed, remoulded or otherwise prepared.

(g) The initial dry density, in tonnes per cubic metre.

(h) The initial moisture content, in percent.

(i) The soil particle density and whether measured, as described in AS 1289.3.5.1, or assumed, in tonnes per cubic metre.

(j) The initial degree of saturation, in percent.

(k) The conditions of the test, e.g. natural moisture or inundated and load at inundation.

(l) Any departure from the procedure described including special loading sequences.

(m) The date of sampling and date of testing.

(n) Any other data or information as requested.

(o) The number of this Australian Standard, i.e. AS 1289.6.6.1.

NOTES ON TEST:

1 **Interpretation of results** The result of any test made 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 **Terminology** In this test the term 'sample' is used to denote the soil submitted to the laboratory for testing and the term 'specimen' refers to a portion of the sample upon which the test is performed.

3 **Suitable grease** Silicone and 'PTFE' greases have been found suitable for the purpose.

4 **Care of the specimen** Precautions should be taken to minimize disturbance of the soil or changes in moisture and density during the specimen preparation. Vibration, distortion, and compression should be particularly avoided.

5 **Cell constants** It is assumed that the mass and dimensions of the cell ring are known.

6 **Alternative inundation procedures** Specimens may be inundated at times or loads other than at the beginning of the test, as in Clause 6(b). 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 is carried out under conditions that minimize the loss of moisture by evaporation from within and around the specimen.

7 **Loading procedure** An alternative loading or reloading schedule may be employed which reproduces the construction stress changes, or obtains better definition of some part of the stress-void-ratio curve or aids in interpreting the field behaviour of the soil. The procedure followed should be clearly indicated in the test report.

8 **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 applied pressure further until the sample begins to consolidate, and take readings of the compression dial gauge at suitable times for the remainder of that load increment.

Alternatively, the initial pressure applied to the specimen can be chosen to minimize swelling. For stiff soils the present effective overburden pressure may be applied and, for firm to soft soils, a value less than the present effective overburden pressure, but based on experience with similar soil types, is recommended.

9 **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.

10 **Calibration correction** With many soils the initial rapid decrease in height immediately after loading is much greater than the calibration correction, determined in Clause 4. This happens if the specimen is not fully saturated and it is then usually difficult to apply the square-root/time method (see Clause 7.1(b)) for the determination of t_{90}.

11 **Field *vs* 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; viz. Terzaghi, I. and Peck, R.B '*Soil Mechanics in Engineering Practice*'. John Wiley & Sons.

NOTES

This Australian Standard was prepared by Committee CE/9, Testing of Soils for Engineering Purposes. It was approved on behalf of the Council of Standards Australia on 12 June 1998 and published on 5 August 1998.

The following interests are represented on Committee CE/9:

Australian Geomechanics Society

AUSTROADS

Crushed Stone Association Australia

Department of Industry, Sport and Tourism, Scientific Services Laboratory, AGAL

Institution of Engineers, Australia

National Association of Testing Authorities, Australia

University of Sydney

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