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Methods of testing soils for engineering purposes

Part 3.6.3: Soil classification tests — Determination of the particle size distribution of a soil — Standard method of fine analysis using a hydrometer

STANDARDS
Australia

AS 1289.3.6.3:2020

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 23 March 2020.

This Standard was published on 9 April 2020.

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This Standard was issued in draft form for comment as DR AS 1289.3.6.3:2019.

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Methods of testing soils for engineering purposes

Part 3.6.3: Soil classification tests — Determination of the particle size distribution of a soil — Standard method of fine analysis using a hydrometer

Preface

This Standard was prepared by the Standards Australia Committee CE-009, Testing of Soils for Engineering Purposes, to supersede AS 1289.3.6.3—2003, *Methods of testing soils for engineering purposes, Soil classification tests—Determination of the particle size distribution of a soil—Standard method of fine analysis using a hydrometer.*

This Standard is part of the AS 1289 series. A list of all parts in this series can be found in the Standards Australia online catalogue.

The objective of this Standard is to establish a method for the quantitative determination of the particle size distribution in a soil using an hydrometer.

The major changes in this edition are as follows:

(a)   Preparation of the sample.

(b)   Pre-treatment relocated to Appendix A.

The terms "normative" and "informative" are used in Standards to define the application of the appendices to which they apply. A "normative" appendix is an integral part of a Standard, whereas an "informative" appendix is only for information and guidance.

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Australian Standard®

Methods of testing soils for engineering purposes

Part 3.6.3: Soil classification tests — Determination of the particle size distribution of a soil — Standard method of fine analysis using a hydrometer

1 Scope

This Standard sets out a method for the quantitative determination of the particle size distribution in a soil from a coarse sand size down, using an hydrometer for particles finer than the 75 μm sieve (see Clause 9 Note 1).

The method as described is applicable if —

(a)   more than 10 % of the material passes the 75 μm sieve as measured in AS 1289.3.6.1; and

(b)   only an ASTM 152H hydrometer conforming to ASTM E100 is used. A method for calibrating an hydrometer is set out in Appendix B.

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 1289.0, *Methods of testing soils for engineering purposes, Part 0: General requirements and list of methods*

AS 1289.1.1, *Methods of testing soils for engineering purposes, Method 1.1:Sampling and preparation of soils—Preparation of disturbed soil samples for testing*

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*

AS 1289.3.6.1, *Methods of testing soils for engineering purposes, Method 3.6.1: Soil classification tests—Determination of the particle size distribution of a soil—Standard method of analysis by sieving*

ASTM E100, *Standard Specification for ASTM Hydrometers*

3 Terms and definitions

For the purposes of this document, the terms and definitions in AS 1289.0 and the following apply.

3.1
factor F_1
volume and hydrometer scale calibration

3.2
factor F_2
temperature correction for soil particle density

3.3
factor F_3
determination of effective particle diameter

2

3.4
may
indicates the existence of an option

3.5
shall
indicates that a statement is mandatory

3.6
should
indicates a recommendation

4 Reagents

Only reagents of recognized analytical grade and distilled water or water of equivalent purity shall be used:

(a)   *Stock dispersing solution* — shall be prepared as follows:

      (i)   Dissolve 33 g of sodium hexametaphosphate together with either 7 g of anhydrous sodium carbonate (Na_2CO_3) or 18.9 g of hydrated sodium carbonate ($Na_2CO_3.10H_2O$) in distilled water to make 1 L of solution.

            The decahydrate ($Na_2CO_3.10H_2O$) is more readily soluble in water than is anhydrous sodium carbonate (Na_2CO_3) which is only sparingly soluble. The use of warm distilled water will also accelerate the solution of the chemicals.

      (ii)   Store the stock solution in a dark bottle away from sunlight. The date of preparation, or expiry date, shall be recorded on the bottle. The stock solution will be unstable and shall not be used if more than one month old.

            NOTE   Sodium hexametaphosphate is recommended as the dispersing agent as it has been found suitable for a wide range of soils. However, lateritic soils cannot be dispersed adequately with sodium hexametaphosphate and the use of sodium phosphate is advised (Wintermyer[1]).

(b)   *Barium chloride solution* — shall be prepared by dissolving 50 g of barium chloride in 1 L of distilled water.

5 Apparatus

The following apparatus shall be used:

(a)   An hydrometer conforming to ASTM E100 and with the following features (see Figure 1):

      (i)   The glass used for the bulb and stem is as free as possible from visible defects.

      (ii)   The stem and bulb are circular in cross-section and symmetrical about the longitudinal axis, with no abrupt changes in cross-section, which may trap air bubbles or hinder cleaning or drying.

      (iii)   The basis of the scale is either density in grams per millilitre (g/mL) at 20 °C or grams per litre (g/L) of colloid in suspension at 20 °C. The g/mL scale is normally calibrated from 0.995 to 1.038 with graduation lines at every 0.0005 g/mL and a maximum permissible scale error of plus or minus one scale division (0.0005 g/mL).

The g/L scale is normally graduated from –2 to +60, with graduation lines every g/L, and a maximum permissible scale error of plus or minus one scale division (1 g/L).

(b)   Two 1 L capacity parallel-sided graduated glass measuring cylinders about 60 mm internal diameter and 450 mm high, marked at 1 L volume and graduated in divisions of 10 mL. Cylinders used in tandem shall have uniform dimensions.

(c)   A thermometer covering the range from 0 °C to 50 °C and accurate to 0.5 °C.

(d)   A high-speed mechanical stirrer, e.g. an electrically driven mixer with a vertical shaft and a speed typically greater than 10 000 rpm, a cup to fit, and equipped with a wire baffle. The container and baffle shall be of material resistant to chemical attack from the reagents used.

NOTE   Alternative mechanical dispersion devices such as rubber mortar and pestle or air jet dispersion devices may be required for some soils. Residual soils of igneous origin suffer severe breakdown when subjected to mechanical stirring. The use of pestle and mortar is also unsatisfactory for these soils and it may be preferable to use an air-jet dispersion cup.

(e)   Sieves, ranging from 2.36 mm to 75 μm, and a receiver, as specified in ISO 3310.

(f)   A balance readable to 0.01g with a limit of performance not exceeding ±0.05 g.

(g)   An oven as specified in AS 1289.0.

(h)   A stop-clock or stopwatch.

(i)   A vernier calliper of at least 150 mm in length and readable to 0.1 mm.

(j)   A beaker.

(k)   A Buchner funnel and filter flask of about 500 mL capacity with cover glass.

(l)   A 100 mL measuring cylinder.

(m)   A wash bottle containing distilled water.

(n)   Filter papers (Whatman No. 54 or similar grade) to fit the Buchner funnel.

(o)   Litmus paper (blue) or suitable universal pH indicator papers.

(p)   Two types of stirrers are specified, a mechanically driven device (preferred) or air jet device. Studies have shown that the air jet device may give significantly different test results.

(q)   A glass rod about 200 mm long and 5 mm diameter.

(r)   A means of obtaining a vacuum, e.g. a filter or vacuum pump.

(s)   A desiccator containing anhydrous silica gel.

(t)   A constant temperature room capable of maintaining the soil suspension during sedimentation at a constant temperature of 20 °C ± 2 °C. The bath or cabinet shall be free of vibration.
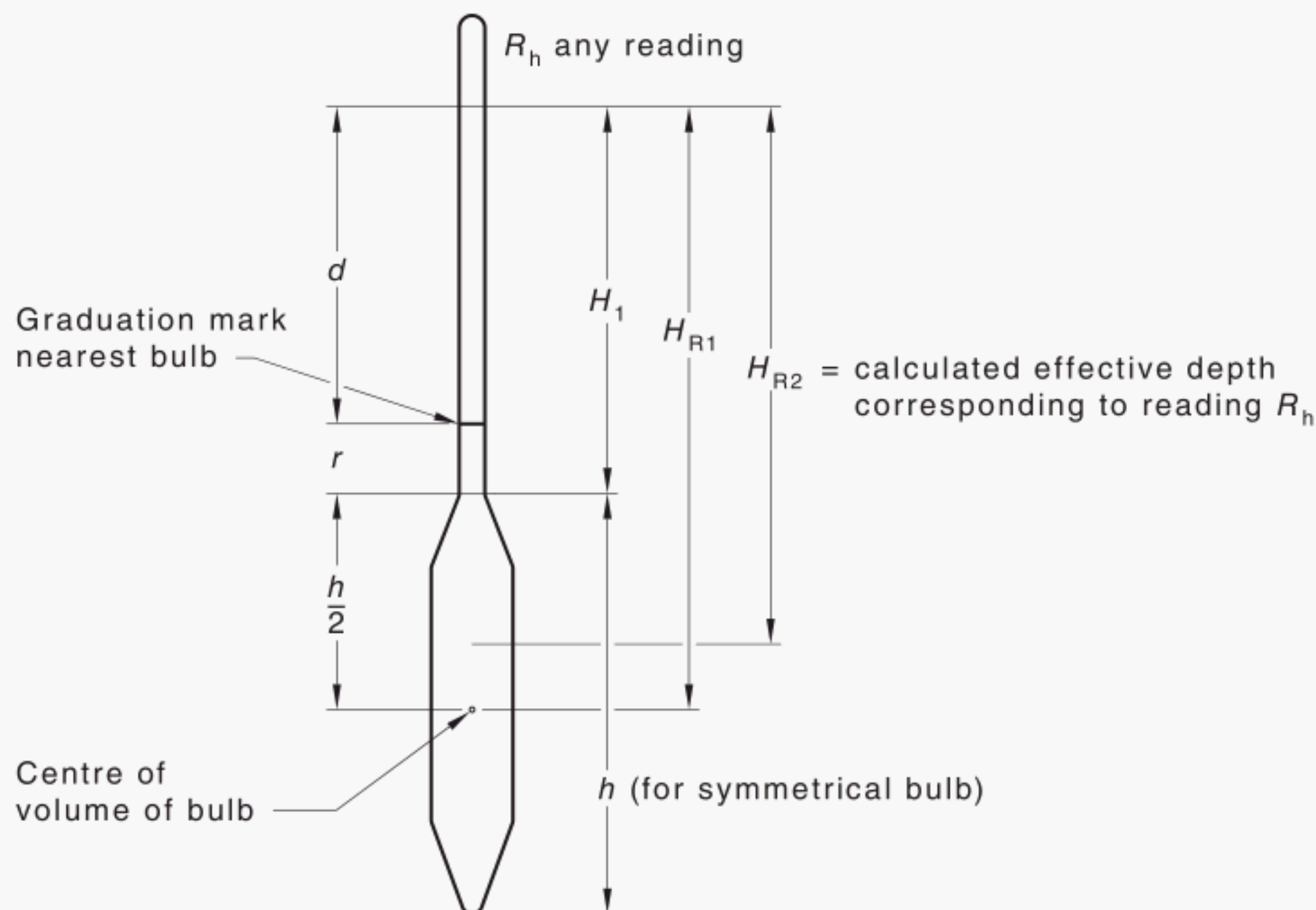
Figure 1 — Hydrometer

6 Determination of factor F_1

6.1 Volume

Determine the volume of the hydrometer bulb (V_h) using one of the following two methods:

(a)   From the volume of water displaced —

   (i)   pour approximately 800 mL of water into the graduated 1 L measuring cylinder, read and record the water level;

   (ii)   immerse the hydrometer carefully in the water, allow it to float, and again read and record the water level; and

   (iii)   record, in millilitres, the difference between the two readings as the volume of the hydrometer bulb.

   NOTE   The error due to inclusion of the stem volume is negligible.

(b)   From the mass of the hydrometer:

   (i)   determine the mass of the hydrometer to the nearest 0.1 g; and

   (ii)   record the mass, in grams, as the volume in millilitres of the hydrometer bulb mark.

   NOTE   The error due to inclusion of the stem volume is negligible.

6.2 Hydrometer scale

The hydrometer scale shall be determined as follows:

(a)   Determine the sectional area of the 1 L cylinder to be used in the test by measuring the distance between two graduations (e.g. 100 mL to 900 mL). Divide the volume, in millilitres,

included between the graduations by the measured distance, in millimetres, and multiply by 1000 to obtain the sectional area (A) in square millimetres.

(b) Measure and record the distance (d), in millimetres, from the graduation mark nearest to the neck of the stem of the hydrometer to each of the other major graduation marks (R_h).

(c) Measure and record the distance (r), in millimetres, from the neck of the bulb to the nearest graduation mark.

(d) Calculate $H_1 = d + r$, in millimetres, corresponding to each graduation mark (see [Figure 1](#)).

(e) Measure the height of the bulb (h), in millimetres, from the neck to the bottom of the bulb. Record this distance as equal to twice the length from the neck of the bulb to its centre of volume.

(f) Calculate the effective depth (H_R), in millimetres, corresponding to each major graduation mark from the following equations —

(i) when the hydrometer remains in the suspension from the start of the test (see Note 1).

$$H_{R1} = H_1 + 0.5h \tag{6(1)}$$

(ii) when the hydrometer is inserted to take a single reading (see Note 2).

$$H_{R2} = H_1 + 0.5\left(h - \frac{1\,000V_h}{A}\right) \tag{6(2)}$$

where

h = twice the distance from the neck of the bulb to its centre of volume, in millimetres

V_h = volume of hydrometer bulb, in millilitres

A = area of measuring cylinder, in square millimetres

NOTE 1   In relation to the effective depth of an hydrometer bulb the relations give the effective depth of the suspension referred to any given hydrometer reading, allowing for the rise of liquid in the graduated cylinder. It is desirable to pair an hydrometer with a calibrated cylinder so that values of H_R only need to be calculated once, when the hydrometer is first calibrated. Further simplification can be obtained by using hydrometers and cylinders manufactured to closely toleranced standard dimensions. For example, if ASTM standard hydrometers and cylinders are used, no calibration is necessary, and the effective depths can be obtained from ASTM D7928.

NOTE 2   The equation for H_{R2} is not completely correct as it assumes that the hydrometer has been immersed for only a negligible time and neglects any previous immersion time. If a calibrated hydrometer is available for each concurrent test, it can be left in the cylinder throughout the test and only H_{R1} needs to be calculated.

(g) Calculate a factor $F_1 = \sqrt{\dfrac{H_R}{10}}$ (see [Clause 10](#) Note 1) and plot curves of F_1, for both H_{R1} and H_{R2} against hydrometer reading R_h (corrected for meniscus only) (see [Clause 10](#) Note 2).

NOTE   For factor F_1, the determination of effective particle diameter in the sedimentation test is based on Stoke's Law, which can be written as:

$$v = \frac{g}{1.8} \times \frac{\rho_s - \rho_w}{\mu} \times \left(D^2 \times 10^{-4}\right) \qquad\qquad 6(3)$$

where

v =   terminal velocity, in millimetres per second

g =   gravitational acceleration, in metres per second squared

ρ_s =   soil particle density, in grams per cubic centimetre

ρ_w =   density of water, in grams per cubic centimetre

μ =   dynamic viscosity of water, in megapascal second

D =   particle diameter, in micrometres

In the hydrometer test,

$$v = \frac{H_g}{60t} \qquad\qquad 6(4)$$

where

t =   time in minutes after the start of the test.

The above equation can be rearranged to read:

$$D = \sqrt{\frac{H_R}{10}} \times 1.7490 \sqrt{\frac{\mu}{\rho_s - \rho_s}} \times \frac{10}{\sqrt{t}}$$
$$= \quad F_1 \times F_2 \times F_3$$

where

F_1, F_2 and F_3 are convenient factors that are multiplied together to give the particle diameter D (micrometres) appropriate to a reading R_h at time t (minutes)

Stoke's Law applied to the hydrometer test can also be solved nomographically (refer to BS 1377).

7 Procedure

7.1 Sample preparation and pre-treatment of soil

For soils that contain organic materials and carbonates, pre-treatment may be required as set out in Appendix A.

A sample shall be prepared using the moist preparation method. Air or oven drying of the sample may lead to secondary cementation of some soil samples. This test should be undertaken in combination with AS 1289.3.6.1 where material is retained on the sieve.

(a)   Obtain a sample that has been prepared in accordance with the procedure prescribed in AS 1289.1.1 and then perform the following steps:

         (i)   Obtain sufficient representative sample passing the 2.36 mm sieve to provide, after riffling or quartering, two subsamples each about 50 g to 100 g and another subsample of about 200 g for determination of soil particle density. The mass of the

smaller subsamples required will vary according to the type of soil, e.g. 50 g with a clayey soil and 100 g with a sandy soil.

NOTE   In relation to sedimentation sample size, Stoke's Law was derived for a single sphere falling in a large body of liquid. It is not applicable to a highly concentrated suspension in which the particles are close enough to influence each other, but if the mass of solid matter in the suspension is not too large so as to cause interparticle interference, the deviation from Stoke's Law is negligible. However, for some heavy clays it may be necessary to limit the suspension to not more than 50 g/L to avoid interference.

(ii)   From the representative sample, obtain the two subsamples of the material passing the 2.36 mm sieve, by riffling or quartering, and determine the moisture content (w) of one subsample in accordance with AS 1289.2.1.1, and the mass of the other subsample (m_3) accurately to the nearest 0.01 g.

(iii)   Place the second subsample (m_3) in the beaker.

(iv)   Calculate the oven-dry mass of the subsample (m_4) from the following equation:

$$m_4 = \frac{m_3 \times 100}{100 + w}$$ 7(1)

where

m_3 =   wet mass of untreated subsample used, in grams

w =   moisture content

(b)   Pre-treatment of soil may be specified in some circumstances, such as where a significant level of organic material is present. Where pre-treatment of the soil is specified, the procedure in Appendix A shall be followed.

7.2   Soil particle density

Determine the soil particle density of a soil subsample in accordance with AS 1289.3.5.1.

If pre-treatment of the soil is required for the hydrometer analysis, pre-treat the subsample for soil particle density in the same manner.

7.3   Dispersion of soils

The procedure shall be as follows:

(a)   Using a subsample obtained from Clause 7.1(a)(i), place in a beaker, and add 100 mL of dispersing agent. If required, add sufficient water to just cover the sample. Cover the beaker with a cover glass and leave it to stand for a minimum of 12 h.

NOTE 1   For highly plastic clay soils, a longer dispersing period may be required.

NOTE 2   For highly plastic clay soils, mechanical dispersion may be required prior to placing over a 75 μm wash sieve.

(b)   Wash the soil on the 75 μm wash sieve using potable or distilled water, taking particular care to limit the volume of liquid in the receiver to 950 mL.

7.4   Preparation for sedimentation

The procedure shall be as follows:

(a)   Transfer the liquid to the stirring device cup and operate for 15 min. If the volume of liquid exceeds the capacity of the cup, this process will need to be completed in multiple steps as follows:

　　　(i)   Transfer the mixture to the high-speed mechanical stirrer or to the air-jet dispersion cup, using a jet of distilled water.

　　　(ii)   Transfer the suspension that has passed through the sieve to the 1 L measuring cylinder and make up to exactly 1 L with distilled water. This makes the suspension to be used in the sedimentation analysis.

(b)   For soils likely to suffer severe structural breakdown, it is recommended that the air dispersion device be used, and mechanical dispersion not be used before washing over the 75 μm sieve.

(c)   In the case of (a) or (b) operate the dispersion device for 15 min. When using the mechanical stirrer use the baffle in the mechanical stirrer container. When using the air-jet dispersion device, operate it at a gauge pressure of 140 kPa ± 10 kPa.

7.5   Sedimentation

The procedure shall be as follows:

(a)   Place the 1 L cylinder containing the suspension in the constant temperature room, or bath and preferably leave it to stand until it has attained the ambient temperature of 20 °C ± 1 °C. Close the mouth of the cylinder with the palm of the hand, or with a suitable watertight stopper or lid, and turn the cylinder end over end thoroughly for about 60 rotations in 1 min.

(b)   Immediately after shaking, place the cylinder on a firm, level and vibration-free place in the constant temperature room or bath. Then proceed as follows:

　　　(i)   Start the stop-clock and record the time of commencement of the test.

　　　(ii)   Immediately immerse the hydrometer to a depth slightly below its floating position and allow it to float freely.

　　　(iii)   Take readings at the top of the meniscus at 0.5-, 1-, 2-, and 4-min intervals and record readings to the nearest gram per litre (or 0.0005 g/mL) (R_h).

　　　(iv)   Remove the hydrometer slowly, rinse it in distilled water, and place it in another cylinder of distilled water, which is at the same temperature as that of the suspension.

　　　(v)   Re-insert the hydrometer in the suspension and take readings at elapsed times of 8, 15 and 30 min and 1, 2, 4 and 8 hrs.

　　　(vi)   Remove the hydrometer after each reading, rinse it, and replace it in the cylinder of distilled water.

　　　(vii)   After the 4 h reading take further readings once or twice daily up to 48 h after dispersion, recording the times of reading. (Always insert and withdraw the hydrometer carefully when taking a reading to avoid undue disturbance of the suspension, allowing 10 s for each operation. Avoid vibration of the sample from any source.)

(c)   Record the temperature of the suspension once during the first 15 min of sedimentation and then after every subsequent reading. Record the temperature, accurate to within ±0.5 °C (see Clause 10 Note 7).

(d)   At the conclusion of the sedimentation test —

    (i)   transfer the contents of the cylinder after decantation to an evaporating dish (mass determined to within 0.01 g);

    (ii)   dry in the oven at 105 °C to 110 °C;

    (iii)   cool in the desiccator and determine the mass of the contents to the nearest 0.01 g; and

    (iv)   record the mass as the mass of the fraction passing the 75 μm sieve (m_{6u}) uncorrected for dispersing agent.

(e)   For soils which do not require pre-treatment, or where the mass of material in suspension at the commencement of the hydrometer analysis has been found in the course of its preparation during fine sieve analysis (refer to AS 1289.3.6.1), omit the drying of the material after hydrometer analysis.

For soils which did require pre-treatment, obtain the mass of the fraction passing the 75 μm sieve (m_6) from the difference between the calculated oven-dry mass (m_4) of the subsample obtained in Clause 7.1(a) and the oven-dry mass (m_5) of the fraction of the sample retained on the 75 μm sieve.

7.6 Corrections

Corrections to the readings shall be made as follows:

(a)   Correction for dispersing agent in the fraction passing 75 μm sieve:

    (i)   Place 100 mL of the dispersing agent solution in an evaporating dish of known mass and dry at 105 °C to 110 °C.

    (ii)   Determine the mass of the contents to the nearest 0.01 g (m_d).

    (iii)   Deduct this mass from the mass (m_{6u}) and record the result as m_6, the correct mass of the fraction passing the 75 μm sieve, i.e. $m_6 = m_{6u} - m_d$.

(b)   Dispersing agent correction to hydrometer readings (see Clause 10 Note 8):

    (i)   Place 100 mL of the dispersing agent solution into a 1 000 mL graduated cylinder, make up to 1 000 mL with distilled water and place the cylinder in the constant temperature room or bath, maintained at 20 °C ± 0.5 °C.

    (ii)   When the solution has attained equilibrium temperature, insert the hydrometer and take a reading. For hydrometers calibrated in grams per litre, record this reading as the correction C_a due to the presence of dispersing agent in the soil suspension. For hydrometer reading in g/mL take the reading minus 1.000 as the correction.

    (iii)   An alternative option to Steps (b)(i) and (b)(ii) is to calculate the correction from the results of Step (a) above. For hydrometers calibrated in grams per litre, the correction is equal to the mass in grams of dispersing agent in the 100 mL sample. For hydrometers calibrated in grams per millilitre, the correction is the mass in grams divided by 1 000.

(c)   Temperature correction (see Clause 10 Note 8):

Obtain the relevant temperature corrections C_t from the chart in Figure 2, which gives the appropriate corrections for hydrometers calibrated at 20 °C. Scale A gives corrections for the g/L hydrometer scale while Scale B gives corrections for the g/mL hydrometer scale.

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(d)   Meniscus correction:

(i)   Insert the hydrometer in a 1 L graduated cylinder containing about 700 mL of distilled water.

(ii)   Align the eye slightly below the plane of the surface of the liquid and raise the eye slowly until the surface, seen as an ellipse, becomes a straight line.

(iii)   Read the graduation where the straight line intersects the hydrometer scale (see Clause 10 Note 9).

(iv)   Read the graduation where the upper limit of the meniscus intersects the hydrometer scale.

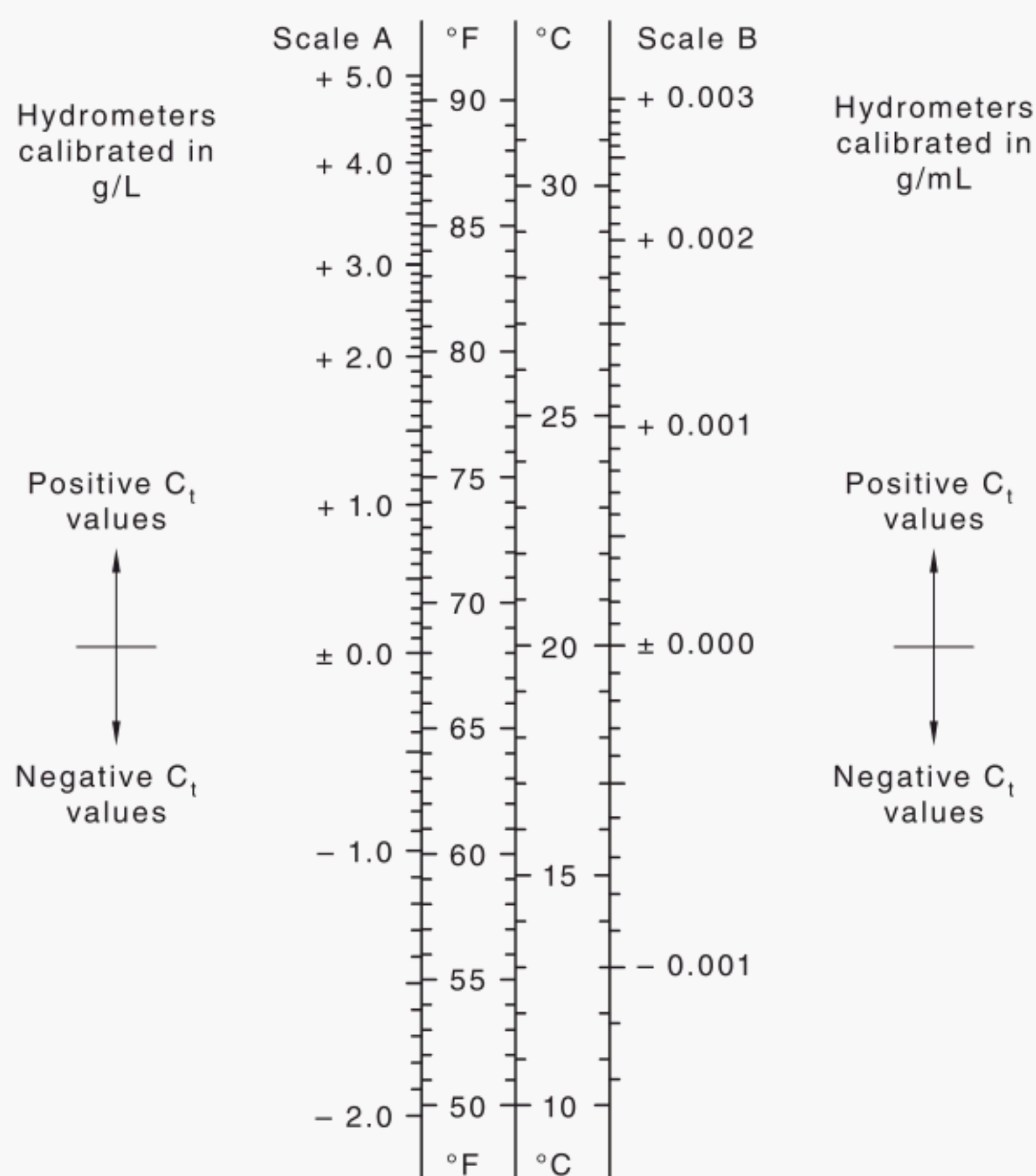(v)   Record the difference between the two readings as the meniscus correction C_m (see Clause 10 Note 10).

Figure 2 — Temperature correction chart for hydrometers calibrated at 20 °C

8   Calculations

8.1   Loss of mass in pre-treatment

Calculate the mass (P) percentage loss during pre-treatment of the fraction passing the 2.36 mm sieve from the following equation:

$$P = \left(1 - \frac{m_5 + m_6}{m_4}\right) \times 100 \qquad\qquad 8(1)$$

where

P = loss during pre-treatment of the fraction passing the 2.36 mm sieve, as a percentage

m_5 = dry mass retained on the 75 μm sieve after pre-treatment, in grams

m_6 = dry mass passing the 75 μm sieve after pre-treatment, in grams

m_4 = dry mass of untreated subsample, in grams

8.2   Fine sieving

The following shall be calculated:

(a)   The dry mass (m_7) of an equivalent complete sample which would have included the same mass of the fraction passing the 2.36 mm sieve as the mass of the subsample used in Clause 7.1 from the following equation:

$$m_7 = \left(m_2 \times \frac{m_3}{m_1}\right) + m_4 \qquad\qquad 8(2)$$

where

m_7 = calculated mass of equivalent sample passing 2.36 mm sieve, in grams

m_2 = dry mass of original sample retained on 2.36 mm sieve, in grams

m_3 = wet mass of untreated subsample used, in grams

m_1 = wet mass of original sample passing 2.36 mm sieve, in grams

m_4 = dry mass of untreated subsample, in grams

(b)   Calculate the percentage of fractions retained on each sieve used, as in the following examples:

(i)   Percentage retained on 2.36 mm sieve (approximates gravel fraction)

$$= \frac{m_2 \times \dfrac{m_3}{m_1}}{m_7} \times 100 \qquad\qquad 8(3)$$

or

$$= \frac{m_7 - m_4}{m_7} \times 100 \qquad\qquad 8(4)$$

(ii) Percentage between 2.36 mm and 600 μm (approximates coarse sand fraction)

$$= \frac{m_{600\mu m}}{m_7} \times 100 \qquad\qquad 8(5)$$

(iii) Percentage between 600 μm and 212 μm (approximates medium sand fraction)

$$= \frac{m_{212\mu m}}{m_7} \times 100 \qquad\qquad 8(6)$$

(iv) Percentage between 212 μm and 75 μm (approximates fine sand fraction)

$$= \frac{m_{75\mu m}}{m_7} \times 100 \qquad\qquad 8(7)$$

Add these percentages progressively to obtain cumulative percentages retained on each sieve.

8.3 Sedimentation calculations

The procedure shall be as follows:

(a) Record the observed data and computed quantities in a table containing the following columns:

Date	Time	Temp °C	Elapsed time (t) min	R'_h	$R_h = R'_h + C_m$	Corrected reading $R_c = R'_h + C_t + C_a$	F_1	F_2	D μm	L %	K %

where

R'_h = the hydrometer reading at the upper rim of the meniscus

(b) For each value of R'_h read and record the relevant value of F_1 from the calibration graph of F_1 v R_h.

(c) For each value of R_h, read and record the value of F_2 from Table 1 for the appropriate sediment temperature and particle density (see Clause 10 Note 11).

(d) For each value of R_h, calculate and record the factor F_3 from the following equation:

$$F_3 = \frac{10}{\sqrt{t}} \qquad\qquad 8(8)$$

where

t = elapsed time since the commencement of sedimentation, in minutes

Alternatively, if the times in Table 2 are used, read the value of F_3 from that table.

(e) Calculate, for each value of R_h, the equivalent particle diameter D, in μm, from the following equation:

$$D = F_1 \times F_2 \times F_3 \qquad\qquad 8(9)$$

(f) Calculate, for each value of R_h, the hydrometer reading, corrected for temperature and dispersing agent R_c, from the equation:

$$R_c = R_h + C_t - C_a$$ 8(10)

Table 1 — Values of Factor F_2

Temp	Soil particle density (ρ_s) g/cm³								
°C	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
10	1.661	1.633	1.606	1.581	1.557	1.534	1.512	1.491	1.470
11	1.637	1.610	1.584	1.559	1.535	1.512	1.491	1.470	1.450
12	1.615	1.588	1.562	1.537	1.514	1.491	1.470	1.449	1.430
13	1.593	1.566	1.540	1.516	1.493	1.471	1.450	1.429	1.410
14	1.571	1.545	1.520	1.496	1.473	1.451	1.430	1.410	1.391
15	1.551	1.525	1.500	1.476	1.454	1.432	1.412	1.392	1.373
16	1.530	1.505	1.480	1.457	1.435	1.414	1.393	1.374	1.355
17	1.511	1.485	1.461	1.438	1.416	1.395	1.375	1.356	1.338
18	1.492	1.467	1.443	1.420	1.399	1.378	1.358	1.339	1.321
19	1.473	1.448	1.425	1.403	1.381	1.361	1.341	1.322	1.304
20	1.455	1.431	1.408	1.385	1.364	1.344	1.325	1.306	1.288
21	1.438	1.413	1.391	1.369	1.348	1.328	1.309	1.290	1.273
22	1.420	1.397	1.374	1.352	1.332	1.312	1.293	1.275	1.258
23	1.404	1.380	1.358	1.337	1.316	1.297	1.278	1.260	1.243
24	1.387	1.364	1.342	1.321	1.301	1.282	1.263	1.246	1.229
25	1.372	1.349	1.327	1.306	1.286	1.267	1.249	1.231	1.215
26	1.356	1.333	1.312	1.291	1.271	1.253	1.235	1.217	1.201
27	1.341	1.319	1.297	1.277	1.257	1.239	1.221	1.204	1.188
28	1.326	1.304	1.283	1.263	1.244	1.225	1.208	1.191	1.175
29	1.312	1.290	1.269	1.249	1.230	1.212	1.194	1.178	1.162
30	1.298	1.276	1.255	1.236	1.217	1.199	1.182	1.165	1.149

Table 2 — Values of Factor F_3

Time minutes	F_3	Time hours	F_2
0.5	14.14	1	1.29
1	10.00	2	0.91
2	7.07	4	0.65
4	5.00	8	0.46
8	3.54	24	0.26
15	2.58	32	0.23
30	1.83	48	0.19

(g)   Calculate, for each value of R_c, the percentage by mass L of particles in the pre-treated sample larger than the corresponding equivalent diameter D from the following equations:

(i)   For hydrometers graduated in grams per litre:

$$L = 1 - \left(\frac{R_c \times a}{m_7} \right) \times 100$$ 8(11)

where

$$a \quad = \quad \frac{0.623\rho_s}{\rho_s - 1}$$

ρ_s = average soil particle density as determined by AS 1289.3.5.1

Some values of a are given in Table 3.

Table 3 — Values of *a*

ρ_s	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
a	1.03	1.02	1.01	1.00	0.99	0.98	0.97	0.96

If the sedimentation sample was obtained from AS 1289.3.6.1, the value of m_7 shall be calculated from data obtained during the sieve analysis from the following equation:

$$m_7 = \frac{m_4 \times 100}{\text{percentage of total sample finer than } 75 \ \mu m} \qquad \qquad 8(12)$$

where

m_7 and m_4 $(= m_{10})$ refer to this method and the percentage finer than 75 μm is obtained from AS 1289.3.6.1.

(ii)   For hydrometers graduated in grams per millilitre:

$$L = \left[1 - \frac{(R_c - 1)}{m_7} \times \frac{\rho_s}{\rho_s - 1} \times 10^3 \right] \times 100 \qquad \qquad 8(13)$$

$$= \left[1 - \frac{1.6a(R_c - 1)}{m_7} \times 10^3 \right] \times 100 \qquad \qquad 8(14)$$

(h)   Record in the table, shown in item (a), values of *L* as percentages of particles in the pre-treated sample (or the whole sample if pre-treatment was omitted) larger than the corresponding values of *D*, for all calculated values of *D*.

(i)   Calculate the percentage *K* finer than each diameter *D*, as the difference between the cumulative percentage *L* larger than *D* and 100 %.

9 Reporting of results

The following shall be reported:

(a)   Plot the results on semi-logarithmic paper. This inclues the tabulation of the percentage of material passing each sieve size and nominal particle diameter for material passing the 75 μm sieve. A suitable chart is shown in AS 1289.3.6.1—2009 Figure 1.

(b)   Loss in pre-treatment as a percentage of the total sample.

(c)   Method of dispersion.

(d)   Type of hydrometer used.

(e)   Sample identification.

(f)   Description of the sample in accordance with AS 1726.3.1.

(g)   Date the test was performed.

(h)   Particle density used.

(i)   Method of sample preparation, i.e. from as received natural state, air-dried, oven-dried at X °C.

(j)   Reference to this test method i.e. AS 1289.3.6.3.

10   Supplementary information

The following notes should be considered in the application of this Test Method.

NOTE 1   The hydrometer method of particle size analysis is specified as the standard test as it is relatively simple to perform and requires only inexpensive apparatus. The accuracy of the results obtained is adequate for engineering purposes.

NOTE 2   In relation to the location of the centre of volume of an hydrometer, the distance ($h/2$) shown on Figure 1 locates the centre of volume of symmetrical bulb (i.e. circular in cross-section and symmetrical about the longitudinal axis). If an asymmetrical bulb is used, determine the centre of volume with sufficient accuracy by projecting the shape of the bulb on to a sheet of paper and locating the centre of gravity of the projected area.

NOTE 3   For oxidation of organic matter, pre-treatment with hydrogen peroxide may be omitted if the quantity of organic matter in the soil is not large. A simple test is to place a few grams of a separate sample of the soil in a dish and add a few drops of peroxide. If no effervescence occurs, omit the pre-treatment. Most organic colloids rehydrate and go into solution in the presence of sodium ions (Baver[2]).

NOTE 4   Omit the acid pre-treatment for carbonate removal wherever possible. As the presence of calcium compounds is usually associated with a pH greater than 7, acid pre-treatment is omitted for soils with a pH of 7 or less. The pH may be measured by any standard method if litmus paper is not used. Some laboratories have found universal pH indicating papers to be more satisfactory. Alternatively, place a few grams of a separate sample of the soil in an evaporating dish and add a few drops of hydrochloric acid. If no effervescence occurs, omit the pre-treatment.

Certain types of predominantly chalky soils should not be pre-treated with acids as this would result in a dissolution of particles. In such cases try other suitable methods for breaking up agglomerations of particles, such as prolonged stirring or rubbing. Agglomerations of soil particles bonded with iron oxides are of a more permanent nature and acid pre-treatment is not carried out.

NOTE 5   In relation to the removal of soluble salts, slightly soluble salts, notably calcium sulfate, will require larger quantities of water for complete dissolution. Considerable time may be saved by repeated washings in the flask or beaker, rather than washing the sample on the filter. Completion of the treatment is indicated by the absence of sulfate ions in the wash water.

NOTE 6   In the wet-sieving operation for the separation of sand particles, grains with diameters just slightly smaller than the apertures of the 75 μm sieve may be held between the sieve meshes. If a large part of the sample passes through the 75 μm sieve during the dry sieving operation, add the material passing to the suspension in the graduated cylinder prior to sedimentation making sure that measured masses are suitably corrected.

NOTE 7   For an error in particle size of not more than 2 %, the temperature of the suspension should not differ from the mean temperature by more than 2°C during the test. This condition is usually satisfied if the range in room temperature is not greater than about 8 °C.

To avoid convection currents, keep the suspension out of direct sunlight and away from any local sources of heat. Cover the measuring cylinder between readings to retard evaporation.

NOTE 8   For hydrometer corrections, it may be convenient to make experimentally a combined dispersing agent and temperature correction, C_a–C_t. If only a small range of temperatures is expected, take hydrometer readings at two temperatures spanning the expected range and use linear interpolation for intermediate temperatures. For hydrometers calibrated in grams per litre the reading is the combined correction; for hydrometers calibrated in grams per millilitre the reading minus 1.000 is the combined correction.

The method of obtaining the dispersing agent correction given in Clause 7.5(b) will also include the base reference mark correction. For calibrated hydrometers, the application of the base reference and scale corrections will supply the true dispersing agent correction C_A. The dispersing agent correction obtained by gravimetric means as in Clause 7.5(a) does not include a base reference correction which, therefore, should be obtained through appropriate calibration procedures.

NOTE 9   Keep the hydrometer stem perfectly clean to obtain a fully developed meniscus around the stem.

NOTE 10   In relation to meniscus correction, hydrometers are calibrated to read correctly at the surface of a liquid. Soil suspensions are not transparent enough to permit a reading to be taken at the surface and the reading R'_h is to be made at the upper rim of the meniscus. The meniscus correction C_m, which is to be added to R'_h, to obtain the true reading R_h, is a constant for each hydrometer.

NOTE 11   The factor F_2 is given by

$$1.7490\sqrt{\frac{\mu}{\rho_s - \rho_w}}$$

The dynamic viscosity of water μ and the density of water ρ_w are both temperature dependent. The values of F_2 in Table 1 have been calculated for various values of ρ_s, and published values of the variations in μ and ρ_w with temperature.

NOTE 12   With soil particle density correction, the precise formula for a is:

$$\frac{\rho_s\left(2.650 - 0.998\right)}{2.650\left(\rho_s - 0.998\right)}$$

but the expression given in the text is compatible with the accuracy of the test.

Appendix A
(normative)

Pre-treatment of soil

A.1   Pre-treated samples

Where a sample requires pre-treatment, the following shall apply:

(a)   If the sample has been filtered after pre-treatment, transfer all of the soil on the filter paper and the funnel to the mechanical dispersion device, using a wash bottle and the minimum quantity of distilled water. Add 100 mL of the dispersing agent solution and warm the mixture gently for 10 min. Additional water may be added provided the container is not more than half filled.

(b)   If the pre-treated sample is in a flask or beaker, add 100 mL of the dispersing agent and warm gently for 10 min. Transfer the mixture to the mechanical dispersion device using a jet of distilled water, but taking care that the container is not more than half filled.

(c)   For soils not containing calcium compounds or soluble salts and having an organic matter content less than 2 % [as measured by AS 1289.4.1.1 (see Clause 10 Note 3)], Steps (d), (e) and (f) may be omitted (see Notes 3, 4 and 5) and the sample described in Step (a) used for the preparation of the suspension (see Clause 10 Note 4).

(d)   For samples obtained during the sieve analysis detailed in AS 1289.3.6.1, where pre-treatment is required, filter the washings on the Buchner funnel and transfer all the soil on the filter paper to the wide mouth conical flask, using the minimum quantity of distilled water.

(e)   To remove organic matter, add 150 mL of hydrogen peroxide to the sample in the flask and stir the mixture gently with a glass rod for a few minutes. Cover the flask with a cover glass and leave it to stand overnight (about 12 h).

   After the mixture has stood, heat it gently, avoiding frothing over, and stir the contents periodically. When vigorous frothing has subsided, reduce the volume to about 50 mL by boiling. With very organic soils (greater than 15 % organic) additional peroxide may be required to complete the oxidation (see Clause 10 Note 3).

(f)   To remove carbonates in the case of soil containing water insoluble carbonate compounds, e.g. calcium carbonate, allow the mixture to cool, add 100 mL of hydrochloric acid, stir with a glass rod for a few minutes and allow to stand for 1 h. If the soil contains a considerable amount of calcium salts, add more acid as required. When the treatment is complete the solution will have an acid reaction to litmus paper. Filter the mixture on the Buchner funnel and wash with warm water until the filtrate shows no acid reaction to litmus (see Clause 10 Note 4).

(g)   To remove soluble salts from saline soils, wash the filter residue after treatment for organic matter into a beaker and add distilled water to 150 mL. Stir the mixture and filter as in Step (d) until the filtrate shows no precipitation with barium chloride solution (see Clause 10 Note 5).

   Better dispersion is ensured by avoiding oven-drying of the sample after pre-treatment. The degree of reversibility of dispersion and rehydration of the colloidal portion of the soil is dependent on the residual moisture content of the sample on drying[2]. After pre-treatment, the majority of soils will disperse easily but certain very heavily flocculated soils may not be dispersed completely by the technique described. Incomplete dispersion is indicated by the formation of relatively large crumbs or "flocs" of soils that fall rapidly through the water,

leaving a sharply defined clear layer above the suspension. In such a case, an additional quantity of the dispersing agent or a different agent may be required[2].

A.2   Reagents

Only reagents of recognized analytical grade and distilled water or water of equivalent purity shall be used. Reagent solutions required to undertake pre-treatment of soils shall be as follows:

(a)   *Hydrogen peroxide*, A 20-volume solution.

(b)   *Hydrochloric acid*, 1 M solution. Prepare by diluting 89 mL of concentrated acid ($\rho = 1.18\,\text{g/cm}^3$) with distilled water to make 1 L of solution.

Appendix B
(normative)

Hydrometer calibration

The procedure given in [Clause 6](#) for the determination of F_1, does not constitute a calibration of the hydrometer. The base reference mark is zero on soil hydrometer as defined in ASTM E100. An hydrometer shall be calibrated by adopting the following procedure:

(a)   Determine the mass (m) of the hydrometer in air to the nearest 0.1 g.

(b)   Immerse the hydrometer in distilled water at 20 °C ± 0.5 °C and take reading (R). The base reference mark correction (R_o) is either of the following as appropriate:

    (i)   For hydrometers reading in g/L: $R_o = -R$

    or

    (ii)   For hydrometers reading in g/mL: $R_o = 1.00 - R$

(c)   At a minimum of five points within the graduated scale on the stem of the hydrometer, measure the mean diameter (D) of the stem to the nearest 0.1 mm using Vernier callipers or equivalent. Calculate the mean value of D and then the mean cross-sectional area (A) of the stem in square millimetres.

(d)   Measure the distance between the base reference mark and each of the major scale graduation marks to the nearest 1 mm. Take 10 readings per mark, preferably shared between two operators. For each set of readings, calculate the mean distance (Δ_a) between the base reference mark and major scale graduation marks.

(e)   Calculate the theoretical distances (Δ_t) between the base reference mark and each major scale graduation mark using either of the following as appropriate:

    (i)   For hydrometers reading in g/L:

$$\Delta_t = \frac{1001.8m}{A} \times \frac{6.244 \times 10^{-4} \times C}{1.0 + 6.244 \times 10^{-4} \times C}$$

    (ii)   For hydrometers reading in g/mL:

$$\Delta_t = \frac{1001.8m}{A} \times \frac{6.244C}{1.0 + 6.244C}$$

    where

        A =   mean cross-sectional area of the stem, in square millimetres

        C =   major scale graduation value

        m =   mass of hydrometer, in grams

(f)   Determine scale distance errors between measured and theoretical values as $E = \Delta_t - \Delta_a$ for each major graduation mark.

(g)   Calculate F_c at each major graduation mark from the following:

      (i)   For g/L scale hydrometer:

$$F_c = \frac{\left(1 + 6.244 \times 10^{-4} C\right)^2}{1.2607}$$

      (ii)   For g/mL scale hydrometer:

$$F_c = \frac{\left(1 + 6.244 C\right)^2}{1.2607}$$

(h)   Calculate the scale correction at each major graduation mark from the following:

$$R_s = F_c \times E$$

(i)   Once a table of combined base reference mark and scale corrections has been prepared for an hydrometer, these corrections shall be applied to all readings of the hydrometer.

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