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*Incorporating
Amendment No. 1*

Methods of test for

Soils for civil engineering purposes —

Part 5: Compressibility, permeability and durability tests

Committees responsible for this British Standard

Amendments issued since publication

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Contents

Foreword

This Part of BS 1377 has been prepared under the direction of the Road Engineering Standards Policy Committee. It is a part revision of clause **5** of BS 1377:1975 which is deleted by amendment.

BS 1377:1975 which has now been withdrawn is replaced by the following Parts of BS 1377:1990:

— *Part 1: General requirements and sample preparation;*

— *Part 2: Classification tests;*

— *Part 3: Chemical and electro-chemical tests;*

— *Part 4: Compaction-related tests;*

— *Part 5: Compressibility, permeability and durability tests;*

— *Part 6: Consolidation and permeability tests in hydraulic cells and with pore pressure measurement*;

— *Part 7: Shear strength tests (total stress);*

— *Part 8: Shear strength tests (effective stress);*

— *Part 9: In-situ tests.*

Reference should be made to Part 1 for further information about each of the Parts.

The following test procedures, additional to those described in the 1975 standard, have been introduced:

a) swelling pressure and settlement on saturation measurements in an oedometer consolidation apparatus;

b) determination of the coefficient of permeability of sands by the constant head permeameter method;

c) determination of the susceptibility to internal erosion of clay soils, using three empirical tests:

1) the pinhole method;

2) the crumb method;

3) the dispersion (sedimentation) method.

d) determination of the susceptibility to frost heave, for which reference is made to BS 812-124.

Some amendments have been made to the one-dimensional oedometer consolidation test, which is nevertheless the same in principle as the test described in the 1975 standard.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced personnel.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 34, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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1 Scope

This Part of BS 1377 describes methods of test for the determination of the consolidation characteristics of soils when subjected to changes in the applied effective stress, the permeability characteristics of sands, the susceptibility of clays to internal erosion by water, and the susceptibility of soils to heave in freezing conditions.

Reference is made to some of the classification tests described in BS 1377-2, and to some of the methods of soil compaction described in BS 1377-4.

Reference is made to Part 1 for general requirements that are relevant to all Parts of this British Standard and for methods of preliminary preparation of soil and specimens for testing.

NOTE   The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 1377 the definitions given in BS 1377-1 apply, together with the following.

2.1
erodibility (dispersibility)

erosion of fine-grained soils by a process in which individual clay particles go into suspension in practically still water

2.2
dispersive soils

soils that are erodible in still water. They usually contain a preponderance of sodium cations in the pore water

3 Determination of the one-dimensional consolidation properties

3.1 General

3.1.1 *Principle.* This method covers the determination of the magnitude and rate of the consolidation of a saturated or near-saturated specimen of soil (see note 1) in the form of a disc confined laterally, subjected to vertical axial pressure, and allowed to drain freely from the top and bottom surfaces. The method is concerned mainly with the primary consolidation phase, but it can also be used to determine secondary compression characteristics.

In this test the soil specimen is loaded axially in increments of applied stress. Each stress increment is held constant until the primary consolidation has ceased. During this process water drains out of the specimen, resulting in a decrease in height which is measured at suitable intervals. These measurements are used for the determination of the relationship between compression (or strain) or voids ratio and effective stress, and for the calculation of parameters which describe the amount of compression and the rate at which it takes place.

NOTE 1   The method described covers the procedure and technique for consolidation tests on naturally deposited soils taken undisturbed from the ground in the form of cores or blocks. The term sample denotes the soil submitted to the laboratory for testing, and the term specimen refers to a portion of the sample upon which the consolidation test is performed.

NOTE 2   Data obtained from this type of consolidation test, if carried out on representative undisturbed samples of good quality, enable the amount of settlement under a structure to be estimated. Values of the coefficient of consolidation can also be calculated from which an indication of a theoretical rate of settlement can be derived. However the predicted settlement times can be greatly in excess of those observed in practice and should be treated with caution.

NOTE 3   The small size of the specimen normally used for this test frequently does not represent adequately the fabric features found in many natural deposits, which collectively dominate the drainage characteristics of the soil en masse and therefore the rate of settlement in-situ.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.1.2 *Environmental requirements.* The test shall be carried out in an area that is free from significant vibrations and other mechanical disturbance. The apparatus shall be sited away from the effects of local sources of heat, direct sunlight and draughts. The test shall be carried out in a laboratory in which the temperature is maintained constant to within ± 4 °C in compliance with **6.1** of BS 1377-1:1990.

3.2 Apparatus

3.2.1 *Consolidation apparatus*

3.2.1.1 The consolidation apparatus, known as the oedometer, shall be of the fixed ring type and shall consist essentially of the features described in **3.2.1.1.1** to **3.2.1.1.5**.

3.2.1.1.1 *A consolidation ring* which shall completely and rigidly support and confine the soil specimen laterally. The ring shall be of corrosion-resistant metal.

The ring shall be provided with a cutting edge to facilitate the preparation of the specimen. The inner surface of the ring shall be smooth.

NOTE 1   The inner surface of the ring may be coated with a low friction material to minimize wall friction. Alternatively silicone grease or petroleum jelly may be used.

The diameter of the consolidation ring shall be determined primarily by the nominal sizes of undisturbed tube samples received for test but also with regard to the character of the soil and the maximum size of particles present in the sample. The inside diameter of the ring used for fine silts and clay soils shall be at least 6 mm smaller than the undisturbed tube sample to permit trimming off no less than 3 mm of soil all around which may have been disturbed during the sampling operation. For coarse silt and sand containing some clay (see note 2), also for soils which contain numerous inclusions such as small stones or hard lumps, (e.g. boulder clay, marl, chalk), and for soils which break or deform badly on extrusion from the sampling tube, the inside diameter of the ring shall be as close as possible to the size of the tube sample because of the difficulty of trimming such specimens (see note 3). The inside diameter shall be not less than 50 mm and not greater than 105 mm.

NOTE 2   The method described is considered unsuitable for cohesionless sands and silts and for such soils a test at zero lateral strain (K_o compression test) in a triaxial apparatus is recommended.

NOTE 3   The inside diameters of some sampling tubes are nominal and it is thus impracticable in such cases to provide a consolidation ring with an inside diameter of the same size as the soil sample.

The height of the ring shall be not less than 18 mm and not more than 0.4 times the internal diameter.

NOTE 4   The selection of a specimen conforming with this range of thickness to diameter ratios is recommended as a reasonable compromise to limit as far as possible the effect of side friction between the specimen and the wall of the ring, and at the same time to keep the effect of specimen disturbance during preparation to a reasonable level. A ring 75 mm in diameter and 20 mm high has been found to be satisfactory for silt and clay soils.

3.2.1.1.2 *Corrosion-resistant porous plates* for placing at the top and bottom surfaces of the test specimen. Their porosity shall allow free drainage of water throughout the test but shall prevent intrusion of soil into their pores. (see **3.4.1**).

The thickness of the plates shall be sufficient to prevent breaking under load, and the material shall be of negligible compressibility under the loads applied during the test. The upper and lower surfaces shall be plane, clean and undamaged.

NOTE 1   Plates of bauxilite or sintered bronze 6 mm to 13 mm thick have been found to be suitable.

The diameter of the top porous plate shall be about 0.5 mm smaller than the inside diameter of the consolidation ring, in order to permit free compression of the soil specimen. A taper towards the upper edge is permissible to minimize the danger of binding, should tilting occur. The bottom porous plate shall be large enough to support the consolidation ring and its specimen adequately.

NOTE 2   The clearance should not be too great otherwise serious penetration of the soil between the side of the porous plate and the consolidation ring may take place; clearances in diameter from about 0.25 mm to about 0.75 mm have been found to be satisfactory.

3.2.1.1.3 *A consolidation cell* of suitable corrosion-resistant material within which is placed the consolidation ring containing the sample. The cell shall accept the consolidation ring with a push fit. The specimen is held between the top and bottom porous plates and rests centrally on the base of the cell. Load is applied to the specimen through a rigid, centrally mounted, corrosion-resistant loading cap fitted with a central seating. The principal features of the cell are illustrated in Figure 1(a).

The cell shall be capable of being filled with water to a level higher than the top of the upper porous plate. The materials comprising the cell and the components which fit into it shall not be corrodible by electro-chemical reaction with each other.

3.2.1.1.4 *A dial gauge* or a displacement transducer referred to as the compression gauge. The gauge shall be supported for measuring the vertical compression or swelling of the specimen throughout the test. It shall be readable to 0.002 mm and shall have a travel of at least 10 mm. Where more than 12 mm travel is required a readability of 0.01 mm is permissible.

3.2.1.1.5 *A loading device* having a rigid bed for supporting the consolidation cell. The device shall enable a vertical force to be applied axially in increments to the test specimen through a loading yoke. Each force increment shall be maintained constant by a stress-control method while permitting increasing vertical compression of the test specimen during the consolidation test. The vertical force applied to the test specimen shall produce calculated intensities of pressure within an accuracy of 1 % or 1 kPa, whichever is the greater. The apparatus shall be capable of accommodating a compression of at least 75 % of the specimen thickness. A counterbalanced lever system, using calibrated weights in increments, is the method commonly employed for applying the vertical force to the test specimen, and the test procedure described in this specification is applicable to this type of stress-control loading.

The force applied to the test specimen shall be applied centrally to the loading cap covering the top porous plate through a central seating. The loading mechanism shall be capable of applying the force immediately and without impact. A range of calibrated weights shall be provided to enable suitable increments of load to be applied to the test specimen.

The loading device shall be securely bolted to the bench or supporting stand which itself shall be securely fixed to the floor or counterbalanced as a safeguard against overturning when the lever is fully loaded.

NOTE   When several oedometers are supported on one bench or stand it is essential to ensure that the support is securely anchored against overturning when all oedometers are fully loaded at the same time.

3.2.2 *Ancillary items*

3.2.2.1 *Apparatus for moisture content determination*, as described in **3.2** of BS 1377-2:1990.

3.2.2.2 *Apparatus for particle density determination,* as described in **8.2** or **8.3** of BS 1377-2:1990 (optional).

3.2.2.3 *A timing device* readable to 1 s.

3.2.2.4 *A supply of water* at room temperature.

3.2.2.5 *A means of reading and recording the maximum and minimum room temperatures.*

3.2.2.6 *A watch glass,* or metal tray, larger in diameter than the consolidation ring.

3.2.2.7 *A metal disc,* of steel, bronze or brass of a thickness equal to the height of the consolidation ring and a diameter about 1 mm smaller than the internal diameter of the ring. The end faces shall be flat, smooth and parallel.

3.2.2.8 *A balance* readable to 0.1 g.

3.2.3 *Apparatus for specimen preparation and measurement.* The apparatus specified in **8.2.1** and **8.2.5** of BS 1377-1:1990 is required for preparing a specimen from a sample in a sampling tube. For preparing a specimen from a block sample, the additional equipment specified in **8.2.6** of BS 1377-1:1990 is required.

3.2.4 *Calibration of apparatus*

3.2.4.1 *Measurements*

3.2.4.1.1 Clean and dry the consolidation ring and the watch glass. Ensure that the cutting edge is true and not damaged.

3.2.4.1.2 Weigh the ring and the watch glass separately to 0.1 g.

3.2.4.1.3 Lubricate the inside face of the ring with a thin smear of silicone grease or petroleum jelly.

3.2.4.1.4 Measure the height of the consolidation ring to 0.05 mm at four or more equally spaced points and calculate the mean height, H_o.

3.2.4.1.5 Measure the internal diameter of the ring to 0.1 mm in two perpendicular directions. Calculate the mean diameter and the area, *A,* in mm^2.

3.2.4.2 *Determination of deformation characteristics of apparatus*

NOTE   Deformation of the apparatus may be significant when testing stiff soils but can often be ignored for soft soils.

3.2.4.2.1 Assemble the consolidation apparatus as described in **3.4** but fit the metal disc in place of the specimen. Do not add water to the cell. Identify the orientation of each component with respect to the loading device by indelible marks.

NOTE   If a filter paper is to be placed against each face of the specimen during a test, similar filter papers should be placed either side of the steel disc for the calibration, either dry or moist depending on the condition for the test.

3.2.4.2.2 Apply increments of force similar to those applied for a test (see **3.5.2**) up to the maximum working load of the apparatus. Each increment shall be sustained only as long as necessary to observe the resulting reading of the compression gauge.

3.2.4.2.3 Record the deformation under each force increment as indicated by the compression gauge.

3.2.4.2.4 Unload the apparatus in decrements corresponding to the loading increments and record the deformations as described in **3.2.4.2.3**.

3.2.4.2.5 Tabulate or plot the deformations as the cumulative corrections, *y,* to be applied to the measured cumulative settlement of the specimen corresponding to each applied force.

3.3 Preparation of specimen

3.3.1 *General requirements.* The test specimen shall be in the form of a disc of proportions specified for the consolidation ring in which it is to be tested (see **3.2.1.1.1**). The mean diameter of the largest particle shall not exceed one-fifth of the height of the ring.

Prepare the specimen from an undisturbed sample of soil, taken either from a sample tube, or as an excavated block sample.

NOTE 1   The test specimen should normally be orientated such that in the laboratory test the soil will be loaded in the same direction relative to the stratum as the applied stress in situ.
NOTE 2   A test specimen may also be prepared by the method described in **3.3.2** from soil that has been compacted into a cylindrical mould.

Avoid loss or gain of moisture by the sample at all stages of preparation, such as by carrying out these operations in a suitably humidified atmosphere.

Carry out cutting and trimming operations using cutting tools appropriate to the nature of the soil. The reference straightedge used for checking flatness shall not be used for trimming.

3.3.2 *Preparation of specimen from sample tube.* Prepare the test specimen from a tube sample as described in **8.6** of BS 1377-1:1990.

3.3.3 *Preparation from block sample.* Prepare the test specimen from an undisturbed sample received in the form of an excavated block by the procedure described in **8.7** of BS 1377-1:1990 (See note 1 to **3.3.1**).

NOTE   This procedure may also be used for a sample that has been extruded from a sampling tube when a jig for holding the cutting ring is not available.

3.3.4 *Specimen measurements*

3.3.4.1 Measure the height of the specimen to 0.05 mm (H_o) in its ring.

NOTE   Alternatively the height of the ring may be accepted as the specimen height if the nature of the soil makes it difficult for the specimen height to be measured satisfactorily.

3.3.4.2 Place the specimen in its ring on the watch glass or tray and weigh immediately to 0.1 g. Determine the initial mass of the specimen, m_o.

3.3.4.3 Take a sample of soil similar to that in the ring for the determination of particle density, if required, and initial moisture content.

NOTE   The moisture content determination enables preliminary values of voids ratio to be calculated during the test, before the final dry mass of the specimen is available.

A suitable form for recording these data is shown as form 5.A of Appendix A.

3.4 Preparation and assembly of apparatus

3.4.1 *Porous plates.* Before using the porous plates in a test they shall be prepared as follows.

a) Clean the surfaces using a natural bristle or nylon brush.

b) Ensure that the pores are not clogged by fine soil particles, and that the plates are readily permeable to water.

NOTE   Removal of soil particles from the pores of the plate can be aided by immersion in an ultrasonic water bath.

c) Saturate the pores by boiling in distilled water for at least 20 min, either over heat at atmospheric pressure, or in a vacuum desiccator in which the pressure has been reduced to about 20 mm of mercury.

d) For saturated soils, or for soils that do not exhibit a high affinity for water, keep the plates saturated in deaerated water until required for use. Immediately before assembly in the consolidation cell remove free surface water with a tissue, ensuring that the pores remain saturated.

e) For soils that readily absorb water, allow the plates to air dry.

3.4.2 *Assembly of consolidation cell*

3.4.2.1 Place the bottom porous plate, prepared by one of the methods described in **3.4.1**, centrally in the consolidation cell.

3.4.2.2 Place the specimen contained in its ring centrally on top of the porous plate.

3.4.2.3 Assemble the cell components so that the consolidation ring is laterally confined and in correct alignment.

3.4.2.4 Place the top porous plate and loading cap centrally on top of the specimen.

3.4.2.5 When assembling the apparatus for a test, ensure that each component is orientated as described in **3.2.4.2.1**.

3.4.3 *Assembly in load frame*

3.4.3.1 Place the consolidation cell in position on the bed of the loading apparatus.

3.4.3.2 Adjust the counterbalanced loading beam so that when the load-transmitting members just make contact with the loading cap the beam is slightly above the horizontal position.

NOTE   Ideally the beam's initial inclination upwards should be about equal to its 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. With highly compressible soils, adjustment of the beam inclination may be necessary during the course of a test but this should be done only at the end of a loading increment when the rate of settlement is very small.

3.4.3.3 Add a small weight to the beam hanger, sufficient to maintain contact between the load-transmitting members while final adjustments are made. The resulting seating pressure on the specimen shall not exceed 2 kPa.

3.4.3.4 Clamp the compression gauge securely into position so that it can measure the relative movement between the loading cap and the base of the cell. Arrange the gauge to allow for measurement of a small amount of swelling of the specimen, while the greater part of the range of travel allows for compression. Record the initial reading of the gauge.

3.5 Test procedure

3.5.1 *Loading sequence.* A range of pressures selected from the following sequence has been found to be satisfactory.

6, 12, 25, 50, 100, 200, 400, 800, 1 600, 3 200 kPa.

NOTE 1   This suggested sequence of pressures follows the generally accepted procedure by which the applied pressure at any stage is double that at the preceding stage in the sequence. This procedure also enables an equal spacing of points to be obtained when the compression characteristics are plotted against the logarithm of the applied pressure as recommended in the standard.

A typical test comprises four to six increments of loading, each held constant for 24 h, and each applied stress being double that of the previous stage. Loading is removed in a smaller number of decrements.

The initial pressure depends on the type of soil. For soils which tend to swell the swelling pressures may be determined at this stage by the method described in **4.1**. The first loading increment shall then be greater than the swelling pressure.

NOTE 2 The greatest pressure should be more than the maximum vertical effective stress likely to occur in situ due to overburden and the proposed construction. Loading of a specimen of overconsolidated soil should, wherever possible, extend into the normal consolidation region. A general guide to the initial pressure to be applied is given in Table 1.

Table 1 — Suggested initial pressures for consolidation test

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

σ'_{vo} represents the estimated present vertical effective stress in situ at the horizon from which the specimen was taken.

p_s represents the swelling pressure.

[a] See BS 5930

3.5.2 *Application of pressure*

3.5.2.1 Record the compression gauge reading as the initial reading for the load increment stage, d_i.

3.5.2.2 Apply the required pressure to the specimen at a convenient moment (zero time) by adding the appropriate weights to the beam hanger without jolting. Remove the weight used for the seating load.

3.5.2.3 Fill the consolidation cell with water after applying the pressure. If the specimen begins to swell, or if the compression virtually ceases within a short time, proceed to the next higher pressure. Alternatively, if required, determine the swelling pressure as described in **4.1**.

NOTE When using a rear-loading type of apparatus an additional weight should be applied to the lever hanger to just counterbalance the weight of water added to the cell.

3.5.2.4 Take readings of the compression gauge at suitable intervals of time. The following periods of elapsed time from zero are convenient. A suitable form for recording the readings is shown as form 5.B in Appendix A.

0, 10, 20, 30, 40, 50 s

1, 2, 4, 8, 15, 30 min

1, 2, 4, 8, 24 h

NOTE The times suggested give a regular spacing of points when plotted, but more frequent readings may need to be taken for soils which compress very rapidly. Readings may be taken at other time intervals so long as they enable the time-compression curve to be plotted with sufficient accuracy.

3.5.2.5 Plot the compression gauge readings against logarithm of time, or square root time, while the test is in progress, either manually or by means of an automatic recorder.

3.5.2.6 Maintain the pressure until the plotted readings indicate that primary consolidation has been completed. A period of 24 h under one pressure is generally adequate but this shall be verified from the plot.

NOTE The length of the consolidation period between successive increments of pressure should be made more or less equal for all increments of pressure. Primary consolidation is normally completed within the 24 h period recommended. For certain highly compressible but impermeable soils it may be necessary to extend the period to 48 h. For certain soils the primary consolidation may be completed well within the 24 h period, or even within the normal working day, making it possible to apply further load increments more frequently.

3.5.2.7 Record the daily maximum and minimum temperatures in the vicinity of the test apparatus to the nearest 1 °C.

3.5.2.8 Record the time and compression gauge reading at the termination of the load increment stage, d_f. This reading becomes the initial reading for the next stage.

3.5.2.9 Increase the pressure to the next value in the selected sequence, as described in **3.5.2.2**, and repeat **3.5.2.4** to **3.5.2.8**.

3.5.2.10 Repeat **3.5.2.9** for further stages of the sequence of loading, making at least four stages in all. The maximum pressure applied to the specimen shall be greater than the effective pressure which will occur in situ due to the overburden and proposed construction.

3.5.3 *Unloading*

3.5.3.1 On completion of the recording of the compression gauge readings in accordance with **3.5.2.6** under the maximum required pressure, unload the specimen as follows if the unloading curve is required. Otherwise proceed at **3.5.4**.

NOTE 1   The unloading portion of the log pressure/voids ratio curve is required in some methods of analysis for estimating the preconsolidation pressure for the soil. Normally the number of unloading stages should be at least half the number of loading stages, and should provide reasonably equally spaced points on a log pressure scale.

NOTE 2   After unloading to the smallest appropriate pressure a second load-unload cycle, possibly up to a higher pressure than before, may be applied if required.

3.5.3.2 Reduce the pressure to a value not less than the last but one value of the loading sequence, at a convenient moment (zero time).

3.5.3.3 Record readings of the compression gauge at convenient intervals such as those indicated in **3.5.2.4**.

3.5.3.4 Plot the readings so that the completion of swelling can be identified.

3.5.3.5 Record the final reading of the compression gauge, and the maximum and minimum daily temperatures.

3.5.3.6 Repeat **3.5.3.2** to **3.5.3.5** at least twice more, finishing with an applied pressure equal to the swelling pressure (if applicable) or to the initial applied pressure.

3.5.3.7 When the compression gauge indicates that equilibrium under the final pressure has been reached proceed to **3.5.4**.

3.5.4 *Dismantling*

3.5.4.1 Drain off the water from the cell. Allow to stand for 15 min to enable free water to drain from the porous plates.

3.5.4.2 Mop up any excess water from within the cell.

3.5.4.3 Remove the load from the specimen and remove the consolidation cell from the apparatus.

3.5.4.4 Dismantle the cell, and weigh the specimen in its ring on the weighed watch glass or tray.

3.5.4.5 Transfer the specimen and ring on the watch glass or tray to the oven maintained at 105 °C to 110 °C, dry the specimen to constant mass and determine the dry mass of the specimen 0.1 g (m_d).

3.6 Calculations and plotting

3.6.1 *General data.* (See form 5.A of Appendix A).

3.6.1.1 Calculate the initial moisture content, w_o (in %), from the specimen trimmings (see **3.3.4.3**).

3.6.1.2 Calculate the initial bulk density, ρ (in Mg/m^3), from the equation

$$\rho = \frac{m_o \times 1000}{A \, H_o}$$

where

m_o is the initial mass of the specimen (in g);

A is the area of the specimen (in mm^2);

H_o is the initial height of the specimen (in mm).

3.6.1.3 Calculate the initial dry density, ρ_d (in Mg/m^3), from the equation

$$\rho_d = \frac{100 \, \rho}{100 + w_o}$$

3.6.1.4 If it is required to plot void ratio against pressure, calculate the initial voids ratio, e_o, from the equation

$$e_o = \frac{\rho_s}{\rho_d} - 1$$

where

ρ_s is the particle density (in Mg/m^3).

3.6.1.5 The initial degree of saturation, S_o, may be calculated as a percentage from the equation

$$S_o = \frac{w_o \, \rho_s}{e_o}$$

This value can be used to indicate whether the test specimen is fully saturated initially.

3.6.2 *Compressibility characteristics*

3.6.2.1 The compressibility characteristics may be illustrated by plotting the compression of the specimen as ordinate on a linear scale against the corresponding applied pressure p (in kP/$^P{}_a$), as abscissa on a logarithmic scale (See form 5.C of Appendix A). Compression is usually indicated in terms of voids ratio, but the actual thickness of the specimen, or the strain expressed as a percentage reduction in thickness referred to the initial thickness, may be used as alternatives.

3.6.2.2 Calculate and plot voids ratios and compressibility data as follows. (See form 5.D of Appendix A).

3.6.2.2.1 Calculate the equivalent height of solid particles, H_s (in mm), from the equation

$$H_s = \frac{H_o}{1 + e_o}$$

where

H_o and e_o are as defined in **3.6.1**.

3.6.2.2.2 Calculate the height of the specimen, H (in mm), at the end of each loading or unloading stage from the equation

$$H = H_o - (\Delta H - y)$$

where

ΔH is the cumulative compression of the specimen (reduction in height) from the initial height as recorded by the compression gauge;

y is the cumulative correction for deformation of the apparatus under the pressure being considered.

3.6.2.2.3 Calculate the voids ratio, e, at the end of each loading or unloading stage, if required, from the equation

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

3.6.2.2.4 Calculate the coefficient volume compressibility, m_v (in m²/MN), for each loading increment from the equation

$$m_v = \left(\frac{H_1 - H_2}{H_1}\right)\left(\frac{1000}{p_2 - p_1}\right)$$

where

H_1 is the height of the specimen at the start of a loading increment (in mm);

H_2 is the height of the specimen at the end of that increment (in mm);

p_1 is the pressure applied to the specimen for the previous loading stage (in kPa);

p_2 is the pressure applied to the specimen for the loading stage being considered (in kPa).

3.6.2.2.5 If required, plot values of voids ratio as ordinate against applied pressure on a logarithmic scale as abscissa (see form 5.C of Appendix A). Draw smooth curves through the points for both the loading and the unloading portions. If the swelling pressure was measured the curves will start and terminate at the swelling pressure. Indicate the value of the initial voids ratio, e_o, on the vertical axis.

3.6.3 *Coefficient of consolidation.* (See form 5.D of Appendix A.)

3.6.3.1 *General.* Two curve fitting methods are recognized for evaluating the coefficient of consolidation, c_v, namely the logarithm-of-time curve-fitting method and the square root time curve-fitting method.

NOTE   The two fitting methods specified generally show reasonable agreement. In some cases the square root plot does not produce a straight line portion whereas the logarithmic plot may be more satisfactorily employed. On the other hand, the reverse may be true as, for example, with soils which exhibit a large amount of secondary compression. Sometimes the square root time curve is best used for determining the corrected zero point and the logarithmic time curve for the theoretical 100 % consolidation point.

3.6.3.2 *Log time curve-fitting method.* (See Figure 2.)

3.6.3.2.1 Locate the corrected zero point by marking off the difference in ordinates between any two points on the initial (convex-upwards) portion of the curve having times in the ratio 1 : 4, and laying off an equal distance above the upper point. Repeat this operation using two other pairs of points having times in the same ratio, and take the average of the compression readings so determined as the corrected zero compression point, denoted by d_0.

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

3.6.3.2.2 Draw and extend the tangents to the two linear portions of the laboratory curve, i.e. at the point of inflexion, and the secondary compression portion. Their intersection gives the compression corresponding to theoretical 100 % primary compression, denoted by d_{100}.

3.6.3.2.3 From the zero and 100 % points, locate the 50 % primary compression point, d_{50}, on the laboratory curve and obtain its time, t_{50} (in min).

3.6.3.2.4 Calculate the coefficient of consolidation, c_v (in m²/year), for this load increment from the equation

$$c_v = \frac{0.026\,\bar{H}^2}{t_{50}}$$

where

$\bar{H}$ is the average specimen thickness for the load increment (in mm), i.e.

$$\bar{H} = \frac{H_1 + H_2}{2}$$

t_{50} is expressed in minutes.

3.6.3.2.5 Repeat **3.6.3.2.1** to **3.6.3.2.4** for each force increment applied to the specimen.

3.6.3.3 *Square root time curve-fitting method.* (See Figure 3.)

3.6.3.3.1 Draw the straight line of best fit to the early portion of curve (usually within the first 50 % of compression) and extend it to intersect the ordinate of zero time. This intersection represents the corrected zero point, denoted by d_0.

3.6.3.3.2 Draw the straight line through the d_0 point which at all points has abscissae 1.15 times as great as those on the best fit line drawn in **3.6.3.3.1**. The intersection of this line with the laboratory curve gives the 90 % compression point, d_{90}.

3.6.3.3.3 Read off the value of t_{90} from the laboratory curve corresponding to the d_{90} point and calculate the value of c_v (in m²/year), from the equation.

$$c_v = \frac{0.111\,\bar{H}^2}{t_{90}}$$

3.6.4 *Temperature correction.* If the average laboratory temperature during the test differs by more than ± 2 °C from 20 °C, the derived values of c_v shall be corrected to the 20 °C values by multiplying by the appropriate correction factor obtained from Figure 4.

NOTE   The temperature correction is given here to enable results from tests carried out at different temperatures to be compared. The accuracy of c_v values derived from this test does not justify the use of temperature corrections to correlate with in situ conditions.

3.6.5 *Coefficient of secondary compression*

3.6.5.1 The coefficient of secondary compression, if required, is derived from the laboratory logarithm of time curve as follows.

3.6.5.2 Extend the linear portion of the secondary compression portion of the curve, obtained as described in **3.6.3.2.2**, so that it covers one complete cycle of log time. It may be necessary to prolong the duration of the load increment to establish a linear relationship.

3.6.5.3 Read off the compression gauge readings at the beginning and end of the cycle, e.g. at 1 000 min and 10 000 min, and calculate the difference, δH_s (in mm), between them.

3.6.5.4 Calculate the coefficient of secondary compression, C_{sec} from the equation

$$C_{\text{sec}} = \frac{\delta H_{\text{s}}}{H_0}$$

where

H_0 is the initial height of the specimen.

3.6.5.5 Repeat **3.6.5.2** to **3.6.5.4** for each of the applied loading stages.

3.7 Reporting results

The test report shall affirm that the test was carried out in accordance with clause **3** of BS 1377-5:1990, and shall include the following, in addition to the relevant information listed in clause **9** of BS 1377-1:1990:

a) a statement of the method used, i.e. the determination of one-dimensional consolidation properties in accordance with clause **3** of BS 1377-5:1990;

b) the initial dimensions of the specimen;

c) the initial moisture content, bulk density and dry density;

d) the particle density indicating whether measured or assumed;

e) the initial void ratio and degree of saturation, if required;

f) the swelling pressure, to two significant figures, if applicable;

g) a plot of the voids ratio or the vertical compression percentage against the logarithm of applied pressure for the complete load-unload cycle;

h) plots of compression against time (log time or square root time or both as appropriate), for each load increment, if required;

i) the calculated values of the coefficient of volume compressibility, m_{v} (in m²/MN), and the coefficient of consolidation, c_{v} (in m²/year), to two significant figures, for each load increment, in the form of a table;

j) values of the coefficient of secondary compression, C_{sec}, for each load increment (if required) to two significant figures;

k) the method of time fitting used;

l) the laboratory temperature at which the test was carried out;

m) the location and depth of the test specimen within the original sample.

4 Determination of swelling and collapse characteristics

4.1 General

The three tests described in this clause use the same apparatus and have the same environmental requirements as the one-dimensional consolidation test described in clause **3**.

The tests comprise the following:

a) *Measurement of swelling pressure.* For a soil which has a swelling capability when allowed access to water, the swelling pressure, p_{s}, is the vertical pressure on the specimen in an oedometer ring required to prevent it swelling. The swelling pressure is usually the starting point and finishing point for the series of pressures applied to a soil of this type in a consolidation test.

b) *Measurement of swelling.* This test enables the swelling characteristics of a laterally confined soil specimen to be measured when it is unloaded from the swelling pressure in the presence of water.

c) *Measurement of settlement on saturation.* In this test the amount by which an unsaturated laterally confined specimen settles due to structural collapse on the addition of water is determined.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

4.2 Apparatus

4.2.1 The apparatus required for these tests, and its calibration, is specified in **3.2**. In addition the following are required.

4.2.1.1 *A range of small calibrated weights* for the oedometer beam hanger, to enable pressures upwards from 2 kPa at intervals of 1 kPa to be applied to the specimen.

4.2.1.2 *A flanged disc* of corrosion-reistant metal with flat and parallel faces, of a diameter about 1 mm less than the diameter of the consolidation ring. The upstand above the flange shall be such as to displace a suitable thickness of specimen from the ring to give a specimen height of about 3 mm to 5 mm less than the height of the ring. (For **4.4** only.) [See Figure 1 b).]

4.2.1.3 *Damp cloth and waterproof plastics film* for protecting a non-inundated specimen from drying out.

4.3 Measurement of swelling pressure

4.3.1 *Preparation of specimen.* Prepare the test specimen in the consolidation ring by one of the methods described in **3.3**. If this test is to be followed by a swelling test the additional procedure described in **4.4.1** shall be followed.

4.3.2 *Preparation and assembly of apparatus.* The procedure shall be generally as described in **3.4**. Prepare the porous plates as described in **3.4.1** a) or **3.4.1** c) and then **3.4.1** d) or **3.4.1** e) depending on the type of soil.

Do not add water to the cell at this stage.

4.3.3 *Test procedure*

4.3.3.1 When the specimen is in equilibrium under the small seating load and the compression gauge has been set and its reading recorded, add water to fill the consolidation cell. At the same instant start the timer.

NOTE   An alternative procedure is to allow the specimen to reach equilibrium under a stress equal to the in situ vertical effective stress before adding water to the cell.

4.3.3.2 Observe the compression gauge and, when it indicates that swelling occurs, add weights to the beam hanger to maintain the gauge reading within 0.01 mm of the corrected zero reading. Record the magnitude of each weight added and the corresponding time.

4.3.3.3 The corrected zero reading is the initial gauge reading adjusted by the correction necessary to allow for deformation of the apparatus due to the present load on the beam hanger. Obtain the correction from the calibration curve derived in **3.2.4.2**.

4.3.3.4 Continue to adjust the hanger weight until equilibrium is established with a compression gauge reading within ± 0.01 mm of the relevant corrected zero reading. This procedure may take several hours, and the approach of equilibrium conditions can be seen by plotting a graph of the cumulative weight on the beam hanger against square root of elapsed time at which each adjustment was made.

NOTE   If the test has to be left unattended for any length of time before equilibrium is established, further swelling should be prevented by loading the hanger with excess weights with the beam resting on its support, maintaining the compression gauge at the existing corrected zero reading.

4.3.3.5 When equilibrium is established calculate the pressure, p_s (in kPa), applied to the specimen from the weights on the beam hanger (inluding the initial seating load).

4.3.3.6 Then either increase the pressure to the next convenient pressure in the required sequence for a consolidation test as described in **3.5**, or reduce the pressure to a convenient value for a swelling test as described in **4.4**, (if the specimen was suitably prepared). Do not reset the compression gauge to zero.

4.3.4 *Reporting result.* When equilibrium is established report the pressure on the specimen to two significant figures as the swelling pressure.

Other data as listed in **3.7** shall be reported as appropriate.

4.4 Measurement of swelling

4.4.1 *Preparation of specimen*

4.4.1.1 Prepare the test specimen in the consolidation ring by one of the methods described in **3.3**, except for weighing. The following additional procedure is required.

4.4.1.2 Determine the thickness of the upstand of the flanged disc to 0.01 mm.

4.4.1.3 Place the flanged disc on the flat, glass plate and place the prepared specimen in the consolidation ring, cutting edge downwards, centrally over the disc, with a disc of filter paper interposed.

4.4.1.4 Push the ring steadily downwards without tilting until the cutting edge is firmly in contact with the flange of the disc.

4.4.1.5 Cut off the extruded portion of soil and trim the specimen flat and flush with the upper end of the ring. Remove the flanged disc and filter paper.

4.4.1.6 Weigh the specimen in its ring on the watch glass or tray and determine the mass of the specimen to 0.1 g.

4.4.1.7 From the thickness of the disc and the measured thickness of the ring calculate the specimen height, H_0, in mm.

4.4.2 *Preparation and assembly of apparatus*

4.4.2.1 The procedure shall be as described in **3.4**, but the porous plates shall be air dried after saturation.

4.4.2.2 Mount the ring containing the specimen with the displaced face uppermost and fit the top porous plate centrally inside the ring. Make the necessary adjustments to bring the beam of the loading apparatus to a horizontal position.

4.4.2.3 Secure the compression gauge in position to allow for measurement of swelling over a range at least equal to the thickness of specimen displaced.

4.4.2.4 Do not add water to the cell at this stage.

4.4.3 *Test procedure*

4.4.3.1 Determine the swelling pressure, as described in **4.3.3.1** to **4.3.3.5**.

4.4.3.2 Record the compression gauge reading. Do not reset it to zero.

4.4.3.3 Reduce the pressure on the specimen to a suitable value by removing weights from the beam hanger.

NOTE   Pressures to which the specimen is unloaded may be those given in **3.5.3**, or may be related to the swelling pressure, p_s, in the sequence.

$$p_s', \frac{p_s'}{2}, \frac{p_s'}{4}, \frac{p_s'}{8} \text{ etc.}$$

If other pressures are more appropriate the sequence should normally be related to a constant ratio.

4.4.3.4 Record readings of the compression gauge and plot the readings as described in **3.5.3.4** to **3.5.3.6**.

4.4.3.5 Repeat **4.4.3.3** and **4.4.3.4** for further stages of the sequence of unloading down to the selected minimum pressure. The total height of the specimen shall not be allowed to exceed the height of the ring.

4.4.3.6 Reload the specimen back to the swelling pressure, following the same sequence of pressures in reverse.

4.4.3.7 If required the procedure described in **3.5.2** onwards may then be followed.

4.4.3.8 Drain water from the cell as described in **3.5.3.7**, dismantle, and make final measurements as described in **3.5.4**.

4.4.4 *Calculation and plotting.* The calculations and graphical plots shall be generally as described in **3.6**. Values of m_v and c_v shall be calculated only for the reloading stages.

4.4.5 *Reporting results.* The relationship between voids ratio or swelling and logarithm of pressure for the swelling/reloading cycle shall be plotted in a similar manner to that derived from a consolidation test [see **3.7** g)].

Other data as listed in **3.7** shall be reported as appropriate.

4.5 Measurement of settlement on saturation

4.5.1 *Preparation of specimen.* Prepare the test specimen in the consolidation ring by one of the methods described in **3.3**.

4.5.2 *Preparation and assembly of apparatus.* The procedure shall be as described in **3.4** but the porous plates shall be air dried after saturation.

Do not add water to the cell at this stage.

4.5.3 *Test procedure*

4.5.3.1 Cover the consolidation cell to prevent the specimen drying out, for example by using damp cloth under plastics film.

4.5.3.2 Apply a suitable sequence of pressure to the specimen as described in **3.5.2.1** to **3.5.2.9** but omitting **3.5.2.3**, up to a pressure equal to the in-situ overburden pressure or the selected relevant value.

4.5.3.3 When equilibrium is established under the selected load fill the cell with water so that the specimen is completely submerged, and start the timer.

4.5.3.4 Record readings of the compression gauge at suitable intervals of time while the pressure on the specimen remains constant, until equilibrium is re-established.

4.5.3.5 Carry out further loading stages as described in **3.5.2** and unloading stages as described in **3.5.3** as appropriate, with the specimen remaining saturated. Dismantle as described in **3.5.4**.

4.5.4 *Calculation and plotting.* The calculations and graphical plots shall be as described in **3.6**. On the plot of compression or void ratio against log pressure the decrease in height of the specimen due to saturation shall be indicated by a vertical line at the constant applied pressure.

Calculate the decrease in height on saturation as a percentage of the specimen height under the same pressure immediately before saturation.

4.5.5 *Reporting results.* Test data as listed in **3.7** shall be reported as appropriate.

Clearly indicate the change in void ratio or height due to saturation on the plot of void ratio or compression against log pressure.

Report the corresponding change in height as a percentage of the specimen height immediately before saturation, to the nearest 0.1 %.

5 Determination of permeability by the constant-head method

5.1 General

5.1.1 *Principle.* The permeability of a soil is a measure of its capacity to allow the flow of water through the pore spaces between solid particles. The degree of permeability is determined by applying a hydraulic pressure gradient in a sample of saturated soil and measuring the consequent rate of flow. The coefficient of permeability is expressed as a velocity.

5.1.2 *Type of test.* Laboratory permeability tests on soils described in this Part of BS 1377 are carried out under constant-head conditions. Permeability tests on undisturbed samples using triaxial cell and hydraulic consolidation cell apparatus are described in BS 1377-6:1990.

The test procedure described in this clause covers the determination of the coefficient of permeability using a constant-head permeameter in which the flow of water through the sample is laminar. The volume of water passing through the soil in a known time is measured, and the hydraulic gradient is measured using manometer tubes.

This procedure is suitable for soils having coefficients of permeability in the range 10^{-2} to 10^{-5} m/s.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

5.2 Apparatus (see Figure 6)

5.2.1 *A permeameter cell* consisting of a cylindrical body of transparent acrylic plastics or similar material, held between removable base and top members of corrosion-resistant metal. The internal diameter of the cell body shall be at least 12 times the maximum particle size of the sample of soil to be tested. Cells of 75 mm and 100 mm diameter are generally suitable. A general arrangement is shown in Figure 5.

Essential requirements are as follows.

a) Top and base plates which, when assembled, make a watertight seal with the cell body.

b) A piston which passes through the centre of the top plate and which can be locked in any vertical position by means of a locking collar, which forms a watertight seal.

c) A perforated plate attached to the lower end of the piston, the size and number of perforations being such that they do not restrict the flow enough to affect the permeability results.

d) A similar perforated plate fitted to the baseplate.

e) Water inlet/outlet connections fitted to the top and base plates.

f) An outlet, usually at the base, fitted with a control valve for regulating the rate of flow of water.

NOTE The control valve is placed at the outlet so that the water in the sample is initially under a small pressure. Any air bubbles released as a result of the pressure drop across a flow restriction escape to atmosphere instead of into the sample.

g) A cylindrical body fitted with three or more glands along its vertical length, for connecting to manometer tubes.

5.2.2 *Two discs of wire gauze* or porous material of a diameter equal to the internal diameter of the cell body. Their permeability shall be greater than that of the soil sample to be tested but the apertures shall be small enough to prevent loss of particles from the sample. One disc is placed at each end of the permeameter cell.

5.2.3 *A vertically adjustable reservoir tank* capable of maintaining a constant-head supply of water to the permeameter cell.

5.2.4 *A supply of clean de-aerated water* to the constant-head reservoir.

NOTE If the provision of a sufficient supply of de-aerated water is not practicable, clean tap-water may be substituted. The presence of bubbles of air in the voids of a laboratory soil sample can appreciably reduce the rate of flow of water in comparison with the in situ condition.

5.2.5 *A discharge reservoir with overflow* to maintain a constant level.

5.2.6 *A set of manometer tubes of glass* or transparent plastics, all of the same internal diameter. They shall be mounted so that their lower ends are about level with the permeameter cell and their upper ends level with the constant-head reservoir surface when at its highest position. Each manometer is connected to a gland on the permeameter cell by flexible tubing with watertight joints.

5.2.7 *A pinch cock* on the flexible tubing adjacent to each gland.

5.2.8 *Filter material* of a suitable grading for placing adjacent to the perforated plates at each end of the permeameter.

NOTE The grading of the filter material depends on the particle size distribution of the test sample. The filter material grading limits should lie between four times the 15 % passing size and four times the 85 % passing size of the test sample. The material should be well graded between those limits.

5.2.9 *Measuring cylinders* of 100 mL, 500 mL and 1 000 mL capacity.

5.2.10 *A large plastics funnel.*

5.2.11 *A scoop,* for placing soil in the funnel.

5.2.12 *A scoop* small enough to fit inside the permeameter cell.

5.2.13 *A flat-ended tamping rod,* long enough to reach to the bottom of the permeameter and about 10 mm diameter.

5.2.14 *A calibrated thermometer* reading to 0.5 °C.

5.2.15 *A stopclock* readable to 1 s.

5.2.16 *A balance* readable to 1 g.

5.2.17 *A steel rule* graduated to 0.5 mm.

5.2.18 *Internal calipers.*

5.3 Selection and preparation of sample

5.3.1 Obtain a representative sample from the original soil sample as described in **7.7** of BS 1377-1:1990. The size of sample shall provide enough material for a test sample or samples as specified in **5.3.3** or in **5.3.6** after removal of material for particle size, particle density and moisture content tests as described in **5.3.2** and **5.3.4**.

NOTE   This test is not suitable for soils containing more than 10 % by mass of material passing the 63 μm sieve in the sample prepared for test.

5.3.2 If required carry out a sieve analysis on a representative portion of the sample, in accordance with **9.2.4** of BS 1377-2:1990.

5.3.3 From the representative portion to be used for the test, remove any particles that are larger than one-twelfth of the diameter of the permeameter cell. The resulting sample shall not be dried. The volume of the sample after removing the oversize material shall be about twice that required to fill the permeameter cell.

5.3.4 Take two or more representative samples from the prepared material for the determination of moisture content and particle density, in accordance with **3.2**, and **8.2** or **8.3**, of BS 1377-2:1990.

5.3.5 Weigh the remainder of the prepared sample to 1 g (m_1).

5.3.6 If a number of tests are to be performed at different densities to establish a relationship between permeability and voids ratio, prepare several samples (one for each determination) as described in **5.3.3**, **5.3.4** and **5.3.5**.

5.4 Preparation and assembly

5.4.1 *Initial preparation of apparatus*

5.4.1.1 Measure the internal diameter of the permeameter cell at several places and record the average diameter to the nearest 1 mm (D).

5.4.1.2 Measure the distance between each manometer gland and the next along the same vertical line, to the nearest 1 mm (x_1, x_2, etc.). (See Figure 5).

5.4.1.3 Ensure that the permeameter cell, gauze or porous discs, perforated plates, glands and joints are clean and free from blockage.

5.4.1.4 Assemble the base plate, with perforated base, to the permeameter cell body.

5.4.1.5 Place the graded filter material in the bottom of the cell to a depth of about 50 mm. Level the surface and place a wire gauze or porous disc on top.

5.4.2 *Placing the test sample.* Place the soil to be tested into the permeameter in such a way as to give a homogeneous deposit at the required density or voids ratio. The final height : diameter ratio of the test sample shall be not less than 2 : 1.

Placing and compaction shall be by one of the following methods.

NOTE 1   Dry pouring of the sample is not included in the placing procedure because removal of air bubbles after inundation can be difficult.

a) *Hand tamping*

1) Place the soil in the permeameter in at least four layers, each of which is of a thickness about equal to half the diameter. Place the first layer on the wire gauze or porous disc, and place subsequent layers on the previously levelled soil layer.

2) Avoid segregation of soil particles when placing, such as by using a small scoop or a container fitted with a hinged base which can be controlled by a length of wire. Tamp each layer with a controlled number of standard blows with the tamping rod, ensuring that the blows are evenly distributed. Level the surface of each layer, and lightly scarify it, before adding the next.

NOTE 2   Damp sandy soils should always be tamped. The loose density obtained by pouring only is usually unstable when flooded with water.

b) *Placing under water*

1) Thoroughly mix the prepared soil with de-aerated water and place the mixture in a suitable funnel fitted with a bung and length of flexible tubing. Support the funnel so that the tubing reaches to about 15 mm above the bottom wire gauze or porous disc.

2) Connect the control valve on the base of the permeameter to the de-aerated water supply and allow de-aerated water to enter the cell to a height of about 15 mm above the wire gauze or porous disc material. Take care that no air bubbles are trapped.

3) Release the soil and water mixture into the cell, raising the funnel so that the end of the tubing is just at the water surface, which shall be maintained at about 15 mm above the surface of the placed material by admitting more water through the base valve.

4) Continue until the cell is filled to the required level. This will result in a saturated sample of uniform density in a loose condition. If this condition is to be maintained, do not disturb the soil or jolt the cell. If higher density is required, tamp or vibrate the material during placement.

5.4.3 *Assembly of apparatus.* After placing the test sample by either **5.4.2** a) or **5.4.2** b) assemble the permeameter cell as follows.

a) Place the upper wire gauze or porous disc on top of the prepared sample. Avoid any disturbance of the sample if it is of a low density.

b) Place the graded filter material on top of the disc to a depth of at least 50 mm.

c) Release the piston in the top plate and withdraw it to its fullest extent.

d) Fit the top plate to the permeameter cell and tighten it down into position.

e) Lower the piston carefully and bed the perforated plate on to the filter material. Hold the piston down firmly and tighten the locking collar in this position.

5.4.4 *Measurements*

5.4.4.1 Determine the mean height of the test sample, L_1 (in mm), by measuring, to 1 mm, the distances between the upper and lower wire gauzes or porous discs at three or more locations around the perimeter.

5.4.4.2 Dry the soil left over and weigh it to the nearest 1 g (m_2), so that the dry mass of soil used in the test sample can be obtained by difference.

5.4.5 *Saturation.* Fill the permeameter cell with water and saturate the sample as follows. [If placing procedure **5.4.2** b) has been followed, start from step d)].

a) Connect the control valve on the base of the permeameter to the de-aerated water supply. Open the top connection and the air bleed to atmosphere, and close the connections to the manometer tubes.

b) Allow de-aerated water (see note to **5.2.4**) to enter the cell and slowly percolate upwards through the sample until it emerges first from the air bleed, which is then closed, and then from the top connection.

NOTE   The water level should rise slowly enough not to cause disturbance of the sample, or piping.

c) Check whether the perforated plate is in firm contact with the filter material, and if necessary re-seat it and re-tighten the locking collar, as in **5.4.3** e). Measure the height of the sample again, as described in **5.4.4.1** and record the average measurement, *L* (in mm), as the height of sample as tested.

d) Close the control valve. Connect the de-aerated water supply to the permeameter top connection, and connect the control valve at the base to the discharge reservoir, without entrapping air.

e) Set the inlet reservoir at a level a little above the top of the permeameter cell and open the supply valve. Open the manometer tube pinch cocks one by one and ensure that no air is trapped in the flexible tubing as water flows into the manometer tubes. The water in all tubes shall reach the level of the reservoir surface.

f) The permeameter cell is now ready for test under the normal condition of downward flow.

g) If a test with upward flow is required, e.g. for investigating piping effects, fit the control valve, connected to the discharge reservoir, to the top of the cell and connect the de-aerated water supply to the base.

5.5 Test procedure for downward flow of water through the sample

5.5.1 Adjust the height of the inlet reservoir to a suitable level with regard to the hydraulic gradient to be imposed on the sample.

NOTE   An initial hydraulic gradient of about 0.2 is often suitable, although a slightly higher value may be more appropriate for finer-grained or more dense soil samples

5.5.2 Open the control valve at the base to produce flow through the sample under a hydraulic gradient appreciably less than unity. Allow the water levels in the manometer tubes to become stable before starting test measurements.

5.5.3 Place a measuring cylinder of suitable capacity under the outlet from the discharge reservoir and simultaneously start the timer.

5.5.4 Measure the quantity of water collected in the cylinder during a given interval of time. Alternatively record the time required to fill the cylinder up to a given volume.

5.5.5 Record the levels of water in the manometer tubes. If the three (or more) levels indicate significant non-uniformity of the hydraulic gradient remove and replace the sample.

5.5.6 Record the temperature of the water in the discharge reservoir.

5.5.7 Repeat **5.5.2** to **5.5.6** at least four more times, or until consistent readings are obtained.

5.5.8 If a series of tests at different hydraulic gradients is required, repeat **5.5.2** to **5.5.7** under progressively increasing hydraulic gradients by opening the control valve further, or by increasing the height of the inlet reservoir as necessary. The hydraulic gradients shall cover the range of interest within the range of laminar flow.

NOTE   Laminar flow is indicated when the relationship between rate of flow and hydraulic gradient (see **5.6.4**) is linear. Deviation from the straight line at high gradients indicates turbulent flow.

5.5.9 If a relationship between coefficient of permeability and voids ratio over a range of voids ratio is required, repeat the whole test from **5.3.3** onwards using different portions of the same soil, but placed and compacted to different densities.

5.6 Calculation and plotting

5.6.1 Calculate the rate of flow, q_1, q_2 etc (in mL/s), during the period of each observation of flow from the equation.

$$q_1 = \frac{Q_1}{t} \text{ etc.}$$

where

Q_1, Q_2, (in mL) etc is the volume of water collected from the outlet reservoir during each time period t (in s).

Calculate the average rate of flow, q, for the set of readings at one hydraulic gradient.

5.6.2 Calculate the hydraulic gradient, i, between the uppermost and lowest manometer gland points from the equation

$$i = \frac{h}{y}$$

where

h is the difference between the two manometer levels (in mm) (see Figure 6);

y is the difference between the corresponding gland points (in mm).

NOTE   The intermediate manometer point is (or points are) used to provide a check on the uniformity of the hydraulic gradient between the outer points. If there are three gland points, $y = x_1 + x_2$. (See **5.4.1.2** and Figure 6).

5.6.3 Calculate the coefficient of permeability, k (in m/s), for one set of readings from the equation

$$k = \left(\frac{q}{i}\right)\left(\frac{R_t}{A}\right)$$

where

A is the area of cross section of the sample (in mm^2);

R_t is the temperature correction factor for the viscosity of water, derived from Figure 4, to standardize the permeability to 20 °C.

5.6.4 If tests have been carried out at different hydraulic gradients, plot the calculated values of rate of flow, q, against hydraulic gradient, i.

5.6.5 Draw the straight line of best fit through the plotted points and determine its slope which is

$$\frac{\Delta q}{\Delta i}$$

5.6.6 When a range of hydraulic gradients is used the coefficient of permeability of the sample may be calculated from the equation

$$k = \left(\frac{\Delta q}{\Delta i}\right)\left(\frac{R_t}{A}\right)$$

5.6.7 Calculate the dry mass, m_3 (in g), of the initial sample from the equation

$$m_3 = m_1\left(\frac{100}{100 + w}\right)$$

where

m_1 is the mass of the initial sample determined as in **5.3.5**, (in g);

w is the moisture content (in %).

5.6.8 Calculate the dry density, ρ_d (in Mg/m^3), of the test sample from the equation

$$\rho_d = \frac{4000\,(m_3 - m_2)}{\Pi\,D^2\,L}$$

where

m_2 is the mass of dry soil remaining after setting up the test sample determined as described in **5.4.4.2**, (in g);

D is the sample diameter (in mm);

L is the overall length of sample (in mm).

5.6.9 Calculate the void ratio, e, of the test sample if required from the equation

$$e = \frac{\rho_s}{\rho_d} - 1$$

where

ρ_s is the particle density (in Mg/m^3).

5.6.10 If the coefficient of permeability is determined at several densities, plot the calculated values of k as ordinates, to a logarithmic scale, against density or voids ratio, e, as abscissae, to a linear scale.

5.7 Reporting results

The test report shall affirm that the test was carried out in accordance with clause **5** of BS 1377-5:1990 and shall include the following, in addition to the relevant information listed in clause **9** of BS 1377-1:1990.

a) a statement of the method used, i.e. the constant-head permeability test in accordance with clause **5** of BS 1377-5:1990 and whether or not de-aerated water was used;

b) the particle size distribution curve for the original sample, if appropriate;

c) the proportion and size of oversize material removed before preparing the test sample;

d) the method of placing and compacting the test sample;

e) the dimensions of the permeameter;

f) the dry density;

g) the voids ratio, if required;

h) the coefficient of permeability, k (in m/s), to two significant figures, for the condition of laminar flow, corrected to 20 °C;

i) the coefficient of permeability for other conditions, if relevant;

j) a plot of coefficient of permeability, k(log scale) against density or voids ratio, e, if appropriate.

6 Determination of dispersibility

6.1 General

6.1.1 *Principle.* Certain fine-grained soils that are highly erodible are referred to as dispersive soils. Dispersive soils cannot be identified by means of conventional soil classification tests, but the qualitative tests described below enable them to be recognized. However, it does not follow that soils classified by these tests as non-dispersive are not susceptible to erosion in some circumstances.

These methods are not applicable to soils with a clay content of less than 10 % and with a plasticity index less than or equal to 4.

6.1.2 *Types of test.* Three tests are described as follows.

a) The pinhole test, in which the flow of water under a high hydraulic gradient through a cavity in the soil is reproduced.

b) The crumb test, in which the behaviour of crumbs of soil in a static dilute sodium hydroxide solution is observed.

c) The dispersion method (double hydrometer test), in which the extent of natural dispersion of clay particles is compared with that obtained with the use of standard chemical and mechanical dispersion.

NOTE   Other factors which are significant in relation to soil erodibility are as follows:
   a) swelling potential. (A test for measuring swelling pressure is described in **4.3**);
   b) clay mineralogy;
   c) chemical composition of dissolved cations in the pore water.

6.2 Pinhole method

6.2.1 *General.* In this test distilled water is caused to flow through a 1 mm diameter hole formed in a specimen of recompacted clay under a controlled hydraulic head. The resistance to erosion of the clay is judged visually by the presence or absence of turbidity in the water which emerges and from measurements of rates of flow and the final hole diameter.

NOTE   The specified test measures the dispersibility of clay in pure water, which is considered to be a basic property of the soil. Clays are considered to be more likely to disperse in pure water than in water containing dissolved salts.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

6.2.2 *Apparatus*

6.2.2.1 *Pinhole test apparatus,* as shown in Figure 7(a), consisting essentially of the following.

a) A rigid cylindrical body of plastics or corrosion-resistant metal, about 100 mm long.

b) Corrosion-resistant end plates, one fitted with water inlet and standpipe connections, the other with an outlet connection.

c) O-ring seals to make a watertight fit between the body and end plates.

d) Three discs, of appropriate diameter, of wire mesh having apertures of 1.18 mm.

e) Nipple of plastics or corrosion-resistant metal, in the form of a truncated cone 13 mm long with a hole of 1.5 mm diameter [Figure 7(b)].

6.2.2.2 *A standpipe tube of glass,* or transparent plastics, of about 3 mm internal diameter and about 1 200 mm long.

6.2.2.3 *A scale for the standpipe tube* marked in millimetres.

6.2.2.4 *A hypodermic needle,* or similar, about 100 mm long, with an external diameter of 1.00 mm ± 0.1 mm.

6.2.2.5 *A burette stand* for supporting the pinhole apparatus, standpipe and scale.

6.2.2.6 *Graduated glass measuring cylinders,* 10 mL, 25 mL, 50 mL (at least two of each).

6.2.2.7 *A stopclock,* or timer, readable to 1 s.

6.2.2.8 *Pea gravel,* consisting of single-size particles of about 5 mm.

6.2.2.9 *A constant-head supply tank,* adjustable between 50 mm and about 1 100 mm above the centreline of the pinhole apparatus.

6.2.2.10 *A supply of distilled water* for the constant-head tank.

6.2.2.11 *A test sieve,* with 2 mm aperture.

6.2.2.12 *A flat ended tamping rod,* or a spring loaded hand tamper.

6.2.2.13 *Apparatus for determination of moisture content.* (See **3.2** of BS 1377-2:1990.)

6.2.2.14 *Apparatus for determining the liquid and plastic limits of the soil.*
(See clauses **4** and **5** of BS 1377-2:1990).

6.2.2.15 *Apparatus for the determination of the moisture/density relationship of the soil.*
(See **3.3** of BS 1377-4:1990).

6.2.3 *Sample preparation and assembly*

6.2.3.1 Do not allow the sample to dry before testing.

NOTE   For many soils the results are affected by drying, especially if the soil after rewetting is not left long enough to mature in the compacted state. Maturing without compaction does not generally achieve the same results.

6.2.3.2 Take a sample of about 150 g of the soil to be tested, at its natural moisture content. Take a second similar sample for the determination of the liquid limit and plastic limit, to be carried out as described in clauses **4** and **5** of BS 1377-2:1990.

6.2.3.3 Remove any particles retained on a 2 mm test sieve from the test sample.

6.2.3.4 Increase or decrease the moisture content to bring the sample to about its plastic limit. Use the thread-rolling procedure described in clause **5** of BS 1377-2:1990 as an indication of the required consistency.

6.2.3.5 Determine the resulting moisture content of the sample as described in **3.2** of BS 1377-2:1990.

6.2.3.6 Fit the outlet end plate to the body of the pinhole apparatus, making a watertight joint.

6.2.3.7 Support the body of the apparatus vertically and place pea gravel to a depth of approximately 50 mm in the bottom of the apparatus, taking care not to block the outlet hole. Level the surface of the gravel and place two discs of wire mesh on top.

6.2.3.8 Compact the test sample into the apparatus in five equal layers, to give a total sample depth of 38 ± 2 mm. Apply an equal compactive effort to each layer such that the resulting dry density of the sample is about 95 % of the dry density corresponding to the optimum moisture content, determined as described in **3.3** of BS 1377-4:1990.

6.2.3.9 Level the surface of the sample and push the nipple into the soil at the centre, using finger pressure, until the upper face is flush with the sample surface.

6.2.3.10 Insert the needle through the nipple and through the compacted sample to form a continuous hole.

6.2.3.11 Place a disc of wire mesh over the sample followed by pea gravel to the top of the body of the apparatus.

6.2.3.12 Fit the top plate to the body, making a watertight joint.

6.2.3.13 Support the apparatus in the burette stand with its cylindrical axis horizontal.

6.2.3.14 Set the constant-head reservoir of the distilled water supply so that the water level can be maintained at a height of 50 ± 5 mm above the centre-line of the apparatus. Close the inlet valve.

6.2.3.15 Connect the inlet on the pinhole apparatus to the supply from the reservoir, and connect the standpipe connection to the standpipe, supported by the burette stand. Place a glass measuring cylinder on a sheet of white paper under the outlet pipe.

6.2.4 *Test procedure*

6.2.4.1 Open the inlet valve to allow water from the reservoir to enter the apparatus and to flow through the sample until a steady rate of flow is obtained with $H = 50 \pm 5$ mm [see Figure 7(a)]. If there is no flow, disconnect the apparatus, reform the hole, and resume from **6.2.3.10**.

6.2.4.2 Within 5 min measure the rate of flow, q (in mL/s), by observing the time required to fill the 10 mL measuring cylinder.

6.2.4.3 Observe and record the appearance, including colour, of the water collected in the measuring cylinder. If it is clear, record that fact.

6.2.4.4 Observe and record the clarity and colour of the collected water by looking through the side of the cylinder against a sheet of white paper, and vertically through the water. If individual particles are discernible, record that fact, together with an indication of the turbidity of the water.

A suitable form for recording the test data is shown as form 5.E in Appendix A.

6.2.4.5 If the collected water is substantially clear after running for about 5 min, continue at **6.2.4.8**.

6.2.4.6 If the water is not substantially clear and the rate of flow has increased to between 1.0 and 1.4 mL/s the test is complete. Proceed to **6.2.4.16**.

NOTE   The limiting rates of flow imposed by the apparatus itself are given approximately as follows:

Inlet head H	Limiting rate of flow q_L
mm	mL/s
50	1.2 to 1.3
180	about 2.7
380	about 3.7
1 020	5 or more

6.2.4.7 If the rate of flow in **6.2.4.6** is less than 1.0 mL/s, continue the test for a further 5 min. If the water is then clear or is only slightly turbid, and the rate of flow is between 0.4 mL/s and 0.8 mL/s, continue at **6.2.4.8**. If the water is distinctly turbid stop the test and proceed to **6.2.4.16**.

6.2.4.8 Increase the head of water, H, to 180 ± 5 mm, and allow the flow to continue for 5 min. Repeat **6.2.4.3** and **6.2.4.4**.

6.2.4.9 If the collected water continues to be clear, or has only a slight trace of turbidity, and the rate of flow is between 0.8 mL/S and 1.4 mL/s, record the fact and proceed to **6.2.4.11**.

6.2.4.10 If the water is not clear and the rate of flow increases to about the limiting value (see note 3 to **6.2.4.6**), stop the test. Proceed to **6.2.4.16**.

6.2.4.11 Increase the head of water, *H,* to 380 ± 5 mm, and allow the flow to continue for 5 min. Repeat **6.2.4.3** and **6.2.4.4**.

6.2.4.12 If the water continues to be clear, or has only a slight trace of turbidity, and the rate of flow is between 1.0 mL/s and 1.8 mL/s, record the fact and continue at **6.2.4.14**.

6.2.4.13 If the water is not clear, or the rate of flow has increased to between 1.4 mL/s and 2.7 mL/s (see note 3 to **6.2.4.6**), stop the test. Proceed to **6.2.4.16**.

6.2.4.14 Increase the head of water, *H,* to 1 020 ± 5 mm and allow the flow to continue for 5 min. Repeat **6.2.4.3** and **6.2.4.4**.

6.2.4.15 Observe and record the rate of flow and whether the collected water continues to be clear, or the extent of turbidity, then stop the test.

6.2.4.16 When the flow tests are completed disconnect the distilled water supply, dismantle the apparatus and remove the specimen intact from the body of the apparatus.

6.2.4.17 Cut the sample in half through its axis.

6.2.4.18 Examine the hole and estimate its diameter, *d* (in mm), by comparison with the needle, or measure its diameter to 0.5 mm using a steel rule. Sketch the configuration of the hole, with measurements, if it is not of uniform diameter.

(**6.2.4.3** to **6.2.4.15** are illustrated as a flow chart in Figure 8).

6.2.5 *Analysis of test data.*(see Form 5.E of Appendix A).

The following test data shall be used for classifying the soil:

a) the appearance of the collected water;

b) the rate of flow of water;

c) the final diameter of the hole in the specimen.

Classify the soil as dispersive soil (category D1 or D2) or non-dispersive soil (categories ND1 to ND4) in accordance with Table 2. (These categories are also indicated in Figure 8).

The results from the test at 50 mm head of water shall be used as the principal means of differentiating dispersive from non-dispersive soils as defined by this test.

6.2.6 *Reporting results.* The test report shall affirm that the test was carried out in accordance with **6.2** of BS 1377-5:1990, and shall include the following, in addition to the relevant information listed in clause **9** of BS 1377-1:1990.

a) a statement of the method used, i.e. the pinhole test in accordance with **6.2** of BS 1377-5:1990;

b) identification details, type and source of the soil sample;

c) the soil description, and whether any coarse particles were removed for the test;

d) the liquid limit, plastic limit and moisture content of the test sample;

e) the density and dry density to which the sample was compacted for test;

f) the rates of flow, duration of flow, and appearance of the collected water, during each hydraulic head applied;

g) the diameter and configuration of the hole after test;

h) whether the soil is classified according to this test as dispersive (categories D1, D2); moderately to slightly dispersive (categories ND4, ND3); or non-dispersive (categories ND2, ND1).

6.3 Crumb method

6.3.1 *General.* In this method, dispersive clay soils are identified by observing the behaviour of a few crumbs of soil placed in a dilute solution of sodium hydroxide.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

6.3.2 *Apparatus and reagent*

6.3.2.1 *A 100 mL glass beaker*

6.3.2.2 *A* 0.001 M *solution of sodium hydroxide* (1 milli-equivalent per litre). Dissolve 0.04g of anhydrous sodium hydroxide in distilled water to make 1 L of solution.

NOTE   For many soils, distilled water provides as good an indicator as the sodium hydroxide solution. The soil is dispersive if a test with distilled water indicates dispersion, but many dispersive clays do not show a dispersive reaction in distilled water even though they do in the solution.

6.3.3 *Procedure*

6.3.3.1 Prepare a few crumbs, each about 6 mm to 10 mm diameter, from representative portions of the soil at the natural moisture content.

6.3.3.2 Drop the crumbs into a beaker about one-third full of the sodium hydroxide solution.

6.3.3.3 Observe the reaction after allowing to stand for 5 min to 10 min.

Table 2 — Classification of soils from pinhole test data

Dispersive classification	Head	Test time for given head	Final flow rate through specimen	Cloudiness of flow at end of test		Hole size after test
				from side	from top	
	mm	min	mL/s			mm
D1	50	5	1.0 to 1.4	dark	very dark	≥ 2.0
D2	50	10	1.0 to 1.4	moderately dark	dark	> 1.5
ND4	50	10	0.8 to 1.0	slightly dark	moderately dark	≤ 1.5
ND3	180	5	1.4 to 2.7	barely visible	slightly dark	≥ 1.5
	380	5	1.8 to 3.2			
ND2	1 020	5	> 3.0	clear	barely visible	< 1.5
ND1	1 020	5	≤ 3.0	perfectly clear	perfectly clear	1.0
Extracted, with permission, from the annual book of ASTM standards. Copyright American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.						

6.3.4 *Observations.* Observe the behaviour of the crumbs in accordance with the following guidelines.

Grade 1: No reaction. Crumbs may slake or run out to form a shallow heap on the bottom of the beaker, but there is no sign of cloudiness caused by colloids in suspension.

Grade 2: Slight reaction. A very slight cloudiness can be seen in the water at the surface of a crumb.

Grade 3: Moderate reaction. There is an easily recognizable cloud of colloids in suspension, usually spreading out in thin streaks at the bottom of the beaker.

Grade 4: Strong reaction. A colloidal cloud covers most of the bottom of the beaker, usually as a thin skin. In extreme cases all the water becomes cloudy.

Grades 1 and 2 represent a non-dispersive reaction, and grades 3 and 4 a dispersive reaction.

6.3.5 *Reporting results.* The test report shall affirm that the test was carried out in accordance with **6.3** of BS 1377-5:1990, and shall include the following, in addition to the relevant information listed in clause **9** of BS 1377-1:1990.

a) A statement of the method used, i.e. the crumb test in accordance with **6.3** of BS 1377-5:1990.

b) Identification details, type and source of the soil sample.

c) Whether the soil is classified according to this test as non-dispersive, and the relevant group from **6.3.4**.

d) Details of the reagent used.

6.4 Dispersion method

6.4.1 *General.* In this method a hydrometer sedimentation test (see **9.5** of BS 1377-2:1990) is carried out on two identical portions of the soil sample, one with and one without the use of a dispersant solution and mechanical shaking or stirring. The ratio between the measured clay fractions provides a measure of the dispersibility of the clay.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

6.4.2 *Apparatus.* The apparatus shall be the same as specified in **9.5.2** of BS 1377-2:1990, except as follows;

a) four 100 mL glass measuring cylinders (see **9.5.2.2**) are required;

b) because chemical pretreatment is not necessary, **9.5.2.13**, **9.5.2.14**, **9.5.2.20** and **9.5.2.21** are not required.

6.4.2.1 Sodium hexametaphosphate solution as specified in **9.5.3.2** of BS 1377-2:1990.

6.4.2.2 Apparatus shall be calibrated as specified in **9.5.4** of BS 1377-2:1990.

6.4.3 *Sample preparation.* Prepare two test specimens of equal mass from the fraction of the undried soil passing the 2 mm sieve, as described in **7.3** and **7.4.5** of BS 1377-1:1990, and in **9.5.5.2** to **9.5.5.4** of BS 1377-2:1990.

Designate the specimens as follows:

Specimen A: To be tested without chemical and mechanical dispersion.

Specimen B: To be tested by the procedure described in **9.5** of BS 1377-2:1990.

6.4.4 *Test procedure*

6.4.4.1 *Specimen A.* The procedure shall be as follows.

a) Add 100 mL of distilled water to the soil in the conical flask and agitate sufficiently to bring the soil into suspension. Do not shake vigorously or use mechanical shaking.

b) Transfer the suspension from the bottle or flask to the 63 μm test sieve placed on the receiver, and wash the soil in the sieve using a jet of distilled water from the wash bottle. The amount of water used during this operation shall not exceed 500 mL.

c) Transfer the suspension that has passed through the sieve to the 1 000 mL measuring cylinder and make up to exactly 1 000 mL with distilled water. (This suspension is used for the sedimentation analysis as described in **9.5.6.3** of BS 1377-2:1990).

d) Transfer the material retained on the 63 μm test sieve to an evaporating dish and dry in the oven maintained at 105 °C to 110 °C.

e) When cool, resieve this material on the sieves down to 63 μm size, as described in **9.3.4** of BS 1377-2:1990. Weigh the material retained on each sieve.

f) Add any material passing the 63 μm sieve to the measuring cylinder.

g) Insert the rubber bung into the cylinder containing the soil suspension, shake it and place it in the constant temperature bath so that it is immersed in water up to the 1 000 mL graduation mark.

h) Fill the second 1 000 mL cylinder with distilled water to the 1 000 mL mark. Insert the rubber bung and place this cylinder in the constant temperature bath alongside the first.

i) Proceed with the hydrometer sedimentation test as described in **9.5.6.3.3** to **9.5.6.3.9** of BS 1377-2:1990 except that the cylinder containing distilled water replaces the cylinder containing dispersant solution in **9.5.6.3.3**, **9.5.6.3.7** and **9.5.6.3.9**.

6.4.4.2 *Specimen B.* Carry out the test as described in **9.5.6.2** and **9.5.6.3** of BS 1377-2:1990.

6.4.5 *Calculations and plotting*

6.4.5.1 Calculate the particle sizes and percentages as described in **9.5.7** of BS 1377-2:1990. (The value of R_o relates to the hydrometer reading in distilled water for specimen A, and in the dispersant solution for specimen B).

6.4.5.2 Draw the resulting particle size distribution curves on a semi-logarithmic chart (see form 2.N of Appendix A of BS 1377-2:1990).

6.4.5.3 Determine the percentage of clay-size particles from the intercept of each curve with the 0.002 mm ordinate, denoted by p_A and p_B (see Figure 9).

6.4.5.4 Calculate the percentage dispersion, equal to

$$\left(\frac{p_A}{p_B}\right) 100$$

where

p_A is the measured percentage of clay without dispersant; and

p_B is the measured percentage of clay with dispersant.

6.4.6 *Reporting results.* The test report shall affirm that the test was carried out in accordance with **6.4** of BS 1377-5:1990, and shall include the following, in addition to the relevant information listed in clause **9** of BS 1377-1:1990.

a) a statement of the method used, i.e. the dispersion method (double hydrometer test) in accordance with **6.4** of BS 1377-5:1990;

b) identification details, type and source of the soil sample;

c) particle size distribution curves obtained with and without dispersion;

d) the percentage dispersion, to the nearest whole number, as determined by this test.

7 Determination of frost heave

7.1 General

The purpose of this test is to determine the frost heave of a soil when compacted into cylindrical specimens at a predetermined moisture content and density. The test may also be carried out on cylindrical specimens of undisturbed soil.

The procedure is lengthy, and is described in BS 812-124, to which reference is made.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

7.2 Preparation of test specimens

7.2.1 *Preparation of soil for test on compacted soil.* The minimum mass of soil required for the complete test is the sum of the following. The mass of each portion will depend on the type of soil.

a) The mass required for determining the particle size distribution, as specified in Table 3 of **9.2.3** of BS 1377-2:1990.

b) The mass required for determining the plasticity index of the fines fraction, if appropriate, as specified in **4.2** of BS 1377-2:1990.

c) The mass required for determining the optimum moisture content and maximum dry density, as specified in **3.2** of BS 1377-4:1990.

NOTE   If the moisture content and density at which test specimens are to be prepared have already been specified this portion is not required.

d) A mass which will provide 20 kg of soil passing a 37.5 mm test sieve, for preparation of a trial specimen and the test specimens.

Subdivide the original sample by a method which ensures that each portion is a representative sample of the whole.

7.2.2 *Preparation of specimens of compacted soil.* Prepare test specimens in accordance with clause **9** of BS 812-124:1989.

7.2.3 *Preparation of undisturbed specimens.* Prepare test specimens of undisturbed soil from undisturbed samples taken in sampling tubes or as block samples. Preparation of undisturbed specimens shall be in accordance with **8.3** or **8.5** of BS 1377-1:1990.
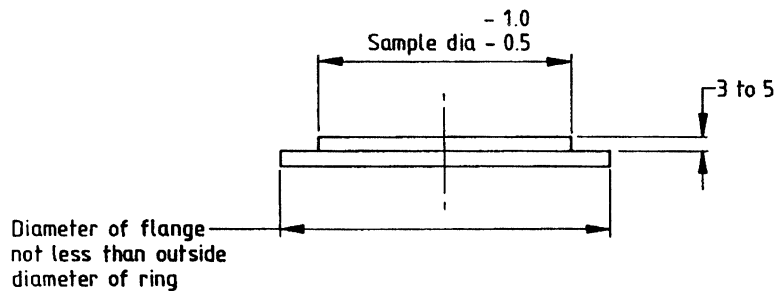
7.3 Test procedure

Carry out the test in accordance with BS 812-124.

NOTE   The precision data given in Table 2 of BS 812-124:1989, are based on aggregates, and should not be applied to soils.
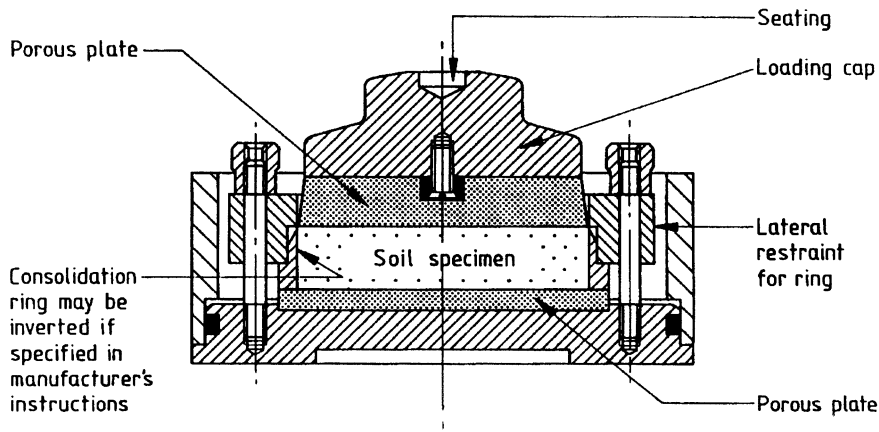
(a) Section of a typical consolidation cell

(b) Flanged disc

All dimensions are in millimetres.
See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

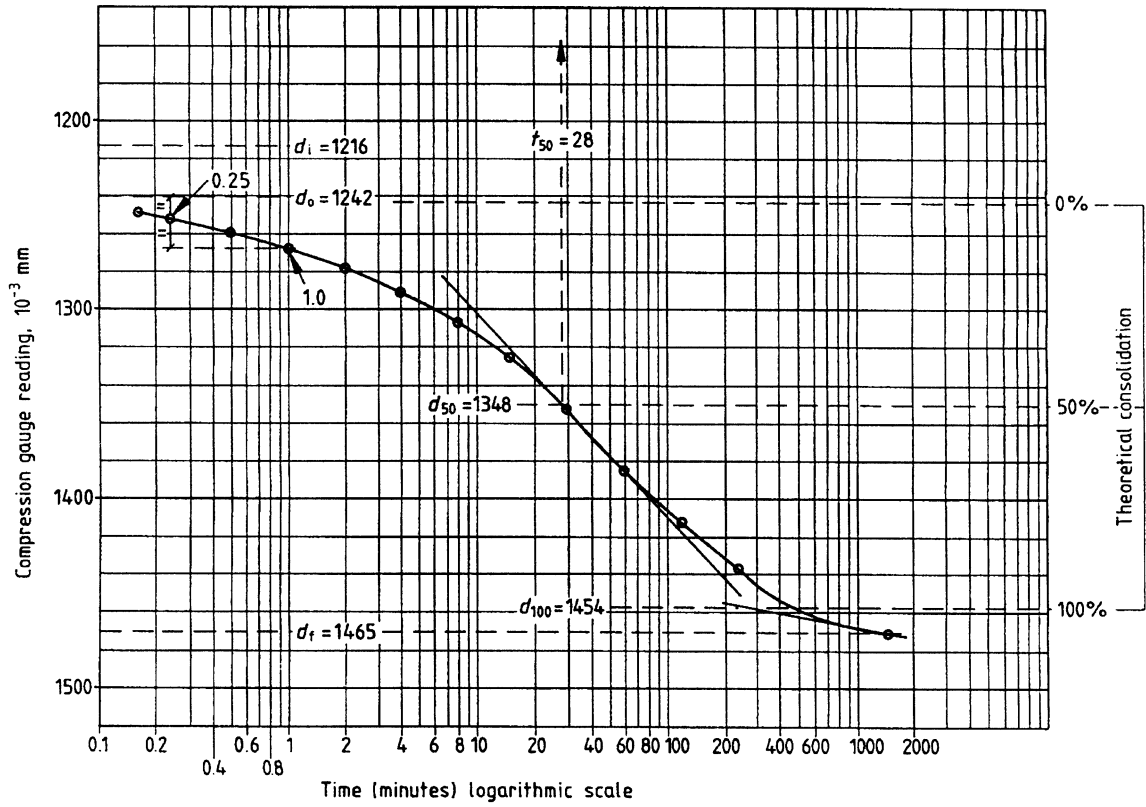**Figure 1 — Section of a typical consolidation cell**

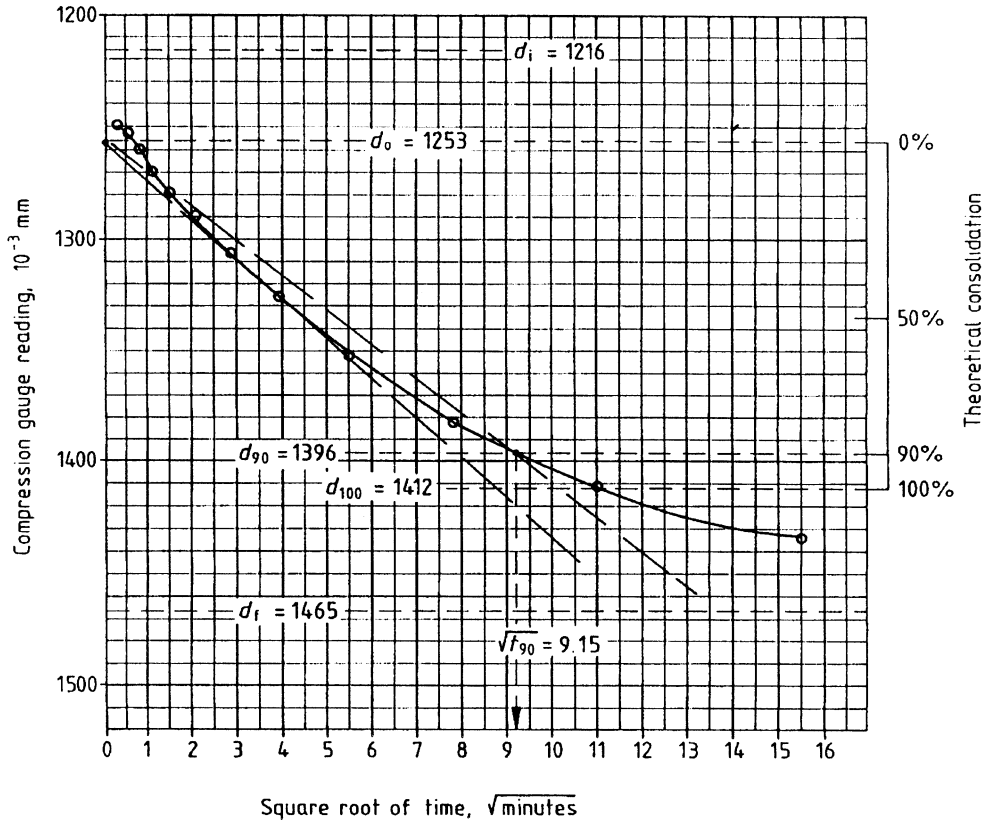Figure 2 — Laboratory consolidation curve: logarithm of time fitting method

Figure 3 — Laboratory consolidation curve: square root of time fitting method
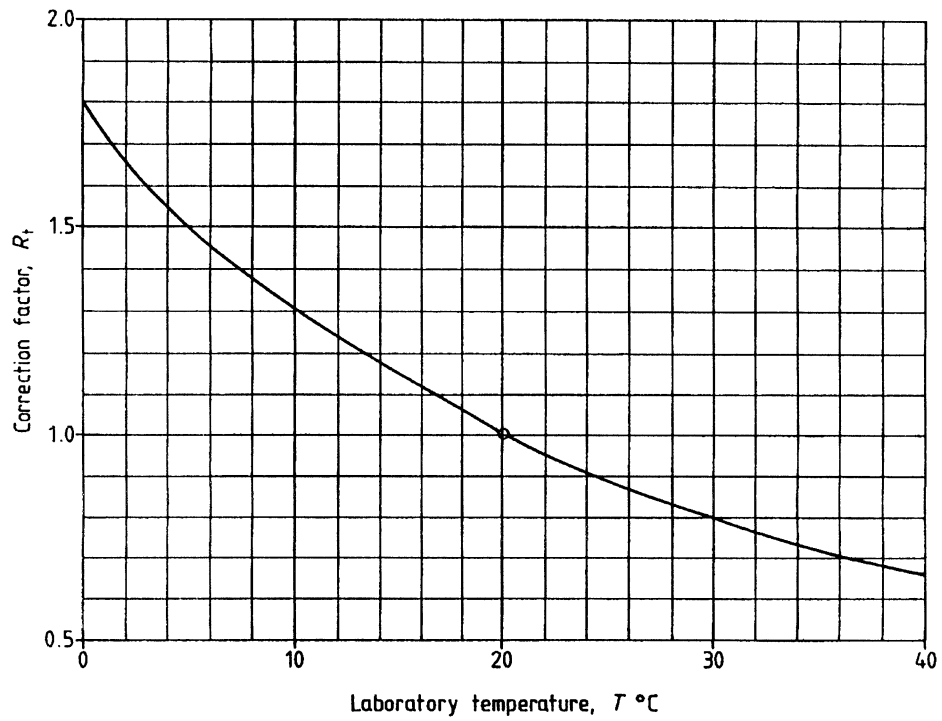
Figure 4 — Temperature correction curve for coefficient of consolidation and permeability

Manometer tubes

Bleed screw

O-ring seal

Upper perforated plate

Manometer connection gland x 3

x1

x2

Tie rod

Lower perforated plate

O-ring seal

Piston

Locking nut

Top connection

O-ring seals

Graded filter material

Wire gauze or porous disc

Acrylic plastics cell body

L

Sample

D

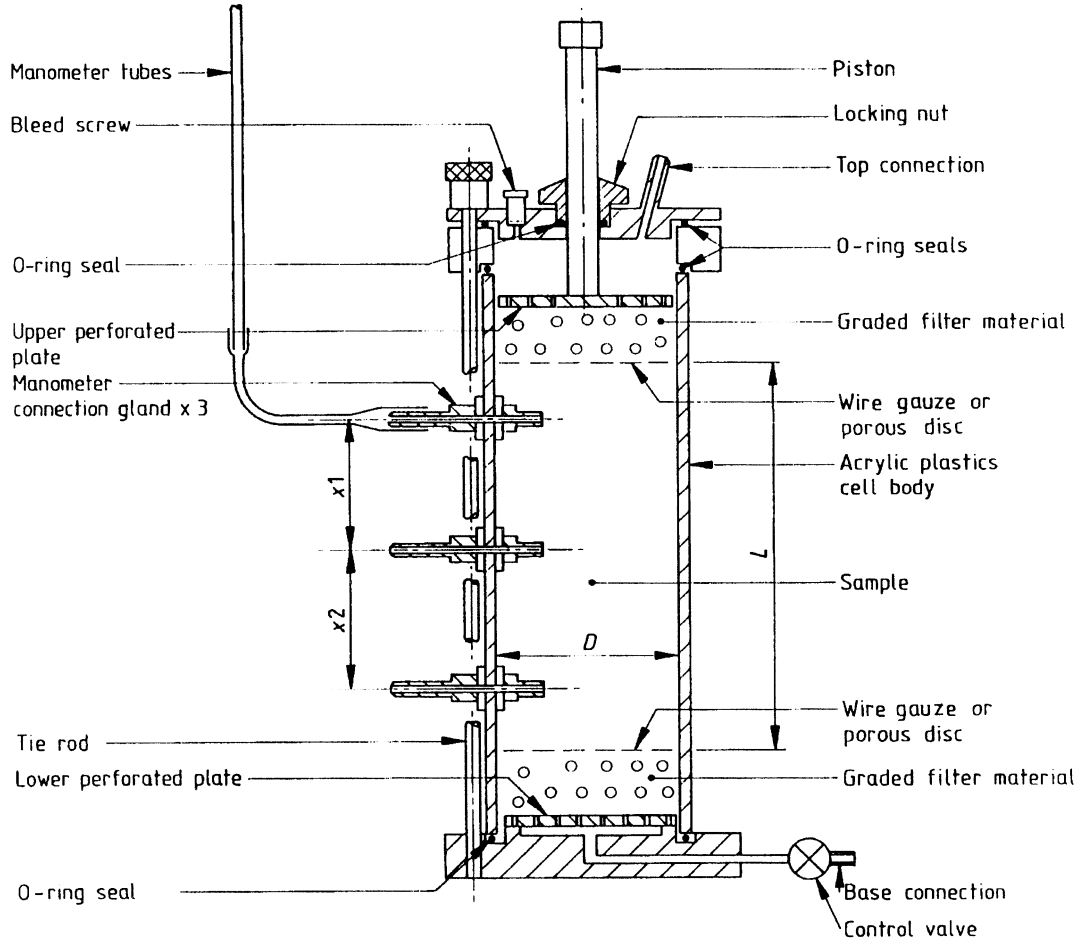Wire gauze or porous disc

Graded filter material

Base connection

Control valve

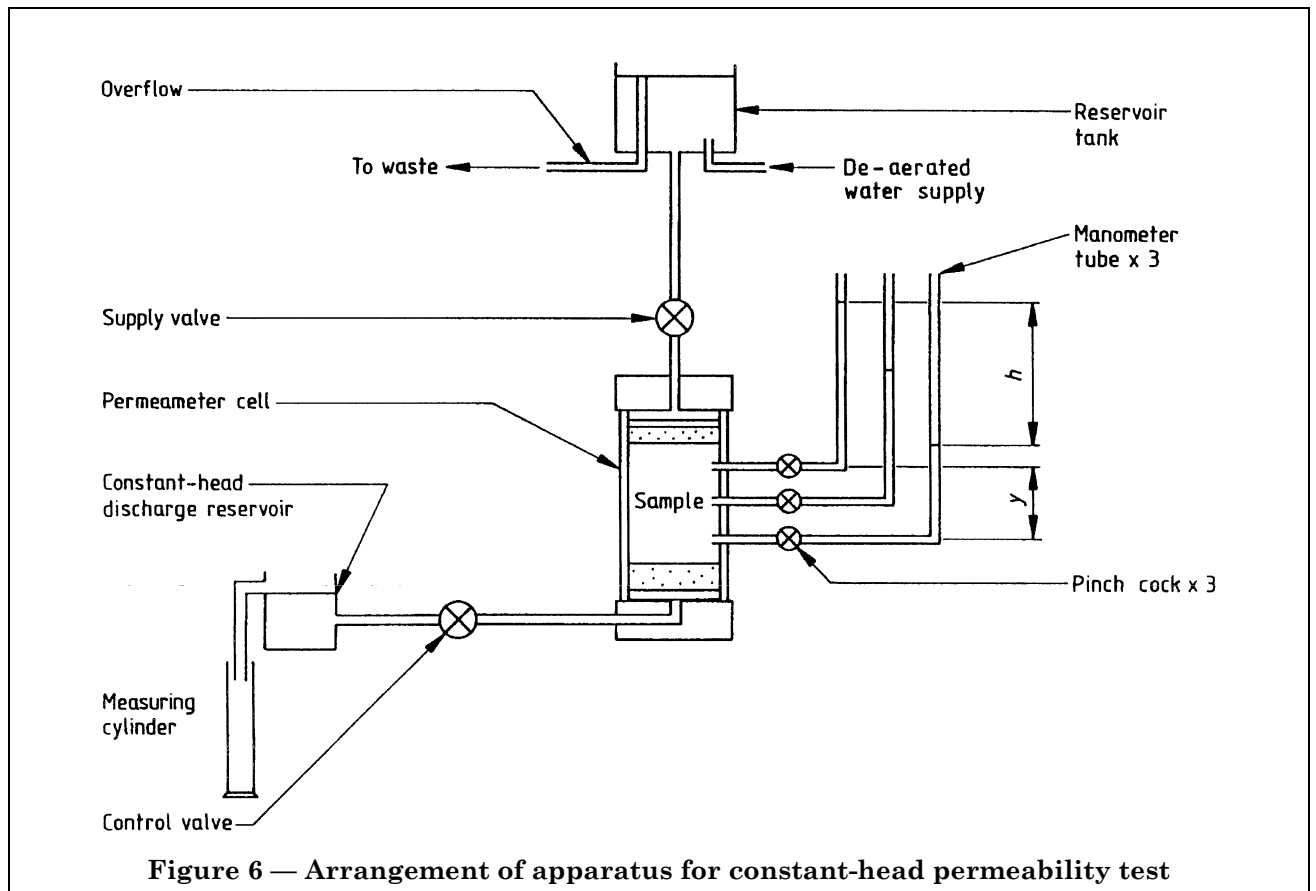**Figure 5 — Section of a typical constant-head permeability cell**
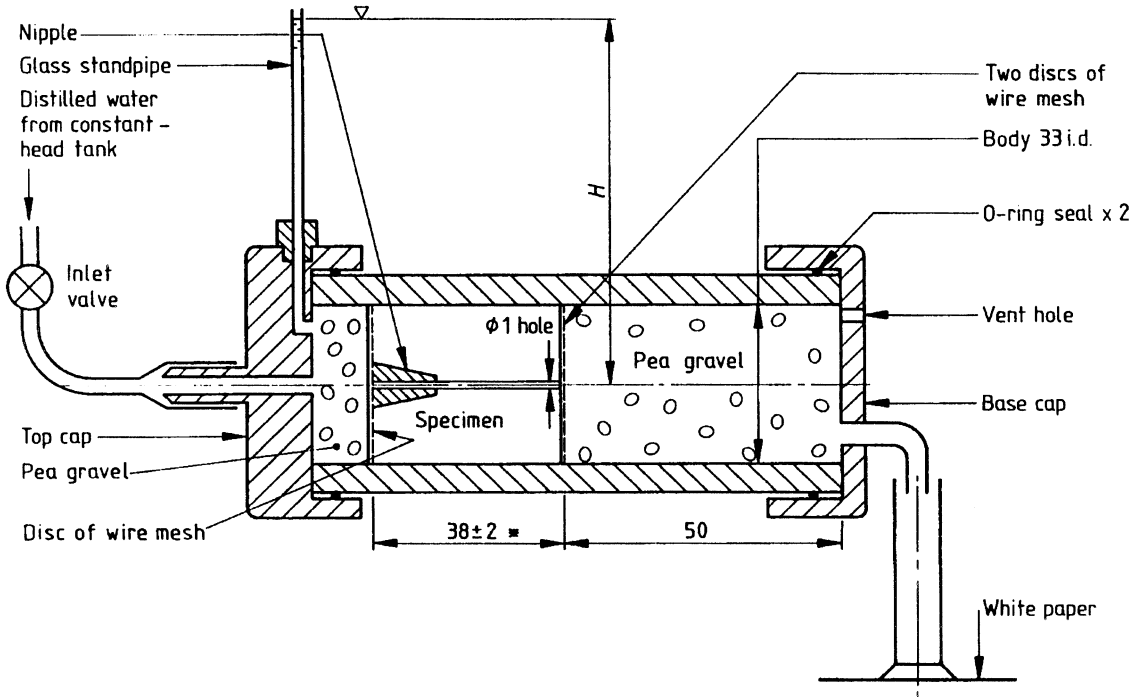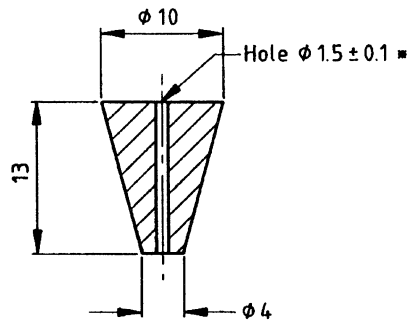
Figure 6 — Arrangement of apparatus for constant-head permeability test

(a) Arrangement for test

(b) Details of nipple

All dimensions are in millimetres.
*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 7 — Section of pinhole test apparatus
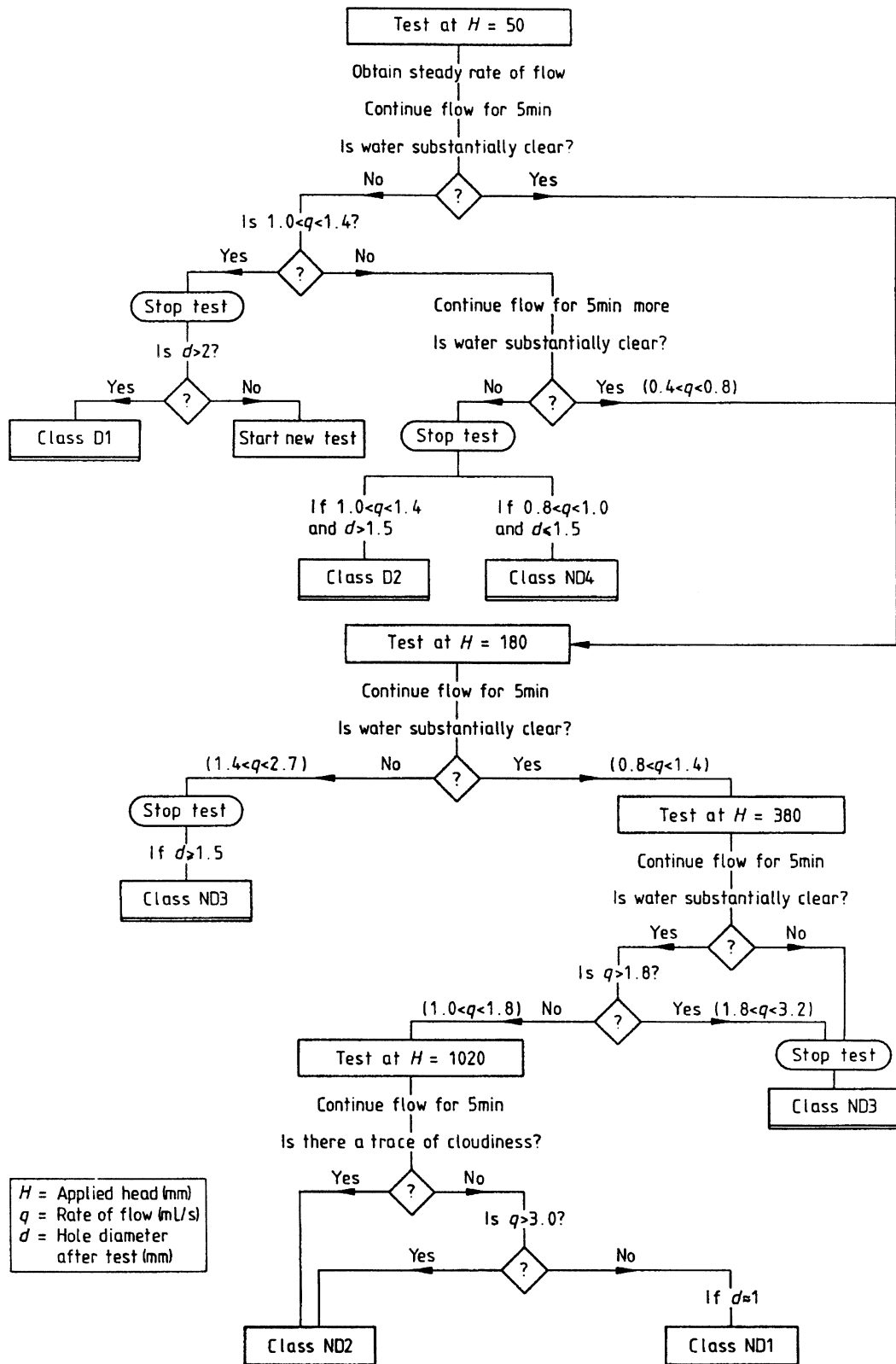
Figure 8 — Flowchart for pinhole test procedure
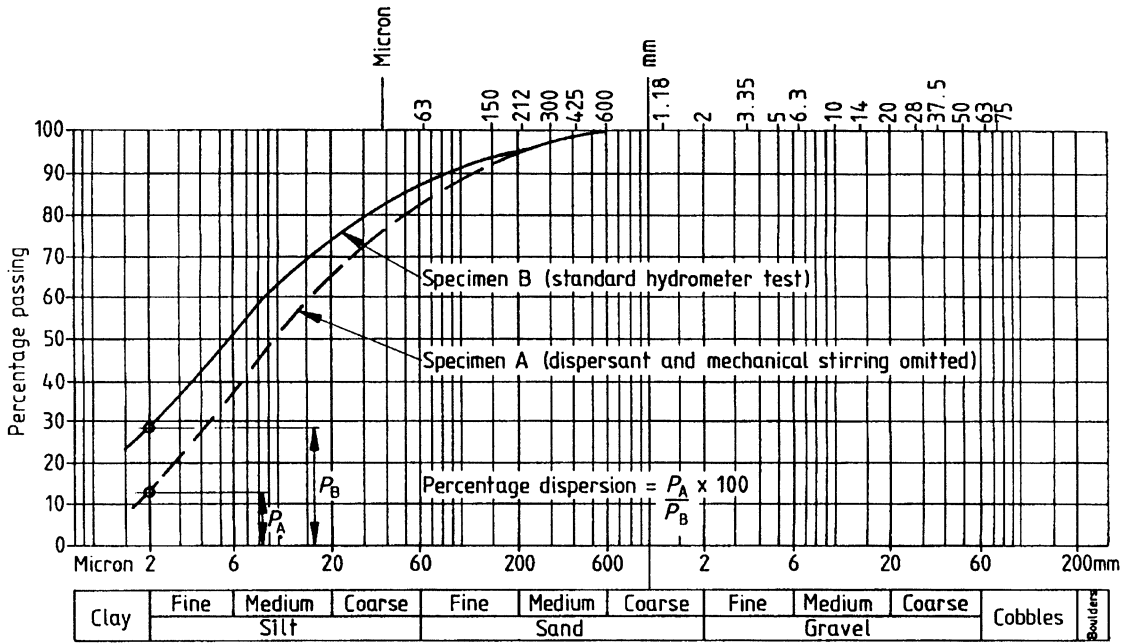
Figure 9 — Typical results from dispersion (double hydrometer) test

Appendix A Typical test data and calculation forms

5.A. Consolidation test — specimen details

5.B Consolidation test — settlement readings

5.C Consolidation test — log pressure/voids ratio curve

5.D Consolidation test — calculations

5.E Dispersibility — pinhole test

These forms are given as examples only; other suitable forms may be used.

Consolidation test — specimen details			
Location	Job ref.		
	Borehole/ Pit no.		
Soil description	Sample no.		
	Depth		m
	Date		

| Test method	BS 1377 : Part 5 : 1990			
Cell no. Ring no.		Particle density measured/assumed* _____ Mg/m³		
DIMENSIONS	Initial specimen	Overall change	Final specimen	Specimen preparation method
Diameter D mm				
Area A mm²				
Height H mm	H_o			
Volume V cm³				

WEIGHINGS		Initial specimen (a)	(b)	Final specimen (c)
Wet soil + ring + tray	g			
Dry soil + ring + tray	g			
Ring + tray	g			
Wet soil	g	m_o	m_o	
Dry soil	g		m_d	m_d
Water	g			
Moisture content (measured)	%			
Moisture content (from trimmings)	%	w_o		
Density	Mg/m³			
Dry density	Mg/m³			
Voids ratio		e_o		
Degree of saturation	%	S_o		
Height of solids	H_s mm			

*Delete as appropriate (a) Using moisture content from trimmings (b) Using data from (a) and (c) (c) Data from specimen after test	

	Operator	Checked	Approved

Form 5.A.

Consolidation test — settlement readings			
Location	Job ref.		
	Borehole/Pit no.		
Soil description	Sample no.		
	Depth		m
	Date		

Test method	BS 1377 : Part 5 : 1990			
Machine no.	Specimen diameter	mm	Height	mm
Cell no.	Lever ratio	:1	Area	mm²
Ring no.	1 kg/lb * on hanger gives pressure of			kPa

LOADING/UNLOADING *

Increment no./date started														
Load kg/lb */pressure kPa														
Mean daily temperature °C														
Elapsed time				t	Clock time	Gauge reading	Cumulative compression mm ΔH	Clock time	Gauge reading	Cumulative compression mm ΔH	Clock time	Gauge reading	Cumulative compression mm ΔH	
h	m	s	t min											
Cumulative correction y														
Net cumulative compression $(\Delta H - y)$														
							Operator	Checked	Approved					

* Delete as appropriate

Form 5.B.

Consolidation test — log pressure/voids ratio curve			
Location	Job ref.		
	Borehole/ Pit no.		
Soil description	Sample no.		
	Depth		m
	Date		

Test method	BS 1377 : Part 5 : 1990

Voids ratio

Applied pressure kPa
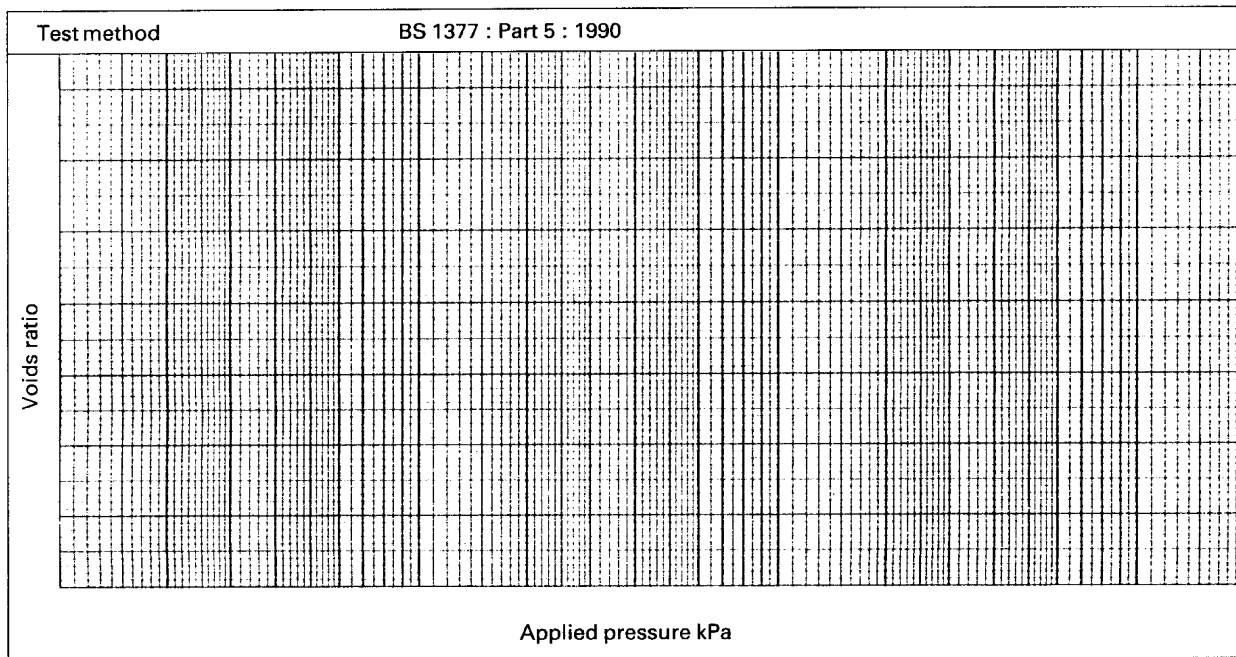
SPECIMEN INITIALLY			
Diameter	mm	Density	Mg/m^3
Height	mm	Moisture content	%
Voids ratio		Dry density	Mg/m^3
Saturation	%	Particle density measured/assumed	Mg/m^3
Depth below surface			m
Swelling pressure			kPa
REMARKS			

Pressure stage kPa	Laboratory coefficients of	
	Compressibility m^2/MN	Consolidation m^2/year

	Operator	Checked	Approved

Form 5.C.

Consolidation test — calculations				
Location		Job ref.		
		Borehole/ Pit no.		
Soil description		Sample no.		
		Depth		m
		Date		
Test method	BS 1377 : Part 5 : 1990			
Machine no.	Specimen diameter	mm	Height H_o	mm
Cell no.	Height of solids H_s	mm		
Ring no.	Initial voids ratio e_o			

VOIDS RATIO					COMPRESSIBILITY					COEFFICIENT OF CONSOLIDATION			
Increment no.	Pressure P	Cumulative compression $(\Delta H - y)$	Consolidated height $H = H_0 - (\Delta H - y)$	Voids ratio $e = \dfrac{H - H_s}{H_s}$	Incremental		$m_v = \dfrac{\delta H}{H_1} \cdot \dfrac{1000}{\delta p}$	t_{50}	$\bar{H} = \frac{1}{2}(H_1 + H_2)$	$c_v =$			
					height change δH	pressure change δp				$\dfrac{0.026\bar{H}^2}{t_{50}}$	$\dfrac{0.111\bar{H}^2}{t_{90}}$		
	kPa	mm	mm		mm	kPa	m²/MN	min	mm	m²/year	m²/year		
0		0		0	0	0	—	—	—	—	—		

	Operator	Checked	Approved

Form 5.D.
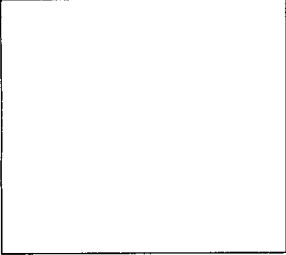
Dispersibility — pinhole test			
Location		Job ref.	
		Borehole/ Pit no.	
Soil description		Sample no.	
		Depth	m
		Date	
Test method	BS 1377 : Part 5 : 1990		

INITIAL SAMPLE

Coarse particles removed: max size	mm
mass g	% by dry mass

AFTER TEST

Moisture content	%
Hole diameter	mm

Sketch

Preparation method		Curing time	
		Density	Mg/m³
Moisture content %	Dry density Mg/m³	Dry density	Mg/m³

Clock time	Hydraulic head H mm	Rate of flow			Colour from side				From top completely clear	Particles falling			Remarks
		Vol. mL	time sec	q mL/s *	dark *	slight to medium *	barely visible *	completely clear *	*	none *	few *	many *	
* Tick as appropriate										Dispersion category			

	Operator	Checked	Approved

Form 5.E.

Publications referred to

Normative reference

BS 812, *Testing aggregates.*

BS 812-124, *Method for determination of frost heave.*

BS 1377, *Methods of test for soils for civil engineering purposes.*

BS 1377-1, *General requirements and sample preparation.*

BS 1377-2, *Classification tests.*

BS 1377-4, *Compaction-related tests.*

BS 1377-6, *Consolidation and permeability tests on hydraulic cells and with pore pressure measurement.*

BS 5930, *Code of practice for site investigations.*

ASTM D4647-87, *Standard test method for identification and classification of dispersive clay soils by the pinhole test.*

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