British Standard

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1990

Incorporating
Amendment No. 1

Methods of test for

Soils for civil engineering purposes —

Part 8: Shear strength tests (effective stress)

Committees responsible for this British Standard

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Association of Consulting Engineers
British Civil Engineering Test Equipment Manufacturers' Association
County Surveyors' Society
Department of the Environment (Building Research Establishment)
Department of the Environment (Property Services Agency)
Department of Transport
Department of Transport (Transport and Road Research Laboratory)
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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BS 1377:1975 which has now been withdrawn is replaced by the following Parts of BS 1377:1990: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.

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 to iv, pages 1 to 30, 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

1.1 General

This Part of BS 1377 specifies procedures for the determination of the effective shear strength parameters for specimens of saturated soil which have been subjected to isotropic consolidation and then sheared in compression, under a constant confining pressure, by increasing the axial strain. The tests apply to specimens in the form of right cylinders of nominal diameters usually from 38 mm to about 100 mm and of a height approximately equal to twice the diameter.

Reference is made to BS 1377-1 for general requirements that are relevant to all Parts of this standard, and for methods of 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.

1.2 Definitions

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

1.2.1
deviator stress ($\sigma_1 - \sigma_3$)

the difference between the major and minor principal stresses, i.e. the principal stress difference in a triaxial test

1.2.2
strain (ϵ) (cumulative strain)

the change in dimension, expressed as a ratio or a percentage, of the initial reference dimension

1.2.3
cell pressure

the pressure of the cell fluid which applies isotropic stress to the specimen. In axial compression tests, it is the total minor principal stress, denoted by σ_3

1.2.4
pore pressure (u)

the pressure of the water in the voids between solid particles as measured in the triaxial test

1.2.5
back pressure (u_b)

pressure applied directly to the pore fluid in the specimen voids

1.2.6
effective confining pressure

the difference between the cell pressure and the pore water pressure

1.2.7
effective consolidation pressure

the difference between the cell pressure and the back pressure against which the pore fluid drains during the consolidation stage, i.e. $\sigma_3 - u_b$

1.2.8
failure

criteria for the stress condition at failure are as follows:

a) maximum deviator stress, i.e. maximum principal stress difference, denoted by $(\sigma_1 - \sigma_3)_f$;

b) maximum effective principal stress ratio ($\sigma_1' : \sigma_3'$);

c) when shearing continues at constant pore pressure (undrained) or with no change in volume (drained), in both cases at constant shear stress.

1.2.9
shear strength

the shear stress on the failure plane at failure (τ_f), i.e. the maximum shear resistance

1.2.10
mohr circle of effective stress at failure

the Mohr circle representing the state of effective stress at failure, the diameter defined by points representing the major and minor effective principal stress at failure

1.2.11
effective shear strength parameters

the slope and intercept of the Mohr-Coulomb effective stress envelope drawn to a set of Mohr circles of effective stress at failure

1.2.12
angle of shear resistance in terms of effective stress (ϕ')

the slope of the Mohr-Coulomb effective stress envelope (See note to **1.2.13**.)

1.2.13
cohesion intercept in terms of effective stress (c')

the intercept of the Mohr-Coulomb effective stress envelope

NOTE The symbols ϕ' and c' are collectively referred to as the effective shear strength parameters.

1.2.14
pore pressure coefficients A and B

changes in total stresses applied to a specimen when no drainage is permitted produces changes in the pore pressure in accordance with the following equation:

$$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$$

where

Δu is the change in pore pressure;

$\Delta\sigma_3$ is the change in total minor principal stress;

$(\Delta\sigma_1 - \Delta\sigma_3)$ is the change in deviator stress;

A and B are the pore pressure coefficients.

NOTE In a saturated soil (except very stiff soils) the value of B is theoretically equal to 1.

1.2.15
pore pressure coefficient at failure (A_f)

the value of the coefficient A at failure

1.2.16
stress path parameters (s', t')

the stress path parameters (in terms of effective stress) can be established from the following equations:

$$s' = \tfrac{1}{2}(\sigma_1' + \sigma_3')$$

$$t' = \tfrac{1}{2}(\sigma_1 - \sigma_3)$$

2 Test criteria

2.1 General

2.1.1 *Compression test.* In this Part of BS 1377, two methods of carrying out the compression test are given, which are as follows.

a) The consolidated-undrained triaxial compression test with measurement of pore pressure.

This test gives the undrained shear strength of a specimen subjected to a known initial effective stress, and the pore pressure changes during shear from which the pore pressure coefficient A can be derived. From a set of tests the effective shear strength parameters at failure, c' and ϕ', can be derived.

b) The consolidated-drained triaxial compression test with measurement of volume change.

This test gives the drained shear strength, and volume change characteristics during shear, of a specimen from which the pore water is allowed to drain freely. From a set of tests the drained effective shear strength parameters at failure, c' and ϕ', can be derived.

For many soils other than heavily-overconsolidated clays, the parameters c' and ϕ', determined from the two types of test, can be considered to be identical for most practical purposes, and are not differentiated in this standard.

Both types of test are carried out in three stages:

1) saturation (clause **5**);
2) consolidation (clause **6**);
3) compression (clause **7** or **8**).

The first two stages saturate the specimen and bring it to the desired state of effective stress for the compression test, and are common to both types of test. The compression stage of the consolidated-undrained test is described in clause **7**, and that of the consolidated-drained test in clause **8**.

The procedures described relate to strain-controlled apparatus for compression in a mechanical load frame, and a detachable triaxial cell. Alternatively, hydraulic triaxial cells may be used, provided that the essential principles are maintained (in which case the procedures may differ in detail).

Preparation and setting up of test specimens are covered in clause **4**.

2.1.2 *Type of drainage.* Drainage takes place from one end of the specimen, or from both ends, depending on the connections to the back pressure system (see **3.3**). When it is necessary to reduce the testing time for specimens of very low permeability, filter paper side drains (see item h) of **3.2**) may be fitted to the cylindrical surface of the specimen. This allows drainage to take place simultaneously from the radial boundary, and from one end or both ends.

2.1.3 *Effective consolidation pressure.* Determination of effective strength parameters usually requires tests on a set of similar specimens consolidated over a range of effective stresses related to the vertical effective stress (σ_v') on the sample of soil in-situ. For a set of three specimens, effective consolidation pressures of

$$\tfrac{1}{2}\sigma_v',\ \sigma_v',\ 2\sigma_v'$$

are often suitable.

NOTE With compacted soils, effective consolidation pressures should be related to the estimated maximum effective stress in the field (σ_v'), and multiples of ½, 1 and 2 times σ_v' are usually appropriate.

2.2 Test conditions

The selected test method (see items a) and b) of **2.1.1**) and the following test conditions shall be specified before starting a series of tests:

a) size of test specimens;
b) number of specimens to be tested as a set;
c) type of drainage;
d) correction to be applied for side drains, if used;
e) method of saturation, or whether saturation may be omitted;
f) effective cell confining pressures;
g) criterion for failure, which shall be selected from the three criteria defined in **1.2.8**.

2.3 Requirements of BS 1377-1

The requirements of BS 1377-1, where appropriate, shall apply to the methods of test described in this Part of BS 1377.

2.4 Environment and safety

These tests shall be carried out in a laboratory in which the temperature is maintained constant within ± 2 °C, in compliance with **6.1** of BS 1377-1:1990. All apparatus shall be protected from direct sunlight, from local sources of heat and from draughts.

HAZARD WARNING. Users of the equipment specified for this Part of BS 1377 should be conversant with regulations for pressure vessels. In particular, triaxial cells and ancillary equipment should not be used at pressures above their safe working pressures.

3 Apparatus

3.1 *Apparatus for preparation of test specimens*

3.1.1 *Undisturbed specimens.* Apparatus for the preparation of undisturbed test specimens shall be as described in **8.2.1** to **8.2.4** of BS 1377-1:1990.

3.1.2 *Compacted specimens.* Apparatus for the preparation of disturbed samples of soil, and for making test specimens by compaction or remoulding, shall be as described in **7.2** of BS 1377-1:1990.

3.1.3 *General apparatus.* The following items are required, as appropriate to the method of preparation and the size of the test specimen:

a) balances, of sufficient capacity to determine the mass of the test specimen to an accuracy of 0.03 %.

b) equipment for the determination of moisture content, as described in **3.2.2** of BS 1377-2:1990.

3.2 *Triaxial cell and accessories*

Details of the triaxial cell and its immediate accessories shall be as follows.

a) *Triaxial cell*, of dimensions appropriate to the size of the test specimen, suitable for use with de-aired water at the internal working pressures required to perform the test. (See note 1.) A gas shall not be used for pressurizing the cell.

NOTE 1 De-aired tap water as specified in **5.2** of BS 1377-1:1990 is normally used as the cell fluid. Distilled or de-ionized water should not be used because of their corrosive effects on certain types of seals.

The main features of the cell are shown diagrammatically in Figure 1, and shall be as follows.

1) Cell top plate of corrosion-resistant material and fitted with an air bleed plug and close-fitting piston guide bushing.

2) Loading piston for applying axial compressive force to the specimen. Lateral bending of the piston during a test shall be negligible. Friction between the piston or seal and its bushing shall be small enough to allow the piston to slide freely under its own weight when the cell is empty. (See note 2.) The clearance between the piston and its bushing or seal shall minimize leakage from the cell (see note 3).

NOTE 2 The piston should be perfectly clean and lightly oiled.

NOTE 3 Friction in the bushing, and leakage of cell fluid past the piston, can be reduced by introducing a layer of castor oil into the cell to cover the cell fluid.

3) Cylindrical cell body, which shall be removable for inserting the specimen, and which shall be adequately sealed to the top plate and base plate (see note 4).

NOTE 4 The cylinder should be made of a transparent material, or fitted with viewing ports, so that the specimen can be observed during the test.

4) Cell base of corrosion-resistant rigid material, incorporating connection ports as shown in Figure 1.

Each port shall be fitted with a valve, or a blanking plug if a valve is not required for the test. The ports are connected as follows:

i) from the base pedestal to the pore pressure measuring device (designated as the pore pressure valve);

ii) from the top cap drainage line to the back pressure system (designated as the back pressure valve);

iii) from the cell chamber to the cell pressurizing system (designated as the cell pressure valve);

iv) a second connection from the base pedestal (designated as the base drainage valve) (see note 5);

NOTE 5 A cell fitted with two base pedestal valves is preferred for effective stress triaxial tests. A cell with a single base pedestal value can be used but this will require some amendments to the procedure. If this type of cell is used the fact should be reported.

v) from the pore pressure measuring device mounting block to the flushing system (designated as the flushing system valve).

The base pedestal shall have a plane horizontal circular surface of a diameter equal to that of specimen. The cylindrical sides shall be smooth and free from scratches.

5) Specimen top cap of light weight impermeable corrosion-resistant material, sufficiently rigid that its deformation under load is negligible compared with that of the specimen. The cap shall be perforated by a drainage hole which can be connected to the back pressure inlet in the cell base by a length of flexible tubing of not more than 2.5 mm internal diameter. The tubing shall be impermeable to water and shall have an expansion coefficient due to internal pressure not exceeding 0.001 mL/m length for every 1 kPa increase in pressure. The cylindrical surface of the cap shall be smooth and free from scratches. A self-aligning seating shall be provided between the cap and the loading piston. (See note 6.)

NOTE 6 A central conical recess with a half-angle of 60° to accommodate a steel ball or the hemispherical end of the piston has been found to be satisfactory.

b) *On-off valves*, which shall be capable of withstanding the maximum working pressure without leakage. They shall produce negligible volume displacement during operation. (See note 7.)

NOTE 7 Ball valves with polytetrafluoroethylene (PTFE) seals have been found to comply with this requirement.

c) *Tubular membrane*, of high-density latex or similar impermeable material to enclose the specimen and provide protection against leakage from the cell fluid. The unstretched internal diameter shall be not less than 90 % of the specimen diameter nor greater than the specimen diameter. The length shall be 50 mm greater than the specimen length. The membrane thickness shall not exceed 1 % of the specimen diameter. (See note 8.)

NOTE 8 Membranes of natural latex rubber are generally used. For specimens up to 50 mm diameter a thickness of 0.2 mm is suitable. For larger specimens a greater thickness is used. Two or more membranes separated by rubber grease may be fitted where there is danger of puncturing by angular particles, or for tests of long duration.

An unused leak-free membrane shall be used for every test. The membrane shall be soaked in de-aired water overnight before use.

d) *Four rubber 0-rings*, for sealing the membrane on to the top cap and base pedestal. Two shall be fitted at each end. The 0-rings shall be of an unstretched diameter of between 80 % and 90 % of the specimen diameter. They shall be free from flaws and necking when stretched.

e) *Membrane stretcher*, to suit the size of the specimen.

f) *O-ring stretcher*, in the form of an openable cylindrical ring to allow for the presence of the top drainage lead when placing 0-rings on the base pedestal and top cap.

g) *Rigid porous discs*, for placing between the specimen ends and the top cap and base. The diameter of the discs shall be the same as that of the specimen, and their surfaces shall be plane and smooth. Their permeability shall be substantially greater than that of the soil, and they shall withstand the maximum vertical pressure (cell pressure plus applied axial load) likely to be imposed. (See note 9.) The discs shall be checked before each use to ensure that they are not clogged by soil particles. They shall be boiled for at least 10 min in distilled water before use and kept immersed in de-aired water until required.

NOTE 9 Discs of porous ceramic, or sintered bronze, have been found to be satisfactory.

h) *Side drains* of Whatman No. 54 filter paper[1] (where applicable). They shall cover no more than 50 % of the curved surface of the specimen. (See note 10.)

NOTE 10 Side drains should be used only on specimens of very low permeability soil in order to reduce the maximum length of drainage path to a distance equal to the specimen radius.

3.3 *Pressure systems and ancillary apparatus*

The pressure systems and ancillary apparatus shall be as follows.

a) *Two independent systems,* for applying and maintaining the desired pressure in the cell and in the specimen drainage line (referred to as the cell pressure system and back pressure system respectively). They shall be capable of maintaining the pressure constant to within ± 0.5 % of the reading indicated. (See note 1.) If air-water systems are used a diaphragm of, for example, butyl rubber shall separate air from water.

NOTE 1 Pressure systems dependent on self-compensating mercury pots (see the warning given in **5.3.2** of BS 1377-1:1990), air pressure regulators, dead-weight pressure cells and oil pressure regulators have been successfully used. Their capacity to supply or take in water should be enough to compensate for cell leakage and drainage to or from the specimen.

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[1] For information on the availability of this product, apply to Enquiries Section, BSI, Linford Wood, Milton Keynes MK14 6LE.

b) *A calibrated pressure gauge of test grade,* for independent measurements of cell pressure and back pressure. (See note 2.) Calibration data shall be clearly displayed. The gauge shall be permanently connected to the two pressure systems by means of a suitable valve or valves. Alternatively, two independent gauges may be used, each permanently connected to its own pressure system.

The level of the pressure gauge relative to a datum level (usually the mid-height of the test specimen) shall be taken into account.

NOTE 2 For measurement of pressures below 50 kPa, a mercury manometer or a calibrated pressure transducer should be used.

c) *A calibrated pore water pressure measuring device,* consisting of an electric pressure transducer reading to 1 kPa mounted in a de-airing block fitted with an air bleed plug. One side of the block shall be fitted to the pore pressure valve on the cell base and the other side shall be fitted to the flushing system valve. The whole assembly when closed shall allow no movement of water into or out of the port leading to the cell base pedestal. The pore pressure assembly shall allow a negligible amount of water to move into or out of the specimen.

d) *A calibrated volume change indicator,* (burette or transducer type) connected into the back pressure line. (See notes 3, 4 and 5.)

NOTE 3 A burette used with a specimen of diameter 38 mm should not normally exceed 50 cm^3 capacity. For specimens of diameter 100 mm or larger, a 100 cm^3 burette is usually suitable. Where small volume changes are to be measured, e.g. with stiff soils or where greater accuracy is required, smaller burettes should be used to obtain the specified resolution. Very compressible soils such as peats may need the use of larger burettes to avoid multiple reversals of flow.

NOTE 4 A pressurized paraffin burette device is suitable if the scale markings can be read to the required degree of accuracy. A transducerized volume-change unit of appropriate range and sensitivity is convenient when an electronic readout or recording system is available. In precise work, or where the differential pressure is small, account should be taken of pressure variations which occur due to movement of the interface between the water and the lower density paraffin in the burettes.

NOTE 5 A volume-change indicator used in this way indicates the change in volume of the specimen only when it is fully saturated.

e) *Glass burette,* open to atmosphere, readable to 0.2 mL, with a thin layer of coloured paraffin on the exposed water surface to prevent loss by evaporation.

NOTE 6 This apparatus is required only for a saturated soil which does not require the application of a back pressure, and is an alternative to the calibrated volume change indicator [see item d)].

f) *Suitable tubing* to connect the components of each pressure system to the cell. The expansion coefficient of the tubing due to internal pressure shall not exceed 0.001 mL/m length for every 1 kPa increase in pressure.

g) *Timing device,* readable to 1 s.

h) *A supply of freshly de-aerated tap water,* as specified in **5.2** of BS 1377-1:1990.

i) *Silicone grease or petroleum jelly.*

NOTE 7 A suitable arrangement of the complete system is shown diagrammatically in Figure 2.

3.4 *Compression test apparatus*

Additional compression test apparatus shall be as follows.

a) *A machine,* capable of applying axial deformation to the specimen at a suitable range of speeds. (See note 1.) The actual rate of machine displacement shall not vary by more than ± 10 % of the desired value when unloaded. The machine shall be capable of providing smoothly an axial deformation sufficient for the requirements of the test.

NOTE 1 A suitable machine would cover the speed-range 0.001 mm/min to 0.5 mm/min.

b) *A means of measuring* the axial deformation of the specimen, readable to 0.01 mm with a range not less than about one-third of the specimen length. The device may consist of a calibrated micrometer dial gauge or displacement transducer, and shall comply with **4.2.1.3** of BS 1377-1:1990.

c) *A calibrated force-measuring device*, of suitable capacity, complying with **4.2.1.6** of BS 1377-1:1990. (See notes 2 and 3.) An externally-mounted device shall be supported by the cross-head of compression machine so as to prevent its own weight being transferred to the test specimen. If the force-measuring device is mounted inside the triaxial cell, allowance shall be made for its compressibility when determining the axial deformation of the specimen.

NOTE 2 The force measuring device can be a load ring, a load transducer, or a submersible load transducer mounted inside the triaxial cell.

NOTE 3 A range of calibrated force measuring devices should be available so that the one most appropriate to the specimen being tested can be selected, in accordance with **4.2.1.6** of BS 1377-1:1990.

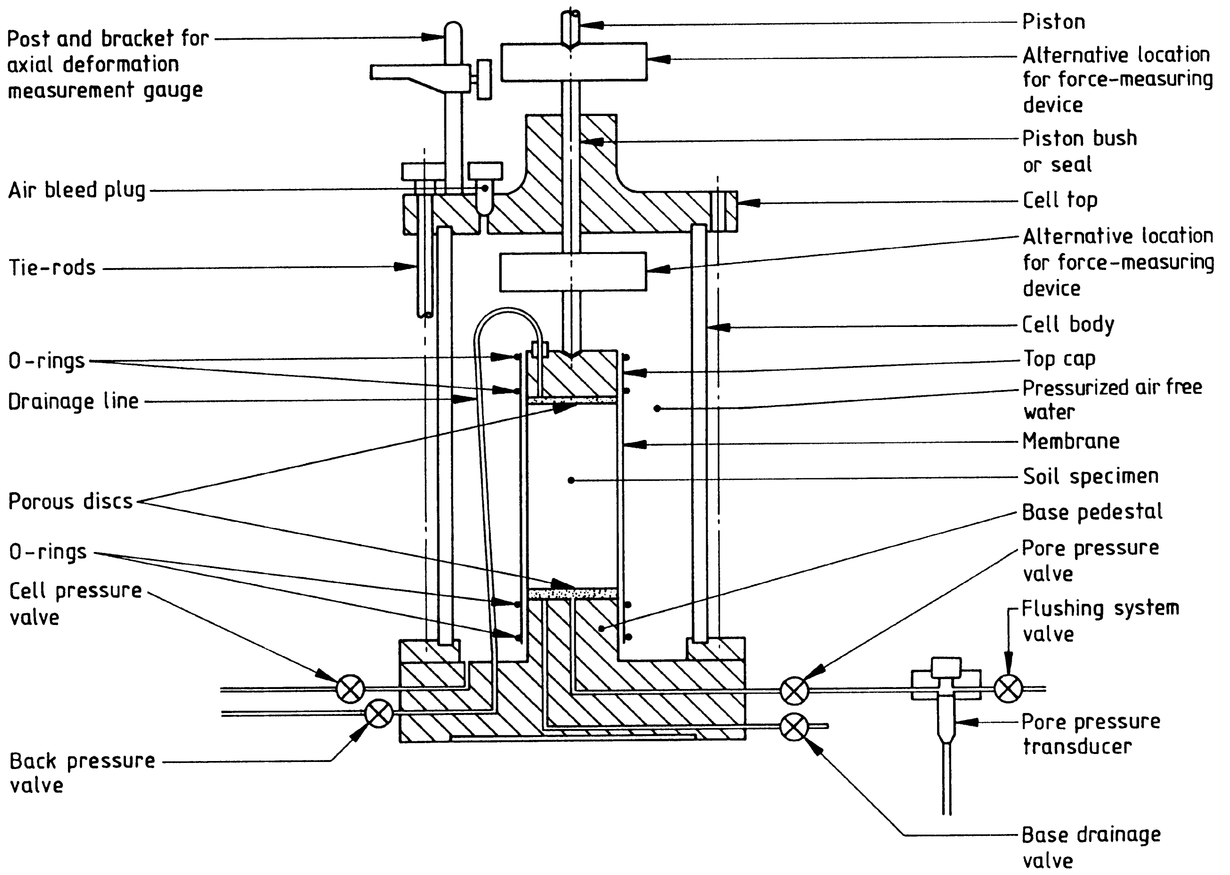


Figure 1 — Essential features of a typical triaxial cell

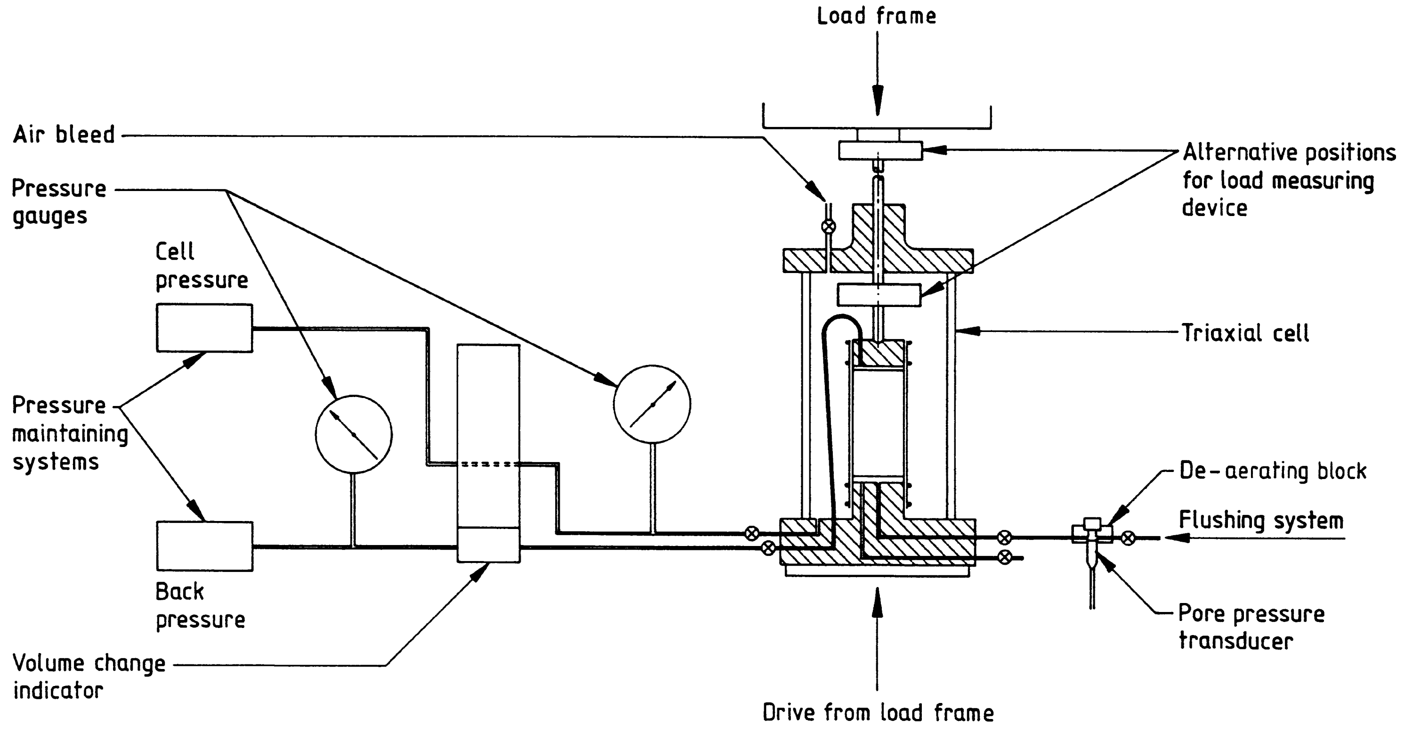


Figure 2 — Typical general arrangement of triaxial test apparatus

3.5 *Preparation and checking of apparatus*

3.5.1 *General.* Apparatus used for triaxial tests shall be subjected to rigorous inspection and check testing before use. The checks described in **3.5.2** to **3.5.6** shall be carried out on the cell pressure, back pressure and pore pressure systems at the stated frequency. Checks on these systems shall be of two kinds, "complete" checks and "routine" checks.

"Complete" checks (see **3.5.2**, **3.5.3** and **3.5.5**) shall be carried out:

a) when any item of new equipment is introduced into a system;

b) if an integral part of a system has been removed, stripped down, overhauled or repaired;

c) at intervals not exceeding 3 months.

"Routine" checks (see **3.5.4** and **3.5.6**) shall be carried out immediately before starting a test.

Before checking, the pressure systems and connecting lines shall be filled with freshly de-aerated water complying with **5.2** of BS 1377-1:1990. (See note.)

NOTE A screw-type hand pump (control cylinder) may be used as an aid to flushing and checking the pressure systems.

The procedures described in **3.5.7** shall be carried out on porous media immediately before each test.

3.5.2 *Cell pressure system (complete check).* A pressure test of the cell pressure system and the triaxial cell shall be made to ensure that the maximum test pressure required can be maintained within the limits stated in item a) of **3.3** at all times during the test.

3.5.3 *Back pressure system (complete check)*

3.5.3.1 Flush freshly de-aerated water through the back pressure connecting line from the volume-change indicator and through the specimen drainage line (whether to the top cap or the base pedestal). In this operation, work the indicator at least twice to its limits of travel, allowing water to pass out of the top cap or base pedestal and replacing it with freshly de-aerated water from the pressure system.

3.5.3.2 Seal the drainage line port with a watertight plug.

3.5.3.3 Pressurize the back pressure system to 750 kPa with the drainage line valve open, and record the volume change indicator reading when steady.

3.5.3.4 Leave the system pressurized for at least 12 h and record the volume change indicator reading again.

3.5.3.5 If the difference between the two readings, after deducting the volume change due to expansion of the tubing, does not exceed 0.1 mL the system can be considered to be leak-free and ready for a test.

3.5.3.6 If the corrected difference exceeds 0.1 mL, investigate and rectify the leaks so that when the steps described in **3.5.3.1** to **3.5.3.4** are repeated, the requirement given in **3.5.3.5** is achieved.

3.5.4 *Back pressure system (routine check).* The following check can be carried out at the same time as the pore pressure system routine check given in **3.5.6**.

a) Flush the back pressure line and drainage connections as in **3.5.3.1**. Close the drainage line valve.

b) Increase the pressure in the back pressure system to 750 kPa, and record the volume change indicator reading after 5 min.

c) Proceed by following the steps described in **3.5.3.4** to **3.5.3.6**.

3.5.5 *Pore pressure system (complete check)*

3.5.5.1 Open the valve between the transducer mounting block and the flushing system. Pass freshly de-aerated water through the mounting block and cell base and out through the base pedestal port, to ensure that the entire system is filled with de-aerated water.

3.5.5.2 Place and secure the cell body on to the cell base, taking care not to pinch the drainage line to the top cap.

3.5.5.3 Open the air bleed on the cell top and fill the cell, via the transducer mounting block, with de-aerated water from the flushing system.

3.5.5.4 Remove the bleed plug in the transducer mounting block and close the pore pressure valve on the cell base.

3.5.5.5 Inject a solution of soft soap into the bleed plug hole. Open the pore pressure valve to allow water from the cell to flow out of that hole, then open the flushing system valve so that water also flows from the de-aerated supply.

3.5.5.6 Screw the bleed plug back into the transducer mounting block while water continues to emerge, and allow the cell to re-fill, then close the bleed plug on the cell.

3.5.5.7 Open the base pedestal drainage valve and allow about 500 mL of de-aerated water to pass through the pedestal to waste. (See note.)

NOTE This is to ensure that any further air, or water containing air, in the transducer mounting block is removed.

3.5.5.8 Pressurize the system to 700 kPa and again allow about 500 mL of water to pass out of the base pedestal drainage valve.

3.5.5.9 Leave the system pressurized for at least 12 h.

3.5.5.10 After this period, check for leaks and if none are found allow about 500 mL of water to pass out of the base pedestal drainage valve. (See note.) If leaks are evident rectify them and then repeat the above procedure.

NOTE A means of detecting leaks that is more positive than visual observation is to connect the system to a sensitive volume change indicator.

3.5.5.11 When checks confirm that the system is free of leaks, close the flushing system valve on the transducer mounting block. Drain water from the cell via the cell pressure valve, with the cell air bleed open after the pressure has been released.

3.5.5.12 Remove the cell body. Seal the pore pressure measurement port on the base pedestal with a watertight plug, without entrapping air.

3.5.5.13 Open the flushing system valve and apply to the base pedestal the maximum pressure achievable within the limitations of the pressure system and the pore pressure transducer.

3.5.5.14 Close the flushing system valve on the transducer mounting block and record the pore pressure reading.

3.5.5.15 If the pore pressure reading remains constant over a minimum 6 h period the pore pressure connections can be assumed to be air-free and leak-free.

3.5.5.16 If there is a decrease in the pressure reading, this indicates that there is a defect in the system. Rectify this defect. Repeat the complete pore pressure system check described in **3.5.5.1** to **3.5.5.14** until the system is proved to be free of entrapped air and leaks.

3.5.6 *Pore pressure system (routine check)*

3.5.6.1 Follow the procedures described in **3.5.5.1** to **3.5.5.11**.

3.5.6.2 Remove the cell body. Keep the base pedestal covered with de-aerated water by fitting a cut-down membrane, secured with O-rings, until the test specimen is ready for setting up.

3.5.7 *Porous media*

3.5.7.1 Inspect the porous discs to ensure that water drains freely through them. Reject discs that are clogged by soil particles.

Before use, boil the discs for at least 30 min in distilled water. Then keep them under de-aerated water in a beaker until required.

3.5.7.2 Immerse filter paper side drains, after trimming, in de-aerated water for a few minutes. Allow surplus water to drain off immediately before fitting the drains to the specimen.

4 Preparation of specimen

4.1 General

4.1.1 *Objective.* These procedures cover the preparation of a cylindrical test specimen from the original soil sample, and include setting up the specimen in the triaxial apparatus. The procedures apply to both consolidated-undrained and consolidated-drained effective stress triaxial compression tests. Specimens shall have a height equal to about twice the diameter, with plane ends normal to the axis.The diameter of the largest particle shall be not greater than one-fifth of the specimen diameter. (See note.)

NOTE If after test a specimen is found to contain larger particles, the size range and mass of these inclusions should be reported.

Specimens might be of undisturbed soil, or of soil that has been compacted under specified conditions. Reference is made to BS 1377-1 for preparation methods.

Careful preparation of specimens is necessary for these tests in order to minimize the effects of disturbance.

4.1.2 ***Principles***

4.1.2.1 *Undisturbed specimens.* Undisturbed specimens shall be prepared with the minimum change of the soil structure and moisture content. (See note 1.) The method of preparation shall depend on whether the sample received in the laboratory is contained in a tube of the same internal diameter as the specimen to be tested, or in a tube of larger diameter, or as a block sample.

NOTE 1 Moisture loss from soil not being used immediately should be prevented by wrapping it in thin clinging plastics film.

When the soil is removed from its sampling tube or container a careful inspection shall be made to ascertain its condition. Any indication of local softening, disturbance, presence of large particles, or other non-uniformity shall be reported. If these features cannot be avoided abandon the sample and use an alternative sample for preparing the test specimen.

NOTE 2 In some instances a larger specimen which contains features such as local softening, disturbance, presence of large particles, etc. would be more representative of the soil as a whole than would a small specimen.

4.1.2.2 *Compacted specimens.* The degree of compaction to be applied when compacting the soil to form specimens shall depend on the relevant field compaction control requirements. The desired compaction shall be achieved by one of the following methods:

a) by compacting the soil into a mould at a specified moisture content, by applying a specified compactive effort;

b) by compacting the soil into a mould at a specified moisture content, to achieve a specified dry density.

NOTE Either method can be used for preparing a sample from which smaller test specimens can be trimmed, or for preparing a large diameter specimen of the size to be tested. For the preparation of a single small test specimen, the method described in item b) is generally used.
The preparation of soil for compaction is described in **7.7** of BS 1377-1:1990.

4.1.3 ***Procedures***

4.1.3.1 *Undisturbed specimens*

4.1.3.1.1 Prepare a specimen from a sample tube of the same internal diameter as the required specimen in accordance with **8.3** of BS 1377-1:1990.

4.1.3.1.2 Prepare a specimen from a sample tube of larger diameter than the required specimen in accordance with **8.4** of BS 1377-1:1990.

4.1.3.1.3 Prepare a specimen from a block sample in accordance with **8.5** of BS 1377-1:1990.

4.1.3.2 *Disturbed specimens*

4.1.3.2.1 Prepare a compacted sample larger than the test specimens, from which one or more test specimens of smaller size are to be taken (see **7.7.4** of BS 1377-1:1990).

4.1.3.2.2 Prepare a compacted specimen of large diameter, e.g. 100 mm in accordance with **7.7.5** of BS 1377-1:1990.

4.1.3.2.3 Prepare a single compacted or remoulded specimen of small diameter. Place the soil in the split mould in at least three layers and compact each layer with the tamping rod. Use a controlled effort, determined by trial beforehand, to achieve the desired specimen density. Mount the specimen on the triaxial base pedestal before removing the split mould.

4.1.3.2.4 Prepare a compacted specimen on the triaxial pedestal. Assemble the split mould on the triaxial cell base, with a latex rubber membrane fitted inside it and around the base pedestal. Compact or tamp the soil into the mould in layers, following the procedures described in **4.1.3.2.2** or **4.1.3.2.3**, according to the specimen diameter. Take care not to disturb or puncture the membrane. Remove the split mould carefully when ready to assemble the triaxial cell.

4.1.4 *Measurements.* On specimens prepared in accordance with **4.1.3**, make the following measurements, ensuring sufficient accuracy to enable the bulk density to be calculated to an accuracy of ± 1 %:

a) length (L_0), in mm;

b) diameter (D_0), in mm;

c) mass (m_0), in g.

NOTE See form 8.A of Appendix A.

4.2 Mounting the test specimen

4.2.1 The procedure for mounting a triaxial test specimen prepared by one of the procedures referred to in **4.1** is described in **4.2.2** to **4.2.13**. For a specimen prepared according to **4.1.3.2.4**, start the procedure at the step described in **4.2.7**.

4.2.2 Place the saturated porous disc by sliding on to a layer of water on the triaxial base pedestal without entrapping air. Remove any surplus water.

4.2.3 Place the specimen on the disc without delay and without entrapping air.

4.2.4 Place the second saturated disc, with excess water removed, on top of the specimen.

4.2.5 If side drains are to be used, allow surplus water to drain from the saturated filter paper and fit it to the curved surface of the specimen. (See note.) Remove any pockets of air by light stroking. Ensure that the drains overlap the porous discs.

NOTE Pore suction in the soil usually holds the drain in place. It may sometimes be more convenient to fit the filter drain before mounting the specimen on the pedestal.

4.2.6 Using the membrane stretcher, place the soaked rubber membrane, after allowing surplus water to drain off, around the specimen. Seal the membrane to the base pedestal using two rubber O-rings. (See note.) Remove air pockets from between the membrane and the specimen by light stroking upwards. No further water shall be inserted between the specimen and membrane.

NOTE A smear of rubber grease on the curved surfaces of the pedestal and top cap improves the seal. Avoid allowing grease to come into contact with the porous discs or filter paper drains.

4.2.7 Place two O-rings around the drainage lead connected to the top loadings cap.

4.2.8 Open the back pressure valve (see Figure 1) momentarily to moisten the top cap, and fit the cap on to the porous disc without entrapping air. Seal the membrane on to the top cap with the two O-rings, using the split-ring stretcher. (See note to **4.2.6**.)

4.2.9 Ensure that the specimen axis is in vertical alignment, and that the drainage line from the top cap will not interfere with fitting the cell body.

4.2.10 Assemble the cell body with the loading piston well clear of the specimen top cap. Check alignment by allowing the piston to slide slowly until it makes contact with the bearing surface on the top cap, then retract the piston. If necessary remove the cell body and correct any eccentricity.

4.2.11 Fill the triaxial cell with de-aerated water, ensuring that all the air is displaced through the bleed plug (see Figure 1). Fill the cell as quickly as possible but without allowing turbulence, which could aerate the water. A layer of castor oil may be introduced on top of the water to act as a piston lubricant and to reduce leakage past the piston.

4.2.12 Keep the air bleed plug (see Figure 1) open until the cell is ready to be pressurized, in order to maintain the pressure at atmospheric.

4.2.13 Apply the first cell pressure increment as soon as possible, as required by the saturation procedure (see **5.3** or **5.4**).

5 Saturation

5.1 General

The objective of the saturation stage is to ensure that all the voids are filled with water. This is often achieved by raising the pore pressure in the specimen to a level high enough for the water to absorb into solution all the air originally in the voids. The pore pressure can be increased either:

a) by applying water pressure (the back pressure) to the specimen, and at the same time increasing the cell pressure in order to maintain a small positive effective stress; or

b) by increasing the cell pressure only.

The saturation process has to take into account two conflicting conditions, as follows.

1) The applied effective stresses should not be so high as to excessively pre-stress or overconsolidate the specimen.

2) The effective stress should not fall below the level required to prevent swelling of soils that have a significant swelling potential (unless this property is to be investigated and steps are taken to make appropriate measurements).

In this clause, two saturation procedures are described. Saturation by applying alternate increments of cell pressure and back pressure is described in **5.3** (see notes 1 and 2). Saturation at constant moisture content is described in **5.4** (see note 3).

NOTE 1 The degree of saturation is estimated by determining the value of the pore pressure coefficient B, and the criterion that B should be greater than or equal to 0.95 usually represents a degree of saturation that is acceptable. (See **5.3**.)

NOTE 2 This procedure may also be followed by increasing the cell pressure and back pressure simultaneously.

NOTE 3 This procedure is necessary when swelling of the specimen would significantly affect measured values such as pore pressure changes during shear. The time required is appreciably longer than when a back pressure is used.

5.2 Basic requirements

The conditions described in a) to d) below shall apply to all saturation procedures except where stated otherwise.

a) Water applied to the specimen from the back pressure system shall be freshly de-aerated in accordance with **5.2** of BS 1377-1:1990.

b) The magnitude of a cell pressure increment shall not exceed 50 kPa, or the effective stress to which the specimen is to be consolidated for the compression test (the "desired effective consolidation pressure"), whichever is less, unless otherwise specified. (See note 1.)

NOTE 1 Cell pressure increments of 50 kPa until a B value of about 0.8 has been achieved, and 100 kPa thereafter, have been found to be suitable for many soil types, provided that the desired effective consolidation pressure is greater than 100 kPa.

c) The difference between cell pressure and back pressure (the "differential pressure") shall be not greater than the desired effective test pressure, or 20 kPa, whichever is less, and shall be not less than 5 kPa. (See note 2.)

NOTE 2 A differential pressure of 10 kPa has been found to be suitable for many soils for which swelling is not significant at this level of effective stress.

d) For a soil with swelling potential, the differential pressure shall not normally be less than the effective stress considered necessary to prevent swelling, or 5 kPa, whichever is greater.

NOTE 3 When observing changes in pore pressure or volume it may be convenient to plot readings against time to ascertain when a steady state has been achieved.

5.3 Saturation by increments of cell pressure and back pressure

5.3.1 *General.* In this method, increments of cell pressure and back pressure are applied alternately. The cell pressure increment stages are carried out without allowing drainage into or out of the specimen, which enables values of the pore pressure coefficient B to be determined at each level of total stress.

Back pressure can be applied to the specimen at the top end, or both ends. For the latter, the back pressure valve and the base drainage valve are both connected to the back pressure system.

5.3.2 *Procedure.* The procedure shall be as follows. (See form 8.B of Appendix A.)

a) Ensure that the back pressure valve or valves and the flushing system valve (see Figure 1) are closed. Apply the first increment of cell pressure immediately after setting up. (See item b) of **5.2**.)

b) Observe the pore pressure until it reaches an equilibrium value, (see note 3 of **5.2**) and record it. If the pore pressure decreases appreciably (possibly after an initial increase) proceed to the step described in item c) without waiting for equilibrium, in order to ensure that the pore pressure does not reach zero.

c) Increase the cell pressure by 50 kPa and repeat the step described in item b). If a steady value of pore pressure is reached, record it, and calculate the change in pore pressure (δu, in kPa) resulting from this increment. Calculate the value of the pore pressure coefficient B from the following equation.

$$B = \frac{\delta u}{50}$$

If B is equal to or greater than 0.95, the specimen can be considered to be saturated and the consolidation stage (see **6.2**) can be started. Otherwise proceed as described in items d) to j) below.

d) Keeping the back pressure valve and the flushing system valve closed, increase the pressure in the back pressure line to a value equal to the cell pressure less the selected differential pressure. (See items c) and d) of **5.2**.) (If the pore pressure at this stage is greater than the intended back pressure a further increment, or increments, of cell pressure shall be applied until the corresponding back pressure exceeds the equilibrium pore pressure, or until the B value equals or exceeds 0.95.)

Record the reading of the back pressure line volume-change indicator (V_1) when it reaches a steady value, i.e. after expansion of the connecting lines.

e) Open the back pressure valve (and the base drainage valve if pressurizing from both ends) to admit the back pressure into the specimen.

f) Observe the pore pressure and the volume-change indicator readings. When the pore pressure becomes equal to the applied back pressure (if pressurizing the top end only, and side drains are not used), and the volume-change indicator shows that movement of water into the specimen has virtually ceased, record these readings (u_2 and V_2 respectively) and close the back pressure valve (and the base drainage valve if appropriate). Monitor the pore pressure until equilibrium is established.

g) If required, calculate the volume of water taken in by the specimen, i.e. its incremental change in volume, during this stage, from the difference between readings V_1 and V_2.

h) Increase the cell pressure by a further suitable increment ($\delta\sigma_3$). (See the step described in item b).) Observe the resulting change in pore pressure (δu), as in the step described in item b). When equilibrium is established, calculate the value of the pore pressure coefficient B from the following equation.

$$B = \frac{\delta u}{\delta\sigma_3}$$

i) Repeat the operations described in steps d) to h) until the pore pressure coefficient B indicates that saturation is achieved. The specimen is considered to be saturated when the pore pressure remains stable after 12 h, or overnight, and the value of B is equal to or greater than 0.95. In certain stiff fissured clays it may not be possible to achieve this, and a value of B of 0.90 which remains unchanged after three successive increments of cell pressure and back pressure as described in steps d) to h) is considered acceptable.

j) If required, calculate the total volume of water taken up by the specimen into the air voids by totalling the differences obtained from the procedures described in item g).

NOTE A graph of B value against cell pressure at the end of each increment, or against pore pressure responses to cell pressure changes, may be plotted.

5.4 Saturation at constant moisture content

5.4.1 *General.* No water shall be allowed to enter or leave the specimen during this procedure, in which saturation is achieved by raising only the cell pressure.

5.4.2 *Procedure.* The procedure shall be as follows.

a) Increase the cell pressure to a nominal level, such as 50 kPa or 100 kPa.

b) Allow the pore pressure to reach equilibrium (see item f) of **5.3.2**).

c) Apply additional equal increments of cell pressure, record the resulting values of pore pressure, as in the steps described in items a) and b) of this clause, and calculate the corresponding B values.

d) The specimen is considered to be saturated when one of the criteria of item i) of **5.3.2** is satisfied.

The saturated specimen is then ready for consolidation to the desired state of effective stress by the procedure given in clause **6**.

6 Consolidation

6.1 General

The consolidation stage follows immediately after the saturation stage (clause **5**), and the same apparatus is used. Consolidation of the specimen for these tests is isotropic. The objective of the consolidation stage is to bring the specimen to the state of effective stress required for carrying out the compression test. Data obtained from the consolidation stage are used for estimating a suitable rate of strain to be applied during compression, for determining when consolidation is complete, and for computing the dimensions of the specimen at the start of the compression stage.

The effective stress in the specimen is increased to the desired value by raising the cell pressure and dissipating the resulting excess pore pressure to an appropriate back pressure. The back pressure should not be reduced below the level of the pore pressure in the final step of the saturation stage, or 300 kPa, whichever is greater.

6.2 Consolidation procedure

After completion of the saturation stage, the back pressure valve (see Figure 1) remains closed and the final pore pressure and volume-change indicator readings are recorded.

The consolidation procedure shall be as follows. (See form 8.C of Appendix A.)

a) Increase the pressure (σ_3) in the cell pressure line and adjust the back pressure if necessary, to give a difference equal to the required effective consolidation pressure (σ_3') such that

$\sigma_3' = \sigma_3 - u_b$.

b) Record the pore pressure when a steady value (u_i) (in kPa) is reached.

NOTE 1 It may be convenient to record and plot readings of pore pressure against time to establish when equilibrium is reached.

NOTE 2 The excess pore pressure to be dissipated is equal to ($u_i - u_b$).

c) Record the reading of the volume-change indicator. At a convenient moment (zero time) start the consolidation stage by opening the back pressure valve or valves.

d) Record readings of the volume-change indicator, at suitable intervals of time.

NOTE 3 Suitable intervals for convenience of plotting the readings against square-root time are 0, ¼, ½, 1, 2¼, 4, 9, 12¼, 16, 25, 36, 64 min, and 2, 4, 8, 16, 24 h. These time intervals 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 square-root time/compression curve to be plotted with sufficient accuracy.

e) Allow consolidation to continue until there is no further significant volume change, and until at least 95 % of the excess pore pressure has been dissipated, i.e. until $U \geq 95$ % in the following equation:

$$U = \frac{u_i - u}{u_i - u_b} \times 100\,\%$$

where

U is the degree of consolidation (in %);

u is the observed pore pressure reading at time t.

f) When consolidation is complete, record the reading of the volume-change indicator and calculate the total change in volume (ΔV_c) during the consolidation stage. Record the pore pressure u_c (in kPa).

g) The consolidated specimen is then ready for either an undrained compression test (clause **7**) or a drained compression test (clause **8**).

6.3 Calculation and plotting

(See form 8.C of Appendix A.)

6.3.1 Calculate the dimension of the specimen after consolidation from the following equations: (See note.)

a) volume: $V_c = V_o - \Delta V_c$

b) area: $A_c = A_o \left[1 - \frac{2}{3}\frac{\Delta V_c}{V_o}\right]$

c) length: $L_c = L_o \left[1 - \frac{1}{3}\frac{\Delta V_c}{V_o}\right]$

where

V_c is the consolidated volume (in cm^3);

V_o is the original specimen volume (in cm^3);

ΔV_c is the change in volume during consolidation as determined from the volume of water draining out of the specimen (in cm^3);

A_c is the consolidated area of cross section (in mm^2);

A_o is the original specimen area of cross section (in mm^2);

L_c is the consolidated length (in mm);

L_o is the original specimen length (in mm).

NOTE If the change in volume during saturation is significant it should be estimated, e.g. from a datum inside the cell for measuring the change in specimen length and included with ΔV_c.

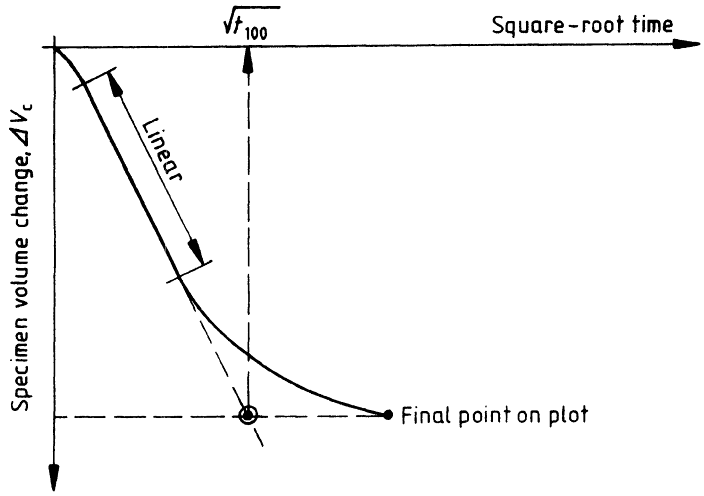


Figure 3 — Idealized triaxial consolidation curve

6.3.2 Plot a graph of the measured volume change against square-root time.

NOTE Percentage pore pressure dissipation may also be plotted against logarithm of time, if measured and if appropriate.

6.3.3 Draw the straight line which best fits the early portion of the plot of volume change against square-root time (this portion normally lies within about the first 50 % of the volume change readings). Draw a horizontal line through the final point on the plot. (See Figure 3.) At the point where these lines intersect, read off the value of square-root time, denoted by $\sqrt{t_{100}}$ and calculate the time intercept of this point, t_{100} (in min).

6.3.4 Calculate the value of the coefficient of consolidation, c_{vi} (in m^2/year) for isotropic consolidation (see note) from the following equation:

$$c_{vi} = \frac{1.65\,D_c^2}{\lambda t_{100}}$$

where

D_c is the diameter of the specimen after consolidation, calculated from the equation $D_c = \sqrt{(4A_c/\pi)}$;

λ is a coefficient which depends on the drainage conditions and the length: diameter ratio (r) of the specimen as shown in Table 1.

NOTE The value of c_{vi} derived in this way should not be applied to engineering settlement calculations because it has been shown to be grossly in error when side drains are used.

6.3.5 Calculate the value of the coefficient of volume compressibility (if required) for isotropic consolidation, m_{vi} (in m^2/MN), from the following equation:

$$m_{vi} = \frac{\Delta V_c / V_o}{u_i - u_c} \times 1000$$

where

ΔV_c is the change in volume of the specimen due to consolidation (in cm^3);

V_o is the original specimen volume (in cm^3);

u_i is the pore pressure at the start of the consolidation stage (in kPa);

u_c is the pore pressure at the end of consolidation (in kPa).

6.3.6 Calculate the significant testing time t_f (in min) in the compression test, from the following equation:

$$t_f = F t_{100}$$

where

F is a coefficient which depends on the drainage conditions, and the type of compression test, i.e. undrained or drained.

Values of F for drained tests, and for undrained tests on non-sensitive specimens that deform in a plastic manner, are included in Table 1. (See notes 1 and 2). For stiff fissured soils and sensitive soils, use the factor given for drained tests for both drained and undrained tests.

NOTE 1 The factor F is based on 95 % dissipation of excess pore pressure induced by shear, which is acceptable for most practicable purposes.

NOTE 2 Soils of relatively high permeability may give calculated times to failure that are unrealistically short. The time to failure should not be less than 2 h.

Table 1 — Factors for calculating c_v and time to failure

Drainage conditions during consolidation	Values of λ		Values of F (for $r = 2$)	
	$L/D = 2$	$L/D = r$	**Drained test**	**Undrained test**[a]
From one end	1	$r^2/4$	8.5	0.53
From both ends	4	r^2	8.5	2.1
From radial boundary and one end	80	$3.2(1 + 2r)^2$	14	1.8
From radial boundary and two ends	100	$4(1 + 2r)^2$	16	2.3

[a] For plastic deformation of non-sensitive soils only.

6.3.7 Estimate the significant strain interval for the test specimen, ϵ_f, as follows.

a) If only the condition at failure (according to the criteria defined in **1.2.8**) is significant, ϵ_f is the estimated strain at which failure will occur.

b) If approximately uniformly-spaced intermediate readings, each requiring equalization of pore pressure, are significant, ϵ_f is the strain increment between each reading.

NOTE This method is necessary when a stress path is to be derived from the test.

6.3.8 Calculate the rate of axial displacement (d_r, in mm/min) to be applied to the specimen from the following equation:

$$d_r = \frac{\varepsilon_f \times L_c}{t_f}$$

where

L_c is the length of the consolidated specimen (in mm);

ϵ_f is the significant strain interval for the test specimen;

t_f is the significant testing time (in min).

This gives the maximum nominal machine speed for the test. (See note.)

NOTE The "machine displacement speed" is the speed as given by the manufacturer for each gear ratio when the machine is running under zero load. The actual speed under load may be less than this. The "closing gap speed" is less than the machine speed due to deformation of the load measuring device and of load frame. The actual rate of axial displacement of the specimen is the "closing gap speed", and allowance should be made for the difference between this and the nominal machine displacement speed if greater accuracy is necessary.

7 Consolidated-undrained triaxial compression test with measurement of pore pressure

7.1 General

In this test, during the compression stage, the cell pressure is maintained constant while the specimen is sheared at a constant rate of axial deformation (strain-controlled compression) until failure occurs. No drainage is permitted and therefore the moisture content remains constant during compression. The resulting changes in pore pressure are usually measured at the base of the specimen, and the rate of axial deformation is applied slowly enough to ensure adequate equalization of excess pore pressures.

The test procedure described in **7.2** to **7.6** relates to a saturated specimen in the triaxial cell which has been brought to the required effective stress by consolidation in accordance with clause **6**.

The requirements of BS 1377-1, where appropriate, shall apply to this test method.

7.2 Compression stage

7.2.1 Set up the triaxial cell on the compression machine if it has stood elsewhere during saturation and consolidation.

7.2.2 Adjust the machine platen, either by hand or by motor drive, until the cell loading piston is brought to within a short distance of the specimen top cap. Record the reading of the force-measuring device during this operation as the initial reading.

NOTE This procedure allows for the combined effects of cell pressure acting on the piston and frictional resistance in the piston bush or seal. If the design of force-measuring device permits, the scale of the device should be adjusted so that the initial reading is zero.

7.2.3 Adjust the compression machine to give a rate of displacement as close as possible to, but not exceeding, that calculated in **6.3.8**.

7.2.4 Make further adjustments to bring the loading piston just into contact with the seating on the top cap of the specimen. Check that the piston is properly seated and in correct alignment, ensuring that the axial load applied to the specimen is as small as possible.

7.2.5 Secure the axial deformation gauge so that it can measure a vertical deformation up to at least 25 % of the specimen length. Observe the initial reading, or set the gauge to read zero.

7.2.6 Ensure that the back pressure valve or valves are closed, the cell pressure valve is open, and the valve to the pore pressure measuring device is open. (See Figure 1.)

7.2.7 Record the following as the initial readings for the compression stage: (See form 8.D of Appendix A.)

a) date and clock time;

b) deformation gauge reading;

c) force device reading;

d) pore pressure;

e) cell pressure.

7.2.8 Apply compression to the specimen and simultaneously start the timer.

7.2.9 Record sets of readings of the deformation gauge, force device and pore pressure at intervals during the test. Record at least 20 sets of readings in order to define the stress-strain curve clearly in the vicinity of failure. (See notes 1 to 3.)

NOTE 1 For a very stiff soil which is likely to fail suddenly at a small strain, readings should be taken at regular intervals of stress rather than of strain to obtain the required number of readings.

NOTE 2 The cell pressure should be checked periodically during the course of the test to ensure that it remains constant.

NOTE 3 Elapsed time readings should be recorded periodically to provide a check on the applied rate of strain.

7.2.10 Calculate values of deviator stress ($\sigma_1 - \sigma_3$) (in kPa) and effective principal stress ratio (σ_1'/σ_3'), as described in **7.4**, and plot them as ordinates against axial strain (in %) as abscissa, while the test is still in progress.

NOTE At the same time, the pore pressure may be plotted against strain, and the stress path of t' against s' (see item l) of **7.4**).

7.2.11 Continue the test until one of following conditions has been clearly identified, depending on the specified failure criterion as defined in **1.2.8**:

a) maximum deviator stress;

b) maximum effective principal stress ratio;

c) constant shear stress and constant pore pressure.

If none of the required failure conditions is evident, terminate the test at an axial strain of 20 %. In this case do not report a shear strength.

7.2.12 Stop the compression stage and close the pore pressure valve to the pore pressure device. Open the flushing system valve to protect the transducer.

7.3 End of test procedures

7.3.1 *Dismantling.* When the compression stage is finished, remove the specimen from the triaxial cell pedestal as quickly as possible so that the absorption of water from the porous discs is kept to a minimum.

The sequence of operations shall be as follows.

a) Ensure that the back pressure valve or valves and the pore pressure line valves are closed. (See Figure 1.)

b) Remove the axial force from the specimen.

c) Reduce the cell pressure to zero and drain the cell.

d) Dismantle the cell and remove the specimen.

e) Remove the top cap, rubber membrane, porous discs, and side drains (if used).

f) Sketch the mode of failure of the specimen.

7.3.2 *Final measurements*

7.3.2.1 Weigh the whole specimen and calculate the final density using the volume V_c (see **6.3.1**) calculated at the end of the consolidation stage.

7.3.2.2 Dry the whole specimen to constant mass, and determine the moisture content of the specimen as a whole, using the procedure described in **3.2** of BS 1377-2:1990. Break down a large sample before placing it in the oven.

7.4 Calculations

(See form 8.D of Appendix A.)

From each set of readings, calculate the following.

a) *Axial strain,* ϵ, given by:

$$\epsilon = \frac{\Delta L}{L_c}$$

where

L_c is the length of the specimen after consolidation (in mm);

ΔL is the change in length (from the initial length) during compression, as determined from the deformation gauge (in mm).

NOTE 1 For the purposes of this British Standard, strains are calculated as cumulative strain, i.e. the change in dimension related to the initial reference dimension.

b) *Area of cross section of the specimen normal to its axis,* assuming that it deforms as a right cylinder. The area, A_s (in mm^2), is given by:

$$A_s = \frac{A_c}{1 - \varepsilon}$$

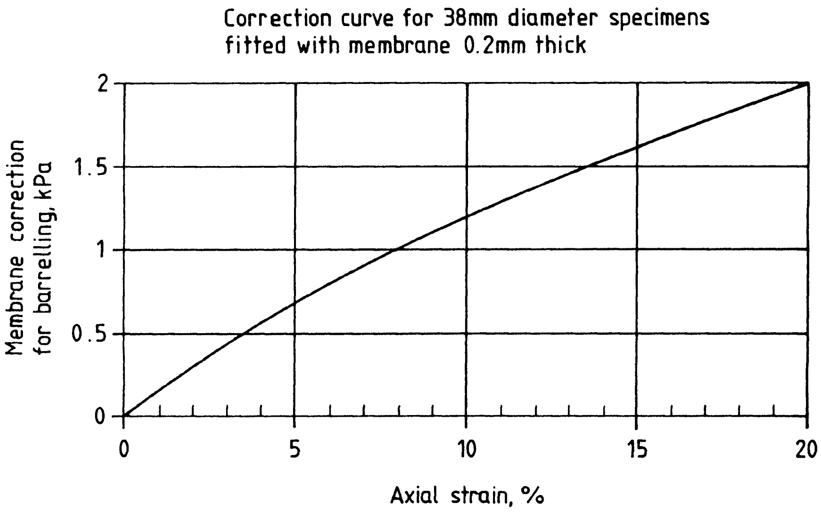


Figure 4 — Membrane correction

where

A_c is the initial area of specimen normal to its axis at the start of compression.

NOTE 2 This equation is based on the assumption that in an undrained test on a fully saturated specimen the volumetric strain is zero.

c) *Axial force, P*(in N), applied to the specimen additional to that due to the cell pressure, given by:

$$P = (R - R_0)C_r$$

where

R is the reading of the force-measuring device (in divisions or digits);

R_0 is the initial reading of the force-measuring device corresponding to zero applied load (in divisions or digits);

C_r is the calibration factor of the force-measuring device (in N/division or digit).

d) *Applied axial stress*, i.e. the measured principal stress difference, or deviator stress $(\sigma_1 - \sigma_3)_m$ (in kPa), given by:

$$(\sigma_1 - \sigma_3)_m = \frac{P}{A_s} \times 1000$$

e) *A membrane correction*, which shall be applied to allow for the restraining effect of the membrane. The curve in Figure 4 gives the correction σ_{mb} to apply to a specimen initially 38 mm diameter enclosed in a membrane 0.2 mm thick. For other conditions the correction obtained from Figure 4 shall be multiplied by:

$$\frac{38}{D_0} \times \frac{t_m}{0.2}$$

to give the value of σ_{mb} to be used,

where

D_0 is the initial specimen diameter (in mm);

t_m is the total thickness of membrane (which may consist of more than one layer) enclosing the specimen (in mm).

f) *A drain correction*. When vertical side drains are fitted, an additional correction, σ_{dr}, shall be applied for strains exceeding 0.02 (2 %). The value for σ_{dr} shall be taken from Table 2.

Table 2 — Corrections for vertical side drains

Specimen diameter	Drain correction, σ_{dr}
mm	kPa
38	10
50	7
70	5
100	3.5
150	2.5

NOTE Corrections for specimens of intermediate diameters may be obtained by interpolation.

NOTE 3 The combined behaviour of membranes and side drains during axial compression is complex and there is no consensus of opinion on the precise corrections to apply. Those corrections given in Table 2 are based on simplifying assumptions and represent compromise values.

g) *Corrected deviator stress,* $(\sigma_1 - \sigma_3)$ (in kPa), given by:

$$(\sigma_1 - \sigma_3) = (\sigma_1 - \sigma_3)_m - \sigma_{mb} - \sigma_{dr}$$

h) *Major principal stress*, σ_1 (in kPa), given by:

$$\sigma_1 = (\sigma_1 - \sigma_3) + \sigma_3$$

where σ_3 is the cell confining pressure.

i) *Effective major and minor principal stresses,* (σ_1' and σ_3' respectively) (in kPa), given by:

$$\sigma_1' = \sigma_1 - u$$

$$\sigma_3' = \sigma_3 - u$$

where

u is the pore pressure.

j) *Effective principal stress ratio,* σ_1'/σ_3'.

k) *Pore pressure coefficient A*, given by:

$$A = \frac{u - u_o}{(\sigma_1 - \sigma_3)}$$

where

u_o is the pore pressure in the specimen at the start of compression.

l) *Stress path parameters, s′* and *t′* (in kPa), if required, in terms of effective stress, given by:

$$s' = ½\ (\sigma_1' + \sigma_3')$$

$$t' = ½\ (\sigma_1 - \sigma_3)$$

7.5 Graphical plots

Plot on graphs the following data.

a) The stress strain curve, with axial strain (usually as percentage) as abscissa and deviator stress as ordinate.

b) Pore pressure change curve, using the same abscissa as in item a), and pore pressure values as ordinate. Mark clearly the initial pore pressure in the compression stage.

c) Effective principal stress ratio, σ_1'/σ_3', plotted as ordinate against axial strain as abscissa.

d) Where failure is defined by a maximum value of deviator stress or effective principal stress ratio or constant deviator stress and pore pressure, derive the appropriate value from a smooth curve drawn through the observed points plotted as in items a) to c) above. (See note.) Read from the curve the corresponding value of axial strain.

NOTE The curve may indicate a maximum value intermediate between two sets of readings.

e) The Mohr circle of effective stress, representing the condition at failure.

f) Stress path, if required, for effective stresses, with values of s' as abscissa and t' as ordinate, on a single plot in which the vertical and horizontal scales are the same.

7.6 Expression of results

7.6.1 *General.* The test report shall affirm that the test was carried out in accordance with clauses **4**, **5**, **6** and **7** of BS 1377-8:1990. It shall contain a statement of the method used, i.e. the consolidated-undrained triaxial compression test with measurement of pore pressure, in addition to the relevant information listed in clause **9** of BS 1377-1:1990.

For each specimen tested, the data listed in **7.6.2** shall be reported. Where a number of specimens are tested as a set, the data shall be combined as outlined in **7.6.3**.

7.6.2 *Single specimen.* The data for each test specimen shall be as follows:

a) depth and orientation of the test specimen within the original sample;

b) initial specimen dimensions;

c) initial moisture content, bulk density;

d) whether side drains were fitted;

e) method used for saturating the specimen, including pressure increments applied and differential pressure, if applicable;

f) pore pressure, cell pressure and value of pore pressure coefficient B at the end of saturation;

g) cell pressure, back pressure and effective pressure used for consolidation;

h) pore pressure and percentage pore pressure dissipation at termination of the consolidation stage;

i) graphical plot of volume change or volumetric strain against square-root time for the consolidation stage, as described in **6.3**.

j) rate of axial displacement applied to the specimen (in millimetres per minute or percent strain per hour);

k) pore pressure and effective stress at the start of the compression stage;

l) failure criterion adopted (see **1.2.8**);

m) axial strain, deviator stress, pore pressure and effective major and minor principal stresses at failure;

n) effective principal stress ratio at failure;

o) sketch of specimen after test, indicating mode of failure;

p) details and magnitude of corrections applied to the measured deviator stress;

q) final density and moisture content;

r) graphical plots, as described in **7.5**.

7.6.3 *Set of specimens.* When a number of specimens taken from one soil sample are tested at different effective pressures for the evaluation of shear strength parameters, numerical data listed in **7.6.2** shall be grouped together and reported as a set.

NOTE 1 Graphical plots as detailed in **7.5** may be presented separately for each specimen, or grouped together on common axes.

NOTE 2 The shear strength parameters in terms of effective stress, i.e. the cohesion, c' (in kPa), and the angle of shear resistance, ϕ' (in degrees) may be derived as follows (but see note 3).

Draw the line of best fit through the plotted points representing values of s' and t' at failure according to the selected failure criterion (see **1.2.8**).

Determine the value of t' where this line intersects the t' axis (t'_0 kPa).

Measure the inclination of this line to the horizontal (Θ degrees).

Calculate the shear strength parameters from the following relationships

$$\sin\phi' = \tan\Theta$$

$$c' = \frac{t_o'}{\cos\phi'}$$

NOTE 3 Individual specimens prepared from a common soil sample, though apparently identical, often differ in their stress-strain behaviour and other properties. Specimen variability may cause difficulties in assigning shear strength parameters which accurately represent the sampled material as a whole.

NOTE 4 Alternatively, the shear strength parameters may be obtained by drawing a linear envelope to the set of Mohr circles of failure (according to the selected failure criterion) and measuring the intercept with the vertical axis (c') and the inclination to the horizontal (ϕ').

8 Consolidated-drained triaxial compression test with measurement of volume change

8.1 General

In this test, during the compression stage, the cell pressure is maintained constant while the specimen is sheared at a constant rate of axial deformation (strain-controlled compression) until failure occurs. Free drainage of pore water from the specimen is allowed. The test is run slowly enough to ensure that pore pressure changes due to shearing are negligible. The required rate of strain can be much slower than that for a consolidated-undrained test on a similar specimen under similar conditions. Since the pore pressure remains virtually constant, the effective confining pressure does not vary. The volume of pore fluid draining out of or into the specimen is measured by means of the volume change indicator in the back pressure line, and is equal to the change in volume of the specimen during shear. Pore pressure can be monitored at the base as a check on the efficacy of drainage.

The test procedure described in **8.2** to **8.6** relates to a saturated specimen in the triaxial cell which has been brought to the required effective stress by consolidation in accordance with clause **6**.

The requirements of BS 1377-1, where appropriate, shall apply to this test method.

8.2 Compression stage

8.2.1 Set up the triaxial cell on the compression machine if it has stood elsewhere during saturation and consolidation.

8.2.2 Adjust the machine platen, either by hand or by motor drive, until the cell loading piston is brought to within a short distance of the specimen top cap. Record the reading of the force-measuring device during this operation as the initial reading.

NOTE This procedure allows for the combined effects of cell pressure acting on the piston and frictional resistance in the piston bush or seal. If the design of force-measuring device permits, the scale of the gauge should be adjusted so that the initial reading is zero.

8.2.3 Adjust the compression machine to give the rate of displacement as close as possible to, but not exceeding, that calculated in **6.3.8**.

8.2.4 Make further adjustments to bring the loading piston just into contact with the seating on the top cap of the specimen. Check that the piston is properly seated and in correct alignment, ensuring that the axial force applied to the specimen is as small as possible.

8.2.5 Secure the axial deformation gauge so that it can measure a vertical deformation up to at least 25 % of the specimen length. Observe the initial reading, or set the dial to read zero.

8.2.6 Ensure that the cell pressure valve and back pressure valve or valves are open, and open the valve to the pore pressure measuring device. (See Figure 1.)

8.2.7 Record the following as the initial readings for the compression stage: (See form 8.E of Appendix A.)

a) date and clock time;

b) deformation gauge reading;

c) force device reading;

d) volume-change indicator reading;

e) pore pressure;

f) cell pressure.

8.2.8 Apply compression to the specimen and simultaneously start the timer.

8.2.9 Record sets of readings of the deformation gauge, force device and volume-change gauge at intervals during the test. Record at least 20 sets of readings in order to define the stress-strain curve clearly in the vicinity of failure. (See notes 1 to 4.)

NOTE 1 For a very stiff soil which is likely to fail suddenly at a small strain, readings should be taken at regular intervals of stress rather than of strain to obtain the required number of readings.

NOTE 2 Readings of pore pressure need not be recorded with every set of readings as long as they do not vary beyond the stated limits (see **8.2.11**).

NOTE 3 The cell pressure and back pressure should be checked periodically during the course of the test to ensure that they remain constant. They should be adjusted as necessary.

NOTE 4 Elapsed time readings should be recorded periodically to provide a check on the actual applied rate of strain.

8.2.10 Calculate values of deviator stress $(\sigma_1 - \sigma_3)$ (in kPa) as described in **8.4**, and plot them as ordinates against axial strain (in %) as abscissa, while the test is still in progress.

NOTE Volumetric strain, or specimen volume change, may also be plotted against strain at the same time.

8.2.11 Observe the pore pressure periodically, and if it varies from the value of the back pressure by more than 4 % of the effective confining pressure, decrease the rate of strain by 50 % or more.

8.2.12 Continue the test until either of the following conditions has been clearly identified, depending on the specified failure criterion as defined in **1.2.8**:

a) maximum deviator stress; or

b) shear deformation continuing at constant volume and constant shear stress.

NOTE If neither of the required failure conditions is evident, terminate the test at an axial strain of 20 %. In this case do not report a shear strength.

8.2.13 Stop the compression stage, close the pore pressure valve to the pore pressure device and close the back pressure valve. Open the flushing system valve to protect the transducer.

8.3 End of test procedures

8.3.1 *Dismantling.* When the compression stage is finished, remove the specimen from the triaxial cell pedestal as quickly as possible so that the absorption of water from the porous discs is kept to a minimum.

The sequence of operations shall be as follows.

a) Ensure that the back pressure valve or valves and the pore pressure line valves are closed. (See Figure 1.)

b) Remove the axial force from the specimen.

c) Reduce the cell pressure to zero and drain the cell.

d) Dismantle the cell and remove the specimen.

e) Remove the top cap, rubber membrane, porous discs, and side drains (if used).

f) Sketch the mode of failure of the specimen.

8.3.2 *Final measurements*

8.3.2.1 Weigh the whole specimen and calculate the final density using the final calculated volume $(V_c - \Delta V)$, where V_c is the volume at the end of the consolidation stage and ΔV is the volume decrease during the compression stage.

8.3.2.2 Dry the whole specimen to constant mass, and determine the moisture content of the specimen as a whole, using the procedure described in **3.2** of BS 1377-2:1990. Break down a large sample before placing it in the oven.

8.4 Calculations

(See form 8.E of Appendix A.)

From each set of readings, calculate the following.

a) *Axial strain,* ϵ, given by:

$$\varepsilon = \frac{\Delta L}{L_c}$$

where

L_c is the length of the specimen after consolidation (in mm);

ΔL is the change in length (from the initial length) during compression, as determined from the deformation gauge (in mm).

NOTE 1 For the purposes of this British Standard, strains are calculated as cumulative strain, i.e. the changes in dimension related to the initial reference dimension.

b) *Volumetric strain due to compression*, ϵ_v, given by:

$$\varepsilon_v = \frac{\Delta V}{V_c}$$

where

ΔV is the change in volume of the specimen from the start of compression (see note 2):

V_c is the volume of the consolidated specimen at the start of compression.

NOTE 2 The sign convention used is that compressive stresses are positive, and therefore a decrease in volume (compression or consolidation) is positive and an increase in volume (dilatancy or swelling) is negative.

c) *Area of cross section of the specimen normal to its axis,* assuming that it deforms as a right cylinder. The area, A_s (in mm^2), is given by:

$$A_s = \frac{1 - \varepsilon_v}{1 - \varepsilon} A_c$$

where

A_c is the initial area of specimen normal to its axis at the start of compression.

d) *Axial force, P* (in N), applied to the specimen additional to that due to the cell pressure, given by:

$$P = (R - R_o)\ C_r$$

where

R is the reading of the force-measuring device (in divisions or digits);

R_o is the initial reading of the force-measuring device corresponding to zero applied load (in divisions or digits);

C_r is the calibration factor of the force-measuring device (in N/division or digit).

e) *Applied axial stress,* i.e. the measured principal stress difference, or deviator stress $(\sigma_1 - \sigma_3)_m$ (in kPa), given by:

$$(\sigma_1 - \sigma_3)_m = \frac{P}{A_s} \times 1000$$

f) *A membrane correction,* which shall be applied to allow for the restraining effect of the rubber membrane. The curve in Figure 4 gives the correction to apply to a specimen initially 38 mm diameter enclosed in a membrane 0.2 mm thick. For other conditions the correction obtained from Figure 4 shall be multiplied by:

$$\frac{38}{D_o} \times \frac{t_m}{0.2}$$

to give the value of σ_{mb} to be used, where

D_o is the initial specimen diameter (in mm);

t_m is the thickness of membrane (which may consist of more than one layer) enclosing the specimen (in mm).

g) *A drain correction.* When vertical side drains are fitted, an additional correction, σ_{dr}, shall be applied for strains exceeding 0.02 (2 %). The value of σ_{dr} shall be taken from Table 2.

NOTE 3 The combined behaviour of membranes and side drains during axial compression is complex and there is no consensus of opinion on the precise corrections to apply. Those corrections given in Table 2 are based on simplifying assumptions and represent compromise values.

h) *Corrected deviator stress* $(\sigma_1 - \sigma_3)$ (in kPa), given by:

$$(\sigma_1 - \sigma_3) = (\sigma_1 - \sigma_3)_m - \sigma_{mb} - \sigma_{dr}$$

i) *Major principal stress,* σ_1 (in kPa), given by:

$$\sigma_1 = (\sigma_1 - \sigma_3) + \sigma_3$$

where

σ_3 is the cell confining pressure.

j) *Effective major and minor principal stresses,* (σ_1' and σ_3') (in kPa), given by:

$$\sigma_1' = \sigma_1 - u$$

$$\sigma_3' = \sigma_3 - u$$

where

u is the pore pressure.

k) *If required, stress path parameters,* s' and t', (in kPa) in terms of effective stress, given by:

$$s' = ½\ (\sigma_1' + \sigma_3')$$

$$t' = ½\ (\sigma_1 - \sigma_3)$$

8.5 Graphical plots

Plot on graphs the following data.

a) The stress strain curve, with axial strain (usually as percentage) as abscissa and deviator stress as ordinate. Where failure is defined by a maximum value of deviator stress, derive the maximum value from a smooth curve drawn through the observed points. (See note.) Read from the curve the corresponding value of axial strain.

NOTE The curve may indicate a maximum value intermediate between two sets of readings.

b) Volume change curve, using the same abscissa as in item a), and volume change (either in cm^3, or as volumetric strain) as ordinate.

c) The Mohr circle of effective stress, representing the condition at failure.

8.6 Expression of results

8.6.1 *General.* The test report shall affirm that the test was carried out in accordance with clauses **4**, **5**, **6** and **8** of BS 1377-8:1990. It shall contain a statement of the method used, i.e. the consolidated-drained triaxial compression test with measurement of volume change, in addition to the relevant information listed in clause **9** of BS 1377-1:1990.

For each specimen tested, the data listed in **8.6.2** shall be reported. Where a number of specimens are tested as a set, the data shall be combined as outlined in **8.6.3**.

8.6.2 *Single specimen.*The data for each test specimen shall be as follows:

a) depth and orientation of the test specimen within the original sample;

b) initial specimen dimensions;

c) initial moisture content, bulk density;

d) whether side drains were fitted;

e) method used for saturating the specimen, including pressure increments applied and differential pressure, if applicable;

f) pore pressure, cell pressure and value of pore pressure coefficient B at the end of saturation;

g) cell pressure, back pressure and effective pressure used for consolidation;

h) pore pressure and percentage pore pressure dissipation at termination of the consolidation stage;

i) graphical plot of volume change or volumetric strain against square-root time for the consolidation stage, as described in **6.3**;

j) rate of axial displacement applied to the specimen (in millimetres per minute or percent strain per hour);

k) pore pressure and effective stress at the start of the compression stage;

l) failure criterion adopted;

m) axial strain, deviator stress, volumetric strain, pore pressure and effective major and minor principal stresses at failure;

n) sketch of specimen after test, indicating mode of failure;

o) details and magnitude of corrections applied to the measured deviator stress;

p) final density and moisture content;

q) graphical plots, as described in **8.5**.

8.6.3 *Set of specimens.* When a number of specimens taken from one soil sample are tested at different effective pressures for the evaluation of shear strength parameters, numerical data listed in **8.6.2** shall be grouped together and reported as a set.

NOTE 1 Graphical plots as detailed in **8.5** may be presented separately for each specimen, or grouped together on common axes.

NOTE 2 The shear strength parameters in terms of effective stress, i.e. the cohesion, c' (in kPa), and the angle of shear resistance, in ϕ' (in degrees) may be derived as follows (but see note 3).

Draw the line of best fit through the plotted points representing values of s' and t' at failure according to the selected failure criterion.

Determine the value of t' where this line intersects the t' axis (t_o' kPa).

Measure the inclination of this line to the horizontal (Θ degrees).

Calculate the shear strength parameters from the following relationships:

$$\sin\phi' = \tan\Theta$$

$$c' = \frac{t_o'}{\cos\phi'}$$

NOTE 3 Individual specimens prepared from a common soil sample, though apparently identical, often differ in their stress-strain behaviour and other properties. Specimen variability may cause difficulties in assigning shear strength parameters which accurately represent the sampled material as a whole.

NOTE 4 Alternatively, the shear strength parameters may be obtained by drawing a linear envelope to the set of Mohr circles of failure (according to the selected failure criterion) and measuring the intercept with the vertical axis (c') and the inclination to the horizontal (ϕ').

Appendix A Typical test data and calculation forms

These test sheets are given as examples only: other suitable forms may be used.

Form 8.A	Triaxial test: specimen data
Form 8.B	Triaxial saturation
Form 8.C	Triaxial consolidation
Form 8.D	Consolidated-undrained triaxial compression test with measurement of pore pressure
Form 8.E	Consolidated-drained triaxial compression with measurement of volume change

Triaxial test: specimen data

Location	Job ref.	
	Borehole/ Pit ref.	
Soil description	Sample no.	
	Depth	m
	Date	
Test method Clauses **4.5, 6, 7/8*** of BS 1377 : Part 8 : 1990	Date	

Consolidated-undrained/consolidated-drained* triaxial compression test

Type of specimen Undisturbed/compacted*	Nominal diameter mm

Preparation procedure

Initial specimen

Length (in mm)		Diameter (in mm)		
....		....		Mass, m_o (in g)
....		....		Moisture content, w_o (in %)
....		....		Dry mass, m_d (in g)
....		....		Area, A_o (in mm^2)
....		....		Volume, V_o (in cm^3)
Mean L_o		Mean D_o		Density, ρ (in Mg/m^3)
				Dry density, ρ_d (in Mg/m^3)

Weighings

		Soil trimmings	Test specimen	
			Initial condition	After test
Container no.				
Specimen + container	g			
Container	g			
Specimen	g		m_o	m_f
Dry specimen + container	g			
Dry specimen	g		m_d	m_d
Moisture	g			
Moisture content	%		w_o	w_f

Operator	Checked	Approved

*Delete as appropriate.

Form 8.A

Triaxial saturation

Location	Job ref.	
	Borehole/ Pit ref.	
Soil description	Sample no.	
	Depth	m
	Date	
Test method Clause **5.3**/**5.4*** of BS 1377 : Part 8 : 1990	Date	

Consolidated-undrained/consolidated-drained* triaxial compression test

With/without* side drains	Date started	Completed
Pressure system no.	Cell no.	Nominal diameter mm

Saturation procedure:*

Cell pressure and back pressure increments/At constant moisture content

Other

Cell pressure (kPa)		Back pressure (kPa)	Pore pressure (kPa)		*B* value	Volume-change indicator† (mL)		
Value σ_3	Increment $\delta\sigma_3$		Reading u	Increment δu	$\frac{\delta u}{\delta\sigma_3}$	Before V_1	After V_2	Difference

Remarks	Total water taken up (mL)		
	Operator	Checked	Approved

* Delete as appropriate.
† If required.

Form 8.B

Triaxial consolidation

Location	Job ref.	
	Borehole/ Pit ref.	
Soil description	Sample no.	
	Depth	m
	Date	
Test method Clause **6** of BS 1377 : Part 8 : 1990	Date	

Consolidated-undrained/consolidated-drained* triaxial compression test

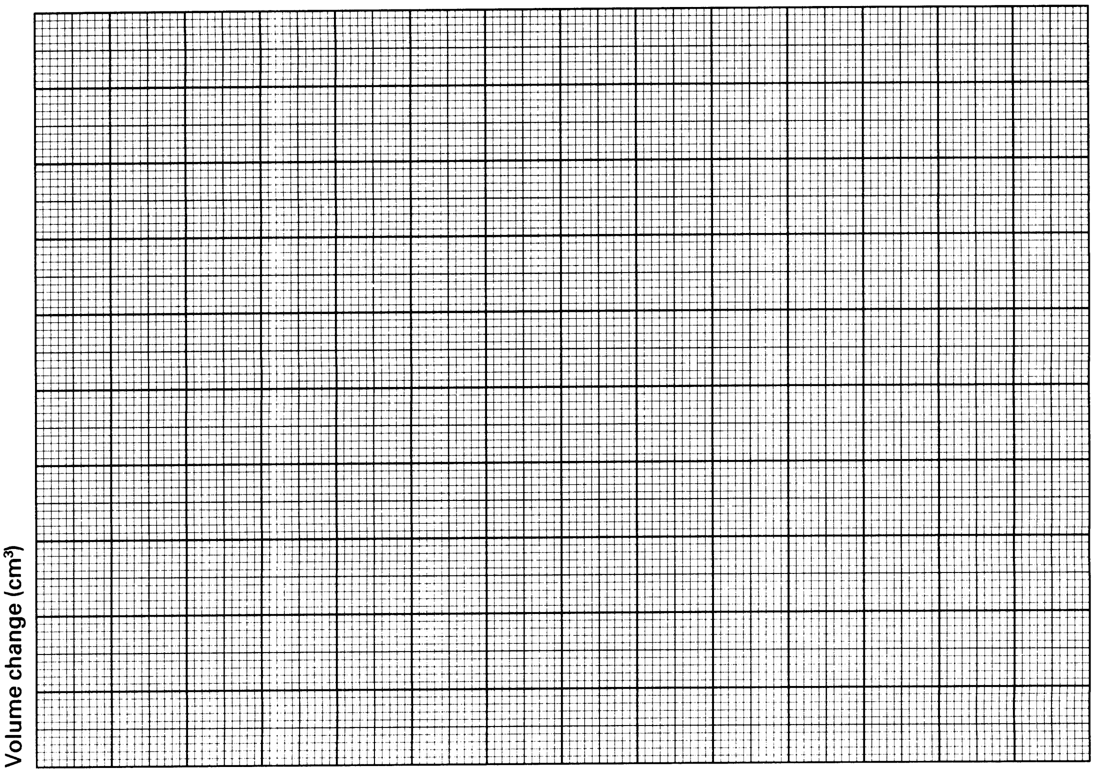
With/without* side drains	Date started	Completed
Pressure system no.	Cell no	

Required effective pressure, σ_3' (in kPa)		Initial diameter, D_o (in mm)	
Cell pressure, σ_3 (in kPa)		Initial length, L_o (in mm)	
Back pressure, u_b (in kPa)		Initial area, A_o (in mm^2)	
Pore pressure after build-up, u_i (in kPa)		Initial volume, V_o (in cm^3)	
Excess pore pressure, $(u_i - u_b)$ (in kPa)			

Consolidation data

Date	Time	Elapsed time t (min)	$\sqrt{t}$	Volume change indicator		Pore pressure		
				Reading (mL)	Difference (mL)	Reading u (kPa)	Difference $(u_i - u)$ (kPa)	Dissipation U (%)
		0	0		0		0	0
Final difference = total consolidation volume change ΔV_c								

Form 8.C



After consolidation			
Consolidated volume, $V_c = V_o - \triangle V_c$	cm^3		Coefficient of volume compressibility $m_{vi} = \frac{1000\,\varepsilon_v}{(u_i - u_c)}$ $m_{vi} =$ m^2/MN
Volumetric strain, $\varepsilon_v = \frac{\triangle V_c}{V_o}$			
Consolidated length, $L_c = L_o(1 - ⅓\,\varepsilon_v)$	mm		
Consolidated area, $A_c = A_o(1 - ⅔\,\varepsilon_v)$	mm^2		
Value of λ	Value of F		Coefficient of consolidation, $c_{vi} = \frac{2.1\,A_c}{\lambda t_{100}}$ = m^2/year
From graph, $\sqrt{t_{100}} =$	$t_{100} =$ min		
Significant testing time, $t_f = Ft_{100} =$ min			
Significant strain: assumed failure/reading intervals*, $\varepsilon_f =$			
Calculated rate of axial displacement, $d_r = \frac{\varepsilon_f L_c}{t_f} =$ mm/min			
Selected machine speed mm/min			
	Operator	Checked	Approved
*Delete as appropriate.			

Form 8.C (*concluded*)

Consolidation undrained triaxial compression test with measurement of pore pressure

Location

Job ref:

Borehole/ Pit ref:

Soil description

Sample no.

Depth m

Date

Test method Clause 7 of BS 1377: Part 8: 1990

Consolidated undrained triaxial compression test

Date

Pressure system no.	Membrane thickness mm	Start of compression	Failure criterion*	Max. deviator stress	Nominal σ_3' kPa
Cell no.		L_c mm		Max. stress ratio	Cell pressure kPa
Machine no.	With/without* side drains	A_c mm^2		Critical state	Machine speed mm/min
Force device no.		V_c cm^3		Axial strain of %	Rate of strain % per h

Date	Time	Axial strain			Area	Axial force				Pore pressure		Deviator stress			Principal stresses				A coeff.	Stress path*	
		Reading	ΔL (mm)	ϵ	A_s (mm^2)	Reading, R	Difference $R-R_o$	C_r (N/div.)	P (N)	u (kPa)	$u-u_o$ (kPa)	$(\sigma_1-\sigma_3)_m$ (kPa)	$\sigma_{mb}+\sigma_{dr}$ (kPa)	$(\sigma_1-\sigma_3)$ (kPa)	σ_1 (kPa)	σ_1' (kPa)	σ_3' (kPa)	Ratio σ_1'/σ_3'	$\frac{u-u_o}{\sigma_1-\sigma_3}$	s' (kPa)	t' (kPa)
			0	0			0		0		0			0				1			0

Operator	Checked	Approved

* Delete as appropriate.

Form 8.D

Consolidation drained triaxial compression test with measurement of volume change

Location		Job ref:	
		Borehole/ Pit ref:	
Soil description		Sample no.	
		Depth	m
		Date	
Test method Clause **8** of BS 1377: Part 8: 1990	Consolidated drained triaxial compression test	Date	

Pressure system no.	Membrane thickness mm	Start of compression	Failure criterion*	Max. deviator stress	Nominal σ_3' kPa
Cell no.		L_c mm			Cell pressure kPa
Machine no.	With/without* side drains	A_c mm^2		Critical state	Machine speed mm/min
Force device no.		V_c cm^3		Axial strain of %	Rate of strain % per h

Date	Time	Axial strain			Axial force				Sample volume			Area	Deviator stress			Principal stresses			Stress path*	
		Read-ing	ΔL mm	ϵ	Read-ing, R	Diff-erence $R-R_o$	C_r (N/div.)	P (N)	Read-ing (mL)	Diff-erence (mL)	ϵ_v	A_s mm^2	$(\sigma_1-\sigma_3)_m$ (kPa)	$(\sigma_{mb}+\sigma_{dr})$ (kPa)	$(\sigma_1-\sigma_3)$ (kPa)	σ_1 (kPa)	σ_1' (kPa)	σ_3' (kPa)	s' (kPa)	t' (kPa)
			0	0		0		0		0	0				0					0

	Operator	Checked	Approved

* Delete as appropriate.

Form 8.E

blank

Publications referred to

BS 1377, *Methods of test for soils for civil engineering purposes.*
BS 1377-1, *General requirements and sample preparation.*
BS 1377-2, *Classification tests.*

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