

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BS 1377:1975 which has now been withdrawn is replaced by the following Parts of BS 1377:1990: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

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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.

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:

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

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

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

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

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 $\frac{1}{2}$, 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 $\pm 2^\circ\text{C}$, 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 valve 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 O-rings*, for sealing the membrane on to the top cap and base pedestal. Two shall be fitted at each end. The O-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 O-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 paper¹⁾ (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.

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 cm³ capacity. For specimens of diameter 100 mm or larger, a 100 cm³ 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 $\pm 10\%$ 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.

