

Methods of test for

Soils for civil engineering purposes —

Part 7: Shear strength tests (total stress)

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Foreword

This Part of BS 1377 has been prepared under the direction of the Road Engineering Standard Policy Committee. It is a part revision of clause 5 of BS 1377:1975 which is superseded by amendment. BS 1377 was first published in 1948 and first appeared in metric form in 1975.

BS 1377:1975 which has now been withdrawn is replaced by the following Parts of BS 1377:1990: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 necessary provisions of a contract. Users of British Standard are responsible for their correct application.

Compliance with a British Standard does not 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 48, 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

This part of BS 1377 describes methods of test for determining shear strength parameters of soils in terms of total stresses, or (in the case of drained direct shear tests) in terms of effective stresses which are equal to total stresses. None of these procedures therefore requires measurement of pore water pressure, which is covered in Part 8 of BS 1377. Shear strength is determined either by measuring the shearing force causing failure (direct shear tests), or by derivation from the measured compressive strength (unconfined or triaxial compression tests).

Reference is made to Part 1 of BS 1377 for general requirements that are relevant to all Parts of this standard, and to Parts 1 and 4 for methods of preparation of soil and of test specimens.

Direct shear tests (clauses 3 to 6) comprise:

- a) laboratory vane test procedure, for soft to firm cohesive soils;
- b) small shearbox procedures for determining the angle of shear resistance of cohesionless soils, and the drained peak and residual shear strength parameters of cohesive soils;
- c) large shearbox procedures for determining similar properties of gravelly soils, or on large block samples;
- d) small ring shear procedure for drained residual shear strength parameters of remoulded clays.

Compression tests (clauses 7 to 9) comprise:

- e) unconfined compression test procedure, in the laboratory and in a portable apparatus for use on site;
- f) triaxial compression test procedure from which the undrained shear strength is derived;
- g) triaxial compression test procedure in several stages on one specimen, for deriving undrained shear strength.

The unconfined compression test procedure using portable apparatus, and the single-stage triaxial compression test, are similar in principle to those given in the 1975 Standard. All the other procedures are new additions.

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

2 Definitions

For the purposes of this Part of BS 1377 the definitions given in 2.1 of BS 1377-1:1990 apply, together with the following.

2.1

unconfined compression strength (q_u)

the compressive strength at failure of a specimen subjected to uniaxial (unconfined) compression. For a saturated clay,

$$q_u = 2c_u$$

where

c_u is the undrained shear

2.2

sensitivity

the ratio of the undrained shear strength of an undisturbed clay specimen to that of the same specimen after remoulding at the same moisture content

2.3

vane shear strength (τ_v)

the shear strength of a soil as determined by applying a torque in the vane shear test

2.4

undrained shear strength (c_u)

the shear strength of a soil under undrained conditions, before drainage of water due to application of stress can take place

2.5

residual strength

the shear strength which a soil can maintain when subjected to large shear displacement after the peak strength has been mobilized

3 Determination of shear strength by the laboratory vane method

3.1 General

This method covers the measurement of the shear strength of a sample of soft to firm cohesive soil without having to remove it from its container or sampling tube. The sample therefore does not suffer disturbance due to preparation of a test specimen. The method may be used for soils that are too soft or too sensitive to enable a satisfactory compression test specimen to be prepared.

The shear strength of the remoulded soil, and hence the sensitivity, can also be determined.

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

3.2 Apparatus

3.2.1 Laboratory vane apparatus, consisting essentially of the following. (A schematic arrangement is shown in Figure 1.)

a) A four-bladed cruciform vane mounted on a rod, the assembly being of stainless steel or plated steel and hard soldered. Typical blade dimensions are 12.7 mm wide and 12.7 mm long, but larger vanes may be used for measuring very low shear strengths. The design shall be such that it causes as little remoulding and disturbance as possible when inserted into a soil sample. The blades shall be as thin as possible, consistent with strength requirements. The area ratio of the vane, as expressed below, shall be as low as possible and shall not exceed 15 %.

$$\text{Area ratio} = \frac{8T(D-d) + \pi d^2}{\pi D^2} \times 100$$

where

D is the overall blade width measured to 0.1 mm (in mm);

T is the thickness of the blades measured to 0.01 mm (in mm);

d is the diameter of the vane rod, including any enlargement due to soldering measured to 0.1 mm (in mm);

b) A device for applying torque to the vane, such as a hand-operated or motorized worm and pinion drive with a suitable scale graduated in 1° intervals to indicate torque and fitted with a maximum reading indicator.

c) At least four calibrated open-coil torsion springs of different stiffnesses, capable of measuring applied torque up to 350 N mm. Each spring shall be calibrated at least once per year to an accuracy of within 2 % of its indicated torque within its working range.

d) A scale graduated in 1° intervals for measuring the angular rotation of the vane relative to the soil in which it is placed.

e) A means of lowering the vane vertically into the soil sample in a continuous smooth movement to the desired depth, such as a hand-operated lead-screw mounted on a rigid frame.

f) A baseplate attached to the frame on which the soil sample in its container can be mounted.

NOTE The arrangement should allow for mounting a 100 mm diameter sampling tube, to enable a test to be carried out on the soil in the tube.

3.2.2 Calibration curve for each torsion spring.

3.2.3 Means of attaching the sample container or tube to the base of the vane instrument.

3.2.4 Soil trimming tools.

3.2.5 Steel rule, readable to 0.5 mm.

3.2.6 Equipment for the determination of moisture content, as given in 3.2 of BS 1377-2:1990.

3.2.7 Stopclock, readable to 1 s.

3.3 Procedure

3.3.1 Attach the sample container securely to the base of the vane apparatus, with the sample axis vertical and located centrally under the axis of the vane.

3.3.2 Trim the upper surface of the sample flat and perpendicular to the axis.

3.3.3 Select a torsion spring that is most appropriate for the estimated strength of the soil and assemble it into the vane apparatus.

3.3.4 Set the pointer and the graduated scale on the torsion head to their zero readings, and ensure that there is no backlash in the mechanism for applying torque.

3.3.5 Lower the vane assembly until the end of the vane just touches the surface of the sample. This provides the datum from which the depth of penetration of the vane can be measured.

3.3.6 Lower the vane assembly further to push the vane steadily into the sample to the required depth. The top of the vane should be at a distance not less than four times the blade width below the surface. Record the depth of penetration.

3.3.7 Apply torque to the vane by rotating the torsion head at a rate of 6 °/min to 12 °/min, until the soil has sheared.

NOTE This is indicated by a decrease in torque and an uncontrolled rotation of the vane.

3.3.8 Record the maximum angular deflection of the torsion spring and the angle of rotation of the vane at the instant of failure.

3.3.9 Rotate the vane rapidly through two revolutions so as to remould the soil in the sheared zone.

3.3.10 Immediately set the scales to zero as in 3.3.4, and repeat 3.3.7 and 3.3.8 for the soil in the remoulded condition.

3.3.11 Raise the vane steadily. As it emerges from the sample prevent excessive disturbance due to tearing of the surface. Wipe the blades clean.

3.3.12 Repeat 3.3.4 to 3.3.11 with the vane positioned at two or more additional locations at the same level in the sample.

NOTE 1 In a 100 mm diameter sampling tube, four additional tests equally spaced at a radius of 30 mm from the centre can be performed using a 12.7 mm vane.

NOTE 2 The centre to centre distance between the points of measurement should be not less than 2.3 times the blade width.

3.3.13 Extrude the sample from its container and take specimens from the level at which the tests were carried out for determining the soil moisture content, using the procedure given in 3.2 of BS 1377-2:1990.

3.3.14 Record a visual description of the soil at the same level.

3.4 Calculations

3.4.1 For each determination calculate the torque applied to shear the soil, M (in N mm), by multiplying the maximum angular rotation of the torsion spring (in degrees) by the calibration factor (in N mm per degree).

3.4.2 Calculate the vane shear strength of the soil, τ_v in kPa) from the equation:

$$\tau_v = \frac{M}{K} \times 1000$$

where

K is a constant which depends on the dimensions of the vane.

NOTE 1 The value of K (in mm³) is given by the following equation, which assumes that the distribution of shear stress is uniform around the perimeter and across the ends of the cylinder of soil at failure.

$$K = \pi D^2 \left(\frac{H}{2} + \frac{D}{6} \right)$$

where

D is the overall width of the vane measured to 0.1 mm (in mm).

H is the length of the vane measured to 0.1 mm (in mm).

The value of K for the vane 12.7 mm wide and 12.7 mm long referred to in 3.2.1 a) is 4 290 mm³.

NOTE 2 The vane dimensions should be checked periodically to ensure that the vane is not distorted or worn.

3.4.3 Calculate the average value of the vane shear strength of the undisturbed soil, τ_v (in kPa).

3.4.4 Calculate the average value of the vane shear strength of the remoulded soil, τ_{vr} (in kPa).

3.4.5 Calculate the moisture content of the soil at the test horizon.

3.5 Test report

The test report shall state that the test was carried out in accordance with clause 3 of BS 1377-7:1990. It shall contain the following, in addition to the information listed in clause 9 of BS 1377-1:1990.

- statement of the method used, i.e. determination of shear strength by the laboratory vane method;
- the average vane shear strength for the undisturbed soil, τ_v (in kPa), to two significant figures;
- the average remoulded shear strength, τ_{vr} (in kPa), to two significant figures, if required;
- the moisture content of the soil at the test horizon;
- dimensions of the vane used in the test;

f) description of soil at the test horizon;

g) location of the test horizon in the sampling tube;

h) the type and diameter of the sampling tube.

4 Determination of shear strength by direct shear (small shearbox apparatus)

4.1 General

4.1.1 Principle. In the direct shear test a square prism of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to a pressure applied normal to that plane. The shearing resistance offered by the soil as one portion is made to slide on the other is measured at regular intervals of displacement. Failure occurs when the shearing resistance reaches the maximum value which the soil can sustain.

By carrying out tests on a set of (usually three) similar specimens of the same soil under different normal pressures, the relationship between measured shear stress at failure and normal applied stress is obtained.

The small shearbox apparatus referred to in this standard is designed for carrying out tests of this kind on soil specimens of 60 mm or 100 mm square and 20 mm to 25 mm high.

4.1.2 Types of test. The shearbox apparatus can be used only for carrying out drained tests for the determination of effective shear strength parameters. There is no control of drainage and the procedure cannot be used for undrained tests.

The test specimen is consolidated under a vertical normal load until the primary consolidation is completed. It is then sheared at a rate of displacement that is slow enough to prevent development of excess pore pressures. Test data enable the effective shear strength parameters c' and ϕ' to be derived.

The residual shear strength parameters c'_R , ϕ'_R can be obtained by extending the tests to give large cumulative displacements by reversals and re-shearing (see 4.5.5.5).

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

4.1.3 Test conditions. The following test conditions shall be specified before a series of tests is started:

- size of test specimens;
- whether undisturbed or remoulded specimens are to be tested;
- for undisturbed specimens, the orientation of the specimens relative to the plane of shear;

- d) for remoulded specimens the moisture content, and either the dry density to be achieved or the compactive effort to be applied;
- e) number of test specimens to be tested as a set;
- f) the normal pressures to be applied;
- g) whether the residual strength is required, and if so the method of reversal (see 4.5.5.5).

4.1.4 Environmental requirements. These tests shall be carried out in a laboratory in which the temperature is maintained constant to within ± 4 °C, in compliance with 6.1 of BS 1377-1:1990. All apparatus shall be protected from direct sunlight, from local sources of heat and from draughts.

4.2 Apparatus

4.2.1 Shearbox apparatus. The small shearbox apparatus enables a square specimen of soil of up to about 25 mm thickness to be sheared horizontally along its mid-height plane while subjected to a vertical stress. The whole apparatus shall be mounted on a rigid bed. The essential requirements are as follows.

- a) A container for the specimen ("the shearbox") which is square in plan and divided horizontally into two halves. The lower half is fitted with a removable grooved baseplate which when fitted allows free movement of water. The shearbox shall be rigid enough to resist distortion under maximum load.

Arrangements shall be provided for locking the two halves of the shearbox securely together while the specimen is being placed, and for lifting the upper half of the box off the lower half by a small controlled vertical displacement without tilt, after applying vertical load to the specimen. When released the lower half shall be able to move freely relative to the upper half.

Typical details of a shearbox are shown in Figure 2. The shearbox is placed in a carriage [see 4.2.1 b)], in which the lower half of the box can be secured rigidly in place. The upper half shall be fitted with a central attachment which ensures that the applied horizontal shearing force is in the same plane as the plane of shear induced in the specimen.

- b) An outer container (the carriage) in which the shearbox can be placed to enable the test specimen to be submerged under water during the test. The carriage is supported on the bed of the machine by a low-friction bearing which allows movement in the longitudinal direction only. A typical assembly is shown diagrammatically in Figure 3.

The materials comprising the shearbox, the outer container and all components which fit into it shall be resistant to corrosion by electro-chemical reaction with each other.

- c) Two porous plates of corrosion-resistant material, about 0.5 mm smaller than the internal plan dimensions of the shearbox. Their porosity shall allow free drainage of water throughout the test but shall prevent intrusion of soil into their pores.

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

- d) Two perforated spacer plates of about the same size in plan as the porous plates, if necessary.

- e) A loading cap to cover the top spacer plate or porous plate, fitted with a central ball seating through which vertical load is applied to the specimen. The cap shall be about 0.5 mm smaller in plan than the internal dimensions of the shearbox, and shall be rigid enough to transmit the vertical load uniformly to the specimen without deformation.

- f) A calibrated means of applying a vertical force to the loading cap such as a loading yoke, preferably counterbalanced, carrying calibrated masses. For high loads a mechanical lever system, preferably counterbalanced, may be used. The vertical force applied to the test specimen shall be known to an accuracy of 1 %. The loading device shall enable the vertical stress to be applied to the specimen without significant impact, for which a screwjack support is advantageous.

- g) A motorized loading device capable of applying horizontal shear to the vertically loaded specimen at constant rates of displacement from which a rate to suit the soil being tested can be selected. The actual rate of displacement shall not vary by more than ± 10 % of the desired value. The machine shall be capable of applying a horizontal displacement to the specimen of at least 8 mm.

- h) (For multi-reversal residual strength tests only.) Suitable fittings to enable the shearbox to be returned to its starting position when the drive motor is reversed.

- i) A calibrated force-measuring device, suitably mounted.

NOTE The force-measuring device may be a load ring or load transducer. Several devices of this kind, of various capacities, should be available, and the one selected for test should be appropriate to the strength of the soil specimen.

j) A calibrated dial gauge or displacement transducer suitably mounted to measure the relative horizontal displacement of the two halves of the shearbox. The gauge shall be readable to 0.01 mm and shall have at least 10 mm travel.

NOTE Alternatively the horizontal displacement indicator can be used to measure the travel of the carriage, from which the relative displacement is obtained by deducting the deflection of the force measuring device. The relationship between dial divisions, or digits, and linear displacement of the force measuring device should be ascertained beforehand.

k) A calibrated dial gauge or displacement transducer capable of measuring the vertical deformation of the specimen during the test, readable to 0.002 mm.

4.2.2 Specimen cutter of suitable corrosion-resistant metal of the same internal dimensions as the required specimen size. The cutter shall be provided with sharp externally-chamfered cutting edges and smooth internal surfaces.

4.2.3 Apparatus for obtaining and trimming a specimen in the cutter, as described in 8.2 of BS 1377-1:1990.

4.2.4 Tool for removing the specimen from the cutter.

4.2.5 Metal tamping rod with a square end about 10 mm across flats.

4.2.6 (Optional). Small hand-held vibrator (an electric engraving tool has been found suitable), fitted with a suitable tamping foot, for vibrating dry cohesionless soil into the shearbox.

4.2.7 Levelling template for trimming the surface of the specimen in the shearbox to a known level.

4.2.8 Calibrated vernier external/internal caliper for measuring the internal dimensions and height of the cutting ring or test specimen to 0.1 mm.

4.2.9 Calibrated vernier depth-gauge or a micrometer gauge on a suitable comparator support for measuring the depth to the top of the specimen when in the shearbox, and the projection of the top cap, to an accuracy of 0.1 mm.

4.2.10 Stopclock, readable to 1 s.

4.2.11 Balance, readable to 0.01 g.

4.2.12 Watch glass or metal tray suitable for holding the specimen and cutter.

4.2.13 Apparatus for determining moisture content, in accordance with 3.2 of BS 1377-2:1990.

4.2.14 Silicone grease or petroleum jelly.

4.3 Checking and preparation of apparatus

4.3.1 Measurements.

NOTE See form 7(a) of Appendix A.

4.3.1.1 Ensure that the specimen cutter is clean and dry, and that the cutting edge is in good condition.

4.3.1.2 Determine and record the mass of the cutter to 0.01 g.

4.3.1.3 Determine the mass of the tray or watch glass to 0.01 g.

4.3.1.4 Verify and record the mean internal dimensions of the cutter to 0.1 mm.

4.3.1.5 Ensure that the shearbox components are clean and dry. Clamp the two halves of the box securely together with the clamping screws, fit the baseplate and assemble the shearbox securely in the carriage.

4.3.1.6 Determine the internal plan dimensions ($L_1 \times L_2$) of the shearbox to 0.1 mm, and calculate the plan area A (in mm²). Determine the mean depth from the top surface of the upper half to the top of the baseplate (h_1) to 0.1 mm.

4.3.1.7 Measure and record the thickness of each porous plate and spacer plate to 0.1 mm. Determine the combined thickness of plates to be used for the test (t_p).

4.3.2 Preparation and assembly of shearbox

4.3.2.1 Apply a thin coating of silicone grease or petroleum jelly to the inside faces of the shearbox and to the surfaces of contact between the two halves of the box.

4.3.2.2 Assemble the shearbox with two halves securely clamped together, fit the baseplate and place it securely in position in the carriage.

4.3.2.3 Place a spacer plate on the base of the box if necessary, followed by a porous plate.

4.4 Preparation of specimen

4.4.1 General. Specimens of either cohesive or non-cohesive soil may be tested in the shearbox. Preparation procedures depend on the type of soil, as indicated below. The size of the largest particle shall not exceed one-tenth of the height of the specimen.

Loss or gain of moisture by the sample shall be avoided at all stages of preparation, such as by carrying out these operations in a suitable humidified atmosphere if necessary.

Normally three similar specimens are prepared from an undisturbed or remoulded cohesive sample, for testing under three different normal pressures. A non-cohesive sample shall be large enough to provide three separate specimens to avoid having to re-use the same material.

Form 7(a) of Appendix A is suitable for recording specimen details and measurements.

4.4.2 Preparation of specimen of undisturbed cohesive soil

4.4.2.1 Weigh the specimen cutter to 0.1 g.

4.4.2.2 Obtain and trim a specimen from the soil sample by using the cutter and guide jig, as described in **8.6** or **8.7** of BS 1377-1:1990.

NOTE For a very compressible soil the initial specimen thickness should be adequate to ensure that after consolidation the plane of the shear is formed near the mid-height.

4.4.2.3 Weigh the specimen in the cutter to 0.1 g, and calculate the initial mass (m_o) of the specimen.

4.4.2.4 Rest the cutter on the top surface of the assembled shearbox with its inside faces in exact alignment with the inside faces of the box.

4.4.2.5 Push the specimen out of the cutter and into the shearbox keeping its upper face horizontal, until it is bedded on to the lower porous plate.

NOTE Alternatively the top porous plate, spacer plate and loading cap could be placed on the specimen first, as described in **4.4.2.7** and **4.4.2.8**, and used to push the specimen into the box.

Avoid consolidating the specimen.

4.4.2.6 Place the upper porous plate firmly on the specimen. Ensure that there is an equal clearance all around the edges of the plates.

4.4.2.7 Measure the distance from the top of the shearbox to the surface of the porous plate to 0.01 mm (h_2).

4.4.2.8 Place a spacer plate if necessary, and the loading cap, on the porous plate with a uniform all-round clearance.

4.4.3 Preparation of specimen of compacted cohesive soil

4.4.3.1 Prepare the soil at the desired moisture content, as described in **7.7.2** of BS 1377-1:1990.

4.4.3.2 Compact the soil with the required compactive effort, or to achieve the desired density, into a suitable container such as a 1 L compaction mould, using the appropriate procedure described in **7.7.4.2** of BS 1377-1:1990.

4.4.3.3 Seal and store the sample in accordance with **7.7.6** of BS 1377-1:1990.

4.4.3.4 Prepare a set of test specimens from the compacted sample and set up each specimen as in **4.4.2**.

NOTE For a very compressible soil the initial specimen thickness should be adequate to ensure that after consolidation the plane of the shear is formed near the mid-height.

4.4.3.5 If there is not enough soil available to fill a compaction mould the specimen may be prepared by compacting or remoulding the soil directly into the specimen cutter, or into the top half of the shearbox, which is first weighed empty. Hold the cutter or half shearbox firmly in contact with a flat surface while tamping the soil evenly into it in three approximately equal layers, using the square-ended tamper. Ensure that the level of the shear surface will pass through the mid-height of the middle layer. Trim, level and weigh the soil in the cutter or shearbox, seal it and allow it to stand for at least 24 h to enable any excess pore pressures to dissipate. Re-weigh before extruding into position in the shearbox.

4.4.4 Preparation of specimen of cohesionless soil

4.4.4.1 General. The procedure depends on whether the soil is dry and can be poured, or damp and needs to be tamped, or saturated.

NOTE 1 For a dry sand the question of drainage does not arise and the cell is assembled with solid spacer plates. For a saturated sand adequate drainage is necessary, and perforated plates should be used.

Soil that is to be placed dry or saturated shall not contain a significant amount of material passing a 63 μm test sieve, to avoid segregation of fine particles, and is therefore referred to as sand.

NOTE 2 A silty soil that is placed in a damp condition and then inundated should not be subjected to a rapid test.

4.4.4.2 Dry sand: loose

4.4.4.2.1 Prepare a quantity of soil somewhat larger than that required for the test specimen, as described in **7.3.5** of BS 1377-1:1990, and determine its mass to 0.1 g.

4.4.4.2.2 Place or pour the sand directly into the assembled shearbox from the quantity of known mass.

NOTE A "loose" density is often achieved by rapid pouring from a small height. The method of placing to achieve the desired density consistently should be ascertained previously by trial.

4.4.4.2.3 Level the surface of the specimen using a suitable template to give a specimen of the appropriate thickness, without disturbing the main body of the placed soil.

4.4.4.2.4 Collect any spilled or removed material, weigh the total of the unused soil to 0.1 g and determine the initial mass of the specimen (m_o) by difference.

4.4.4.2.5 Place the porous plate on the specimen. Gently bed down the plate to form a level surface, ensuring there is a uniform clearance all round.

4.4.4.2.6 Measure the distance from the top of the shearbox to the top surface of the plate, to 0.1 mm (h_2).

4.4.4.2.7 Place the top spacer plate (if necessary) and the loading cap carefully on top of the porous plate, with a uniform clearance all round. Avoid jolting or bumping the shearbox during these operations.

4.4.4.3 Dry sands: compacted

4.4.4.3.1 Prepare a quantity of soil somewhat larger than that required for the test specimen, as described in 7.3.5 of BS 1377-1:1990, and determine its mass to 0.1 g.

4.4.4.3.2 Place the sand from the quantity of known mass evenly into the shearbox and apply a controlled amount of tamping with the square-ended tamper, or apply vibration to the specimen through the plate for as long as necessary, to achieve the desired density.

NOTE The amount of tamping or vibration required to give the desired density should be ascertained previously by trial.

4.4.4.3.3 Trim and measure the specimen and fit the top plates and loading cap as described in 4.4.4.2.2 to 4.4.4.2.7.

4.4.4.4 Saturated sands

4.4.4.4.1 Prepare a quantity of soil somewhat larger than that required for the test specimen, as described in 7.3.5 of BS 1377-1:1990, and determine its mass to 0.1 g.

4.4.4.4.2 Fit the bottom spacer plate (if necessary) and porous plate in the shearbox, and fill it and the carriage with water to the level corresponding to the top of the specimen.

4.4.4.4.3 Place a known dry mass of sand in water, boil for about 10 min and allow to cool, or place under vacuum to remove air bubbles.

4.4.4.4.4 Place the saturated sand into the shearbox and compact it by vibration to achieve the desired density.

NOTE It is not practicable to obtain a saturated specimen of "loose" density under these conditions.

4.4.4.4.5 Collect all surplus sand, dry and weigh it to 0.1 g and determine the dry mass of the specimen (m_o) by difference.

4.4.4.4.6 Trim and measure the specimen and fit the top plates and loading cap as described in 4.4.4.2.3 to 4.4.4.2.7.

4.4.4.5 Partially saturated cohesionless soil

4.4.4.5.1 Prepare a quantity of soil somewhat larger than that required for the test specimen, as described in 7.3.5 of BS 1377-1:1990, and determine its mass to 0.1 g.

4.4.4.5.2 If necessary adjust the moisture content of the prepared soil to the value required for the test specimen. Determine its mass to 0.1 g and verify its moisture content.

4.4.4.5.3 Place the material in the shearbox, fitted with bottom plates, and compact by tamping as described in 4.4.4.3.2.

4.4.4.5.4 Trim and measure the specimen and fit the top plates and loading cap as described in 4.4.4.2.3 to 4.4.4.2.7.

4.5 Test procedure

4.5.1 Initial adjustments

4.5.1.1 Position the carriage on its bearings on the machine bed, and adjust the drive unit to the correct starting point of the shear test. Secure the horizontal displacement gauge in position.

4.5.1.2 Measure the height of the top of the load cap above the top of the box (h_3) to 0.1 mm.

4.5.1.3 Assemble the loading system so that the loading yoke is supported by the ball seating on top of the load cap.

NOTE If provision is made for supporting the weight of the yoke when first placed on the ball seating, or the yoke is counterbalanced, the initial vertical settlement can be measured by the vertical movement gauge, and 4.5.1.2 and 4.5.1.4 are not necessary.

4.5.1.4 Measure the height of the top of the load cap above the top of the box again (h_4) to 0.1 mm. The difference ($h_3 - h_4$) gives the settlement of the specimen under the seating pressure provided by the loading yoke.

4.5.1.5 Secure the vertical deformation gauge in position so that it can measure the vertical movement of the centre of the loading cap, ensuring that it allows enough movement in either direction. Record the initial zero reading.

4.5.2 Consolidation

4.5.2.1 Apply a normal force to the specimen, to give the desired vertical (normal) stress, σ_n (in kPa), smoothly and as rapidly as possible without jolting. Start the clock at the same instant if consolidation readings are significant.

NOTE Dry sand or free-draining saturated sand consolidates very rapidly, therefore consolidation readings are not necessary and a rapid test is suitable. For all other soils, time readings should normally be recorded.

If the consolidation readings are not significant, continue at 4.5.3.

4.5.2.2 Except when testing dry soils, as soon as possible after applying the normal force fill the carriage with water to a level just above the top of the specimen, and maintain it at that level throughout the test.

4.5.2.3 Record readings of the vertical deformation gauge and elapsed time at suitable intervals to allow a graph to be drawn of vertical deformation as ordinate, against square-root of elapsed time as abscissa. A plot of vertical deformation against time to a logarithmic scale may also be made. Continue until the plotted readings indicate that primary consolidation is complete. Form 7(b) of Appendix A is suitable for recording and plotting these data.

4.5.2.4 Using the square-root time plot, extend the approximately linear portion of the graph (which normally lies between just after zero time to about 50 % of primary consolidation) downwards. Identify the point at which this line intersects the horizontal line through the final point on the curve of primary consolidation, and read off the value ($\sqrt{t_{100}}$) on the square-root time axis.

4.5.2.5 Calculate the value of t_{100} (min.), and the minimum time to failure, i.e. to mobilization of maximum shear resistance by the specimen, t_f (min.), from the equation.

$$t_f = 12.7t_{100}$$

NOTE This test does not permit the derivation of a reliable value of coefficient of consolidation, c_v .

4.5.2.6 Estimate the likely horizontal shear deformation of the specimen at failure (in mm). Divide it by t_f to obtain the maximum rate of displacement (in mm/min) to be applied during the shear test.

4.5.3 Final adjustments

4.5.3.1 On completion of the consolidation stage and before shearing (see 4.5.4 or 4.5.5) make the following checks and adjustments described in 4.5.3.2 to 4.5.3.7.

4.5.3.2 Rate of displacement:

- for a rapid test in which consolidation takes place very rapidly, the rate of displacement should induce failure within a period of 5 min to 10 min;
- for a slow test set the constant rate of displacement device to give a rate of displacement not greater than that calculated in 4.5.2.5 and 4.5.2.6.

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 the load frame. The actual rate of relative displacement of the two halves of the specimen is the "closing gap speed" and allowance should be made for the difference between this and the nominal machine speed if greater accuracy is required.

4.5.3.3 Ensure that all adjacent components from the constant rate of displacement device through to the load measuring device and its point of restraint are properly in contact, but under zero horizontal load.

4.5.3.4 For a multi-reversal test only, ensure that the necessary components for providing reverse travel are correctly fitted, with minimum backlash.

4.5.3.5 Remove the clamping screws which lock the two halves of the shearbox together.

4.5.3.6 Raise the upper half of the box, keeping it level, by turning the lifting screws. The amount of clearance between the two halves should be enough to prevent them coming together during the test, but shall not permit extrusion of the soil between them. Retract the lifting screws.

NOTE For fine-grained soils, lifting by a half-turn of the screws is usually sufficient. For sandy soils the lift might need to be slightly greater but should not exceed about 1 mm.

4.5.3.7 Record the initial readings of the horizontal displacement gauge, the vertical deformation gauge and the force measuring device.

4.5.4 Shearing: single stage tests

NOTE See form 7(c) of Appendix A.

4.5.4.1 Shear the specimen to failure as described in 4.5.4.2 to 4.5.4.10, using the rate of shear displacement selected in accordance with 4.5.3.2.

4.5.4.2 Start the test and at the same instant start the timer. Record readings of the force measuring device, the horizontal displacement gauge, the vertical deformation gauge and elapsed time, at regular intervals of horizontal displacement such that at least 20 readings are taken up to the maximum load ("peak" shear strength).

NOTE Intervals of horizontal displacement of 0.1 mm often meet this requirement. For brittle specimens such as dense sand, sets of data should be recorded at frequent intervals of force, instead of displacement, to ensure that enough readings are taken. For plastic materials the intervals may be greater than normal.

4.5.4.3 Take additional readings as the maximum horizontal force is approached, so that if the "peak" occurs it can be clearly defined.

4.5.4.4 During the test, monitor the rate of relative displacement of the two halves of the shearbox against elapsed time regularly, if appropriate. If this rate exceeds the maximum rate calculated in 4.5.2.6, reduce the speed of travel accordingly.

4.5.4.5 Continue shearing and taking readings beyond the maximum force, or until the full travel of the apparatus has been reached if there is no defined peak, then stop the test.

4.5.4.6 Reverse the direction of travel of the carriage and return the two halves of the shearbox to their original alignment.

4.5.4.7 If the specimen was sheared under water, siphon off the water from around the specimen and allow to stand for about 10 min to enable free water to drain from the porous plates.

4.5.4.8 Remove the vertical force and loading yoke from the specimen.

4.5.4.9 Transfer the specimen from the shearbox to a small tray, taking care not to lose any soil. Remove any free water with a tissue.

4.5.4.10 Weigh the specimen on the tray to 0.1 g.

4.5.4.11 Dry the soil in an oven at 105 °C to 110 °C and determine its dry mass (m_d) to 0.1 g, and its final moisture content.

4.5.5 Shearing: multi-reversal test

NOTE 1 See form 7(c) of Appendix A.

NOTE 2 The multi-reversal shear test enables the residual shear strength as well as the peak strength of a soil to be determined.

4.5.5.1 Connect the reverse-travel attachments (see 4.5.3.4).

4.5.5.2 Shear the specimen at the rate of shear displacement selected in accordance with 4.5.3.2 b). Take readings at suitable intervals as described in 4.5.4.2 and 4.5.4.3.

4.5.5.3 During the test, monitor the rate of relative displacement as described in 4.5.4.4.

4.5.5.4 Continue shearing and taking readings beyond the maximum force and until the full travel of the apparatus has been reached.

4.5.5.5 Return the shearbox to its starting position by one of the following reversal procedures:

- a) Machine-drive reversal and re-shearing. Reverse the direction of travel until the two halves of the shearbox return to their original alignment. Adjust the rate of reverse displacement so that the reversing operation takes place over a period of time about equal to the time from the start of shearing to reaching peak shearing force.

NOTE Shear stresses during reverse travel have no significance.

- b) Reversal by hand and re-shearing. Reverse the direction of travel as in 4.5.5.5 a) but by hand winding the machine within a period of a few minutes. Allow to stand at least 12 h to enable pore pressure equilibrium to be re-established.

- c) Rapid multi-reversals by hand. Apply five to ten backward and forward traverses within a period of a few minutes by hand winding, to establish a shear plane, finishing with the original alignment. Allow to stand at least 12 h as in 4.5.5.5 b).

4.5.5.6 Verify that the horizontal displacement gauge and the force measuring device have returned to their initial zero readings, and record the reading of the vertical displacement gauge.

4.5.5.7 Re-shear the specimen as in 4.5.5.2 to 4.5.5.4, applying the rate of displacement as used for the reverse travel in 4.5.5.5 a).

4.5.5.8 Repeat 4.5.5.5 to 4.5.5.7 as many times as necessary to obtain a repeatable residual value of the shear resistance. Stop the test at the end of the final forward shearing travel.

4.5.5.9 Siphon off the water from around the specimen and allow to stand for about 10 min to enable free water to drain from the porous plates.

4.5.5.10 Remove the vertical force and loading yoke from the specimen.

4.5.5.11 Separate the two halves of the specimen by pushing in the direction of shear during the test.

4.5.5.12 Record the significant features of both sides of the surface of shear, with the aid of sketches.

NOTE These features may be recorded photographically if required.

4.5.5.13 Transfer both halves of the specimen to a small tray, taking care not to lose any soil. Remove any free water with a tissue.

4.5.5.14 Weigh the specimen and tray to 0.1 g.

4.5.5.15 Dry the specimen to constant mass and determine the dry mass (m_d) to 0.1 g and the final moisture content, using the procedure of 3.2 of BS 1377-2:1990.

4.6 Calculations and plotting

4.6.1 General data

NOTE See form 7(a) of Appendix A.

4.6.1.1 Calculate the initial moisture content, w_o (in %), from the equation

$$w_o = \frac{m_o - m_d}{m_d} \times 100$$

where

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

m_d is the final dry mass of the specimen (in g).

4.6.1.2 Calculate the initial dry density, ρ_d (in Mg/m³) from the equation

$$\rho_d = \frac{m_d \times 1000}{AH_o}$$

where

A is the plan area of the specimen (in mm²);

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

NOTE For an undisturbed specimen trimmed in the specimen cutter, H_o is equal to the height of the cutter.

For a disturbed specimen formed in the shearbox, H_o is calculated from h_1 (see 4.3.1.6) h_2 (see 4.4.2.7) and the appropriate plate thickness t_p (see 4.3.1.7).

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

$$\rho = \frac{m_o \times 1000}{AH_o}$$

4.6.1.4 Calculate the initial voids ratio, e_o , (if required) from the equation

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

where

ρ_s is the particle density (in Mg/m^3) (which may be measured, or assumed).

4.6.1.5 Calculate the initial degree of saturation, S_o , (if required) as percentage from the equation

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

4.6.1.6 Calculate the voids ratio, e , at the end of the consolidation stage, and at the end of shearing (if required) from the equation

$$e = e_o - \frac{\Delta H}{H_o}(1 + e_o)$$

where

ΔH is the calculated change in height (vertical deformation) of the specimen (in mm) from the initial zero reading.

NOTE If the change in specimen height after shearing is required, the settlement under the seating pressure, ($h_3 - h_4$) (see 4.5.1.4) should be taken into account.

4.6.2 Stresses and displacements

NOTE See form 7(c) of Appendix A.

4.6.2.1 From each set of data obtained during the shear test calculate the horizontal shear force, P (in N), applied to the specimen.

4.6.2.2 Calculate the shear stress on the surface of shear, τ (in kPa), for each set of readings from the equation

$$\tau = \frac{P}{A} \times 1000$$

where

A is the initial plan area of the specimen (in mm^2).

NOTE The continual change in the area of contact is not normally taken into account.

4.6.2.3 The normal stress, σ_n , (in kPa), applied to the specimen (see 4.5.2.1) is given by the equation

$$\sigma_n = \frac{9810m}{A}$$

where

m is the mass of the hanger and hanger weights (or equivalent mass if a lever-arm loading system is used) applied to the loading cap (in kg).

NOTE The continual change in the area of contact is not normally taken into account.

4.6.2.4 In the second and subsequent travels of a multi-reversal test, calculate forward displacement for each set of readings by adding the observed displacement to the cumulative forward displacement at the end of the previous travel.

4.6.2.5 Calculate the cumulative vertical deformation for each set of readings relative to the datum corresponding to the initial specimen height.

4.6.3 Graphical plots: single stage tests

NOTE 1 See form 7(d) of Appendix A.

For each specimen of a set of single-stage tests, plot the following graphs.

- Shear stress (in kPa) as ordinates against horizontal displacement (in mm) as abscissae.
- Change in height (vertical deformation) of the specimen (in mm) as ordinates against horizontal displacement (in mm) as abscissae, if required. If preferred the changes in height may be plotted in terms of voids ratio by using the equation given in 4.6.1.6.
- From each stress-displacement graph read off the value of the maximum shear stress (the "peak" strength) and the corresponding horizontal displacement and change in specimen height.
- Plot each value of peak strength, τ_f (in kPa), as ordinates against the corresponding normal stress, σ_n (in kPa) applied for that test as abscissae, both to the same linear scale.
- If it can be assumed that the relationship is linear, the slope of the line and its intercept with the shear strength axis can be derived from the line of best fit through the plotted points. The slope gives the angle of shearing resistance ϕ' (in degrees), and the intercept gives the apparent cohesion c' (in kPa), both in terms of effective stress.

NOTE 2 Peak and residual strength relationships may show non-linearity, and their interpretation requires further consideration.

4.6.4 Graphical plots: multi-reversal tests

NOTE 1 See form 7(d) of Appendix A.

For each specimen of a set of multi-reversal tests, plot the following graphs.

- Shear stress (in kPa) as ordinates, against cumulative forward displacement (in mm) as abscissae, for each shearing stage in succession.

b) Change in height (vertical deformation) of the specimen (in mm) as ordinates, against cumulative forward movement (in mm) as abscissae, as above, if required.

c) From the first stage stress-displacement graph for each specimen read off the value of the maximum shear stress (the “peak” strength, τ_f (in kPa) and the corresponding cumulative displacement and change in specimen height (in mm).

d) From the later stages determine the residual value of shear stress τ_r (in kPa) which each stage tends to approach.

e) Plot each value of maximum strength, τ_f (in kPa), and residual strength, τ_r (in kPa), as ordinates against the corresponding normal stress, σ_n (in kPa), applied for that test as abscissae, both to the same linear scale.

f) If it can be assumed that the relationships are linear, the slopes of the lines and their intercepts with the shear strength axis can be derived from lines of best fit through the two sets of plotted points. The slope of the maximum strength envelope gives the angle of shearing resistance ϕ' (in degrees), and the intercept gives the apparent cohesion c' (in kPa), both in terms of effective stress for the maximum condition. The slope and intercept of the residual strength envelope give the residual angle of shearing resistance ϕ'_R (in degrees) and the residual cohesion value c'_R (in kPa).

NOTE 2 Peak and residual strength relationships may show non-linearity, and their interpretation requires further consideration.

4.7 Test report

The test report shall state that the test was carried out in accordance with clause 4 of BS 1377-7:1990. It shall contain the following, in addition to the information listed in clause 9 of BS 1377-1:1990:

- a) statement of the method used, i.e. determination of the shear strength by direct shear in the small shearbox apparatus, using the procedure of 4.5.4 or 4.5.5, as appropriate;
- b) initial dimensions of the specimens;
- c) initial moisture content, bulk density, and dry density;
- d) particle density, indicating whether measured or assumed;
- e) initial voids ratio and degree of saturation, if required;

f) tabulated values for each specimen of the applied normal stress, maximum shear stress, corresponding horizontal relative displacement and, if relevant, the residual shear stress, final cumulative displacement and number of traverses;

g) rate or rates of horizontal displacement;

h) method used for reversing the shearbox in multi-reversal tests;

i) whether the specimens were tested dry or submerged;

j) graphical plots of settlement against square-root time for each specimen, if relevant;

k) graphical plots of shear stress, and if required, the change in specimen thickness, against cumulative horizontal displacement for each specimen;

l) graphical plots of maximum shear stress, and residual shear stress if relevant, against normal applied stress, showing the derivation of c' , ϕ' , and c'_R , ϕ'_R if relevant;

m) (only if the plotted relationships are linear) angle of shearing resistance, ϕ' , to the nearest $\frac{1}{2}^\circ$, and cohesion intercept, c' (in kPa) to two significant figures, for the maximum condition; and, if appropriate, ϕ'_R and c'_R for the residual condition.

5 Determination of shear strength by direct shear (large shearbox apparatus)

5.1 General

5.1.1 Principle. The principle of this method is the same as that described in clause 4 for the small shearbox apparatus.

The large shearbox referred to in this standard is designed for carrying out tests on soil specimens up to 305 mm square and 150 mm high.

5.1.2 Types of test. The same types of drained test can be performed with this apparatus as with the small shearbox, outlined in 4.1.2. However, the dimensions of the specimen may enable some particles up to 20 mm in size to be included.

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

5.1.3 Test conditions. The following test conditions shall be specified before starting a series of tests:

- a) size of test specimen;
- b) whether undisturbed or remoulded specimens are to be tested;
- c) for undisturbed specimens, the orientation of the specimens relative to the plane of shear;