

Methods of test for

Soils for civil engineering purposes —

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

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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 (Property Services Agency)
- Department of the Environment (Building Research Establishment)
- Department of Transport
- Department of Transport (Transport and Road Research Laboratory)
- Coopted members

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Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
1 Scope	1
2 Definitions	1
3 Determination of consolidation properties using a hydraulic cell	2
3.1 General	2
3.2 Apparatus	2
3.3 Preparation of specimens	9
3.4 Cell assembly	13
3.5 Procedure for consolidation test with one-way vertical drainage	15
3.6 Procedure for consolidation test with two-way vertical drainage	23
3.7 Procedure for consolidation test with drainage radially outwards	25
3.8 Procedure for consolidation test with drainage radially inwards	27
4 Determination of permeability in a hydraulic consolidation cell	28
4.1 General	28
4.2 Apparatus for preparation of specimens	29
4.3 Apparatus for permeability test	29
4.4 Calibration of apparatus	29
4.5 Preparation and checking of apparatus	30
4.6 Preparation of test specimen	30
4.7 Assembly of cell	30
4.8 Test procedures	30
4.9 Calculations	31
4.10 Reporting results	32
5 Determination of isotropic consolidation properties using a triaxial cell	32
5.1 General	32
5.2 Apparatus	33
5.3 Preparation and setting up of specimen	37
5.4 Saturation	38
5.5 Procedure for triaxial consolidation with vertical drainage	40
5.6 Calculations, plotting and analysis	41
5.7 Test report	42
6 Determination of permeability in a triaxial cell	43
6.1 General	43
6.2 Apparatus for preparation of specimens	43
6.3 Apparatus for permeability test	43
6.4 Preparation and checking of apparatus	45
6.5 Preparation and setting up of specimen	45
6.6 Saturation	45
6.7 Consolidation	45
6.8 Procedure for measurement of permeability	45
6.9 Calculations	46
6.10 Reporting results	46
Appendix A Typical test data and calculation forms	48
Figure 1 — Drainage and loading conditions for consolidation tests in hydraulic cells	3
Figure 2 — Arrangement of hydraulic cell for vertical drainage consolidation [test type (a)]	4

	Page
Figure 3 — Arrangement for load calibration of diaphragm	11
Figure 4 — Connections to hydraulic consolidation cell for consolidation test with radial drainage to periphery [test type (f)]	16
Figure 5 — Derivation of t_{50} from log time curves	21
Figure 6 — Derivation of t_{50} and t_{90} from power function curves	23
Figure 7 — Temperature correction curve	24
Figure 8 — Arrangement of cell and equipment for triaxial consolidation test	35
Figure 9 — Derivation of t_{50} from plot of pore pressure dissipation against log time	44
Figure 10 — Arrangement of cell and equipment for triaxial permeability test	47
Publication referred to	Inside back cover

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 superseded 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 64, 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 specifies methods of test for determination of consolidation and permeability characteristics of saturated soils using apparatus which is more complex than that used for the tests described in Part 5.

Two types of equipment are used:

- a) hydraulically loaded one-dimensional consolidation cell;
- b) a triaxial consolidation cell.

The most significant capabilities of both types of apparatus are:

- 1) measurement of pore water pressure;
- 2) control of drainage;
- 3) application of back pressure to the specimen.

Consolidation or triaxial cells of large diameter enable large specimens to be tested so that some account can be taken of the effects of the soil fabric.

These procedures appear for the first time in this standard.

Reference should be 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.

2 Definitions

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

2.1

diaphragm pressure of a hydraulic consolidation cell

the pressure applied to the fluid above the flexible loading diaphragm

2.2

applied total stress

the mean pressure actually transmitted to the surface of the specimen

2.3

free strain loading

application of a uniformly distributed pressure to the surface of the specimen from the flexible diaphragm

2.4

equal strain loading

application of pressure to the surface of the specimen through a rigid disc so that the surface always remains plane

2.5

pore pressure ratio

the ratio of the incremental change in pore pressure to the applied increment of vertical stress when drainage is not allowed

2.6

cell pressure (σ_3)

the pressure of the cell fluid which applies isotropic stress to the specimen in a triaxial cell

2.7

back pressure (u_b)

pressure applied directly to the pore fluid in the specimen voids

2.8

effective cell pressure

the difference between the cell pressure and pore water pressure

2.9

effective consolidation pressure (σ'_3)

the difference between the cell pressure and the back pressure against which the pore fluid drains during the consolidation stage, calculated as:

$$\sigma'_3 = \sigma_3 - u_b$$

2.10

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 equation

$$\Delta u = B\{\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)\}$$

where

Δu is the change in pore pressure;

$\Delta\sigma_1$ is the change in total major principal stress;

$\Delta\sigma_3$ 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.

3 Determination of consolidation properties using a hydraulic cell

3.1 General

3.1.1 Introduction. These procedures cover the determination of the magnitudes and rates of consolidation of soil specimens of relatively low permeability using hydraulically loaded apparatus. They provide a convenient means of testing large specimens, and enable drainage in either the horizontal or vertical directions to be investigated. The specimen is in the form of a cylinder confined laterally, subjected to vertical axial pressure applied hydraulically.

The apparatus and procedures described here are based on the extendable-bellows type of hydraulic cell. Specimen diameters typically range from 75 mm to 254 mm. Other types of hydraulically loaded cell, incorporating for instance a rolling-seal diaphragm, are also available. The test method is not restricted to a particular design of cell provided that the essential requirements are fulfilled.

3.1.2 Types of test. In this type of cell, pressure may be applied to the surface of the specimen either directly from the flexible diaphragm (giving a uniform stress distribution, the “free strain” condition), or through a rigid loading plate which ensures that the top surface remains plane (the “equal strain” condition). With either type of loading the following drainage conditions are possible. The various configurations are indicated diagrammatically in Figure 1, as follows:

- a) vertical drainage to the top surface only, with measurement of pore pressure at the centre of the base [Figure 1(a) and Figure 1(b)];
- b) vertical drainage to both top and bottom surfaces [Figure 1(c) and Figure 1(d)];
- c) radial drainage outwards to the periphery only, with measurement of pore pressure at the centre of the base [Figure 1(e) and Figure 1(f)];
- d) radial drainage inwards to a central drain with measurement of pore pressure at one or more points off centre [Figure 1(g) and Figure 1(h)].

Each method requires its own curve-fitting procedure and multiplying factors for deriving the relevant coefficient of consolidation. The factors also depend on whether data are derived from pore pressure measurements at a single point, or from “average” measurements (volume change or settlement) for the specimen as a whole.

3.1.3 Test conditions. The following test conditions shall be specified before starting a test:

- a) size of test specimen;
- b) drainage conditions;

- c) loading conditions;
- d) location of pore pressure measurement point (when required);
- e) whether void ratios are to be calculated and plotted;
- f) sequence of effective pressure increments and decrements;
- g) criterion for terminating each primary consolidation and swelling stage;
- h) whether secondary compression characteristics are required.

The requirements of Part 1 of this standard, where appropriate, shall apply to the test methods described in this clause.

3.1.4 Environmental requirements and safety

3.1.4.1 Temperature. These tests shall be carried out in a laboratory in which the temperature is maintained constant to within $\pm 2^\circ\text{C}$, in accordance with 6.1 of BS 1377-1:1990. All apparatus shall be protected from direct sunlight, from local sources of heat and from draughts.

3.1.4.2 Hazard warning

NOTE Users of this equipment should be conversant with regulations for pressure vessels.

Consolidation cells and ancillary equipment shall not be used at pressures above their safe working pressures.

3.2 Apparatus

3.2.1 Hydraulic consolidation cell and accessories

3.2.1.1 General requirements for the cell

3.2.1.1.1 All metal body components shall be impervious and corrosion resistant. The cell body, top and base shall all be of the same material to minimize the possible effects of electrolytic corrosion.

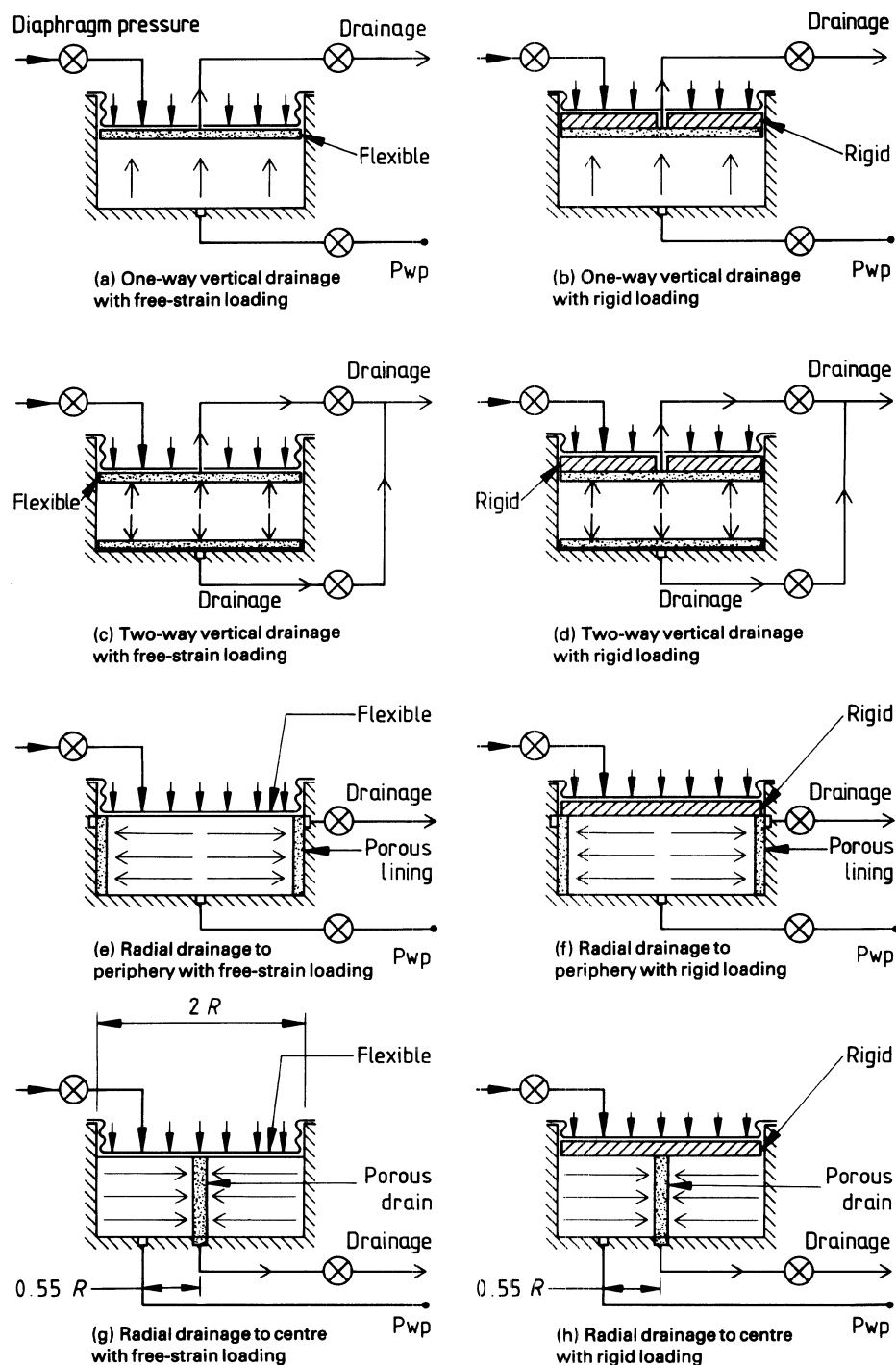
3.2.1.1.2 The cell when assembled shall be capable of withstanding sustained internal water pressures of up to 1 000 kPa without significant leakage or distortion.

NOTE The main features of the extending-bellows type of a 250 mm diameter cell are shown diagrammatically in Figure 2.

3.2.1.2 Components of the cell

3.2.1.2.1 Cell body, the inside face of which shall be smooth and free from pitting.

NOTE The internal surface of the body and base may be lined with a thin smooth impervious layer of plastics material bonded on, to reduce wall and base friction and inhibit corrosion.



Pwp is the pore water pressure.

Figure 1 — Drainage and loading conditions for consolidation tests in hydraulic cells

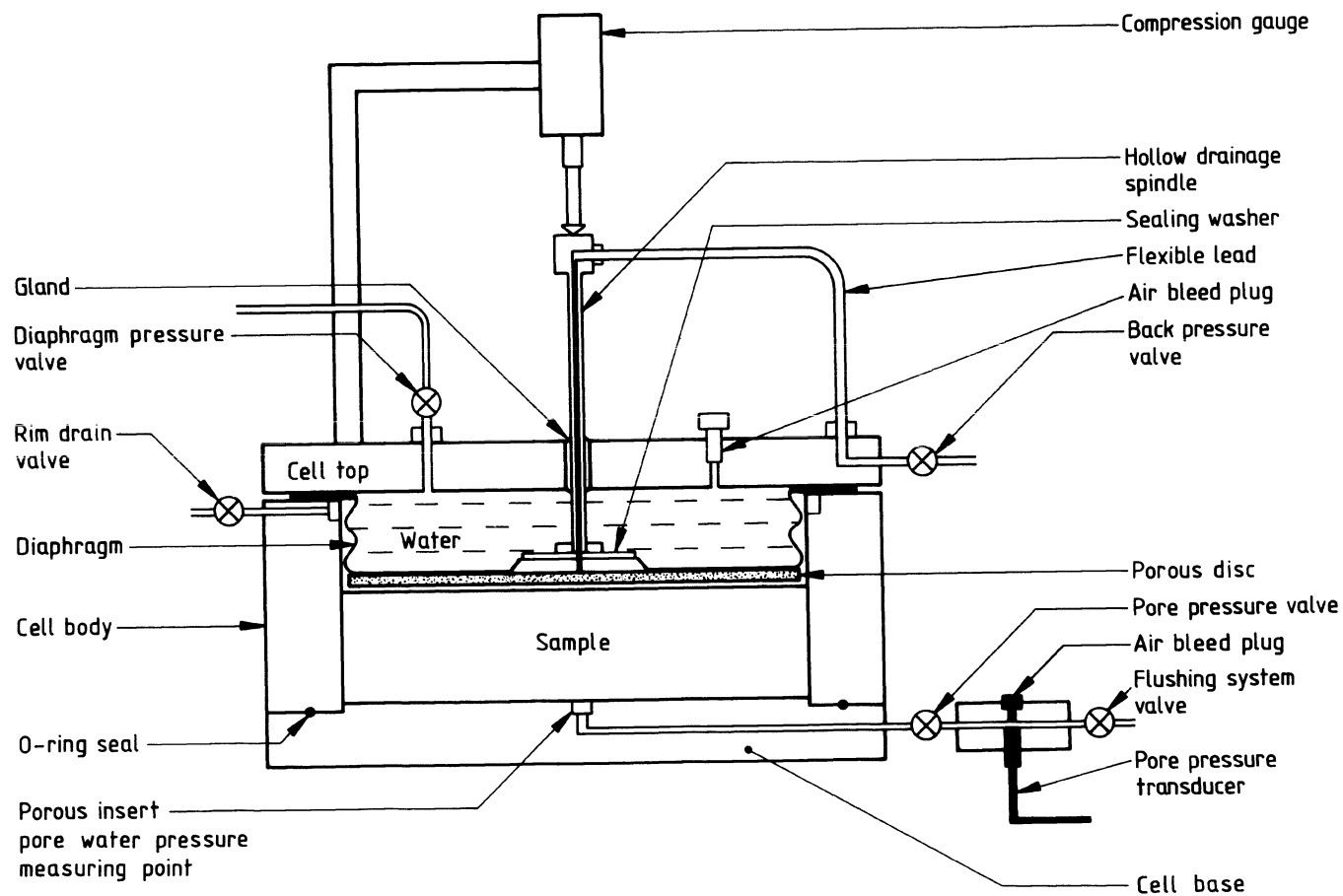


Figure 2 — Arrangement of hydraulic cell for vertical drainage consolidation [test type (a)]

3.2.1.2.2 Top cover, fitted with an air bleed plug and a bushing or seal for a hollow rod (the drainage stem) which is attached to an impermeable flexible diaphragm, e.g. of butyl rubber. Since the drainage stem permits drainage to take place from the top face of the specimen, provision shall be made for measurement of the vertical movement of that face.

3.2.1.2.3 The diaphragm, selected from a range of diaphragms of various stiffnesses so that it is appropriate to the soil type and the type of test.

NOTE In cells using a bellows type of diaphragm the folds pressing against the cell wall can impede the removal of excess water for some considerable time. It is advantageous to fit a strip or collar of porous plastics material between the diaphragm and the rim drainage aperture to provide a free drainage path which enables this water to be removed quickly.

3.2.1.2.4 Cell base, incorporating a central recess for a porous insert (the pore pressure measurement point) connected to a valve on the periphery.

NOTE Pore pressure is usually measured at the centre of the base of the specimen in tests with vertical drainage. Some cell bases of large diameter are fitted with additional off-centre pore pressure points, one (or more) of which is used for some tests in which radial drainage takes place.

3.2.1.2.5 Connection ports incorporated into the top cover and cell base as shown in Figure 2. Each port shall be fitted with either a valve, or a blanking plug if it is not required for the test. The ports shall be connected as follows (the corresponding valve designations are indicated in brackets):

- a) from the pore pressure measurement point in the cell base to the pore pressure measuring device (the pore pressure valve);
- b) from the pore pressure measuring device mounting block to the flushing system (the flushing system valve);
- c) from the diaphragm pressurizing chamber to the diaphragm pressure system (the diaphragm pressure valve);
- d) from the top of the specimen via the drainage stem to the back pressure system (the back pressure valve);
- e) from the rim drain (when required) to the back pressure system (the rim drain valve).

3.2.1.2.6 Porous discs, for the drainage and pore pressure measuring points. Their permeability shall be substantially greater than that of the soil, and they shall withstand the maximum vertical pressure likely to be imposed. 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 deaerated water until required.

3.2.1.2.7 On-off valves, capable of withstanding the maximum working pressure without leakage. They shall produce negligible volume displacement during operation.

NOTE Ball valves with PTFE seals have been found to comply with this requirement.

3.2.1.2.8 Flexible porous disc, to act as a drainage layer through which water from the specimen can drain into the hollow spindle to the back pressure line. The diameter of the disc shall be about 1 mm less than the internal diameter of the cell. It shall be flexible enough to accommodate non-uniform surface settlement of the larger diameter specimens. In other respects the disc shall comply with **3.2.1.2.6**.

3.2.1.2.9 Rigid metal circular loading plate, with detachable lifting handle, to provide "equal strain" loading when required. A plug shall be provided to fill the central hole when necessary.

3.2.1.2.10 Peripheral drain, of porous plastics material of about 1.5 mm thick, for radial drainage tests. The inside face of the material shall be smooth.

3.2.1.2.11 Drainage disc, of porous plastics material up to 3 mm thick, for use as a drainage layer when two-way vertical drainage is used.

3.2.2 Instrumentation attached to the cell

3.2.2.1 A calibrated dial gauge or displacement transducer, referred to as the compression gauge, complying with **4.2.1.3** of BS 1377-1:1990. It shall be suitably supported for measuring the vertical compression or swelling of the specimen throughout the test. For specimens up to 75 mm diameter the gauge shall be readable to 0.002 mm and have a travel of at least 10 mm.

NOTE For larger specimens the resolution and range of travel should be appropriate to the stiffness of the soil specimen.

3.2.2.2 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 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 no more than a negligible amount of water to move into or out of the specimen.

3.2.3 Ancillary equipment for preparation and operation of the cell

3.2.3.1 Two independent pressure systems, for applying and maintaining the desired pressure in the cell and in the specimen drainage line (referred to as the diaphragm pressure system and back pressure system respectively). They shall be capable of maintaining the pressure constant to within $\pm 0.5\%$.

NOTE Pressure systems dependent on self-compensating mercury pots (see Warning 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 any leakage and drainage to or from the specimen.

If air-water systems are used a diaphragm, e.g. of butyl rubber, shall separate air from water.

3.2.3.2 *A calibrated pressure gauge*, of test grade, for independent measurements of diaphragm pressure and back pressure, complying with 4.2.1.7 of BS 1377-1:1990.

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

Calibration data shall be clearly displayed. The gauge shall be permanently connected to the two pressure systems.

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

Alternatively, two independent gauges may be used, each permanently connected to its own pressure system.

3.2.3.3 *A calibrated volume-change indicator* (burette or transducer type) complying with 4.2.1.8 of BS 1377-1:1990, connected into the back pressure line.

NOTE 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.

3.2.3.4 *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 for every 1 kPa increase in pressure.

3.2.3.5 *Timing device*, readable to 1 s.

3.2.3.6 *Materials*, as follows:

- a) *silicone grease or petroleum jelly*;
- b) *porous plastics sheets*, about 1.5 mm and 3.5 mm thick;
- c) *disc of latex rubber*, or similar impermeable material to cover the metal disc under the centre of the diaphragm (required for 3.7 only);
- d) *a supply of de-aerated tap water*, as specified in 5.2 of BS 1377-1:1990.

3.2.3.7 *Pressurized system for distribution of de-aerated water*.

3.2.3.8 *Immersion tank* (optional), to enable the cell to be assembled under water.

3.2.3.9 *A calibrated thermometer*, readable to 0.5 °C.

3.2.4 *Equipment for specimen preparation and measurement*

3.2.4.1 *Procedures*. Procedures are given for the preparation of three types of specimen:

- a) specimen of undisturbed soil from a sampling tube (see 3.3.2);
- b) specimen of undisturbed soil from a block sample (see 3.3.3);
- c) specimen of compacted soil (see 3.3.4 to 3.3.7).

3.2.4.2 *Equipment for preparation of specimen from an undisturbed sampling tube or block sample*

3.2.4.2.1 *Two cutting shoes*, each clearly identified, having internal diameters as follows:

- a) equal to the internal diameter of the cell;
- b) equal to the internal diameter of the cell less twice the thickness of the porous plastics lining material.

The tolerance range for these dimensions shall be between 99.8 % and 100 % of the relevant diameter.

Each shoe shall be capable of being securely attached to the top flange of the cell body so that its internal face is in precise alignment with the cell wall or face of the lining material.

NOTE With soft soils it might be difficult to intrude a specimen of the precise diameter into the cell without disturbance. There may then be some advantage in using a slightly smaller cutting shoe to obtain a fractional clearance. The undersize should not exceed 1 mm for a 250 mm diameter cell, or the same proportion for other sizes.

3.2.4.2.2 *Extruder* (for a sample taken in a sampling tube), suitable for ejecting the undisturbed sample from the sampling tube through the cutting shoe directly into the cell body. Extrusion shall be vertically upwards to avoid distortion of soft soils, and in the same direction relative to the tube as the soil entered the tube. The device shall enable the cell body assembly to be securely held in place with its axis in alignment with the direction of extrusion.

3.2.4.2.3 *A means of holding the cell* (for a block sample), with cutting ring and maintaining it in alignment while it is pushed into the block sample.

3.2.4.2.4 *Balance*, of sufficient capacity and accuracy to determine the mass of the specimen in the cell to an accuracy of within 0.1 %.

3.2.4.2.5 *Equipment for determination of moisture content* (see 3.2 of BS 1377-2:1990).

3.2.4.2.6 *Equipment for determination of soil particle density* (see 8.2 or 8.3 of BS 1377-2:1990).

3.2.4.2.7 *Cutting and trimming tools*, appropriate to the type of soil, such as:

- a) sharp trimming knife;
- b) spatula;
- c) wire saw of fine piano wire;

- d) cheese-wire;
- e) metal straightedge at least 50 mm longer than the specimen diameter.

3.2.4.2.8 *A flat surface*, about 500 mm square (or flat glass plate for the smallest size of cell).

3.2.4.2.9 *Vernier calipers*, for measuring the internal diameter of cells up to 150 mm diameter.

NOTE For larger cells a calibrated engineer's steel rule of suitable length with 0.5 mm graduations is suitable.

3.2.4.2.10 *A calibrated depth gauge*, for measuring the height of the test specimen in the cell, readable to 0.1 mm.

3.2.4.2.11 *Mandrel and guide jig*, for forming a central drainage hole (required only for tests in which drainage takes place to the centre).

3.2.4.2.12 *Fine sand*, or other suitable drainage material, for use in a central drainage well.

3.2.4.2.13 *A reference straightedge*, such as an engineer's steel rule.

3.2.4.3 *Equipment for preparation of a specimen of compacted soil*

3.2.4.3.1 The items listed in **3.2.4.3.2** to **3.2.4.3.6** are required for the preparation of soil and for compacting it into the consolidation cell, in addition to the items listed in **7.2** of BS 1733-1:1990.

3.2.4.3.2 *Test sieve of aperture size*, approximately one-sixth of the height of the test specimens to be prepared.

3.2.4.3.3 *Measuring cylinder*.

3.2.4.3.4 *Metal rammer*, as described either in **3.3.2** (2.5 kg rammer), or in **3.5.2** (4.5 kg rammer), of BS 1377-4:1990, as appropriate.

3.2.4.3.5 *Trimming tool*, for preparing a flat surface on the specimen inside the cell at a given depth below the top end of the cell.

3.2.4.3.6 Items **3.2.4.2.4** to **3.2.4.2.12**, as appropriate.

3.2.5 *Calibration of cell*

3.2.5.1 *Measurements*. The following measurements of the cell and its accessories shall be determined and recorded; linear measurements shall be made to an accuracy of 0.5 % and measurements of mass to an accuracy of 0.1 %:

- a) internal diameter of cell body, and of body with peripheral drain fitted;
- b) overall height of cell body;
- c) internal depth from top edge of cell body to the base when bolted together;
- d) thickness of porous disc, porous plastic disc, and porous peripheral drain material;
- e) thickness of rigid loading disc;

- f) mass of cell body with normal attachments;
- g) mass of cell body assembled on base, including bolts and attachments;
- h) mass of rigid disc and each porous disc (dry);
- i) mass of a typical porous liner;
- j) projection of the drainage spindle above the cell top when the diaphragm is at the upper and lower limits of its extension (to the nearest mm);
- k) thickness of diaphragm.

3.2.5.2 *Calibration of diaphragm*

3.2.5.2.1 The force exerted by the diaphragm on a rigid top platen may be less than that calculated from the hydraulic pressure and cross-sectional area of the cell, owing to diaphragm stiffness and side friction.

NOTE Friction may be reduced by applying a film of silicone grease or petroleum jelly to the inside wall of the cell behind the diaphragm when a peripheral drain is not used.

The difference between the actual and the calculated force shall be determined. This effect is more significant in a small cell than in a large one, and can vary with both the applied pressure and the diaphragm extension, and is greatest at low pressures. This correction does not apply to "free strain" tests.

3.2.5.2.2 The force applied by the diaphragm can be measured by the following method which has been found to be satisfactory, but alternative methods may be used.

Mount the inverted cell (without base) on the platen of a load frame fitted with a suitable calibrated force measuring device in the manner shown in Figure 3, and then pressurize the water under the diaphragm. The actual pressure, σ (kPa), applied to the area of cross section of the cell is given by the equation

$$\sigma = \frac{P + 9.81m}{A} \times 100$$

where

P is the force measured by the force measuring device (in N);

m is the mass of the rigid plate (in kg);

A is the area of the cell (in mm²).

The relationship between diaphragm pressure, p_d , and the pressure correction to be applied, δp (where $\delta p = p_d - \sigma$), can be plotted for a load-unload cycle up to the maximum working pressure. Similar calibration curves may be obtained for a range of diaphragm extensions.

The actual pressure σ on the specimen for a diaphragm pressure p_d at a certain extension of the diaphragm is given by the equation $\sigma = p_d - \delta p$ if the pressure due to the depth of water above the diaphragm is neglected.

This calibration automatically allows for the absence of pressure on the external diameter of the drainage spindle.

Repeat the calibration at intervals to allow for changes in the characteristics of the diaphragm with time.

3.2.6 Preparation and checking of apparatus

3.2.6.1 General. Apparatus used for tests in the hydraulic cell shall be subjected to rigorous inspection and check testing before use. The checks described in 3.2.6.2 to 3.2.6.6 shall be carried out on the diaphragm pressure, back pressure and pore pressure systems at the frequency stated below. Checks on these systems are of two kinds, “complete” checks and “routine” checks.

“Complete” checks in accordance with 3.2.6.2, 3.2.6.3 and 3.2.6.5 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 in accordance with 3.2.6.4 and 3.2.6.6 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.

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 3.2.6.7 shall be carried out on porous discs, and on any porous drainage materials fitted into the cell, immediately before each test.

3.2.6.2 Diaphragm pressures system (complete check). A pressure test of the diaphragm and its pressure system shall be made to ensure that the maximum test pressure stated in 3.2.1 can be maintained at all times during a test.

3.2.6.3 Back pressure system (complete check)

3.2.6.3.1 Flush freshly de-aerated water through the back pressure connecting line from the volume-change indicator and through the specimen drainage line. In this operation work the indicator at least twice to its limits of travel, allowing water to pass out of the drainage stem and replacing it with freshly de-aerated water from the pressure system.

3.2.6.3.2 Seal the end of the drainage stem with a watertight plug.

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

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

3.2.6.3.5 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.

3.2.6.3.6 If the corrected difference exceeds 0.1 mL investigate the leaks and rectify them so that when 3.2.6.3.1 to 3.2.6.3.4 are repeated the requirement 3.2.6.3.5 is achieved.

3.2.6.4 Back pressure system (drainage stem or rim drain) (routine check)

NOTE The following check can be carried out at the same time as the pore pressure system check given in 3.2.6.6.

3.2.6.4.1 Flush the back pressure line and drainage connections as in 3.2.6.3.1. Close the drainage line valve.

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

3.2.6.4.3 Proceed as in 3.2.6.3.4 to 3.2.6.3.6.

3.2.6.5 Pore pressure system (complete check)

3.2.6.5.1 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 port. Continue until no air bubbles are visible in the emerging water, to ensure that the entire system is filled with de-aerated water.

3.2.6.5.2 Close the pore pressure valve on the cell base and then remove the bleed plug in the transducer mounting block.

3.2.6.5.3 Inject a solution of soft soap into the bleed plug hole. Open the flushing system valve so that water flows from the de-aerated supply and out of the bleed hole.

3.2.6.5.4 Screw the bleed plug back into the transducer mounting while water continues to emerge.

3.2.6.5.5 Open the pore pressure valve and allow about 500 mL of de-aerated water to pass out of the pore pressure measurement port (see note), then close the valve.

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

3.2.6.5.6 Seal the porous insert in the pore pressure measurement port, while water is emerging in order to avoid trapping air, by covering with a piece of latex rubber and a small flat metal disc held down by a clamping arrangement.

3.2.6.5.7 Pressurize the system to 700 kPa and again allow about 500 mL of water to pass out of the pore pressure measurement port.

3.2.6.5.8 Leave the system pressurized for at least 12 h.

3.2.6.5.9 After this period, check for leaks and if none are found allow about 500 mL of water to pass out of the pore pressure measurement port.

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

If leaks are evident rectify them and repeat **3.2.6.5.1** to **3.2.6.5.8**.

3.2.6.5.10 When checks confirm that the system is free of leaks, open the flushing system valve and the pore pressure valve and apply the maximum pressure achievable within the limitations of the pressure system and the pore pressure transducer to the cell base.

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

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

3.2.6.5.13 If there is a decrease in the pressure reading this indicates that there is a defect in the system, which shall be rectified. The complete pore pressure system check described above shall be repeated until the system is proved to be free of entrapped air and leaks.

3.2.6.5.14 Pass freshly de-aerated water through the connection to any ports in the cell base that are not to be used. When they are completely filled, close the valves on these lines and keep them closed throughout the test.

3.2.6.6 Pore pressure system (routine check)

3.2.6.6.1 Follow the procedures described in **3.2.6.5.1** to **3.2.6.5.9**.

3.2.6.6.2 When checks confirm that the system is free of leaks, close the flushing system valve on the transducer mounting block.

3.2.6.6.3 Keep the cell base covered with de-aerated water until the test specimen is ready for setting up.

3.2.6.7 Porous media

3.2.6.7.1 The drainage disc shall be inspected and checked to ensure that water drains freely through it. A disc that is clogged by soil particles shall be rejected.

Before use, boil a porous disc for at least 10 min, and a porous plastics disc for at least 30 min, in distilled water, and then keep it under de-aerated water until required.

3.2.6.7.2 Boil porous insets for pore pressure measuring points in distilled water for the times stated in **3.2.6.7.1** before use, and discard them when clogged with soil particles.

3.2.6.7.3 Boil porous plastics lining material in distilled water for at least 30 min before use. Place the smooth side towards the soil, but do not grease it. The material shall be used once only and then discarded.

3.2.6.7.4 Sand for use in a central drainage well shall be de-aerated by boiling in distilled water and allowed to cool in an airtight container.

3.3 Preparation of specimens

3.3.1 General

3.3.1.1 Types of specimen. Test specimens shall be cylindrical with plane ends normal to the axis, and of a height/diameter ratio of 1/2.5 to 1/4. Specimens may be of undisturbed soil, or of disturbed soil that is compacted or compressed into the cell.

Five methods of specimen preparation are described:

- a) *method 1* (see **3.3.2**): preparation of an undisturbed specimen from a sampling tube;
- b) *method 2* (see **3.3.3**): preparation of a specimen from a block sample;
- c) *method 3* (see **3.3.5**): compaction of disturbed soil into the cell by applying a specified compactive effort;
- d) *method 4* (see **3.3.6**): compaction of disturbed soil into the cell to achieve a specified dry density;
- e) *method 5* (see **3.3.7**): compression of disturbed soil into the cell under static pressure to achieve a specified dry, density.

The preparation of soil for compaction is given in **3.3.4**. (Form 6.A of Appendix A is suitable for recording specimen details and measurements.)

3.3.1.2 Undisturbed specimens. Specimens are prepared by method 1 or method 2, depending on the type of sample. Method 2 may also be used for taking a specimen from a suitably trimmed exposure on site.

The diameter of the largest particle included in the specimen should not exceed one-sixth of the specimen height.

NOTE 1 If after test a specimen is found to contain larger particles the size range and mass of these inclusions should be reported.

An undisturbed specimen shall be carefully selected to represent as closely as possible the condition of the soil in-situ especially with regard to the soil "fabric". Undisturbed specimens shall be prepared with the minimum change of the soil structure and moisture.

NOTE 2 In soils containing laminations, equilibrium of pore pressure throughout the whole specimen might take more time than is indicated by pore pressure measurement at a single point because of variations in permeability at successive horizons.

NOTE 3 Preparation of undisturbed specimens should be carried out in an atmosphere in which the relative humidity is controlled at not lower than 40 %. Moisture loss from soil not being used immediately should be prevented by wrapping in clinging plastics film followed by aluminium foil.

3.3.1.3 Compacted specimens. Specimens may be prepared by dynamic compaction (methods 3 and 4), or by static compression (method 5). These methods relate to compaction or compression into the larger sizes of consolidation cell. Specimens of smaller sizes can be trimmed from soil that is first compacted into a 1 L compaction mould, or a CBR mould (see clauses 3 and 7 respectively of BS 1377-4:1990), in the same way as preparing undisturbed specimens.

The diameter of the largest particle present in the soil shall not exceed one-sixth of the specimen height.

3.3.2 Preparation of undisturbed specimen from sample tube

3.3.2.1 Samples taken from site in tubes shall whenever possible be extruded, trimmed and fitted into the cell body in one operation.

NOTE 1 When this is not practicable the sample should be extruded from the tube and treated in the same way as a block sample (see 3.3.3).

NOTE 2 In very organic clays and silts, oxidation can take place in contact with air which releases bubbles of gas. Extrusion of these soils should ideally be carried out under water, e.g. by mounting a horizontal extruder ram in a water tank.

The procedure for vertical extrusion is as described in 3.3.2.2 to 3.3.2.15.

3.3.2.2 Attach the cutting shoe of the correct diameter to the top end of the cell body, ensuring that the cutting edge is exactly in alignment with the cell wall. If the test is to be carried out with radial drainage to the periphery, fit the saturated peripheral drain into the cell body first using the appropriate diameter of cutting shoe (see 3.2.4.2.1); intrude the sample as quickly as possible before the drain loses its saturation.

3.3.2.3 Assemble the sample tube and cell body with shoe on the extruder, ensuring correct alignment and secure fixing.

3.3.2.4 Extrude the sample until the cell is filled with a few millimetres surplus at the top end. Remove parings from around the shoe during extrusion to prevent obstruction to movement of the sample.

3.3.2.5 Sever the sample at the level of the cutting edge of the shoe.

3.3.2.6 Detach the cell and shoe from the extruder and remove the cutting shoe. Support the underside of the specimen by spatula blades before lifting.

3.3.2.7 Trim the specimen at each end flush with the cell body flange.

3.3.2.8 Use a cylindrical spacer of appropriate thickness, and slightly smaller than the cell diameter, to push out the unwanted length of specimen; cut off this length.

3.3.2.9 Trim the cut end of the specimen (which will be the bottom face) flush with the upper edge of the cell. Remove any protruding particles carefully; fill the resulting void with fine material from the trimmings, and press in well.

3.3.2.10 Weigh the cell with the specimen to an accuracy of within 0.1 %. Measure the distance from the surface of the specimen to the top end of the cell body to 0.5 mm and calculate the initial specimen height (H_0).

3.3.2.11 Cover the de-aired cell base (prepared as in 3.2.6.6) with a thin film of de-aerated water.

3.3.2.12 Place two thin steel spatulas under the bottom flange of the cell body to retain the specimen flush with the flange while it is lifted. Slide the specimen on to the flooded cell base without entrapping any air, and remove the spatulas. Bolt the body to the cell base by progressively tightening opposite pairs of bolts. Ensure that the body is properly sealed on the base sealing ring, and that it is tightened down uniformly. Close the flushing system valve.

3.3.2.13 Fill the top of the cell above the specimen with de-aerated water only if the soil is not susceptible to swelling or is not sensitive to a moisture content change under zero stress.

NOTE For a soil that is susceptible to swelling or sensitive to moisture content change the swelling pressure is determined by the procedure in 3.5.2.2, by allowing water to percolate up from the base.

3.3.2.14 Take representative samples from the soil trimmings for determination of moisture content.

3.3.2.15 Assemble the cell top in accordance with 3.4.

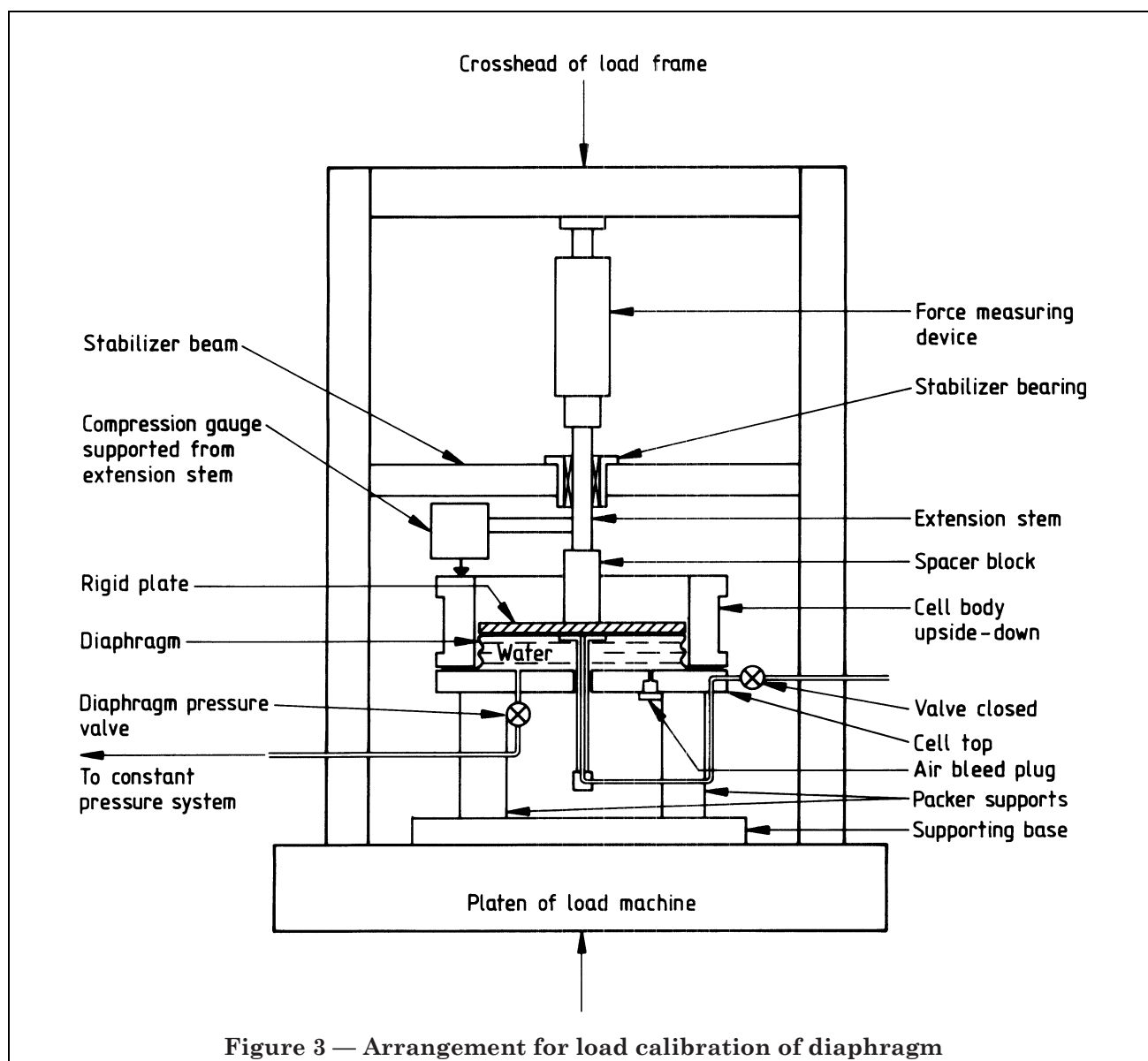


Figure 3 — Arrangement for load calibration of diaphragm

3.3.3 Preparation of specimen from block sample

3.3.3.1 The procedure given in 3.3.2.2 to 3.3.3.8 enables a specimen to be fitted into the cell body from a block sample, or from a sample already extruded from a tube, or from a suitably trimmed exposure on site.

NOTE A sample taken on site should be trimmed flush to the cell flanges at each end, covered with a rubber sealing sheet and securely clamped to hold it in place protected from the atmosphere, before transporting to the laboratory.

3.3.3.2 Trim the surfaces of the specimen level and reasonably flat.

3.3.3.3 Place the cell, fitted with plastics liner if needed and the appropriate cutting shoe, on the levelled surface, cutting edge down.

3.3.3.4 With a sharp blade trim the soil a few centimetres ahead of the shoe to about 3 mm larger than its internal diameter.

3.3.3.5 Push the cell downwards, keeping its axis vertical, so that the cutting shoe pares away the outer 1.5 mm or so of the soil. With soft soils the weight of a 250 mm cell alone may be enough to advance it downwards. For stiff soils, jacking against a load frame may be necessary. A spirit level on the uppermost flange provides a guide to prevent tilting.

NOTE Correct alignment is easier to maintain if the apparatus referred to in 3.2.4.2.3 is used.

3.3.3.6 Continue 3.3.3.4 and 3.3.3.5 until the cell is completely filled, with a few millimetres surplus projecting at the top.

3.3.3.7 Lift off the cell with specimen, underpinning it with spatulas, take off the cutting shoe, and complete the trimming as in **3.3.2.7** to **3.3.2.14**.

3.3.3.8 Assemble the cell top in accordance with **3.4**.

3.3.4 Preparation of soil for compacted specimens

3.3.4.1 Soil for compaction into a large consolidation cell shall be prepared as described in **3.3.4.2** to **3.3.4.5**.

3.3.4.2 Remove any particles larger than one-sixth of the height of the specimen to be tested, by passing the soil through the appropriate sieve if necessary.

3.3.4.3 Bring the soil to the desired moisture content by thoroughly mixing with the appropriate amount of water, allowing for evaporation loss.

3.3.4.4 Take at least two representative specimens for determination of the moisture content.

3.3.4.5 Place the prepared soil in a sealed container, weigh to an accuracy of 0.1 % and store for at least 24 h before use.

3.3.5 Compaction by specified compactive effort

3.3.5.1 The prepared and weighed soil is compacted into the cell and made ready for test as described in **3.3.5.2** to **3.3.5.14**.

3.3.5.2 Attach the cell base to the body. The cell is first fitted with a peripheral drain if appropriate; the drainage material shall not be greased.

3.3.5.3 Close the valves between the cell and the pore pressure measuring system.

3.3.5.4 Place the cell assembly on a solid base, e.g. a concrete floor or plinth.

3.3.5.5 Place a quantity of prepared soil in the cell such that when compacted it occupies a little over one-half or one-third or one-fifth of the final specimen height, depending on the number of layers used.

3.3.5.6 Apply the requisite compactive effort equivalent to 2.5 kg compaction or 4.5 kg compaction (see **3.3** and **3.5** respectively of BS 1377-4:1990).

NOTE The method of compaction depends on the type of soil and the relevant conditions. Trial tests using different degrees of compaction may be necessary to achieve a uniform specimen of the required density.

3.3.5.7 Repeat **3.3.5.5** and **3.3.5.6** the appropriate number of times to produce a specimen of the required height.

3.3.5.8 Trim the top face of the compacted specimen to form a flat level surface, using a gauged depth trimming tool. Avoid tearing out hard particles. Return the trimmings to the remains of the prepared sample, and weigh the total remains to an accuracy of 0.1 %.

3.3.5.9 Determine the mass of soil used in the specimen by difference.

3.3.5.10 Determine the height of the specimen (H_o) to the nearest 0.5 mm by measuring down to the trimmed surface from the top of the cell body.

3.3.5.11 Take representative samples from the remaining soil for determination of moisture content.

3.3.5.12 If the soil is susceptible to swelling or is sensitive to a moisture content change it shall not be covered with water. (See note to **3.3.2.13**).

3.3.5.13 Seal the specimen and allow it to stand for at least 24 h before starting a test, to enable excess pore pressures to dissipate.

3.3.5.14 Assemble the cell top in accordance with **3.4**.

3.3.6 Compaction to a specified density

3.3.6.1 The procedure is similar to that given in **3.3.5** but is modified as described in **3.3.6.2** to **3.3.6.7**.

3.3.6.2 Assemble and connect the cell body and base as in **3.3.5.2** and **3.3.5.3**.

3.3.6.3 Calculate the mass of soil required to form a specimen of the desired height and volume from the specified density.

3.3.6.4 Weigh out this mass of soil from the prepared sample.

3.3.6.5 Compact the soil into the cell in layers, using a controlled degree of compaction, so that it forms a homogeneous specimen of the desired height (see note to **3.3.5.5**).

3.3.6.6 Trim, measure and prepare the specimen as in **3.3.5.8** to **3.3.5.13**.

NOTE The final measurements give the actual specimen dimensions and density, which may differ slightly from the desired values.

3.3.6.7 Assemble the cell top in accordance with **3.4**.

3.3.7 Preparation of specimen under static pressure

3.3.7.1 A specimen is prepared in the consolidation cell by static compression to give a specified dry density as described in **3.3.7.2** to **3.3.7.12**.

3.3.7.2 Attach the cell base, prepared as in **3.2.6.6**, to the body. First fit the cell with a peripheral drain if appropriate; the drainage material shall not be greased.

3.3.7.3 Close the valves between the cell and the pore pressure measuring system.

3.3.7.4 Place a weighed quantity of soil corresponding to one layer into the cell and spread it evenly, using a tamping rod if appropriate.

3.3.7.5 Place suitable spacer blocks on the soil and apply a static load until the required height of soil is formed.

NOTE The method used for compression depends on the type of soil and the relevant conditions. Trial tests using different amounts of soil and compression loads may be necessary to achieve a uniform specimen of the required density.

3.3.7.6 Repeat **3.3.7.4** and **3.3.7.5** for succeeding layers until the specimen is of the required height.

3.3.7.7 Level the surface of the specimen as in **3.3.5.8** and weigh any soil removed. Determine the mass of specimen by difference.

3.3.7.8 Verify the height of the specimen (H_o) to the nearest 0.5 mm by measuring down to the trimmed surface from the top of the cell body.

3.3.7.9 Take representative samples from the remaining soil for determination of moisture content.

3.3.7.10 If the soil is susceptible to swelling or is sensitive to a moisture content change it shall not be covered with water (see note to **3.3.2.13**).

3.3.7.11 Seal the specimen and allow it to stand for at least 24 h before starting a test, to enable excess pore pressures to dissipate.

3.3.7.12 Assemble the cell top in accordance with **3.4**.

3.4 Cell assembly

3.4.1 General. Before the cell can be finally assembled the operations given in one of **3.4.2** to **3.4.5** shall be carried out, depending on the type of test to be performed. These operations follow on from the preparation of the specimen (see **3.3**) and relate to **3.5** to **3.8** respectively.

In all cases the cell cover is then fitted as in **3.4.6** and initial observations are made and recorded as described in **3.4.7**.

3.4.2 Consolidation with vertical drainage and pore pressure measurement

3.4.2.1 "Free strain" loading

3.4.2.1.1 Place a saturated flexible porous disc centrally on the surface of the specimen, without entrapping air.

3.4.2.1.2 Pore pressure and drainage connection are as shown in Figure 2. The rim drain valve remains closed.

3.4.2.1.3 Cover the specimen and porous disc with de-aerated water, as appropriate.

3.4.2.2 "Equal strain" loading

3.4.2.2.1 Place a porous disc on top of the specimen, followed by the rigid loading plate. Avoid entrapping air. Ensure that the central hole of the plate aligns with the hole in the drainage spindle.

3.4.2.2.2 Pore pressure and drainage connections are as in **3.4.2.1**.

3.4.2.2.3 Cover the specimen and porous disc with de-aerated water, if appropriate.

3.4.3 Consolidation with two-way vertical drainage

3.4.3.1 The procedure is similar to that given in **3.4.2**, with the following variations.

3.4.3.2 Before transferring the specimen to the cell base (see **3.3.2.12**), place a saturated porous disc of the specimen diameter on the base, without entrapping air.

3.4.3.3 When tightening the cell body on to the base allow the thickness of the disc to displace the specimen upwards.

3.4.3.4 Allow for the thickness of the disc when measuring the specimen height, and the mass of the disc when weighing. Otherwise the setting-up procedure is the same as in **3.3.2**, and **3.4.2.1** or **3.4.2.2**.

3.4.3.5 The flushing system valve (see Figure 2) is connected to the same back pressure system as the back pressure valve, and becomes the bottom drainage valve. Pore pressures are not measured. The volume-change indicator measures the total volume of water draining out of the specimen from both faces. The rim drain valve remains closed.

3.4.3.6 Cover the specimen and porous disc with de-aerated water, if appropriate.

3.4.4 Consolidation with outward radial drainage

3.4.4.1 The procedure is similar to that given in **3.4.2**, with the variations given in **3.4.4.2** to **3.4.4.6**.

3.4.4.2 Fit a lining of porous plastics material against the cell wall, to act as a peripheral drain, before inserting the specimen.

3.4.4.3 Place an impervious membrane, such as a disc of latex rubber, on the surface of the specimen without entrapping air. For a "free strain" test the membrane shall be flexible.

3.4.4.4 For an "equal strain" test, place the circular steel plate on top of the membrane without entrapping air, and plug the central hole.

3.4.4.5 Connect the back pressure system to the rim drain valve (see Figure 4), through which drainage takes place. The back pressure valve is not used and remains closed, with the connection between it and the end of the hollow stem filled with de-aerated water. Pore pressure is measured at the centre of the base, as shown in Figure 4.

3.4.4.6 Cover the specimen and porous disc with de-aerated water, if appropriate.

3.4.5 Consolidation with inward radial drainage

3.4.5.1 The procedure is similar to that given in 3.4.2 with the variations given in 3.4.5.2 to 3.4.5.10.

3.4.5.2 Pore pressure is measured at a point offset from the centre, usually at a distance of $0.55 R$ from the centre, where R is the radius of the specimen. The central point is used for drainage, and the pore pressure valve is connected to the back pressure system.

3.4.5.3 The back pressure valve and the rim drain valve are not used and remain closed.

3.4.5.4 Immediately after trimming the surface of the specimen form a vertical hole in its centre by using a suitable mandrel.

NOTE The hole diameter should be as close as possible to 5 % of the specimen diameter, because the theoretical analysis for calculation of the coefficient of consolidation, c_{vi} , is based on a hole diameter ratio of 1.20.

3.4.5.5 Flush the hole with de-aerated water upwards from the central base port to ensure that there is no obstruction and no smeared material remaining on the porous insert.

3.4.5.6 Add clean de-aerated water to the hole to approximately two-thirds full.

3.4.5.7 Place the saturated sand (prepared as in 3.2.6.7.4) steadily into the hole through a tube, so as to obtain a loose state of packing. Avoid jolting or vibrating the cell after placing.

3.4.5.8 When the hole is full check that water drains freely through the sand and out through the pore pressure valve, keeping the sand saturated. Trim the top surface of the specimen if necessary and cover with de-aerated water if appropriate.

3.4.5.9 For a “free strain” test place an impervious flexible disc on top of the specimen without entrapping air.

3.4.5.10 For an “equal strain” test place the circular steel plate on top of the specimen without entrapping air, and plug the central hole.

3.4.6 Fitting the cell cover

3.4.6.1 After preparing the specimen for test in the cell by one of the methods given above fit the cell cover to the cell body over a sink or large tray, as described in 3.4.6.2 to 3.4.6.5.

3.4.6.2 Support the cell cover over the cell body and partly fill the diaphragm with water so that it can be lowered into the cell without creasing.

NOTE For the large cells this operation is facilitated if the cell cover is temporarily supported while water is placed in the diaphragm, and then supported on spacer blocks on the cell body flange while the diaphragm is eased into the cell.

Allow displaced water to overflow from the top of the cell body, and seat the diaphragm on to the disc covering the specimen. Ensure that no air is trapped.

3.4.6.3 Bolt the cell cover to the body, tightening the bolts evenly ensuring that the flange of the diaphragm is properly seated between them.

NOTE When the specimen is not first covered with water because of its tendency to swell, air can be removed from behind the diaphragm by applying suction to the rim drain valve after bolting on the top cover, but this operation requires care to prevent disturbance to the specimen.

3.4.6.4 Fill the space above the diaphragm with water, displacing air through the air bleed, which is connected to a moderate vacuum to facilitate removal of all the air.

3.4.6.5 Apply a small seating pressure, P_{do} (not exceeding 10 kPa), to the diaphragm. Open the rim drain valve momentarily to release excess water from behind the diaphragm and to ensure that it remains seated on the disc covering the specimen.

3.4.7 Final adjustments

3.4.7.1 Adjustments necessary before starting the test, and initial observations, are as described in 3.4.7.2 to 3.4.7.8.

3.4.7.2 Ensure that the flushing system valve remains closed throughout the test, so as to isolate the pore pressure transducer from the flushing system.

3.4.7.3 Secure the compression dial gauge or transducer in position with the stem properly seated, allowing for a small upward movement.

3.4.7.4 Record the compression gauge reading as the datum value corresponding to the diaphragm seating pressure, p_{do} .

3.4.7.5 Record the initial steady pore water pressure, u_o , corresponding to p_{do} .

3.4.7.6 From the diaphragm pressure calibration data ascertain the pressure, p_o , applied to the specimen corresponding to the diaphragm seating pressure, p_{do} .

3.4.7.7 Set the back pressure system to the desired value, not less than u_o , keeping the appropriate drainage line valve closed.

3.4.7.8 Record the reading of the volume-change indicator on the back pressure line when equilibrium is established.

3.5 Procedure for consolidation test with one-way vertical drainage

3.5.1 General. This test allows for pore pressure to be measured at the bottom face of the specimen while drainage takes place from the top face. The specimen is set up as described in 3.4.2 with either “free strain” or “equal strain” loading. The procedure follows on from the adjustments and initial observations described in 3.4.7, and consists of the following stages:

- a) saturation and measurement of swelling pressure;
- b) undrained loading (pore pressure build-up) (in a number of increments);
- c) consolidation (pore pressure dissipation) (in a number of increments);
- d) unloading;
- e) dismantling.

3.5.2 Saturation

3.5.2.1 Objective. The objective of the saturation stage is to ensure that all the voids are filled with water. This may be achieved by raising the pore water pressure in the specimen to a level high enough for the water to absorb into solution all the air originally in the voids. The degree of saturation is estimated by determining the ratio $\delta u / \delta \sigma$, where δu is the incremental change in pore pressure resulting from an incremental change in vertical stress of $\delta \sigma$ when no drainage is allowed (see note 2 of 3.3.1.2). The criterion $\delta u / \delta \sigma = 0.95$ is usually accepted as an indication of sufficient saturation.

NOTE Values of the ratio $\delta u / \delta \sigma$ which can be expected when full saturation is reached or closely approached depend on the stiffness of a clay soil. In certain stiff fissured clays it may not be possible to obtain a ratio of 0.95, and a value of 0.90 which remains unchanged after three successive increments of diaphragm pressure and back pressure, as described in 3.5.2.3, is then considered acceptable.

3.5.2.2 Measurement of swelling pressure. A soil that is susceptible to swelling shall not be allowed free access to water without provision for applying a vertical confining stress to prevent swell. Initial saturation is effected by allowing de-aerated water to enter at the base and to percolate upwards, while observing the compression gauge.

If this indicates an upward movement increase the seating pressure applied to the diaphragm to hold the reading at the initial value. When conditions become steady, record the diaphragm pressure.

NOTE 1 Considerably longer than 24 h might be needed to reach steady conditions in large specimens of low permeability soils.

The difference between the corresponding vertical stress applied to the surface of the specimen and the pressure of the water applied to the base is reported as the “swelling pressure”.

Pockets of air remaining between the diaphragm and the cell wall may be removed by the application of a vacuum through the rim drain valve (see Figure 2), but this should be done with great care.

During the subsequent saturation stage the effective vertical stress applied to the specimen shall not at any time be less than the swelling pressure.

NOTE 2 The pressure differential between the vertical applied pressure and the base water pressure should be not less than the swelling pressure, nor large enough to cause premature consolidation of soft soils. A differential pressure of 10 kPa has been found to be suitable for many soils that are not susceptible to swelling.

3.5.2.3 Saturation procedure (see form 6.B of Appendix A.)

3.5.2.3.1 Increments of diaphragm and back pressure are applied alternately. The diaphragm pressure increment stages are carried out without allowing drainage into or out of the specimen, which enables values of the pore pressure ratio $\delta u / \delta \sigma$ to be determined at each level of total stress.

The procedure is as described in 3.5.2.3.2 to 3.5.2.3.13.

3.5.2.3.2 Record the initial pore water pressure (u_0) as soon as it has reached a steady value after applying the pressure p_0 on the specimen corresponding to the diaphragm seating pressure p_{d0} . Ensure that the back pressure valve (see Figure 2) is closed.

3.5.2.3.3 Increase the diaphragm pressure to give the required first stage pressure on the specimen (p_1).

NOTE 1 Cell pressure increments of 50 kPa for the first two stages, and 50 kPa or 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.

Observe the pore water pressure until it reaches a steady value (u_1).

NOTE 2 A graphical plot of pore pressure reading against time may be made to verify when the steady state condition is reached (see note 2 of 3.3.1.2).

3.5.2.3.4 Calculate the value of ratio $\delta u / \delta \sigma$ from the equation

$$\frac{\delta u}{\delta \sigma} = \frac{u_1 - u_0}{p_1 - p_0}$$

3.5.2.3.5 Keeping the back pressure valve closed, increase the pressure in the back pressure line to a value equal to the vertical pressure p_1 less the selected differential pressure (see note 2 to 3.5.2.2). Record the reading of back pressure line volume-change indicator (v_1) when it reaches a steady value, to allow for expansion of connecting lines.

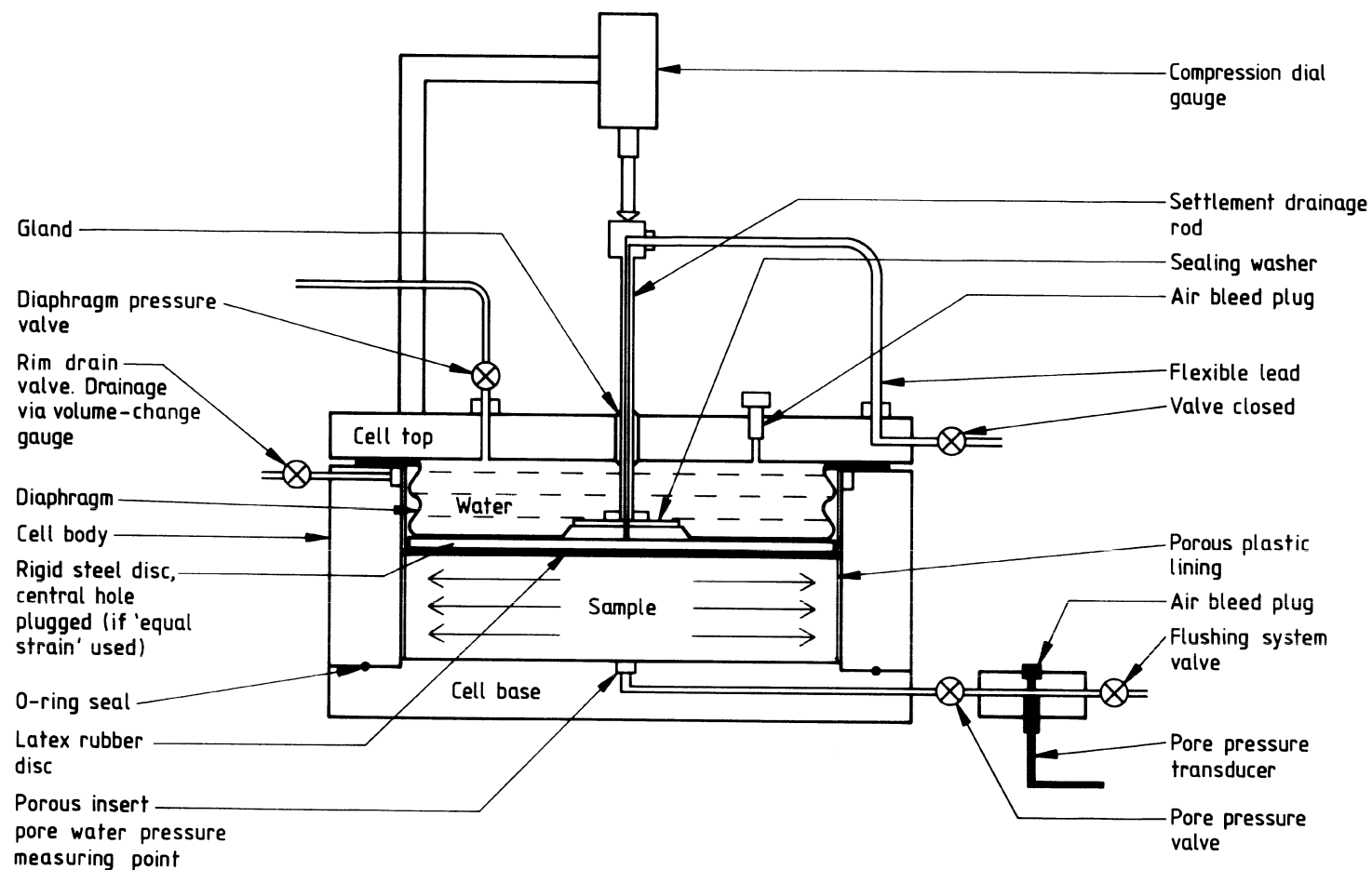


Figure 4 — Connections to hydraulic consolidation cell for consolidation test with radial drainage to periphery [test type (f)]