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*Amendment No. 1*

Methods of test for

# Soils for civil engineering purposes —

## Part 9: In-situ tests

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# Committees responsible for this British Standard

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# Contents

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# Foreword

This Part of BS 1377 has been prepared under the direction of the Road Engineering Standards Policy Committee. It is a revision of the in-situ test methods described in BS 1377:1975 which are superseded by amendment.

BS 1377:1975 which has now been withdrawn is replaced by the following Parts of BS 1377:1990: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

Regarding the in-situ test methods in BS 1377:1975, all have been retained except Test 15(C), determination of the dry density of fine-,medium- and coarse-grained soils by the hand scoop method. Regarding Test 15(C), a new test for coarse-grained soils has been substituted, based on a water replacement method that provides a more reliable result. With Test 19, determination of the penetration resistance using the split-barrel sampler, the method has been revised to conform more closely to international practice.

In addition to the change in the method for determining the density of coarse-grained soils, referred to above, the opportunity has been taken to add other test methods as follows:

Determination of the in-situ bulk density and moisture content of fine-, medium- and coarse-grained soils by attenuation of gamma rays and moderation of neutrons respectively.

Determination of the penetration resistance using the fixed 60° cone and friction sleeve (the static cone penetration test CPT).

Determination of the dynamic probing resistance using the 90° cone (dynamic probing DP).

Determination of the vertical deformation and strength characteristics of soil by the plate loading test.

Determination of the settlement characteristics of soil for lightly loaded foundations by the shallow pad maintained load test.

Determination of the in-situ California Bearing Ratio (CBR).

Determination of the in-situ apparent resistivity of soil.

Determination of the in-situ redox potential of soil.

In each of the test methods the measurement of only one value of the overall result is required. It is recognized that it is necessary in many practical applications to make a number of tests in order to obtain a mean value and an indication of its reliability. Guidance on the number of measurements required and the treatment of the results obtained is regarded as being beyond the scope of this Part of the standard.

Consideration was given to the inclusion of a test method for pressure meters but it was decided that it would be restrictive at this stage to formulate a standard.

General information relevant to the tests and common specification requirements applicable to a number of tests are given in Part 1 of this standard. Reference should always be made to this Part for any particular in-situ test method. For general information on site investigation procedures, especially with regard to safety precautions, reference should be made to BS 5930:1981.

Typical forms are included for a number of the test methods to illustrate how the results may conveniently be recorded and calculated. The layout of such forms is a matter of individual preference. This information is given in Appendix A.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately experienced people, for whose guidance it has been prepared.

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 66, an inside back cover and a back cover.

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

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# 1 Scope

This Part of BS 1377 describes in-situ methods of test on soils for civil engineering purposes, i.e. tests made directly on the soil in place as distinct from laboratory tests, described in Parts 2 to 8 of this standard, for which samples first need to be taken. The methods described in this Part of this standard have been arranged in groups either according to the purpose of the test or the mode of execution. These groups are as follows.

a) Five methods for the determination of the in-situ density.

b) Three methods for the determination of penetration resistances.

c) Four methods for the determination of the vertical deformation and strength characteristics.

d) Two methods for the determination of the in-situ corrosivity characteristics.

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

# 2 In-situ density tests

## 2.0 Introduction

This clause specifies five methods for determining the in-situ density of soil, four of which use the direct measurements of mass and volume, the choice of which depends upon the type of material, and one method uses gamma rays. The last named also includes the measurement of moisture content with nuclear gauges that combine both facilities.

## 2.1 Sand replacement method suitable for fine- and medium-grained soils (small pouring cylinder method)

2.1.1 *General.* This method covers the determination in-situ of the density of natural or compacted fine- and medium-grained soils for which a 115 mm diameter sand-pouring cylinder is used in conjunction with replacement sand (see note 1). The method is applicable to layers not exceeding 150 mm in thickness (see note 2).

NOTE 1 With granular materials having little or no cohesion particularly when they are wet, there is a danger of errors in the measurement of density by this method. These errors are caused by the slumping of the sides of the excavated density hole and always result in an over-estimation of the density.

NOTE 2 For layers between 150 mm and 250 mm in thickness the test described in 2.2 should be used.

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

### 2.1.2 *Apparatus*

2.1.2.1 *A pouring cylinder,* similar in detail to that shown in Figure 1.

2.1.2.2 *Suitable tools for excavating holes in soil,* e.g. a bent spoon dibber and a scraper tool, similar to that shown in Figure 2, to make a level surface.

2.1.2.3 *Cylindrical, metal, calibrating container,* with an internal diameter of 100 ± 2 mm and an internal depth of 150 ± 3 mm of the type illustrated in Figure 3, fitted with a lip 50 mm wide and about 5 mm thick surrounding the open end.

2.1.2.4 *Balance,* readable to 1 g.

2.1.2.5 *Glass plate,* a convenient size being one at least 10 mm thick and about 500 mm square.

2.1.2.6 *Metal tray or container* to take excavated soil, a convenient size being one about 300 mm in diameter and about 40 mm deep.

2.1.2.7 *A cylindrical, steel core cutter* (for fine-grained cohesionless soils), 130 mm long and 100 ± 2 mm internal diameter, with a wall thickness of 3 mm bevelled at one end. One suitable type is illustrated in Figure 6. This cutter shall be kept lightly greased.

2.1.2.8 *Apparatus for moisture content determination* as specified in BS 1377-2:1990.

2.1.2.9 *A metal tray* about 300 mm square and about 40 mm deep with a 100 mm diameter hole in the centre.

2.1.3 *Material.* The replacement sand shall be a clean closely graded silica sand which provides a bulk density that is reasonably consistent. The grading of the sand shall be such that 100 % passes a 600 µm test sieve and 100 % is retained on the 63 µm test sieve. In addition it shall be free from flakey particles, silt, clay and organic matter. Before using, it shall have been oven dried and stored in a loosely covered container to allow its moisture content to reach equilibrium with atmospheric humidity.

NOTE Generally a storage period, after oven drying, of about 7 days is sufficient for the moisture content of the sand to reach equilibrium with the atmospheric humidity. The sand should be mixed thoroughly before use. If sand is salvaged from holes in compacted soils after carrying out this test, it should be sieved, dried and stored again before it is used in further sand replacement tests.

### 2.1.4 *Calibrations*

#### 2.1.4.1 *Determination of the mass of sand in the cone of the pouring cylinder*

2.1.4.1.1 Fill the pouring cylinder so that the level of the sand in the cylinder is within about 15 mm of the top. Find its total initial mass, $m_1$, to the nearest 1 g and always use the same initial mass for every calibration. Maintain this constant throughout the tests for which the calibration is used. Allow a volume of sand equivalent to that of the excavated hole in the soil (or equal to that of the calibrating container) to run out.

Close the shutter on the pouring cylinder and place he cylinder on a plane surface, e.g. the glass plate.

2.1.4.1.2 Open the shutter on the pouring cylinder and allow sand to run out. Do not tap or otherwise vibrate during this period. When no further movement of sand takes place in the cylinder, close the shutter and remove the cylinder carefully.

2.1.4.1.3 Collect the sand on the glass plate that had illed the cone of the pouring cylinder and determine ts mass, $m_2$, to the nearest 1 g.

2.1.4.1.4 Repeat these measurements at least three imes and calculate the mean value of $m_2$.

2.1.4.2 *Determination of the bulk density of the sand* $\rho_a$)

2.1.4.2.1 Determine the internal volume, $V$ (in mL), of the calibrating container.

NOTE The following method for determining the volume of the alibrating container has been found both convenient and accurate

Place the empty container on the flat pan of the balance, ensuring that the upper rim of the container is horizontal, if necessary by embedding he base in modelling clay or similar material. Note he mass of the container, together with any modelling clay, to the nearest 1 g ($m_5$). Then fill the calibrating container almost completely with water, taking care not to spill water upon the pan of the balance or the outside of the container. Lay a straightedge across the top of the container and add water slowly and carefully by means of a dropping rod until the water just touches the straightedge. Remove the straightedge and note the mass of the container plus water to the nearest 1 g ($m_6$). Repeat the measurement a number of times to obtain an accurate mean value of $m_6$. For the repeat tests it is only necessary to remove a small amount of water by means of the dropping rod and to refill the container to the level of the straightedge. The volume of the calibrating container, $V$ (in mL), is given by the equation:

$$V = m_6 - m_5$$

2.1.4.2.2 Place the pouring cylinder concentrically on the top of the calibrating container after it has been filled to the constant mass, $m_1$, as specified in 2.1.4.1.1. Keep the shutter on the pouring cylinder closed during this operation. Open the shutter and allow the sand to run out. Do not tap the pouring cylinder or otherwise vibrate it during this period. When no further movement of sand takes place in the cylinder, close the shutter. Remove the pouring cylinder with the sand remaining in it and determine their combined mass, $m_3$, to the nearest 1 g.

NOTE The calibrating container should stand on a large tray during this part of the test procedure to collect the sand overflowing from the cone when the cylinder is removed.

2.1.4.2.3 Repeat these measurements at least three times and calculate the mean value of $m_3$.

NOTE Since variations in atmospheric humidity affect the moisture content of the sand, and hence its bulk density, the calibration should be made, or at least checked, during each day's work. To overcome the effects of slight variations in grading and particle shape between batches of sand, each batch should be sampled and calibrated.

### 2.1.5 *Procedure*

2.1.5.1 Expose a flat area, approximately 450 mm square, of the soil to be tested and trim it down to a level surface, preferably with the aid of the scraper tool. Brush away any loose extraneous material.

2.1.5.2 Lay the metal tray on the prepared surface with the hole over the portion of the soil to be tested. Using this hole as a pattern, excavate a round hole, approximately 100 mm in diameter and the depth of the layer to be tested up to a maximum of 150 mm deep. Do not leave loose material in the hole and do not distort the immediate surround to the hole. Carefully collect all the excavated soil from the hole and determine its mass, $m_w$, to the nearest 1 g. Remove the metal tray before placing the pouring cylinder in position over the excavated hole.

NOTE Take care in excavating the hole to see that the hole is not enlarged by levering the excavating tool against the side of the hole, as this will result in lower densities being recorded.

2.1.5.3 *Alternative method for fine-grained cohesionless soils* (see note).

Without using the metal tray, press the steel core cutter (Figure 6) evenly and carefully into the soil untill its top edge is flush with the levelled surface. Excavate the soil to a depth of about 120 mm within the core cutter by means of suitable tools. Carefully collect the excavated soil and determine its mass, $m_w$, to the nearest 1 g. Keep the core cutter in position during the remainder of the testing procedure.

NOTE The procedure specified in **2.1.5.3** should only be employed when the fine-grained cohesionless soil is in such a condition that, when using the procedure specified in **2.1.5.2**, a cylindrical hole cannot be formed because of the instability of the sides of the hole. The use of the core cutter will produce some disturbance in the soil and, where this procedure is necessary, due allowance should be made for a lower standard of accuracy than would normally be expected with the sand replacement method.

2.1.5.4 Place a representative sample of the excavated soil in an airtight container and determine its moisture content, $w$, as specified in BS 1377-2:1990. Alternatively, the whole of the excavated soil shall be dried and its mass, $m_d$, determined.

**2.1.5.5** Place the pouring cylinder, filled to the constant mass, $m_1$, as specified in **2.1.4.1.1** so that the base of the cylinder covers the hole concentrically. Ensure the shutter on the pouring cylinder is closed during this operation. Open the shutter and allow sand to run out; during this period do not vibrate the cylinder or the surrounding area. When no further movement of the sand takes place close the shutter. Remove the cylinder and determine its mass, $m_4$, to the nearest 1 g.

**2.1.6** *Calculations*[1] *and expression of results.* Calculate the mass of sand, $m_a$ (in g), required to fill the calibrating container from the equation:

$$m_a = m_1 - m_3 - m_2$$

where

$m_1$ is the mass of cylinder and sand before pouring into calibrating container (in g);

$m_2$ is the mean mass of sand in cone (in g);

$m_3$ is the mean mass of cylinder and sand after pouring into calibrating container (in g).

Calculate the bulk density of the sand, $\rho_a$ (in Mg/m$^3$), from the equation:

$$\rho_a = \frac{m_a}{V}$$

where

$V$ is the volume of the calibrating container (in mL).

Calculate the mass of sand required to fill the excavated hole, $m_b$ (in g), from equation:

$$m_b = m_1 - m_4 - m_2$$

where

$m_1$ is the mass of cylinder and sand before pouring into hole (in g);

$m_2$ is the mean mass of sand in cone (in g);

$m_4$ is the mass of cylinder and sand after pouring into hole (in g).

Calculate the bulk density of the soil, $\rho$ (in Mg/m$^3$), from the equation:

$$\rho = \left(\frac{m_w}{m_b}\right)\rho_a$$

where

$m_w$ is the mass of soil excavated (in g);

$m_b$ is the mass of sand required to fill the hole (in g);

$\rho_a$ is the bulk density of sand (in Mg/m$^3$).

Calculate the dry density, $\rho_d$ (in Mg/m$^3$), from the equation:

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

where

$w$ is the moisture content of the soil (in %).

or

$$\rho = \left(\frac{m_d}{m_b}\right)\rho_a$$

where

$m_d$ is the mass of dry soil from the hole (in g);

$m_b$ is the mass of sand required to fill the hole (in g).

**2.1.7** *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information:

a) the method of test used;

b) the in-situ bulk and dry densities of the soil (in Mg/m$^3$) to the nearest 0.01 Mg/m$^3$;

c) the moisture content, as a percentage to two significant figures;

d) the information required by clause **9** of BS 1377-1:1990.

### 2.2 Sand replacement method suitable for fine-, medium- and coarse-grained soils (large pouring cylinder method)

**2.2.1** *General.* This method covers the determination in situ of the density of natural or compacted soil containing coarse- grained particles which make the test described in **2.1** difficult to perform. It is an alternative to that test for fine- and medium-grained soils and should be used instead of that test for layers exceeding 150 mm, but not exceeding 250 mm in thickness (see note).

With granular materials having little or no cohesion, particularly when they are wet, there is a danger of errors in measurement of density by this method. These errors are caused by the slumping of the sides of the excavated density hole and always result in an over-estimation of density. In such cases the test described in **2.3** should be selected.

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[1] See form 9(a) of Appendix A.

The test described in **2.3** should also be used when very coarse-grained material is present.

NOTE If for any reason it is necessary to excavate holes other than 250 mm the calibrating container should be replaced by one with the same depth as the hole excavated, or its effective depth reduced to that of the hole excavated.

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

### 2.2.2 *Apparatus*

**2.2.2.1** *A pouring cylinder* similar in detail to that shown in Figure 4.

**2.2.2.2** *Suitable tools for excavating holes* in compacted soil, e.g. a bent spoon dibber, large screwdriver and/or pointed steel rod about 250 mm ong and 7 mm to 10 mm in diameter with a handle.

**2.2.2.3** *Cylindrical metal calibrating container* with an internal diameter of 200 ± 5 mm and an internal depth of 250 mm (see note to **2.2.1**), of the type shown in Figure 5, fitted with a lip about 75 mm wide and about 5 mm thick surrounding the open end.

**2.2.2.4** *Balance*, readable to 10 g.

NOTE The total mass of the pouring cylinder and sand is large so that the method of filling and weighing is to weigh the sand in two or three containers and tip it into the pouring cylinder before using. Take care to see that the same constant initial mass as is used in calibrating the apparatus is used for each density measurement. Sufficient sand should be used so that about 4 kg to 5 kg of sand is left in the pouring cylinder after the test is completed.

**2.2.2.5** *A glass plate or other plane surface*, a convenient size being one at least 10 mm thick and about 500 mm square.

**2.2.2.6** *Metal trays or containers* to take the excavated soil and to take the supply of sand to fill the pouring cylinder.

**2.2.2.7** *Apparatus for moisture content determination* as specified in BS 1377-2:1990.

**2.2.2.8** *A metal tray* about 500 mm square and about 50 mm deep with a 200 mm diameter hole in the centre.

**2.2.3** *Material.* The replacement sand shall be a clean closely graded silica sand which provides a bulk density that is reasonably consistent. The grading of the sand shall be such that 100 % passes a 600 µm test sieve and 100 % is retained on a 63 µm test sieve. In addition it shall be free from flakey particles, silt, clay and organic matter. Before use it shall have been oven dried and stored in a loosely covered container to allow its moisture content to reach equilibrium with atmospheric humidity.

NOTE After oven drying, a storage period generally of about 7 days is sufficient for the moisture content of the sand to reach equilibrium with the atmospheric humidity. The sand should not be stored in airtight containers and should be mixed thoroughly before use. If sand is salvaged from holes in compacted soils after carrying out this test, it is advisable to sieve, dry and store this sand again before it is used in further sand replacement tests.

### 2.2.4 *Calibrations*

#### 2.2.4.1 *Determination of the mass of sand in the cone of the pouring cylinder*

**2.2.4.1.1** Fill the pouring cylinder with a given initial mass of sand, $m_1$, weighed to the nearest 10 g and always use the same initial mass for every calibration. Maintain this mass constant throughout the tests for which the calibration is used (see note to **2.2.2.4**). Allow a volume of sand equivalent to that of the excavated hole in the soil, or equal to that of the calibrating container, to run out. Close the shutter on the pouring cylinder and place the cylinder on a plane surface, e.g. the glass plate.

**2.2.4.1.2** Open the shutter on the pouring cylinder and allow sand to run out. Do not tap or otherwise vibrate the pouring cylinder during this period. When no further movement of sand takes place in the cylinder, close the shutter and carefully remove the cylinder.

**2.2.4.1.3** Collect the sand on the plane surface that had filled the cone of the pouring cylinder and determine its mass, $m_2$, to the nearest 10 g.

**2.2.4.1.4** Repeat these measurements at least three times and calculate the mean value of $m_2$.

#### 2.2.4.2 *Determination of the bulk density of the sand* ($\rho_a$)

**2.2.4.2.1** Determine the internal volume, $V$ (in mL), of the calibrating container by the mass of water required to fill it. (See note to **2.2.2.4**.)

NOTE The following method for determining the volume of the calibrating container has been found both convenient and accurate.

Place the empty calibrating container on a flat surface, ensuring that its upper rim is horizontal, if necessary by embedding the base in modelling clay or similar material. Fill a suitable container (or containers) with water and weigh ($m_5$) to the nearest 10 g and then fill the calibrating container almost completely with water from the weighed container. Lay a straightedge across the top of the calibrating container and add more water slowly and carefully from the weighed container by means of a dropping rod until the water just touches the straightedge. Take care that no water is spilled during these operations. Then reweigh the water container (or containers) ($m_6$).

Repeat the measurement a number of times to obtain an accurate mean value for $m_6$. For the repeat tests it is only necessary to remove a small amount of water from the filled calibrating container by means of the dropping rod, return it to the weighed container, and to refill the calibrating container to the level of the straightedge. The volume of the calibrating container, $V$ in mL, is given by the following equation:

$$V = m_5 - m_6$$

**2.2.4.2.2** Place the pouring cylinder concentrically on the top of the calibrating container and fill with the constant mass of sand ($m_1$) as specified in **2.2.4.1.1**. Keep the shutter on the pouring cylinder closed during this operation. Open the shutter and allow the sand to run out. Do not tap or otherwise vibrate the pouring cylinder during this period. When no further movement of the sand takes place in the cylinder, close the shutter. Remove the pouring cylinder and determine the mass of sand remaining in it ($m_3$) to the nearest 10 g.

NOTE The calibrating container should stand on a large tray during this part of the test procedure, to collect the sand overflowing from the cone when the cylinder is removed.

**2.2.4.2.3** Repeat these measurements at least three times, and calculate the mean value of $m_3$.

NOTE Since variations in atmospheric humidity affect the moisture content of the sand, and hence its bulk density, the calibration should be made, or at least checked, during each day's work. To overcome the effects of slight variations in grading and particle shape between batches of sand, each batch should be sampled and calibrated.

### 2.2.5 *Procedure*

**2.2.5.1** Expose a flat area, approximately 600 mm square, of the soil to be tested and trim it down to a level surface. Brush away any loose extraneous material.

**2.2.5.2** Lay the metal tray on the prepared surface with the hole over the portion of the soil to be tested. Using this hole as a pattern excavate a round hole, approximately 200 mm in diameter and the depth of the layer to be tested up to a maximum of 250 mm (see note to **2.2.1**). Do not leave loose material in the hole and do not distort the immediate surround to the hole. Carefully collect the excavated soil from the hole and determine its mass ($m_w$) to the nearest 10 g.

Remove the metal tray before placing the pouring cylinder in position over the excavated hole.

NOTE Care should be taken in excavating the hole to see that the hole is not enlarged by levering the excavating tool against the side of the hole, as this will result in lower densities being recorded.

**2.2.5.3** Place a representative sample of the excavated soil in an airtight container and determine its moisture content, $w$, as specified in BS 1377-2:1990.

**2.2.5.4** Place the pouring cylinder filled with the constant mass of sand ($m_1$) as specified in **2.2.4.1.1** so that the base of the cylinder covers the hole concentrically. Keep the shutter on the pouring cylinder closed during this operation. Open the shutter and allow sand to run out; during this period do not vibrate the pouring cylinder or the surrounding area. When no further movement of the sand takes place, close the shutter. Remove the pouring cylinder and determine the mass of sand remaining in it ($m_4$) to the nearest 10 g.

**2.2.6** *Calculations*[2] *and expression of results.* Calculate the mass of sand required to fill the calibrating container, $m_a$ (in g), from the equation:

$$m_a = m_1 - m_3 - m_2$$

where

$m_1$ is the mass of sand before pouring in the calibrating container (in g);

$m_2$ is the mean mass of sand in cone (in g);

$m_3$ is the mean mass of sand after pouring into the calibrating container (in g).

Calculate the bulk density of the sand, $\rho_a$ (in Mg/m$^3$), from the equation:

$$\rho_a = \frac{m_a}{V}$$

where

$V$ is the volume of the calibrating container (in mL).

Calculate the mass of sand required to fill the excavated hole, $m_b$ (in g), from the equation:

$$m_b = m_1 - m_4 - m_2$$

where

$m_1$ is the mass of sand before pouring into the hole (in g);

$m_2$ is the mean mass of sand in cone (in g);

$m_4$ is the mass of sand after pouring into the hole (in g).

Calculate the bulk density of the soil, $\rho$ (in Mg/m$^3$), from the equation:

$$\rho = \left(\frac{m_w}{m_b}\right) \rho_a$$

where

$m_w$ is the mass of soil excavated (in g);

$m_b$ is the mass of sand required to fill the hole (in g);

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[2] See form 9(a) of Appendix A.

$\rho_a$ is the bulk density of the sand (in $Mg/m^3$).

Calculate the dry density, $\rho_d$ (in $Mg/m^3$), from the equation:

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

where

$w$ is the moisture content of the soil (in %).

2.2.7 *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following nformation.

a) The method of test used.

b) The in-situ bulk and dry densities of the soil (in $Mg/m^3$) to the nearest 0.01 $Mg/m^3$.

c) The moisture content, as a percentage, to two significant figures.

d) The information required by clause **9** of BS 1377-1:1990.

### 2.3 Water replacement method suitable for coarse-grained soils

2.3.1 *General.* This method covers the determination in-situ of the density of natural or ompacted coarse-grained soil using a circular density ring on the ground surface and a flexible plastics sheet to retain water to determine the volume of an excavated hole. The method is used in oarse and very coarse soils when the other methods or determining the field density are unsuitable because the volume excavated would be unrepresentative.

Alternative density determinations may be made as ollows:

a) for the total material within the hole excavated (see **2.3.5.1**):

1) to an unspecified depth;

2) to a specified depth;

3) in successive tests as a hole is progressively deepened in order to determine the variation of density with increasing depth, e.g. when placing and compacting material in specified stages.

b) for the proportion of the soil finer than a specified size, normally not less than coarse gravel (see **2.3.5.2**).

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

2.3.2 *Apparatus.* The following list of apparatus applies to both procedures a) and b). (See **2.3.5.1** and **2.3.5.2** respectively.) The number and size of the items will vary with the type of material present and the size of the hole to be excavated.

2.3.2.1 *Density ring* of rigid construction providing an unobstructed inner surface that is of a right cylinder approximately 100 mm high for rings up to 500 mm nominal internal diameter and 200 mm high for larger diameters. The ring shall be provided externally with a means for securing its position on the ground surface, e.g. metal spikes. The ring diameter shall be several times larger than the largest-sized particle (see note).

NOTE As a general guide the ring diameter should be at least five times the size of the largest particle in well-graded soil but more if uniformly coarse. Diameters usually range from 500 mm to 2.5 m. Ring sizes larger than 500 mm nominal diameter are usually constructed in several segments which can be assembled at the site. If necessary to ensure rigidity of the ring it should be fitted with an external flange.

2.3.2.2 *Rigid straightedge* sufficiently long to level the area of the density ring to be used.

2.3.2.3 *Spirit level* of suitable length to use with the straightedge in order to level the density ring.

2.3.2.4 *Pointer gauge assembly* consisting of an adjustable vertical pointer that can be locked in a fixed position, which is mounted on a datum bar that is removable during the test and can be replaced precisely so that the pointer is in the same position. The tip of the pointer is used to judge the final water level.

NOTE For the smaller density rings the pointer may be mounted on a datum bar supported on legs which remain in position throughout the test and are driven into the ground outside the ring. For the larger rings, which are generally more stable, it is usual for the datum bar to be slightly longer than the diameter of the ring and for it to rest on the rim of the ring, marking the position so that it can be returned precisely to the same position. In this case the pointer is in the centre of the datum bar with a clamp for adjusting the height.

2.3.2.5 *Calibrated water containers* (see also **2.3.4.1**), of suitable capacity for the water supply, each with a volume measuring gauge and a suitable delivery hose which shall be fitted with a valve close to the exit in order to facilitate close control of the water flow into the flexible plastics sheet. Graduations on the measuring gauges shall be clearly marked and shall permit measurements to be made within 0.3 % of the volume of the hole excavated.

2.3.2.6 *Balance or balances readable to 100 g.*

2.3.2.7 *Sample containers*, suitable for holding the excavated soil and for the measurement of its mass.

NOTE Soils and absorbent rocks holding significant amounts of water require containers with close-fitting lids. For material consisting of predominantly hard, non-absorbent rock of negligible moisture content open containers are satisfactory.

**2.3.2.8** *Digging tools* for excavating and removing material from the hole, e.g. pick, shovel, vibrating hammer and chisel point, crowbar, broom, handbrush and scoop.

NOTE When very coarse material may be encountered in the excavation it is advisable to provide mechanical excavation and lifting equipment.

**2.3.2.9** *Self-priming pump* with suction and delivery hose for removing water from within the flexible plastics sheet.

**2.3.2.10** *Mixing equipment* for the quick-setting plaster, such as a bucket and a perforated disc on the end of a pole.

**2.3.2.11** *Apparatus for moisture content determination* as specified in BS 1377-2:1990.

**2.3.2.12** *Test sieves*, if required.

**2.3.2.13** *Apparatus for dry density determination* as specified in clause **7** of BS 1377-2:1990, if required.

### 2.3.3 *Materials*

**2.3.3.1** *Flexible plastics sheet* that will mould to the shape of the hole yet is sufficiently thick not to be punctured by angular material.

NOTE Black polyethylene sheet 0.1 mm thick in 2 m to 4 m squares is suitable for density rings up to 1.5 m nominal diameter. Alternatively a prefabricated cylindrical liner 0.1 mm thick may be used with density rings 500 mm diameter and smaller. Polyethylene sheet 0.2 mm thick in 6 m to 8 m squares is suitable for density rings above 1.5 m and up to 2.5 m nominal diameter.

The use of transparent flexible sheeting aids identification of leaks in relatively dry materials and can assist when moulding the sheeting to fit the shape of the hole.

**2.3.3.2** *Plaster of Paris.*

**2.3.3.3** *Clean water.*

### 2.3.4 *Calibration*

**2.3.4.1** *Calibrated water containers.* Calibrate each container, fitted with its delivery hose and control valve, by locating it on a level base and filling with clean water to the top graduation on the volume measuring gauge. Then drain via the hose successive volumes into a separate container so that the water level drops to each graduation in turn. Calculate each successive volume of water in litres as it is drained into the separate container by weighing or volume measurement. Plot the actual cumulative volume of water in each calibrated container against the graduation scale.

**2.3.5** *Procedure.* Since there are stages in both test procedures which cannot be repeated, all observations and recordings shall be independently checked as the test proceeds.

**2.3.5.1** *Procedure for determining the density of the total material within the hole excavated*

**2.3.5.1.1** Select a suitable size of density ring such that its internal diameter exceeds by five times the size of the largest particle expected to be present.

**2.3.5.1.2** Prepare a horizontal flat area, sufficiently large to accommodate the selected density ring, and remove all loose material and sharp projections from the surface.

**2.3.5.1.3** Mix the plaster of Paris with water into a thick quick-setting paste sufficient to bed the density ring. Mark the position to be occupied by the density ring. Place a thin layer of the plaster paste over the area to be covered by the annulus of the density ring.

**2.3.5.1.4** Bed the density ring on the plaster paste ensuring that there are no voids remaining between the ring and the prepared surface of the ground. Secure the ring in place using the spikes. Trim away any surplus plaster paste from inside the ring.

**2.3.5.1.5** Set up the pointer gauge assembly so that the datum bar can be removed from the test area between readings and the tip at the lower end of the adjustable vertical pointer can be returned to a fixed position below the top of the ring.

Remove the datum bar and locked pointer to a safe position away from the test area, leaving the support in place if this is part of the assembly.

**2.3.5.1.6** Select a suitable size of the plastics sheet or liner and check that it is undamaged and without punctures. Place the plastics sheet over the ring and prepared surface ensuring that it closely conforms to the surface of the soil and the inside of the ring. Replace the datum bar and locked pointer.

**2.3.5.1.7** Fill the space contained by the plastics sheet up to the precise level of the tip of the locked pointer with water from a calibrated container. While filling ensure that the plastics sheet makes full contact with the prepared surface and the inside of the density ring.

After filling observe the water level at the pointer tip for several minutes in order to determine whether water is leaking through the plastics sheet. If leaking occurs or is suspected replace the plastics sheet with a sound piece and repeat the volume measurement.

The measured volume of water used shall be within 0.1 % of the total volume being measured. This volume is the initial reading ($R_i$) which shall be recorded in litres.

**2.3.5.1.8** Remove the datum bar and locked pointer to a safe position. Remove the water and the plastics sheet, checking the prepared surface for indication of leakage. If leaking is found to have occurred repeat stages **2.3.5.1.6** and **2.3.5.1.7**.

**3.5.1.9** Excavate with the digging tools a hole ithin the density ring as nearly cylindrical as racticable taking care not to displace the ring or he plaster filling. With non-cohesive soil, articularly when wet, the sides of the excavation ill need to be inclined to prevent slumping. arefully collect all the excavated material in uitable containers, which shall be fitted with lids r soils and absorbent rock fragments, and number hem consecutively. As the hole is deepened avoid ndercutting the ring and use mechanical lifting evices if necessary for removing very large aterial clear of the hole and over the ring. Leave in lace any large rocks that protrude when forming e hole boundary.

eep the floor and wall of the hole flat and free from harp protrusions which may puncture the plastics heet. Cease excavating when the depth of the hole more or less equal to its diameter, except when pecified otherwise such as when testing particular yers.

nsure the hole is finally cleared of all loose aterial with the wall and base left undisturbed.

**3.5.1.10** Weigh each container of excavated aterial, as well as any separate very coarse-sized aterial, to the nearest 100 g and record the result ith the container number. After deducting the asses of the containers, sum the individual masses the material in order to obtain the total excavated ass ($m_w$).

**3.5.1.11** When moisture or absorbent material is resent in all or part of the excavated soil and rock hich may affect the dry density determination, etermine the moisture content as specified in S 1377-2:1990.

he moisture content shall be representative of the hole of the material excavated, therefore collect a presentative portion for this moisture content etermination in a separate airtight container by crementally sampling each individual portion of e excavated material after determining the total ass ($m_w$).

**3.5.1.12** Select a suitable size of the plastics sheet d check that it is undamaged and without nctures. Place the plastics sheet over the ring and wn into the hole gently, ensuring that there is fficient to conform to the wall and base of the hole. eplace the datum bar and locked pointer.

**3.5.1.13** Fill the space contained by the plastics eet with water from the calibrated containers up the precise level of the tip of the locked pointer, as t for the initial volume measurement ee **2.3.5.1.7**). While filling, loosely support the plastics sheet away from the hole wall in the upper part in order to allow the rising water to form the lining to the shape of the hole and the inside of the ring.

NOTE For the larger test holes it may be convenient initially to use a large tank for the bulk of the filling and finish by drawing from a smaller tank to bring the water level more slowly up to the level of the tip of the locked pointer.

After filling observe the water level at the pointer tip for several minutes in order to check for leaks as during the initial volume measurements, replacing the plastics sheet and refilling if necessary. The total measured volume of water used for the filling shall be within 0.1 % of the total volume being measured. This volume is the final reading ($R_f$) which shall be recorded in litres.

**2.3.5.1.14** Remove the datum bar and locked pointer to a safe position. Remove the water and plastics sheet, checking the hole for indications of leakage. If leaking is found to have occurred repeat **2.3.5.1.12** and **2.3.5.1.13**.

**2.3.5.1.15** Dismantle the apparatus and backfill the hole.

**2.3.5.2** *Procedure for determining the density of the proportion of the soil finer than a specified size*

**2.3.5.2.1** Proceed as specified in **2.3.5.1.1** to **2.3.5.1.9**.

**2.3.5.2.2** Separate all the material larger than the specified size which has been excavated from the hole using test sieves where appropriate and if grading is required. Determine and record the total mass ($m_s$) of this oversize material in kg.

**2.3.5.2.3** Determine the moisture content ($w_p$) of the proportion remaining represented by the material finer than the specified size, as specified in BS 1377-2:1990.

**2.3.5.2.4** Determine the volume of the proportion of the soil finer than the specified size by one or other of the following methods.

a) Proceed as specified in **2.3.5.1.12** and **2.3.5.1.13** except that the oversize material shall be placed in the hole after positioning the plastics sheet and before filling with water to obtain the volume in litres ($R_p$).

Take special care to avoid puncturing the plastics sheet when replacing the oversize material.

b) Complete **2.3.5.1.12** and **2.3.5.1.13** to determine the total volume of the hole. Determine the volume of the oversize material ($v_s$), for deduction, either by water displacement as specified in **7.4** of BS 1377-2:1990 or by calculation from the mass and apparent density of the material.

**2.3.5.2.5** Proceed as specified in **2.3.5.1.14** and **2.3.5.1.15**.

### 2.3.6 *Calculations*[3] *and expression of results*

**2.3.6.1** *For the total material in the hole excavated.* Calculate the volume, $v_h$ (in m$^3$), of the hole from the equation:

$$v_h = \frac{R_f - R_i}{1000}$$

where

$R_i$ is the initial volume of water in the density ring and above the prepared surface (in L);

$R_f$ is the final volume of water in the hole and density ring (in L).

Calculate the bulk density, $\rho$ (in Mg/m$^3$), of the soil from the equation:

$$\rho = \frac{m_w}{v_h \times 1000}$$

where

$m_w$ is the wet mass of all the material from the hole (in kg).

Calculate the dry density, $\rho_d$ (in Mg/m$^3$), of the soil from the equation:

$$\rho_d = \frac{\rho \times 100}{100 + w}$$

where

$w$ is the moisture content (in %) of the soil, determined as specified in BS 1377-2:1990.

**2.3.6.2** *For the proportion of the soil finer than a specified size*

a) Where the oversize material has been replaced in the hole, calculate the dry density, $\rho_{dp}$ (in Mg/m$^3$), of the remaining proportion of the soil from the equation:

$$\rho_{dp} = \left(\frac{m_w - m_s}{R_p - R_i}\right)\left(\frac{100}{100 + w_p}\right)$$

where

$m_w$ is the wet mass of all the material from the hole (in kg);

$m_s$ is the mass as excavated of the oversize material (in kg);

$R_p$ is the final volume of water in the hole containing the oversize material (in L);

$R_i$ is the initial volume of water in the density ring and above the prepared surface (in L);

$w_p$ is the moisture content (in %) of the proportion remaining determined as specified in BS 1377-2:1990.

b) Where the volume of oversize material has been separately determined calculate the dry density, $\rho_d$ (in Mg/m$^3$), of the remaining proportion of the soil from the equation:

$$\rho_{dp} = \left(\frac{m_w - m_s}{v_h - v_s}\right)\left(\frac{100}{100 + w_p}\right)$$

where, in addition to the above table of symbols,

$v_h$ is the volume of the hole (in m$^3$) (see **2.3.6.1**);

$v_s$ is the volume of the oversize material (in m$^3$).

**2.3.7** *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) The method of test used.

b) The in-situ bulk and dry densities of the soil (in Mg/m$^3$), to the nearest 0.01 Mg/m$^3$

c) The moisture content, as a percentage, to the nearest 0.5 %.

d) The fraction of the soil for which the density has been determined (if appropriate).

e) The grading analysis (if appropriate).

f) The approximate diameter and depth of the hole, and whether either was specified or not.

g) The methods of determining the mass and volume of coarse and oversize material if carried out separately.

h) The information required by clause **9** of BS 1377-1:1990.

## 2.4 Core cutter method for cohesive soils free from coarse-grained material

**2.4.1** General. This method covers the determination of the density of natural or compacted soil in-situ.

NOTE This method may be less accurate than the sand replacement method test (see **2.2**) and is not recommended unless speed is essential, or unless the soil is well compacted but sufficiently soft for the cutter to be driven easily.

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

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[3] See form 9(b) of Appendix A.

### 4.2 *Apparatus*

4.2.1 *Cylindrical steel core cutter*, 130 mm long d of 100 ± 2 mm internal diameter, with a wall ickness of 3 mm bevelled at one end, of the type ustrated in Figure 6. The cutter shall be kept eased.

TE If the average density over a smaller depth is required, n the appropriate length of cutter should be used.

4.2.2 *Steel dolly*, 25 mm high and of 100 mm ternal diameter, with a wall thickness of 5 mm, ted with a lip to enable it to be located on top of e core cutter (see Figure 6).

4.2.3 *Steel rammer* of the type illustrated in gure 6.

4.2.4 *Balance*, readable to 1 g.

4.2.5 *Palette knife*, a convenient size is one having blade approximately 200 mm long and 30 mm de.

4.2.6 *Steel rule*, graduated to 0.5 mm.

4.2.7 *Grafting tool*, or spade, and a pickaxe.

4.2.8 *Straightedge*, e.g. a steel strip about 300 mm ng, 25 mm wide and 3 mm thick, with one bevelled ge.

4.2.9 *Apparatus for moisture content termination*, as specified in BS 1377-2:1990.

4.2.10 *Apparatus for extracting samples* from the tter (optional).

### 4.3 *Procedure*

4.3.1 Calculate the internal volume of the core tter in cubic centimetres from its dimensions hich shall be measured to the nearest 0.5 mm ($V_c$).

4.3.2 Weigh the cutter to the nearest 1 g ($m_c$).

4.3.3 Expose a small area, approximately 300 mm uare, of the soil layer to be tested and level it. emove loose extraneous material. Place the core tter with its cutting edge on the prepared surface. ace the steel dolly on top of the cutter, and ram the tter down into the soil layer until only out 10 mm of the dolly protrudes above the rface, care being taken not to rock the cutter. Dig e cutter out of the surrounding soil taking care to low some soil to project from the lower end of the tter. Trim the ends of the core flat to the ends of e cutter by means of the straightedge.

TE Where driving causes shortening of the sample in the ter, or there is difficulty in digging out the cutter, it may be nd preferable to remove the soil from around the outside of the ter and slightly in advance of the cutting edge as it is driven wn. Care needs to be taken not to cause voids inside the cutter trimming away the soil a short distance outside the wall of the tter. Jacking the cutter down against a fixed reaction instead of using the rammer may also assist in ensuring that it is driven more precisely and straight than by using the rammer.

2.4.3.4 Determine the mass of the cutter containing the core to the nearest 1 g ($m_s$).

2.4.3.5 Remove the core from the cutter, crumble it and place a representative sample in an airtight tin and determine its moisture content, $w$, using the method specified in BS 1377-2:1990.

2.4.4 *Calculations*[4] *and expression of results.* Calculate the bulk density of the soil, $\rho$ (in Mg/m$^3$), from the equation:

$$\rho = \frac{m_s - m_c}{V_c}$$

where

$m_s$ is the mass of soil and core cutter (in g);

$m_c$ is the mass of core cutter (in g);

$V_c$ is the internal volume of core cutter (in mL).

Calculate the dry density, $\rho_d$(in Mg/m$^3$), from the equation:

$$\rho d = \frac{100\,\rho}{100 + w}$$

where

$w$ is the moisture content of the soil (in %).

2.4.5 Test report. The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information:

a) the method of test used;

b) the in-situ bulk and dry densities of the soil (in Mg/m$^3$) to the nearest 0.01 Mg/m$^3$;

c) the moisture content, (in %), to two significant figures;

d) the information required by clause 9 of BS 1377-1:1990.

### 2.5 Nuclear methods suitable for fine-, medium-, and coarse-grained soils

2.5.1 Safety precautions. The nuclear equipment used in this test method utilizes radioactive materials emitting ionizing radiations which may be hazardous to health unless proper precautions are taken. Therefore before testing commences it is essential that users of this equipment are aware of the potential hazards and comply with all applicable government regulations concerning the precautions to be taken and routine procedures to be followed with this type of equipment.

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See form 9(c), Appendix A.

Keep time spent near the gauge to a minimum in order to minimize radiation effects.

NOTE The following documents regulate the use etc of nuclear gauges in the UK.

a) Radioactive Substances Act 1960.

b) Radioactive Substances (Carriage by Road) (Great Britain) Regulations 1985 and associated Code of Practice.

c) Ionising Radiations Regulations 1985 with the associated Approved Code of Practice —"The protection of persons against ionising radiation arising from any work activity" (ACoP). Part 2, section 8, of ACoP is relevant.

d) Section 6 of the Health and Safety at Work, etc., Act, 1974, HSW 74, (as amended by the Consumer Protection Act, 1987, and modified by Regulation 32 of the Ionising Radiations Regulations, 1985, IRR 85).

Advice regarding a), b) and c) may be obtained from the National Radiological Protection Board, Chilton, Oxon. OX11 0RQ. Advice regarding d) may be obtained from the Health and Safety Executive, Magdalen House, Stanley Precinct, Bootle, Merseyside L20 3QZ.

**2.5.2** *General.* This method covers the determination in situ of the density and moisture content of natural or compacted fine-, medium-, and coarse-grained soils by means of a nuclear gauge designed to operate on the ground surface.

The method is indirect for both measurements and does not necessarily provide the average value within the zone of influence of the test.

The standard means of measuring density and moisture content with nuclear gauges have been taken together because the gauges normally combine both facilities. Hence such gauges provide a rapid non-destructive technique for determining in-situ bulk and dry density as well as the moisture content. However gauges capable only of measuring bulk density may be used to carry out this test method.

The direct measurements made with the nuclear gauge consist of:

a) *bulk density*, i.e. the combined masses of solids and water per unit volume of the soil; and

b) *moisture density*, i.e. the mass of water per unit volume of the soil. Note that this value is not the same as moisture content.

The terms bulk density and moisture density have been used throughout this standard when describing the measurements in order to distinguish them from the derived values of dry density and moisture content. Many gauges are microprocessor-controlled and are able to provide derived values of dry density and moisture content.

The test is suitable for most fine-, medium- and coarse- grained soils (see note) where the plan area of the gauge is of a sufficient size to provide a representative sample. The presence of occasional coarse gravel-sized particles or larger material completely surrounded by fine-, and medium-grained soil should be revealed by tests giving unusually high-density results. Where the soil is composed mainly of coarse particles their maximum nominal size should not exceed 37.5 mm.

Bulk density measurements may be made using these gauges in two different modes. These modes of operation are referred to as:

c) *direct transmission;* and

d) *backscatter.*

The principles upon which each is based are shown in Figure 7. Direct transmission is the preferred type for a density measurement and should be used where possible because of its deeper zone of influence.

Moisture density can be determined only by using the backscatter type of transmission [see Figure 7(a)]. However, some gauges permit measurement of moisture density while at the same time measuring bulk density by either mode of operation.

The zone of influence including the depth below the surface for either type of measurement is not precise and will depend on the design of the gauge and, in the case of the bulk density determination, will vary with the type of transmission. Typically the measurement depth for bulk density is between 50 mm and 300 mm. In the case of a moisture content determination about half of the measured count rate may refer to the uppermost 50 mm; the overall depth tests will vary with the moisture density.

NOTE Test results for both types of transmission may be affected by a number of factors.

e) *Both measurements:*

1) heterogeneity of the soil which may cause a bias to particular parts within the zone of influence;

2) surface texture of the soil, the effect of which should be minimized by ensuring maximum contact between the gauge and soil being tested.

f) *Density measurements:*

1) layers of compacted soil can contain significant vertical gradients of density such that the state of compaction at the top may bear little relation to the average density conditions throughout the layer. The backscatter test, by its mode of operation, is concentrated on soil close to the surface. Direct transmission is preferred as it largely eliminates these effects by its ability to test equally all parts of the layer to the total depth to which the source is inserted;

2) chemical composition of soil, such as blast furnace slag, which makes it unsuitable for testing.

g) *Moisture density measurements:*

1) Constituent material containing hydrogen which is not removed during the oven-drying process. Examples of such soils would be those containing organic matter or chemically bound water such as gypsum of a sufficient amount to affect the result.

2) Some elements such as cadmium, boron and chlorine can have an effect on the measurement of moisture content since they have high thermal-neutron capture probabilities. When these elements are present this method has to be used with caution.

3) Where the soil contains constituent material that affects moisture content measurements made with nuclear gauges, if this proportion is sensibly constant then it may be possible to adjust the calibration curve as described in **2.5.6.3.3**.

riations in the design of the nuclear gauges are ch that in describing this method it has not been ssible to detail fully the operation of the gauge d reference is made to the manufacturer's ndbook.

### .3 *Principles*

**.3.1** *Bulk density.* The method uses the enuation of gamma rays from a gamma source ually in a moveable probe) due to Compton ttering and photo-electric absorption. The ensity of radiation arriving at the detector ually fixed in the gauge base) which is directly ated to the electron density provides an ication of the bulk density by comparison with an propriate calibration.

**2.5.3.2** *Moisture density.* The method uses the moderation (slowing down) of neutrons from a fast neutron source due to collisions principally with hydrogen nuclei. The intensity of radiation reaching the detector, which is directly related to the rate of arrival of moderated neutrons, provides an indication by comparison with an appropriate calibration, of the amount of moisture present within the volume of the zone of influence assuming that water represents the principal source of hydrogen present in the soil.

NOTE Both neutron source and detector are usually in fixed positions near to the gauge base and separate from the bulk density measurements devices. Thus, although the moisture density test is separate from the bulk density test, gauges with these facilities are generally designed so that both determinations may be made at the same time, whether the bulk density is being determined by direct transmission or backscatter.

### 2.5.4 *Apparatus*

**2.5.4.1** *Calibrated nuclear surface gauge* suitable for bulk density and moisture density measurements. It shall contain sealed nuclear sources adequately shielded for safety during storage and use, and suitable detectors and readout devices with electric batteries all within a housing of rugged construction that is water and dust-resistant. For the determination of bulk density by direct transmission the housing shall also contain an extendable probe for locating the bulk density measuring gamma source in a preformed hole in the soil to be tested. The probe aperture shall be fitted with an automatic shutter and shield mechanism which closes when the source is withdrawn into the safe position.

A manufacturer's handbook and current certificate of calibrations, and an approved transport case, shall also be provided.

A nuclear gauge limited to bulk density measurements may be used provided it complies with this specification in all relevant respects.

The gauge shall be recalibrated as in **2.5.5** and/or **2.5.6** as appropriate after any repair or overhaul involving change of the sources, detectors or reference blocks.

NOTE If defects in a source are suspected or if a source is damaged or thought to be damaged the equipment should be left in its storage box and the manufacturer or an authorized agent notified immediately.
Handling and repair should be undertaken only by suitably equipped and properly trained personnel.

**2.5.4.2** *Reference block* of suitable material for checking the gauge operation and to establish conditions for reproducible standard count rates. The reference block shall have the same serial number as the gauge and shall not be interchangeable between gauges.

NOTE The reference block should be kept clean and free from adhering particles, which may cause a poor contact with the gauge and result in an erroneous standard count rate.

**2.5.4.3** *Gamma radiation monitor.*

**2.5.4.4** *Test area preparation equipment,* i.e. suitable tools for levelling the ground at the site of the test, such as shovel, trowel, brush and straightedge.

**2.5.4.5** *Steel drive pin and hammer and/or suitable auger with template* to form and position the test hole for the direct transmission test for bulk density measurements. The drive pin should produce a hole up to 3 mm larger than the external diameter of the gauge probe.

**2.5.4.6** *Gauge log* to record standardization (see **2.5.7**) and stability (see **2.5.8**) test results.

**2.5.4.7** *Calibration results.* These may be in the form of charts and may also be stored in the memory bank of the readout system.

**2.5.4.8** *Dry clean fine quartz sand* for bedding gauge on uneven surfaces.

### 2.5.5 *Calibration for bulk density measurements*

**2.5.5.1** *Manufacturer's bulk density calibration.* This calibration shall initially be carried out in accordance with ASTM D2922[5]. Every 24 months the manufacturer's calibration shall be checked using not less than three of the standard density blocks as described in ASTM D2922.

**2.5.5.2** *Initial site calibration for bulk density.* Calibrate the nuclear gauge in accordance with this clause for each mode of operation to be used for the test and at each test depth if used in direct transmission. The calibration procedure will depend upon the nature of the measurement application. These categories are as follows:

a) ground investigation comparative tests;

b) ground investigation absolute tests;

c) compliance tests for compacted material.

1) *Ground investigation comparative tests.* These tests require no initial site calibration, provided that the data obtained are used only for comparative purposes on the particular site. The test report shall clearly state that the comparative test method has been used and that no initial site calibration was carried out.

2) *Ground investigation absolute tests.* Carry out an initial test before using the gauge at any location or when any significant change of soil type occurs. Do this by selecting a suitable location and performing a minimum of three separate nuclear density gauge tests followed by a series of suitable alternative in-situ test methods, such as sand/water replacement or core cutter methods as described in **2.1** to **2.4**. If each of the field tests varies by less than 3 % from the nuclear density gauge result then adjustment of the manufacturer's calibration is not necessary. Where there is a difference of 3 % or greater then a soil calibration shall be made as described in **2.5.5.3** for the mode of operation to be used. Where this is to be by direct transmission the gauge shall be calibrated at each test depth. Two alternative calibration methods are given using either containers or in-situ tests. Normally for both modes of operation calibration by the separate container method is preferred.

NOTE The alternative in-situ methods may produce data with an inherent scatter which itself exceeds 3 %. It is important therefore to carry out sufficient in-situ tests to provide reliable data. Where there is a doubt soil calibration using the container method should be carried out. (See **2.5.5.3.1**.)

3) *Compliance tests for compacted material.* Where the nuclear gauge is to be used for compliance tests on compacted material, carry out the initial site calibration using a single container test as specified in **2.5.5.3.1** prepared at the lower limit of compliance of bulk density plus or minus 2 %.

**2.5.5.3** *Soil calibration for bulk density.* Carry out a minimum of five separate calibration tests on the selected soil as described below using a range of different bulk densities which fully cover the span of expected use with as uniform a spread as practicable. Two alternative methods are described.

**2.5.5.3.1** *Calibration by the container method.* Proceed as follows.

a) Select a suitable container (or containers) having sufficiently rigid walls and base not to deform when soil is placed and compacted within it, and a sufficient size not to change the observed count (or count rate) if made larger in any dimension.

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[5] See reference list of standards on inside back cover.

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NOTE Containers with internal plan dimensions of approximately 500 mm long by 380 mm wide have proved satisfactory for equipment presently available (1990). For direct transmission, the depth of the container can be matched to the sample depth for which the soil calibration is required; in this case the depth of the container should be equal to the appropriate hole depth referred to in **2.5.9.1**. For calibration with the backscatter mode of operation, a minimum depth of 230 mm is adequate.

b) Place the clean empty container on a level rigid base, measure the internal dimensions to the nearest 1 mm and calculate the internal volume. Determine the mass of the empty container if this is to be used to obtain the total mass of soil to be placed within the container.

c) Prepare a block of selected soil within the container to a density within the required range (see note). Finish the top of the block level with the top of the container. From the known total mass of soil placed in the container and its internal volume calculate the bulk density of the soil.

NOTE Care should be taken to avoid the occurrence of significant density gradients when filling the container except when the depth of the container is matched to the sampling depth of the nuclear gauge in the case of direct transmission testing. Variations in the method of preparation, other than of overall bulk density, may produce erroneous data and great care should, therefore, be taken in preparation. If there is any doubt the calibration should be checked using an alternative approved method.

d) Within 1 h of filling the container measure the bulk density with the nuclear gauge in the same manner as described for making site measurements of bulk density and according to the mode of operation for which the calibration is being made.

**2.5.3.2** *Calibration by the in-situ method.* Proceed follows.

a) Carefully select an area for a minimum of five calibration tests in order to provide as close agreement as practicable to the range of densities likely to be found at the test location.

b) Measure the in-situ bulk density with the nuclear gauge in the same manner as described for making site measurements of bulk density and according to the mode of operation for which the calibration is being made.

c) Carry out at each calibration test location an appropriate alternative in-situ test method, such as sand/water replacement or core cutter method as described in **2.1** to **2.4** to determine an alternative bulk density measurement.

**2.5.3.3** Derivation of the calibration. Proceed follows.

a) Plot the bulk densities obtained from the alternative in-situ tests or from the dimensions and masses of soil placed in the container(s) against the nuclear bulk density measurements.

b) Calculate the least-square best fit line from the data and obtain an adjusted bulk density from the equation:

$$\text{Adjusted bulk density} = b\rho_n \pm a \text{ (in Mg/m}^3\text{)}$$

where

$b$ and $a$ are the slope and intercept respectively as determined in the least-square analysis;

$\rho_n$ is the nuclear gauge bulk density (in Mg/m$^3$).

Use the results of the analysis to adjust the manufacturer's calibration where this is incorporated in the gauge electronics.

c) Repeat the calibration every 3 months when testing is to continue for a particular calibration for longer than this period.

### 2.5.6 *Calibration for moisture density measurements*

**2.5.6.1** *Manufacturer's moisture density calibration.* This calibration shall initially be carried out in accordance with ASTM D3017. Every 24 months the manufacturer's calibration shall be checked for the nuclear gauge.

**2.5.6.2** *Initial site calibration for moisture density.* Calibrate the gauge in accordance with this clause depending upon the nature of the measurement calibration. These categories are:

a) Ground investigation comparative tests.

b) Ground investigation absolute tests.

c) Compliance tests for compacted material.

1) *Ground investigation comparative tests.* These tests require no initial site calibration provided that the data obtained are used only for comparative purposes on a particular site. The test report shall clearly state that the comparative test method has been used and that no initial site calibration was carried out.

2) *Ground investigation absolute tests.* Carry out an initial test before using the gauge at any location or when any significant change of soil type occurs. Do this by selecting a suitable location and performing a minimum of two separate nuclear gauge tests following the procedure as in **2.5.6.3**, at different moisture densities spanning the range of expected use. For each nuclear gauge test determine the quantity of water present per unit volume of the soil from a standard bulk density measurement other than the nuclear gauge method, and the moisture content by the method described in BS 1377-2:1990.

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Compare the alternative density and moisture content results with the nuclear gauge moisture density measurements. If each of the results of the alternative tests varies by not more than 0.01 Mg/m$^3$ of water from the nuclear gauge result, and some of the alternative test results are greater and some less than the nuclear gauge results, then adjustment of the manufacturer's calibration is not necessary. Where the results of the alternative tests all lie in one direction some gauges include a facility for a constant adjustment.

Where there is a difference between the previous calibration and the check points that is greater than 0.01 Mg/m$^3$ of water carry out a soil calibration as described in **2.5.6.3**. Two soil calibration procedures are given using either containers or in-situ tests. Normally the container method is preferred.

NOTE The alternative in-situ test methods may produce data with an inherent scatter which itself exceeds 0.01 Mg/m$^3$ of water. It is important therefore to carry out sufficient alternative tests to provide reliable data. Where there is a doubt the full soil calibration should be carried out as given in **2.5.6.3**.

3) Compliance tests for compacted material. Where the nuclear gauge is to be used for compliance tests on compacted material, carry out the initial site calibration using a single container of soil as specified in **2.5.6.3** prepared at the upper limit of compliance for moisture content and at the maximum achievable bulk density at that moisture content, plus zero or minus 2 % of the wet weight of the soil.

**2.5.6.3** *Soil calibration for moisture density.* The procedures are similar to those described in **2.5.5.3** except that a minimum of three separate calibration tests shall be carried out on the selected soil using a range of different moisture densities which fully cover the span of the expected use. Two alternative methods are given.

**2.5.6.3.1** *Calibration by the container method.* Proceed as follows.

a) Select a suitable container (or containers) having sufficiently rigid walls and base not to deform when soil is placed and compacted within it, and a sufficient size not to change the observed count (or count rate) if made larger in any dimension.

NOTE Containers with internal dimensions of approximately 600 mm long by 460 mm wide by 450 mm deep have proved satisfactory for equipment presently available (1990).

b) Place the soil in the container(s) as described in **2.5.5.3.1** b) and c) in a manner to provide a uniform bulk density and moisture density.

c) Carry out the nuclear measurement following the principles described in **2.5.5.3.1** d).

d) Calculate the bulk density of the soil block from the internal volume of the container and the mass of wet soil. Then take a representative sample of the wet soil in the container and determine the moisture content by the method described in BS 1377-2:1990.

e) Calculate the moisture density, i.e. the mass of water present per unit volume of placed soil.

**2.5.6.3.2** Calibration by the in-situ method. Proceed as follows, the procedure being similar to that described in **2.5.5.3.2**. After the nuclear measurement calculate the moisture density of the soil in the same place by an alternative in-situ bulk density test method such as sand/water replacement or core cutter method, as described in **2.1** to **2.4**, and the moisture content of the in-situ soil by the method described in BS 1377-2:1990.

**2.5.6.3.3** *Derivation of the calibration.* Proceed as follows.

a) Use the two sets of data on moisture density, i.e. the count ratio or moisture density measurement by the existing gauge calibration and the results of the alternative test methods to obtain the required calibration.

b) The relation of the best fit for moisture density is normally linear. Use the results of the analysis to adjust the manufacturer's calibration when this is incorporated in the gauge electronics.

c) Where the new calibration points all lie uniformly on one side of the previous calibration, it may be due to the presence of chemically bound water in the soil. Some gauges include a facility to provide a constant adjustment of the result to suit such cases.

d) Repeat soil calibrations for moisture density measurements every 3 months when testing is to continue for a particular calibration for longer than this period.

**2.5.7** *Gauge standardization procedure.* Carry out the standardization of the gauge on the reference block for each type of measurement at the start and end of each day's use. This procedure shall also be repeated after 8 h of continuous use, but may be carried out more frequently if appropriate. Retain a permanent record of these data. If the gauge is switched off repeat the standardization procedure.

TE All nuclear gauges are subject to long-term ageing of the rces (radioactive decay), electronic components and the ectors. Local geography may cause background radiation to y, which can change the gauge performance. Gauges are refore calibrated in terms of a ratio of the measurement count e for each radioactive source to a count rate made on a erence block.

e procedure is as follows:

a) Switch on the gauge and allow for normalization if required in accordance with the manufacturer's handbook. This period will usually be not less than 15 min. If the gauge is to be used either continuously or intermittently during the day, do not switch the gauge off. Perform the test with the gauge located at least 7 m away from other nuclear gauges and at least 1.5 m from any large structure which may affect the gauge readings.

b) Place the gauge on the reference block and ensure that the bulk density gamma source is correctly located. For each type of measurement, i.e. bulk density and moisture density, take at least four repetitive readings of the standard count rate each of 1 min period and calculate the mean value. Alternatively if available on the gauge, one measurement over a period of 4 min or more is acceptable. Either constitutes one standardization check.

c) Make a record of the results of each standardization check with the date of the measurements in the gauge log in order to retain a continuity of the results.

d) Check whether the arithmetical mean value in each case is within the limits set by the following equation and record the value of $N_s$ in the gauge log, using the equation:

$$N_s=N_o \pm 2.0\sqrt{\frac{N_o}{P_c}}$$

where

$N_s$ is the average value of the current standard count rate;

$N_o$ is the average of the past four values of $N_s$ taken prior to use;

$P_c$ is the amount of prescale applied to the detector counts prior to display. The manufacturer should supply this value. If no prescale is built into the gauge the value is 1;

) If $N_s$ is within the limits permitted above, the $N_s$ can be used to determine the count rate ratios or the current day's use of the gauge.

f) If $N_s$ is outside the permitted limits repeat at least twice more the procedure for determining the average standard count rate. If all three or two of the three determinations are outside the acceptable limits, withdraw the gauge from service until the fault is rectified.

g) If the standardization at the end of the working period gives values outside the permitted limits all results within that working period are invalidated.

**2.5.8** *Gauge stability procedure.* Carry out the gauge stability check for each type of measurement at least once a month when in general daily usage and at least once every 3 months otherwise.

The procedure shall be as follows.

a) Follow the gauge standardization procedure in **2.5.7** except that a series of at least 16 repetitive readings of the standard count rate, each of a 1 min period, are carried out with the gauge on the reference block for each type of measurement. Do not move the gauge during this process.

b) Separately record each of the measurements for each radioactive source in the gauge log with the date of the measurements.

c) Determine the standard deviation (SD) and determine the average value of each series of repetitive measurements.

d) Check that each stability ratio, expressed as the standard deviation divided by the square root of the average value, lies within the manufacturer's quoted range for the gauge. Take into account any prescale value used and record the results in the gauge log.

e) Where either of the stability ratios falls outside the manufacturer's specified range or the trend in successive checks is erratic withdraw the gauge from service until the fault is rectified.

**2.5.9** *Test procedure.* The following particulars are subdivided according to the mode of operation used for bulk density measurements. The addition of moisture density measurements, with gauges including this facility, may be taken at the same time as the bulk density measurements in either bulk density mode of operation of the gauge. Where moisture density, as the mass of water per unit volume, is separately required follow the procedure for a backscatter test omitting the operations concerning bulk density but return the bulk density measurement gamma source inside its shielded housing with the shutter closed.

**2.5.9.1** *Direct transmission procedure for bulk density.*
Proceed as follows.

a) Standardize the gauge as described in **2.5.7**.

b) Select and prepare a test location at which the bulk density and moisture density are to be measured.

Perform the test with the gauge located at least 7 m away from other nuclear gauges and normally at least 1.5 m from any large structure which may affect gauge readings.

When having to make a test within 1.5 m of a trench wall or structure and the gauge moisture density is to be used to determine dry density, then, in order to take account of the effects of reflected radiation, it is necessary that a moisture count over a 1 min period be made with the gauge placed on the reference block within 10 mm of the test position for each such test and to use the same orientation as for the tests. Moreover the gauge should always be kept at least 150 mm clear of any vertical projection. Calculate the difference between this count and the reference moisture count obtained as described in **2.5.7** and use the moisture offset value so obtained to adjust all subsequent moisture counts made at this location. Follow the procedures given in gauge manufacturer's handbook to incorporate the moisture offset value.

c) Remove extraneous material from the test position, which shall be essentially flat and free of depressions.

d) Using the template as a guide, drill or drive a hole for the probe to the appropriate depth. The depth of the hole may need to be greater than the depth over which the bulk density is to be determined. (Consult the manufacturer's handbook for advice on the appropriate hole depth.) Mark the soil surface in order to locate the gauge correctly with respect to the position of the hole for the probe.

e) Place the gauge on the test location and ensure there is good overall contact between the base of the gauge and the soil being tested. When in doubt, maximize contact between gauge base (which shall be kept clean and free of adhering particles without bringing the hands in contact with the base) and surface by using small quantities of fine dry sand or fines of material under test to fill small surface voids. This material shall not form an added layer.

f) Insert the probe to the selected depth according to the manufacturer's handbook.

g) Pull the gauge in the direction that will bring the probe against the side of the hole, closest to the detector location in the gauge housing.

h) Follow the gauge manufacturer's handbook to obtain a gauge bulk density reading, and if required a gauge moisture density reading, both with a minimum test period of 1 min using the built-in timer.

NOTE In order to minimize radiation effects move away from the gauge when not operating it and during counts.

If desired, the gauge may be rotated about the axis of the probe and further measurements made. Normally for two determinations the gauge is rotated through 180° and the two results averaged. Alternatively the volume of soil measured can effectively be increased by repeating the test at immediately adjacent (vertically or horizontally) locations and averaging the two results.

If the test is repeated in a vertically adjacent location, and the results are to be averaged, the top of the second test shall be at the level of the depth selected for the insertion of the probe in the first test.

i) Take the field readings of bulk density and moisture density at the test location, and record them where necessary.

Adjust the field values if necessary using the calibration charts. Some gauges contain microprocessors capable of storing a user-determined calibration which automatically corrects the displayed data.

j) Retract the extendable probe into the housing, ensure the shutter is closed and check that the radioactive source is safely housed. Use the gamma radiation monitor to establish that the radiation profile is within the limit set by the manufacturer's handbook.

**2.5.9.2** *Backscatter procedure for bulk density and moisture content.* Proceed as follows.

a) Follow the procedure given in **2.5.9.1** a), paragraphs 1 and 2 b), d) and f).

When having to make a test within 1.5 m of a trench wall or structure in order to take account of the effects of reflected radiation it is important that a second gauge standardization procedure as given in **2.5.7** a) and b) is made within 10 mm of the test position for each such test and to use the same orientation as for the tests. Moreover the gauge should always be kept at least 150 mm clear of any vertical projection.

b) Follow the gauge manufacturer's handbook to obtain a gauge bulk density reading and gauge moisture density reading, both with a minimum test period of 1 min using the built-in timer.

NOTE In order to minimize radiation effects move away from the gauge when not operating it and during counts.

f desired, the gauge may be rotated about the xis of the probe and further measurements nade. Normally for two determinations the auge is rotated through 180° and the two esults averaged.

lternatively the volume of soil measured can ffectively be increased by repeating the test at mmediately adjacent locations and averaging he two results.

) Take the field readings of bulk density and oisture density at the test location and record hem where necessary.

djust the field values if necessary using the alibration charts. Some gauges contain nicroprocessors capable of storing a ser-determined calibration which automatically orrects the displayed data.

) Retract the extendable probe into its housing, nsure the shutter is closed and check that the adioactive source is safely housed. Use the amma radiation monitor to establish that the adiation profile is within the limit set by the nanufacturer's handbook.

10 *Calculations and expression of the results*

10.1 *Dry density.* Calculate the dry density, n Mg/m$^3$), from the equations:

) *for nuclear gauge determinations*

$$\rho_d = \rho - W$$

here

$\rho$ is the bulk density of the soil (in Mg/m$^3$) determined with the nuclear gauge;

$W$ is the moisture density, i.e. the mass of water per unit volume of soil (in Mg/m$^3$) determined with the nuclear gauge.

) *for laboratory determination of moisture ontent*

$$\rho_d = \frac{100\rho}{100 + w}$$

where

$\rho$ is the bulk dentisy of the soil (in Mg/m$^3$) determined with the nuclear gauge;

$w$ is the moisture content of the soil (in %) as determined by the method given in BS 1377-2:1990.

0.2 *Moisture content.* Calculate the moisture ent, $w$ (as %), from the equation:

$$= \frac{100\ W}{\rho - W}$$

where

$W$ is the moisture density, i.e. the mass of water per unit volume of soil (in Mg/m$^3$) determined with the nuclear gauge;

$\rho$ is the bulk density of the soil (in Mg/m$^3$) determined with the nuclear gauge.

**2.5.11** *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) Method of test used.

b) The in-situ bulk density of the soil (in Mg/m$^3$) to the nearest 0.01 Mg/m$^3$, and mode of operation of the gauge.

c) Where applicable, the moisture content (in %) to two significant figures.

d) Where applicable, the dry density of the soil (in Mg/m$^3$) to the nearest 0.01 Mg/m$^3$.

e) Nature of measurement application (**2.5.5.2** and/or **2.5.6.2**).

f) The model and serial number of the gauge.

g) The information required by clause **9** of BS 1377-1:1990.

## 3 In-situ penetration tests

### 3.0 Introduction

This clause describes methods for determining three different types of penetration resistance of soil. All are empirical methods of testing the strength of soil at various depths below a particular location. The cone penetration test and the dynamic probing test are usually carried out independently of the borehole and other tests; the former being the more precise while the latter uses much simpler apparatus. The standard penetration test is for use in a borehole.

### 3.1 Determination of the penetration resistance using the fixed 60° cone and friction sleeve (static cone penetration test CPT)

**3.1.1** *General.* This method covers the determination of the resistance of soils in situ to the continuous penetration at a slow uniform rate of a series of push rods having a cone at the base, and measuring continuously or at selected depth intervals the penetration resistance of the cone and, if required, the local friction resistance on a friction sleeve and pore pressure in the vicinity of the cone and sleeve.

This method requires the use of a penetrometer tip with electrical sensors as defined in **3.1.2.4**, thereby permitting continuous readings and an instant read-out. This is not intended to prohibit the use of the older type of mechanical penetrometer, where readings are taken through inner push rods thrusting against load capsules mounted on the thrust machine. It should be noted that the mechanical penetrometer does not give precisely the same readings as would be obtained by the electrical penetrometer tip, which is now specified as standard. In submitting reports, the type of penetrometer and penetrometer tip which has been used should always be given.

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

**3.1.2** *Apparatus.* The complete apparatus, known as the penetrometer, shall consist of the parts described in **3.1.2.1** to **3.1.2.11**.

**3.1.2.1** *Penetrometer tip.* The penetrometer tip shall comprise a cylindrical terminal body which is mounted on the lower end of the push rods. The tip shall contain: a) the cone at the base, b) close above the base externally, the friction sleeve,.where fitted, c) internally, the sensing devices for measurement of the cone and sleeve resistances, d) internally an inclinometer where fitted (see note) and e) piezometric sensors where fitted.

The axes of the cone friction sleeve, if included, and the body of the penetrometer tip shall be coincident.

The diameter of the penetrometer tip shall nowhere be 0.3 mm smaller or 1 mm larger than the diameter of the base of the cone. In the case of a penetrometer tip with a friction sleeve, no part of the penetrometer tip shall project beyond the sleeve diameter. Seals shall be fitted at the ends of the sleeve and at the base of the cone to prevent entry of soil particles.

The gap width between base of cone and base of friction sleeve shall not exceed 5 mm except when occupied by another sensor in which case the overall width, including the sensor, shall not exceed 15 mm. The external diameter, except where seals are fitted, shall correspond to the diameter of the cone base.

Examples of suitable penetrometer tips are shown in Figure 8.

NOTE Where the ground conditions are expected to cause the penetrometer tip to become inclined, or where penetrations in excess of about 20 m are to be made, it is desirable for a two-directional inclinometer to be incorporated in the penetrometer tip to indicate its inclination.

**3.1.2.2** 60° *cone.* The cone of hard-wearing material shall consist of a lower externally shaped conical part with a nominal base diameter of 35.7 mm (nominal base area 1 000 mm$^2$) and an apex angle of 60°, with an upper cylindrical extension limited to 5 mm. Figure 9 shows the permitted tolerances including allowances for wear, surface finish and typical manufacturing dimensions.

**3.1.2.3** *Friction sleeve.* An independent cylindrical unit, which shall nowhere be smaller than the external diameter of the cone base or 0.35 mm larger than the external diameter of the cone base. The length shall be such that its external peripheral area is $150 \times 10^2$ mm$^2$. Figure 10 shows the permitted tolerances, including allowances for wear, surface finish and typical manufacturing dimensions.

**3.1.2.4** *Cone and friction sleeve sensors.* The sensing devices for measuring the cone and frictional resistance shall be constructed in such a way that possible eccentricity of these resistances cannot influence the readings. The sensing device fitted to the cone shall measure only the axial force imposed on the cone by the soil below it. The device fitted to the friction sleeve shall measure only shear stresses and not normal stresses. Electronic sensors shall be temperature-compensated.

**3.1.2.5** *Piezometric sensor.* If required, pore pressures may be measured at the penetrometer tip. The sensor shall be capable of measuring water pressure to an accuracy of ± 5 % down to a limit of ± 0.2 m of water and shall be protected against the entry of soil particles by a filter of wear-resistant material.

NOTE The position and type of piezometric sensor has not been specified as these will vary according to what is to be measured and the soil type. Two sensors at different locations may be required.

**3.1.2.6** *Push rods.* Push rods shall consist of steel cylindrical tubes, each 1 m nominal effective length, screwed or attached together to bear against each other, and with sufficient wall thickness, to form a rigid-jointed series with a continuous straight axis (see Figure 10). The minimum quality of the steel shall correspond to that specified for upset drill rods in BS 4019-1. The bore of the rods may be used for conveying the measuring signals from the sensing devices to the measuring equipment at the surface.

The external diameter of the push rods shall be such that it does not influence measurements at the penetrometer tip. Normally the external diameter of the push rods is 36 mm ± 1 mm. Smaller external diameters may be used continuously or at intervals along the string to reduce soil friction acting on the push rods providing that the distance between commencement of the smaller diameter push rods and the cone base shall be at least 1 m.

deflection from a straight line through the ends he mid-point of a 1 m long push rod shall not ed a) 0.5 mm for the five lowest push rods and mm for the remainder. For any pairs of joined h rods the deflection from a straight line through mid-points of the rods at the joint shall also not ed these limits. The push rods shall be checked r every test in ground conditions known to be ducive to rod bending, e.g. large depths of very soils over hard layers, or soils containing ented zones or coarse material. Rods with ssive deflections shall not be reused until ightened.

E Curvature and eccentricity may be simply observed by ling the rod with a straight rod and rolling the latter on a e surface.

2.7 *Friction reducer.* A ring, fixed on the outside he push rods, with an external diameter larger n the base of the cone, to reduce soil friction ng on the push rods.

position of this ring on the push rods shall be e than 400 mm above the base of the cone and at t 200 mm above the top of the friction sleeve.

2.8 *Push rod guides.* Guides shall be provided for part of the push rods protruding above the soil, for the rod length exposed in water, in order to vent buckling when the required penetration ssure increases beyond the safe limit for the osed upstanding length of push rods.

2.9 *Calibrated measuring equipment.* Direct dings of the resistance of the cone and local ion sleeve (if fitted), and of the piezometric sor (if fitted) shall be available individually for play throughout a test and shall supplement tape ther recording techniques where provided.

2.10 *Thrust machine.* The thrust machine shall onstructed such that a) the reaction providing thrust does not influence the resistance, by ing the screw anchors or ballast supports at a icient distance from the push rods, b) the hine shall not move relative to the soil surface ore than 0.5 mm per kN of thrust during the hing action, c) the machine shall be capable of a inuous thrust stroke of at least 1 m, d) the rate enetration during driving of the penetrometer hall be capable of being controlled at a rate 0 ± 5 mm/s and thereafter maintained at a stant rate during the entire stroke even if dings are taken intermittently. (see note at end .1.4.7), e) means shall be provided to thrust the h rods vertically into the ground and when essary provide support for the push rod guides.

2.11 *Spirit level* to observe verticality of the st machine and the push rods and their ation.

### 3.1.3 *Calibrations*

3.1.3.1 Initial calibration before use and recalibration records shall be retained in the penetrometer calibrations register for each individual item of measuring equipment, referred to by its reference number. A copy of the current calibration certificates recording the calibration or recalibration results, and dates when made, shall accompany each measuring device during its use on site, and be available for inspection.

3.1.3.2 *Measuring equipment for resistances.* Calibration of each force-measuring instrument shall be made before and after every 2 000 m of use, and after a repair or overhaul.

3.1.3.3 *Grading of resistance-measuring equipment.* Taking into account all parts of the systems including the sensors, signal transmission, signal conversion, recording and display together with the maximum required compensations to be provided for temperature variations and eccentricity of stress on the cone or sleeve, the precision shall be not more than the larger of the following values:

5 % of the actual applied resistance;

1 % of the maximum value that is permitted for the range of the equipment.

This overall grading shall be verified in accordance with BS 1610, but the grading limits specified therein shall be disregarded.

3.1.3.4 *Piezometric sensors.* Calibrations shall be made before and after every 2 000 m of use, and after a repair or overhaul. The precision requirements are as specified in **3.1.2.5**.

3.1.3.5 *Linear recordings.* Where equipment is incorporated in the penetrometer for recording the penetration of the tip this apparatus shall be calibrated before and after every 2 000 m of use, and after a repair or overhaul. The precision requirements shall be better than 0.1 m.

### 3.1.4 **Procedure**

3.1.4.1 The principle to be followed shall be that of continuous testing in which the resistance measurements are made while all elements of the penetrometer tip are moving downwards simultaneously and at the standard rate of penetration.

3.1.4.2 *Pretest checks.* Make the following inspections before each test and replace defective items of apparatus with others in sound condition.

a) *Push rods.* Stand the push rod vertically, spin it, and observe whether it wobbles while it is rotating. If there is wobble discard the rod or check it for compliance with **3.1.2.6**..

b) *Cone and friction sleeve.* Check that the wear does not exceed the permitted tolerances (see **3.1.2.2** and **3.1.2.3**).

c) *Seals between different elements of the penetrometer tip.* Check for wear and remove any particles of soil present that might interfere with the measurements.

d) *Electric cable for signal transmission from the penetrometer tip.* Check for sound outer cover and ensure it is already threaded through sufficient push rods not to affect continuous testing.

**3.1.4.3** *Selection of test location.* In order to obviate disturbance locate the test position at least 1 m from previously performed cone penetration tests not more than 10 m deep or at least 1.5 m where the depth exceeded 10 m, or 25 borehole diameters from previous boreholes.

**3.1.4.4** *Piezometric sensors.* Ensure that there is full saturation of the filter and other spaces of the measuring system prior to each test.

NOTE Impregnation with silicon oil, glycerine or glycerine and water has been found to reduce re-entry of air prior to penetrating below the water table.

**3.1.4.5** *Verticality.* Erect the thrust machine to provide thrust on the push rods in as near a vertical direction as practicable. The maximum deviation of the thrust direction from the vertical shall not exceed 2 %.

**3.1.4.6** *Penetration.* After joining the penetrometer tip to the leading push rod place them in the machine so that their axis coincides with the thrust direction.

Where a friction reducer is used ensure that it is located as described in **3.1.2.7**.

Check that verticality is maintained throughout the test by observing the verticality of the upstanding push rod immediately after adding an additional push rod. Discontinue the test if it exceeds the specified limit, and recommence the test at least 1 m from the discarded test location.

Use the push rod guides when the required penetration pressure begins to exceed the buckling resistance of the upstanding length of the push rods and thereafter keep them in use to the end of the test.

Complete each penetration test in one continuous operation to the full depth required. Record the duration of abnormal delays beyond 30 min at the depths to which they correspond. Stoppages in which the delay exceeds 2 h shall mean that the test is completed at that depth and a separate test shall be used if a greater depth is to be tested.

**3.1.4.7** *Rate of penetration.* The rate of penetration whether or not readings are being taken shall normally be 20 ± 5 mm/s.

NOTE In hard or very compact ground, especially at depth, it may not be possible to achieve the standard rate of penetration.

**3.1.4.8** *Data for site record and the intervals of measurements.* Measure and record the following:

either:

a) the axial force ($Q_c$) acting on the cone (in kN); and

b) the frictional force ($Q_s$) acting on the sleeve (in kN);

or direct measurements when machine facilities permit of:

c) the cone resistance ($q_c$) (in MPa) (see **3.1.5.1**); and

d) the local unit side friction resistance ($f_s$) (in MPa) (see **3.1.5.2**);

and when required:

e) the pore water pressure ($u$) acting on the piezometric sensor (in kPa); and/or

f) the inclinometer value (in degrees or radians).

g) the depth of the cone base below the ground surface corresponding to the above measurements. Measure the depth to an accuracy of at least 100 mm.

Take a continuous series of measurements if possible, except for the inclinometer, otherwise take readings at linear intervals that do not exceed 200 mm.

NOTE A presentation of inclinometer values at 1 m intervals should normally be adequate.

Note sounds from, or unusual vibrations of, the push rods, (representing indications of the presence of coarse material or obstructions), and note the depths corresponding to when they occurred.

Record any unusual event during the test including the depths at which the push rods may have been extracted over a limited height in order to break the lateral resistance, and then been pushed back into the soil.

**3.1.4.9** *Post-test checks and records.* Check and record the following at the end of each test.

a) Immediately upon completion of each test, when the resistance measuring equipment is unloaded, record the reading for both the cone and friction sleeve if fitted and used.

b) Inspect the cone, sleeve, seals and piezometers where fitted, for damage and wear since the commencement of the test.

Inspect the push rods for alignment and damage.

Where wear of the sleeve or cone has taken place during the test such that either has reached a state where during the test it should have been replaced, the test shall remain valid but shall include in the reports a statement describing the condition of the sleeve and cone at the end of the test.

c) Record, where possible, the depth to the water level in the hole after withdrawal of the penetrometer tip, or the depth at which, the hole collapsed.

d) Record whether the test hole has been backfilled, and if so by which method.

e) Record the identification number of the penetrometer tip used for the test.

f) Record the dates and reference numbers of the calibration certificates for the measuring devices.

g) Record the name of the operator in charge of the crew which performed the test.

### .5 *Calculations and expression of the results*

**.5.1** *Cone resistance.* Calculate the cone istance, $q_c$ (in MPa), from the equation:

$$q_c = \left(\frac{Q_c}{A_c}\right) 10^3$$

ere

$Q_c$ is the axial force acting on the cone (in kN);

$A_c$ is the area of the base of the cone (in mm$^2$).

**.5.2** *Local unit side friction resistance.* Calculate e local unit side friction resistance, $f_s$ (in MPa), m the equation:

$$f_s = \left(\frac{Q_s}{A_s}\right) 10^3$$

ere

$Q_s$ is the frictional force acting on the sleeve (in kN);

$A_s$ is the external surface area of the sleeve (in mm$^2$).

**.5.3** *Friction ratio and friction index.* Calculate e friction ratio ($R_f$) and the friction index ($I_f$) for asurements of the cone resistance ($q_c$) and local it side friction resistance ($f_s$) at the same depth when the cone was at the level corresponding to e mid-point of the sleeve.

*Friction ratio.* Calculate the friction ratio, $R_f$ (in %), from the equation:

$$R_f = \left(\frac{f_s}{q_c}\right) 100$$

**3.1.6** *Test report*[6]. The report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) The method of test used.

b) Graphic representations with respect to the depth of the following measurements:

cone resistance ($q_c$) (in MPa);

local unit side friction resistance ($f_s$) (in MPa);

friction ratio ($R_f$): horizontal axis;

pore water pressure ($u$): horizontal axis, where appropriate.

c) Readings of the inclinometer, if taken, beyond a limit to be specified.

d) The capacity and type of the penetrometer used.

e) The type of resistance-measuring system used.

f) The type of the penetrometer tip and cone used and the capacities of the different resistance-measuring devices used and their conditions with respect to wear.

g) If piezometric sensors are used, their position and the type of filter.

h) The depth over which a friction reducer or push rods with reduced diameter has been used.

i) The depth at which push rods have been partly withdrawn in order to reduce the side friction resistance.

j) Details of any unusual event or abnormal interrruption to the test.

k) Observations on sounds from or unusual vibrations of the push rods and the depths corresponding to when they occurred.

l) The depth to the water level in the hole remaining after withdrawal of the penetrometer tip or the depth at which the hole collapsed.

m) Whether or not the test hole was backfilled.

n) The information required by clause **9** of BS 1377-1:1990.

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See form 9(d) of Appendix A.

### 3.2 Determination of the dynamic probing resistance using the 90° cone (dynamic probing DP)

**3.2.1** *General.* This method covers the determination of the resistance of soils in situ to the intermittent penetration of a 90° cone when driven dynamically in a standard manner. A continuous record is provided with respect to depth of the resistance of the cone in contrast to the standard penetration test (see **3.3**), but there are no sampling facilities. Two different sizes of apparatus are specified.

Dynamic probing can be used to detect soft layers and to locate strong layers, e.g. in cohesionless soils for end-bearing piles. The results of dynamic probing should normally be checked by boring in conjunction with sampling, particularly with respect to the competence of a bearing stratum.

When interpreting the test results obtained in cohesive soils and in soils at depth, caution has to be taken when friction along the extension rods becomes significant.

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

**3.2.2** *Principle.* The basis of the test with either size of apparatus consists of dropping with a free-fall a hammer a standard distance on to an anvil to effect the semi-continuous penetration, normally from the ground surface, of a series of parallel-sided extension rods carrying a 90° pointed cone at the lower end. At regular intervals, in order to minimize rod friction and to keep the hole straight and vertical, the rods are turned and the torque is measured. The results consist of a plot showing the number of blows of the hammer to drive the cone each 100 mm in depth and the values of the torque (in N m) at specified intervals.

**3.2.3** ***Apparatus***

**3.2.3.1** Dimensions of the parts of the apparatus that vary for the two types of equipment are given in Table 1.

**3.2.3.2** Requirements common to both sizes are as described in **3.2.3.2.1** to **3.2.3.2.7**:

**3.2.3.2.1** 90° *cone.* The cone of steel or cast iron shall consist of a lower externally shaped conical part having a 90° apex angle with an upper cylindrical extension (mantle) of a length equal to the diameter of the base of the cone. Between the cylindrical part and the lowermost extension rod the transition may be abrupt or conical with a length equal to the diameter of the cone as shown in Figure 11.

The cone may be sacrificial or retained for recovery. In either case the cone shall be attached to the push rod so that it cannot be moved laterally on the extension rod by more than 0.2 mm nor become inclined about its vertical axis.

When the cone is retained for repeated testing, the maximum permissible wear shall be 2 mm with respect to the diameter of the cone, and 5 mm with respect to the cone tip length.

**3.2.3.2.2** *Extension rods.* Extension rods shall have a uniform external diameter that can be screwed or attached together to bear against each other and with sufficient wall thickness to form a rigid and flush jointed series with a continuous straight axis. Each rod or coupling shall contain at least one pair of flats suitable for use with the torque wrench and for connecting and disconnecting the rods.

The steel shall be of a quality of at least that specified for upset drill rods in BS 4019-1. Permanent deformations shall be capable of being corrected.

The deflection at the mid-point of an extension rod measured from a straight line through the ends shall not exceed a) 0.5 mm per 1 m of rod for the lowermost 4 m of rods and b) 1 mm per 1 m for the remainder. For any pairs of joined extension rods the deflection at the joint from a straight line through the mid-points of the rods shall also not exceed these limits.

Rods shall be checked visually for straightness before use in each test and, if a deflection is suspected, a measurement shall be made (see note). Where the limit is exceeded the deflection shall be corrected or the rod discarded. After every 20 uses the rods shall be checked by rolling the rods through 360° on a flat surface. Defective rods shall not be reused until straightened.

NOTE Curvature and eccentricity may be simply observed by coupling the rod with a straight rod and rolling the latter on a plane surface.

## Table 1 — Dimensions and masses for the two types of dynamic probing apparatus[a]

| Part | Type of probing apparatus | |
|---|---|---|
| | Dynamic probing (heavy) DPH | Dynamic probing (super heavy) DPSH |
| iving device | | |
| Hammer: Mass (kg) | 50 ± 0.5 | 63.5 ± 0.5 |
| Standard drop (mm) | 500 ± 10 | 750 ± 20 |
| Length to diameter (breadth) ratio | $\geq 1 \leq 2$ | $\geq 1 \leq 2$ |
| Anvil: Diameter (mm) | $100 < d < 0.5\ D$ | $100 < d < 0.5\ D$ |
| Mass of anvil and guide rod (kg) (max.) | 18 | 30 |
| ° Cone | | |
| Nominal area of cone (cm$^2$) | 15 | 20 |
| Cone base diameter (*D*) new (mm) | 43.7 ± 0.3 | 50.5 ± 0.5 |
| Cone base diameter, worn (mm) (min.) | 42 | 49 |
| Cone mantle length (mm) | 43.7 ± 1 | 50.5 ± 2 |
| Cone taper angle upper (deg.) | 11 | 11 |
| Cone tip length (*L*) new (mm) | 21.9 ± 0.1 | 25.3 ± 0.4 |
| Cone tip permissible wear (mm) (max.) | 4 | 5 |
| xtension rods | | |
| Mass of rod (kg/m) (max.) | 6 | 8 |
| Diameter O.D (*d*) nominal (mm) (max.) | 35 | 35 |
| Effective length (mm) | Up to 2 ± 0.1 % | Up to 2 ± 0.1 % |

See Figure 11

2.3.2.3 *Driving device.* The driving device shall mprise the following.

a) A hammer made of steel and provided with an axial hole with a diameter which is 3 mm to 4 mm larger than that of the guide rod.

b) A pick-up and release mechanism to ensure that the hammer has a free fall throughout the full range of its standard drop and shall not influence the acceleration and deceleration of the hammer or the rods. The velocity of the hammer shall be negligible when the hammer is released at its upper limit.

c) A guide arrangement to permit the hammer to drop with minimal resistance, and to ensure the hammer strikes the anvil squarely.

d) An anvil made of steel with an integral threaded portion to connect squarely and rigidly on to the top of the uppermost extension rod. The axis of the anvil, guide arrangement and extension rods shall be straight with a maximum deviation of 5 mm/m.

NOTE A damper may be incorporated in the anvil to minimize damage to the equipment. When fitted it should be reported. The effect of dampers may vary with age and design, hence caution should be used when correlating results.

3.2.3.2.4 *Probing rig.* The probing rig shall consist of a stable frame for driving the extension rods and cone vertically with a) a guide to provide lateral support for that part of the extension rods protruding above the soil, b) a means for handling and operating the driving device and c) a means for extracting the rods and a retained cone.

The supports of the rig shall be sufficiently far from the cone not to influence the results.

The guide for supporting the protruding part of the extension rods shall be such that not more than 1.2 m of rod is unsupported at any time during the test. Further, if the driving device is not separately provided with a guide, then not more than 0.6 m of rod shall be unsupported where the blow count is in excess of five blows per 100 mm.

3.2.3.2.5 *Torque measuring wrench* suited to the width between flats on the extension rods and with a capacity not less than 200 N m. The graduations shall not exceed 5 N m.

3.2.3.2.6 *Wrenches* for connecting and disconnecting the joints in the rods.

3.2.3.2.7 *Spirit level* to observe verticality of the extension rods and their deviation.

### 3.2.4 *Procedure*

**3.2.4.1** *Selection of test location.* In order to obviate disturbance locate the test position at least 1 m from previously performed cone penetration or dynamic probing tests not more than 10 m deep or at least 1.5 m where the depth exceeds 10 m, or 25 borehole diameters from previous boreholes.

**3.2.4.2** *Verticality.* Erect the probing rig to drive and guide the extension rods and cone in as near a vertical direction as practicable. The maximum acceptable deviation from the vertical at the ground surface when setting up the cone and lowermost extension rod shall be 2 %. Guide the cone and extension rods at the beginning of the test.

NOTE Preboring with a hole slightly larger than the cone may be used.

**3.2.4.3** *Driving.* Ensure the connections between the cone and lowermost extension rods, between the successive rods, and between the uppermost rod and the driving device are made tight. When removing the driving device ensure that the extension rods are not turned.

Lower the pick-up assembly so as to avoid significant impact on the hammer. Raise the hammer slowly to ensure that the inertia of the hammer does not carry it above the defined height on the driving device.

Drive continuously as far as this is practicable. Record any interruptions which are longer than 5 min in the site log.

When using a sacrificial cone ensure that the cone cannot become detached from the extension rods prematurely when the rods are being driven or rotated.

Drive the cone at a rate of 15 to 30 blows per minute. Record the number of blows for each 100 mm increment of penetration.

The deviation of the extension rods from the vertical during driving shall not exceed 5 %.

**3.2.4.4** *Rotation.* Rotate the extension rods with the torque measuring wrench at a rate of 1½ turns every metre in order to observe the friction and record the maximum torque required to rotate the rods at each test level to the nearest 5 N m.

NOTE It should also be recorded if separate precautions are taken to minimize rod friction, such as the use of casing behind the cone and around the extension rods, or if drilling mud or water is poured around the rods at the surface or ejected from within the rods behind the cone.

**3.2.4.5** *Post-test check.* Examine for straightness and wear the cone and extension rods used for the test before reuse.

**3.2.5** *Test report*[7]. The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) The method of test used.

b) Graphic representation with respect to depth of the following measurements:

1) the number of standard blows to drive the cone each 100 mm increment;

2) the maximum torque required to rotate the extension rods at each test level (in N m) and the use of any separate precautions against friction such as casing, drilling mud or water.

c) The type of dynamic probing used for the test.

d) The type of rod used.

e) Whether a damper was fitted to the anvil and if so its type.

f) The duration of individual delays in minutes and the test levels at which they occurred.

g) Details of any unusual event during driving, e.g. penetration without blows, temporary obstructions, artesian conditions.

h) A note if the cone has been left buried in the ground and the elevation.

i) Whether or not the dynamic probing was backfilled.

j) The information required by clause 9 of BS 1377-1:1990.

## 3.3 Determination of the penetration resistance using the split-barrel sampler (the standard penetration test SPT)

**3.3.1** *General.* This method covers the determination of the resistance to soils at the base of a borehole to the penetration of the split-barrel sampler when driven dynamically in a standard manner, and the obtaining of a disturbed sample for identification purposes.

The test is used mainly in sands.

NOTE The test can also be used in gravels or gravelly sand in which case the drive shoe may be replaced by a solid 60° cone, but when this accessory is used in any type of ground the result should be reported separately from the standard test using the open drive shoe, and with the preface: SPT(C).

**3.3.2** *Principle.* The basis of the test consists of dropping with a free fall a hammer of mass 63.5 kg on to a drive head from a height of 760 mm. The number of such blows ($N$) necessary to achieve a penetration of the split-barrel sampler of 300 mm (after its penetration under gravity and below the seating drive) is regarded as the penetration resistance ($N$).

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[7] See form 9(e), of Appendix A.

e requirements of Part 1 of this standard, where ropriate, shall apply to the test methods cribed in this clause.

### .3 *Apparatus*

.3.1 *Boring equipment.* The boring equipment ll be capable of providing a clean hole before ertion of the sampler and shall ensure that the etration test can be performed in relatively disturbed soil. When wash boring, a e-discharge bit shall be used and not a tom-discharge bit. The process of jetting through open tube sampler and then testing when the ired depth is reached shall not be permitted. en shell and auger boring with temporary ing, the drilling tools shall have diameters not re than 90 % of the internal diameter of the ing. When boring in soil that will not allow a hole emain stable, casing and/or mud shall be used.

e area that is exposed in the base of the borehole or to testing may influence the result and sequently the borehole diameter shall always be orted. Where the borehole diameter has been uced with increasing depth the lowermost size ll have been continued for at least 1 m before mencing the test.

TE The test was originally made in washborings 65 mm 00 mm diameter. A significant effect on the result may begin ccur when the diameter is 150 mm or more.

.3.2 *Split barrel sampler assembly.* The sampler embly shall have the shape and dimensions wn in Figure 12.

drive shoe and split barrel, both having a iform bore of the same diameter, shall be made of el with a smooth surface externally and ernally. The drive shoe shall be made of hardened el. It shall be replaced when it becomes damaged istorted to avoid the test result being affected. coupling shall contain a 25 mm nominal meter ball check valve seated in an orifice of not than 22 mm nominal diameter which shall be ted below the venting. The ball and its seat shall onstructed and maintained to provide a ertight seal when the sampler is withdrawn. ernative designs of check valves are permitted vided they give equal or better performance.

.3.3 *Drive rods.* The rods used for driving the pler assembly shall be made of steel of a quality have a stiffness equal to or greater than type drill rods complying with BS 4019. For holes per than 20 m, rods with a stiffness equal to or ater than type BW drill rods and complying with 4019 shall be used. Rods heavier than 10.0 kg/m inal shall not be used. Only straight rods shall sed and periodic checks for straightness shall be de on site, including the threaded connections ween consecutive rods.

When measured over the whole length of each rod the relative deflections shall not be greater than 1 in 1 000.

The rods shall be tightly coupled by screw joints.

3.3.3.4 *Drive assembly.* The drive assembly of an overall mass not exceeding 115 kg shall comprise the following.

a) A hammer made of steel and weighing 63.5 ± 0.5 kg.

b) A pick-up and release mechanism which shall ensure that the hammer has a free fall of 760 ± 20 mm, and shall not influence the acceleration and deceleration of the hammer or the rods. The velocity of the hammer shall be negligible when the hammer is released at its upper limit.

c) A guide arrangement which shall permit the hammer to drop with minimal resistance and to ensure the hammer strikes the anvil squarely.

d) A drive-head (anvil) made of steel, with a mass between 15 kg and 20 kg, which shall be tightly screwed to the top of the drive rods.

### 3.3.4 *Procedure*

NOTE The reliability of the test result is very dependent upon rigorous attention being given to ensure that the several manual operations required for the test procedure are correctly executed.

3.3.4.1 *Preparing the borehole.* Clean out the borehole carefully to the test elevation using equipment that will ensure the soil to be tested is not disturbed. When boring below the groundwater table or sub-artesian conditions maintain at all times the water or mud level in the borehole at a sufficient distance above the groundwater level to minimize disturbance of the soil at the base of the borehole. Maintain the water or mud level in the borehole throughout the test to ensure hydraulic balance at the test elevation (see note).

Withdraw the drilling tools slowly from the ground and up the borehole (when filled with water) to prevent suction and consequent loosening of the soil to be tested. When casing is used, do not drive it below the level at which the test is to commence.

NOTE Particular attention should be given where groundwater under excess pressure is encountered, as sometimes found when penetrating through an impervious layer into a pervious layer below groundwater level. Any operations that give an opportunity for an upward flow of water to loosen the soil should also be recorded.

3.3.4.2 *Executing the test.* Lower the sampler assembly to the bottom of the borehole on the drive rods with the drive asembly on top. Record the initial penetration under this total dead-weight. Where this penetration exceeds 450 mm omit the seating drive and test drive and record the "*N*" value as zero.

After the initial penetration, carry out the test in two stages:

a) *Seating drive*: Using standard blows the seating drive shall be a penetration of 150 mm or 25 blows whichever is first reached.

b) *Test drive*: The number of blows required for a further penetration of 300 mm and this is termed the penetration resistance (*N*). If the 300 mm penetration cannot be achieved in 50 blows terminate the test drive.

The rate of application of hammer blows shall not be excessive such that there is the possibility of not achieving the standard drop or preventing equilibrium conditions prevailing between successive blows.

NOTE For test driving in soft rock the test drive should be terminated after 100 blows if a penetration of 300 mm has not been achieved.

Record the number of blows required to effect each 75 mm of penetration for both the seating and test drives. If the seating or test drive is terminated before the full penetration, record the depth of penetration for the corresponding 25 blows and/or 50 blows respectively.

**3.3.4.3** *Removal of the sample and labelling*. Raise the drive rods and open the sampler. Place a representative portion of the soil core from the bottom 300 mm drive in an airtight container to prevent loss of the soil moisture. If more than one type of soil is encountered in the drive use a separate container for each type of soil and record the depths between which each portion was taken.

Fix labels to the containers with the following information:

a) site;

b) borehole number;

c) sample number;

d) depth of penetration;

e) length of recovery;

f) date of sampling;

g) standard penetration resistance (*N*) and borehole diameter.

**3.3.5** *Test report*. The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) The method of test used.

b) The penetration resistance of the test drive *N* (number of blows). Tests made with the solid 60° cone to be prefaced SPT(C).

c) The depths between which the test drive was made.

d) The number of blows for the seating drive and the test drive.

e) If required, the number of blows per 75 mm penetration for the seating and test drives.

f) The depth to the bottom of the borehole before the test and the initial penetration of the sampler.

g) The further penetration achieved if the test drive was limited to 50 blows.

h) The boring method, internal diameter of borehole from which the test was made and if temporary casing or mud was used.

i) The drive rod type and size used.

j) Information on the groundwater level and the water or mud level in the borehole at the start of each test.

k) Observations concerning the stability of strata tested or obstructions encountered during the tests which will assist the interpretation of the test results.

l) The information required by clause **9** of BS 1377-1:1990.

## 4 In-situ vertical deformation and strength tests

### 4.0 Introduction

This clause decribes four methods for investigating in-situ strength and load settlement characteristics of soil. The plate loading test (**4.1**) and the shallow pad maintained load test (**4.2**) are particularly suited for the design of foundations or footings for buildings where it is considered that the mass characteristics of the soil would differ significantly from the results of laboratory tests, or where more precise values of settlement are required. The in-situ CBR (**4.3**) is generally concerned only with pavement design and the control of subgrade construction of soils with a maximum particle size not exceeding 20 mm. The determination of the vane shear strength of weak intact cohesive soils is described in **4.4**.

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## Determination of the vertical deformation d strength characteristics of soil by the te loading test

.1 *General.* This method covers the ermination of the vertical deformation and ength characteristics of soil in situ by assessing force and amount of penetration with time when igid plate is made to penetrate the soil. Uses are valuate the ultimate bearing capacity, the shear ength and deformation parameters of the soil eath the plate without entailing the effects of mple disturbance. The method may be carried out he ground surface, in pits, trenches or adits, and depth in the bottom of a borehole.

e requirements of Part 1 of this standard, where propriate, shall apply to the test methods cribed in this clause.

.2 *Preliminary considerations.* The form of paratus and the testing procedure selected shall vide a safe method for conducting the test. Before s possible to select the apparatus and plan the t procedure the following information is required:

) an estimate of the expected strength and deformation characteristics of the soil to be tested n order to judge the required loading and the size f the apparatus;

b) the elevation of the loading plate with respect o the loading frame and whether the plate is to e in an open position or in a borehole;

) the parameters to be determined and their equired precision (see **4.1.6.4.1** and **4.1.6.4.2**). In he case of a constant rate of penetration test the ate of penetration and its tolerance limits;

) the size of loading plate to be used. The plate ize shall be as large as practicable taking into ccount the soil fabric and having regard to the mount of reaction required and the means of obilizing it, the magnitude of the other pparatus and the size of pit or borehole required;

OTE When evaluating the shear strength of fissured clays e plate diameter should be at least 300 mm and more than e times the average spacing between fissures where acticable. When testing granular soil the plate diameter ould exceed at least five times the nominal size of the arsest material generally present.

) the maximum reaction load, the range of loads be measured and how the total load is to be rovided;

the settlement range to be measured and the ccuracy required.

### 4.1.3 *Apparatus*

**4.1.3.1** *General.* The particular form of each item in the following list of apparatus is not fixed and shall be determined in accordance with the degree of precision required and the considerations given in **4.1.2**.

**4.1.3.1.1** *A loading plate of rigid construction.* The plate shall be rigid and nominally flat on the underside. The top shall contain a guide to locate the loading column, particularly where the test is to be in a borehole. The longitudinal axis of the loading column and the centre of the plate shall be coincident and the contact shall be such that any tendency for the plate to tilt is resisted. A ball seating shall not be permitted.

The plan area of the plate shall be determined within ± 1 %.

**4.1.3.1.2** *Reaction loading system.* Provision of the reaction load may be made in several different ways including by kentledge, such as water in tanks or concrete blocks, by tension piles or by jacking against an existing reaction such as a structure. In all cases the reaction load or its supports shall be placed sufficiently far from the proposed test position so as to reduce the influence on the results to a tolerable level. (See note 1.)

Care shall be taken to ensure that the reaction load remains stable throughout the test without the possibility of load tilting or collapsing. (See note 2.)

The loading column shall be of sufficient strength to prevent undue buckling under the maximum load and in the case of borehole tests shall be well clear of the borehole walls.

NOTE 1 In the case of tension piles the normal practice is for their centres to be at least three times the plate diameter from the centre of the plate.

NOTE 2 In addition to the reaction load it will normally be necessary to provide a loading frame, a loading column and a hydraulic jack or other appropriate type of load measuring device.

**4.1.3.1.3** *Calibrated force measurement system.* To obtain the required accuracy it may be necessary to have more than one force-measuring device to cover the load range desired up to the defined maximum reaction load. (See **4.1.2.** e).)

**4.1.3.1.4** *Deformation measurement system.* The deformation measurements shall be made to the required accuracy, independently of the loading column and from a datum independent of the other components of the test apparatus. Where a dial gauge or other measuring device is used in the centre of the plate, a reference beam may serve as the datum. Alternatively, levelling directly on to the plate may be adopted. When the test is in an excavation or borehole a separate reference column or invar tape shall be used to project the measurements to the plate.

All settlement devices, e.g. dial gauges, shall be readable to ± 0.05 mm.

**4.1.3.1.5** *Temperature gauge and thermo-couple system.* When temperature measurements are specified a thermometer readable to 0.5 °C with the equivalent accuracy and covering the temperature range expected during the test shall be provided. When, due to the duration of the test, changes in temperature occur which could affect the level of the deformation measuring systems, such as in the case of incremental or maintained load tests, a thermo-couple system shall be provided to monitor the temperature of the reference beam and its other components likely to be affected.

NOTE The effects of temperature on the distortion of the reference system are particularly important where it is required to measure small settlements. Precise levelling may be better when temperature effects are likely to be significant. The effect of different air temperatures on the load measurement devices also needs to be taken into account.

**4.1.3.1.6** *Test area preparation equipment.* Suitable primary excavation equipment to penetrate rapidly close to the test level, such as mechanical diggers or boring equipment, including the casing, will be required. Temporary ground support may be necessary. When the test is to be carried out below groundwater level in permeable ground a system of wells outside and below the test position will usually be necessary.

NOTE In favourable circumstances when the seepage is small and the test is to be made in a borehole it may be possible to use a system of seals in the casing.

For exposing undisturbed soil at the test level select suitable hand digging tools such as a sharp-edged spade, trowel, hand brush and dust pan. Also provide a straight steel cutting edge, spirit level and measuring tape for preparing a flat level test area of sufficient size for the loading plate.

**4.1.3.1.7** *Mixing equipment* for quick setting plaster if used.

**4.1.3.1.8** *Levelling equipment,* readable to 0.1 mm and a stable datum when specified. The levelling staff shall have a bubble attached to it so that the verticality of the staff can be checked.

**4.1.3.1.9** *Field dry density test apparatus,* when specified, complying with clause **2** of this standard and suitable for the soil type expected to be tested.

**4.1.3.1.10** *Containers* for disturbed and undisturbed samples, suitable for the soil type expected to be tested.

### 4.1.4 *Materials*

**4.1.4.1** *Quick setting gypsum plaster* for tests on cohesive soils.

NOTE High strength gypsum plaster is needed. A suitable plaster mix consists of 2½ parts by weight of quick setting gypsum plaster of the alpha hemi-hydrate type to 1 part of cold water. This may be poured from a bucket. The initial set occurs after about 15 min from first mixing. A wet strength of about 30 000 kPa is reached in about 1 h. Normally two or three buckets full are required per test depending upon the plate size.

**4.1.4.2** *Clean dry sand* for tests on granular soils.

### 4.1.5 *Calibration*

**4.1.5.1** *Calibrated force measurement.* For high precision tests reverification of the calibration shall be carried out before and after each usage in the field. The temperature shall be recorded during these calibrations and the effects of variations shall be recorded within the range of temperature to be expected during the test.

**4.1.5.2** *Deformation measurement.* Instruments, used for measuring deformations, such as levelling equipment shall be maintained in adjustment according to manufacturer's instructions.

### 4.1.6 *Procedure*

**4.1.6.1** *Primary excavation.* Excavate to the test level as quickly as practicable to minimize the effects of stress relief, particularly when in cohesive soils. Install temporary ground support as necessary, particularly if persons are to enter the excavation to work (see note 1). Where the test is to be made below the groundwater level in permeable ground, install the equipment for water lowering and lower the water level before the excavation reaches the water table in order to prevent ground disturbance. (See note 2.)

Review the method of excavation when within about 0.5 m of the test level in order to ensure that the remaining soil is removed by careful means to minimize local disturbance at the test level prior to its preparation.

NOTE 1 The object is to place the plate and make the test on soil that is as undisturbed as possible and not significantly affected by opening of discontinuities, wetting or climatic change such as frost action.

NOTE 2 When forming the primary excavation in boreholes, casing is normally essential especially near the surface to keep debris and water out of the hole. Where the ground at depth is self-supporting deeper casing may be omitted for constant rate of penetration tests subject to safety requirements, but for incremental loading tests, where the duration is generally longer, casing should extend to the bottom of the hole in order to minimize inward seepage of groundwater with consequent weakening of the soil conditions. Use preferably an auger in boreholes with clays when within about 0.5 m of the test level and then change to a flat-bottomed bucket auger to produce a flat-bottomed hole at the test level. The diameter of the borehole for a depth equivalent to one plate diameter should aproximate to the diameter of the plate.

**4.1.6.2** *Preparation at test level.* Carefully trim off and remove all loose material and any embedded fragments so that the area for the plate is generally level and as undisturbed as possible. Hollows shall not be infilled with soil.

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tests on cohesive soils proceed as soon as sible thereafter to pour and spread the paste of quick-setting plaster to obtain a level surface more than 15 mm to 20 mm thick. Immediately paste is spread, bed the plate.

tests on granular soils fill any hollows with n dry sand to produce a level surface on which to the plate.

final preparation of the test level in boreholes ll be done if possible by hand for deformation dulus measurements.

en carrying out manual operations in a pit or the e of a borehole comply with BS 5573.

en lowering the plate down a borehole take care to scrape clay from the side of the borehole.

tect the test area and the apparatus from isture changes, sunlight and the effects of erse weather as soon as the test level is exposed throughout the test.

.6.3 *Preparation and erection of loading and suring apparatus.* Place in a convenient position reaction loading, force measurement and ormation measurement systems ready for mediate erection as soon as the plate is in ition. When tension piles are to be used for the ction install these ready for use before the test a is exposed.

e care not to preload the test plate during ction of the reaction loading and force asurement systems. Position the loading column trally over the plate and make it vertical so that reaction load is applied direct to the plate hout eccentricity.

e check levels on the test datum or reference m before the test commences and refer the level stable benchmark clear of the load site.

E Erection of the deformation measurement system pendent of the other apparatus will usually be the last ation.

.6.4 *Test loading and records of measurements.* en specified, note and record the local air perature during testing and take this into ount when recording the load measurements.

.6.4.1 *Constant rate of penetration test.* This test uitable when the undrained loading racteristics of the soil are required.

ly the load in a controlled manner such that the cted rate of penetration is uniform and tinuous.

tinue the test until the penetration reaches at st 15 % of the plate width. Where there is no clear ication of failure prior to the 15 % penetration ultimate load may be defined by the load causing enetration equivalent to approximately 15 % of plate width.

Intermediate cycles of unloading and reloading may be made during the constant rate of penetration test at various stages to obtain an indication of the relative amounts of reversible (elastic) and irreversible deformation that have occurred.

Plot applied pressure versus penetration as the test proceeds. Record separately the value of the peak load recorded. Measurements of the applied load and penetration shall be to the required accuracy.

4.1.6.4.2 *Incremental loading test.* This test is suitable when the drained loading characteristics of the soil are required.

In order to decide the loading for the increments make an initial estimate of the likely maximum load to be applied. Select at least five more or less equally spaced increments and apply the increments cumulatively to the plate. If the maximum load to be applied is that required for the proposed design bearing pressure apply the load in more or less equal cumulative increments which give not more than one-fifth of the design pressure.

Intermediate cycles of unloading and reloading may be made during the incremental loading test at various stages to obtain an indication of the relative amounts of reversible (elastic) and irreversible deformation that have occurred. If the period of time occupied by such cycles when testing cohesive soil is sufficiently rapid so as not to permit a significant dissipation in pore pressure, the slope of the load/deformation curve may be used to determine the undrained deformation modulus or an approximation to it.

Record the load for each increment and ensure that the load is kept constant. Record the settlement under each load increment against time, commencing with the application of the load. Make frequent measurements in the early stages and increase the time interval between measurements as the settlement rate decreases. Measurements of the load and settlement shall be to the required accuracy.

NOTE The load should preferably be maintained at each increment until the penetration of the plate has ceased. This time will depend upon the soil type and the permeability. Tests on cohesive soils should be continued at least until all the primary consolidation is complete, judged according to the settlement versus log time plot.

When specified, to obtain the required precision during the incremental loading tests record temperatures regularly. When changes in temperature occur make additional level measurements referred to the stable benchmark and correct if necessary the settlement readings taken from the reference beam.

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**4.1.6.5** Record the reference datum level and air temperature to the required accuracy when specified immediately prior to the release of all reaction load on the plate. Immediately upon release of all the reaction load on the plate and before dismantling the apparatus relevel the test datum or reference beam with respect to the stable benchmark clear of the loading area. Record this measurement alongside the initial measurement and the time and date when made. The record shall also include the regular measurements of the air temperature throughout the test when specified.

**4.1.6.6** *Density measurements.* Where specified, make in-situ density measurement tests on the soil immediately beneath the plate in accordance with clause **2** upon completion of the test loading and when the plate is removed.

NOTE The type of density test depends upon the type of soil present.

**4.1.6.7** *Sample record.* Take samples of the soil immediately beneath the plate and down to at least twice the plate width in order to examine the ground stressed by the loading and retain the samples in such a manner as to preserve where possible their structure and moisture content. Where possible take undisturbed samples, otherwise take disturbed samples in order to carry out, where required, classification tests including the determination of moisture content, Atterberg limits and particle density in accordance with test methods specified in BS 1377-2:1990.

**4.1.6.8** *Duration of the test.* Keep a record of the time and date when each stage of the procedure was commenced and completed, together with details of any delays.

### 4.1.7 *Calculation and expression of the results*

**4.1.7.1** *Maximum applied pressure.* Calculate the maximum applied pressure, $q$ (in kPa), beneath the plate from the general equation:

$$q = \frac{\dfrac{W_e \times 9.81}{1000} + P}{A}$$

where

$W_e$ is the total mass of the apparatus acting on the plate before adding the applied load, and including the mass of the plate (in kg);

$P$ is the applied force to cause failure. When this is not clearly defined use the force causing a penetration of 15 % of the plate width (in kN);

$A$ is the area of the base of the plate (in $m^2$).

**4.1.8** *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) The method of test used.

b) For the constant rate of penetration test, the graphic representation between applied pressure and penetration. The rate of penetration shall also be given.

c) For the incremental loading test, the graphic representation between deformation and time from the start of the test and, if required, graphic representations between:

1) deformation and time from start of each load increment;

2) deformation and logarithm of time from start of each load increment;

3) load and the final settlement at end of each load increment.

d) The maximum applied pressure (in kPa).

e) The maximum deformation.

f) The in-situ density of the soil and its moisture content if required.

g) The depth of the test level from ground level.

h) A description of the reaction load.

i) The plate size.

j) The information required by clause 9 of BS 1377:1990.

k) the distance between the edge of the loaded plate and the wall of the excavation.

## 4.2 Determination of the settlement characteristics of soil for lightly loaded foundations by the shallow pad maintained load test

**4.2.1** *General.* This method covers the determination of the settlement characteristics of soil in-situ by a test in which a constant load is applied to the ground for a period of several weeks through a pad located at shallow depth. The test is suitable for estimating the settlement caused by structures with lightly loaded shallow foundations built on filled ground and on some types of soft natural soils where the weakest ground in the profile is immediately beneath the test pad.

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test should make it possible to estimate the lement that will occur due to an applied dation load. However, it should be recognized t there may be other causes of settlement besides ker formations at depth, e.g. with uncompacted settlement may occur due to self-weight, apse compression due to a rising water table and ay of organic matter. The test is solely confined roviding an indication of the magnitude of lement of the ground immediately beneath the t pad.

TE It is important that the test results are not considered to e sole evidence on which to base the design of the dations of the proposed structure. Precautions should be n by means of borings or pits to ensure that the test area is esentative of the weakest part of the site, also that weaker nd does not exist within the zone of influence beneath the plete structure.

requirements of Part 1 of this standard, where ropriate, shall apply to the test methods cribed in this clause.

### .2 *Apparatus*

.2.1 *Rigid rectangular pad* of suitable ensions (see note 1) and known mass. The larger ension ($B_1$) and the smaller dimension ($B_2$) of rectangular pad shall be such that $B_2/B_1 > 0.8$. shall be not smaller than 1 m. The pad shall be ed with four levelling stations (see note 2) at its iphery equidistant from the centre of the pad and n each other. The levelling stations shall be essible when the pad is loaded.

TE 1 The dimensions of the loading pad should be related to width of the footings of the structure to be built on the site. ropriate loading pad dimensions are tabulated below for erent footing widths.

| | | | | |
|---|---|---|---|---|
| trip footing width | (in m) | 0.5 | 1.0 | 1.5 |
| ectangular test pad area | (in m$^2$) | 1.0 | 2.25 | 4.0 |

eneral the ground to a depth of not more than $2B_2$ will be cted by the loading test and the properties of the ground at ter depths will have little influence on the test results.

TE 2 The levelling stations should not be liable to accidental age during loading or to damage by vandals.

.2.2 *Kentledge* of known mass sufficient to vide the required bearing pressure.

TE It is recommended that the maximum net bearing sure applied to the ground during the loading test should be less than 1.2 times as large as the maximum net bearing sure which will be applied by the foundation load or the gn net bearing pressure whichever is the greater.

.2.3 *Levelling equipment.* Surveyor's level with od and staff capable of measuring to a resolution t least 0.1 mm. The levelling staff shall have a ble attached to it so that the verticality of the ff can be checked. The levelling equipment shall maintained in adjustment according to the nufacturer's instructions.

4.2.2.4 *Levelling datum stations* which shall not move more than 0.5 mm during the course of the test.

NOTE A 1 m length of 25 mm diameter steel rod set vertically in concrete with the top of the rod cut level and fixed close to ground level has been found to form a suitable datum.

### 4.2.3 *Procedure*

4.2.3.1 *Levelling datum stations.* Establish two levelling datum stations for the load test at a distance from each other of at least $3B_1$. Locate the levelling datum stations at a distance of at least $3B_1$ from the centre of the load test. The datum stations shall be near enough to the load test so that levelling observations have a closing error not exceeding 1.0 mm.

4.2.3.2 *Preparation of test area.* Excavate the area of the load test to the required depth and prepare a level surface. The excavated area shall be sufficiently large to make possible the installation of the loading pad but no larger.

NOTE The depth of the pad below ground level should be the same as the foundation depth of the structure to be built on the site.

4.2.3.3 *Installation of pad.* The pad shall be either cast in situ or prefabricated.

4.2.3.3.1 *Cast in-situ pad.* Place the concrete directly onto the prepared surface of the soil. The upper surface of the pad shall be flat and level. The pad thickness and the steel reinforcement shall be such as to ensure that the pad behaves in a rigid manner and does not crack under the load applied in the test. Allow sufficient time between casting the pad and starting the load test for the concrete to have gained adequate strength.

4.2.3.3.2 *Prefabricated pad.* Place a layer of sand, nowhere exceeding 100 mm in thickness, and with a level surface, on the prepared soil surface. Bed the prefabricated pad onto the sand.

NOTE A simple method of carrying out the test involves the use of a heavy-duty steel waste skip to form both the prefabricated loading pad and a container to hold the kentledge. When the skip has been bedded on the thin layer of sand it is filled with sand of known bulk density. A thin layer of concrete is placed over the sand to discourage unauthorized removal of the sand. If a greater net bearing pressure is required, a second skip can be placed onto the top of the first sand-filled skip before placing the concrete and after levelling the sand to provide a stable base. The second skip is then filled with sand and capped with concrete. The four lifting lugs on the skip can be used as the levelling datum stations.

**4.2.3.4** *Initial measurements.* Using the levelling equipment establish first the difference in height between the two datum stations. Immediately prior to the application of load to the pad, measure the difference in height between each of the four levelling stations on the pad and the two levelling datum stations, the round of observations starting and finishing at datum station 1. If the closing error is more than 1.0 mm repeat the round of observations. Take all observations with the staff placed on the levelling station or datum station and held vertically.

**4.2.3.5** *Loading sequence.* Apply the load so that it is evenly distributed over the pad. Where the load is mobilized above the pad, and prior to its application, ensure that it is kept stable sufficiently far from the test position so as to reduce the influence on the results to a tolerable level. Apply the load in a number of equal increments. Use at least two increments. Measure the settlement of the pad immediately following the application of each load increment using the procedure specified in **4.2.3.4**. Record the time at which each load increment is applied and each set of levels is taken. Intermediate increments of load need be maintained only for the period corresponding to the immediate settlement.

**4.2.3.6** *Maintained load test.* When the final load increment has been applied and the immediate settlement has been measured using the procedure specified in **4.2.3.4**, take further measurements of settlement at suitable intervals of time.

NOTE It will facilitate the plotting of the results if the further measurements are made at the following intervals of time after the completion of loading: 5 min, 10 min, 30 min, 1 h, 2 h, 5 h, 10 h, 1 day, 2 days, 5 days, 10 days, 20 days, 30 days, 40 days and 50 days.

With fill materials a minimum period of 30 days is recommended for the test and it is preferable to continue the test for at least 50 days. With some soft natural soils the minimum test period may be even longer.

**4.2.3.7** *Unloading.* Remove the load in equal decrements corresponding to the incremental application of load. Immediately following each load decrement measure the vertical movement of the pad using the procedure specified in **4.2.3.4**.

**4.2.4 *Calculations and expression of the results***

**4.2.4.1** *Bearing pressure.* Calculate the mean net bearing pressure, $q$ (in kPa), applied to the ground through the pad at each stage of the loading sequence from the following equations.

With the pad in position but no load increment applied:

$$q = \frac{W_p}{B_1 \times B_2} - \rho g h$$

With one load increment applied:

$$q_1 = \frac{W_n + W_p}{B_1 \times B_2} - \rho g h$$

With all the load increments applied:

$$q_f = \frac{W + W_p}{B_1 \times B_2} - \rho g h$$

where

| | |
|---|---|
| $W_p$ | is the weight of the pad (in kN); |
| $W$ | is the total load applied to the pad in n equal increments (in kN) |
| $\rho$ | is the bulk density of the excavated soil determined in accordance with clause **2** (in Mg/m$^3$) |
| $h$ | is the depth of the soil excavated (in m) |
| $W_n$ | is the incremental load (in kN) |
| $B_1$, $B_2$ | are the lengths of the sides of the pad (in m) |
| $g$ | is 9.81 m/s$^2$. |

**4.2.4.2** *Settlement.* Calculate the difference in height between the centre of the loading pad and the levelling datums for each set of levelling observations. In a set of levelling observations, the measurements on the levelling datum stations are $l_1$ and $l_2$ respectively and onto the four levelling stations are $l_a$, $l_b$, $l_c$ and $l_d$.

Calculate the difference in height, $d$ (in m), between the centre of the pad and the datum stations by the equation:

$$d = \frac{l_1 + l_2}{2} - \frac{l_a + l_b + l_c + l_d}{4}$$

Calculate the settlement of the pad, $s$ (in m), at each set of levelling observations by the equation:

$$s = d_o - d$$

where

$d_o$ (in m) is calculated from the initial measurements taken before the load is applied.

**4.2.5** *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) The method of test used.

b) For the maintained load test the graphic representation between settlement and time elapsed since the application of the load and between settlement and the logarithm of the elapsed time.

c) For each intermediate incremental load test the graphic representation between applied net bearing pressure and settlement. This shall include the unloading as well as the loading sequence.

d) The maximum applied net bearing pressure (in kPa).

e) The maximum settlement (in m).

f) The type of loading pad, its dimensions and mass.

g) The information required by clause **9** of BS 1377-1:1990.

## 3 Determination of the in-situ California earing Ratio (CBR)

**3.1** *General.* This method covers the termination of the California Bearing Ratio BR) of a soil tested in situ, with a selected erburden pressure, by causing a cylindrical unger to penetrate the soil at a given rate and mparing the relationship between force and netration into the soil to that for a standard aterial. At certain values of penetration the lifornia Bearing Ratio (CBR) is defined in the rm of a percentage, as the ratio of the force exerted the soil to a standard force that would be exerted a specified crushed rock compacted and confined a given manner. The CBR test may also be carried t in the laboratory on soil in a mould ee clause **7** of BS 1377-4:1990).

n account of the plunger size the test is ppropriate only to material having a maximum rticle size not exceeding 20 mm. Hence where aterial of this size or larger is possibly present neath the test surface this should be checked after aking the test and reported.

he requirements of Part 1 of this standard, where ppropriate, shall apply to the test methods scribed in this clause.

**3.2** *Apparatus.* The apparatus described in **4.3.2.1** **4.3.3.** is required, most of which is illustrated hematically and assembled in Figure 13. When sembled the overall rigidity shall be sufficient to it the capacity of the jack.

**3.2.1** *Cylindrical corrosion-resistant metal unger,* the lower end of which shall be of hardened eel and 49.65 ± 0.1 mm in diameter (nominal oss-sectional area 1935 mm$^2$). The minimum ngth shall be 100 mm.

**3.2.2** *Jack* for applying the test force through the unger at a controlled rate. The minimum capacity all be 45 kN. The minimum extension shall 50 mm. The mechanism shall suit a constant rate extension of 1.0 ± 0.2 mm/min. The jack shall be ovided with a swivel head to connect with the action frame for ease of alignment of the plunger.

**4.3.2.3** *Metal extension rods* for coarse height adjustment of the plunger. The overall length will depend upon the height of the reaction frame above the ground.

**4.3.2.4** *Adjustable metal extension rod,* such as a screw thread and bolt assembly, for the initial seating adjustment of the height of the plunger relative to the soil surface.

**4.3.2.5** *Reaction load.* The provision of the reaction load, incorporating the frame on which to attach the jack, may be in any convenient form such that it acts as a stable deadweight with its normal supports placed sufficiently far from the jack not to influence the results of the soil being tested.

NOTE 1 The required reaction load will depend on the strength of the soil being tested and may be less than the capacity of the jack. Ballasted vehicles are commonly used.

NOTE 2 Where the reaction load is on springs, as when using a vehicle, in order to prevent upward movement during the tests affecting the rate of penetration, separate jacks, to take the weight of the vehicle, should be used to remove the load from the springs.

**4.3.2.6** *Annular surcharge discs*

**4.3.2.6.1** Two discs suitably slotted or consisting of semi-circular segments. Each disc shall have a mass equal to 4.5 kg ± 100 g, an internal diameter between 52 mm and 54 mm and a nominal external diameter of 250 mm.

**4.3.2.6.2** Two discs, each with a mass equal to 9.0 kg ± 200 g with a similar shape and the same diameters as specified in **4.3.2.6.1**.

**4.3.2.6.3** Discs with other masses and shape may be used to represent the actual surcharge. The tolerance shall correspond to that specified above. The bottom disc shall be 250 mm in diameter.

**4.3.2.7** *Calibrated force-measuring devices.* Three ranges are required depending upon the CBR value as follows:

a) for CBR values up to approximately 8 % a 2 kN capacity force-measuring device readable to 2 N;

b) for CBR values from approximately 8 % to approximately 40 % a 10 kN capacity force-measuring device readable to 10 N;

c) for CBR values above approximately 40 % a minimum of 40 kN capacity force-measuring device readable to 50 N.

The force-measurement devices shall each include a substantial purpose-made transit case in order to prevent damage when the devices are not in use.

**4.3.2.8** *Linear measurement system* for determining the vertical penetration of the plunger and to enable the rate of penetration to be controlled, consisting of a datum bar, supports and penetration measurement gauge. The datum bar shall be held firmly in position with the supports placed outside the area of influence of the test. The measurement gauge shall be readable to 0.01 mm over a range of at least 25 mm.

NOTE A dial gauge indicating 1 mm/rev is convenient since the specified rate of penetration of 1 mm/min can be controlled conveniently by keeping the hand of the dial gauge in step with the second hand of a watch.

**4.3.2.9** *Clock* for controlling the rate of plunger penetration readable to 1 s.

**4.3.2.10** *Straight steel cutting edge* to prepare a flat area for the test. Suitable dimensions for the cutting edge are 500 mm by 25 mm by 3 mm.

**4.3.2.11** *Container for sample* of sufficient size for laboratory tests.

**4.3.3** *Materials.* Clean dry sand for placing beneath the lowest surcharge disc on uneven surfaces.

**4.3.4** ***Procedure***

**4.3.4.1** Remove from the test area any material which is not representative of the soil to be tested, and prepare a circular area of about 500 mm in diameter such that it is flat and horizontal, taking special care with the central area on which the plunger will bear.

The minimum spacing between adjacent tests shall be 250 mm.

**4.3.4.2** Position the reaction load and its supports, such as the jacks when using a vehicle, so that the cylindrical plunger after assembly is directly over the central area to be tested. Fit the jack (in the fully retracted position), extension rods, force-measurement device and cylindrical plunger on to the reaction load frame such that the whole assembly hangs vertically with the lower face of the plunger about 25 mm above the soil surface to be tested.

**4.3.4.3** Carefully lower the cylindrical plunger so that its lower surface just comes into contact with the soil. Ensure the assembly is vertical.

**4.3.4.4** Place a sufficient number of surcharge discs, one on top of another, around the central test area and plunger to correspond with the specified overburden pressure for the test. Select the number nearest to the specified value.

NOTE Use a thin layer of sand to seat the bottom surcharge disc on uneven soil but keep the sand off the central test area.

**4.3.4.5** Assemble and position the linear measurement system as shown typically in Figure 13.

**4.3.4.6** Apply a seating force to the plunger, depending on the expected CBR value as follows.

CBR value up to 5 % : 10 N
CBR value from 5 % to 30 % : 50 N
CBR value above 30 % : 250 N

Record the reading of the force-measuring device as the initial zero reading (because the seating force is not taken into account during the test) or reset the force measurement device to read zero.

**4.3.4.7** Reset to zero the penetration measurement gauge or record its initial zero reading.

**4.3.4.8** Start the test so that the plunger penetrates the soil at a uniform rate of 1 ± 0.2 mm per minute, and at the same instant start the clock.

**4.3.4.9** Record the force measurement in kN at intervals of penetration of 0.25 mm, to a total penetration not exceeding 7.5 mm.

NOTE 1 If the operator plots the force penetration curve as the test is being carried out, the test can be terminated when the indicated CBR value falls below its maximum value. Thus if the CBR at 2.5 mm were seen to be 6 % but by 3.5 mm penetration it could be seen to have fallen below 6 %, the test could be stopped and the result reported as:

| | |
|---|---|
| 2.5 mm penetration | 6 % |
| 5.0 mm penetration < | 6 % |

NOTE 2 Where the available reaction is found to be inadequate to achieve a penetration of 2.5 mm the maximum recorded foce on the plunger and the corresponding penetration from the start of the test (see **4.3.4.8**) should be reported.

**4.3.4.10** At the completion of the test and after removal of the surcharge discs and any sand that may have been used, take a sample of about 350 g from beneath the central test area for dispatch to the laboratory for determination of its moisture content as specified in BS 1377-2:1990. Record a description of the soil and whether any soil particles greater than 20 mm in size were present beneath the plunger.

**4.3.4.11** Where the bulk density has to be determined the test shall be made in an appropriate manner according to the grading at a location just outside the area influenced by the CBR test.

**4.3.5** ***Calculations, plotting*[8] *and expression of the results***

**4.3.5.1** *Force-penetration curve.* Calculate the force applied to the plunger from each reading of the force-measuring device observed during the penetration test.

---

[8] See form 9(f) of Appendix A.

OTE Alternatively, readings of the force-measuring device y be plotted directly against penetration readings. Forces are n calculated only at the appropriate penetration values as 4.3.5.2 (after correction if necessary).

ot each value of force as ordinate against the rresponding penetration as abscissa and draw a ooth curve through the points.

e normal type of curve is convex upwards as own by the curve labelled test 1 in Figure 14, and eds no correction.

the initial part of the curve is concave upwards as own for test 2 (curve OST in Figure 14), the llowing correction is necessary. Draw a tangent at e point of greatest slope, i.e. the point of inflexion, and produce it to intersect the penetration axis at The corrected curve is represented by *QST*, with origin at *Q* from which a new penetration scale n be marked.

he graph continues to curve upwards as for test 3 Figure 14, and it is considered that the netration of the plunger is increasing the soil nsity and therefore its strength, the above rection is not applicable.

.5.2 *Calculation of California Bearing Ratio.* The ndard force-penetration curve corresponding to a R value of 100 % is shown by the heavy curve in ure 15. The forces corresponding to this curve : 11.5 kN at 2 mm penetration, 13.2 kN at 2.5 n, 17.6 kN at 4 mm, 20 kN at 5 mm, 22.2 kN 6 mm and 26.3 kN at 8 mm.

e CBR value obtained from a test is the force read m the test curve (after correction and calculation ecessary) at a given penetration expressed as a centage of the force corresponding to the same netration on the standard curve. Curves resenting a range of CBR values are included in ure 15.

etrations of 2.5 mm and 5 mm are used for culating the CBR value. From the test curve th corrected penetration scale if appropriate) d off the forces corresponding to 2.5 mm d 5 mm penetration. Express these as a centage of the standard forces at these etrations, i.e. 13.2 kN and 20 kN respectively. e the higher percentage as the CBR value.

he force-penetration curve is plotted on a gram similar to Figure 15, the CBR value at each etration can be read directly without further putation if the correction described .3.5.1 for test 2 is not required. The same gram can be used for small forces and low CBR ues if both the force scale (ordinate) and the elled CBR values (abscissa) are divided by 10 as wn in brackets in Figure 15.

4.3.6 *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) The method of test used.

b) The California Bearing Ratio (CBR) to two significant figures.

c) The graphic representation of the relationship between applied force and penetration, showing corrections if appropriate.

d) The moisture content of soil beneath the central test area.

e) If the reaction load was inadequate the maximum recorded force and the corresponding penetration from the start of the test.

f) The surcharge discs used and their equivalent overburden pressure.

g) The presence or otherwise beneath the central test area of soil particles 20 mm or larger in size and their size and position with respect to the plunger.

h) The information required by clause **9** of BS 1377-1:1990.

## 4.4 Determination of in-situ vane shear strength of weak intact cohesive soils

**4.4.1** *General.* This method covers the determination in situ of the shear strength of weak intact cohesive soils using a vane of cruciform section, which is subjected to a torque of sufficient magnitude to shear the soil.

The test is suitable for very soft to firm intact saturated cohesive soils.

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

**4.4.2** *Apparatus.* The vane test apparatus shall be either the borehole or penetration type (see Figure 16).

**4.4.2.1** *For tests from the bottom of a borehole.* This type consists essentially of the following apparatus described in **4.4.2.1.1** to **4.4.2.1.4**.

**4.4.2.1.1** *A vane of cruciform shape*, preferably of high grade stainless steel. The length *H* shall be twice the overall blade width *D* (see Figure 17). Experience has shown that for soils up to a shear strength of 50 kPa, a vane approximately 150 mm long by 75 mm wide is suitable. For soils of shear strength between 50 kPa and 75 kPa a smaller vane approximately 100 mm long by 50 mm wide is satisfactory.

The design of the vane shall be such that it causes as little remoulding and disturbance as possible when inserted into the ground for a test. The blades shall be as thin as possible, consistent with the strength requirements, and have a cutting edge at the lower end. The rod on which the vane is mounted, normally of high tensile steel, shall preferably not exceed 13 mm in diameter. The area ratio of the vane, expressed as a percentage, as given by the following equation, shall be kept as low as possible and shall not exceed 12 %.

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

where

$D$ is the overall blade width (in mm);

$T$ is the thickness of vane blades (in mm);

$d$ is the diameter of vane rod, below the sleeve, including any enlargement due to welding (in mm).

A diagram illustrating a typical design for a vane is given in Figure 17. The vane rod shall be enclosed by a suitably designed sleeve from just above the blades and throughout the length it penetrates the soil to exclude soil particles and the effects of soil adhesion. The sleeve shall be packed with grease. This sleeve shall commence above the blades at a distance equivalent to about two diameters of the vane rod.

**4.4.2.1.2** *Extension rods* about 1 m in length. These shall be sufficiently strong to be able to stand axial thrust, allow a reasonable amount of lack of linearity, and be fitted with a coupling which makes it impossible for the rods to tighten or twist relative to each other.

**4.4.2.1.3** *Steady bearings* to keep the rods central inside the borehole.

**4.4.2.1.4** *Calibrated torque measuring instrument* preferably with height adjustment and capable of being clamped in the required position. The base of the instrument shall be capable of being fixed to the ground. An apparatus in which the mechanism is rotated by a worm and pinion where the worm is driven by a hand wheel has been found to be satisfactory. Moving parts shall be mounted in ball or roller bearings to reduce friction to a minimum. The mechanism shall be designed so that the backlash is small. The instrument shall have a torque capacity of approximately 100 N m and an accuracy of 1 % or better of the indicated torque from 10 N m to the instrument's maximum reading.

**4.4.2.2** *For direct penetration from ground surface.* This type consists essentially of the following:

a) *a vane* as specified in **4.4.2.1.1**;

b) *a vane protecting shoe* for each size of vane (see Figure 18);

c) *extension rods* as specified in **4.4.2.1.2** (see Figure 16);

d) *extension tubes* about 1 m in length with couplings on the outer face to case the hole;

e) *a calibrated torque measuring instrument as* specified in **4.4.2.1.4**.

**4.4.3** *Pretest check.* The apparatus shall be checked for satisfactory operation prior to each usage in the field.

**4.4.4** ***Procedure***

**4.4.4.1** *For tests at the bottom of a borehole*

**4.4.4.1.1** Lower the vane, together with its extension rods, into the borehole which shall normally be cased for its whole depth. Take care that the rod couplings remain tight while the vane is lowered. Place sufficient bearings to steady the rods laterally throughout the length of the rods. The spacing of the bearings shall depend upon the rigidity of the extension rods, and shall normally be between 3 m and 9 m.

**4.4.4.1.2** With the vane resting at the bottom of the borehole and with the rods located centrally at the top of the borehole, push the vane steadily without twisting, a distance of not less than three times the diameter of the borehole into the undisturbed soil or at least twice the length of the vane, whichever is the greater.

**4.4.4.1.3** Place the torque head over the top of the upper extension rod and then adjust it to the required height. Couple the instrument to the extension rods. Fix the base of the torque head firmly to the ground. Set the measuring gauge to zero taking care that any backlash in the torque head has been taken up.

**4.4.4.1.4** Rotate the torque head until the soil is sheared by the vane. Read the gauge at maximum deflection, thus indicating the torque required to shear the soil.

Rotate the torque head throughout the test at a rate within the range 0.10°/s to 0.20°/s (6°/min to 12°/min).

**4.4.4.1.5** Remove the torque measuring instrument and withdraw the vane from the ground.

**4.4.4.2** *For direct penetration from ground surface*

**4.4.4.2.1** Lock the vane in place inside the protecting shoe, and jack or drive to the required depth using a light boring rig or tripod. Take care that the rods remain tight while the vane is lowered. Place steady bearings about every 3 m to centralize and reduce friction between the rods and extension pipes.

The design of the vane shall be such that it causes as little remoulding and.disturbance as possible when inserted into the ground for a test. The blades shall be as thin as possible, consistent with the strength requirements, and have a cutting edge at the lower end. The rod on which the vane is mounted, normally of high tensile steel, shall preferably not exceed 13 mm in diameter. The area ratio of the vane, expressed as a percentage, as given by the following equation, shall be kept as low as possible and shall not exceed 12 %.

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

where

$D$ is the overall blade width (in mm);

$T$ is the thickness of vane blades (in mm);

$d$ is the diameter of vane rod, below the sleeve, including any enlargement due to welding (in mm).

A diagram illustrating a typical design for a vane is given in Figure 17. The vane rod shall be enclosed by a suitably designed sleeve from just above the blades and throughout the length it penetrates the soil to exclude soil particles and the effects of soil adhesion. The sleeve shall be packed with grease. This sleeve shall commence above the blades at a distance equivalent to about two diameters of the vane rod.

**4.4.2.1.2** *Extension rods* about 1 m in length. These shall be sufficiently strong to be able to stand axial thrust, allow a reasonable amount of lack of linearity, and be fitted with a coupling which makes it impossible for the rods to tighten or twist relative to each other.

**4.4.2.1.3** *Steady bearings* to keep the rods central inside the borehole.

**4.4.2.1.4** *Calibrated torque measuring instrument* preferably with height adjustment and capable of being clamped in the required position. The base of the instrument shall be capable of being fixed to the ground. An apparatus in which the mechanism is rotated by a worm and pinion where the worm is driven by a hand wheel has been found to be satisfactory. Moving parts shall be mounted in ball or roller bearings to reduce friction to a minimum. The mechanism shall be designed so that the backlash is small. The instrument shall have a torque capacity of approximately 100 N m and an accuracy of 1 % or better of the indicated torque from 10 N m to the instrument's maximum reading.

**4.4.2.2** *For direct penetration from ground surface.* This type consists essentially of the following:

a) *a vane* as specified in **4.4.2.1.1**;

b) *a vane protecting shoe* for each size of vane (see Figure 18);

c) *extension rods* as specified in **4.4.2.1.2** (see Figure 16);

d) *extension tubes* about 1 m in length with couplings on the outer face to case the hole;

e) *a calibrated torque measuring instrument as* specified in **4.4.2.1.4**.

**4.4.3** *Pretest check.* The apparatus shall be checked for satisfactory operation prior to each usage in the field.

### 4.4.4 *Procedure*

**4.4.4.1** *For tests at the bottom of a borehole*

**4.4.4.1.1** Lower the vane, together with its extension rods, into the borehole which shall normally be cased for its whole depth. Take care that the rod couplings remain tight while the vane is lowered. Place sufficient bearings to steady the rods laterally throughout the length of the rods. The spacing of the bearings shall depend upon the rigidity of the extension rods, and shall normally be between 3 m and 9 m.

**4.4.4.1.2** With the vane resting at the bottom of the borehole and with the rods located centrally at the top of the borehole, push the vane steadily without twisting, a distance of not less than three times the diameter of the borehole into the undisturbed soil or at least twice the length of the vane, whichever is the greater.

**4.4.4.1.3** Place the torque head over the top of the upper extension rod and then adjust it to the required height. Couple the instrument to the extension rods. Fix the base of the torque head firmly to the ground. Set the measuring gauge to zero taking care that any backlash in the torque head has been taken up.

**4.4.4.1.4** Rotate the torque head until the soil is sheared by the vane. Read the gauge at maximum deflection, thus indicating the torque required to shear the soil.

Rotate the torque head throughout the test at a rate within the range 0.10°/s to 0.20°/s (6°/min to 12°/min).

**4.4.4.1.5** Remove the torque measuring instrumen and withdraw the vane from the ground.

**4.4.4.2** *For direct penetration from ground surface*

**4.4.4.2.1** Lock the vane in place inside the protecting shoe, and jack or drive to the required depth using a light boring rig or tripod. Take care that the rods remain tight while the vane is lowered Place steady bearings about every 3 m to centralize and reduce friction between the rods and extension pipes.

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**4.4.2.2** When the vane and protecting shoe have netrated to the required depth, push the vane eadily without twisting a distance of at least 0.5 m to the undisturbed soil below the protecting shoe.

**4.4.2.3** Position the torque head as specified 4.4.4.1.3.

**4.4.2.4** Rotate tile vane as specified in **4.4.4.1.4**.

**4.4.2.5** Remove the torque measuring instrument d pull back the vane fully into its protecting shoe, fore removing it from the ground.

**4.5** *Calculation*[9]. Calculate the vane shear rength of the soil, $\tau_f$ (in kPa), from the equation:

$$\tau_f = \frac{M}{K}$$

here

$M$ is the torque to shear the soil (in N m);

$K$ is a constant depending on dimensions and shape of the vane.

ssuming the distribution of the shear strength is niform across the ends of a cylinder and around the rimeter then:

$$K = \pi \frac{D^2 H}{2}\left(1 + \frac{D}{3H}\right) 10^{-6}$$

here

$D$ is the measured width of vane (in mm);

$H$ is the measured height of vane (in mm).

s the ratio of length to width of the vane is 2 to 1 e value of $K$ may be simplified in terms of the ameter so that it becomes:

$K = 3.66D^3 \times 10^{-6}$

TE It is important that these dimensions are checked riodically to ensure the vane is not distorted or worn.

**4.6** *Test report*. The test report shall affirm that e test was carried out in accordance with this Part this standard and shall contain the following formation.

a) The method of test used.

b) The vane shear strength (in kPa) to two significant figures.

c) The type of vane test apparatus.

d) The method of calculating the result when different from that specified in **4.4.5**.

e) The information required by clause **9** of BS 1377-1:1990.

## 5 In-situ corrosivity tests

### 5.0 Introduction

This clause of the standard describes two methods for determining in-situ the likelihood of underground corrosion of buried metal structures.

The results of these tests should be interpreted by a specialist.

### 5.1 Determination in-situ of the apparent resistivity of soil

**5.1.1** *General*. This method covers the determination of the electrical resistivity of soil tested in situ for a selected depth or a range of depths. (See note 1.)

The test is used to assess the corrosivity of the soil towards various metals. Resistivity is the electrical resistance of an element of unit cross-sectional area and unit length. Its value indicates the relative capability of the soil to carry electric currents. Generally the severity of corrosion decreases as the apparent resistivity rises.

The method consists of passing a current (see note 2) into the ground between two electrodes (A, B) and measuring the consequent apparent resistivity between another two electrodes (C, D) situated at equi-distant spacings (AC, CD and DB) and collinear between electrodes A and B. This arrangement corresponds to the conventional "Wenner", equally spaced, four electrode configuration. Two separate measurements of the resistivity are made for a test at each selected depth with the electrodes set at approximately right angles for the two measurements. When testing in borrow areas one measurement may be made with the electrodes in the same line as the direction of the test locations and another with the electrodes set at approximately right angles to the line of tests.

Resistivity may also be measured in the laboratory (see clause **10** of BS 1377-3:1990).

NOTE 1 The resistivity measurement represents the average resistivity of a hemisphere of soil of a radius more or less equal to the spacing between adjacent electrodes as used in the test. The selected depth of a test is therefore more or less equal to the spacing of adjacent electrodes and bears no relation to the embedment depth of the electrodes. The selected depth of a test is commonly taken as equal to the proposed depth of the buried metal inclusion, e.g. a pipeline.

NOTE 2 The test method specified is based on the use of alternating current. Direct current measurements are also made in resistivity tests but these are generally more concerned with geological investigations. The use of direct current can cause polarization effects and can thus lead to an uncharacteristically high resistance being measured. For this reason direct current measurements are not permissible in this type of test.

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See form 9(g) of Appendix A.

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NOTE 3 The measurements are rendered unreliable if beneath the test location electrical conductors are present such as metal pipes, cables or other conducting objects, also if the soil formation contains highly conductive materials such as ferruginous soil which is not typical of the formation.

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

**5.1.2** *Apparatus*

**5.1.2.1** *Calibrated earth impedance ohmmeter,* suitable for measurements by Wenner equally spaced, four-electrode configuration. The ohmmeter shall have a performance complying with class 2.5 of BS 89 and shall produce an internally generated attenuating current supply of frequency between 100 Hz and 150 Hz provided either by a rotating generator or by an oscillator with a direct current supply. The total measuring range shall be at least 0 Ω to 1 900 Ω with a readability to at least three significant figures. The instrument shall be recalibrated at intervals not exceeding 2 yrs.

A copy of the manufacturer's operating instructions shall be available at all times when in use.

**5.1.2.2** *Electrodes.* Set of four metal rods, each typically about 500 mm long and about 10 mm to 20 mm nominal diameter, with one end pointed for driving into the soil. The electrodes shall be formed with a handle and have a low electrical resistance contact point for wire connection. The rod material shall be a good electrical conductor and the surface shall be clean and uncorroded. Suitable material for the rods is stainless steel, brass or copper-plated steel rods.

**5.1.2.3** *Insulated wire cable.* Set of four reels of robust insulated stranded copper wire suitable for use with earth resistance meter, and each of sufficient length depending upon the maximum anticipated spacing of the electrodes. Cable complying with BS 6231, type BK PVC-insulated flexible cable, 1.5 mm$^2$ nominal cross-sectional area of conductor has been found to be suitable. Each reel of wire shall have fitted at one end a robust clamp to ensure low electrical resistance contact with the electrode, and at the other a suitable terminal to fit the ohmmeter.

**5.1.2.4** *Installation equipment,* such as a 1 kg hammer for inserting the electrodes into the soil.

**5.1.2.5** *Linear measuring equipment* for setting out, such as a measuring tape.

**5.1.3** *Procedure.* Tests shall not be made when the soil is frozen or flooded. At the site of each resistivity test proceed as follows working at the ground surface or the base of an excavation.

NOTE Safety precautions should be taken in accordance with the manufacturer's instructions when using the ohmmeter, particularly if working near high-tension systems. In this case rubber gloves should be worn and the operator should stand on a rubber mat or wear rubber shoes.

**5.1.3.1** Select the test location, the length of which shall be three times the selected test depth, where the soil conditions are anticipated to be uniform and away from large non-conductive bodies such as boulders or concrete foundations.

NOTE Highly conductive bodies, such as existing metal pipes and electric cables should not be within about one half the selected depth of the test unless they are at right angles to the line of the electrodes.

**5.1.3.2** Install the two electrodes for transmitting the a.c. current, A and B, so that they are spaced apart a distance equal to three times the selected test depth, and such that each electrode penetrates into the soil at the ground surface for a depth of at least 150 mm and over this length is in full contact with the soil. The maximum penetration of the electrodes beyond the minimum of 150 mm shall not exceed one-twentieth of the selected test depth. The minimum spacing between these electrodes A and B shall be 3 m.

NOTE Where topsoil is present at the test location the electrodes should be driven through it to penetrate into the subsoil.

**5.1.3.3** Install the other two electrodes, C and D, directly between and in line with electrodes A and B, such that all three spacings between the four electrodes are equi-distant. The specifications for the penetration and contact of these electrodes shall be the same as for electrodes A and B.

NOTE When the soil around the electrodes is relatively dry such that there is poor conductivity between the electrode and the soil, it is permissible to wet the soil in the vicinity of the electrodes.

**5.1.3.4** Connect the appropriate terminals on the ohmmeter to the four electrodes with the insulated wire cable.

**5.1.3.5** Apply a stable a.c. current to electrodes A and B, operating the ohmmeter in accordance with the manufacturer's instructions, which may require the test current level to be adjusted before taking the measurements.

**5.1.3.6** Record the measurement of the soil resistance between electrodes C and D when the instrument reading becomes stable. Record values to two significant figures.

**5.1.3.7** Remove the electrodes and repeat the procedure specified above, firstly for other selected depths if required at the same test location, and secondly such that the line of the electrodes is approximately at right angles to the line of the first measurement or series of measurements. If the two measurements at a selected depth differ by more than 15 % of the mean value they shall be repeated.

1.4 *Calculation and expression of the results.* alculate the apparent resistivity, $r_s$ n Ω m (see note)], for each measurement at the test cation from the equation:

$$r_s = 2\ (\pi\ a\ R)$$

here

$a$ is spacing between adjacent electrodes (in m);

$R$ is measured resistance (in Ω).

he value of the apparent resistivity shall be ported to two significant figures.

OTE This is to conform with SI units. The customary unit, m cm, is equal to 0.01 Ω m.

1.5 *Test report.* The test report shall affirm that e test was carried out in accordance with this Part this standard and shall contain the following formation.

a) The method of test used.

b) The mean value of the apparent resistivity (in Ω m) to two significant figures.

c) The two individual values of apparent resistivity and their directions when more than 15 % different to their mean value.

d) The distance between adjacent electrodes in metres, and the selected test depth. If the spacing difference is not equal to three times the test depth, the reason for that difference.

e) The information required by clause **9** of BS 1377-1:1990.

### 2 Determination in-situ of the redox otential of soil

.2.1 *General.* This method covers the etermination of the redox potential eduction/oxidation) of soil tested in situ at a lected depth by measuring the electro-chemical tential between a platinum electrode and a turated calomel reference electrode. The test is ed to indicate the likelihood of microbial corrosion metals by sulphate-reducing bacteria which can oliferate in anaerobic conditions.

e redox potential is principally related to the ygen in the soil, and a high value indicates that a latively large amount is present. Anaerobic icrobial corrosion can occur if a soil has a low ygen content and hence a low redox potential.

This standard requires the use of a calomel reference probe as defined in **5.2.2.2**, in order to be consistent with the laboratory test method (see clause **11** of BS 1377-3:1990). This is not intended to prohibit the use of the other established portable versions of reference probes, e.g. copper/copper sulphate and silver/silver chloride (see note). In submitting reports the type of reference probe used and the correction factor applied to convert the measurement to the standard hydrogen electrode shall be given.

Redox potential may also be measured in the laboratory (see clause **11** of BS 1377-3:1990).

NOTE Where the other types of reference probes, e.g. copper/copper sulphate and silver/silver chloride, are used it is very important to note that their preparation and storage procedures are different from that required for calomel probes and the manufacturer's instructions should be followed. Moreover copper/copper sulphate probes are not suitable in chloride contaminated soil or in alkaline environments when silver/silver chloride should be used. Copper/copper sulphate cells are also sensitive to heat, light and a wide variety of chemicals.

The correction factors for reference probes to convert the measurement to the standard hydrogen electrode are as follows:

| | | |
|---|---|---|
| Mercury/mercuric chloride | 240[a] mV | at 25 °C |
| Copper/copper sulphate | 316 mV | |
| Silver/silver chloride | 246 mV[b] | |

[a] The factor of 240 is normally rounded to 250 for the purposes of this test.

[b] In 3 % sodium chloride solution.

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

**5.2.2** ***Apparatus***

**5.2.2.1** *Platinum probe* of a design having two separate platinum electrodes embedded in the nose piece. Also a means of protection when not in use. The probe shall have a connecting lead permitting the inclusion of each platinum electrode individually in an electrical circuit. Each connection shall be separately identified.

**5.2.2.2** *Calomel reference probe,* having a mercury/mercuric chloride reference electrode which can be refilled and with a connection to a porous ceramic junction. The calomel reference electrode shall be kept clean when not in use by being stored in a sealed container. The precipitation of crystals shall be prevented when not in use, particularly at the porous junction, by storing upright and closing the breather hole.

NOTE The platinum and calomel probes are often separate and the latter made of glass which can make field use sometimes difficult. The National Corrosion Service at the National Physical Laboratory (NPL)[10] has designed and supplies a robust redox probe that combines both the pair of platinum electrodes and a calomel reference probe mounted together behind a steel-tipped nose cone that is fitted on the end of a steel tube which can be driven into fine- and medium-grained soils. The NPL redox probe is supplied complete with ancillary equipment for cleaning the electrodes.

5.2.2.3 *Calibrated millivoltmeter,* having a performance complying with class 1.5 of BS 89. The total measuring range shall be at least 0 V d.c. to 2 V d.c. with a readability at least to 10 mV. The input impedance shall be not less than $10^6$ Ω and the polarity (positive or negative) shall be marked on the two input terminals.

The instrument shall include suitable insulated flexible electric cable and connectors for use with the probes.

The instrument shall be recalibrated at intervals not exceeding 2 yrs.

5.2.2.4 *Installation equipment* consisting of a soil auger, spade and trowel to excavate soil to test level, and, where soil is compact, a 1 kg hammer and spike.

5.2.2.5 *pH measuring apparatus* as specified and calibrated in accordance with clause **9** of BS 1377-3:1990.

5.2.2.6 *Disturbed sample container* of glass or dense plastic, that can be hermetically sealed.

NOTE When a sample from the test location is required for microbiological examination, a glass container of a size suitable to hold about 500 mL will need to have been cleaned and sterilized by scalding with boiling water beforehand. Alternatively medically sterilized plastic bags may be used. Fill the container completely and minimize air voids.

### 5.2.3 *Materials*

5.2.3.1 *Saturated solution* of potassium *chloride* in a screw-topped plastic bottle either with pouring lip suitable for filling the reservoir of the calomel reference probe or a separate small dropper or syringe. 500 mL is a suitable quantity.

5.2.3.2 *Jeweller's rouge.*

5.2.3.3 *Colourless methylated spirits,* 70 % by volume with 30 % by volume distilled water, in a screw-topped wide-mouth bottle. 500 mL is a suitable quantity.

5.2.3.4 *Distilled water.* Two differently marked wash bottles full for cleaning platinum electrodes. 500 mL is a suitable quantity for each bottle.

5.2.3.5 *Paper tissues and absorbent-type surgical cotton wool swabs.*

### 5.2.4 *Procedure*

NOTE Thorough cleanliness of the probes is essential for reliable results.

5.2.4.1 Assemble from the storage unit according to the manufacturer's operating instructions the calomel reference probe, ensuring that the unit is full of a saturated solution of potassium chloride and that this moistens the porous junction. Remove any air bubbles in the potassium chloride solution by gently tapping the probe and remove excess fluid from the porous junction.

NOTE 1 During use on site it is important to prevent precipitation of crystals at the porous junction. This may be done by keeping the probe between tests in distilled water in a wide-necked bottle with a rubber bung to ensure that the porous junction is kept moist.

Clean and polish each platinum electrode. Initially smear the surfaces lightly with moist jeweller's rouge and use gentle abrasive action with cotton wool swabs. Follow with a single wash using the methylated spirits. Afterwards wash thoroughly with distilled water. Lastly dry each electrode with clean paper tissues.

NOTE 2 Where the platinum electrode is dipped into distilled water for washing, the bottles will need separate identification to select the correct sequence when reused.

5.2.4.2 Connect the positive terminal of the millivoltmeter with the electric cable to one of the platinum electrodes and the negative terminal to the calomel reference electrode, but leave the circuit open. This circuit shall be considered to give positive readings.

5.2.4.3 Tests shall always be made below the level of organic growth. A hole not less than 150 mm in diameter is needed to reach the selected level when using separate probes. A combined redox probe may be driven from the surface to the selected level in weak soil, otherwise it may be necessary to auger or dig a hole part way.

5.2.4.4 If the probes are separate install them about 100 mm apart in the hole. The platinum probe shall penetrate at least 100 mm to ensure full soil contact below any disturbed surface material. A combined redox probe shall be pressed into position sufficiently to obtain full soil contact on the electrodes.

5.2.4.5 Rotate the platinum probe about a quarter turn without letting air reach the probe. Close the electric circuit then take the reading as soon as the voltage becomes stable. It may be necessary to wait 30 s or more for stable conditions to be reached. Where the probes are separate turn the platinum probe one revolution under firm hand pressure to ensure good contact. Rotate the combined redox probe a half to one revolution.

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[10] National Physical Laboratory, Teddington, Middlesex TW11 0LW.

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Record the reading to the nearest 10 mV when the oltage is steady and record whether it is positive or egative.

OTE Very occasionally the current between the platinum lectrode and the reference electrode will be in the reverse irection such as to require the connections to the millivoltmeter o be reversed. In this case the reading should be considered to be egative.

**5.2.4.6** Transfer the electric circuit to the other latinum electrode, connecting it again to the ositive terminal of the millivoltmeter, and repeat he procedure as specified in **5.2.4.5**. Record the eading to the nearest 10 mV and its polarity.

**.2.4.7** If the two readings differ by more han 20 mV remove the probes, reclean the latinum electrodes and re-install in a different osition at the test site. Do not install the probes in he original position because oxygen will have enetrated and a false reading could result. Repeat he procedures as specified in **5.2.4.5** and **5.2.4.6**.

**.2.4.8** Remove the probes and clean the electrodes aking note of the requirements of **5.2.2.2** nd **5.2.4.1**.

**.2.4.9** Place a disturbed sample from the position of he test in an hermetically sealed container.

**.2.4.10** Determine the pH of the sample by the ethod specified in clause **9** of BS 1377-3:1990.

**.2.5** *Calculations and expression of the results.* The ean of the two acceptable readings and their sign hall be recorded as the potential of the platinum robe, $E_p$, to the nearest 10 mV. Calculate the redox otential, $E_h$ (in mV), to the nearest 10 mV from the quation:

$$E_h = E_p + 250 + 60\,(\text{pH} - 7)$$

where

$E_p$ is the potential of the platinum probe (in mV) (may be a positive or negative value);

pH is the value of the acidity of an aqueous solution of the soil at the test position as determined by the method specified in clause **9** of BS 1377-3:1990;

250 is the correction factor for a calomel reference probe to convert the measurement to the standard hydrogen electrode.

**5.2.6** *Test report.* The test report shall affirm that the test was carried out in accordance with this Part of this standard and shall contain the following information.

a) The method of test used.

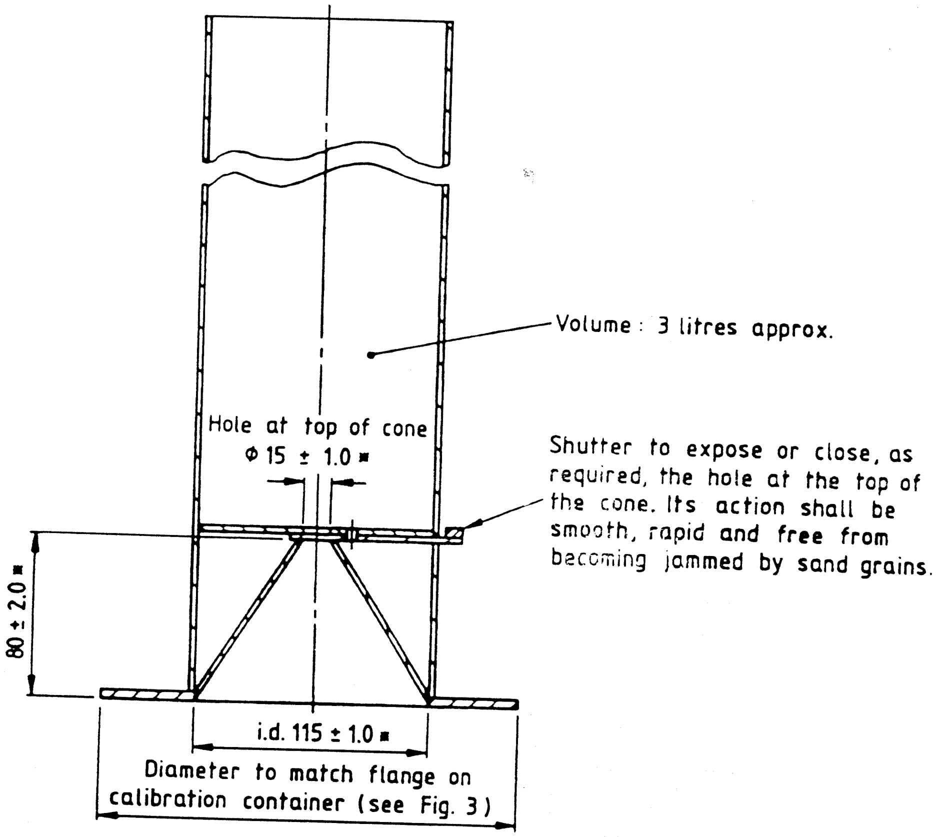
b) The mean value of the potential (in mV) of the two platinum probes to the nearest 10 mV.

c) The redox potential (in mV) to the nearest 10 mV.

d) The pH value.

e) The type of reference probe used in the test.

f) The information required by clause **9** of BS 1377-1:1990.

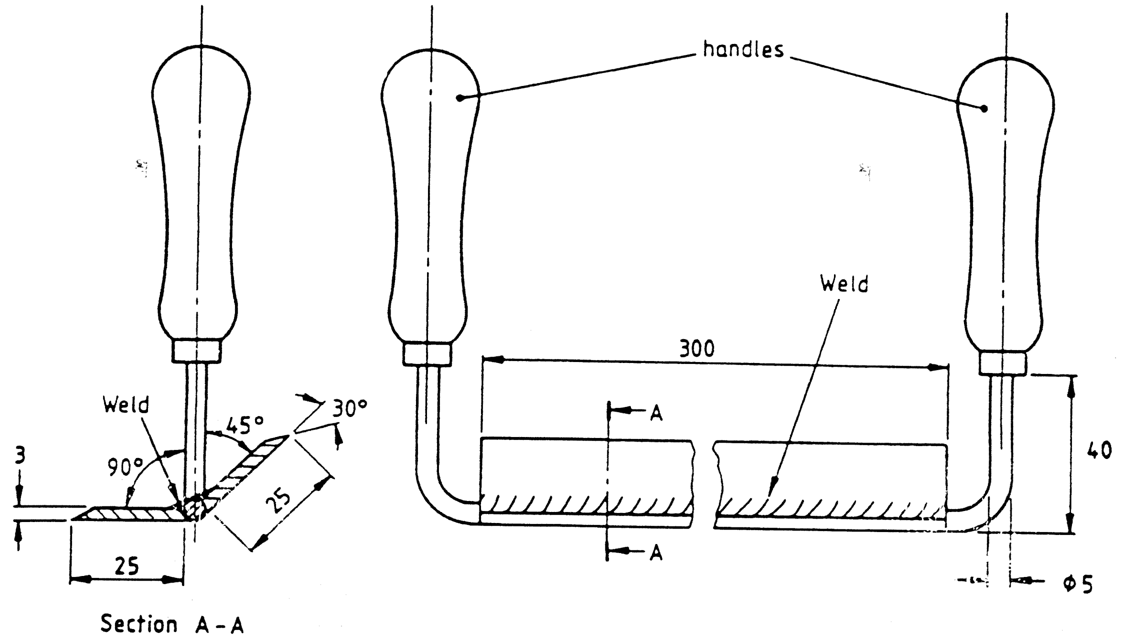


*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

All dimensions are in millimetres

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

Figure 1 — Small pouring cylinder for the determination of the density of fine-and medium-grained soils



See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

All linear dimensions are in millimetres

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

Figure 2 — Scraper for levelling surface of soil

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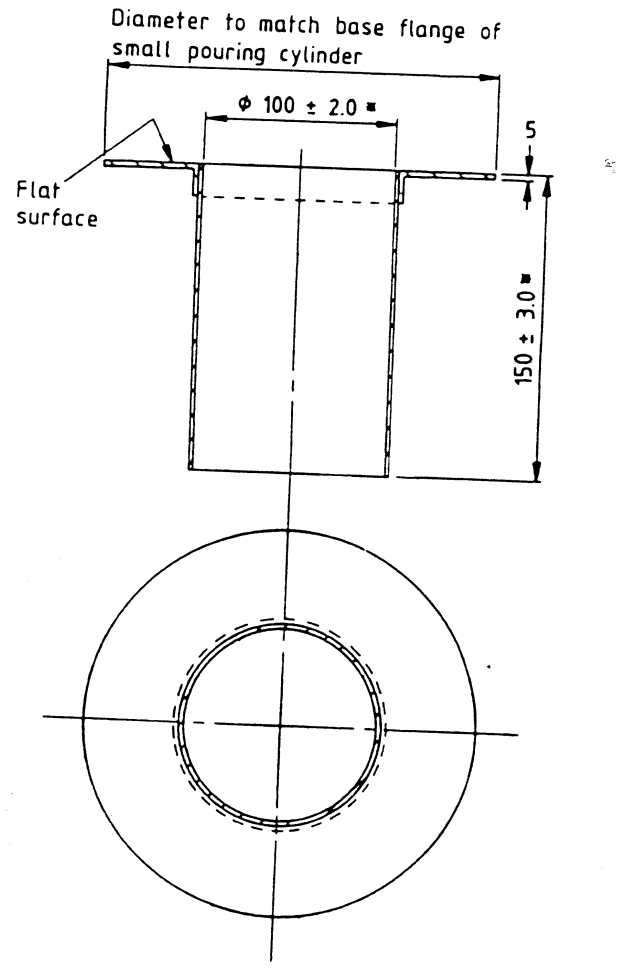


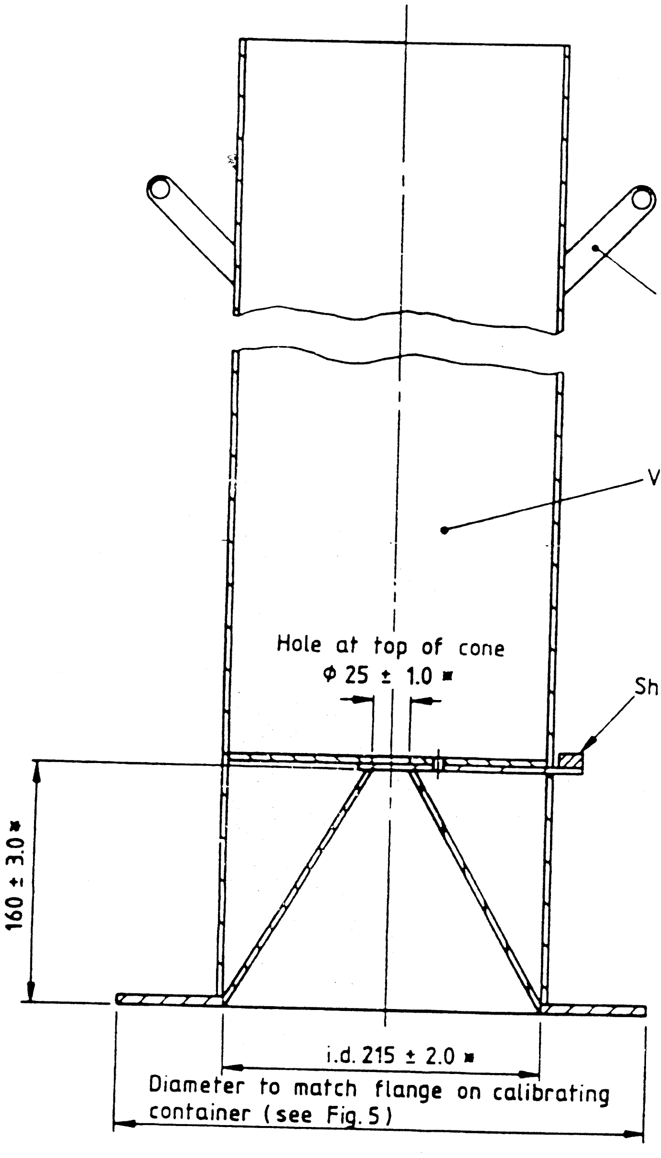
NOTE. It is important that metal joints within the calibrating container do not form crevices because these will affect the accuracy of the calibration.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

All dimensions are in millimetres

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

Figure 3 — Calibrating container for use with the small pouring cylinder

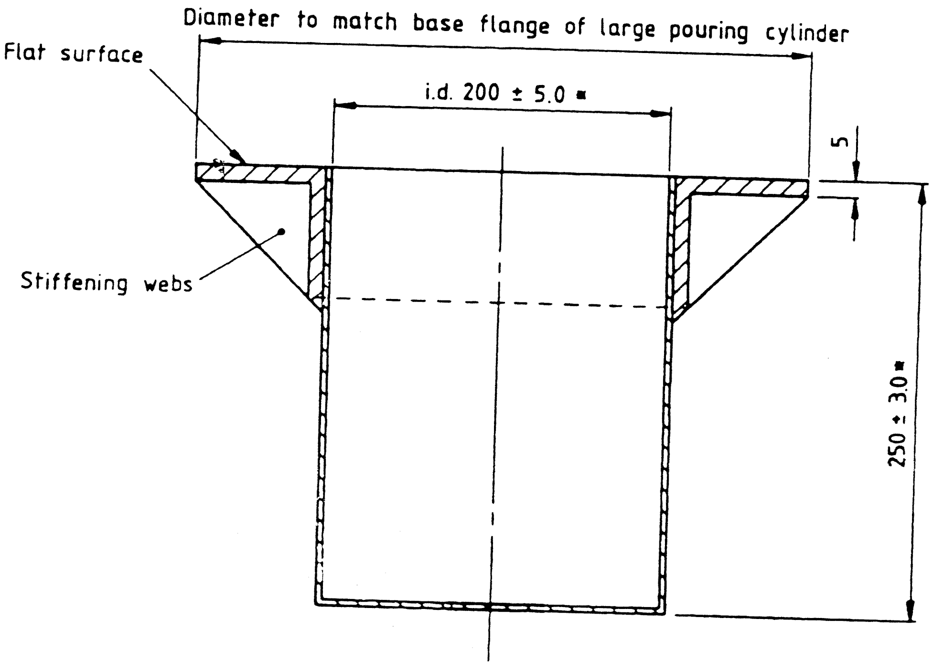


*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

All dimensions are in millimetres

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

Figure 4 — Large pouring cylinder for the determination of the density of fine-, medium- and coarse-grained soils



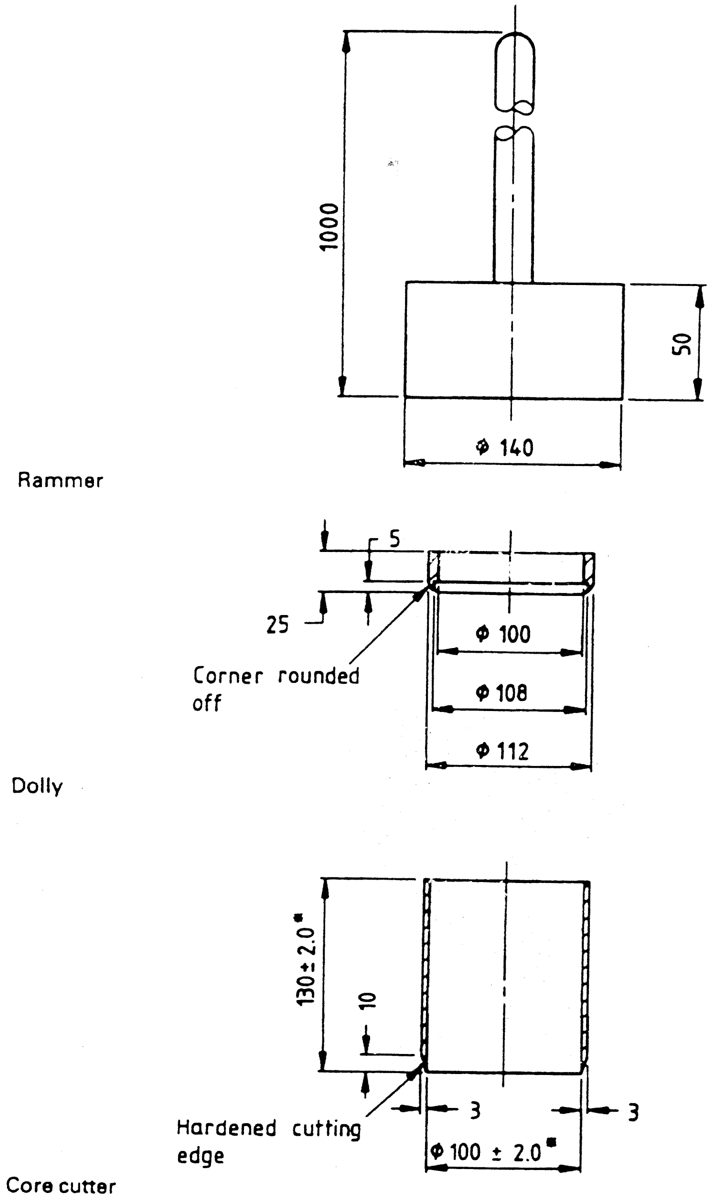
NOTE. It is important that metal joints within the calibrating container do not form crevices because these will affect the accuracy of the calibration.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

All dimensions are in millimetres

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

Figure 5 — Calibrating container for use with large pouring cylinder



*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

All dimensions are in millimetres

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

Figure 6 — Core cutter apparatus for soil density determination

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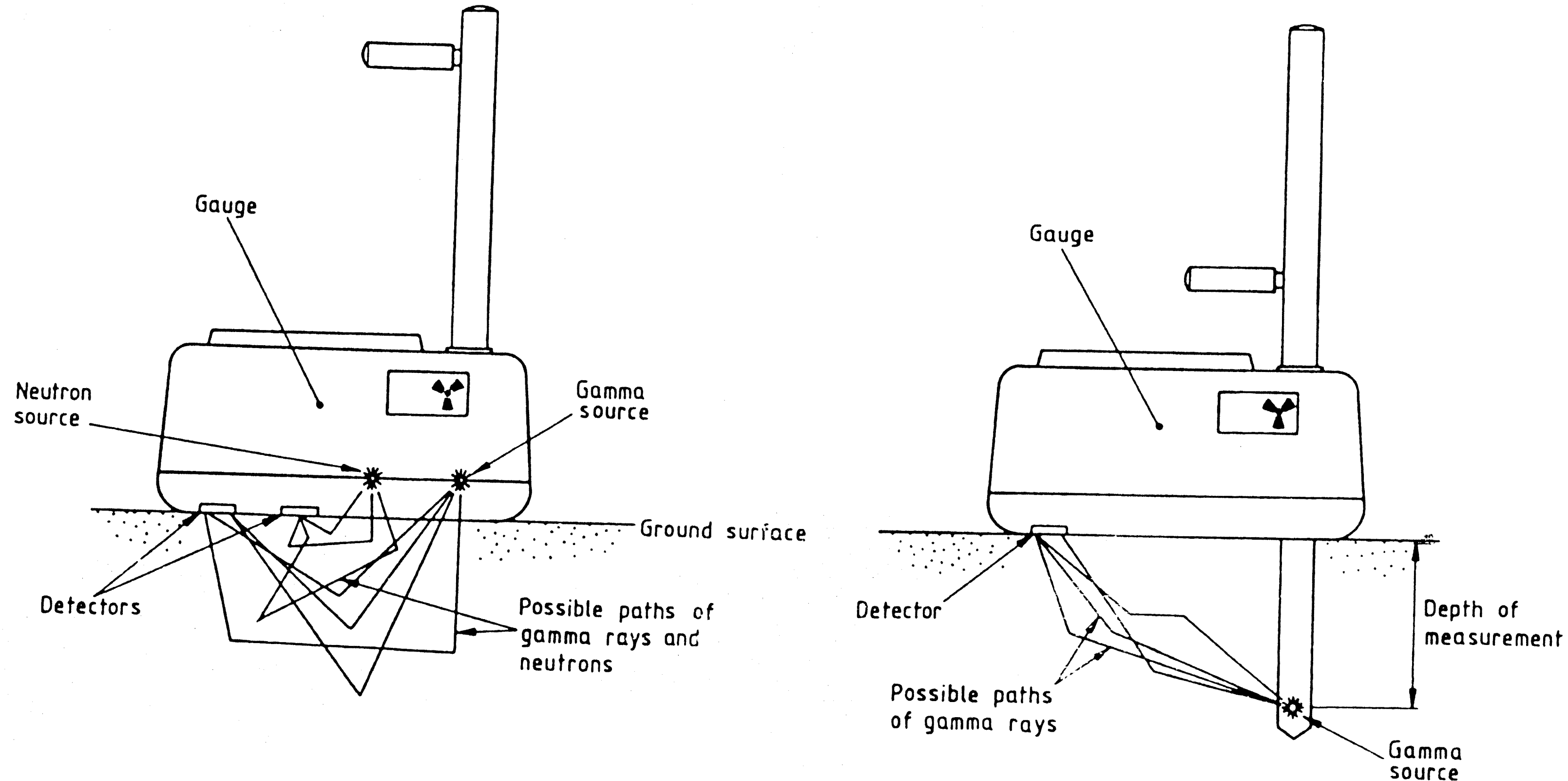
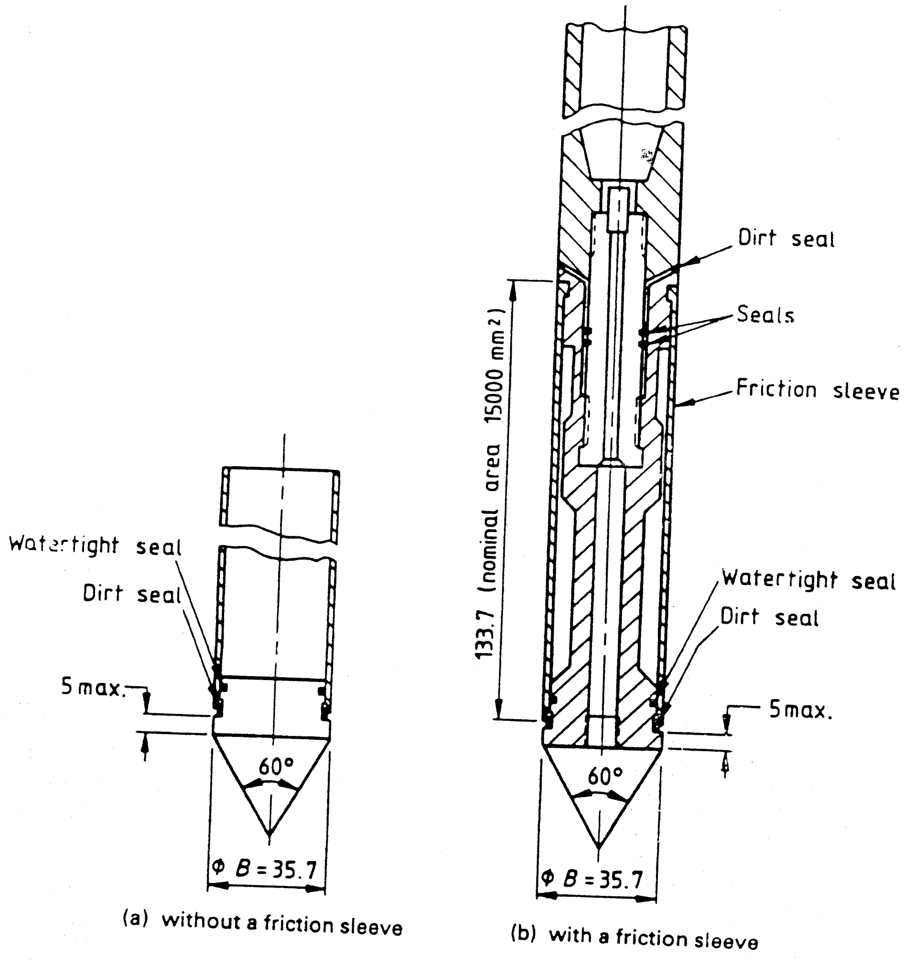


(a) Backscatter

(b) Direct transmission

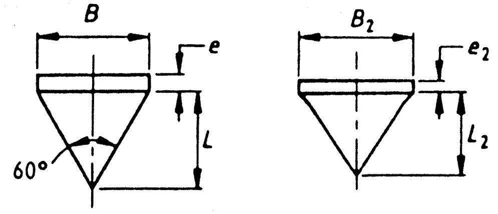
Figure 7 — Modes of operation of nuclear surface density and moisture gauges



See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

All linear dimensions are in millimetres

Figure 8 — Examples of penetrometer tips with and without a friction sleeve



(a) Standard cone
Nominal projected area 1000 mm²

(b) Permissible limits of wear

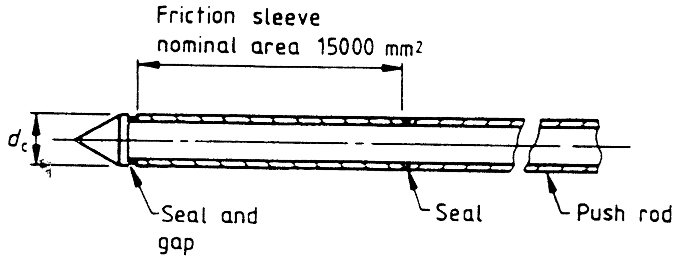
| All dimensions in millimetres | Permitted tolerances | | Typical dimensions for manufacture |
|---|---|---|---|
| | Maximum | Minimum (incl. wear) | |
| Base diameter (*B*) | 36.0 | 35.3 ($B_2$) | 36.00 + 0.00<br>− 0.05 |
| Cone height (*L*) | 31.2 | 24.0 ($L_2$) | 31.0 ± 0.2 |
| Cylindrical extension (*e*) | 5.0 | 2.0 ($e_2$) | 4.80 ± 0.15 |

NOTE 1. The cylindrical extension (*e*) may be increased up to 15 mm where a piezometric unit is fitted in this position.

NOTE 2. Roughness of the conical surface at manufacture should not exceed 1 µm.

NOTE 3. Cones with a visible asymmetrical wear should be rejected.

Figure 9 — Permitted tolerances, including allowances for wear, surface finish and typical manufacturing dimensions for the standard cone for the cone penetration test



| All dimensions in millimetres | Permitted tolerances | | Typical dimensions for manufacture |
|---|---|---|---|
| | Maximum | Minimum (incl. wear) | |
| External diameter of sleeve | $d_c + 0.35$ | $d_c$ | $36.00^{+0.05}_{-0.00}$ |
| External surface area | $1.53 \times 10^4$ mm$^2$ | $1.47 \times 10^4$ mm$^2$ | — |
| External length subject to surface area requirements | 135.0 | 132.5 | 134.00 ± 0.05 |

NOTE 1. $d_c$ = base diameter of actual attached cone.

NOTE 2. External surface roughness in the direction of the longitudinal axis should be between 0.25 µm and 0.75 µm.

Figure 10 — Permitted tolerances, including allowances for wear, surface finish and typical manufacturing dimensions for the standard friction sleeve for the cone penetration test

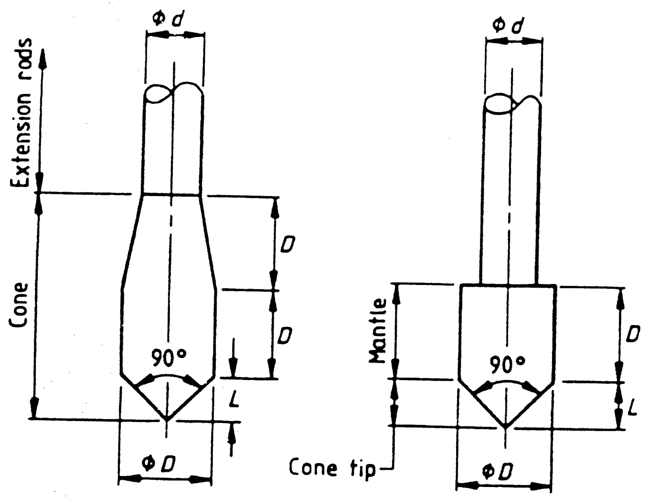
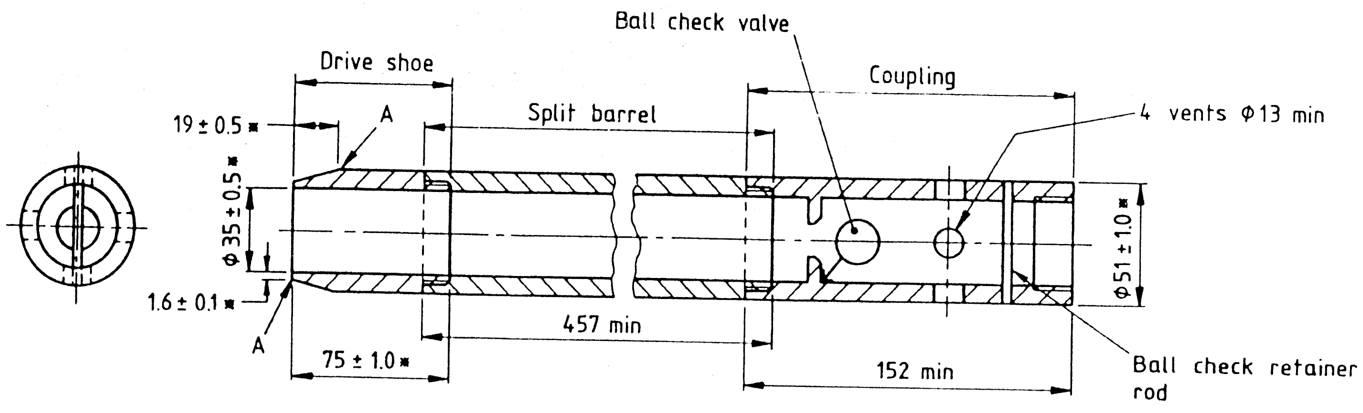


Figure 11 — Alternative forms of 90 cone for dynamic probing (for dimensions see Table 1)



*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

All dimensions are in millimetres

Corners at A may be slightly rounded.

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

Figure 12 — Split-barrel sampler assembly

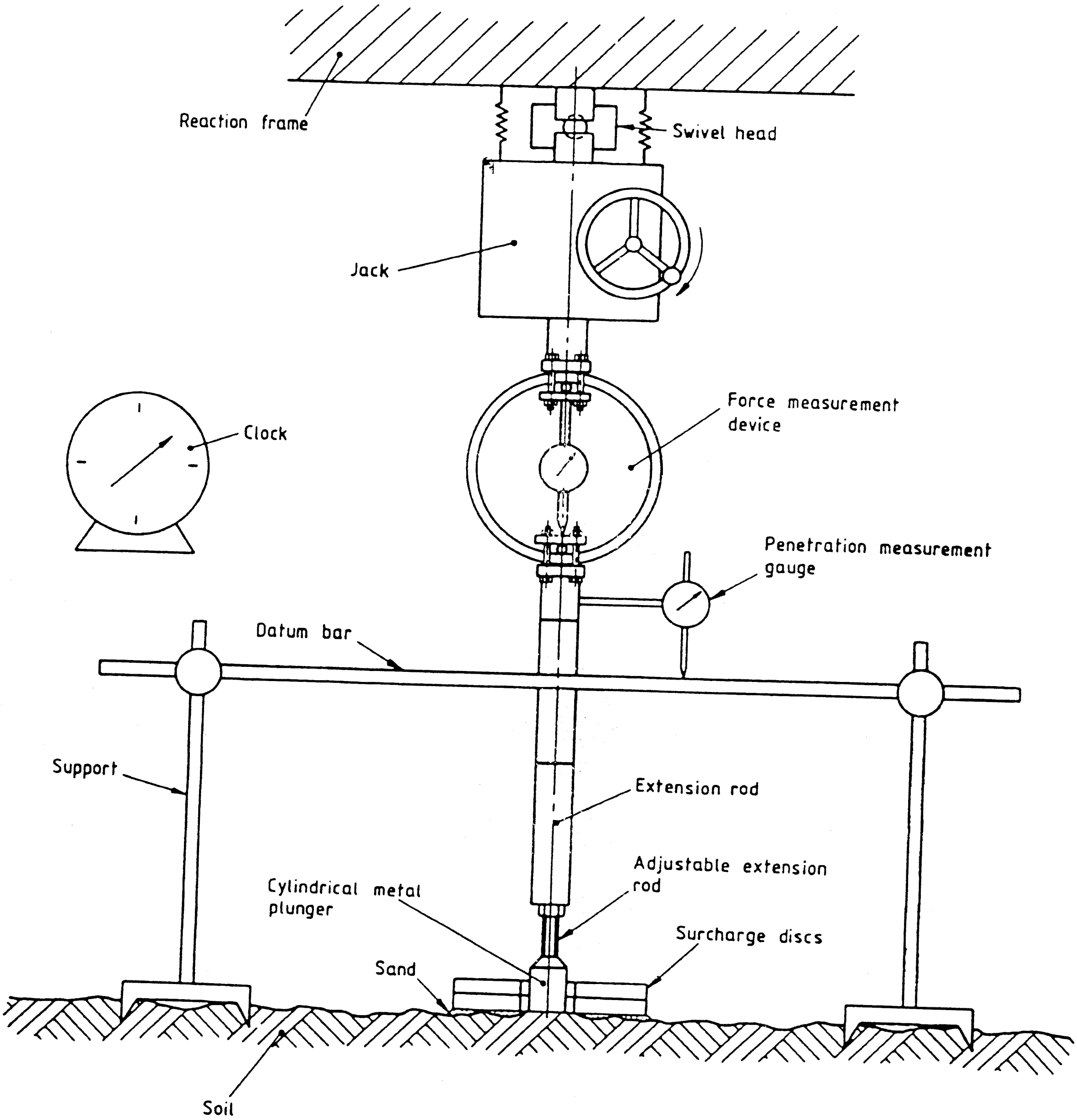


Figure 13 — Typical arrangement for in-situ CBR test apparatus

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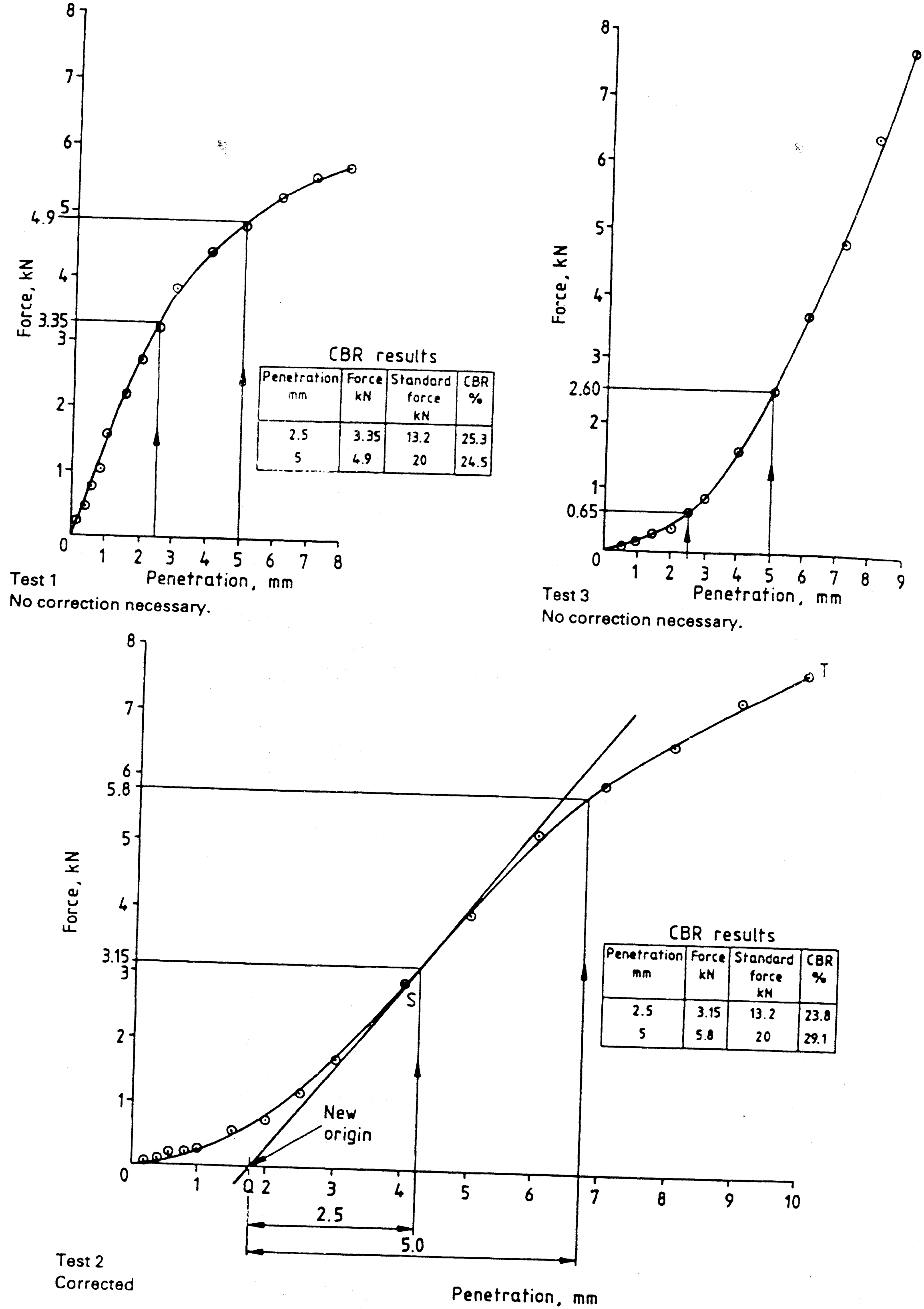


CBR results

| Penetration mm | Force kN | Standard force kN | CBR % |
|---|---|---|---|
| 2.5 | 3.35 | 13.2 | 25.3 |
| 5 | 4.9 | 20 | 24.5 |

CBR results

| Penetration mm | Force kN | Standard force kN | CBR % |
|---|---|---|---|
| 2.5 | 3.15 | 13.2 | 23.8 |
| 5 | 5.8 | 20 | 29.1 |

Figure 14 — Typical CBR test results curves

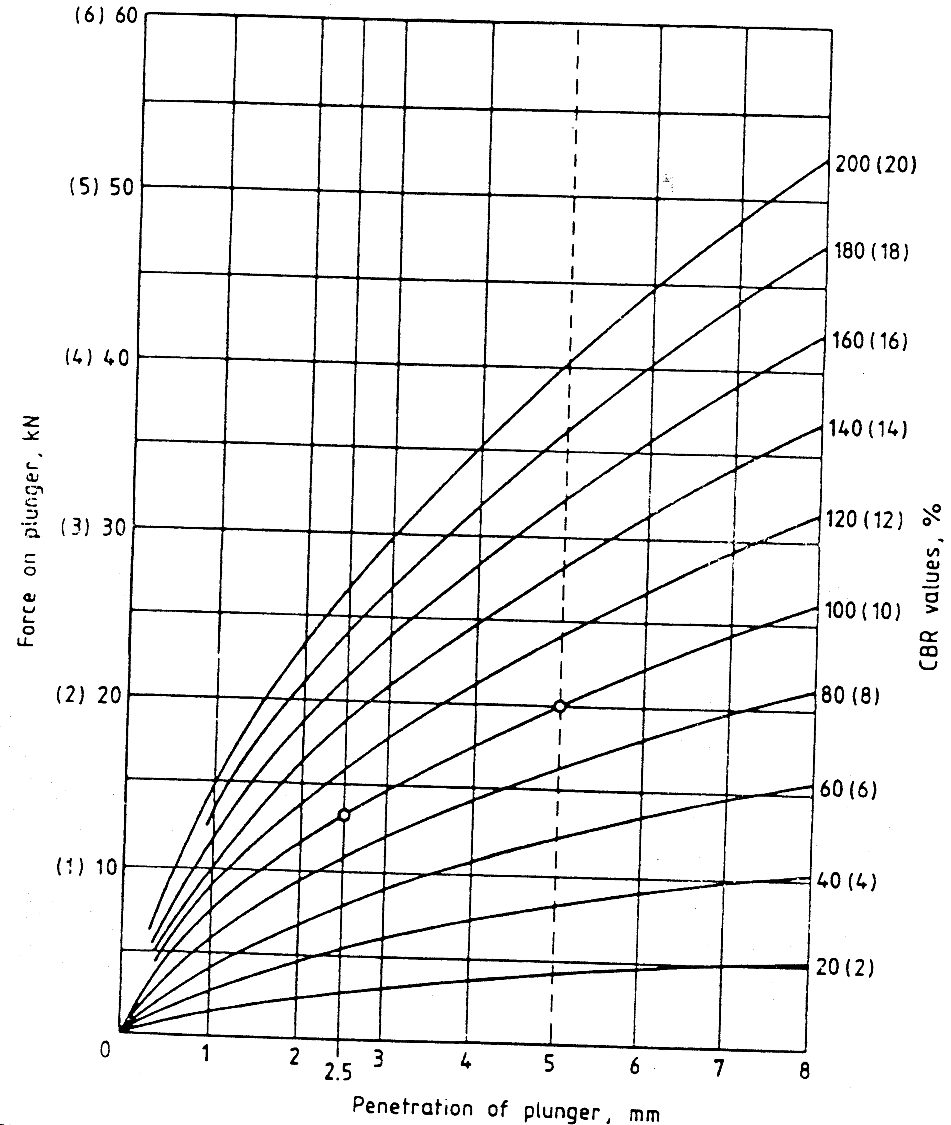
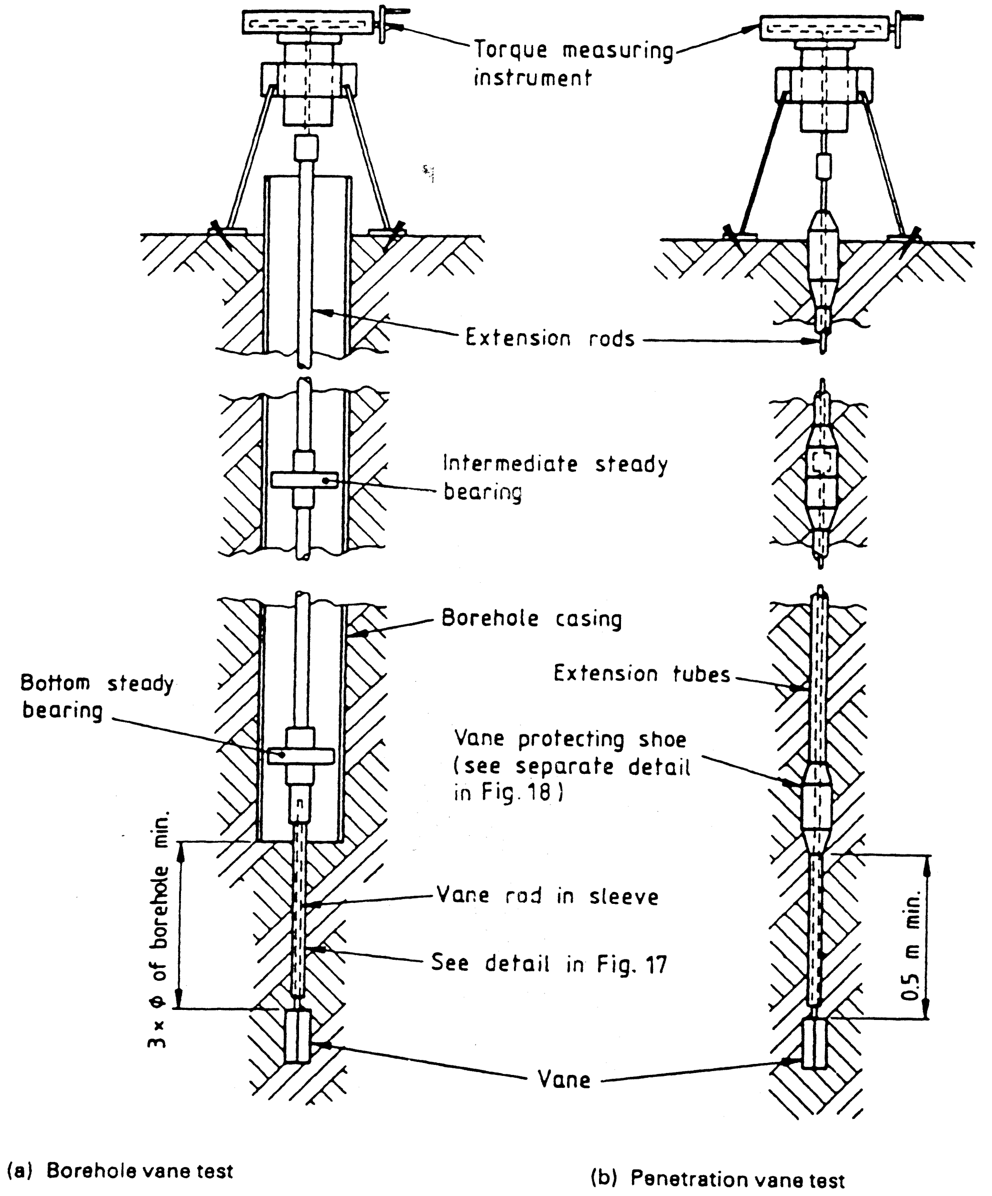


Figure 15 — Force-penetration curves for a CBR value of 100 % and other CBR values



(a) Borehole vane test

(b) Penetration vane test

Figure 16 — Typical arrangements for in-situ vane test apparatus

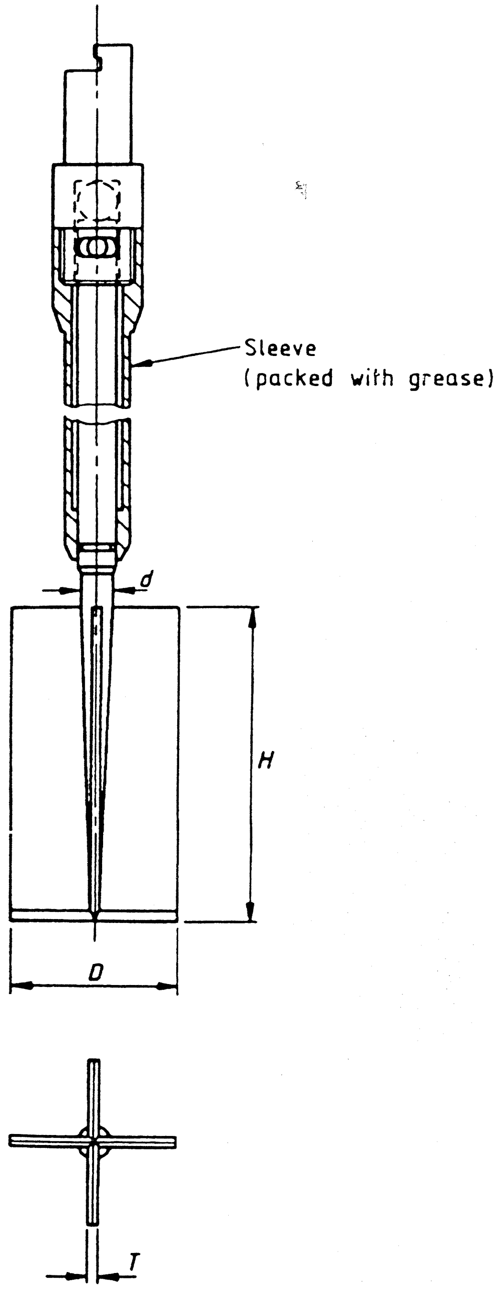


Figure 17 — Typical borehole vane and rod mounting

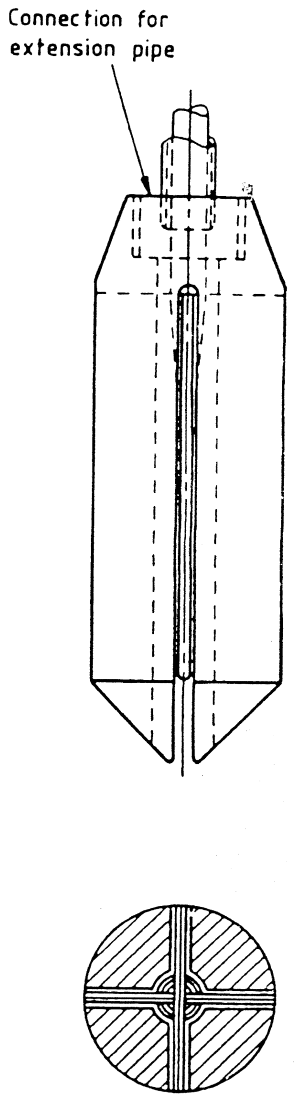


Figure 18 — Typical vane protecting shoe

## Appendix A Typical test data and calculation forms

The following test sheets are given as examples; other suitable forms may be used.

| Form | Title |
|---|---|
| 9 (a) | In-situ density test<br>Sand replacement methods |
| 9 (b) | In-situ density test<br>Water replacement method |
| 9 (c) | In-situ density test<br>Core cutter method |
| 9 (d) | Cone penetration test |
| 9 (e) | Dynamic probing test |
| 9 (f) | In-situ CBR test |
| 9 (g) | In-situ vane shear strength test |

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*In-situ density test (sand replacement method)*

| | | |
|---|---|---|
| Location | Job ref. | |
| | Test no. | |
| Soil description | Sample no. | |
| | Depth excavated | mm |
| Test method BS 1377-9:1990 { 2.1 small pouring cylinder[a]<br>2.2 large pouring cylinder[a] | Date | |

| | |
|---|---|
| Calibration<br>Mean mass of sand in cone of pouring cylinder $(m_2)$ | g |
| Volume of calibrating container $(V)$ | mL |
| Mass of sand before pouring $(m_1)$ | g |
| Mean mass of sand after pouring $(m_3)$ | g |
| Mean of sand to fill calibrating container $(m_a = m_1 - m_3 - m_2)$ | g |
| Bulk density of sand $\rho_a = \frac{m_a}{V}$ | Mg/m$^3$ |

| | | | | | | |
|---|---|---|---|---|---|---|
| Test number | | | | | | |
| Mass of wet soil from hole $(m_w)$ | g | | | | | |
| Mass of sand before pouring $(m1)$ | g | | | | | |
| Mass of sand after pouring $(m4)$ | g | | | | | |
| Mass of sand in hole $(mb = m_1 - m_4 - m_2)$ | g | | | | | |
| Ratio $\frac{m_w}{m_b}$ | | | | | | |
| Bulk density $\rho = \frac{m_w}{m_b} \times \rho_a$ | Mg/m$^3$ | | | | | |
| Moisture content container no. | | | | | | |
| Moisture content $(w)$ | % | | | | | |
| Dry density $\rho_d = \frac{100\ \rho}{100 + w}$ | Mg/m$^3$ | | | | | |

[a] Delete as appropriate

| Operator | Checked | Approved |
|---|---|---|
| | | |

Form 9 (a)

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*In-situ density test (water replacement method)*

| | | |
|---|---|---|
| Location | Job ref. | |
| | Test no. | |
| Soil description | Sample no. | |
| Test method* BS 1377 : Part 9 : 1990 : **2.3** | Date | |

Ring diameter: ........................ mm   Depth of hole: ............ mm (if specified: Yes/No*)

Volume of test hole

1. Surface correction
   Initial volume of water in ring above prepared surface
   ($R_i$) .................................. L
2. Test hole + ring
   Final volume of water in hole and density ring
   ($R_f$) .................................. L
   (Alternative: hole + ring-oversize material ($R_p$) .......................... L)
3. Total volume of test hole:

$$V_h = \frac{R_f - R_i}{1000} = \text{..........................} \ \text{m}^3$$

Wet mass of material

Material + drum 1 ..... kg
Drum 1 .............. kg Material ............ kg
Material + drum 2 ..... kg
Drum 2 .............. kg Material ............ kg
Material + drum 3 ..... kg
Drum 3 .............. kg Material ............ kg
Material + drum 4 ..... kg
Drum 4 .............. kg Material ............ kg

Wet mass of total material ($m_w$) .................. kg

LABORATORY TESTS

Moisture content

Container no: ..............................
Mass of wet soil + container .................. g
Mass of dry soil + container .................. g
Mass of container .................. g
Mass of moisture .................. g
Mass of dry soil .................. g

For total material
Moisture content ($w$) ...................... %

For smaller than specified size
Moisture content ($w_p$) ...................... %

Mass and volume of oversize material

Specified size limit ........................ BS sieve
Container no: ........................................
Method of separation: ........................................
........................................
Mass of oversize material ($m_s$) .................. kg
Volume of oversize material ($v_s$) .................. m$^3$

For total material:

$$\text{Bulk density } (\rho) \ \frac{m_w}{V_h \times 1000} = \text{..............} \ \text{Mg/m}^3$$

$$\text{Dry density } (\rho_d) = \frac{\rho \times 100}{100 + w} = \text{.............} \ \text{Mg/m}^3$$

For material finer than specified limit:

(a) Where oversize material replaced in hole:

$$\text{Dry density} = \frac{m_w - m_s}{R_p - R_i} \times \frac{100}{100 + W_p} = \text{...........} \ \text{Mg/m}^3$$

(b) Where volume oversize material obtained separately:

$$\text{Dry density} = \frac{m_w - m_s}{V_h - V_s} \times \frac{100}{100 + W_p} = \text{...........} \ \text{Mg/m}^3$$

*Delete as appropriate

| Operator | Checked | Approved |
|---|---|---|
| | | |

**Form 9 (b)**

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*In situ density test (core cutter method)*

| | | |
|---|---|---|
| Location | Job ref. | |
| | | |
| Soil description and applicable test numbers. | Sample no. | |
| | | |
| Test method<br>BS 1377-9:1990: **2.4** | Date | |

Length of core cutter: .................... mm

Volume of core cutter ($V_c$) ......... cm$^3$

| | | | | | | |
|---|---|---|---|---|---|---|
| Test number | | | | | | |
| Mass of core cutter and wet soil ($m_s$) | g | | | | | |
| Mass of core cutter ($m_c$) | g | | | | | |
| Mass of west soil ($m_s - m_c$) | g | | | | | |
| Bulk density $\rho = \frac{m_s - m_c}{V_c}$ | Mg/m$^3$ | | | | | |
| Moisture content container no. | | | | | | |
| Moisture content ($w$) | % | | | | | |
| Dry density $\rho_d = \frac{100\,\rho}{100 + w}$ | Mg/m$^3$ | | | | | |

| | | | |
|---|---|---|---|
| | Operator | Checked | Approved |
| | | | |

Form 9 (c)

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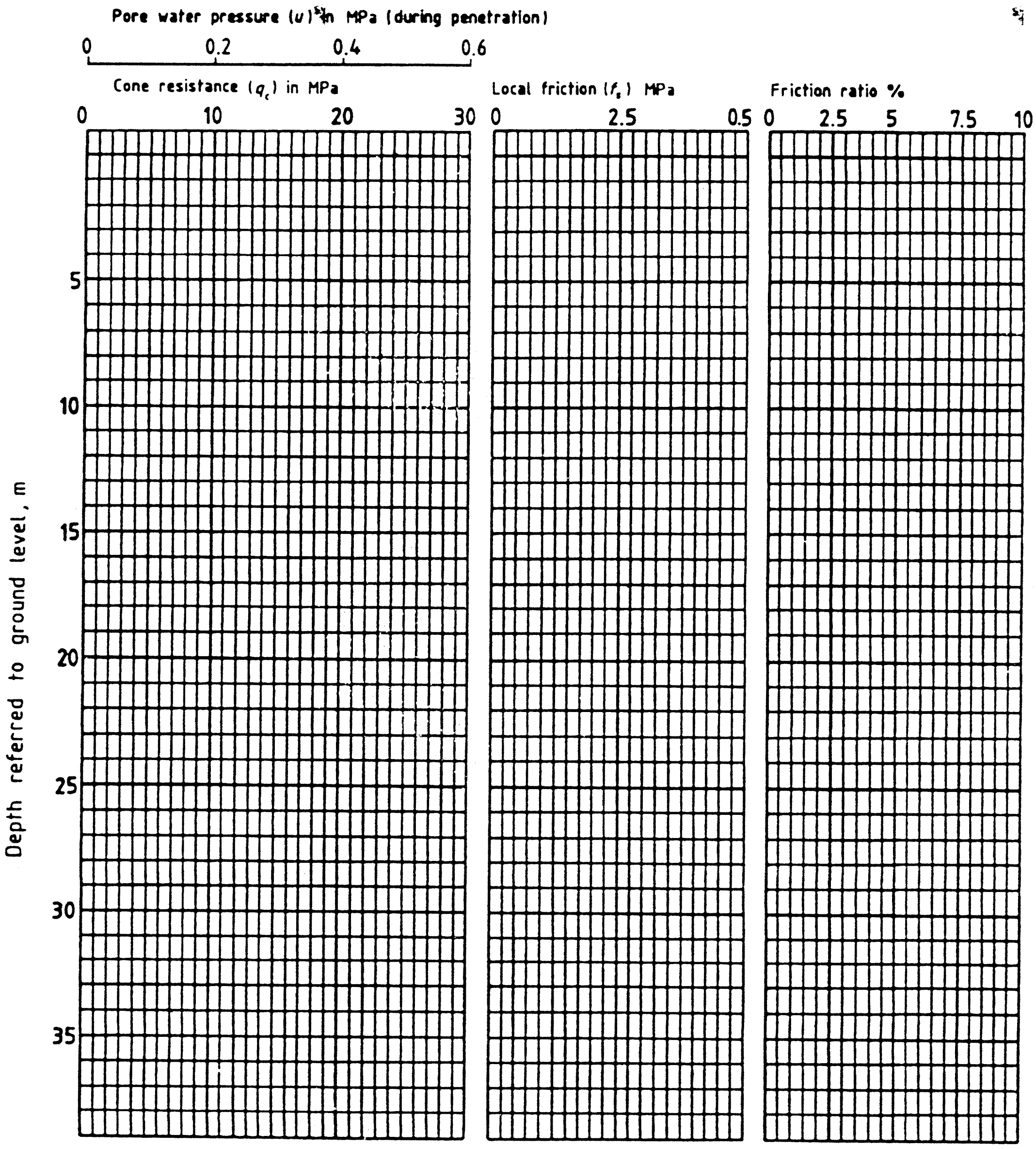
*Static cone penetration test*

| | | | | |
|---|---|---|---|---|
| Location | Job ref. | | Date | |
| | Ground level (ordnance datum) | m | Test no. | |
| Test method BS 1377 : Part 9 : 1990 : **3.1** | | | | |



Machine type...................... Capacity..................... Cone no. ...................... Capacity ............. Calib. ref .............

Measurement system: Elect/Mech* Sleeve no. ........................................ Capacity ............. Calib. ref .............

Depth to water ..........m Piezocone no. ................................................ Capacity ............. Calib. ref .............

Hole backfilled Yes/No* Type ........................................................................

*Delete as appropriate Filter position ...........................................................

| | | | |
|---|---|---|---|
| | Operator | Checked | Approved |
| | | | |

Form 9 (d)

*Dynamic probing test*

| | | | | |
|---|---|---|---|---|
| Location | Job ref. | | Date | |
| | Ground level (ordnance datum) | m | Test no. | |
| Test method BS 1377 : Part 9 : 1990 : 3.2 | | | | |

| Depth m | Blows per 100 mm | Blow count | Torque (in N.m) | Remarks |
|---|---|---|---|---|
| | | 0 10 20 30 | | |
| 0 | | | | |
| 1.0 | | | | |
| 2.0 | | | | |
| 3.0 | | | | |
| 4.0 | | | | |
| 5.0 | | | | |
| 6.0 | | | | |
| 7.0 | | | | |
| 8.0 | | | | |
| 9.0 | | | | |
| 10.0 | | | | |

Hammer: type/mass ........................................ kg
Standard drop ........................................ mm
Damper: Yes/No* Type ........................................
Cone: type/diameter ........................
Rod: type/diameter ........................
Cone left behind: Yes/No*
Hole backfilled: Yes/No*

*Delete as appropriate

| | | | |
|---|---|---|---|
| | Operator | Checked | Approved |
| | | | |

Form 9 (e)

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*In-situ CBR test*

| | |
|---|---|
| Location | Job ref. |
| | Test no. |
| Soil description | Sample no. |
| | |
| Test method BS 1377 : Part 9 : 1990 : **4.3** | Date |

NOTE. Test applicable only when maximum particle size beneath plunger does not exceed 20 mm.

Area of annulus of disc used ................................................ mm² Jack/load ring no. ................................................

Mass of surcharge ................................................ kg Calibration ref: ................................................

RECORDINGS Moisture content of sample ................................................ %

NOTE. Penetration and force readings after seating load zeroed.

| **Penetration of plunger** | **Force on plunger** | |
|---|---|---|
| mm | Load gauge | kN |
| 0.25 | | |
| 0.50 | | |
| 0.75 | | |
| 1.00 | | |
| 1.25 | | |
| 1.50 | | |
| 1.75 | | |
| 2.00 | | |
| 2.25 | | |
| 2.50 | | |
| 2.75 | | |
| 3.00 | | |
| 3.25 | | |
| 3.50 | | |
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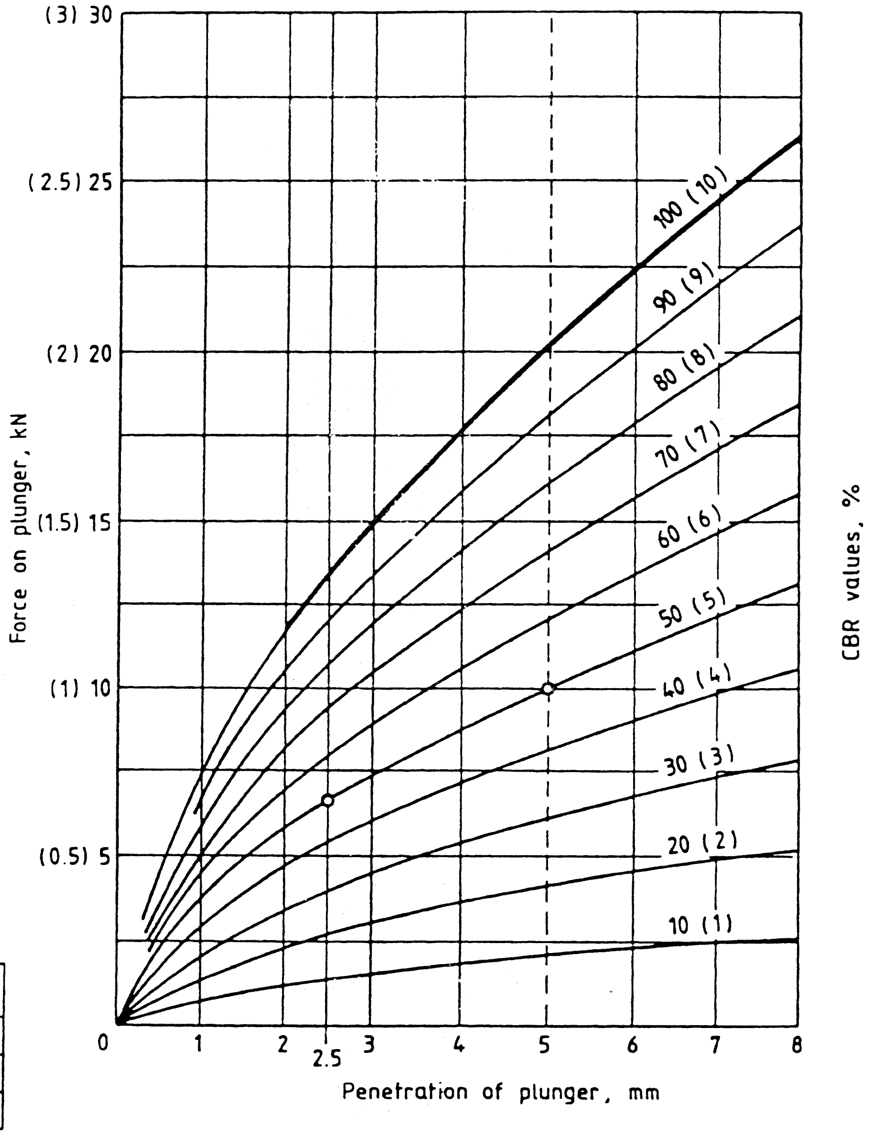
| 5.75 | | |
| 6.00 | | |
| 6.25 | | |
| 6.50 | | |
| 6.75 | | |
| 7.00 | | |
| 7.25 | | |
| 7.50 | | |



RESULTS

| **Penetration** | **Force** | **Standard force** | **CBR** |
|---|---|---|---|
| mm | kN | kN | % |
| 2.5 | | 13.2 | |
| 5.0 | | 20.0 | |

**In-situ CBR value** ........................ %

| | | | |
|---|---|---|---|
| | Operator | Checked | Approved |
| | | | |

**Form 9 (f)**

*In-situ vane shear strength test*

| | | |
|---|---|---|
| Location | Job ref. | |
| | Borehole/Test no.[a] | |
| | Sheet no. | |

| | | |
|---|---|---|
| Test method<br>BS 1377-9:1990: **4.4** | Ground level:<br>(Ordnance datum) m | Weather: |
| Vane dimensions: height mm; Dia. mm | Instrument no. .................. | Date |
| Vane constant, *K*: mm$^3$ × 10$^{-6}$ | Depth to ground water level: | |

Test record Rate of loading .............. radians/min or degree/min.[a]

| Depth of borehole below ground level | Depth of vane tip | Max. force applied and time to failure | | Value of frictional force | Torque, *M* | Shear strength *M*/*K* | Remarks (soil description at test levels, etc.) |
|---|---|---|---|---|---|---|---|
| m | m | N | min s. | N | N m | kPa | |
| | | | | | | | |

[a] Delete as appropriate

| Operator | Checked | Approved |
|---|---|---|
| | | |

Form 9 (g)

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# Publications referred to

BS 89, *Specification for direct acting indicating electrical measuring instruments and their accessories.*

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

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

BS 1377-2, *Classification tests.*

BS 1377-3, *Chemical and electro-chemical tests.*

BS 1610, *Materials testing machines and force verification equipment.*

BS 4019, *Specification for rotary core drilling equipment.*

BS 4019-1, *Basic equipment.*

BS 5573, *Code of practice for safety precautions in the construction of large diameter boreholes for piling and other purposes.*

BS 5930, *Code of practice for site investigations*[11].

BS 6231, *Specification for PVC-insulated cables for switchgear and controlgear wiring.*

ASTM D2922 American Society for Testing and Materials. Standard test methods for density of soil and soil aggregate in place by nuclear methods (shallow depth).

ASTM D3017 American Society for Testing and Materials. Standard test methods for moisture content of soil and soil-aggregate in place by nuclear methods (shallow depth).

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[11] Referred to in the forword only.

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