

Methods of test for

Soils for civil engineering purposes —

Part 9: In-situ tests

ICS 93.020

Committees responsible for this British Standard

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- British Civil Engineering Test Equipment Manufacturers' Association
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- Department of the Environment (Property Services Agency)
- Department of the Environment (Building Research Establishment)
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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 It is a revision of the in-situ test methods described in BS 1377:1975 which are superseded by amendment.

NOTE Amendment 2 to this standard removes text superseded by BS EN ISO 22476-2 and BS EN ISO 22476-3, and makes reference to the relevant standard for each affected subclause.

BS 1377:1975 which has now been withdrawn is replaced by the following Parts of BS 1377:1990: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 cannot 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 62, an inside back cover and a back cover.

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

1 Scope

This Part of BS 1377 describes 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 μ m test sieve and 100 % is retained on the 63 μ m 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 the 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 filled the cone of the pouring cylinder and determine its mass, m_2 , to the nearest 1 g.

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

2.1.4.2 *Determination of the bulk density of the sand (ρ_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 calibrating 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 the base in modelling clay or similar material. Note the 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 until 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 *Calculations¹⁾ 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, ρ_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, ρ (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);

ρ_a is the bulk density of sand (in Mg/m^3).

Calculate the dry density, ρ_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.

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 long 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 (ρ_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 Calculations²⁾ 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, ρ_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, ρ (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);

²⁾ See form 9(a) of Appendix A.

ρ_a is the bulk density of the sand
(in Mg/m^3).

Calculate the dry density, ρ_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 information.

- The method of test used.
- The in-situ bulk and dry densities of the soil (in Mg/m^3) to the nearest 0.01 Mg/m^3 .
- The moisture content, as a percentage, to two significant figures.
- 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 compacted 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 coarse and very coarse soils when the other methods for determining the field density are unsuitable because the volume excavated would be unrepresentative.

Alternative density determinations may be made as follows:

- for the total material within the hole excavated (see 2.3.5.1):
 - to an unspecified depth;
 - to a specified depth;
 - 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.
- 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 appropriate, shall apply to the test methods described 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.

2.3.5.1.9 Excavate with the digging tools a hole within the density ring as nearly cylindrical as practicable taking care not to displace the ring or the plaster filling. With non-cohesive soil, particularly when wet, the sides of the excavation will need to be inclined to prevent slumping. Carefully collect all the excavated material in suitable containers, which shall be fitted with lids for soils and absorbent rock fragments, and number them consecutively. As the hole is deepened avoid undercutting the ring and use mechanical lifting devices if necessary for removing very large material clear of the hole and over the ring. Leave in place any large rocks that protrude when forming the hole boundary.

Keep the floor and wall of the hole flat and free from sharp protrusions which may puncture the plastics sheet. Cease excavating when the depth of the hole is more or less equal to its diameter, except when specified otherwise such as when testing particular layers.

Ensure the hole is finally cleared of all loose material with the wall and base left undisturbed.

2.3.5.1.10 Weigh each container of excavated material, as well as any separate very coarse-sized material, to the nearest 100 g and record the result with the container number. After deducting the masses of the containers, sum the individual masses of the material in order to obtain the total excavated mass (m_w).

2.3.5.1.11 When moisture or absorbent material is present in all or part of the excavated soil and rock which may affect the dry density determination, determine the moisture content as specified in BS 1377-2:1990.

The moisture content shall be representative of the whole of the material excavated, therefore collect a representative portion for this moisture content determination in a separate airtight container by incrementally sampling each individual portion of the excavated material after determining the total mass (m_w).

2.3.5.1.12 Select a suitable size of the plastics sheet and check that it is undamaged and without punctures. Place the plastics sheet over the ring and down into the hole gently, ensuring that there is sufficient to conform to the wall and base of the hole. Replace the datum bar and locked pointer.

2.3.5.1.13 Fill the space contained by the plastics sheet with water from the calibrated containers up to the precise level of the tip of the locked pointer, as set for the initial volume measurement (see **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 Calculations³⁾ 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, ρ (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, ρ_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, ρ_{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, ρ_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.

- The method of test used.
- The in-situ bulk and dry densities of the soil (in Mg/m^3), to the nearest $0.01 \text{ Mg}/\text{m}^3$
- The moisture content, as a percentage, to the nearest 0.5 %.
- The fraction of the soil for which the density has been determined (if appropriate).
- The grading analysis (if appropriate).
- The approximate diameter and depth of the hole, and whether either was specified or not.
- The methods of determining the mass and volume of coarse and oversize material if carried out separately.
- 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.

³⁾ See form 9(b) of Appendix A.

2.4.2 Apparatus

2.4.2.1 Cylindrical steel core cutter, 130 mm long and of 100 ± 2 mm internal diameter, with a wall thickness of 3 mm bevelled at one end, of the type illustrated in Figure 6. The cutter shall be kept greased.

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

2.4.2.2 Steel dolly, 25 mm high and of 100 mm internal diameter, with a wall thickness of 5 mm, fitted with a lip to enable it to be located on top of the core cutter (see Figure 6).

2.4.2.3 Steel rammer of the type illustrated in Figure 6.

2.4.2.4 Balance, readable to 1 g.

2.4.2.5 Palette knife, a convenient size is one having a blade approximately 200 mm long and 30 mm wide.

2.4.2.6 Steel rule, graduated to 0.5 mm.

2.4.2.7 Grafting tool, or spade, and a pickaxe.

2.4.2.8 Straightedge, e.g. a steel strip about 300 mm long, 25 mm wide and 3 mm thick, with one bevelled edge.

2.4.2.9 Apparatus for moisture content determination, as specified in BS 1377-2:1990.

2.4.2.10 Apparatus for extracting samples from the cutter (optional).

2.4.3 Procedure

2.4.3.1 Calculate the internal volume of the core cutter in cubic centimetres from its dimensions which shall be measured to the nearest 0.5 mm (V_c).

2.4.3.2 Weigh the cutter to the nearest 1 g (m_c).

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

NOTE Where driving causes shortening of the sample in the cutter, or there is difficulty in digging out the cutter, it may be found preferable to remove the soil from around the outside of the cutter and slightly in advance of the cutting edge as it is driven down. Care needs to be taken not to cause voids inside the cutter by trimming away the soil a short distance outside the wall of the cutter.

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 Calculations⁴⁾ and expression of results.

Calculate the bulk density of the soil, ρ (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, ρ_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:

- the method of test used;
- the in-situ bulk and dry densities of the soil (in Mg/m^3) to the nearest 0.01 Mg/m^3 ;
- the moisture content (in %) to two significant figures;
- 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.

⁴⁾ 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.

Variations in the design of the nuclear gauges are such that in describing this method it has not been possible to detail fully the operation of the gauge and reference is made to the manufacturer's handbook.

2.5.3 Principles

2.5.3.1 Bulk density. The method uses the attenuation of gamma rays from a gamma source (usually in a moveable probe) due to Compton scattering and photo-electric absorption. The intensity of radiation arriving at the detector (usually fixed in the gauge base) which is directly related to the electron density provides an indication of the bulk density by comparison with an appropriate 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 D2922⁵⁾. 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.

⁵⁾ See reference list of standards on inside back cover.

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.

2.5.5.3.2 Calibration by the in-situ method. Proceed as 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.

2.5.5.3.3 Derivation of the calibration. Proceed as 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;

ρ_n is the nuclear gauge bulk density (in Mg/m³).

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.

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.