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Introduction

Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international and European standards, comments will be reviewed by the relevant UK national committee before submitting the consensus UK vote and comments. If the draft standard is approved, it is usual for the resulting published standard to be adopted as a British Standard.

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BS 1377-9:2025
Methods of test for soils for civil engineering
purposes – Part 9: In-situ tests

DRAFT

Foreword

Publishing information

This part of BS 1377 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on XX MONTH 2025. It was prepared by Technical Committee B/526, *Geotechnics*. A list of organizations represented on this committee can be obtained on request to the committee manager.

Supersession

This part of BS 1377 supersedes BS 1377-9:1990, which is withdrawn.

Relationship with other publications

BS 1377 is published in the following parts:

- Part 1: *General requirements and sample preparation*;
- Part 2: *Classification tests and determination of geotechnical properties*;
- Part 3: *Chemical and electro-chemical testing*; and
- Part 9: *In-situ tests*.

Information about this document

This is a full revision of the document, and introduces the following principal changes:

- additional test methods have been added, including complex impedance method for estimating in-situ density and water content; electromagnetic method for estimating in-situ density and water content; dynamic cone penetrometer tests for assessment of in-situ CBR; and hand vane tests.

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It has been assumed in the preparation of this part of BS 1377 that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this document are presented in roman (i.e. upright) type. Its methods are expressed as a set of instructions, a description, or in sentences in which the principal auxiliary verb is “shall”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the *Shorter Oxford English Dictionary* is used (e.g. “organization” rather than “organisation”).

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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 BS 1377-2, for which samples first need to be taken. The methods described in this part of BS 1377 have been arranged in groups either according to the purpose of the test or the mode of execution.

These groups are as follows.

- a) Seven methods for the determination of the in-situ density comprising four methods by direct measurement of density and three indirect methods by correlation of other properties of the soil.
- b) Four principal methods for the determination of in-situ penetration resistance comprising three types of static cone penetration test, dynamic probing, dynamic cone penetration tests and the standard penetration test.
- c) Four methods for the determination of the vertical deformation and strength characteristics comprising the plate load test, shallow pad maintained load test, in-situ California bearing resistance (CBR) test and in-situ vane test.
- d) Two methods for the determination of the in-situ corrosivity characteristics.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions, or limits the application, of this document¹⁾. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

ASTM D2922, *Standard test methods for density of soil and soil-aggregate in place by nuclear methods (shallow depth)*

ASTM D3017, *Standard test method for water content of soil and rock in place by nuclear methods (shallow depth)*

ASTM D7698, *Standard test method for in-place estimation of density and water content of soil and aggregate by correlation with complex impedance method*

ASTM D7830/D7830M, *Standard test method for in-place density (unit weight) and water content of soil using an electromagnetic soil density gauge*

BS 1377-1:2016, *Methods of test for soils for civil engineering purposes – Part 1: General requirements and sample preparation*

BS 1377-2, *Methods of test for soils for civil engineering purposes – Part 2: Classification tests and determination of geotechnical properties*²⁾

BS 1377-3:2018+A1:2021, *Methods of test for soils for civil engineering purposes – Part 3: Chemical and electro-chemical testing*

BS 5930, *Code of practice for ground investigations*³⁾

BS 6231, *Electric cables – Single core PVC insulated flexible cables of rated voltage 600/1 000 V for switchgear and controlgear wiring*

¹⁾ Documents that are referred to solely in an informative manner are listed in the Bibliography.

²⁾ This standard also gives an informative reference to BS 1377-2:2022.

³⁾ This standard also gives an informative reference to BS 5930:2015+A1:2020.

BS EN ISO 17892-1, *Geotechnical investigation and testing – Laboratory testing of soil – Part 1: Determination of water content*

BS EN ISO 17892-2, *Geotechnical investigation and testing – Laboratory testing of soil – Part 2: Determination of bulk density*

BS EN ISO 22476-1, *Geotechnical investigation and testing – Field testing – Part 1: Electrical cone and piezocone penetration test*

BS EN ISO 22476-2, *Geotechnical investigation and testing – Field testing – Part 2: Dynamic probing*

BS EN ISO 22476-3, *Geotechnical investigation and testing – Field testing – Part 3: Standard penetration test*

BS EN ISO 22476-9, *Geotechnical investigation and testing – Field testing – Part 9: Field vane test (FVT and FVT-F)*

BS EN ISO 22476-12, *Geotechnical investigation and testing – Field testing – Part 12: Mechanical cone penetration test (CPTM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in BS 1377-1:2016 apply.

4 In-situ density tests

COMMENTARY ON CLAUSE 4

This clause specifies seven 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 should be deemed to be definitive methods. The remaining three methods measure other properties of the soil matrix to estimate a density figure by correlation. Equipment for these methods also includes the indirect measurement of water content.

The requirements of BS 1377-1, where applicable, apply to the test methods described in this clause.

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

4.1.1 Principle

This method covers the determination in situ of the density of natural or compacted fine- and medium-grained soils for which a nominal 115 mm diameter sand-pouring cylinder is used in conjunction with replacement sand (see Note 1). The method is not to be used for measurements 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 depths between 150 mm and 250 mm in thickness, the test described in 4.2 should be used for direct density measurements of fine and medium grained soils.*

4.1.2 Materials

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 use, it shall have been oven dried and stored in a loosely covered container to allow its water content to reach equilibrium with atmospheric humidity.

If sand is salvaged from holes in compacted soils after carrying out this test, it shall be sieved, dried and stored again before it is used in further sand replacement tests.

NOTE Generally a storage period, after oven drying, of about 7 days is sufficient for the water 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. Where material is salvaged from holes with a clay fraction, the material should be wet sieved.

4.1.3 Apparatus

4.1.3.1 *Pouring cylinder*, similar in detail to that shown in Figure 1.

4.1.3.2 *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.

4.1.3.3 *Cylindrical, metal calibrating container*, with an internal diameter of (100 ± 2) mm and an internal depth equivalent to the depth being tested of the type illustrated in Figure 3, fitted with a lip at least 50 mm wide and about 5 mm thick surrounding the open end.

4.1.3.4 *Balance*, readable to 1 g, maximum permissible error at least.

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

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

4.1.3.7 *Cylindrical, steel core cutter* (for fine-grained cohesionless soils), meeting the requirements of **4.4.2.1**. One suitable type is illustrated in Figure 4. This cutter shall be kept lightly greased.

4.1.3.8 *Apparatus for water content determination*, as specified in BS EN ISO 17892-1.

4.1.3.9 *Metal tray*, about 300 mm square and about 40 mm deep with a nominal 100 mm diameter hole in the centre.

Figure 1 – Small pouring cylinder for the determination of the density of fine- and medium-grained soils

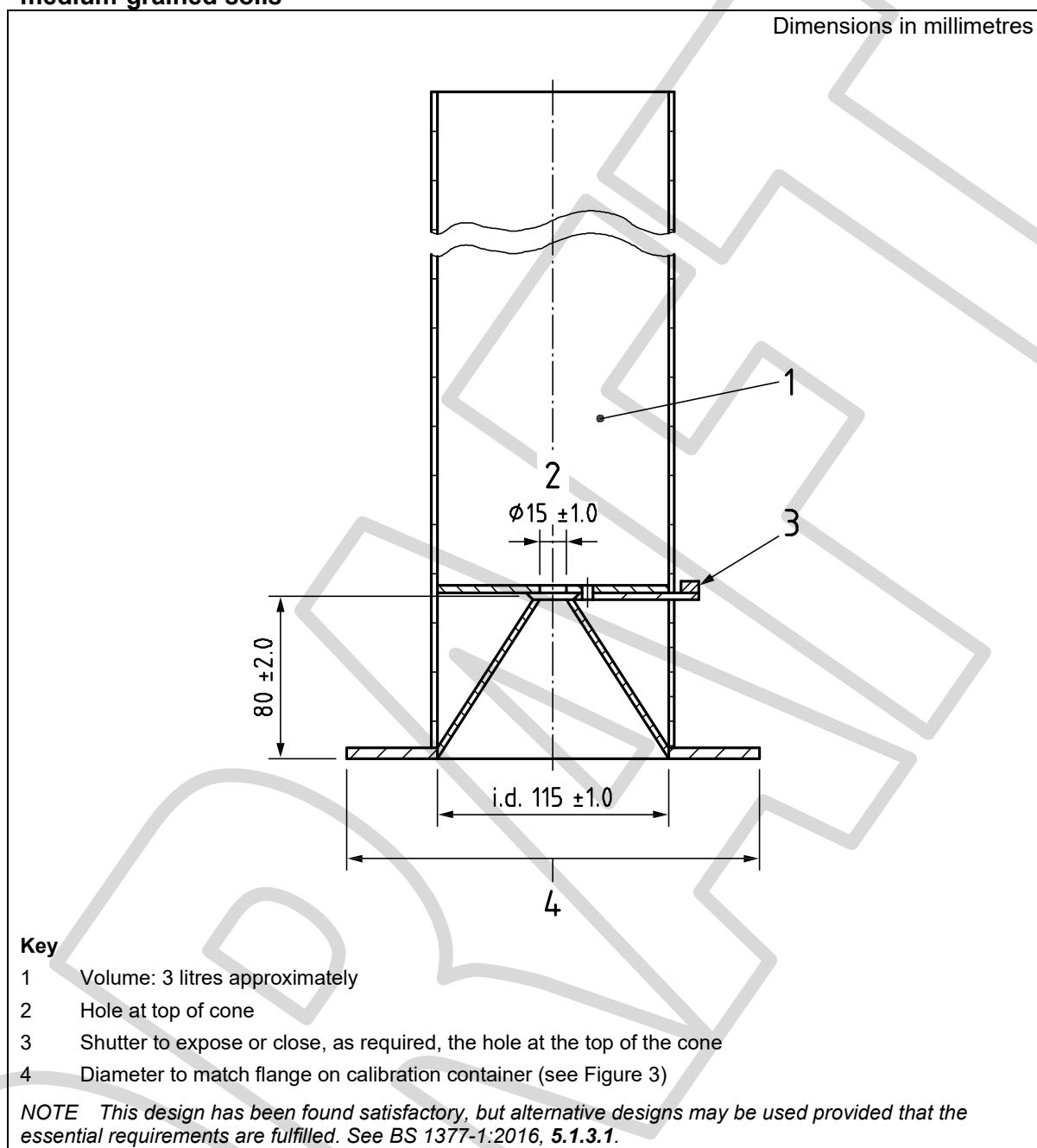


Figure 2 – Scraper for levelling surface of soil

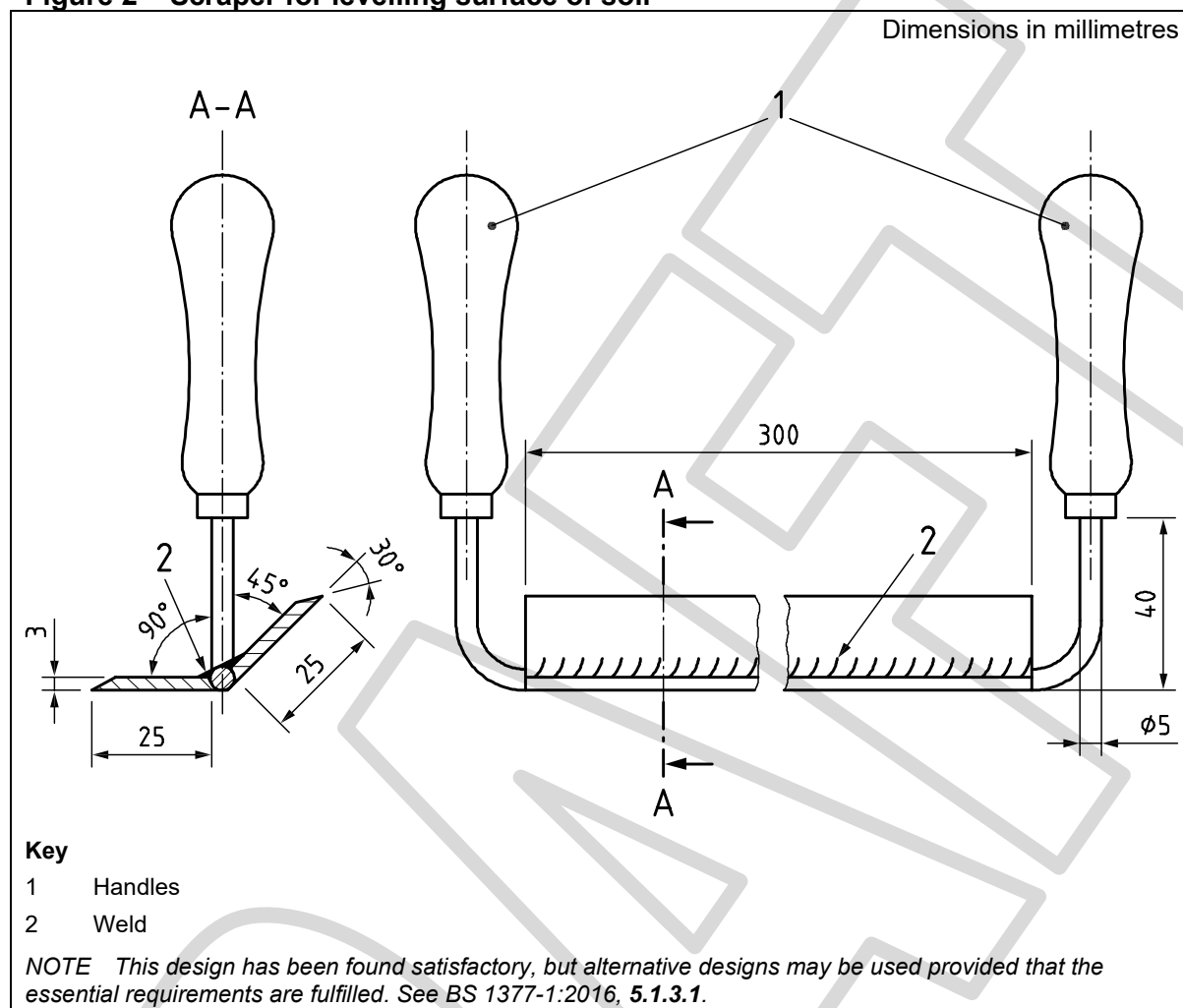


Figure 3 – Calibrating container for use with the small pouring cylinder

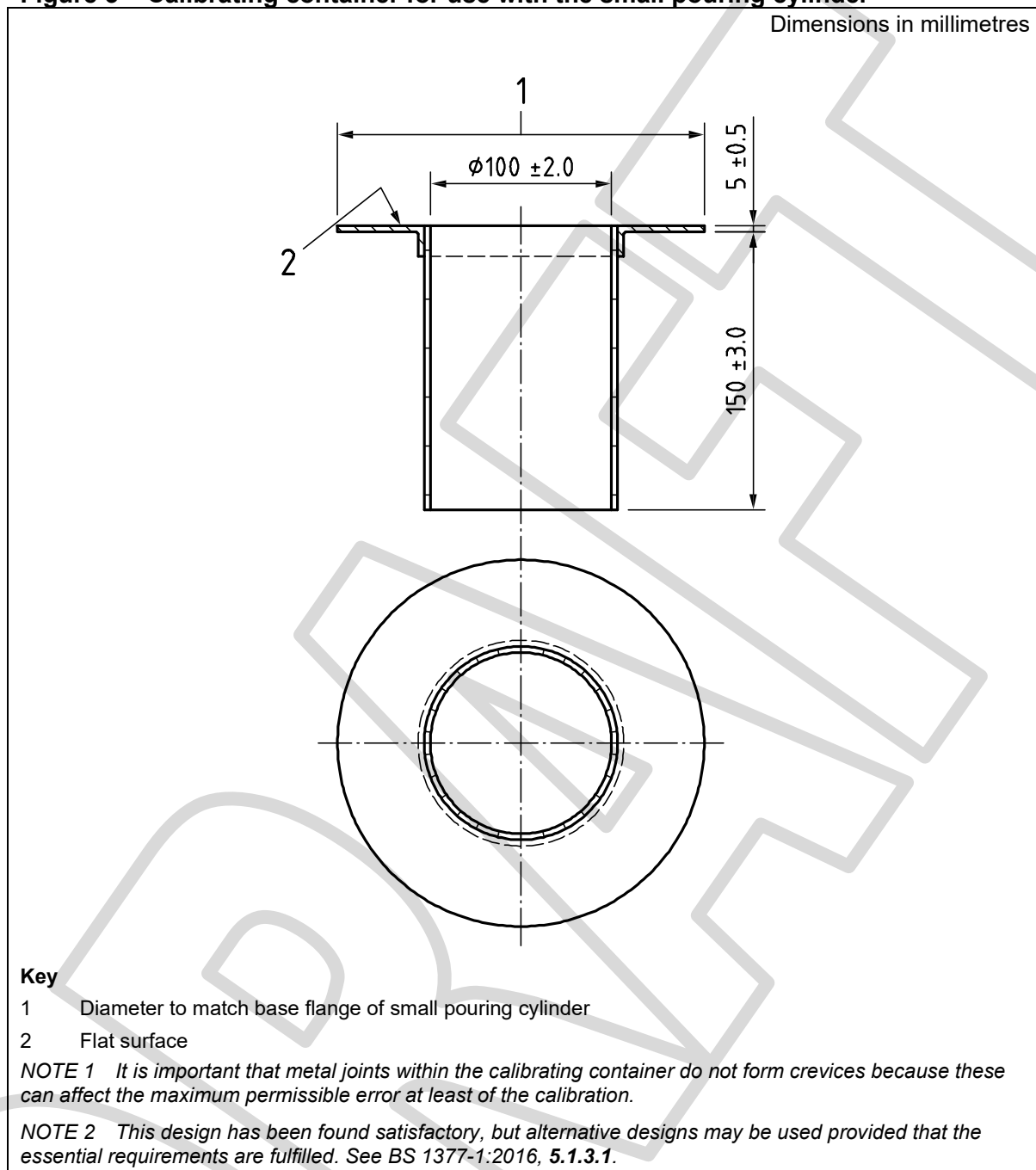
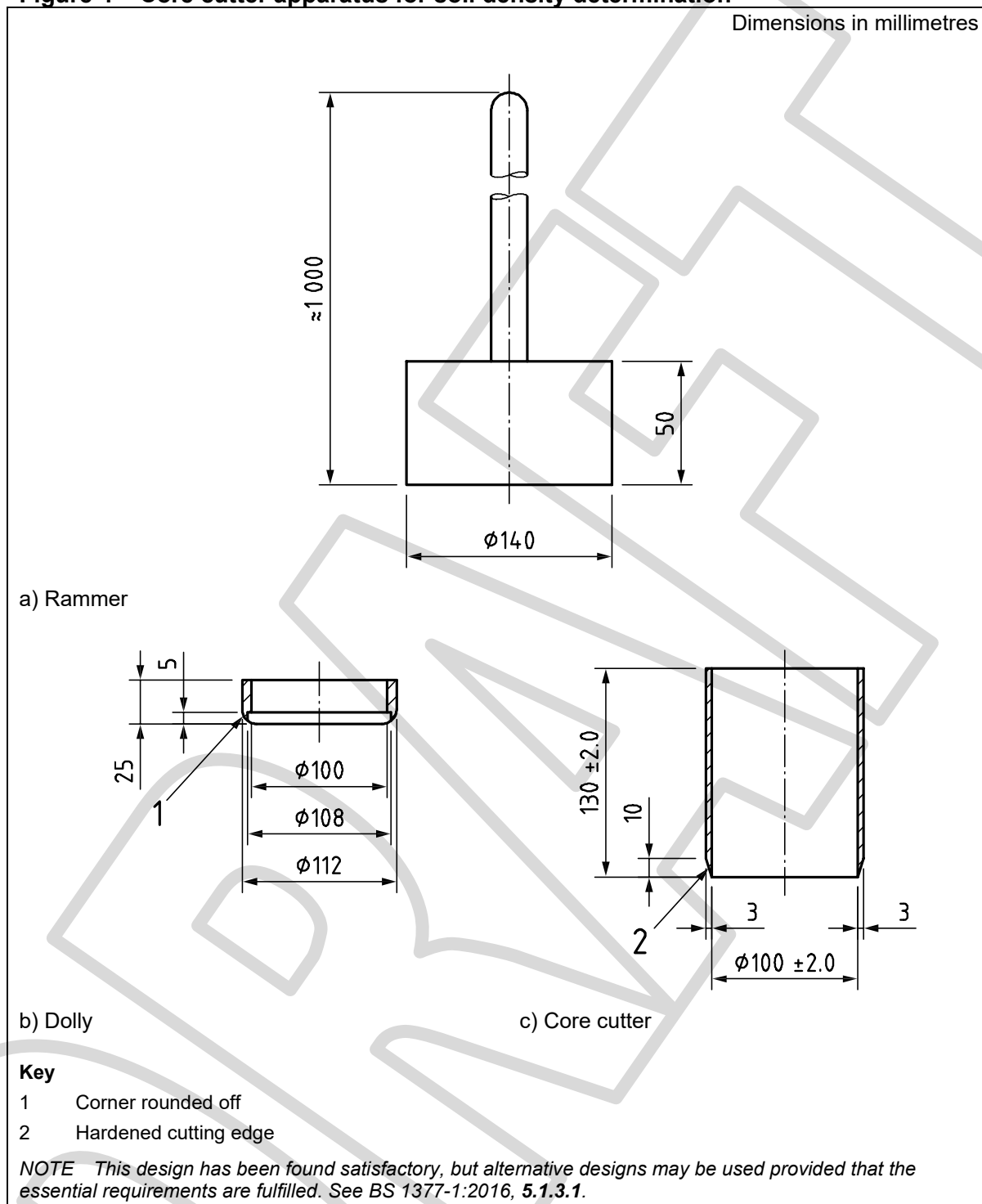


Figure 4 – Core cutter apparatus for soil density determination



4.1.4 Calibrations

4.1.4.1 Determination of the mass of sand in the cone of the pouring cylinder

4.1.4.1.1 Fill the pouring cylinder so that the level of the sand in the cylinder is within about 15 mm of the top. Do not tap or otherwise vibrate during this period. 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.

4.1.4.1.2 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 remove the cylinder.

4.1.4.1.3 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.

4.1.4.1.4 Repeat these measurements at least three times for a total of at least four measurements and calculate the mean value of m_2 .

4.1.4.2 Determination of the bulk density of the sand (ρ_a)

4.1.4.2.1 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, with the upper rim of the container horizontal, achieved, 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 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 at least three times for a total of at least four measurements 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:

$$V = m_6 - m_5$$

4.1.4.2.2 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 **4.1.4.1.1**. Keep the shutter on the pouring cylinder closed during this operation. Open the shutter and allow the sand to run out. Do not tap or otherwise vibrate the pouring cylinder 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.

4.1.4.2.3 Repeat these measurements at least three times for a total of at least four measurements and calculate the mean value of m_3 .

4.1.4.2.4 As variations in atmospheric humidity can affect the water content of the sand, and hence its bulk density, the calibration shall be checked, during each day's work by performing one measurement in accordance with **4.1.4.2.2**. If this is not within the documented range of measurements recorded in **4.1.4.2.3** then **4.1.4.1** and **4.1.4.2.2** shall be repeated.

4.1.4.2.5 To overcome the effects of slight variations in grading and particle shape between batches of sand, each batch shall be sampled and calibrated in accordance with **4.1.4**.

4.1.5 Procedure

4.1.5.1 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.

4.1.5.2 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 cylindrical 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. The hole shall be excavated in such a way that the hole is not enlarged by levering the excavating tool against the side of the hole, as this can result in lower densities being recorded. Collect all the excavated soil from the hole, taking measures to protect the soil from loss of water during the excavation process, 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.

4.1.5.3 If the fine-grained cohesionless soil is in such a condition that, when following the procedure specified in **4.1.5.2**, a cylindrical hole cannot be formed because of the instability of the sides of the hole, the following method shall be used. Without using the metal tray, press the steel core cutter (see Figure 4) evenly and carefully into the soil until its top edge is flush with the levelled surface. Excavate the hole to within about 10 mm of the depth of the core cutter used. 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 use of the core cutter can produce some disturbance in the soil and, where this procedure is necessary, due allowance should be made for a lower standard of the maximum permissible error at least than would normally be expected with the sand replacement method. Where the core cutter used is not the same depth as the calibrating container, the depth of the calibrating container should be adjusted and the determination of the bulk density of the sand repeated.

4.1.5.4 Place a representative sample of the excavated soil in an airtight container and determine its water content (w) as specified in BS EN ISO 17892-1. Alternatively, the whole of the excavated soil shall be dried and its mass (m_d) determined.

4.1.5.5 Place the pouring cylinder, filled to the constant mass (m_1) as specified in **4.1.4.1.1** 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 cylinder and determine its mass (m_4) to the nearest 1 g.

*NOTE The mass of sand remaining in the cylinder ought to be comparable to that for the mass retained in **4.1.4.2.2**. Where there is a difference of 20% or more, the test should be repeated to confirm the validity.*

4.1.6 Calculations and expression of results

NOTE See Figure A.1 in Annex A.

4.1.6.1 General

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 before pouring into calibrating container (in g).

Calculate the dry 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 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 mean mass of cylinder and sand after pouring into calibrating container (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 soil excavated (in g);

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

ρ_a is the dry 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 water content of the soil (in %).

or

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

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).

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

4.1.6.2 Degree of compaction

When required, calculate the degree of compaction, D_c (in %), from the equation:

$$D_c = \frac{\rho_d}{\rho_{mdd}} \times 100$$

where:

- D_c is the degree of compaction (in %) to the nearest 0.1%;
- ρ_{mdd} is the measured maximum dry density, as measured in accordance with BS 1377-2 (in Mg/m³), to the nearest 0.01 Mg/m³.

4.1.6.3 Air voids

When required, calculate the air voids, V_s , from the equation:

$$1 - \left(\frac{\rho_d}{\rho_s} \times \left(1 + \left(\frac{w}{100\rho_w} \times \rho_s \right) \right) \right)$$

where:

- ρ_s is the particle density as measured in accordance with BS 1377-2 (in Mg/m³), to the nearest 0.01 Mg/m³;
- ρ_w is the density of water (in Mg/m³), assumed equal to 1;
- V_s is the volume of air voids in the soil, expressed as a percentage of the total volume of the soil, to the nearest 0.1%.

4.1.7 Test report

The test report shall affirm that the test was carried out in accordance with this part of BS 1377 and shall contain the following information.

- The method of test used.
- The in-situ bulk and dry densities of the soil (in Mg/m³) to the nearest 0.01 Mg/m³.
- The water content, as a percentage to one decimal place.
- Where applicable, the degree of compaction of the soil (in %) to the nearest 0.1%.
- Where applicable, the air voids of the soil (in %) to the nearest 0.1%.
- The information required by BS 1377-1:2016, Clause 10.
- Any deviations from this test method.

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

4.2.1 Principle

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 4.1 difficult to perform. It is an alternative to the 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 1).

NOTE 1 If for any reason it is necessary to excavate holes other than 250 mm the calibrating container should be replaced by one with the equivalent depth as the hole excavated, or its effective depth reduced to that of the hole excavated.

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.

NOTE 2 In such cases the test described in 4.3 should be selected. The test described in 4.3 should also be used when very coarse-grained material is present.

4.2.2 Materials

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 water content to reach equilibrium with atmospheric humidity.

If sand is salvaged from holes in compacted soils after carrying out this test, it shall be sieved, dried and stored again before it is used in further sand replacement tests.

NOTE Generally a storage period, after oven drying, of about 7 days is sufficient for the water 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. Where material is salvaged from holes with a clay fraction the material should be wet sieved.

4.2.3 Apparatus

4.2.3.1 *Pouring cylinder*, similar in detail to that shown in Figure 5.

4.2.3.2 *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.

4.2.3.3 *Cylindrical, metal calibrating container*, with an internal diameter of (200 ± 5) mm and an internal depth of (250 ± 5) mm (see 4.2.1, Note 1), of the type shown in Figure 6, fitted with a lip at least 75 mm wide and about (5 ± 2) mm thick surrounding the open end.

4.2.3.4 *Balance*, readable to 10 g, maximum permissible error at least.

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. The same constant initial mass as is used in calibrating the apparatus should be used for each density measurement.

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

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

4.2.3.7 *Apparatus for water content determination*, as specified in BS EN ISO 17892-1.

4.2.3.8 *Metal tray*, about 500 mm square and about 50 mm deep with a nominal 200 mm diameter hole in the centre.

Figure 5 – Large pouring cylinder for the determination of the density of fine-, medium- and coarse-grained soils

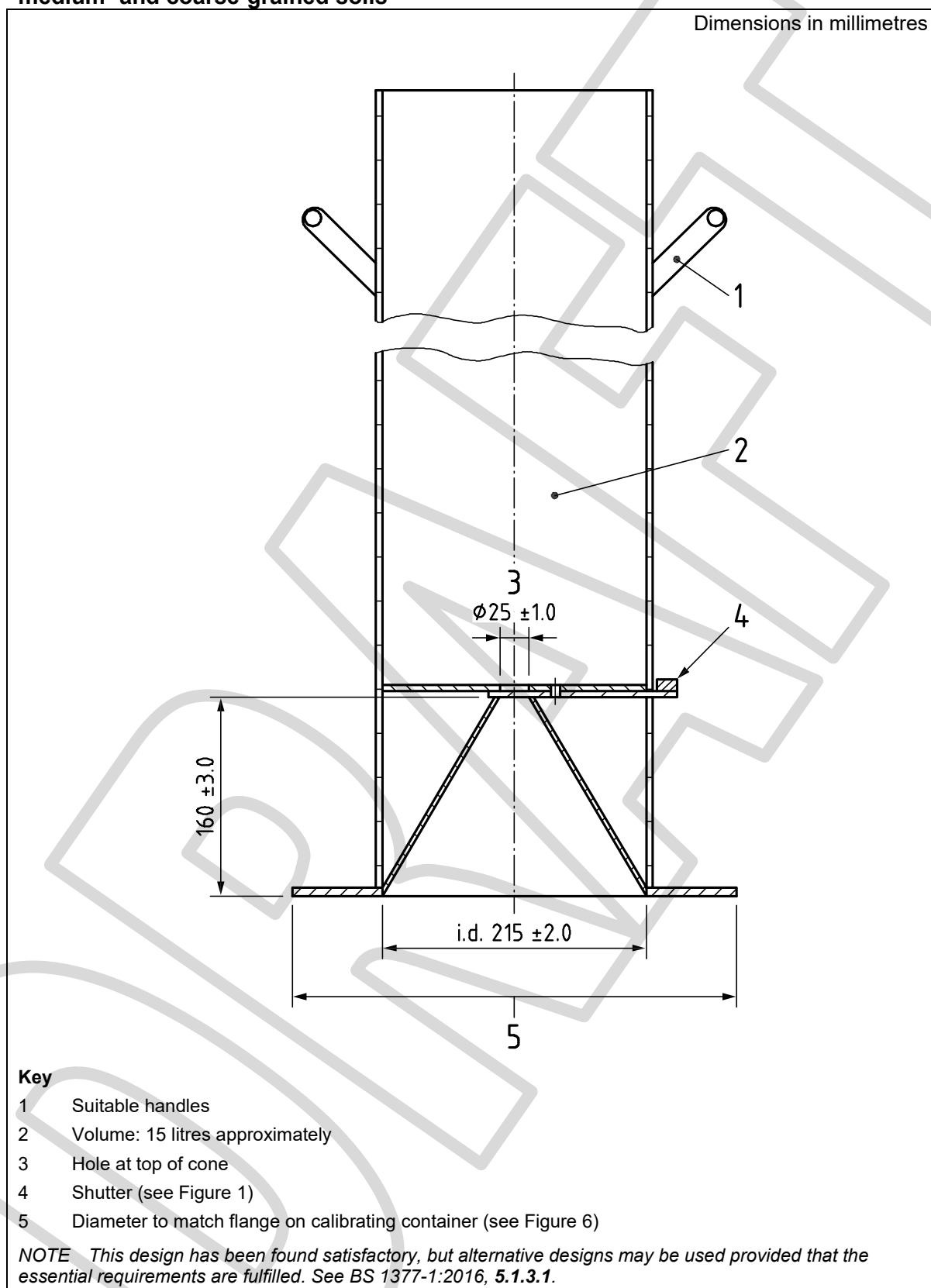
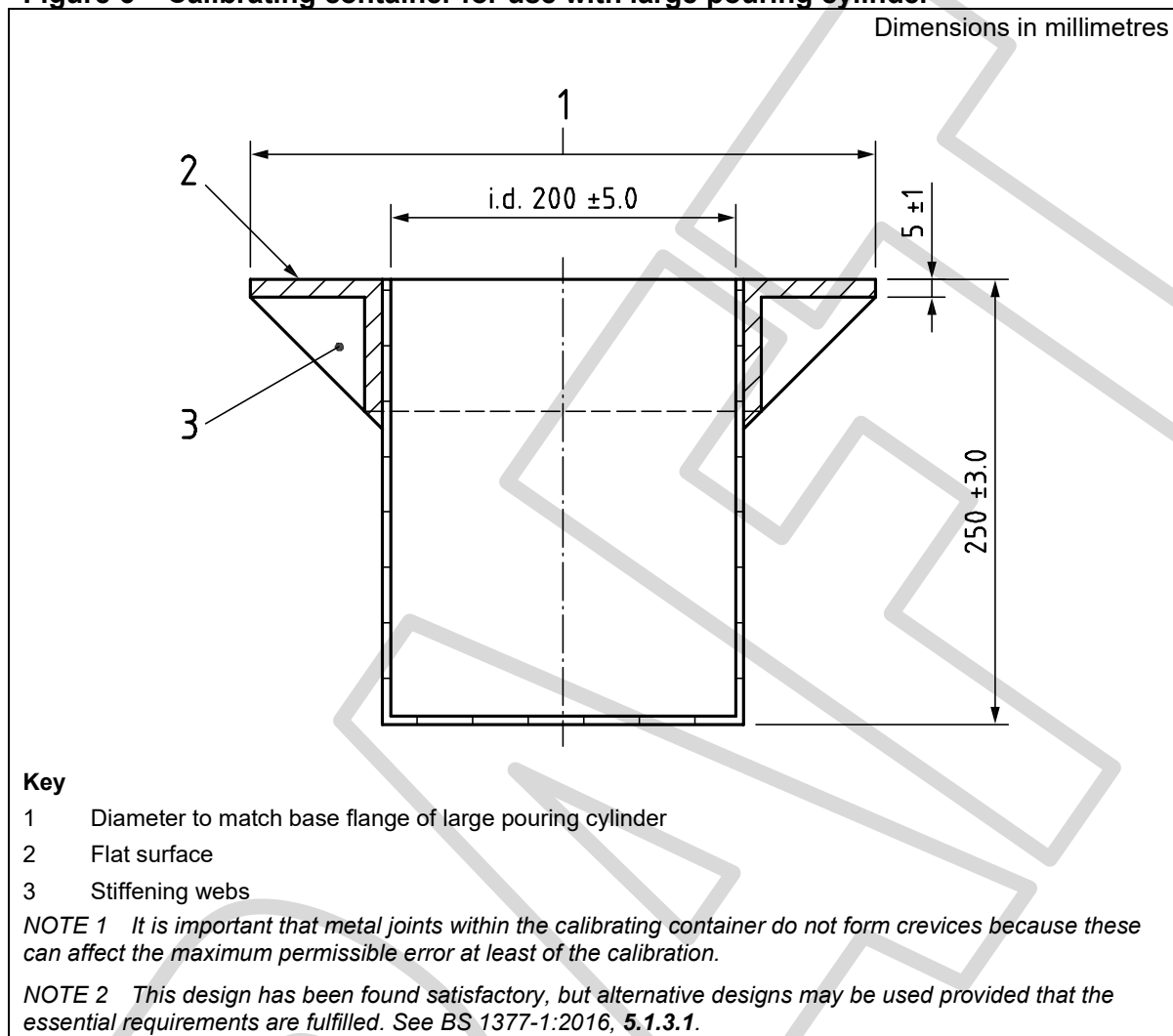


Figure 6 – Calibrating container for use with large pouring cylinder



4.2.4 Calibrations

4.2.4.1 Determination of the mass of sand in the cone of the pouring cylinder

4.2.4.1.1 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 4.2.3.4). Use a sufficient amount of sand so that about 4 kg to 5 kg of sand is left in the pouring cylinder after the test is completed. 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.

4.2.4.1.2 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 remove the cylinder.

4.2.4.1.3 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.

4.2.4.1.4 Repeat these measurements at least three times for a total of at least four measurements and calculate the mean value of m_2 .

4.2.4.2 Determination of the bulk density of the sand (ρ_a)

4.2.4.2.1 Determine the internal volume, V (in mL), of the calibrating container by the mass of water required to fill it.

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, with the upper rim horizontal, achieved, 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 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 at least three times for a total of at least four measurements 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 equation:

$$V = m_5 - m_6$$

4.2.4.2.2 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 **4.2.4.1.1**. 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.

4.2.4.2.3 Repeat the measurement at least three times for a total of at least four measurements and calculate the mean value of m_3 .

4.2.4.2.4 As variations in atmospheric humidity can affect the water content of the sand, and hence its bulk density, the calibration shall be checked, during each day's work by performing one measurement in accordance with **4.2.4.2.2**. If this is not within the documented range of measurements recorded in **4.2.4.2.3** then **4.2.4.1** and **4.2.4.2.2** shall be repeated.

4.2.4.2.5 To overcome the effects of slight variations in grading and particle shape between batches of sand, each batch shall be sampled and calibrated in accordance with **4.2.4**.

4.2.5 Procedure

4.2.5.1 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.

4.2.5.2 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 cylindrical hole, approximately 200 mm in diameter and the depth of the layer to be tested up to a maximum of 250 mm (see Note 1 to **4.2.1**). Do not leave loose material in the hole and do not distort the immediate surround to the hole. The hole shall be excavated in such a way that the hole is not enlarged by levering the excavating tool against the side of the hole, as this can result in lower densities being recorded. Collect the excavated soil from the hole, taking measures to protect the soil from loss of water during the excavation process, 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.

4.2.5.3 Place a representative sample of the excavated soil in an airtight container and determine its water content (w) as specified in BS EN ISO 17892-1.

4.2.5.4 Place the pouring cylinder filled with the constant mass of sand (m_1) as specified in **4.2.4.1.1** 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.

NOTE The mass of sand remaining in the cylinder ought to be comparable to that for the mass retained in **4.2.4.2.2**. Where there is a difference of 20% or more, the test should be repeated to confirm the validity.

4.2.6 Calculations and expression of results

NOTE See Figure A.1 in Annex A.

4.2.6.1 General

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 before pouring into calibrating container (in g).

Calculate the dry density of the sand, ρ_a (in Mg/m³), 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 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 mean mass of cylinder and sand after pouring into calibrating container (in g).

Calculate the bulk density of the soil, ρ (in Mg/m³), from the equation:

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

where:

- m_w is the 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/m³).

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

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

where:

- w is the water content of the soil (in %).

4.2.6.2 Degree of compaction

When required, calculate the degree of compaction, D_c (in %), from the equation:

$$D_c = \frac{\rho_d}{\rho_{mdd}} \times 100$$

where:

- D_c is the degree of compaction (in %) to the nearest 0.1%;
 ρ_{mdd} is the measured maximum dry density, as measured in accordance with BS 1377-2 (in Mg/m³), to the nearest 0.01 Mg/m³.

4.2.6.3 Air voids

When required, calculate the air voids, V_s , from the equation:

$$1 - \left(\frac{\rho_d}{\rho_s} \times \left(1 + \left(\frac{w}{100\rho_w} \times \rho_s \right) \right) \right)$$

where:

- ρ_s is the particle density as measured in accordance with BS 1377-2 (in Mg/m³), to the nearest 0.01 Mg/m³;
 ρ_w is the density of water (in Mg/m³), assumed equal to 1;
 V_s is the volume of air voids in the soil, expressed as a percentage of the total volume of the soil, to the nearest 0.1%.

4.2.7 Test report

The test report shall affirm that the test was carried out in accordance with this part of BS 1377 and shall contain the following information.

- The method of test used.
- The in-situ bulk and dry densities of the soil (in Mg/m³) to the nearest 0.01 Mg/m³.
- The water content, as a percentage, to one decimal place.
- Where applicable, the degree of compaction of the soil (in %) to the nearest 0.1%.
- Where applicable, the air voids of the soil (in %) to the nearest 0.1%.

- f) The information required by BS 1377-1:2016, Clause **10**.
- g) Any deviations from this test method.

4.3 Water replacement method suitable for coarse-grained soils

4.3.1 Principle

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:

- a) for the total material within the hole excavated (see **4.3.5.1**):
 - 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; and/or
- b) for the proportion of the soil finer than a specified size, normally not less than coarse gravel (see **4.3.5.2**).

4.3.2 Materials

4.3.2.1 Flexible plastics sheet, that moulds to the shape of the hole yet is sufficiently thick not to be punctured by angular material.

NOTE 1 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.

NOTE 2 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.

4.3.2.2 Plaster of Paris.

4.3.2.3 Clean water.

4.3.3 Apparatus

COMMENTARY ON 4.3.3

The following list of apparatus applies to both procedures in **4.3.5** (see **4.3.5.1** and **4.3.5.2** respectively). The number and size of the items varies with the type of material present and the size of the hole to be excavated.

4.3.3.1 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 for the rigidity of the ring it should be fitted with an external flange.

4.3.3.2 Rigid straightedge, sufficiently long to level the area of the density ring to be used.

4.3.3.3 Spirit level, of suitable length to use with the straightedge in order to level the density ring.

4.3.3.4 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.

4.3.3.5 Calibrated water containers (see 4.3.4.1), 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.

4.3.3.6 Balance or balances, readable to 100 g, maximum permissible error at least.

4.3.3.7 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 water content open containers are satisfactory.

4.3.3.8 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 is encountered in the excavation, it is advisable to provide mechanical excavation and lifting equipment.

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

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

4.3.3.11 Apparatus for water content determination, as specified in BS EN ISO 17892-1.

4.3.3.12 Test sieves, if required.

4.3.3.13 Apparatus for dry density determination, as specified in BS EN ISO 17892-2, if required.

4.3.4 Calibration

4.3.4.1 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.

4.3.5 Procedure

COMMENTARY ON 4.3.5

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

4.3.5.1 Procedure for determining the density of the total material within the hole excavated

4.3.5.1.1 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.

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

4.3.5.1.3 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.

4.3.5.1.4 Bed the density ring on the plaster paste in such a way 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.

4.3.5.1.5 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.

4.3.5.1.6 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, checking that it closely conforms to the surface of the soil and the inside of the ring. Replace the datum bar and locked pointer.

4.3.5.1.7 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, check 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.

4.3.5.1.8 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 **4.3.5.1.6** and **4.3.5.1.7**.

4.3.5.1.9 Excavate with the digging tools a hole within the density ring as nearly cylindrical as practicable, whilst not displacing the ring or the plaster filling. With non-cohesive soil, particularly when wet, the sides of the excavation shall be inclined to prevent slumping. 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 can 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.

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

4.3.5.1.10 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).

4.3.5.1.11 When water or absorbent material is present in all or part of the excavated soil and rock, which can affect the dry density determination, determine the water content as specified in BS EN ISO 17892-1.

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

4.3.5.1.12 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, determining that there is sufficient material to conform to the wall and base of the hole. Replace the datum bar and locked pointer.

4.3.5.1.13 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 **4.3.5.1.7**). 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 might 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.

4.3.5.1.14 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 stages **4.3.5.1.12** and **4.3.5.1.13**.

4.3.5.1.15 Dismantle the apparatus and backfill the hole.

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

4.3.5.2.1 Proceed as specified in **4.3.5.1.1** to **4.3.5.1.9**.

4.3.5.2.2 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.

4.3.5.2.3 Determine the water content (w_p) of the proportion remaining represented by the material finer than the specified size, as specified in BS EN ISO 17892-1.

4.3.5.2.4 Determine the volume of the proportion of the soil finer than the specified size by one of the following methods.

- a) Proceed as specified in **4.3.5.1.12** and **4.3.5.1.13**, 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). Avoid puncturing the plastics sheet when replacing the oversize material.
- a) Complete **4.3.5.1.12** and **4.3.5.1.13** to determine the total volume of the hole. Determine the volume of the oversize material (v_s), for deduction, either by fluid displacement as specified in BS EN ISO 17892-2 or by calculation from the mass and apparent density of the material.

4.3.5.2.5 Proceed as specified in **4.3.5.1.14** and **4.3.5.1.15**.

4.3.6 Calculations and expression of results

NOTE See Figure A.2 in Annex A.