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BS 1377-2 — Methods of test for soils for civil engineering purposes

Part 2: Classification tests and determination of geotechnical properties

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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 31 March 2022. It was prepared by Subcommittee B/526/3, *Ground investigation and ground testing*, under the authority of Technical Committee B/526, *Geotechnics*. A list of organizations represented on these committees can be obtained on request to their committee manager.

Supersession

This part of BS 1377 supersedes [BS 1377-2:1990](#), [BS 1377-4:1990](#), [BS 1377-5:1990](#), [BS 1377-6:1990](#) and [BS 1377-7:1990](#), which are withdrawn.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 (this document)*
- Part 3: *Chemical and electrochemical tests*
- Part 9: *In-situ tests*

[BS 1377-1](#) provides general information relating to the tests, common calibration and specification requirements and general requirements for testing laboratories and fieldwork. This information is required for tests for which no BS EN ISO standard is available. [BS EN ISO 17892](#) standards include specific requirements for sample preparation, equipment maintenance and calibration for each test which take precedence.

[BS 1377-3](#) describes test methods for determining the amount of chemical substances in soil and groundwater.

This part of BS 1377 includes reference to BS EN ISO 17892 (all parts) for the relevant test and provides non-contradictory complementary information on the test methods.

Information about this document

This publication can be withdrawn, revised, partially superseded or superseded. Information regarding the status of this publication can be found in the Standards Catalogue on the BSI website at bsigroup.com/standards, or by contacting the Customer Services team.

Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

This part of BS 1377 consolidates the tests included in [BS 1377-2:1990](#), [BS 1377-4:1990](#), [BS 1377-5:1990](#), [BS 1377-6:1990](#) and [BS 1377-7:1990](#) into one document as follows:

- [BS 1377-2:1990](#), Part 2: Classification tests
- [BS 1377-4:1990](#), Part 4: Compaction-related tests
- [BS 1377-5:1990](#), Part 5: Compressibility, permeability and durability tests
- [BS 1377-6:1990](#), Part 6: Consolidation and permeability tests in hydraulic cells and with pore pressure measurement

- [BS 1377-7:1990](#), Part 7: Shear strength tests (total stress)
- [BS 1377-8:1990](#), Part 8: Shear strength tests (effective stress)

The following tests that were included in BS 1377:1990 have been withdrawn:

[BS 1377-2:1990](#), Clause 6.3 Volumetric shrinkage test (definitive method)

[BS 1377-2:1990](#), Clause 6.4 Volumetric shrinkage test (subsidiary method)

[BS 1377-7:1990](#), Clause 9 Multistage unconsolidated undrained triaxial test

Presentational conventions

The provisions of this standard 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 specifies methods of test for the classification of soil and for the determination of geotechnical properties of soils in the laboratory.

Most of these tests are required for the determination of geotechnical behaviour of soils in accordance with BS EN 1997 (all parts) and [BS 5930](#).

This part of BS 1377 includes:

- a) common laboratory tests required for the classification of soils;
- b) determination of compaction characteristics of soils for earthworks, permeability, compressibility and erodibility; and
- c) determination of shear strength of soils in terms of both total and effective stresses.

NOTE Where EN ISO test methods are available, these are normatively referenced and commentary provided to assist in their application.

[BS 1377-1](#) specifies requirements that include details of sample preparation and equipment calibration that are relevant to tests described in this part of BS 1377, unless otherwise detailed in the referenced [BS EN ISO 17892](#) standard.

2 Normative references

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

[BS 812-124:2009](#), *Testing aggregates – Part 124: Method for determination of frost heave*

BS EN ISO 17892-1:2014, *Geotechnical investigation and testing – Laboratory testing of soil – Part 1: Determination of water content*

BS EN ISO 17892-2:2014, *Geotechnical investigation and testing – Laboratory testing of soil – Part 2: Determination of bulk density*

BS EN ISO 17892-3, *Geotechnical investigation and testing – Laboratory testing of soil – Part 3: Determination of particle density*

[BS EN ISO 17892-4:2016](#), *Geotechnical investigation and testing – Laboratory testing of soil – Part 4: Determination of particle size distribution*

[BS EN ISO 17892-5:2017](#), *Geotechnical investigation and testing – Laboratory testing of soil – Part 5: Incremental loading oedometer test*

[BS EN ISO 17892-7:2018](#), *Geotechnical investigation and testing – Laboratory testing of soil – Part 7: Unconfined compression test*

[BS EN ISO 17892-8:2018](#), *Geotechnical investigation and testing – Laboratory testing of soil – Part 8: Unconsolidated undrained triaxial test*

BS EN ISO 17892-9:2018, *Geotechnical investigation and testing – Laboratory testing of soil – Part 9: Consolidated triaxial compression tests on water saturated soils*

[BS EN ISO 17892-10:2018](#), *Geotechnical investigation and testing – Laboratory testing of soil – Part 10: Direct shear tests*

[BS EN ISO 17892-11](#), *Geotechnical investigation and testing – Laboratory testing of soil – Part 11: Permeability tests*

BS EN ISO 17892-12:2018+A1:2021, *Geotechnical investigation and testing – Laboratory testing of soil – Part 12: Determination of liquid and plastic limits*

3 Terms and definitions

For the purposes of this part of BS 1377, the terms and definitions given in [BS 1377-1](#) apply.

4 Determination of water content

COMMENTARY ON CLAUSE 4

Water is present in most naturally occurring soils. The amount of water, expressed as a proportion by mass of the dry solid particles, previously known as the moisture content, has a profound effect on soil behaviour. In this context, a soil is “dry” when no further water can be removed at a temperature not exceeding 110 °C.

Water content is required as a guide to classification of natural soils and as a control criterion in recompacted soils and is measured on samples used for most field and laboratory tests. The oven-drying method is the definitive procedure used in standard laboratory practice.

In some situations, e.g. in the field control of earthworks, a rapid method of measurement of water content might be required and a number of rapid methods are available, such as the sand bath method, the microwave oven-drying method and the calcium carbide method. These methods are not necessarily appropriate for all soil types and when used on a particular soil, the oven-drying method could also be used as a check.

A procedure for determining the water content at full saturation of chalk is described in [4.2](#).

4.1 Oven-drying method

Water content shall be determined in accordance with BS EN ISO 17892-1.

NOTE 1 This method covers the determination of the water content of a specimen of soil as a percentage of its dry mass.

NOTE 2 A microwave oven should not be used for the determination of water content by the definitive method for soils containing clay or organic matter or some other minerals due to the difficulty maintaining the temperature of the soil below 110 °C before all the water is removed. Higher temperatures than this can alter the chemical composition of some minerals, including some clay.

NOTE 3 Certain soils contain gypsum, which on heating, loses its water of crystallization. The water content determined by this method is affected by approximately 0.2% for each 1% of gypsum. If it is suspected that gypsum is present in the soil the water content samples should be dried at no more than 50 °C and possibly for a longer time. The presence of gypsum might be in the field description or visible in the sample and can be identified by heating a small quantity of soil on a metal plate. Grains of gypsum turn white within a few minutes, whereas most other mineral grains remain unaltered.

NOTE 4 If the water content is to be related to the Atterberg limits, e.g. for determining the liquidity or consistency index, and the soil contains material retained on a 425 µm sieve, the measured water content, w (%), can be corrected to give the equivalent water content, $w < 0.425$ (%), of the fraction passing the 425 µm sieve, as described in BS EN ISO 17892-12:2018+A1:2021, Annex B.

NOTE 5 For further information on testing saline samples refer to BS EN ISO 17892-1:2014, Annex C.

4.2 Method for saturation water content of chalk

4.2.1 General

COMMENTARY ON 4.2.1

The saturation water content of intact chalk lumps can be used, together with dry density or chalk crushing value, to classify chalk in relation to its behaviour as a freshly placed fill material. This test is based on the determination of the dry density of the chalk lump, using the “immersion in water method”, and the calculation from it of the potential water content at saturation, assuming a value of 2.70 Mg/m³ for the particle density of the chalk solids.

The dry density of the chalk lump shall be determined in accordance with the immersion in fluid method in BS EN ISO 17892-2:2014 and the saturation water content calculated as described in [4.2.2](#) to [4.2.5](#).

4.2.2 Apparatus

The apparatus for determination of the dry density shall be as given in BS EN ISO 17892-2:2014, [4.2](#).

4.2.3 Procedure

The procedure for preparation of the equipment and performance of the test shall be in accordance with BS EN ISO 17892-2:2014, [5.2](#).

4.2.4 Calculations and expression of results

Calculate the volume, bulk and dry density of the specimen in accordance with the formulas in BS EN ISO 17892-2:2014, Clause [6](#).

Calculate the saturation water content, w_s (%), from the formula:

$$w_s = 100 \left(\frac{1}{\rho_d} - \frac{1}{2.7} \right)$$

where:

2.7 is the particle density of the chalk (in Mg/m³);

ρ_d is the dry density of the specimen (in Mg/m³).

Express the saturation water content to 0.1%.

4.2.5 Test report

The test report shall affirm that the test was carried out in accordance with BS EN ISO 17892-2:2014 and calculated in accordance with [4.2](#). The test report shall contain the following:

- the information required by BS EN ISO 17892-2:2014, Clause [7](#); and
- the saturation water content.

5 Determination of liquid limit

COMMENTARY ON CLAUSE 5

The liquid limit is the empirically established water content at which a soil passes from the liquid state to the plastic state. It provides a means of classifying a soil, especially when the plastic limit (see [Clause 6](#)) is also known.

Two types of test are specified. The primary method is the cone penetrometer method as it is a static test, is easier to perform and gives more reproducible results. The second method is the “Casagrande Test”. This test introduces dynamic effects and is susceptible to discrepancies between operators.

For both types of test an alternative rapid “one-point” procedure is given, which might give less accurate results. It may be used where the liquid limit of the material is well understood and for which robust correlation factors have been established.

5.1 General

COMMENTARY ON 5.1

This method covers the determination of the liquid limit of a sample of soil in its natural state, or of a sample of soil from which material retained on a 425 μm sieve has been removed.

Whenever possible, the tests shall be carried out on soil from its natural state. The soil shall not be dried as this might affect the results. For all these tests, the sample preparation shall be as specified in [BS EN ISO 17892-12](#).

NOTE 1 [BS EN ISO 17892-12](#) requires the fraction of soil retained on a 0.4 mm sieve or the nearest sieve to be removed prior to the liquid and plastic limit tests. In this British Standard it is assumed that the material coarser than 0.425 μm has been removed, in accordance with normal practice.

NOTE 2 The method using the cone penetrometer (see [5.2](#)) is preferred to the Casagrande apparatus (see [5.4](#)), as the test is both easier to carry out and is capable of giving more reproducible results. The cone penetrometer apparatus is easier to maintain in correct adjustment and the test procedure is less dependent on the judgement of the operator. The results obtained with the cone penetrometer might differ slightly from those with the Casagrande apparatus, but in most cases up to a liquid limit of 100 these differences are not significant and are less than the normal variations likely to be obtained using the Casagrande apparatus.

5.2 Cone penetrometer method (definitive method)

The liquid limit by the cone penetrometer method shall be determined using the preferred four-point method in accordance with BS EN ISO 17892-12:2018+A1:2021.

5.3 One-point cone penetrometer method

COMMENTARY ON 5.3

This method enables the liquid limit of a soil sample to be determined from a specimen at a single water content. This method enables a result to be obtained when only a small amount of soil is available. The one-point method using the cone penetrometer is likely to give results that are less reliable than those obtained from the four-point method and is therefore suitable only where a possibly less accurate result is acceptable.

5.3.1 General

The liquid limit using the one-point cone penetrometer method shall be carried out in accordance with [BS EN ISO 17892-12](#).

NOTE The one-point method might be appropriate in soils whose plasticity is well understood and for which robust correlation factors have been established.

If it is suspected that the liquid limit is higher than approximately 100%, the definitive method specified in [5.2](#) shall be followed using the appropriate size of sample.

5.3.2 Calculations and expression of results

Calculate the average water content and average cone penetration of the test specimen in accordance with BS EN ISO 17892-12:2018+A1:2021, **6.2.4**.

Obtain the factor corresponding to the cone penetration and the water content range from the correlation for the material.

Calculate the liquid limit from the formula:

$$\text{liquid limit} = \text{water content} \times \text{factor (y)}$$

and express the result to the nearest whole number.

NOTE 1 Where a correlation specific to the material is not available, the calculations below may be used to obtain the correction factor for values of cone penetration between 17 mm and 23 mm.

For water contents above 50%:

$$y = -0.05148862462 \cdot x^{3/2} + 0.6762352454 \cdot x - 3.111248446 x^{1/2} + 5.99547486$$

For water contents from 35% to 50%:

$$y = 0.06657770957 \cdot x^{3/2} - 0.8635642783 \cdot x + 3.568302692 x^{1/2} - 3.640579582$$

For water contents below 35%:

$$y = 0.1455303844 \cdot x^{3/2} - 1.933088964 x + 8.421347111 x^{1/2} - 11.0173682$$

where:

x is the cone penetration (in mm);

y is the factor.

NOTE 2 Use of these formulas removes the need to interpolate between values. Table 1 provides a simplified summary of the data from Clayton and Jukes [1].

Table 1 — Factors for one-point cone penetrometer liquid limit test

Cone penetration mm	Factors for water content ranges		
	below 35%	35% to 50%	above 50%
17	1.042	1.058	1.055
18	1.030	1.039	1.036
19	1.015	1.020	1.018
20	1.000	1.000	1.000
21	0.984	0.984	0.984
22	0.971	0.968	0.967
23	0.961	0.954	0.949
plasticity	low	intermediate	high

SOURCE: Clayton and Jukes, 1978, [1]

5.3.3 Test report

The test report shall be in accordance with [BS EN ISO 17892-12](#) and, where appropriate, this British Standard.

5.4 Casagrande apparatus method

COMMENTARY ON 5.4

This is an alternative method for the determination of the liquid limit of a sample of natural soil, or of a sample of soil from which material retained on a 425 µm sieve has been removed.

The Casagrande apparatus specified in BS EN ISO 17892-12:2018+A1:2021 differs from that previously specified in BS 1377-2. The results might differ from those obtained using the previous apparatus and the cone penetration method is preferred.

The liquid limit using the Casagrande apparatus method shall be carried out in accordance with BS EN ISO 17892-12:2018+A1:2021.

NOTE The method using the Casagrande apparatus was the original procedure for determining the liquid limit but experience has shown that it is difficult to maintain the apparatus in accordance with this British Standard and the results are subject to the judgement of the operator. Results obtained using the Casagrande apparatus might differ slightly from those obtained from the cone method up to a liquid limit of 100 but in most cases these differences are not significant and are less than the normal variations likely to be obtained using the Casagrande apparatus. For liquid limits above 100 the cone method appears to give lower values. For these reasons the method using the cone penetrometer is preferred, but provided that the Casagrande apparatus is correctly maintained and the test procedure is strictly adhered to, satisfactory results can be obtained.

5.5 One-point Casagrande method

5.5.1 General

COMMENTARY ON 5.5.1

This method enables the liquid limit of a soil sample to be determined from a specimen at a single water content and enables a result to be obtained when only a small amount of soil is available.

This method shall be used instead of the four-point method only when the plasticity is understood and for which robust correlation factors have been established. The liquid limit using the one-point Casagrande method shall be carried out in accordance with [BS EN ISO 17892-12](#).

NOTE The one-point method using the Casagrande apparatus is likely to give results that are less reliable than those obtained from the four-point method in [5.4](#) and is suitable only where a less accurate result is acceptable.

5.5.2 Calculations and expression of results

Calculate the average water content of the specimen and the average number of rotations (bumps) of the repeated determinations, as specified in BS EN ISO 17892-12:2018+A1:2021, **6.3.4**.

Calculate the liquid limit from the correlation for that material using the formula:

$$\text{liquid limit} = \text{water content} \times \text{factor}$$

Express the result to the nearest whole percentage number.

5.5.3 Test report

The test report shall be in accordance with [BS EN ISO 17892-12](#) and, where appropriate, this British Standard.

6 Determination of plastic limit and plasticity index

COMMENTARY ON CLAUSE 6

The plastic limit is the empirically established water content at which a soil becomes too dry to be plastic. It is used together with the liquid limit to determine the plasticity index, which, when plotted against the liquid limit on the plasticity chart (see [BS EN ISO 14688-2:2018](#), Figure 1), provides a means of classifying fine soils. It is recognized that the results are subject to the judgement of the operator and that some variability in results is likely to occur.

6.1 General

COMMENTARY ON 6.1

This method covers the determination of the plastic limit of a sample of soil in its natural state, or of a sample of soil from which material retained on a 425 µm sieve has been removed.

The plastic limit shall be determined in accordance with [BS EN ISO 17892-12](#).

6.2 Additional parameters

Where required, additional parameters, including the liquidity index, consistency index and activity index, shall be calculated in accordance with BS EN ISO 17892-12:2018+A1:2021, Annex B.

NOTE 1 [BS EN ISO 17892-12](#) requires the fraction of soil retained on a 0.4 mm sieve or the nearest sieve to be removed prior to the liquid and plastic limit tests. In this British Standard it is assumed that the material coarser than 0.425 µm has been removed, in accordance with normal practice.

NOTE 2 Based on NOTE 1, the correction for water content may be based on the percentage of material retained and passing the 425 µm sieve, as described in BS EN ISO 17892-12:2018+A1:2021, Annex B.

7 Determination of shrinkage characteristics—Linear shrinkage

COMMENTARY ON CLAUSE 7

Shrinkage due to drying is significant in clays but less so in silts and sands. These tests enable the shrinkage limit, w_s , of clays to be determined, i.e. the water content below which a clay ceases to shrink. They also provide ways of quantifying the amount of shrinkage likely to be experienced by clays, in terms of the shrinkage ratio, volumetric shrinkage and linear shrinkage.

These factors are also relevant to the converse condition of expansion due to wetting.

A standard test method for determining the shrinkage factors of a soil paste by immersion in water is given in ASTM D4943-18. This method determines the shrinkage limit, shrinkage ratio and volumetric shrinkage and allows the calculation of the equivalent linear shrinkage.

The standard method for the direct determination of the total linear shrinkage of a soil paste is given in [Clause 7](#).

Previous editions of this British Standard included methods that used mercury to determine the change in volume of the specimen during drying. These procedures should no longer be used. Alternative methods have been developed, e.g. by laser scanning (P. R. N. Hobbs et al, 2014 [\[2\]](#)) to determine the volume/water content curve during drying.

7.1 General

NOTE This method covers the determination of the linear shrinkage of the fraction of a soil specimen passing a 425 µm test sieve from linear measurements on a bar of soil.

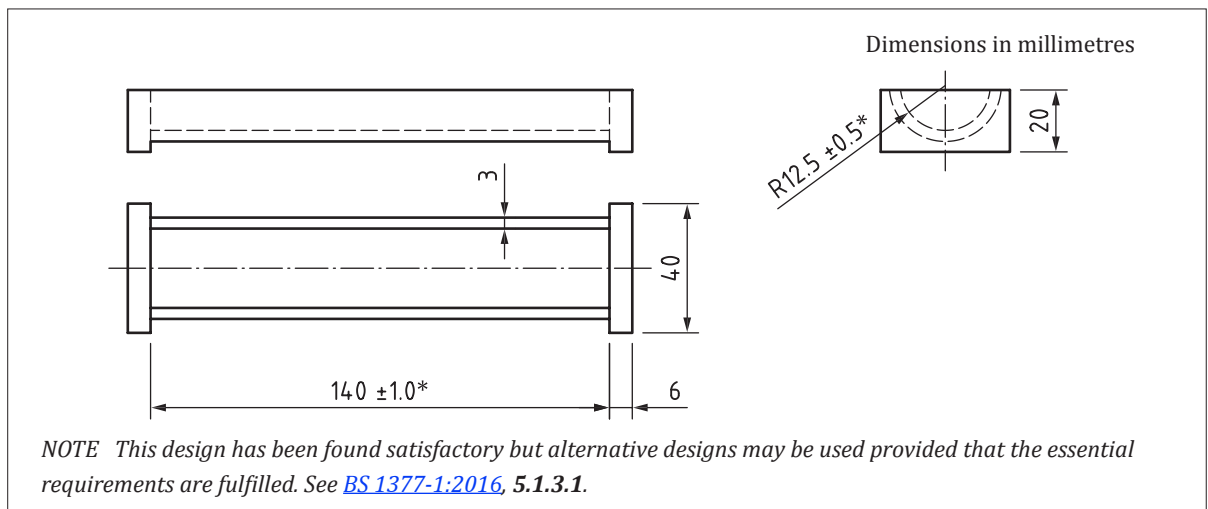
The requirements of [BS 1377-1](#), as appropriate, shall apply to this test method.

7.2 Apparatus

7.2.1 Two palette knives or spatulas.

7.2.2 Flat, glass plate, a convenient size being 10 mm thick and about 500 mm square, or an evaporating dish of approximately 150 mm diameter.

7.2.3 Mould made of brass or other suitable material conforming to the essential details in [Figure 1](#).

Figure 1 — Mould for linear shrinkage test

7.2.4 Silicone grease or petroleum jelly.

7.2.5 Drying oven, capable of maintaining temperatures of 60 °C to 65 °C and of 105 °C to 110 °C.

7.2.6 A means of measuring a length of up to 150 mm to within 0.5 mm, such as an engineers' steel rule or vernier callipers.

7.2.7 Distilled or deionized water, in accordance with [BS 1377-1:2016](#), 6.1.

7.3 Preparation of apparatus

Clean the mould thoroughly and apply a thin film of silicone grease or petroleum jelly to its inner faces to prevent the soil adhering to the mould.

7.4 Procedure

7.4.1 Place a specimen of approximately 150 g from the material passing through the 425 µm test sieve, obtained as specified in BS EN ISO 17892-12:2018+A1:2021, 5.2, on the flat, glass plate or in the evaporating dish.

7.4.2 Add distilled/deionized water if necessary and mix thoroughly using the palette knives until the mass becomes a smooth homogeneous paste with a water content at approximately the liquid limit of the soil.

NOTE The required consistency gives a cone penetration of approximately 20 mm in the cone penetrometer liquid limit device using the 80g/30° cone or requires approximately 25 bumps of the Casagrande apparatus. This water content is not critical to within a few percent.

7.4.3 Place the soil/water mixture in the mould such that it is slightly proud of the sides of the mould. Gently jar the mould to remove any air pockets in the mixture.

7.4.4 Level the soil along the top of the mould with the palette knife and remove all soil adhering to the rim of the mould by wiping with a damp cloth.

7.4.5 Place the mould where the soil/water can air dry slowly in a position free from draughts until the soil has shrunk away from the walls of the mould. Complete the drying, first at a temperature not exceeding 65 °C until shrinkage has largely ceased and then at 105 °C to 110 °C to complete the drying.

7.4.6 Remove from the oven and place in a desiccator with dry self-indicating desiccant. When cool, measure the mean length of the soil bar. If the specimen has become curved during drying, carefully

remove it from the mould and measure the lengths of the top and bottom surfaces. The mean of these two lengths shall be taken as the length of the oven dry specimen.

NOTE If a specimen cracks badly, or breaks, such that measurement is difficult, the test should be repeated at a slower drying rate.

7.5 Calculations and expression of results

Calculate the linear shrinkage of the soil as a percentage of the original length of the specimen, L_o (in mm), from the formula:

$$\text{Percentage of linear shrinkage} = \left(1 - \frac{L_D}{L_o} \right) 100$$

where:

L_D is the length of the oven-dry specimen (in mm).

7.6 Test report

The report shall affirm that the test was carried out in accordance with [7.1](#) and shall include the:

- method of test used;
- value of the linear shrinkage of the soil;
- proportion of soil that passes the 425 μm sieve test;
- history of the specimen, e.g. whether tested in the natural state or after wet sieving or after any other process; and
- information required by [BS 1377-1:2016](#), Clause 10.

8 Determination of density

COMMENTARY ON CLAUSE 8

In this British Standard, density is expressed in terms of mass density. The bulk density of a soil, ρ , is the mass per unit volume of the soil deposit, including any water it contains. The dry density, ρ_d , is the mass of dry soil contained in a unit volume. Both are expressed in Mg/m^3 .

Weight density (unit weight, kN/m^3), denoted by γ , is used when calculating the force exerted by a mass of soil, and is derived from the mass density by the formula:

$$\gamma = \rho g$$

where:

g is 9.807, the acceleration due to gravity (in m/s^2).

Density tests shall be performed in accordance with one of the three test methods prescribed in BS EN ISO 17892-2.

NOTE The linear displacement method applies to soils that can be formed into a regular geometric shape, the volume of which can be calculated from linear measurements. In the immersion in fluid method, the volume of the specimen is determined by weighing it submerged in a fluid (typically water). In the fluid displacement method, the volume is measured by displacement of fluid (usually water).

9 Determination of particle density

9.1 General

COMMENTARY ON 9.1

Different particle sizes within a specimen of soil often have different particle densities. These methods of test give the average particle density for the range of sizes, including their distribution, contained in the specimen tested. In some instances, it might be desirable to measure the particle density separately on separate size fractions.

The particle density shall be determined using a pycnometer in accordance with BS EN ISO 17892-3 either by fluid displacement or by gas displacement, or by the gas jar method in accordance with [9.2](#) of this British Standard.

NOTE The size required depends on the particle size of the soil. The fluid pycnometer method described in BS EN ISO 17892-3 is suitable for soils under approximately 4 mm, or soils crushed to meet this requirement. The gas jar method may be used for coarser grained soils with up to 10% of particles greater than 37.5 mm.

9.2 Gas jar method

COMMENTARY ON 9.2

This method is suitable for soil containing up to 10% of particles retained on a 37.5 mm test sieve. Coarse particles in excess of this should be broken down to less than this size before testing. If these particles contain internal voids, tests on the broken-down material could lead to results different from those given by tests on the whole material.

9.2.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply.

9.2.2 Sample preparation

9.2.2.1 A sample of soil of approximately 1 kg mass shall be obtained as specified in [BS 1377-1:2016](#), **8.3** and **8.4.4**. Coarse material in excess of 10% retained on a 37.5 mm test sieve, or any particles retained on a 50 mm test sieve, shall be broken down to less than 37.5 mm size.

9.2.2.2 At least two specimens shall be obtained from the sample by riffing. For fine-grained soils, each specimen shall be of approximately 200 g, and for coarse-grained soils of approximately 400 g. The specimens shall be oven dried, normally at 105 °C to 110 °C, and then stored in airtight containers until required.

Oven drying for the soil at 105 °C to 110 °C has been specified for convenience. If there is any reason to believe that this will change the particle density due to loss of water of hydration, the soil shall be dried at no more than 80 °C (50 °C if gypsum is present) and the drying temperature shall be reported.

9.2.3 Apparatus

9.2.3.1 Gas jar, 1 L in capacity, fitted with a rubber bung.

NOTE A gas jar has been found to make a very effective pycnometer but any container of similar capacity can be used provided that it can be shaken in a mechanical shaking apparatus, and provided that the mouth can be sealed in such a way that its volume is constant.

9.2.3.2 Ground glass plate, for closing the gas jar.

- 9.2.3.3** *Mechanical shaking apparatus*, capable of rotating the gas jar, end over end, at approximately 50 revolutions per minute.

NOTE An end-over-end shaker has been specified but shaking machines giving a vibrating motion would also be suitable. The choice of shaking machine depends on the type of pycnometer used.

- 9.2.3.4** *Balance*, readable to 0.1 g.

- 9.2.3.5** *Thermometer*, to cover the temperature range 0 °C to 50 °C, readable to 1 °C.

- 9.2.3.6** *Drying oven*, capable of maintaining a temperature of 105 °C to 110 °C.

9.2.4 Procedure

- 9.2.4.1** Clean and dry the gas jar and ground glass plate and weigh them together to the nearest 0.2 g (m_1).

- 9.2.4.2** Transfer the first soil specimen from its sealed container directly into the gas jar. Weigh the gas jar, ground glass plate and contents to the nearest 0.2 g (m_2).

- 9.2.4.3** Add approximately 500 mL of water at a temperature within ± 2 °C of the average room temperature during the test to the soil. Insert the rubber stopper into the gas jar and for medium- and coarse-grained soils (as defined in [BS 1377-1:2016](#), Clause 4) set aside for at least 4 h.

NOTE If there is a large difference between the air temperature and water temperature, sufficient water should be drawn for the required number of tests and allowed to stand in the room in which the tests are being done until the temperature is within the given range.

- 9.2.4.4** At the end of this period, or immediately after the addition of water in the case of fine-grained soils, shake the gas jar by hand until the particles are in suspension.

- 9.2.4.5** Place the gas jar securely in the shaking apparatus and shake for a period of 20 min to 30 min.

- 9.2.4.6** Remove the stopper carefully and wash any soil particles adhering to the stopper or to the top of the gas jar into the jar. Disperse any froth with a fine spray of water. Add water to the gas jar to within 2 mm of the top and allow the soil to settle for a few minutes, then fill the gas jar to the brim with more water. Place the ground glass plate on the top of the jar taking care not to trap any air under the plate.

NOTE This operation might be easier if the gas jar is inclined under a slow stream of water while the ground glass plate is slid upwards over the rim.

- 9.2.4.7** Dry the gas jar and plate carefully on the outside and weigh the whole to the nearest 0.2 g (m_3).

- 9.2.4.8** Empty the gas jar, wash it out thoroughly and fill it to the brim with water at a temperature within ± 2 °C of the average room temperature. Place the ground glass plate in position taking care not to trap any air under the plate. Ensure that the water in the jar contains no air bubbles.

- 9.2.4.9** Dry the gas jar and plate carefully on the outside and weigh the whole to the nearest 0.2 g (m_4).

- 9.2.4.10** Repeat [9.2.4.2](#) to [9.2.4.7](#) using the second specimen of the same soil so that two values of particle density can be obtained. If the results differ by more than 0.03 Mg/m³ repeat the tests.

9.2.5 Calculations and expressions of results

Calculate the particle density, ρ_s (in Mg/m³), from the formula:

$$\rho_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

where:

- m_1 is the mass of gas jar and ground glass plate (in g);
- m_2 is the mass of gas jar, plate and soil (in g);
- m_3 is the mass of gas jar, plate, soil and water (in g); and
- m_4 is the mass of gas jar, plate and water (in g).

Calculate the average of the two results if they differ by no more than 0.03 Mg/m³.

Express the average value of particle density to the nearest 0.01 Mg/m³.

9.2.6 Test report

The test report shall affirm that the test was carried out in accordance with [9.2](#) and shall include:

- a) the method of test used;
- b) the average value of the particle density of the soil specimen; and
- c) the information required by [BS 1377-1:2016](#), Clause 10.

10 Determination of particle size distribution

The particle size distribution shall be determined in accordance with [BS EN ISO 17892-4](#).

NOTE 1 Two methods of sieving are specified. Wet sieving is the definitive method applicable to all soils. Dry sieving is suitable only for coarse soils containing insignificant quantities of silt and clay.

Two methods of determining the size distribution of fine particles down to the clay size by sedimentation are specified, namely the pipette method and the hydrometer method. In both methods the density of the soil suspension at various intervals of time is measured.

Combined sieving and sedimentation procedures enable a continuous particle size distribution curve of a soil to be plotted from the size of the coarsest particles down to the clay size.

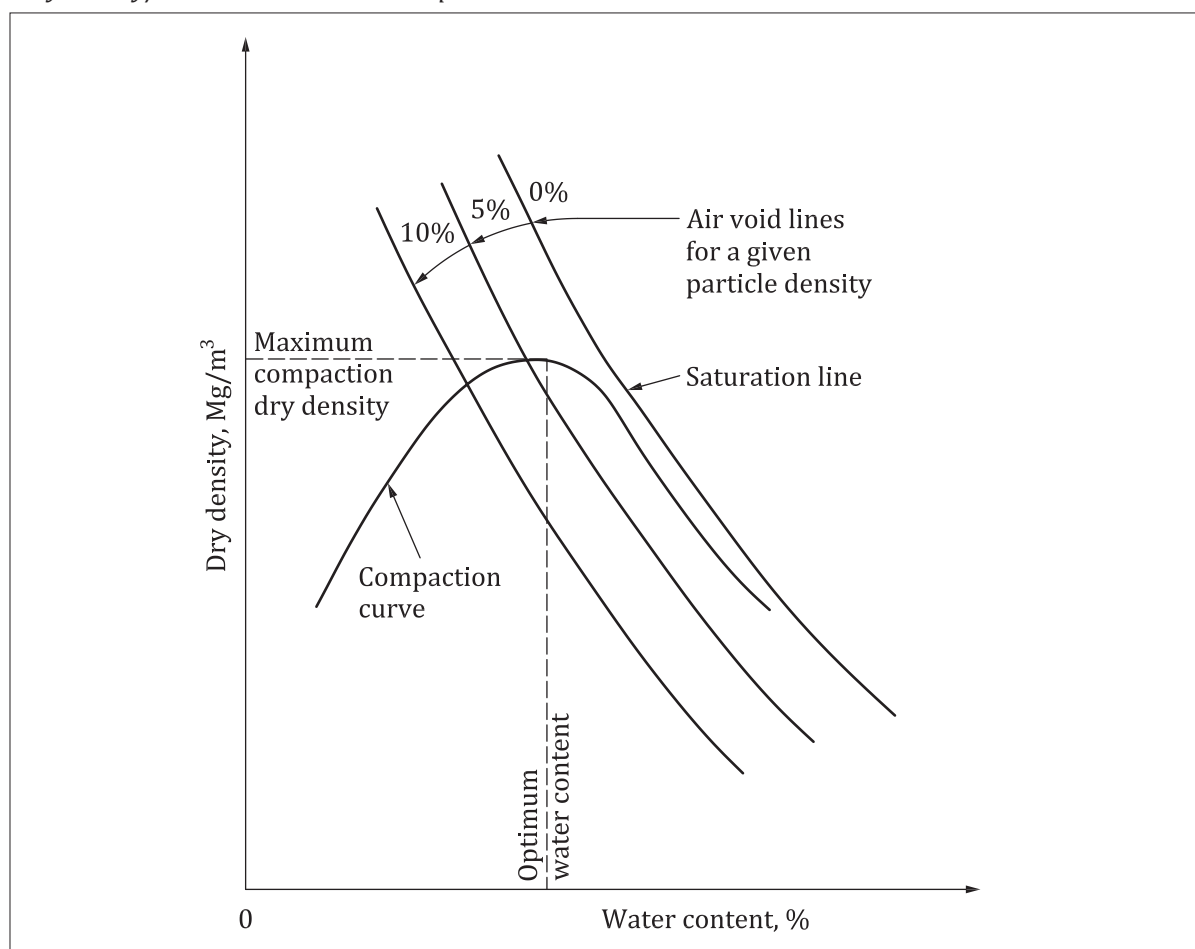
NOTE 2 If it is known that aggregations of particles might remain after sample preparation, they may be broken down in such a way as to avoid crushing the individual particles using an action no more severe than that applied by a rubber pestle.

11 Determination of dry density/water content relationship

11.1 General

COMMENTARY ON 11.1

Compaction of soil is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the soil. The dry density that can be achieved depends on the degree of compaction applied and on the amount of water present in the soil. (The terms used in compaction tests are illustrated in [Figure 2](#).) For a given degree of compaction of a given fine soil there is an optimum water content at which the dry density obtained reaches a maximum value. For coarse soils, an optimum water content might be difficult to define.

Figure 2 — Dry density/water content relationship curve

For some highly permeable soils such as clean gravels and coarse clean sands, the results of the laboratory compaction test might provide only a poor guide for specifications on field compaction. The laboratory test might indicate meaningless values of water content in these free-draining materials and the maximum dry density is often lower than the state of compaction, which can be readily obtained in the field. For these soils one of the maximum dry density tests described in [Clause 12](#) would be more appropriate.

The objective of the tests described in [Clause 11](#) is to obtain relationships between compacted dry density and soil water content, using two magnitudes of manual compactive effort, or compaction by vibration.

Three types of compaction test are described, each with procedural variations related to the nature of soil. The first is the light compaction test in which a 2.5 kg rammer is used. The second is the heavy manual compaction test which gives a much greater degree of compaction by using a 4.5 kg rammer with greater drop on thinner layers of soil. The third type of test makes use of a vibrating hammer for compaction.

For the light and heavy manual compaction tests, a compaction mould of 1 L internal volume shall be used for soil in which all particles pass a 20 mm test sieve. If there is a limited number of particles up to 37.5 mm size, equivalent tests shall be carried out in the larger California Bearing Ratio (CBR) mould.

NOTE 1 Specifications for compaction by rammer in the CBR mould are based on the same compactive effort per unit volume of soil as in the 1 L compaction mould. The variable effects of side wall friction might result in differences between the densities achieved in the two moulds. For a series of tests on a particular soil, one size of mould should be used consistently.

NOTE 2 The vibrating hammer test is intended mainly for coarse soils passing a 37.5 mm test sieve, with no more than 30% retained on a 20 mm test sieve.

For the vibrating hammer test, the soil shall be compacted into a CBR mould.

NOTE 3 For each type of test, alternative procedures depend on whether or not the soil contains particles susceptible to crushing during compaction. Methods of sample preparation covering most possible requirements are described in [11.2](#). Compaction test procedures are described separately in [11.3](#), [11.4](#), [11.5](#), [11.6](#) and [11.7](#). The compaction procedures are summarized in [Table 2](#).

Table 2 — Summary of compaction procedures

Compactive effort	Mass of rammer kg	Type of mould used	Soil particles susceptible to crushing	
			No	Yes
Light	2.5	1 L	11.3.4.1	11.3.4.2
		CBR	11.4.4.1	11.4.4.2
Heavy	4.5	1 L	11.5.4.1	11.5.4.2
		CBR	11.6.4.1	11.6.4.2
Vibration	Vibrating	CBR	11.7.5.1	11.7.5.2

NOTE 1 1 L = 1 L compaction mould, see [11.3.2.1](#).

NOTE 2 CBR = CBR mould, see [11.4.2.1](#).

NOTE 3 Soil susceptibility to crushing, see [11.2.1a](#).

11.2 Preparation of samples for compaction tests

COMMENTARY ON 11.2

The method of preparation of samples for these tests and the quantity of soil required depend on the size of the largest particles present and whether or not the soil particles are susceptible to crushing during compaction. The assessment of these factors is covered in [11.2.1](#).

For soils containing particles not susceptible to crushing, one sample only is required for test and it can be used several times after progressively increasing the amount of water.

Relevant sample preparation methods are described in [11.2.3](#) and [11.2.4](#).

For soils containing particles that are susceptible to crushing, it is necessary to prepare separate batches of soil at different water contents, each for compacting once only, otherwise the characteristics of the material will progressively change after each application of compaction. Consequently, a much larger sample is required. Relevant sample preparation methods are described in [11.2.6](#) and [11.2.7](#).

For stiff, fine soils, which need to be shredded or chopped into small lumps, the result of a compaction test depends on the size of the resulting pieces. Furthermore, the densities obtained in the test will not necessarily be directly related to densities obtained in situ. The method used for breaking down fine soil, and the size of pieces obtained, should be recorded. Suggested methods are to shred the soil so that it can pass through a 5 mm test sieve, or to chop it into pieces, e.g. to pass a 20 mm test sieve.

11.2.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

For preliminary assessment, the initial soil sample for testing shall be obtained in accordance with the procedure described in [BS 1377-1:2016](#), [8.6.1](#) to [8.6.3](#). The procedures to be used

for sample preparation and for carrying out the compaction test shall be selected based on the following assessment:

- a) ascertain whether the soil particles are susceptible to crushing during compaction. If in doubt, assume that they are susceptible;

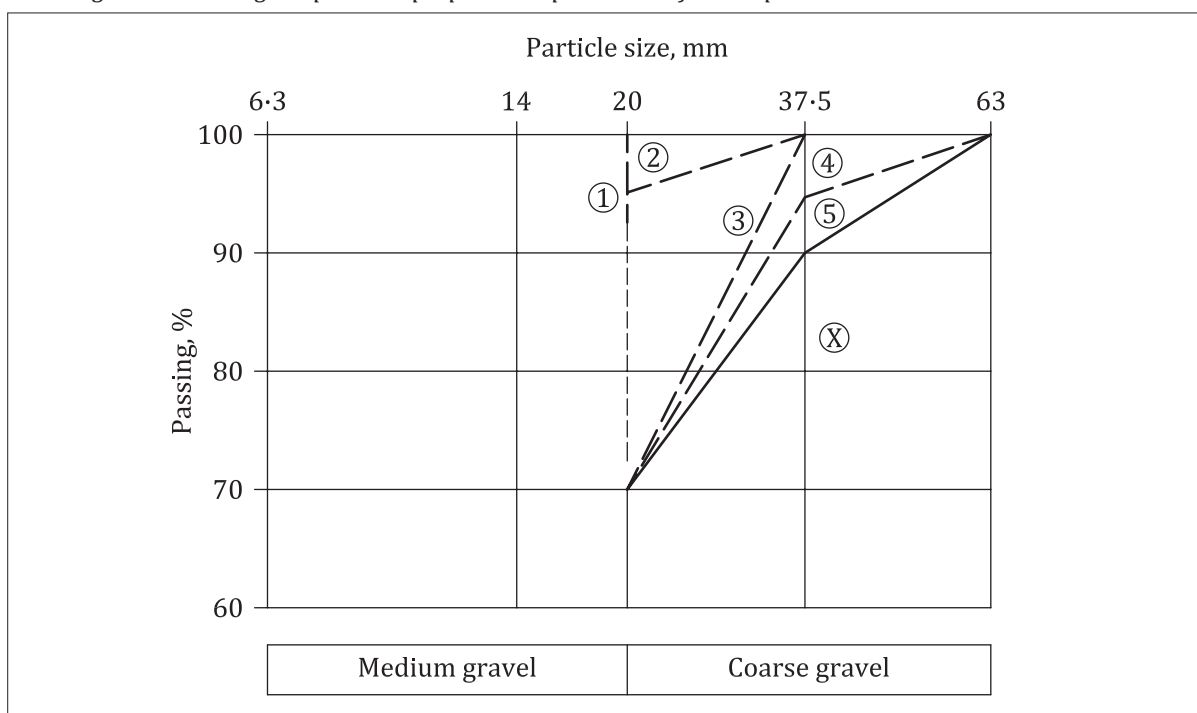
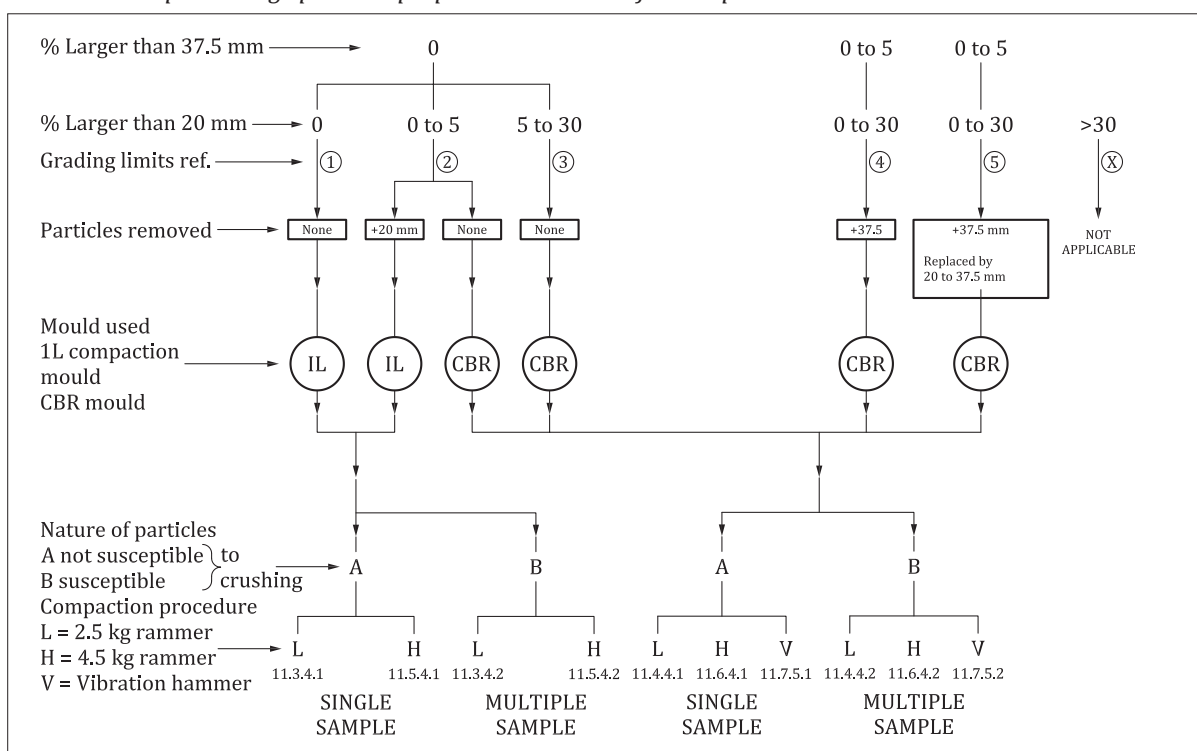
NOTE The soil should be considered susceptible to crushing during compaction if the sample contains coarse material of a weaker nature, e.g. weaker limestone, sandstone, which would be reduced in size by the action of the 2.5 kg rammer. The procedure described in [11.3.4.2](#), [11.4.4.2](#), [11.5.4.2](#), [11.6.4.2](#) and [11.7.5.2](#) for soils susceptible to crushing during compaction should be applied to all soils if it is practicable to do so.

- b) determine the approximate percentages (to an accuracy of $\pm 5\%$) by mass of particles in the soil specimen passing the 20 mm and 37.5 mm test sieves. If the material used for this assessment is to be used for the compaction test it shall not be dried, and the dry mass of soil finer than 20 mm can be determined by measuring the water content using a representative portion. If enough soil is available to meet the requirements of [Clause 10](#), a separate specimen may be used for this sieving operation;
- c) based on these percentages, the soil can be assigned to one of the grading zones (1) to (5) in [Table 3](#), which are also shown diagrammatically in [Figure 3](#). If a grading curve passes through more than one zone, the highest-numbered zone applies. A soil with a grading curve passing through zone X is not suitable for these tests;
- d) the method of specimen preparation, the minimum mass of soil required and the type of mould to use for the compaction test are indicated in [Table 3](#), which takes account of the above factors; and
- e) the selection of methods is also shown in the form of a flow chart in [Figure 4](#).

Table 3 — Summary of sample preparation procedures

Grading zone	Minimum % passing test sieves		Preparation procedure clause reference		Minimum mass of prepared soil required (kg)		Type of mould used
	20 mm	37.5 mm	(A) Not susceptible to crushing	(B) Susceptible to crushing	(A) Not susceptible to crushing	(B) Susceptible to crushing	
1	100	100	11.2.3.1	11.2.3.2	6	15	1 L
2	95	100	11.2.3.3	11.2.3.4			
3	70	100	11.2.4.1	11.2.4.2	15	40	CBR
4	70	95	11.2.4.3	11.2.4.4			
5	70	90	11.2.4.5	11.2.4.6			
X	Less than 70	Less than 90	Test not applicable				

NOTE 1L = one litre compaction mould, CBR = CBR mould.

Figure 3 — Grading limits relating to specimen preparation procedures for compaction tests**Figure 4** — Flow chart representing specimen preparation methods for compaction tests

11.2.2 Apparatus

11.2.2.1 Test sieves, with aperture sizes 63 mm, 37.5 mm, 20 mm, with receiver.

11.2.2.2 Balance, readable to 5 g.

11.2.2.3 Balance, readable to 1 g.

11.2.2.4 Corrosion-resistant metal or plastic tray with sides, e.g. approximately 80 mm deep, of a size suitable for the quantity of material to be used.

11.2.2.5 *Large metal scoop.*

11.2.2.6 *Palette knife or spatula.*

11.2.2.7 *Watertight containers, e.g. strong polythene bags.*

11.2.2.8 *Apparatus for determination of water content, as described in BS EN ISO 17892-1.*

11.2.2.9 *An implement for shredding stiff soil.*

11.2.3 Preparation of soils for compaction in 1 L mould

11.2.3.1 Grading zone (1) for soils passing a 20 mm test sieve not susceptible to crushing

11.2.3.1.1 Prepare and subdivide the initial sample in accordance with the procedures described in [BS 1377-1:2016, 8.6](#), to produce a representative specimen of approximately 6 kg of the soil.

11.2.3.1.2 Add a suitable amount of water depending on the soil type and mix thoroughly.

NOTE 1 The amount of water to be mixed with soil at the commencement of the test varies with the type of soil under test. In general, with coarse soils, a water content of 4% to 6% might be suitable, while with fine soils a water content approximately 8% to 10% below the plastic limit of the soil would typically be suitable.

NOTE 2 It is important that the water is mixed thoroughly and adequately with the soil, since inadequate mixing gives rise to variable test results. This is particularly important with fine soils when adding a substantial quantity of water. With clays of high plasticity, or where hand mixing is used, storage of the mixed sample in a sealed container for a minimum period of 24 h before continuing with the test is the most satisfactory way of distributing the water uniformly.

11.2.3.1.3 If the soil initially contains too much water, allow it to partially air dry to the lowest water content at which the soil is to be compacted and mix thoroughly.

11.2.3.1.4 If the soil is fine, seal in an airtight container and store for at least 24 h.

11.2.3.2 Grading zone (1) for soils passing a 20 mm sieve susceptible to crushing

11.2.3.2.1 Subdivide the initial sample to produce five or more representative specimens, each of approximately 2.5 kg, using the procedure described in [BS 1377-1:2016, 8.6](#).

11.2.3.2.2 Mix each specimen thoroughly with a different amount of water to give a suitable range of water contents (see Note 1 and Note 2 to [11.2.3.1.2](#)). The range of water contents shall be such that at least two values lie either side of the optimum at which the maximum dry density occurs.

NOTE The water added to each specimen should be such that a range of water contents is obtained that includes the optimum water content. In general, increments of 1% to 2% are suitable for coarse soils and of 2% to 4% for fine soils. To increase the accuracy of the test it might be desirable to prepare specimens with smaller increments of water in the region of the optimum water content.

11.2.3.2.3 If the soil initially contains more water than is required for the compaction at the lower water contents, allow these specimens to partially dry to the desired water contents and mix thoroughly.

11.2.3.2.4 If the soil is fine, seal each specimen in an airtight container and store for at least 24 h.

11.2.3.3 Grading zone (2) for soils passing the 37.5 mm test sieve with at least 95% passing a 20 mm test sieve not susceptible to crushing

11.2.3.3.1 Weigh to 0.1% by mass the whole sample and record the mass.

11.2.3.3.2 Remove and weigh to 0.1% by mass the material retained on the 20 mm test sieve.

NOTE The removal of small amounts of stone (up to 5%) retained on a 20 mm test sieve is likely to affect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density.

- 11.2.3.3.3 Subdivide the finer material and proceed, as described in [11.2.3.1](#).
- 11.2.3.3.4 Alternatively, the whole sample can be used, as described in [11.2.4.1](#), for compaction in a CBR mould.
- 11.2.3.4 **Grading zone (2) for soils passing the 37.5 mm test sieve with at least 95% passing a 20 mm test sieve susceptible to crushing**
- 11.2.3.4.1 Weigh the whole sample and record the mass.
- 11.2.3.4.2 Remove and discard the material retained on the 20 mm test sieve (see Note to [11.2.3.3.2](#)).
- 11.2.3.4.3 Subdivide the finer material to produce five or more representative specimens, as described in [11.2.3.2](#).
- 11.2.3.4.4 Alternatively, the whole sample can be used, as described in [11.2.4.1](#), for compaction in a CBR mould.

11.2.4 Preparation of soils in a CBR mould

11.2.4.1 Grading zone (3) for soils passing the 37.5 mm test sieve with 70% to 95% passing a 20 mm test sieve not susceptible to crushing

Prepare and subdivide the initial sample using the procedure described in [BS 1377-1:2016, 8.6](#) to produce a representative specimen of approximately 15 kg of the soil, otherwise proceed as described in [11.2.3.1](#).

NOTE The exclusion of the large proportion of particles coarser than 20 mm from this type of soil could have a large effect on the density obtained in the compaction mould compared with that obtainable with the soil as a whole, and the optimum water content would also be affected. The larger CBR mould is, therefore, specified for this type of material.

11.2.4.2 Grading zone (3) for soils passing the 37.5 mm test sieve with 70% to 95% passing a 20 mm test sieve susceptible to crushing

Subdivide the initial sample to produce five or more representative specimens, each of approximately 6 kg, using the procedure described in [BS 1377-1:2016, 8.6](#), otherwise, proceed as described in [11.2.3.2](#).

11.2.4.3 Grading zone (4) for soils containing at least 95% passing the 37.5 mm test sieve and at least 70% passing a 20 mm test sieve not susceptible to crushing

11.2.4.3.1 Weigh the whole sample and record the mass to the nearest 5 g.

11.2.4.3.2 Remove and weigh the material retained on the 37.5 mm test sieve.

NOTE The exclusion of the large proportion of particles coarser than 20 mm from this type of soil could have a large effect on the density obtained in the compaction mould compared with that obtainable with the soil as a whole, and the optimum water content would also be affected. The larger CBR mould is, therefore, specified for this type of material.

11.2.4.3.3 Subdivide the finer material to produce a 15 kg specimen, otherwise proceed, as described in [11.2.3.1](#).

11.2.4.4 Grading zone (4) for soils containing at least 95% passing the 37.5 mm test sieve and at least 70% passing the 20 mm test sieve susceptible to crushing

11.2.4.4.1 Weigh the whole sample and record the mass to the nearest 5 g.

11.2.4.4.2 Remove and weigh the material retained on the 37.5 mm test sieve.

NOTE The exclusion of the large proportion of particles coarser than 37.5 mm from this type of soil could have a large effect on the density obtained in the compaction mould compared with that obtainable with the soil as a whole, and the optimum water content would also be affected. The larger CBR mould is, therefore, specified for this type of material.

11.2.4.4.3 Subdivide the finer material to produce five or more representative specimens, as described in [11.2.3.2](#).**11.2.4.5 Grading zone (5) for soils with 90% to 95% passing the 37.5 mm test sieve, and at least 70% passing a 20 mm test sieve not susceptible to crushing****11.2.4.5.1** Weigh the soil sample to the nearest 5 g.**11.2.4.5.2** Remove and weigh the material retained on the 37.5 mm test sieve.**11.2.4.5.3** Replace this material by the same quantity of material of similar characteristics that passes the 37.5 mm test sieve and is retained on the 20 mm test sieve.

NOTE The substitution of large particles by smaller, similar particles is generally considered to give dry densities in the laboratory test which compare reasonably well with those obtained in the field. Alternatively, the coarser material can be removed for the test and a correction applied to the maximum dry density based on the displacement of the soil matrix by stones of known particle density.

11.2.4.5.4 Subdivide the material to produce a specimen of approximately 15 kg of the soil, otherwise proceed as described in [11.2.3.1](#).**11.2.4.6 Grading zone (5) for soils containing 90% to 95% passing the 37.5 mm test sieve and at least 70% passing a 20 mm test sieve susceptible to crushing****11.2.4.6.1** Weigh the soil sample to the nearest 5 g.**11.2.4.6.2** Remove and weigh the material retained on the 37.5 test sieve.**11.2.4.6.3** Replace this material by the same quantity of material of similar characteristics that passes the 37.5 mm test sieve and is retained on the 20 mm test sieve (see Note to [11.2.4.5.3](#)).**11.2.4.6.4** Subdivide the material to produce five or more 6 kg specimens of the soil, otherwise proceed as described in [11.2.3.2](#).**11.3 Compaction method using 2.5 kg rammer with 1 L mould***COMMENTARY ON 11.3*

This test covers the determination of the dry density of soil with more than 95% passing the 20 mm test sieve when it is compacted in a specified manner over a range of water contents. The range includes the optimum water content at which the maximum dry density for this degree of compaction is obtained. In this test a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into a 1 L compaction mould.

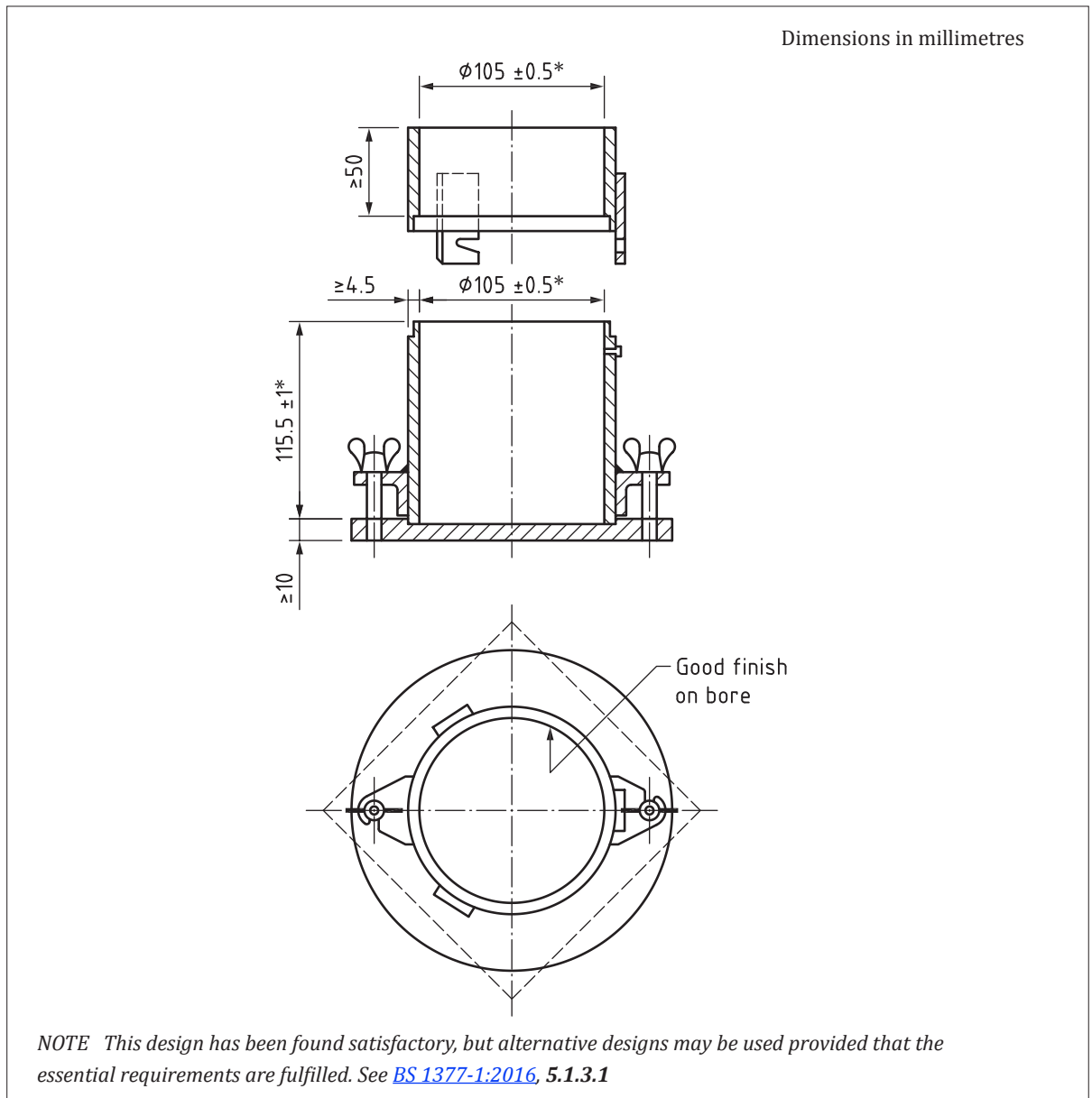
11.3.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

11.3.2 Apparatus**11.3.2.1** *Cylindrical, corrosion-resistant metal mould, i.e. the compaction mould, having a nominal internal volume of 1 L. The mould shall be fitted with a detachable baseplate and a removable extension.*

The essential dimensions are shown in [Figure 5](#), which also indicates one suitable design of mould. The internal faces shall be smooth, clean and dry before each use.

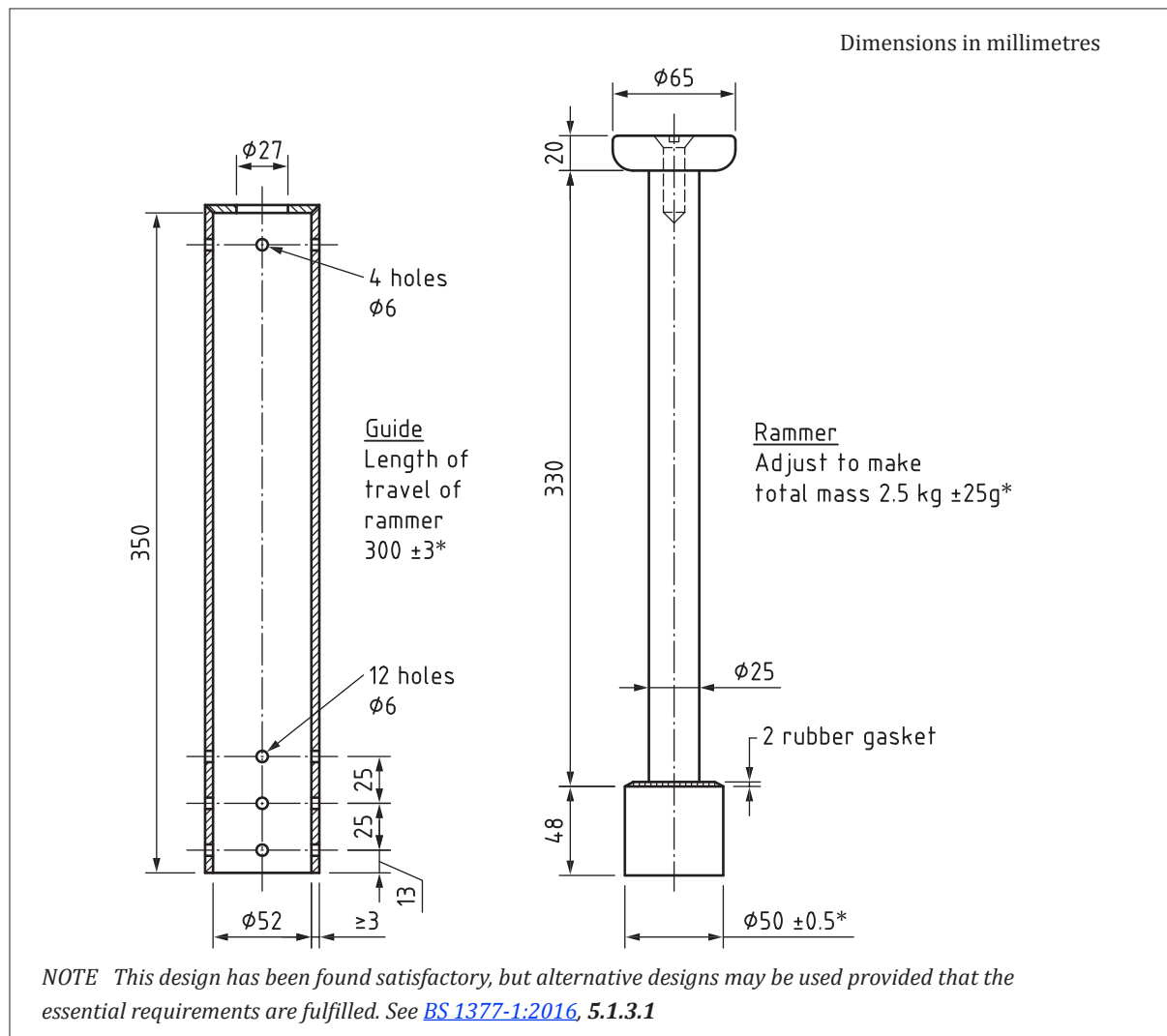
Figure 5 — Mould for compaction test (1 L mould)



- 11.3.2.2** *Metal rammer*, having a (50 ± 0.5) mm diameter circular face, and weighing $2.5 \text{ kg} \pm 25 \text{ g}$. The rammer shall be equipped with a suitable arrangement for controlling the height of drop to (300 ± 3) mm.

NOTE 1 A suitable form of hand apparatus is shown in [Figure 6](#).

NOTE 2 A motorized form of the apparatus may be used provided that the essential dimensions of the rammer and mould are adhered to and provided that the density achieved is within $\pm 2\%$ of density achieved by using the hand rammer. The machine should be firmly supported on a heavy solid base, such as a concrete floor or plinth.

Figure 6 — 2.5 kg rammer for compaction test

11.3.2.3 Balance, readable to 1 g.

11.3.2.4 Palette knife or spatula.

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

11.3.2.6 Test sieves, of aperture sizes 37.5 mm and 20 mm and a receiver.

11.3.2.7 Corrosion-resistant metal or plastics tray with sides, e.g. about 80 mm deep, of a size suitable for the quantity of material to be used.

11.3.2.8 Apparatus for water content determination, as described in BS EN ISO 17892-1.

11.3.2.9 Apparatus for extracting specimens from the mould (optional).

11.3.3 Preparation of sample

Prepare the test sample, as described in [11.2.3.1](#), [11.2.3.2](#), [11.2.3.3](#) or [11.2.3.4](#), as appropriate.

11.3.4 Procedure

11.3.4.1 Compaction procedure for soil particles not susceptible to crushing

- 11.3.4.1.1** Weigh the mould with baseplate attached to 1 g (m_1). Measure the internal dimensions to 0.1 mm.
- 11.3.4.1.2** Attach the extension to the mould and place the mould assembly on a solid base, e.g. a concrete floor or plinth.
- 11.3.4.1.3** Place a quantity of moist soil in the mould such that when compacted it occupies a little over one-third of the height of the mould body.
- 11.3.4.1.4** Apply 27 blows from the rammer dropped from a height of 300 mm above the soil as controlled by the guide tube. Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed by soil in the guide tube (see K. H. Head, 2006 [3]).
- 11.3.4.1.5** Repeat [11.3.4.1.3](#) and [11.3.4.1.4](#) twice more, so that the amount of soil used is sufficient to fill the mould body, with the surface not more than 6 mm proud of the upper edge of the mould body.
- NOTE* It is necessary to control the total volume of soil compacted, since it has been found that if the amount of soil struck off after removing the extension is too great, the test results will be inaccurate.
- 11.3.4.1.6** Remove the extension, strike off the excess soil and level off the surface of the compacted soil carefully to the top of the mould using the straightedge. Replace any coarse particles, removed in the levelling process, by finer material from the specimen, well pressed in.
- 11.3.4.1.7** Weigh the soil and mould with baseplate to 1 g (m_2).
- 11.3.4.1.8** Remove the compacted soil from the mould and place it on the metal tray. Take a representative specimen of the soil for determination of its water content, as described in BS EN ISO 17892-1.
- 11.3.4.1.9** Break up the remainder of the soil, rub it through the 20 mm test sieve and mix with the remainder of the prepared test specimen.
- 11.3.4.1.10** Add a suitable increment of water and mix thoroughly into the soil.

NOTE The water added for each stage of the test should be such that a range of water contents is obtained which includes the optimum water content. In general, increments of 1% to 2% are suitable for coarse soils and of 2% to 4% for fine soils. To increase the accuracy of the test it is often advisable to reduce the increments of water in the region of the optimum water content.

- 11.3.4.1.11** Repeat [11.3.4.1.3](#) to [11.3.4.1.10](#) to give a total of at least five determinations. The water contents shall be such that the optimum water content, at which the maximum dry density occurs, lies near the middle of the range.

11.3.4.2 Compaction procedure for soil particles susceptible to crushing

- 11.3.4.2.1** Weigh, measure and prepare the mould, as described in [11.3.4.1.1](#) and [11.3.4.1.2](#).
- 11.3.4.2.2** Carry out a compaction test on each of the prepared specimens, as described in [11.3.4.1.3](#) to [11.3.4.1.8](#).
- 11.3.4.2.3** Discard the remainder of each compacted specimen.

11.3.5 Calculations, plotting and expression of results

- 11.3.5.1** Calculate the internal volume, V (in cm³), of the mould.

11.3.5.2 Calculate the bulk density, ρ (in Mg/m³), of each compacted specimen using the formula:

$$\rho = \frac{m_2 - m_1}{v}$$

where:

- m_1 is the mass of mould and baseplate (in g); and
 m_2 is the mass of mould, baseplate and compacted soil (in g).

11.3.5.3 Calculate the dry density, ρ_d (in Mg/m³), of each compacted specimen using the formula:

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

where:

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

11.3.5.4 Plot the dry densities obtained from a series of determinations as y-axis against the corresponding water contents on the x-axis. Draw a curve of best fit to the plotted points and identify the position of the maximum on this curve. Read off the values of dry density and water content, to three significant figures, corresponding to that point (see [Figure 2](#)).

NOTE The maximum might lie between two observed points but when drawing the curve, care should be taken not to exaggerate its peak.

11.3.5.5 On the same graph, plot the curves corresponding to 0%, 5% and 10% air voids, calculated using the formula:

$$\rho_d = \frac{1 - \frac{V_a}{100}}{\frac{1}{\rho_s} + \frac{W}{100\rho_w}}$$

where:

- ρ_d is the dry density (in Mg/m³);
 ρ_s is the particle density (in Mg/m³);
 ρ_w is the density of water (in Mg/m³), assumed equal to 1;
 V_a is the volume of air voids in the soil, expressed as a percentage of the total volume of the soil (equal to 0%, 5%, 10% for the purpose of this plot);
 W is the water content (%) (see [Figure 2](#)).

11.3.6 Test report

The test report shall affirm that the test was carried out in accordance with [11.3](#) and contain the:

- method of test used;
- sample preparation procedure and whether a single sample or separate samples were used. In the case of stiff, fine soil, the size of pieces to which the soil was broken down shall be stated;
- experimental points and the smooth curve drawn through them showing the relationship between water content and dry density;
- compaction dry density corresponding to the maximum dry density on the water content/dry density curve, reported as the maximum dry density to the nearest 0.01 (in Mg/m³);
- percentage water content corresponding to the maximum compaction dry density on the water content/dry density curve reported as the optimum water content to two significant figures;

- f) amount of stone retained on the 20 mm and 37.5 mm test sieves reported to the nearest 1% by dry mass;
- g) grading zone (1 to 5);
- h) particle density and whether measured (and if so, the method used) or assumed; and
- i) information required by [BS 1377-1:2016](#), 10.1.

11.4 Compaction method using 2.5 kg rammer with CBR mould

COMMENTARY ON 11.4

This test covers the determination of the dry density of soil containing some coarse gravel when it is compacted in a specified manner over a range of water contents. The range includes the optimum water content at which the maximum dry density for this degree of compaction is obtained. In this test a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into a CBR mould.

The test is suitable for soils containing no more than 30% by mass of material retained on the 20 mm test sieve, which may include some particles retained on the 37.5 mm test sieve.

This method may also be used for finer soils, which would normally be compacted in the 1 L mould when it is required to perform a CBR test (see [15.4](#)) on the compacted soil at each water content.

11.4.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

11.4.2 Apparatus

11.4.2.1 *Cylindrical, corrosion-resistant, metal mould*, i.e. the CBR mould, with a detachable baseplate and a removable extension, as described in [15.2.2.2](#).

11.4.2.2 *Hand or motorized, metal rammer*, having a 50 mm diameter circular face and weighing 2.5 kg, as described in [11.3.2.2](#).

11.4.2.3 *Balance*, readable to 5 g.

11.4.2.4 *Large scoop*.

11.4.2.5 *Other items*, as specified in [11.3.2.4](#) to [11.3.2.9](#).

11.4.3 Preparation of specimen

Prepare the test specimen as described in [11.2.4.1](#), [11.2.4.2](#), [11.2.4.3](#), [11.2.4.4](#), [11.2.4.5](#) or [11.2.4.6](#), as appropriate.

11.4.4 Procedure

11.4.4.1 Compaction procedure for soil particles not susceptible to crushing

11.4.4.1.1 Weigh the CBR mould with baseplate attached, to 5 g (m_1). Measure the internal dimensions to 0.5 mm.

11.4.4.1.2 Attach the extension to the mould and place the mould assembly on a solid base, e.g. a concrete floor or plinth.

11.4.4.1.3 Place a quantity of moist soil in the mould such that when compacted it occupies a little over one-third of the height of the mould body.

11.4.4.1.4 Apply 62 blows from the rammer dropped from a height of 300 mm above the soil. Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed by soil in the guide tube (see K. H. Head, 2006 [3]).

11.4.4.1.5 Repeat [11.4.4.1.3](#) and [11.4.4.1.4](#) twice more, so that the amount of soil is sufficient to fill the mould body, with the surface not more than 6 mm proud of the upper edge of the mould body.

NOTE It is necessary to control the total volume of soil compacted, since it has been found that if the amount of soil struck off after removing the extension is too great, the test results will be inaccurate.

11.4.4.1.6 Remove the extension, strike off the excess soil and level off the surface of the compacted soil carefully to the top of the mould using the straightedge. Any coarse particles removed in the levelling process shall be replaced by finer material from the specimen, well pressed in.

11.4.4.1.7 Weigh the soil and mould with baseplate to 5 g (m_2).

11.4.4.1.8 Remove the compacted soil from the mould and place it on the metal tray. Take a representative specimen of the soil for determination of its water content, as described in BS EN ISO 17892-1.

11.4.4.1.9 Break up the remainder of the soil, rub it through the 20 mm or the 37.5 mm test sieve and mix with the remainder of the prepared test specimen.

11.4.4.1.10 Add a suitable increment of water and mix thoroughly into the soil.

NOTE The water added for each stage of the test should be such that a range of water contents is obtained which includes the optimum water content. In general, increments of 1% to 2% are suitable for coarse soils and of 2% to 4% for fine soils. To increase the accuracy of the test it is often advisable to reduce the increments of water in the region of the optimum water content.

11.4.4.1.11 Repeat [11.4.4.1.3](#) to [11.4.4.1.10](#) to give a total of at least five determinations. The water contents shall be such that the optimum water content, at which the maximum dry density occurs, lies near the middle of the range.

11.4.4.2 Compaction procedure for soil particles susceptible to crushing

11.4.4.2.1 Weigh, measure and prepare the CBR mould, as described in [11.4.4.1.1](#) and [11.4.4.1.2](#).

11.4.4.2.2 Carry out a compaction test on each of the prepared specimens in turn, as described in [11.4.4.1.3](#) to [11.4.4.1.8](#).

11.4.4.2.3 Discard the remainder of each compacted specimen.

11.4.5 Calculations

For plotting and expression of results, proceed as described in [11.3.5](#).

11.4.6 Test report

The test report shall be in accordance with [11.3.6](#).

11.5 Compaction method using 4.5 kg rammer with 1 L mould

COMMENTARY ON 11.5

This test covers the determination of the dry density of soil with more than 95% passing the 20 mm test sieve when it is compacted in a specified manner over a range of water contents. The range includes the optimum water content at which the maximum dry density for this degree of compaction is obtained. In this test the compactive effort is greater than in that described in [11.3](#): the mass of the rammer is 4.5 kg, the height of fall is 450 mm, and the number of compacted layers is five. The same 1 L compaction mould is used.

11.5.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

11.5.2 Apparatus

11.5.2.1 *Cylindrical corrosion-resistant metal mould*, i.e. the 1 L compaction mould, as specified in [11.3.2.1](#).

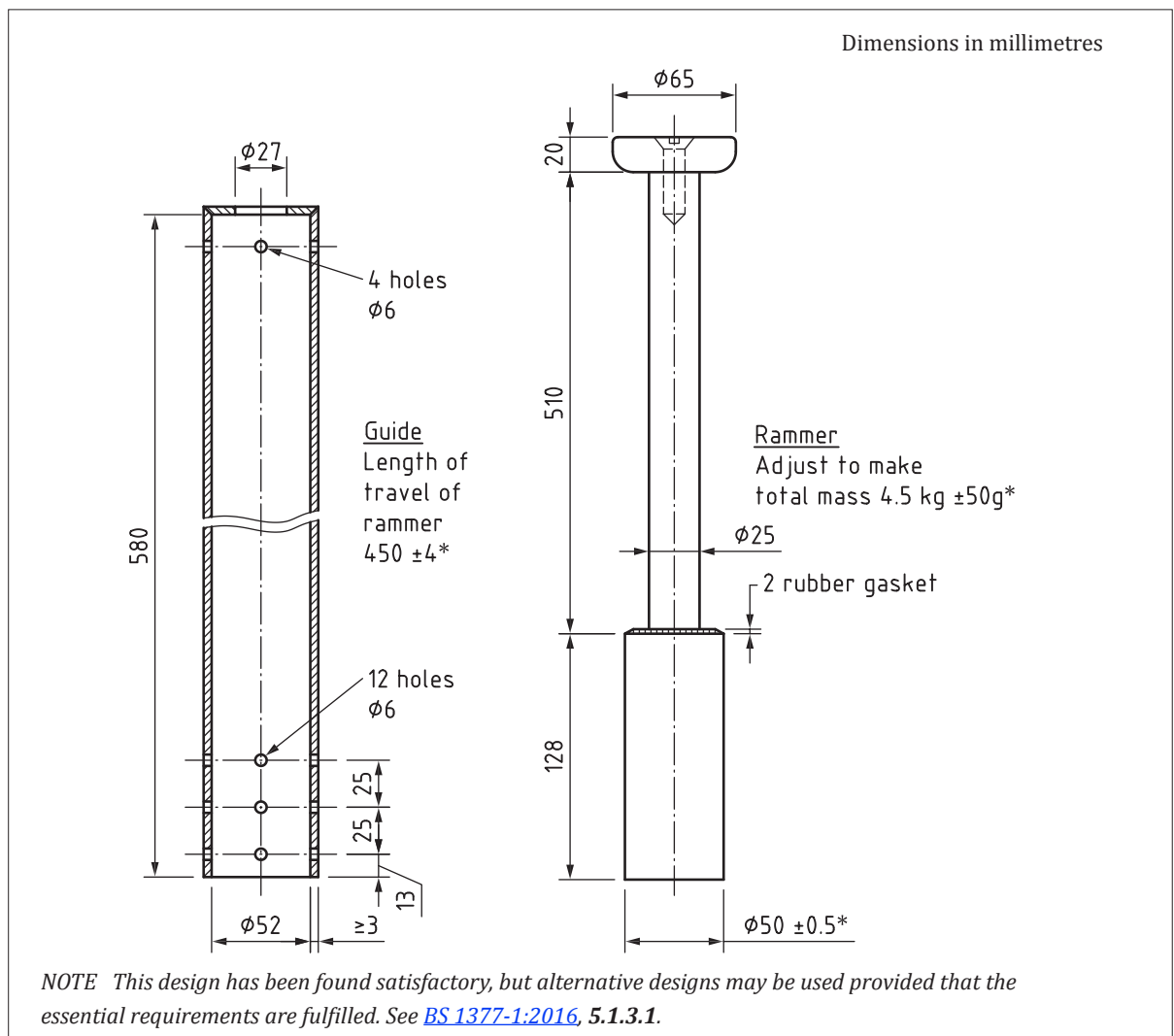
11.5.2.2 *Metal rammer*, having a (50 ± 0.5) mm diameter circular face, and weighing $4.5 \text{ kg} \pm 50 \text{ g}$. The rammer shall be equipped with a suitable arrangement for controlling the height of drop to (450 ± 4) mm.

NOTE 1 A suitable form of hand apparatus is shown in [Figure 7](#).

NOTE 2 A motorized form of the apparatus may be used provided that the essential dimensions of the rammer and mould are adhered to, and provided that the density achieved is within $\pm 2\%$ of the density achieved by using the hand rammer. The machine should be supported on a heavy solid base such as a concrete floor or plinth.

Other items, as specified in [11.3.2.3](#) to [11.3.2.9](#).

Figure 7 — 4.5 kg rammer for compaction test



11.5.3 Preparation of specimen

Prepare the test specimen, as described in [11.2.3.1](#), [11.2.3.2](#), [11.2.3.3](#) or [11.2.3.4](#), as appropriate.

11.5.4 Procedure

11.5.4.1 Compaction procedure for soil particles not susceptible to crushing

- 11.5.4.1.1** Weigh the mould with baseplate attached to 1 g (m_1). Measure the internal dimensions to 0.1 mm.
- 11.5.4.1.2** Attach the extension to the mould and place the mould assembly on a solid base, e.g. a concrete floor or plinth.
- 11.5.4.1.3** Place a quantity of moist soil in the mould such that when compacted it occupies a little over one-fifth of the height of the mould body.
- 11.5.4.1.4** Apply 27 blows from the rammer dropped from a height of 450 mm above the soil as controlled by the guide tube. Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed by soil in the guide tube (see K. H. Head, 2006 [3]).
- 11.5.4.1.5** Repeat [11.5.4.1.3](#) and [11.5.4.1.4](#) four more times so that the amount of soil used is sufficient to fill the mould body, with the surface not more than 6 mm proud of the upper edge of the mould body (see Note to [11.3.4.1.5](#)).
- 11.5.4.1.6** Remove the extension, strike off the excess soil and level off the surface of the compacted soil carefully to the top of the mould using the straightedge. Replace any coarse particles, removed in the levelling process, by finer material from the specimen, well pressed in.
- 11.5.4.1.7** Weigh the soil and mould with baseplate to 1 g (m_2).
- 11.5.4.1.8** Remove the compacted soil from the mould and place it on the large metal tray. Take a representative specimen of the soil for determination of its water content, as described in BS EN ISO 17892-1.
- 11.5.4.1.9** Break up the remainder of the soil, rub it through the 20 mm test sieve and mix with the remainder of the prepared test specimen.
- 11.5.4.1.10** Add a suitable increment of water (see Note to [11.3.4.1.10](#)) and mix it thoroughly into the soil.
- 11.5.4.1.11** Repeat [11.5.4.1.3](#) to [11.5.4.1.10](#) to give a total of at least five determinations. The water contents shall be such that the optimum water content, at which the maximum dry density occurs, lies near the middle of the range.

11.5.4.2 Compaction procedure for soil particles susceptible to crushing

- 11.5.4.2.1** Weigh, measure and prepare the mould, as described in [11.5.4.1.1](#) and [11.5.4.1.2](#).
- 11.5.4.2.2** Carry out a compaction test on each of the prepared specimens in turn, as described in [11.5.4.1.3](#) to [11.5.4.1.8](#).
- 11.5.4.2.3** Discard the remainder of each compacted specimen.

11.5.5 Calculations

For plotting and expression of results, proceed as described in [11.3.5](#).

11.5.6 Test report

The test report shall be in accordance with [11.3.6](#).

11.6 Method using 4.5 kg rammer with CBR mould

COMMENTARY ON 11.6

This test covers the determination of the dry density of soil containing some coarse gravel when it is compacted in a specified manner over a range of water contents. The range includes the optimum water content at which the maximum dry density for this degree of compaction is obtained. In this test the compactive effort is greater than that described in [11.4](#): the mass of the rammer is 4.5 kg, the height of fall is 450 mm, and the number of compacted layers is five. The soil is compacted into a CBR mould.

The test is suitable for soils containing no more than 30% by mass of material retained on the 20 mm test sieve, which might include some particles retained on the 37.5 mm test sieve.

11.6.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

11.6.2 Apparatus

11.6.2.1 *Cylindrical, corrosion-resistant metal mould, i.e. the CBR mould, as described in [15.2.2.2](#).*

11.6.2.2 *Hand or motorized metal rammer weighing 4.5 kg, as described in [11.5.2.2](#).*

11.6.2.3 *Balance, readable to 5 g.*

11.6.2.4 *Large scoop.*

11.6.2.5 *Other items, as specified in [11.3.2.4](#) to [11.3.2.9](#).*

11.6.3 Preparation of specimen

Prepare the test specimen, as described in [11.2.4.1](#), [11.2.4.2](#), [11.2.4.3](#), [11.2.4.4](#), [11.2.4.5](#), or [11.2.4.6](#), as appropriate.

11.6.4 Procedure

11.6.4.1 Compaction procedure for soil particles not susceptible to crushing

11.6.4.1.1 Weigh the mould with baseplate attached to 5 g (m_1). Measure the internal dimensions to 0.5 mm.

11.6.4.1.2 Attach the extension to the mould and place the mould assembly on a solid base, e.g. a concrete floor or plinth.

11.6.4.1.3 Place a quantity of moist soil in the mould such that when compacted it occupies a little over one-fifth of the height of the mould body.

11.6.4.1.4 Apply 62 blows from the rammer dropped from a height of 450 mm above the soil as controlled by the guide tube. Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed by soil in the guide tube (see K. H. Head, 2006 [[3](#)]).

11.6.4.1.5 Repeat [11.6.4.1.3](#) and [11.6.4.1.4](#) four more times so that the amount of soil used is sufficient to fill the mould body, with the surface not more than 6 mm proud of the upper edge of the mould body (see Note to [11.4.4.1.5](#)).

11.6.4.1.6 Remove the extension, strike off the excess soil and level off the surface of the compacted soil carefully to the top of the mould using the straightedge. Replace any coarse articles, removed in the levelling process, by finer material from the specimen, well pressed in.

11.6.4.1.7 Weigh the soil and mould with baseplate to 5 g (m_2).

- 11.6.4.1.8** Remove the compacted soil from the mould and place it on the large metal tray. Take a representative specimen of the soil for determination of its water content, as described in BS EN ISO 17892-1.
- 11.6.4.1.9** Break up the remainder of the soil, rub it through the 20 mm or the 37.5 mm test sieve and mix with the remainder of the prepared test specimen.
- 11.6.4.1.10** Add a suitable increment of water (see Note to [11.4.4.1.10](#)) and mix thoroughly into the soil.
- 11.6.4.1.11** Repeat [11.6.4.1.3](#) to [11.6.4.1.10](#) to give a total of at least five determinations. The water contents shall be such that the optimum water content, at which the maximum dry density occurs, lies near the middle of the range.

11.6.4.2 Compaction procedure for soil particles susceptible to crushing

- 11.6.4.2.1** Weigh, measure and prepare the mould, as described in [11.6.4.1.1](#) and [11.6.4.1.2](#).
- 11.6.4.2.2** Carry out a compaction test on each of the prepared specimens, as described in [11.6.4.1.3](#) to [11.6.4.1.8](#).
- 11.6.4.2.3** Discard the remainder of each compacted specimen.

11.6.5 Calculations

For plotting and expression of results, proceed as described in [11.3.5](#).

11.6.6 Test report

The test report shall be in accordance with [11.3.6](#).

11.7 Compaction method using vibrating hammer

COMMENTARY ON 11.7

This test covers the determination of the dry density of soil, which contains some particles up to coarse gravel size, when it is compacted by vibration in a specified manner over a range of water contents. The range includes the optimum water content at which the maximum dry density for the specified degree of compaction is obtained. In this test the soil is compacted into a CBR mould using an electrically operated vibrating hammer.

The test is suitable for certain soils containing no more than 30% by mass of material retained on the 20 mm test sieve, which may include some particles retained on the 37.5 mm test sieve. It is not generally suitable for fine soils.

11.7.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

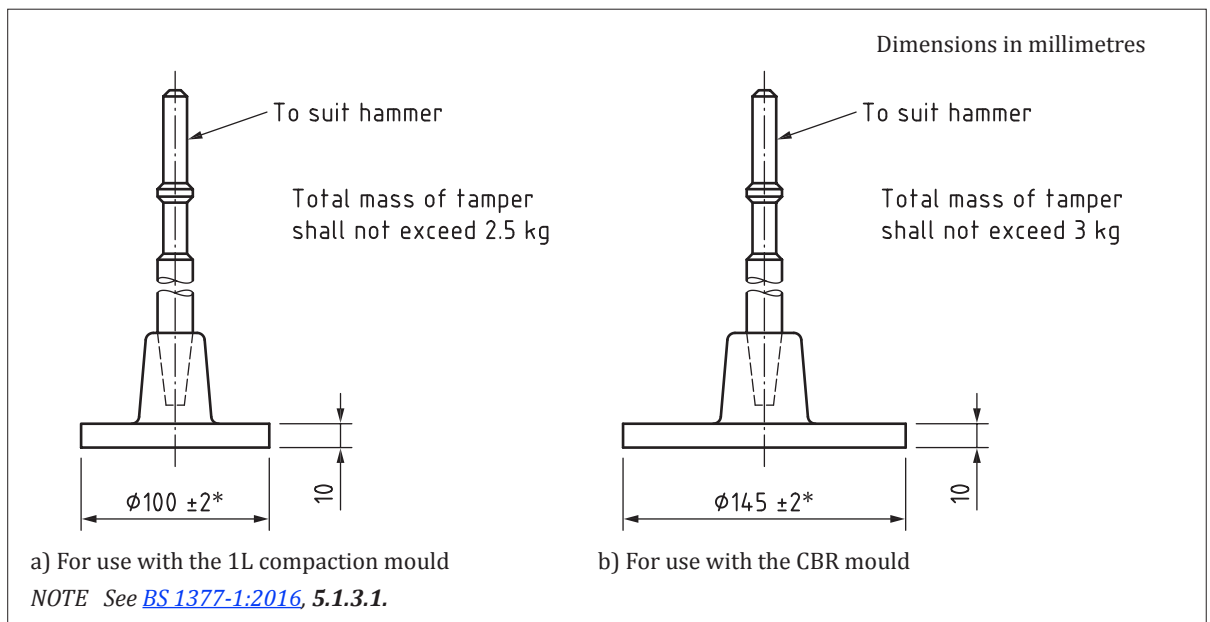
11.7.2 Apparatus

- 11.7.2.1** *Cylindrical, corrosion-resistant metal mould, i.e. the CBR mould, as described in [15.2.2.2](#).*
- 11.7.2.2** *Electric vibrating hammer, having a power consumption between 600 W and 800 W and operating at a frequency between 25 Hz to 60 Hz.*

NOTE For safety reasons the vibrating hammer should operate on 110 V, and an earth leakage circuit breaker should be included between the hammer and the mains supply.
- 11.7.2.3** *Steel tamper for attachment to the vibrating hammer. Essential dimensions are shown in [Figure 8 b\)](#), which also indicates one suitable design of tamper.*
- 11.7.2.4** *Supporting guide frame for vibrating hammer (optional).*

- 11.7.2.5** *Depth gauge or steel rule*, or other device which enables the sample depth to be measured to an accuracy of 0.5 mm.
- 11.7.2.6** *Balance*, readable to 5 g.
- 11.7.2.7** *Straightedge*, e.g. a steel strip approximately 300 mm long, 25 mm wide, and 3 mm thick, with one bevelled edge.
- 11.7.2.8** *Test sieves*, of aperture sizes 37.5 mm and 20 mm, and receiver.
- 11.7.2.9** *Corrosion-resistant metal or plastics tray with sides*, e.g. about 80 mm deep, of a size suitable for the quantity of material to be used.
- 11.7.2.10** *Scoop*.
- 11.7.2.11** *Apparatus for the determination of water content*, as described in BS EN ISO 17892-1.
- 11.7.2.12** *Stopclock*, readable to 1 s.
- 11.7.2.13** *Apparatus for extracting compacted specimens from the mould* (optional).

Figure 8 — *Tampers for vibrating hammer compaction tests*



11.7.3 Calibration of vibrating hammer

11.7.3.1 General

The vibrating hammer shall be maintained in accordance with the manufacturer's instructions. Its working parts shall not be badly worn.

The calibration test described in [11.7.3.3](#) shall be carried out to determine whether the vibrating hammer is in satisfactory working order, and able to conform to the requirements of the test described in [11.7.5](#).

The pressure check described in [11.7.3.4](#) shall be made by the operator carrying out the calibration test.

11.7.3.2 Material

Clean, dry, silica sand shall be used in accordance with the grading in [Table 4](#). The sand shall not have been used previously.

Table 4 — Grading for calibration sand

Sieve size (µm)	Percentage passing
850	100
600	≥75
425	≤25
300	0

This sand shall be sieved through a 600 µm test sieve and the coarse fraction discarded.

11.7.3.3 Calibration test

11.7.3.3.1 Take a (5 ±0.1) kg specimen of the sand specified in [11.7.3.2](#), which has not been used previously, and mix it with water in order to raise its water content to (2.5 ±0.5)%.

11.7.3.3.2 Compact the wet sand in a cylindrical metal mould of 152 mm diameter and 127 mm depth, using the vibrating hammer as specified in [11.7.5.1](#).

NOTE The operator can typically judge the required pressure to apply with sufficient accuracy after first carrying out the check described in [11.7.3.4](#).

11.7.3.3.3 Carry out a total of three tests, all on the same specimen of sand, and determine the mean dry density. Determine the dry density values to the nearest 0.002 Mg/m³.

11.7.3.3.4 If the range of values in the three tests exceeds 0.01 Mg/m³, repeat the procedure. The vibrating hammer shall be suitable for use in the vibrating compaction test if the mean dry density of the sand exceeds 1.74 Mg/m³.

11.7.3.4 Pressure check

Apply pressure combined with vibration to ensure the required degree of compaction. A downward force on the specimen surface of 300 N to 400 N shall be applied, this being greater than the force needed to prevent the hammer bouncing on the soil.

The required pressure shall be assessed by applying the vibrating hammer, without vibration, to a platform scale. The required force is applied when a mass of 30 kg to 40 kg is indicated.

11.7.4 Preparation of specimen

Prepare the test specimen, as described in [11.2.4.1](#), [11.2.4.2](#), [11.2.4.3](#), [11.2.4.4](#), [11.2.4.5](#) or [11.2.4.6](#), as appropriate.

11.7.5 Procedure

11.7.5.1 Compaction procedure for soil particles not susceptible to crushing

11.7.5.1.1 Weigh the mould, with baseplate and extension attached, to 5 g (m_1). Measure the internal dimensions to 0.5 mm.

11.7.5.1.2 Attach the extension to the mould and place the mould assembly on a solid base, e.g. a concrete floor or plinth.

11.7.5.1.3 Place a quantity of moist soil in the mould such that when compacted it occupies a little over one-third of the height of the mould body.

11.7.5.1.4 Place the circular tamper on the soil and compact with the vibrating hammer for (60 ±2) s. During this period apply a steady downward force on the hammer so that the total downward force on the sample, including that from the mass of the hammer, is between 300 N and 400 N (see Note to [11.7.3.3.2](#)).

NOTE A disc of polythene (polyethylene) sheet may be placed immediately beneath the tamper plate to prevent sand particles moving up through the annular gap.

- 11.7.5.1.5** Repeat [11.7.5.1.3](#) and [11.7.5.1.4](#) twice more.
- 11.7.5.1.6** Remove any loose material lying on the surface of the sample around the sides of the mould.
- 11.7.5.1.7** Lay a straightedge across the top of the extension collar and measure down to the surface of the sample to an accuracy of 0.5 mm. Take readings at four points spaced evenly over the surface of the sample, all at least 15 mm from the side of the mould. Calculate the mean height, h (in mm), of the sample. If the sample is less than 127 mm or more than 133 mm in height, reject it and repeat the test from [11.7.5.1.3](#) until a sample of the required height is obtained.
- 11.7.5.1.8** Weigh the soil and mould with baseplate and extension to 5 g (in m^2).
- 11.7.5.1.9** Remove the compacted soil from the mould and place it on the metal tray. Take a representative specimen of the soil for determination of its water content, as described in BS EN ISO 17892-1.
- 11.7.5.1.10** Break up the remainder of the soil, rub it through the 20 mm or the 37.5 mm test sieve and mix with the remainder of the prepared test specimen.
- 11.7.5.1.11** Add a suitable increment of water and mix thoroughly into the soil.

NOTE The water added for each stage of the test should be such that a range of water contents is obtained which includes the optimum water content. In general, increments of 1% to 2% are suitable for sandy and gravelly soils. To increase the accuracy of the test it is often advisable to reduce the increments of water in the region of the optimum water content.

- 11.7.5.1.12** Repeat [11.7.5.1.3](#) to [11.7.5.1.11](#) to give a total of at least five determinations. The water contents shall be such that the optimum water content, at which the maximum dry density occurs, lies near the middle of the range.

11.7.5.2 Compaction procedure for soil particle susceptible to crushing

NOTE The soil should be considered susceptible to crushing during compaction if the sample contains coarse material of a soft nature, e.g. weaker limestone, sandstone, which is reduced in size by the action of the vibrating hammer. The procedure described in this subclause for soils susceptible to crushing during compaction can be applied to all coarse soils if it is convenient to do so.

- 11.7.5.2.1** Weigh, measure and prepare the CBR mould, as described in [11.7.5.1.1](#) and [11.7.5.1.2](#).
- 11.7.5.2.2** Carry out a compaction test on each of the prepared specimens in turn, as described in [11.7.5.1.3](#) to [11.7.5.1.9](#).
- 11.7.5.2.3** Discard the remainder of each compacted specimen.

11.7.6 Calculations, plotting and expression of results

- 11.7.6.1** Calculate the bulk density, ρ (in Mg/m^3), of each compacted specimen using the formula:

$$\rho = \left(\frac{m_2 - m_1}{Ah} \right) 1000$$

where:

- m_1 is the mass of mould and baseplate and extension (in g);
- m_2 is the mass of mould, baseplate and extension and compacted soil (in g);
- h is the height of the compacted specimen (in mm); and
- A is the circular area of the mould (in mm^2).

- 11.7.6.2** Calculate the dry density, ρ_d (in Mg/m^3), of each compacted specimen using the formula:

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

where:

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

- 11.7.6.3** Plot the dry densities obtained from a series of determinations on the y-axis against the corresponding water contents on the x-axis. Draw a curve of best fit to the plotted points and identify the position of the maximum on this curve. Read off the values of dry density and water content, to three significant figures, corresponding to that point (see [Figure 2](#)).

NOTE The maximum may lie between two observed points however, when drawing the curve, care should be taken not to exaggerate its peak.

- 11.7.6.4** On the same graph, plot the curves corresponding to 0%, 5% and 10% air voids, calculated using the formula:

$$\rho_d = \frac{1 - \frac{V_a}{100}}{\frac{1}{\rho_s} + \frac{W}{100\rho_w}}$$

where:

ρ_d is the dry density in (in Mg/m^3);

ρ_s is the particle density (in Mg/m^3);

ρ_w is the density of water (in Mg/m^3), assumed equal to 1;

V_a is the volume of air voids in the soil, expressed as a percentage of the total volume of the soil (equal to 0 %, 5 %, 10 % for the purpose of the plot); and

w is the water content (%).

NOTE See [Figure 2](#) with regard to the dry density/water content relationship curve.

11.7.7 Test report

The test report shall affirm that the test was carried out in accordance with [11.7](#) and contain the:

- method of test used;
- specimen preparation procedure and whether a single specimen or separate specimens were used;
- experimental points and the smooth curve drawn through them showing the relationship between water content and dry density;
- compaction dry density corresponding to the maximum dry density on the water content/dry density curve reported as the maximum dry density to the nearest 0.01 (in Mg/m^3);
- percentage water content corresponding to the maximum compaction dry density on the water content/dry density curve reported as the optimum water content to two significant figures;
- amount of particles retained on the 37.5 mm test sieve and 20 mm test sieve reported to the nearest 1% by dry mass;
- grading zone (1 to 5);
- particle density and whether measured (and if so, the method used) or assumed; and
- information required by [BS 1377-1:2016](#), **10.1**.

12 Determination of maximum and minimum dry densities for coarse soils

COMMENTARY ON CLAUSE 12

An indication of the state of compaction of a coarse (free-draining) soil is obtained by relating its dry density to its maximum and minimum possible densities (the limiting densities). The tests described in this clause enable these parameters to be determined for coarse soils.

Two tests are described for the determination of maximum density, one for sands and one for gravelly soils. In both tests the soil is compacted under water with a vibrating hammer. The test on sands is carried out in a 1 L mould. Gravelly soils are compacted in a CBR mould using a procedure similar to that described in [11.7](#).

Two tests are described for determination of minimum density. One is a simple dry shaking test for sands and the other is a dropping test for gravelly soils.

The in-situ density can be related to the limiting densities by means of the density index.

When the amount of material is limited or the material is likely to be crushed during testing, alternative methods are available, see S. Knudsen et al. 2020 [4]. These are the preferred methods for offshore investigations in accordance with [BS EN ISO 19901-8](#).

12.1 Determination of maximum density of sands

COMMENTARY ON 12.1

This test covers the determination of the maximum density to which a clean sand can be compacted. The method is suitable for sands containing a small amount of material passing a 63 μm test sieve and up to 10% of fine gravel passing a 6.3 mm test sieve. The soil is compacted into a 1 L mould under water using an electric vibrating hammer.

Use of a vibrating hammer is appropriate for free-draining soils containing only a small proportion (typically not exceeding 10% by mass) of material finer than 63 μm , as some fine material is likely to escape from the sample during vibration.

This test is not applicable to soils containing particles susceptible to crushing when compacted by the vibrating hammer.

12.1.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

12.1.2 Apparatus

12.1.2.1 *Cylindrical, corrosion-resistant metal mould, i.e. the 1 L mould, with baseplate and extension, as described in [11.3.2.1](#).*

12.1.2.2 *Electric vibrating hammer, as specified in [11.7.2.2](#).*

NOTE For safety reasons, the vibrating hammer should operate on 110 V and an earth leakage circuit breaker should be included between the hammer and the mains supply.

12.1.2.3 *Steel tamper for attachment to the vibrating hammer.*

NOTE Essential dimensions are shown in [Figure 8 a\)](#), which also indicates one suitable design of tamper.

12.1.2.4 *Supporting guide frame for vibrating hammer (optional).*

12.1.2.5 *Watertight container, large enough to hold the compaction mould.*

12.1.2.6 *Balance, readable to 1 g.*

- 12.1.2.7 *Straightedge*, e.g. a steel strip approximately 300 mm long, 25 mm wide, and 3 mm thick, with one bevelled edge.
- 12.1.2.8 *Test sieves*, of aperture sizes 2 mm and 6.3 mm, and receiver.
- 12.1.2.9 *Palette knife or spatula*.
- 12.1.2.10 *Large metal tray*, with sides about 80 mm deep.
- 12.1.2.11 *Small metal tray*, with sides about 50 mm deep.
- 12.1.2.12 *Bucket or similar watertight container*.
- 12.1.2.13 *Small scoop*.
- 12.1.2.14 *Drying oven*, capable of maintaining a temperature of 105 °C to 100 °C.
- 12.1.2.15 *Stop clock*, readable to 1 s.
- 12.1.2.16 *Apparatus for extracting compacted specimens from the mould* (optional).
- 12.1.2.17 *Water container of approximately 5 L capacity*.

12.1.3 Calibration of vibrating hammer

The vibrating hammer shall be checked and calibrated, as specified in [11.7.3](#).

12.1.4 Preparation of sample

- 12.1.4.1 Take enough material from the soil prepared, as described in of [BS 1377-1:2016](#), 8.6.4, to enable at least two test specimens to be prepared.
- 12.1.4.2 Sieve the soil on a 6.3 mm test sieve. The retained material may be broken down to sizes between 2 mm and 6.3 mm provided that the total proportion by mass in this size range does not exceed 10%.
- 12.1.4.3 Mix the soil thoroughly on the large metal tray and divide into at least two representative specimens of approximately 3 kg each.
- 12.1.4.4 Pour each prepared specimen into warm water in a bucket or suitable container and stir thoroughly to remove air bubbles.
- 12.1.4.5 Cover the container and allow to stand for several hours, e.g. overnight, to cool.

12.1.5 Procedure

- 12.1.5.1 Measure the internal dimensions of the compaction mould to 0.1 mm.
- 12.1.5.2 Attach the extension to the mould and place the mould assembly in the watertight container on a solid base, e.g. a concrete floor or plinth. Pour water to approximately 50 mm depth in the mould body and to the same level in the surrounding container.
- 12.1.5.3 Add a specimen of the soil-water mixture to the mould with the scoop, placing it carefully under the water surface without loss of fines and without segregation of coarse particles. The quantity of specimen should be such that the mould is about one-third filled when compacted. Add water to the surrounding container up to the same level as in the mould. Make the soil surface approximately level.
- 12.1.5.4 Place the circular tamper on the soil and compact with the vibrating hammer for at least 2 min or until there is no further significant decrease in sample height. During this period apply a steady downward force on the hammer so that the total downward force on the sample (including that from the mass of the hammer) is between 300 N and 400 N.

NOTE 1 For safety reasons the vibrating hammer should be protected from water splashing up from the mould and its container.

NOTE 2 The operator can usually judge the required pressure to apply with sufficient accuracy after first carrying out the calibration specified in [11.7.3.4](#).

NOTE 3 A disc of polyethene (polyethylene) sheet can be placed immediately beneath the tamper plate to prevent sand particles moving up through the annular gap.

- 12.1.5.5** Repeat [12.1.5.3](#) and [12.1.5.4](#) twice more, ensuring that the surface of the specimen is always under water. After compaction of the third layer, its surface shall be at least level with, but not more than 6 mm proud of, the mould body.

NOTE The tamper should be removed with care to avoid disturbance of the sand surface by creating suction.

- 12.1.5.6** Remove the mould containing the soil from the container, clean off any adhering soil from the outside and allow free water to drain from the specimen.
- 12.1.5.7** Remove the extension carefully and trim off the compacted soil level with the top of the mould, using the straightedge. Refill cavities, left by removal of any coarse particles, with finer material, well pressed in.
- 12.1.5.8** Extract the compacted soil from the mould into the small weighed metal tray, without loss of any soil particles.
- 12.1.5.9** Dry the soil in an oven at 105 °C to 110 °C, weigh when cool and determine the mass of soil, m (in g), to 1 g.
- 12.1.5.10** Repeat [12.1.5.2](#) to [12.1.5.9](#) using the second batch of prepared specimen.
- 12.1.5.11** If the dry masses from the two tests differ by more than 50 g, repeat the procedure using fresh specimens of the soil.

12.1.6 Calculations and expression of results

- 12.1.6.1** Calculate the internal volume, V (in cm³), of the mould.
- 12.1.6.2** Calculate the maximum dry density (ρ_{dmax}) of the soil (in Mg/m³) using the formula:

$$\rho_{\text{dmax}} = \frac{m}{V}$$

where:

m is the greater of the two dry masses of soil compacted into the mould (in g).

- 12.1.6.3** Express the result to the nearest 0.01 Mg/m³.

12.1.7 Test report

The test report shall affirm that the test was carried out in accordance with [12.1](#) and shall contain the:

- method of test used;
- maximum dry density;
- percentage of material retained on the 6.3 mm test sieve and whether it was replaced by smaller particles; and
- information required by [BS 1377-1:2016](#), **10.1**.

12.2 Maximum density of gravelly soils

COMMENTARY ON 12.2

This test covers the determination of the maximum density to which a gravel or sandy gravel can be compacted. The method is suitable for soils passing the 37.5 mm test sieve and containing a small amount of material passing the 63 μm test sieve. The soil is compacted into a CBR mould using a vibrating hammer.

Use of a vibrating hammer is appropriate for free-draining soils containing only a small proportion (typically not exceeding 10% by mass) of material finer than 63 μm , as some fine material is likely to escape from the sample during vibration.

This test is not applicable to soils containing particles susceptible to crushing when compacted by the vibrating hammer.

12.2.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

12.2.2 Apparatus

12.2.2.1 *Cylindrical, corrosion-resistant metal mould, i.e. the CBR mould, as described in [15.2.2.2](#).*

12.2.2.2 *Vibrating hammer, as specified in [11.7.2.2](#).*

NOTE For safety reasons the vibrating hammer should operate on 110 V and an earth leakage circuit breaker should be included between the hammer and the mains supply.

12.2.2.3 *Steel tamper for attachment to the vibrating hammer, as specified in [11.7.2.3](#). [See [Figure 8 b](#)].*

12.2.2.4 *Supporting guide frame for vibrating hammer (optional).*

12.2.2.5 *Watertight container, large enough to hold the mould.*

12.2.2.6 *Balance, readable to 5 g.*

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

12.2.2.8 *Test sieves, of aperture sizes 37.5 mm and 20 mm and a receiver.*

12.2.2.9 *Two corrosion-resistant, metal or plastics trays, with sides, e.g. approximately 80 mm deep, of a size suitable for the quantity of material to be used.*

12.2.2.10 *Bucket, or similar waterproof container.*

12.2.2.11 *Scoop.*

12.2.2.12 *Drying oven, capable of maintaining a temperature of 105 °C to 110 °C.*

12.2.2.13 *Stopclock, readable to 1 s.*

12.2.2.14 *Apparatus for extracting compacted specimens from the mould.*

12.2.2.15 *Water container, of approximately 10 L capacity.*

12.2.3 Calibration of vibrating hammer

The vibrating hammer shall be checked and calibrated, as specified in [11.7.3](#).

12.2.4 Preparation of specimen

- 12.2.4.1 Take enough material from the soil prepared as described in [BS 1377-1:2016](#), 8.6.4, to enable at least two test specimens to be prepared.
- 12.2.4.2 Sieve the soil on a 37.5 mm test sieve. The retained material can be broken down to sizes between 20 mm and 6.3 mm provided that the total proportion by mass in this size range does not exceed 30%.
- 12.2.4.3 Mix the soil thoroughly and divide into at least two representative specimens of approximately 8 kg each.
- 12.2.4.4 Pour each prepared specimen into warm water in a bucket or suitable container and stir thoroughly to remove air bubbles.
- 12.2.4.5 Cover the container and allow to stand for several hours, e.g. overnight, to cool.

12.2.5 Procedure

- 12.2.5.1 Measure the internal dimensions of the mould to 0.5 mm.
- 12.2.5.2 Attach the extension to the mould and place the mould assembly in the watertight container on a suitable base, e.g. a concrete floor or plinth. Pour water to approximately 50 mm depth in the mould body, and to the same level in the surrounding container.
- 12.2.5.3 Add some of the soil-water mixture to the mould with the scoop, placing it carefully under the water surface without loss of fines and without segregation of coarse particles and continue until the mould is about one-third filled when compacted. Add water to the surrounding container up to the same level as in the mould. Make the soil surface approximately level.
- 12.2.5.4 Place the circular tamper on the soil and compact with the vibrating hammer. Apply a steady downward force between 300 N and 400 N for at least 3 min or until there is no further significant decrease in sample height.

NOTE 1 For safety reasons the vibrating hammer should be protected from water splashing up from the mould and its container.

NOTE 2 The operator can usually judge the required pressure to apply with sufficient accuracy after first carrying out the calibration described in [11.7.3.4](#).

NOTE 3 A disc of polyethylene (polyethylene) sheet can be placed immediately beneath the tamper plate to prevent sand particles moving up through the annular gap.

- 12.2.5.5 Repeat [12.2.5.3](#) and [12.2.5.4](#) twice, each adding a third of the height of the mould after compaction, ensuring the specimen is always under water. After compaction of the third layer its surface shall be at least level with, but not more than 6 mm proud of, the mould body.

NOTE The tamper should be removed with care to avoid disturbance of the soil surface by creating suction.

- 12.2.5.6 Remove the mould containing the soil from the container, clean off any adhering soil from the outside and allow free water to drain from the specimen.
- 12.2.5.7 Remove the extension carefully and trim off the compacted soil level with the top of the mould, using the straightedge. Refill cavities left by removal of any coarse particles with finer material, well pressed in.
- 12.2.5.8 Extract the compacted soil from the mould into a weighed metal tray, without loss of any soil particles.

- 12.2.5.9** Dry the soil in an oven at 105 °C to 110 °C, weigh when cool and determine the mass of soil, m (in g), to 5 g.
- 12.2.5.10** Repeat [12.2.5.2](#) to [12.2.5.9](#) using the second batch of prepared specimen.
- 12.2.5.11** If the dry masses from the two tests differ by more than 150 g, repeat the procedure using fresh specimens of the soil.

12.2.6 Calculations and expression of results

- 12.2.6.1** Calculate the internal volume, V (in cm³), of the mould.
- 12.2.6.2** Calculate the maximum dry density of the soil, ρ_{dmax} (in Mg/m³), using the formula:

$$\rho_{dmax} = \frac{m}{v}$$

where:

m is the greater of the two dry masses of soil compacted into the mould (in g).

- 12.2.6.3** Express the result to the nearest 0.01 Mg/m³.

12.2.7 Test report

The test report shall affirm that the test was carried out in accordance with [12.2](#) and shall contain the:

- method of test used;
- maximum dry density;
- percentage of material retained on the 37.5 mm test sieve and whether it was replaced by smaller particles; and
- relevant information required by [BS 1377-1:2016](#), **10.1**.

12.3 Minimum density of sands

COMMENTARY ON 12.3

This test covers the determination of the minimum density which a clean, dry sand can sustain. This does not necessarily relate to a state attainable in the field. The method is suitable for sands containing up to about 10% of fine material passing the 63 µm test sieve and with no material retained on the 2 mm test sieve. The dry sand is shaken in a glass cylinder and allowed to fall freely, thereby entrapping air and forming a grain structure enclosing the maximum possible volume of voids.

12.3.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.

12.3.2 Apparatus

- 12.3.2.1** 1 L glass measuring cylinder, graduated to 20 mL, preferably without a pouring lip.
- 12.3.2.2** Rubber bung, to fit the cylinder or a piece of rubber membrane and a rubber O-ring or other suitable material to seal its mouth.
- 12.3.2.3** Balance, readable to 1 g.
- 12.3.2.4** Drying oven, capable of maintaining a temperature of 105 °C to 110 °C, in accordance with [BS 1377-1:2016](#), **5.2.2.1**.

12.3.2.5 2 mm test sieve, and receiver.

12.3.3 Preparation of specimen

12.3.3.1 Prepare the sand in accordance with [BS 1377-1:2016](#), **8.6.4**, and pass it through a 2 mm test sieve if necessary.

12.3.3.2 Obtain a representative test specimen of (1 000 ±1) g.

12.3.4 Procedure

12.3.4.1 Place the weighed specimen of sand in the glass cylinder and fit the bung or cover.

12.3.4.2 Shake the cylinder to loosen the sand and invert it a few times.

12.3.4.3 Turn the cylinder upside down, pause until all the sand is at rest, then quickly turn it right way up. Stand the cylinder on a flat surface without jarring it.

12.3.4.4 Record the volume reading (*V*) at the mean level of the surface of the sand to the nearest 10 mL. Avoid shaking or jolting the cylinder during this operation.

12.3.4.5 Repeat [12.3.4.2](#), [12.3.4.3](#) and [12.3.4.4](#) to give at least 10 readings.

12.3.5 Calculations and expression of results

Calculate the minimum dry density of the sand, ρ_{smin} (in Mg/m³), using the formula:

$$\rho_{smin} = \frac{1\,000}{V}$$

where:

V is the greatest of the 10 or more volume readings recorded (in mL).

Express the result to the nearest 0.01 Mg/m³.

12.3.6 Test report

The test report shall affirm that the test was carried out in accordance with [12.3](#) and shall contain the:

- a) method of test used;
- b) minimum dry density;
- c) percentage of material retained on the 2 mm test sieve; and
- d) relevant information required by [BS 1377-1:2016](#), **10.1**.

12.4 Minimum density of gravelly soils

COMMENTARY ON 12.4

This test covers the determination of the minimum density at which a gravel or sandy gravel can be placed. This method is suitable for gravelly soils passing the 37.5 mm test sieve and containing no more than 10% of fine material passing the 63 µm test sieve. The soil is allowed to fall freely into a CBR mould, forming a grain structure enclosing the maximum possible volume of voids.

12.4.1 General

The requirements of [BS 1377-1](#), where appropriate, shall apply to this test method.