

Methods of test for

Soils for civil engineering purposes —

Part 4: Compaction-related tests

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Foreword

This Part of BS 1377 has been prepared under the direction of the Road Engineering Standards Policy Committee. It is a revision of Clause 4 of BS 1377:1975 which is superseded by amendment. BS 1377 was first published in 1948 and first appeared in metric form in 1975. BS 1377:1975 which has now been withdrawn is replaced by the following Parts of BS 1377:1990:

- *Part 1: General requirements and sample preparation;*
- *Part 2: Classification tests;*
- *Part 3: Chemical and electro-chemical tests;*
- *Part 4: Compaction-related tests;*
- *Part 5: Compressibility, permeability and durability tests;*
- *Part 6: Consolidation and permeability tests in hydraulic cells and with pore pressure measurement;*
- *Part 7: Shear strength tests (total stress);*
- *Part 8: Shear strength tests (effective stress);*
- *Part 9: In-situ tests.*

Reference should be made to Part 1 of BS 1377 for further information about each of the Parts.

The following methods of test, additional to those described in the 1975 standard, have been introduced.

Determination of the maximum and minimum densities of granular soils.

Determination of the moisture condition value.

Determination of the chalk crushing value.

In the dry density/moisture relationship tests, and the California Bearing Ratio (CBR) test, sample preparation procedures have been set out in more detail than before, with explanatory flow diagrams.

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

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 63 and a back cover.

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1 Scope

This Part of BS 1377 describes methods of test for determining characteristics related to the compaction of soils, which can be used as a basis for specifying requirements for soils compacted in the field.

This Part also includes a method for assessing an empirical strength criterion (the CBR value) of a compacted or undisturbed soil used as a sub-grade material for pavement construction.

Reference is made to some of the classification tests described in BS 1377-2.

Reference is made to BS 1377-1 for general requirements that are relevant to all Parts of this standard, and for methods of preliminary preparation of soil for testing.

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

2 Terms and definitions

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

3 Determination of dry density/moisture content relationship

3.1 General

3.1.1 Principle. 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 which 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 6.) For a given degree of compaction of a given cohesive soil there is an optimum moisture content at which the dry density obtained reaches a maximum value. For cohesionless soils an optimum moisture content might be difficult to define.

NOTE For some highly permeable soils such as clean gravels, uniformly graded and coarse clean sands, the results of the laboratory compaction test may provide only a poor guide for specifications on field compaction. The laboratory test might indicate meaningless values of moisture 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 4 would be more appropriate.

The objective of the tests described in this clause is to obtain relationships between compacted dry density and soil moisture content, using two magnitudes of manual compactive effort, or compaction by vibration.

3.1.2 Types of test. Three types of compaction test are described, each with procedural variations related to the nature of the soil. The first is the light manual compaction test in which a 2.5 kg rammer is used. The second is the heavy manual compaction test which is similar but gives a much greater degree of compaction by using a 4.5 kg rammer with a greater drop on thinner layers of soil.

For both these tests a compaction mould of 1 L internal volume is used for soil in which all particles pass a 20 mm test sieve. If there is a limited amount of particles up to 37.5 mm size, equivalent tests are 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 If more than 30 % of material is retained on a 20 mm test sieve the material is too coarse to be tested.

The third type of test makes use of a vibrating hammer, and is intended mainly for granular soils passing a 37.5 mm test sieve, with no more than 30 % retained on a 20 mm test sieve. The soil is compacted into a CBR mould.

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 3.2. Test procedures are described separately in 3.3, 3.4, 3.5, 3.6 and 3.7.

The compaction procedures are summarized in Table 1.

Table 1 — Summary of compaction procedures

Test procedure clause reference	Mass of rammer kg	Soil particles susceptible to crushing	Type of mould used
3.3.4.1	2.5	)	1L
3.5.4.1	4.5	) no (a)	
3.3.4.2	2.5	)	1L
3.5.4.2	4.5	) yes (b)	
3.4.4.1	2.5	)	CBR
3.6.4.1	4.5	) no (a)	
3.4.4.2	2.5	)	CBR
3.6.4.2	4.5	) yes (b)	
3.7.5.1	(vibrating hammer)	no (a)	CBR
3.7.5.2		yes (b)	
1 L = 1 L compaction mould, as described in 3.3.2.1. CBR = CBR mould, as described in 7.2.2.2. (a) and (b) refer to methods in Table 2.			

3.2 Preparation of samples for compaction tests

3.2.1 General. 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 on whether or not the soil particles are susceptible to crushing during compaction. The assessment of these factors is covered in 3.2.2.

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 3.2.4 and 3.2.5.

For soils containing particles that are susceptible to crushing, it is necessary to prepare separate batches of soil at different moisture 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 3.2.6 and 3.2.7.

For stiff, cohesive 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 cohesive soil, and the size of pieces obtained, should be recorded. Suggested methods are to shred the soil so that it could pass through a 5 mm test sieve, or to chop it into pieces, e.g. to pass a 20 mm test sieve.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.2.2 Preliminary assessment. The initial soil sample for testing shall be obtained in accordance with the procedure described in 7.6.1 to 7.6.3 of BS 1377-1:1990. The procedures to be used for sample preparation and for carrying out the compaction test shall be selected on the basis of 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 granular material of a soft nature, e.g. soft limestone, sandstone, etc., which would be reduced in size by the action of the 2.5 kg rammer. The procedure described in 3.3.4.2, 3.4.4.2, 3.5.4.2, and 3.6.4.2 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 sample 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 may be determined by measuring the moisture content using a representative portion. If enough soil is available to meet the requirements of Clause 9 of BS 1377-2:1990 a separate sample may be used for this sieving operation.

c) On the basis of these percentages the soil can be assigned to one of the grading zones (1) to (5) in Table 2, which are also shown diagrammatically in Figure 1. 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 sample preparation, the minimum mass of soil required, and the type of mould to use for the compaction test are indicated in Table 2, which takes account of the above factors.

e) The selection of methods is also shown in the form of a flow chart in Figure 2.

3.2.3 Apparatus

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

3.2.3.2 *A balance* readable to 5 g.

3.2.3.3 *A balance* readable to 1 g.

3.2.3.4 *A 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.

3.2.3.5 *A large metal scoop*.

3.2.3.6 *A palette knife or spatula*.

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

3.2.3.8 *Apparatus for determination of moisture content* as described in 3.2 of BS 1377-2:1990.

3.2.3.9 *An implement for shredding stiff, cohesive soil*.

3.2.4 *Preparation of soils not susceptible to crushing for compaction in 1 L mould*.

3.2.4.1 *Grading zone (1) for soils passing the 20 mm test sieve*.

3.2.4.1.1 Prepare and subdivide the initial sample by the procedures described in 7.6 of BS 1377-1:1990 to produce a representative sample of about 6 kg of the soil.

3.2.4.1.2 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 will vary with the type of soil under test. In general, with sandy and gravelly soils a moisture content of 4 % to 6 % would be suitable, while with cohesive soils a moisture content about 8 % to 10 % below the plastic limit of the soil would usually 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 cohesive 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.

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

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

3.2.4.2 *Grading zone (2) for soils passing the 37.5 mm test sieve with at least 95 % passing the 20 mm test sieve*

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

3.2.4.2.2 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.

3.2.4.2.3 Subdivide the finer material and proceed as described in 3.2.4.1.

Alternatively, the whole sample can be used as described in 3.2.5.1 for compaction in a CBR mould.

3.2.5 Preparation of soils not susceptible to crushing for compaction in CBR mould

3.2.5.1 *Grading zone (3) for soils passing the 37.5 mm test sieve with 70 % to 95 % passing the 20 mm test sieve*

Prepare and subdivide the initial sample using the procedure described in 7.6 of BS 1377-1:1990 to produce a representative sample of about 15 kg of the soil, otherwise proceed as described in 3.2.4.1.

3.2.5.2 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

3.2.5.2.1 Weigh the whole sample and record the mass.

3.2.5.2.2 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 moisture content would also be affected. The larger CBR mould is therefore specified for this type of material.

3.2.5.2.3 Subdivide the finer material to produce a 25 kg sample, otherwise proceed as described in **3.2.4.1**.

3.2.5.3 Grading zone (5) for soils with 90 % to 95 % passing the 37.5 mm test sieve, and at least 70 % passing the 20 mm test sieve

3.2.5.3.1 Weigh the soil sample.

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

3.2.5.3.3 Replace this material by the same quantity of material of similar characteristics which 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.

3.2.5.3.4 Subdivide the material to produce a sample of approximately 15 kg of the soil, otherwise proceed as described in **3.2.4.1**.

3.2.6 Preparation of soils susceptible to crushing for compaction in 1 L mould

3.2.6.1 Grading zone (1) for soils passing the 20 mm test sieve

Table 2 — Summary of sample preparation methods

Grading zone	Minimum percentage passing test sieves		Preparation procedure clause reference		Minimum mass of prepared soil required		Type of mould used
	20 mm	37.5 mm	(a)	(b)	(a)	(b)	
(1)	100 %	100 %	3.2.4.1	3.2.6.1	) kg	kg	1 L
(2)	95	100	3.2.4.2	3.2.6.2	) 6	15	
(3)	70	100	3.2.5.1	3.2.7.1	)		
(4)	70	95	3.2.5.2	3.2.7.2	) 15	40	CBR
(5)	70	90	3.2.5.3	3.2.7.3	)		
(x)	less than 70	less than 90	(Tests not applicable)				
(a) Soil particles not susceptible to crushing during compaction. (b) Soil particles susceptible to crushing during compaction. 1 L = one-litre compaction mould. CBR = CBR mould.							

3.2.6.1.1 Subdivide the initial sample to produce five or more representative samples, each of about 2.5 kg, using the procedure described in **7.6** of BS 1377-1:1990.

3.2.6.1.2 Mix each sample thoroughly with a different amount of water to give a suitable range of moisture contents (see notes 1 and 2 to **3.2.4.1.2**). The range of moisture 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 sample should be such that a range of moisture contents is obtained which includes the optimum moisture content. In general, increments of 1 % to 2 % are suitable for sandy and gravelly soils and of 2 % to 4 % for cohesive soils. To increase the accuracy of the test it might be desirable to prepare samples with smaller increments of water in the region of the optimum moisture content.

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

3.2.6.1.4 If the soil is cohesive seal each sample in an airtight container and store for at least 24 h.

3.2.6.2 *Grading zone (2) for soils passing the 37.5 mm test sieve with at least 95 % passing the 20 mm test sieve*

3.2.6.2.1 Weigh the whole sample and record the mass.

3.2.6.2.2 Remove and discard the material retained on the 20 mm test sieve (see note to **3.2.4.2.2**).

3.2.6.2.3 Subdivide the finer material, and proceed as described in **3.2.6.1**.

Alternatively, the whole sample can be used as described in **3.2.7.1** for compaction in a CBR mould.

3.2.7 Preparation of soils susceptible to crushing for compaction in CBR mould

3.2.7.1 *Grading zone (3) for soil passing the 37.5 mm test sieve with 70 % to 95 % passing the 20 mm test sieve*

Subdivide the initial sample to produce five or more representative samples each of approximately 6 kg using the procedure described in **7.6** of BS 1377-1:1990, otherwise proceed as described in **3.2.6.1**.

3.2.7.2 *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*

3.2.7.2.1 Weigh the whole sample and record the mass.

3.2.7.2.2 Remove and weigh the material retained on the 37.5 mm test sieve (see note to **3.2.5.2.2**).

3.2.7.2.3 Subdivide the finer material, and proceed as described in **3.2.7.1**.

3.2.7.3 *Grading zone (5) for soils containing 90 % to 95 % passing the 37.5 mm test sieve, and at least 70 % passing the 20 mm test sieve*

3.2.7.3.1 Weigh the soil sample.

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

3.2.7.3.3 Replace this material by the same quantity of material of similar characteristics which passes the 37.5 mm test sieve and is retained on the 20 mm test sieve. (See note to **3.2.5.3.3**).

3.2.7.3.4 Subdivide the material to produce five or more 6 kg samples of the soil, otherwise proceed as described in **3.2.6.1**.

3.3 Method using 2.5 kg rammer for soils with particles up to medium-gravel size

3.3.1 *General.* This test covers the determination of the dry density of soil passing a 20 mm test sieve when it is compacted in a specified manner over a range of moisture contents. The range includes the optimum moisture 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.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.3.2 Apparatus

3.3.2.1 *A 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 3 which also indicates one suitable design of mould. The internal faces shall be smooth, clean and dry before each use.

3.3.2.2 *A 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. One suitable form of hand apparatus is shown in Figure 4.

NOTE 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 ± 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.

3.3.2.3 *A balance* readable to 1 g.

3.3.2.4 *A palette knife or spatula.*

3.3.2.5 *A straightedge*, e.g. a steel strip about 300 mm long, 25 mm wide, and 3 mm thick, with one bevelled edge.

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

3.3.2.7 *A 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.

3.3.2.8 *Apparatus for moisture content determination*, as described in 3.2 of BS 1377-2:1990.

3.3.2.9 *Apparatus for extracting specimens from the mould* (optional).

3.3.3 *Preparation of sample*. Prepare the test sample as described in 3.2.4.1, 3.2.4.2, 3.2.6.1 or 3.2.6.2 as appropriate.

3.3.4 Procedure

3.3.4.1 *Compaction procedure for soil particles not susceptible to crushing*

3.3.4.1.1 Weigh the mould with baseplate attached to 1 g (m_1).

Measure the internal dimensions to 0.1 mm.

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

3.3.4.1.3 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.

3.3.4.1.4 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.

3.3.4.1.5 Repeat 3.3.4.1.3 and 3.3.4.1.4 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.

3.3.4.1.6 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 sample, well pressed in.

3.3.4.1.7 Weigh the soil and mould with baseplate to 1 g (m_2).

3.3.4.1.8 Remove the compacted soil from the mould and place it on the metal tray. Take a representative sample of the soil for determination of its moisture content as described in 3.2 of BS 1377-2:1990.

3.3.4.1.9 Break up the remainder of the soil, rub it through the 20 mm test sieve and mix with the remainder of the prepared test sample.

3.3.4.1.10 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 moisture contents is obtained which includes the optimum moisture content. In general, increments of 1 % to 2 % are suitable for sandy and gravelly soils and of 2 % to 4 % for cohesive soils. To increase the accuracy of the test it is often advisable to reduce the increments of water in the region of the optimum moisture content.

3.3.4.1.11 Repeat 3.3.4.1.3 to 3.3.4.1.10 to give a total of at least five determinations. The moisture contents shall be such that the optimum moisture content, at which the maximum dry density occurs, lies near the middle of the range.

3.3.4.2 *Compaction procedure for soil particles susceptible to crushing*

3.3.4.2.1 Weigh, measure and prepare the mould as described in 3.3.4.1.1 and 3.3.4.1.2.

3.3.4.2.2 Carry out a compaction test on each of the prepared samples as described in 3.3.4.1.3 to 3.3.4.1.8.

3.3.4.2.3 Discard the remainder of each compacted sample.

3.3.5 *Calculations, plotting and expression of results* (see form 4.A of Appendix A)

3.3.5.1 Calculate the internal volume, V (in cm^3), of the mould.

3.3.5.2 Calculate the bulk density, ρ (in Mg/m^3), of each compacted specimen from the equation

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

where

m_1 is the mass of mould and baseplate (in g);

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

3.3.5.3 Calculate the dry density, ρ_d (in Mg/m^3), of each compacted specimen from the equation

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

where

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

3.3.5.4 Plot the dry densities obtained from a series of determinations as ordinates against the corresponding moisture contents as abscissae. 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 moisture content, to three significant figures, corresponding to that point. (See Figure 6.)

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

3.3.5.5 On the same graph, plot the curves corresponding to 0 %, 5 % and 10 % air voids, calculated from the equation

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

where

ρ_d is the dry density (in Mg/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 this plot);

w is the moisture content (in %).

(See Figure 6.)

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

- a) the method of test used;
- b) the sample preparation procedure, and whether a single sample or separate samples were used. In the case of stiff, cohesive soil the size of pieces to which the soil was broken down shall be stated;
- c) the experimental points and the smooth curve drawn through them showing the relationship between moisture content and dry density;
- d) the dry density corresponding to the maximum dry density on the moisture content/dry density curve, reported as the maximum dry density to the nearest 0.01 (in Mg/m^3);
- e) the percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve reported as the optimum moisture content to two significant figures;
- f) the amount of stone retained on the 20 mm and 37.5 mm test sieves reported to the nearest 1 % by dry mass;
- g) the particle density and whether measured (and if so the method used) or assumed;
- h) the information required by 9.1 of BS 1377-1:1990.

3.4 Method using 2.5 kg rammer for soils with some coarse gravel-size particles

3.4.1 General. 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 moisture contents. The range includes the optimum moisture 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.

NOTE 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 7.4) on the compacted soil at each moisture content.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.4.2 Apparatus

3.4.2.1 A cylindrical, corrosion-resistant, metal mould, i.e. the CBR mould, with a detachable baseplate and a removable extension as described in 7.2.2.2.

3.4.2.2 A hand or motorized, metal rammer, having a 50 mm diameter circular face, and weighing 2.5 kg, as described in 3.3.2.2.

3.4.2.3 A balance readable to 5 g.

3.4.2.4 A large scoop.

3.4.2.5 Other items as specified in 3.3.2.4 to 3.3.2.9.

3.4.3 Preparation of sample. Prepare the test sample as described in 3.2.5.1, 3.2.5.2, 3.2.5.3, 3.2.7.1, 3.2.7.2 or 3.2.7.3 as appropriate.

3.4.4 Procedure

3.4.4.1 Compaction procedure for soil particles not susceptible to crushing

3.4.4.1.1 Weigh the CBR mould with baseplate attached, to 5 g (m_1).

Measure the internal dimensions to 0.5 mm.

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

3.4.4.1.3 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.

3.4.4.1.4 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.

3.4.4.1.5 Repeat **3.4.4.1.3** and **3.4.4.1.4** 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.

3.4.4.1.6 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 sample, well pressed in.

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

3.4.4.1.8 Remove the compacted soil from the mould and place it on the metal tray. Take a representative sample of the soil for determination of its moisture content as described in **3.2** of BS 1377-2:1990.

3.4.4.1.9 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 sample.

3.4.4.1.10 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 moisture contents is obtained which includes the optimum moisture content. In general, increments of 1 % to 2 % are suitable for sandy and gravelly soils and of 2 % to 4 % for cohesive soils. To increase the accuracy of the test it is often advisable to reduce the increments of water in the region of the optimum moisture content.

3.4.4.1.11 Repeat **3.4.4.1.3** to **3.4.4.1.10** to give a total of at least five determinations. The moisture contents shall be such that the optimum moisture content, at which the maximum dry density occurs, lies near the middle of the range.

3.4.4.2 *Compaction procedure for soil particles susceptible to crushing*

3.4.4.2.1 Weigh, measure and prepare the CBR mould as described in **3.4.4.1.1** and **3.4.4.1.2**.

3.4.4.2.2 Carry out a compaction test on each of the prepared samples in turn as described in **3.4.4.1.3** to **3.4.4.1.8**.

3.4.4.2.3 Discard the remainder of each compacted sample.

3.4.5 *Calculations, plotting and expression of results.* Proceed as described in **3.3.5**.

3.4.6 *Test report.* The test report shall comply with **3.3.6**.

3.5 Method using 4.5 kg rammer for soils with particles up to medium-gravel size

3.5.1 *General.* This test covers the determination of the dry density of soil passing a 20 mm test sieve when it is compacted in a specified manner over a range of moisture contents. The range includes the optimum moisture 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 **3.3**, the mass of the rammer being increased to 4.5 kg, the height of fall to 450 mm, and the number of compacted layers from three to five. The same 1 L compaction mould is used.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.5.2 Apparatus

3.5.2.1 *A cylindrical corrosion-resistant metal mould*, i.e. the 1 L compaction mould, as specified in **3.3.2.1**.

3.5.2.2 *A 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. One suitable form of hand apparatus is shown in Figure 5.

NOTE 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 ± 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.

3.5.2.3 *Other items*, as specified in **3.3.2.3** to **3.3.2.9**.

3.5.3 Preparation of soil. Prepare the test sample as described in **3.2.4.1**, **3.2.4.2**, **3.2.6.1** or **3.2.6.2** as appropriate.

3.5.4 Procedure

3.5.4.1 Compaction procedure for soil particles not susceptible to crushing

3.5.4.1.1 Weigh the mould with baseplate attached to 1 g (m_1).

Measure the internal dimensions to 0.1 mm.

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

3.5.4.1.3 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.

3.5.4.1.4 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.

3.5.4.1.5 Repeat **3.5.4.1.3** and **3.5.4.1.4** 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 **3.3.4.1.5**)

3.5.4.1.6 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 sample, well pressed in.

3.5.4.1.7 Weigh the soil and mould with baseplate to 1 g (m_2).

3.5.4.1.8 Remove the compacted soil from the mould and place it on the large metal tray. Take a representative sample of the soil for determination of its moisture content as described in **3.2** of BS 1377-2:1990.

3.5.4.1.9 Break up the remainder of the soil, rub it through the 20 mm test sieve and mix with the remainder of the prepared test sample.

3.5.4.1.10 Add a suitable increment of water (see note to **3.3.4.1.10**) and mix it thoroughly into the soil.

3.5.4.1.11 Repeat **3.5.4.1.3** to **3.5.4.1.10** to give a total of at least five determinations. The moisture contents shall be such that the optimum moisture content, at which the maximum dry density occurs, lies near the middle of the range.

3.5.4.2 Compaction procedure for soil particles susceptible to crushing

3.5.4.2.1 Weigh, measure and prepare the mould as described in **3.5.4.1.1** and **3.5.4.1.2**.

3.5.4.2.2 Carry out a compaction test on each of the prepared samples in turn as described in **3.5.4.1.3** to **3.5.4.1.8**.

3.5.4.2.3 Discard the remainder of each compacted sample.

3.5.5 Calculations, plotting and expression of results. Proceed as described in **3.3.5**.

3.5.6 Test report. The test report shall comply with **3.3.6**.

3.6 Method using 4.5 kg rammer for soils with some coarse gravel-size particles

3.6.1 General. 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 moisture contents. The range includes the optimum moisture 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 **3.4**, the mass of the rammer being increased to 4.5 kg, the height of fall to 450 mm, and the number of compacted layers from three to 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 may include some particles retained on the 37.5 mm test sieve. (See note to **3.4.1**.)

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.6.2 Apparatus

3.6.2.1 *A cylindrical, corrosion-resistant metal mould*, i.e. the CBR mould, as described in 7.2.2.2.

3.6.2.2 *A hand or motorized metal rammer* weighing 4.5 kg, as described in 3.5.2.2.

3.6.2.3 *A balance* readable to 5 g.

3.6.2.4 *A large scoop*

3.6.2.5 *Other items* as specified in 3.3.2.4 to 3.3.2.9.

3.6.3 *Preparation of sample*. Prepare the test sample as described in 3.2.5.1, 3.2.5.2, 3.2.5.3, 3.2.7.1, 3.2.7.2 or 3.2.7.3 as appropriate.

3.6.4 Procedure

3.6.4.1 *Compaction procedure for soil particles not susceptible to crushing*

3.6.4.1.1 Weigh the mould with baseplate attached to 5 g (m_1).

Measure the internal dimensions to 0.5 mm.

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

3.6.4.1.3 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.

3.6.4.1.4 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.

3.6.4.1.5 Repeat 3.6.4.1.3 and 3.6.4.1.4 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 3.4.4.1.5.)

3.6.4.1.6 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 particles, removed in the levelling process, by finer material from the sample, well pressed in.

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

3.6.4.1.8 Remove the compacted soil from the mould and place it on the large metal tray. Take a representative sample of the soil for determination of its moisture content as described in 3.2 of BS 1377-2:1990.

3.6.4.1.9 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 sample.

3.6.4.1.10 Add a suitable increment of water (see note to 3.4.4.1.10) and mix thoroughly into the soil.

3.6.4.1.11 Repeat 3.6.4.1.3. to 3.6.4.1.10 to give a total of at least five determinations. The moisture contents shall be such that the optimum moisture content, at which the maximum dry density occurs, lies near the middle of the range.

3.6.4.2 *Compaction procedure for soil particles susceptible to crushing*

3.6.4.2.1 Weigh, measure and prepare the mould as described in 3.6.4.1.1 and 3.6.4.1.2.

3.6.4.2.2 Carry out a compaction test on each of the prepared samples as described in 3.6.4.1.3 to 3.6.4.1.8.

3.6.4.2.3 Discard the remainder of each compacted sample.

3.6.5 *Calculations, plotting and expression of results*. Proceed as described in 3.3.5.

3.6.6 *Test report*. The test report shall comply with 3.3.6.

3.7 Method using vibrating hammer

3.7.1 General. This test covers the determination of the dry density of soil, which may contain some particles up to coarse gravel size, when it is compacted by vibration in a specified manner over a range of moisture contents. The range includes the optimum moisture 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 cohesive soils.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

3.7.2 Apparatus

3.7.2.1 A cylindrical, corrosion-resistant metal mould, i.e. the CBR mould, as described in 7.2.2.2.

3.7.2.2 An 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.

3.7.2.3 A steel tamper for attachment to the vibrating hammer. Essential dimensions are shown in Figure 7(b), which also indicates one suitable design of tamper.

3.7.2.4 Supporting guide frame for vibrating hammer (optional).

3.7.2.5 A depth gauge or steel rule, or other device which enables the sample depth to be measured to an accuracy of 0.5 mm.

3.7.2.6 A balance readable to 5 g.

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

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

3.7.2.9 A 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.

3.7.2.10 A scoop.

3.7.2.11 Apparatus for the determination of moisture content as described in 3.2 of BS 1377-2:1990.

3.7.2.12 A stopwatch readable to 1 s.

3.7.2.13 Apparatus for extracting compacted specimens from the mould (optional).

3.7.3 Calibration of vibrating hammer

3.7.3.1 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 3.7.3.3 shall be carried out to determine whether the vibrating hammer is in satisfactory working order, and able to comply with the requirements of the test described in 3.7.5.

The pressure check described in 3.7.3.4 shall be made by the operator carrying out the calibration test.

3.7.3.2 Material. Clean, dry, silica sand, from the Woburn Beds of the Lower Greensand in the Leighton Buzzard district¹⁾. The grading shall be such that at least 75 % passes the 600 μm sieve and is retained on the 425 μm test sieve and 100 % passes the 850 μm test sieve and is retained on the 300 μm test sieve. Dry and not previously used sand shall be used. This sand shall be sieved through a 600 μm test sieve and the coarse fraction shall be discarded.

¹⁾ For information on the availability of materials, apply to Enquiry Section, Linford Wood, Milton Keynes MK14 6LE, enclosing a stamped addressed envelope for reply.

3.7.3.3 Calibration test

3.7.3.3.1 Take a 5 ± 0.1 kg sample of the sand specified in **3.7.3.2**, which has not been used previously, and mix it with water in order to raise its moisture content to 2.5 ± 0.5 %.

3.7.3.3.2 Compact the wet sand in a cylindrical metal mould of 152 mm diameter and 127 mm depth, using the vibrating hammer as specified in **3.7.5.1**.

NOTE The operator can usually judge the required pressure to apply with sufficient accuracy after first carrying out the check described in **3.7.3.4**.

3.7.3.3.3 Carry out a total of three tests, all on the same sample of sand, and determine the mean dry density. Determine the dry density values to the nearest 0.002 Mg/m^3 .

3.7.3.3.4 If the range of values in the three tests exceeds 0.01 Mg/m^3 , repeat the procedure. Consider the vibrating hammer suitable for use in the vibrating compaction test if the mean dry density of the sand exceeds 1.74 Mg/m^3 .

3.7.3.4 Pressure check. Apply pressure combined with vibration to ensure the required degree of compaction. A downward force on the sample 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.

3.7.4 Preparation of sample. Prepare the test sample as described in **3.2.5.1**, **3.2.5.2**, **3.2.5.3**, **3.2.7.1**, **3.2.7.2** or **3.2.7.3** as appropriate.

3.7.5 Procedure

3.7.5.1 Compaction procedure for soil particles not susceptible to crushing

3.7.5.1.1 Weigh the mould, with baseplate and extension attached, to 5 g (m_1).

Measure the internal dimensions to 0.5 mm.

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

3.7.5.1.3 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.

3.7.5.1.4 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 **3.7.3.3.2**).

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

3.7.5.1.5 Repeat **3.7.5.1.3** and **3.7.5.1.4** twice more.

3.7.5.1.6 Remove any loose material lying on the surface of the sample around the sides of the mould.

3.7.5.1.7 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 **3.7.5.1.3** until a sample of the required height is obtained.

3.7.5.1.8 Weigh the soil and mould with baseplate and extension to 5 g (in m_2).

3.7.5.1.9 Remove the compacted soil from the mould and place it on the metal tray. Take a representative sample of the soil for determination of its moisture content as described in **3.2** of BS 1377-2:1990.

3.7.5.1.10 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 sample.

3.7.5.1.11 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 moisture contents is obtained which includes the optimum moisture 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 moisture content.

3.7.5.1.12 Repeat **3.7.5.1.3** to **3.7.5.1.11** to give a total of at least five determinations. The moisture contents shall be such that the optimum moisture content, at which the maximum dry density occurs, lies near the middle of the range.

3.7.5.2 *Compaction procedure for soil particle susceptible to crushing*

NOTE The soil should be considered susceptible to crushing during compaction if the sample contains granular material of a soft nature, e.g. soft limestone, sandstone, etc., which is reduced in size by the action of the vibrating hammer. The procedure described in **3.7.5.2** for soils susceptible to crushing during compaction can be applied to all granular soils if it is convenient to do so.

3.7.5.2.1 Weigh, measure and prepare the CBR mould as described in **3.7.5.1.1** and **3.7.5.1.2**.

3.7.5.2.2 Carry out a compaction test on each of the prepared samples in turn as described in **3.7.5.1.3** to **3.7.5.1.9**.

3.7.5.2.3 Discard the remainder of each compacted sample.

3.7.6 *Calculations, plotting and expression of results* (see form 4.B, Appendix A)

3.7.6.1 Calculate the bulk density, ρ (in Mg/m^3), of each compacted specimen from the equation

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

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 sample (in mm);

A is the circular area of the mould (in mm^2).

3.7.6.2 Calculate the dry density, ρ_d (in Mg/m^3), of each compacted specimen from the equation

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

where

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

3.7.6.3 Plot the dry densities obtained from a series of determinations as ordinates against the corresponding moisture contents as abscissae. 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 moisture content, to three significant figures, corresponding to that point. (See Figure 6.)

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

3.7.6.4 On the same graph, plot the curves corresponding to 0 %, 5 % and 10 % air voids, calculated from the equation

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

where

- ρ_d is the dry density (in Mg/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 this plot);
 - w is the moisture content (in %).
- (See Figure 6.)

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

- a) the method of test used;
- b) the sample preparation procedure, and whether a single sample or separate samples were used;
- c) the experimental points and the smooth curve drawn through them showing the relationship between moisture content and dry density;
- d) the dry density corresponding to the maximum dry density on the moisture content/dry density curve reported as the maximum dry density to the nearest 0.01 (in Mg/m^3);
- e) the percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve reported as the optimum moisture content to two significant figures;
- f) the amount of stone retained on the 37.5 mm test sieve reported to the nearest 1 % by dry mass;
- g) the particle density and whether measured (and if so the method used) or assumed;
- h) the information required by 9.1 of BS 1377-1:1990.

4 Determination of maximum and minimum dry densities for granular soils

4.1 General

4.1.1 Principle. An indication of the state of compaction of a cohesionless (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 section enable these parameters to be determined for cohesionless soils.

4.1.2 Types of tests. 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 3.7.

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.

4.2 Determination of maximum density of sands

4.2.1 General. 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 $63\ \mu\text{m}$ 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.

NOTE 1 Use of a vibrating hammer is appropriate for free-draining soils containing only a small proportion (usually not exceeding 10 % by mass) of material finer than $63\ \mu\text{m}$, since some fine material is likely to escape from the sample during vibration.

NOTE 2 This test is not applicable to soils containing particles susceptible to crushing when compacted by the vibrating hammer.

The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.