British Standard

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Incorporating
Amendment Nos 1
and 2

Sampling and examination of bituminous mixtures for roads and other paved areas —

Part 104: Methods of test for the determination of density and compaction

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Road Engineering Standards Policy Committee (RDB/-) to Technical Committee RDB/36 upon which the following bodies were represented:

British Aggregate Construction Materials Industries
British Civil Engineering Test Equipment Manufacturers' Association
British Tar Industry Association
County Surveyor's Society
Department of the Environment (Property Services Agency)
Department of Transport (Highways)
Department of Transport (Transport and Road Research Laboratory)
Institute of Asphalt Technology
Institute of Petroleum
Institution of Civil Engineers
Institution of Highways and Transportation
Mastic Asphalt Council and Employers' Federation
Mastic Asphalt Producers' Association
Refined Bitumen Association Ltd.
Sand and Gravel Association Ltd.
Society of Chemical Industry
Coopted members

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Contents

Foreword

This Part of BS 598 has been prepared under the direction of Technical Committee B/510.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 12, an inside back cover and a back cover.

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

1 Scope

This Part of BS 598 describes two methods for determining the density and compaction of bituminous mixtures for roads and other paved areas. The first method describes how to determine the percentage refusal density of core samples of 150 mm nominal diameter cut from compacted bituminous mixtures. This method is intended to apply only to coated macadam dense roadbases or basecourses that have cooled to ambient temperatures and have a minimum layer thickness complying with Table 1 of BS 4987-2:1973.

The second method describes how to measure the density of cores.

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

2 Definitions

For the purposes of this Part of BS 598 the definitions given in BS 6100 apply, together with the following.

2.1
initial dried bulk density

the mass per unit volume, including voids, of the specimen after being placed in an oven until the mass is stable

2.2
refusal density

the mass per unit volume, including voids, of the specimen compacted to refusal in accordance with the test method

2.3
percentage refusal density (PRD)

the ratio of the initial dried bulk density of the sample to the refusal density expressed as a percentage

2.4
bulk density (for use in the calibration of the vibrating hammer)

the mass of a material (including solid particles and any contained water) per unit volume including voids

2.5
repeatability (*r*)

the value below which the absolute difference between two single test results obtained with the same method on identical test material under the same conditions (same operator, same apparatus, same laboratory and a short interval of time) may be expected to lie with a specified probability; in the absence of other indications, the probability is 95 %

2.6
reproducibility *(R)*

the value below which the absolute difference between two single test results obtained with the same method on identical test material under different conditions (different operators, different apparatus, different laboratories and/or different time) may be expected to lie with a specified probability; in the absence of other indications, the probability is 95 %

2.7
single test result

the value obtained by applying the standard test method fully, once, to a single specimen; it may be the mean of two or more observations or the result of a calculation from a set of observations as specified by the standard test method

3 Determination of the percentage refusal density (PRD)

3.1 Principle

The initial dried bulk density of the core sample of bituminous mixture is measured by weighing the sample in air and water, the sample being coated in paraffin wax to prevent the ingress of water. After removal of the wax coating, the sample is then heated and compacted with a vibrating hammer "to refusal". The final density of the sample is then measured by weighing the sample in air and water. The percentage refusal density is a measure of the relative state of compaction of the sample.

3.2 Materials

3.2.1 *Paraffin wax* of known density at a temperature of 20 °C. The wax shall be capable of covering the core with an uncracked impervious coating.

NOTE Paraffin wax with a congealing point between 49 °C and 50 °C, type BDH 29839, is satisfactory. A coating with optimum properties is obtained when the liquid wax is maintained at a temperature of 55 ± 3 °C.

3.2.2 *Paper discs* to prevent the ends of the core from sticking to the base plate (see **3.3.5**) or the tamping foot (see **3.3.10**).

3.2.3 *Silicone grease*, such as one conforming to Ministry of Defence Standard 59-10[1], for use as a releasing agent.

3.2.4 *Talcum powder* of pharmaceutical quality.

3.2.5 *Inert void-filling material.*

3.3 Apparatus

NOTE Apparatus should be calibrated and traceable as recommended in appendix A.

3.3.1 *A ventilated drying cabinet thermostatically* controlled maintain a temperature of between 25 °C and 45 °C.

3.3.2 *A balance* capable of weighing up to 10 kg to an accuracy of ± 1 g, with an attachment to facilitate the weighing of cores in water.

3.3.3 *A bath* suitable for holding molten paraffin wax.

3.3.4 *A water bath* maintained at a temperature of 20 ± 5 °C for immersing the sample while suspended from the balance.

3.3.5 *A split core mould and base plate* (Figure 1).

NOTE The design of the apparatus required in **3.3.5** is subject to crown copyright. The Secretary of State for Transport has agreed with BSI to make available, through the Transport and Road Research Laboratory, licences to market and manufacture this apparatus on non-exclusive and non-discriminatory terms in the form of royalty payments of 7 % of the net selling price of the apparatus. Applicants for licences should apply to the Director, Transport and Road Research Laboratory, Department of Transport, Old Wokingham Road, Crowthorne, RG11 6AU.

3.3.6 *One spare base plate* (only one spare base plate is needed for a complete set of moulds).

3.3.7 *A heating oven with fan-assisted circulation* and of sufficient capacity and power to raise the temperature of the cores and moulds from ambient to the temperatures specified in Table 1.

3.3.8 *An electric vibrating hammer*, complying with appendix B.

3.3.9 *A* 50 mm *or* 75 mm *wide paint-stripping knife and a pallet knife.*

3.3.10 *A* 102 ± 2 mm *diameter tamping foot and* 146 ± 2 mm *diameter tamping foot* for use with the electric vibrating hammer (see **3.3.8**).

3.3.11 *A* 300 mm *metric steel rule*, complying with BS 4372.

3.3.12 *A pair of external calipers*, complying with BS 3123.

3.3.13 *A stopclock or watch*

3.3.14 *A thermometer*, capable of measuring temperatures in the range 35 °C to 160 °C with an accuracy of 1 °C.

3.3.15 *A diamond-impregnated saw*, capable of slicing cores.

3.3.16 *A refrigerator or deep freeze*

3.3.17 *A paint brush* for applying wax.

3.4 Preparation of test specimen

3.4.1 Cut a core of 150 mm to 153 mm diameter in accordance with BS 598-100.

NOTE If the core is more than 150 mm deep and/or consists of more than a single layer it will be necessary to saw or split the core to produce valid test specimens.

3.4.2 Measure the diameter of the core to the nearest 1 mm in two directions using the external calipers and steel rule.

3.4.3 If any layer in the core is greater than 150 mm in depth saw the core so that the layer becomes two specimens of similar depth.

NOTE The sawing of multi-layer cores into separate layers should also be considered at this stage as it is often more efficient than splitting.

3.4.4 Place the core or sawn portions of the core, with axis vertical and flattest face down, in the drying cabinet at a temperature below 45 °C.

NOTE Low-temperature drying of cores is essential to ensure that the core does not become distorted. Typically a period of 16 h is necessary at 40 °C, but with voided cores a lower temperature may be necessary.

3.4.5 If the core consists of more than one layer of material, remove from the drying cabinet when warmed (after about 4 h) and separate the layers immediately by placing the core on a flat surface and working the paint-stripping knife or pallet knife around the cirumference of the core at the interface between layers. If the bond between layers is such that this method fails then allow the core to cool, saw at the interface and return the layer or layers required for test to the cabinet, as described in **3.4.4**.

3.4.6 Dry the core to constant mass. The core shall be considered to be at constant mass when the difference between successive weighings at 2-hourly intervals does not exceed 0.05 %.

NOTE For convenience, it is recommended that the successive weighings to determine constant mass should be carried out whilst the core is warm.

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[1] MOD Standard 59-10 "Insulating and filling compounds (insulating compound, electric/silicone grease type" published by Directorate of Standardization, Ministry of Defence, London.

3.4.7 Remove any loose material from the core and record that this has been done.

3.5 Procedure

3.5.1 Allow the core, or portion of core, to cool to ambient temperature and weigh it in air to the nearest 1 g.

3.5.2 Seal the surface of the core by immersing it in the molten paraffin wax.

To facilitate the later removal of the wax coating the core may be lightly dusted with talcum powder prior to coating.

If talcum powder is used the procedure described in appendix D shall be followed (see **D.2**).

NOTE 1 The wax may be applied by first chilling the core in a refrigerator to a temperature of about 5 °C for 30 min (or less time in a freezer) and then dipping the core in the molten wax. Brushing the surface of the wax with hot wax may be necessary to fill any pinholes.

NOTE 2 It is not uncommon for small pieces of material to be lost from the surfaces of the core during cutting and subsequent handling. Where this occurs there is no need for any special treatment. Where, however, significant surface voids appear to be due to poor compaction then their volume should be taken into account by filling with an inert material, e.g. plasticine, and the appropriate adjustments made to the calculations (see **D.3**).

NOTE 3 If the sample is judged to be impermeable or nearly so, wax coating may not be necessary.

3.5.3 Allow the wax to harden for about 20 min. Then weigh the waxed core to the nearest 1 g, first in air, and then suspended in the water bath at 20 ± 5 °C.

3.5.4 Scrape the wax off the core with the pallet knife so as to reduce the mass of the core and wax to less than 1.005 times the mass of the dry core in air.

3.5.5 Coat the split mould and base plate (see Figure 1) with a thin film of silicone grease and place a filter paper on the base plate.

3.5.6 Insert the core, with the flatter of its two ends uppermost, into the mould. Tighten the mould and clamp the mould to the base plate.

3.5.7 Place the assembly without the shank and tamping foot but including the additional base plate in a preheated oven maintained at the temperature specified in Table 1 for the grade of binder in use. Retain in the oven until the centre of the core has attained the temperature specified in Table 1.

NOTE Arrangements should be made for preheating the tamping feet, as required by **3.5.10** and **3.5.12**.

Table 1 — Temperature of cores and moulds for compaction to refusal

Binder type	Binder grade	Temperature at test
		°C
Bitumen	50 pen	150 ± 5
	100 pen	140 ± 5
	200 pen	130 ± 5
Tar	C50	90 ± 5
	C54	95 ± 5
	C58	100 ± 5

3.5.8 Condition the operating mechanism of the vibrating hammer by running it for at least 2 min on a blank specimen before beginning **3.5.10**.

3.5.9 Remove the assembly from the oven and place it on a level rigid floor. Ensure that the mould is tightened until the split is closed. Place a paper disc on the exposed surface of the core.

3.5.10 Immediately compact the core with the vibrating hammer, using the 102 mm diameter tamping foot previously warmed to above 60 °C and coated with a thin layer of silicone grease.

Hold the hammer firmly with the shaft vertical and move the tamping foot from one position to another around the mould as specified in **3.5.11**. Give 2 s to 10 s compaction at each position. Move the tamping foot from one position to the next before material bulges above the edge of the tamping foot (see Figure 1).

NOTE 1 To keep the mould in position whilst compaction is taking place it is advisable to use a panel of 20 mm plywood with a central hole of suitable dimensions to accommodate the mould base.

NOTE 2 The period of compaction at each position will depend on the material.

NOTE 3 The downward force applied to the compaction hammer by the operator should be greater than that required in order to stop the hammer bouncing on the specimen. A means of determining this force is described in **B.5.3**.

3.5.11 Position the tamping foot in contact with the side of the mould and compact the core in the following points of the compass sequence: N, S, W, E, NW, SE, SW, NE. Repeat this sequence until the total compaction period amounts to 2 min ± 5 s.

3.5.12 When the compaction process specified in **3.5.11** is complete, remove any irregularities on the surface of the core by using the vibrating hammer fitted with the previously warmed 146 mm diameter tamping foot coated with a thin layer of silicone grease.

3.5.13 Clamp the spare base plate, lightly greased, to the top of the mould. Invert the mould and remove the original base plate ensuring that a paper disc adheres to each end of the core. Place the original base plate in the oven; this now becomes the spare base plate. Drive the core into contact with the base plate with the vibrating hammer fitted with the 146 mm tamping foot coated with silicone grease.

3.5.14 Repeat the compaction procedure specified in **3.5.10**, **3.5.11** and **3.5.12**.

3.5.15 Allow the core to cool in air for at least 2 h and then remove it from the mould by loosening the screws and tapping the mould to destroy the adhesion.

3.5.16 Remove the paper discs.

3.5.17 Weigh the core in air and suspend in water at 20 ± 5 °C to the nearest 1 g.

3.5.18 If the core has been cut in two (see **3.4.3**) or if it has been split into layers (see **3.4.5**) carry out the procedure described in **3.5.1** to **3.5.17** for each specimen or layer.

3.6 Calculation and expression of results

3.6.1 When neither talcum powder nor an inert filler is used in the procedure the value of the percentage refusal density (PRD) is calculated, by first calculating the initial dried bulk density G (in Mg/m^3), and the refusal density H (in Mg/m^3) from the following equations:

$$G = \frac{A}{(B - C) - \left(\frac{(B - A)}{D}\right)}$$

where

A is the mass of the dry core in air (in g);

B is the mass of the waxed core in air (in g);

C is the mass of the waxed core in water (in g);

D is the density of the wax (in Mg/m^3).

$$H = \frac{1}{1 - \left(\frac{F}{E}\right)}$$

where

F is the mass of the compacted core in water (in g);

E is the mass of the compacted core in air (in g).

$$\text{PRD} = \frac{100G}{H}$$

where

G is the initial dried bulk density (in Mg/m^3);

H is the refusal density (in Mg/m^3).

3.6.2 Express the percentage refusal density to the nearest 0.1.

3.6.3 If the core has been split into layers (see **3.4.5**) or cut in half (see **3.4.3**) the percentage refusal density of the core is the average of the value obtained for each layer or half.

NOTE An example of a calculation form suitable for use in the determination of the percentage refusal density where neither talcum powder nor an inert filler is used is shown in appendix C.

3.7 Precision

The best current estimates for repeatability and reproducibility are as follows.

Repeatability	1.2
Reproducibility	1.8

NOTE 1 The precision data were determined from an experiment conducted in 1982 using 10 laboratories and 60 samples. The repeatability and reproducibility values given above apply for a range of percentage refusal density values from 92.3 to 99.2.

NOTE 2 The precision data were obtained on roadbase material in layers of thickness not less than 100 mm.

3.8 Test report

The test report shall affirm that the percentage refusal density was determined in accordance with this Part of BS 598. The test report shall include the following additional information:

a) the name and address of the testing laboratory;

b) a unique serial number for the test report;

c) the name of the client;

d) a description and an identification of the sample, and the date of receipt;

e) the identification of the test method including information on the use of talcum powder or an inert filler where appropriate;

f) any deviations, additions to or exclusions from the test method;

g) the measured diameter of the core;

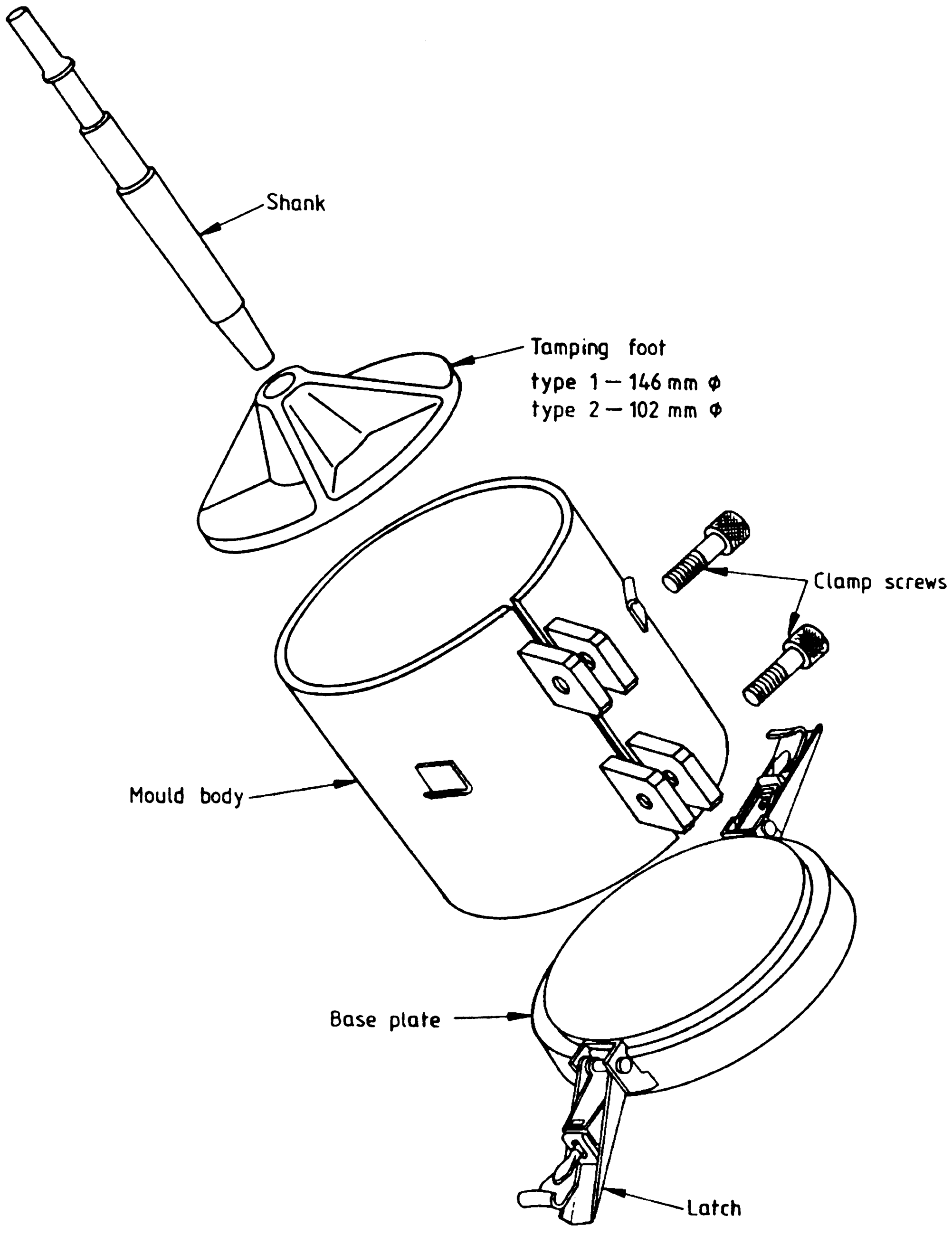
h) the total depth of core received;

i) the depth of individual test specimens and whether loose material was removed;

j) individual values of the percentage refusal density for each test specimen;

k) the signature of the person accepting technical responsibility for the test report;

l) the date of issue.



Essential dimensions (inspection) of closed mould excluding base plate:

internal diameter	152.45 + 0.5 mm
length	170 ± 0.5 mm

Figure 1 — Typical compaction assembly

4 Measurement of density of cores

4.1 General

4.1.1 Where cores of laid mixed material are taken, e.g. for assessing the performance of rollers, determine the density of each core by the following method.

Where wearing courses contain precoated chippings, remove these before determining densities of cores.

4.1.2 The diameter of core samples shall be at least 150 mm; the use of too small a specimen may lead to inaccurate results. The cores shall be as regular in shape as possible.

NOTE When measuring the density of a core of a compacted layer, cores need not be waxed, provided all the cores are treated similarly. For reference purposes, however, waxing is recommended.

4.2 Apparatus

4.2.1 *Water bath*, of such dimensions that the specimen may be hung freely in it.

4.2.2 *Balance*, suitable for carrying the weight of the specimen hanging from its balance arm or hook, and capable of weighing to an accuracy of 0.05 % of the load.

NOTE The balance should be calibrated and traceable as recommended in appendix A.

4.2.3 *Metal grid*, suspended, by means of a length of wire at each corner, from one end of the balance arm or hook.

4.2.4 *Paraffin wax*, of known relative density.

4.3 Procedure

4.3.1 Remove any coated chippings forming a part of a wearing course, by warming to not more than 60 °C and carefully levering the chippings out, using, for example, a screwdriver.

4.3.2 Weigh the specimen in air (W_1) and, if necessary, wax and weigh again (W_2).

4.3.3 Fill the water bath with water and weigh the grid totally immersed in water. Reweigh with the specimen added, ensuring both grid and specimen are totally immersed and that the specimen is free from air bubbles.

4.4 Calculation and expression of results

Calculate the mass of the specimen in water (W_3) as the difference between the two weighings.

Calculate the core density D (in Mg/m^3) for unwaxed specimen from the following equation:

$$D = \frac{W_1}{W_1 - W_3}$$

where

W_1 is the mass of specimen in air (in g);

W_3 is the mass of specimen in water (in g).

Calculate the core density D (in Mg/m^3) for waxed specimen from the following equation:

$$D = \frac{S_5 W_1}{S_5(W_2 - W_4) - (W_2 - W_1)}$$

where

W_1 is the mass of specimen in air before waxing (in g);

W_2 is the mass of specimen in air after waxing (in g);

W_4 is the mass of waxed specimen in water (in g);

S_5 is the relative density of wax.

NOTE If calculation of the air voids in a specimen is required, the procedure described in appendix E should be followed.

Express the core density to the nearest 0.001 Mg/m^3.

4.5 Test report

The test report shall affirm that the core density was determined in accordance with this Part of BS 598. The test report shall include the following additional information:

a) the name and address of the testing laboratory;

b) a unique serial number for the test report;

c) the name of the client;

d) a description and an identification of the sample, and the date of receipt;

e) the measured diameter of the core;

f) the total depth of core received;

g) the depth of individual test specimens and whether loose material was removed;

h) individual values of core density for each test specimen;

i) the signature of the person accepting technical responsibility for the test report;

j) the date of issue.

Appendix A Recommendations for equipment control and calibration

A.1 General

Calibration of all critical equipment used in the performance of tests in this British Standard should be traceable to national standards as recommended in this appendix. Systems used should comply with BS 5781.

A.2 External calibration

(carried out under contract by an external organization)

Traceability should be established by the issue of a certificate for the relevant item giving details of:

a) the calibration;

b) the traceability route, i.e. British Calibration Service (BCS), National Physical Laboratory (NPL) or National Weights and Measures Laboratory (NWML);

c) the description and serial number of any reference/transfer standard involved;

d) the signature of the personnel performing or responsible for the calibration.

A.3 In-house calibration

(carried out by the staff of the testing laboratory)

When traceability is to be established by in-house calibration, the following conditions should be met:

a) the calibration should be performed in accordance with written procedures applicable to the items;

b) the reference/transfer standards used should have valid certification provided by BCS, NPL, or NWML or acceptable international bodies;

c) the reference/transfer standards should be used solely for calibration purposes;

d) the documentation should be as recommended in **A.2** and should be retained.

A.4 Balance and weights

A.4.1 Balances should be calibrated using reference weights at least once every 9 months; with frequent use, 6 months is preferable.

A.4.2 Reference weights for in-house calibrations should be kept secure in a suitable environment, separate from working weights and should be recalibrated and certificated at least every 5 years.

A.5 Stopclocks and watches

Stopclocks and watches should be calibrated at least once every 3 months.

A.6 Thermometry

A.6.1 For the methods described in this standard, stamped, mercury-in-glass thermometers complying with BS 593 are sufficient. Such thermometers should be recalibrated or replaced every 5 years as indicated in appendix A of BS 593:1974.

A.6.2 If thermocouples are used they should be calibrated against a reference thermocouple, platinum resistance or reference mercury-in-glass thermometer at least once every 6 months.

A.6.3 Reference thermocouples or reference platinum resistance thermometers should be recalibrated at least once every 2 years and reference mercury-in-glass thermometers at least once every 5 years.

A.7 BS test sieves

A.7.1 Only test sieves complying with BS 410 should be used and their certificates should be retained throughout their working life.

A.7.2 Sieves should be marked with a set reference and only used as a constituent of that set. When new sieves are incorporated into a set they should be marked appropriately and the individual certificate filed.

A.7.3 Sieve control systems should be as follows.

a) *Visual checks*. The conditions of all sieves should be visually checked and recorded at frequent intervals by designated personnel. Twice per week will be sufficient in most cases. Any discrepancies noted should be referred to a designated senior person who should decide whether to recalibrate or replace the suspect sieve.

b) *Standard gradings*. A laboratory standard sample should be established and graded on each set of sieves in use at least once every 3 months. Alternatively gradings obtained using working sieves can be repeated on a set of sieves kept solely for calibration purposes and compared. The results of standard grading comparisons should be considered by designated personnel who should decide whether any individual sieve should be replaced or investigated.

A.8 Test sand for determining suitability of vibrating hammer

A.8.1 On receipt the test sand (see **B.3**) should be given a unique batch number which should be marked indelibly on the container(s).

A.8.2 A sample for grading should be obtained from the container(s) in accordance with BS 812-102 and tested in accordance with BS 812-103.

A.8.3 If compliance is achieved the material should be placed in stock and brought into service when required.

Appendix B Test method for determining the suitability of a vibrating hammer for use in the percentage refusal density test

B.1 Vibrating hammer

The vibrating hammer to be tested for use in the percentage refusal density test shall be electric. It shall have a power consumption in the range 750 W to 1 000 W and operate at a frequency of 20 Hz to 50 Hz[2].

NOTE It is important that the hammer should have been maintained properly in accordance with the manufacturer's instructions. A new hammer may need to be "run in" in order to meet the requirements of this test.

B.2 Apparatus

B.2.1 *General.* The apparatus described in **B.2.2** to **B.2.7** is required in addition to that used for the percentage refusal density test.

B.2.2 *A cylindrical metal mould* having an internal diameter of 152 mm and an internal effective height of 127 mm, with a detachable baseplate and a collar 50 mm deep as specified in Test 16 of BS 1377[3]. A thin coating of oil shall be applied to the internal faces of the mould and collar before each test.

B.2.3 *Test sieves* of sizes 600 µm, 425 µm and 300 µm complying with BS 410.

B.2.4 *A steel straightedge*, at least 300 mm long, complying with BS 5204-2.

B.2.5 *A depth gauge* capable of measuring the sample depth to an accuracy of 0.5 mm.

B.2.6 *A large metal tray,* with convenient size of 600 mm × 500 mm and with sides 80 mm deep.

B.2.7 *A stopwatch or stopclock*

B.2.8 *Apparatus for determining moisture content* as specified for Tests 1(A), 1(B), or 1(C) in BS 1377.

B.3 Materials

Ten kilograms of dry and not previously used Leighton Buzzard silica sand is required. It shall comply with the grading requirements of Table 2[2].

Table 2 — Grading of sand

BS test sieve	by mass passing
µm	%
600	100
425	0 to 25
300	0

B.4 Preparation of sample

Mix water with the sand sufficient to raise its moisture content to 2.5 ± 0.5 %.

B.5 Procedure

B.5.1 Weigh the mould, with its 50 mm collar and baseplate firmly fixed, and then stand it on a solid base, e.g. a concrete floor or plinth.

B.5.2 Condition the operating mechanism of the vibrating hammer by running it for at least 2 min on a blank specimen before beginning **B.5.3**.

B.5.3 Use the vibrating hammer fitted with a 146 mm diameter circular steel tamper to compact a quantity of the moist sand in the mould. Compact the sand in three layers of nearly equal mass sufficient to give a specimen of 130 ± 3 mm deep after compaction. Compact each layer for a period of 60 ± 2 s. Throughout this period apply a firm downward pressure to the vibrating hammer so that the total downward force, including that resulting from the mass of the hammer and tamper, shall be 350 ± 50 N.

NOTE The application of pressure combined with vibration is essential to ensure the required degree of compaction. The downward force required of 350 ± 50 N, including that resulting from the mass of the hammer and tamper, is greater than that required in order to prevent the hammer bouncing on the specimen. It is recommended that when an operator lacks experience in this test the vibrating hammer should be applied initially without vibration to a platform scale where a mass of 35 ± 5 kg should be registered when the required force is applied.

B.5.4 When the final layer has been compacted, remove any loose material around the sides of the mould from the surface of the specimen.

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[2] Information on suitable hammers and silica sand may be obtained from BSI Central Enquiries, Linford Wood, Milton Keynes, MK 14 6LE.

[3] BS 1377:1975 is under revision and will be published as separate Parts.

B.5.5 Lay the straightedge across the top of the collar of the mould and measure to an accuracy of 0.5 mm the depth of the specimen below the top collar. Take readings at four points spread evenly over the surface of the specimen, all at least 15 mm from the side of the mould.

B.5.6 Calculate the mean height of the specimen. If the specimen is more than 133 mm or less than 127 mm in height, reject it and repeat the procedure.

B.5.7 Weigh to the nearest 5 g the mould, together with the collar, baseplate and sand.

B.5.8 Remove the compacted sand specimen from the mould and place it on the large metal tray. Take a representative sample of the specimen and determine its moisture content in accordance with Test 1(A), 1(B) or 1(C) of BS 1377.

B.6 Calculation and expression of results

B.6.1 Calculate the bulk density d (in Mg/m^3) of the compacted specimen from the equation:

$$d = \frac{(m_2 - m_1)10^3}{0.25\pi K^2 h}$$

where

m_1 is the mass of the mould + base + collar (in g);

m_2 is the mass of the mould + base + collar + compacted specimen (in g);

K is the diameter of the mould (in mm);

h is the height of the specimen (in mm).

B.6.2 Calculate the dry density, d_d (in Mg/m^3) from the equation:

$$d_\mathrm{d} = \frac{100d}{100 + w}$$

where

d is the bulk density of the compacted specimen (in Mg/m^3);

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

B.6.3 Express the dry density value to the nearest 0.002 Mg/m^3.

B.6.4 Perform three tests on the same sample of sand and determine the mean dry density. If the range of values in the three tests exceeds 0.03 Mg/m^3, repeat the procedure.

B.6.5 Consider the vibrating hammer suitable for use in the percentage refusal density test if the mean dry density of the sand exceeds 1.74 Mg/m^3.

B.7 Calibration certificate

The calibration certificate shall affirm that the vibrating hammer was tested in accordance with this Part of BS 598. The calibration certificate shall include the following additional information:

a) the name of the manufacturer of the hammer and the model, type and serial number of the hammer;

b) the mean value of the dry density of the sand;

c) the individual values of the separate determinations of the dry density of the sand.

Appendix C Calculation form for determining the percentage refusal density where neither talcum powder nor an inert filler is used

The following is an example of a calculation form for use in the determination of percentage refusal density where neither talcum powder nor inert filler is used. Other suitable forms may be used.

Core No.	
Mass of dry core in air (g)	A
Mass of waxed core in air (g)	B
Mass of waxed core in water (g)	C
Density of wax (Mg/m^3)	D
Mass of compacted core in air (g)	E
Mass of compacted core in water (g)	F
Calculations	
Initial dried bulk density G (Mg/m^3) $G = \frac{A}{(B-C)-\left(\frac{B-A}{D}\right)}$	G
Refusal density H (Mg/m^3) $H = \frac{1}{1-\left(\frac{F}{E}\right)}$	H
Percentage refusal density (PRD) $\mathrm{PRD} = \frac{100G}{H}$	PRD

Appendix D Use of talcum powder or inert filler

D.1 Principle

The standard percentage refusal density test allows the use of talcum powder to facilitate the removal of wax coating and an inert filler for surface voids as alternative operations. The use of these materials entails extra weighing stages and thus extra steps in the calculations.

D.2 Use of talcum powder

If the core is dusted with talcum powder, an extra weighing for "mass of dry core plus talcum powder in air" is necessary after carrying out the procedure in **3.5.1**.

The value of the percentage refusal density PRD is thus calculated by first calculating the initial dried bulk density G (in Mg/m^3) and the refusal density H (in Mg/m^3) from the following equations:

$$G = \frac{A_1}{(B - C) - \left[\frac{(A_2 - A_1)}{D_2} + \frac{(B - A_2)}{D_1}\right]}$$

where

A_1 is the mass of the dry core in air (in g);

A_2 is the mass of the dry core plus talcum powder in air (in g);

B is the mass of the waxed core plus talcum powder in air (in g);

C is the mass of the waxed core plus talcum powder in water (in g);

D_1 is the density of the wax (in Mg/m^3);

D_2 is the density of the talcum powder (in Mg/m^3).

$$H = \frac{1}{1 - \left(\frac{F}{E}\right)}$$

where

F is the mass of the compacted core in water (in g);

E is the mass of the compacted core in air (in g);

$$\text{PRD} = \frac{100G}{H}$$

where

G is the initial dried bulk density (in Mg/m^3);

H is the refusal density (in Mg/m^3).

D.3 Use of an inert void-filling material

Where it is considered necessary to fill large surface voids with an inert filler to obtain the correct measure of core volume, an extra weighing for "mass of dry core plus inert filler" is necessary after carrying out the procedure in **3.5.1**.

The value of the percentage refusal density PRD is thus calculated by first calculating the initial dried bulk density G (in Mg/m^3), and the refusal density H (in Mg/m^3) from the following equations:

$$G = \frac{A_1}{(B - C) - \left[\frac{(B - A_2)}{D_1}\right]}$$

where

A_1 is the mass of the dry core in air (in g);

A_2 is the mass of the dry core plus inert filler in air (in g);

B is the mass of the waxed core plus inert filler in air (in g);

C is the mass of the waxed core plus inert filler in water (in g);

D_1 is the density of the wax (in Mg/m^3);

$$H = \frac{1}{1 - \left(\frac{F}{E}\right)}$$

where

F is the mass of the compacted core in water (in g);

E is the mass of the compacted core in air (in g).

$$\text{PRD} = \frac{100G}{H}$$

where

G is the initial dried bulk density (in Mg/m^3);

H is the refusal density (in Mg/m^3).

Appendix E Determination of air voids in the specimen

E.1 Procedure

From the results of determinations of the composition of the specimen and the relative densities of the constituent materials, calculate the theoretical volume of the specimen, that is the volume the material would occupy if there were no voids, and hence the theoretical maximum relative density, S_T, of the mixture.

For the course aggregate use the relative density on an oven-dried basis, but where the absorption is 1 % or greater, use the mean between the apparent relative density and the relative density on an oven-dried basis in this calculation.

For the fine aggregate use the apparent relative density.

E.2 Calculation

When W_1, W_2, W_3 and W_B represent the respective percentages by mass of the coarse aggregate, fine aggregate filler and binder used in a particular mix and when S_1, S_2, S_3 and S_B represent the respective relative densities, determined as described in BS 812-2 for the aggregates and BS 4699 for the binder, the theoretical maximum relative density, S_T, of the mixture is calculated by the following equation:

$$S_T = \frac{100}{\left(\frac{W_1}{S_1}\right) + \left(\frac{W_2}{S_2}\right) + \left(\frac{W_3}{S_3}\right) + \left(\frac{W_B}{S_B}\right)}$$

The percentage of voids in the mix, V_M, is calculated from the following equation:

$$V_M = \left(\frac{S_T - S_M}{S_T}\right) 100$$

where

S_M is the relative density of the specimen

The percentage of voids in the mineral aggregate, V_A, in the moulded specimen is calculated from the following equation:

$$V_A = V_M + \left(\frac{W_B S_M}{S_B}\right)$$

The percentage of voids filled with binder, V_F, is calculated from the following equation:

$$V_F = \left(\frac{W_B S_M}{V_A S_B}\right) 100$$

blank

Publications referred to

BS 410, *Specification for test sieves.*

BS 593, *Specification for laboratory thermometers.*

BS 598, *Sampling and examination of bituminous mixtures for roads and other paved areas.*

BS 598-100, *Methods for sampling for analysis.*

BS 598-102, *Analytical test methods.*

BS 812, *Testing aggregates.*

BS 812-2, *Methods for determination of physical properties.*

BS 812-102, *Methods for sampling.*

BS 812-103, *Methods for determination of particle size distribution.*

BS 1377, *Methods of test for soils for civil engineering purposes.*

BS 3123, *Specification for spring calipers and spring dividers.*

BS 4372, *Specification for engineers' steel measuring rules.*

BS 4699, *Methods for determination of density or relative density of petroleum and petroleum products (pyknometer methods).*

BS 4987, *Coated macadam for roads and other paved areas.*

BS 4987-2,*Specification for transport, laying and compaction.*

BS 5204, *Specification for straightedges.*

BS 5204-2, *Steel or granite straightedges of rectangular section.*

BS 5781, *Measurement and calibration systems.*

BS 6100, *Glossary of building and civil engineering terms.*

Specification for Highway works. 6th edition, 1986. Published by the Department of Transport.

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