

Stabilized materials for civil engineering purposes —

Part 2: Methods of test for cement-stabilized and lime-stabilized materials

Committees responsible for this British Standard

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- British Aggregate Construction Materials Industries
- British Cement Association
- British Civil Engineering Test Equipment Manufacturers' Association
- British Coal Corporation
- County Surveyors' Society
- Department of the Environment (Property Services Agency)
- Department of the Environment (Building Research Establishment)
- Department of Transport
- Federation of Civil Engineering Contractors
- Institution of Civil Engineers
- Institution of Highways and Transportation
- Institution of Structural Engineers
- Rothamsted Experimental Station
- Society of Chemical Industry

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- Association of Consulting Engineers
- Refined Bitumen Association Ltd.
- Co-opted members

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Foreword

This Part of BS 1924 has been prepared under the direction of the Road Engineering Standards Policy Committee. It is Part 2 of a revision in two Parts of BS 1924:1975, which is now withdrawn.

The two Parts of BS 1924 are:

- *Part 1: General requirements, sampling, sample preparation and tests on materials before stabilization;*
- *Part 2: Methods of test for cement-stabilized and lime-stabilized materials.*

The tests for materials in the unstabilized state are given in Part 1 by reference to other British Standards. Except where they are seldom used, or the test procedures are identical in all respects, the tests for materials in the stabilized condition included in Part 2 are given in full, although they may be similar to tests in other British Standards. This is to provide a complete and comprehensive document for use by testing laboratories, and because the tests themselves have to be modified to take account of the presence of the stabilizing agent. This particularly applies to sample preparation.

The title of the standard has been amended to reflect the wider scope of this revision, which is intended to cover, in addition to soils, materials which when stabilized with cement or lime may be used for civil engineering purposes. Although concerned principally with Portland cement, hydrated lime (calcium hydroxide) and quicklime (calcium oxide) it is also applicable to other cements and types of lime, including those in which pulverized fuel ash (pfa) or slag are the major components.

This revision includes all the tests, with minor exceptions, for materials stabilized with lime or cement that were included in the 1975 edition but does not include any tests for materials stabilized with bitumen. In deciding to exclude tests for bitumen-stabilized materials from the revision the Committee consulted extensively on the currency and use of the tests in the 1975 edition and on the existence of or need for other tests. Reader's comments are invited on the need for and contents of a further part (Part 3) of this standard for such tests.¹⁾

Lime, and to a lesser extent cement, may also be used to modify rather than to stabilize a material. Modified materials are usually natural soils and probably fine-grained but may be by-products of industrial processes, e.g. colliery spoil. The object of the modification process is to improve the properties of the soil such as shear strength, durability, etc. but the modified material retains many of the properties of soil. The process may, for example, be used to render an unsuitable material suitable for modifying the plasticity characteristics. In these cases the tests in this standard may be suitable but equally the soil tests in BS 1377 referred to in the text may be considered to be applicable to measure the change in properties caused by modifying the soil or other material.

The following tests are included in this standard for the first time:

- a) determination of moisture content by microwave oven, nuclear gauge and by the calcium carbide method;
- b) determination of the moisture condition value;
- c) determination of frost heave;
- d) determination of tensile strength;
- e) determination of the plate loading value;
- f) determination of the degree of carbonation;
- g) determination of the initial consumption of lime.

Typical forms are included for all test methods to illustrate how the results may be conveniently calculated and recorded.

¹⁾ Comments should be sent to the Secretary, Technical Committee RDB/9, BSI, 2 Park Street, London W1A 2BS.

It has been assumed in the drafting of this standard that the execution of its provisions is entrusted to appropriately experienced people, for whose guidance it has been prepared.

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

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 104, 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.

Section 1. Scope, definitions and classification tests

1.1 Scope

This Part of BS 1924 describes methods of test for materials stabilized with cement or lime for civil engineering purposes.

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

1.2 Definitions

For the purposes of this Part of BS 1924 the definitions given in BS 1924-1 apply.

1.3 Determination of moisture content

1.3.1 Principle

The methods based on heating to remove water assume that all the “free” water in the stabilized material is removed in the heating process and that “chemically bound” water such as water of hydration is not removed by the test procedure. This is generally true for most materials likely to be encountered but problems can occur with materials that contain hydrated salts such as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) that lose water at temperatures below 105 °C (see note 1 to 1.3.3.2.3).

The definitive method of measuring moisture content is the oven-drying method given in 1.3.3 and is based on drying at 105 to 110 °C to remove the water.

Two subsidiary test procedures based on heating to remove the water are also included. Two other subsidiary methods neither of which is based on heating the samples to remove the water are also included. The first of these procedures relies on the reaction of water in the aggregate with calcium carbide to evolve acetylene, the amount of which can be assessed by the pressure it generates in a confined space. In the second the moisture content of the material under test is determined by placing a fast neutron source and a neutron detector on or adjacent to the material under test. The intensity of slow or moderated neutrons detected is dependent on the hydrogen content of the material under test and hence indirectly to the moisture content.

The requirements of BS 1924-1 shall, where appropriate, apply to this test method.

1.3.2 Sampling

The sample received at the laboratory (the laboratory sample) shall be taken in accordance with 5.3 of BS 1924-1:1990.

1.3.3 Oven-drying method (Definitive method)

1.3.3.1 Apparatus

1.3.3.1.1 Apparatus for all materials

1.3.3.1.1.1 An oven capable of maintaining a temperature of 105 °C $\pm$ 5 °C.

1.3.3.1.2 Apparatus for fine-grained materials

1.3.3.1.2.1 A glass weighing bottle, fitted with a ground glass stopper or cap, or a suitable airtight corrosion-resistant metal container.

NOTE A convenient size is one about 50 mm diameter and 25 mm high.

1.3.3.1.2.2 A balance, of 250 g minimum capacity, readable to 0.01 g.

1.3.3.1.2.3 A desiccator, containing anhydrous silica gel.

NOTE 1 A convenient size is 200 mm to 250 mm diameter.

NOTE 2 It is preferable to use self-indicating silica gel as the desiccant can be periodically dried at 110 °C to maintain its blue colour.

1.3.3.1.3 Apparatus for medium-grained materials

1.3.3.1.3.1 An airtight corrosion-resistant container, of about 500 g capacity.

1.3.3.1.3.2 A balance, of 1 kg minimum capacity, readable to 0.1 g.

1.3.3.1.3.3 A medium-sized scoop (see Figure 2 of BS 1924-1:1990).

1.3.3.1.4 Apparatus for coarse-grained materials

1.3.3.1.4.1 An airtight corrosion-resistant container, of about 3 kg capacity.

1.3.3.1.4.2 A balance, of 10 kg minimum capacity, readable to 1 g.

1.3.3.1.4.3 A large scoop (see Figure 2 of BS 1924-1:1990).

1.3.3.2 Procedure

1.3.3.2.1 Reduce the laboratory sample by the procedure described in 3.5 of BS 1924-1:1990 to produce a test portion of mass not less than given in Table 1 appropriate to the material.

Table 1 — Minimum mass of test portions

Grouping of material	Minimum mass of test portion	Accuracy of weighing
	g	g
Fine-grained	30	0.01
Medium-grained	300	0.1
Coarse-grained	3 000	1.0

1.3.3.2.2 Clean and dry the weighing bottle or container, weigh it to the accuracy given in Table 1 and record the mass (m_1). Take the test portion of minimum mass, crumble and place it loosely in the container or weighing bottle. Replace the lid or stopper and then weigh the container or bottle and contents to the same degree of accuracy as before. Record the mass (m_2).

1.3.3.2.3 Remove the lid or stopper, and place the container or bottle with its lid and contents in the oven and dry at $105 \pm 5^\circ\text{C}$ (see note 1) for a period which will vary with the amount of material being dried in the oven. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see note 2) at intervals of 4 h do not exceed 0.1 % of the original mass of the sample (see note 2). Do not replace the lid or stopper while the sample is in the oven.

NOTE 1 Some materials contain gypsum which on heating at the specified temperature loses its water of crystallization. The moisture content determined by this method will be affected by approximately 0.2 % for each 1 % of gypsum. If it is suspected that gypsum is present the moisture content samples should be dried at no more than 80°C and possibly for a longer time. The presence of gypsum can be identified by heating a small quantity of the material on a metal plate. Grains of gypsum will turn white within a few minutes, whereas most other minerals remain unaltered. If the standard conditions are not used, the drying conditions used should be stated in the test record.

NOTE 2 16 h to 24 h is usually a sufficient length of time for drying most materials, but large or wet samples will require longer. The drying time will also depend on the amount of material in the oven.

1.3.3.2.4 After drying, remove the container, or bottle, and contents from the oven and replace the lid and allow to cool.

NOTE It is impracticable to cool large samples of material in a desiccator and, if the lids of the containers fit well, it is unlikely that the samples will absorb any water from the air during cooling. However, if glass weighing bottles were used for fine-grained material, the container and contents should be allowed to cool in a desiccator and the stoppers should not be replaced until the material has cooled to room temperature.

1.3.3.2.5 After cooling weigh the container, or bottle, and contents to the same degree of accuracy as previously and record the mass (m_3).

1.3.3.3 Calculations and expression of results

NOTE A typical data and calculation form for the determination of the moisture content by the oven-drying method is given in form A of Appendix A.

Calculate the moisture content (w) of the test portion as a percentage of the dry mass of solids from the equation:

$$w = 100(m_2 - m_3)/(m_3 - m_1)$$

where

m_1 is the mass of container (in g);

m_2 is the mass of container and wet material (in g);

m_3 is the mass of container and dry material (in g).

Express the value of moisture content to the nearest 0.1 % of the dry mass of solids.

1.3.4 Sand-bath method

NOTE This method covers the determination of the moisture content of a test portion of stabilized material as a percentage of the dry mass of solids. It is intended as a rapid alternative to the definitive method described in 1.3.3 but is less accurate and is more suitable as a site test. The method should not be used if it is suspected that the material contains gypsum, calcareous matter or organic material, e.g. unburnt coal in minestone and pulverized-fuel ash (pfa).

1.3.4.1 Apparatus

1.3.4.1.1 Apparatus for all materials

1.3.4.1.1.1 *Equipment for heating the sand-bath*, e.g. an electric hot-plate or a gas-ring.

1.3.4.1.2 Apparatus for fine-grained materials

1.3.4.1.2.1 *An airtight, heat- and corrosion-resistant container*, approximately 50 mm in diameter and 25 mm deep.

1.3.4.1.2.2 *A balance*, of 250 g minimum capacity, readable to 0.1 g.

1.3.4.1.2.3 *A sand-bath*, containing clean sand to a depth of at least 25 mm and large enough to take the container.

NOTE A larger bath may be used to heat several containers at once.

1.3.4.1.2.4 *A palette knife* or other implement for stirring the test portion during drying.

NOTE A convenient size is one having a blade 100 mm long and 20 mm wide.

1.3.4.1.3 Apparatus for medium-grained materials

1.3.4.1.3.1 *A heat-resistant tray*, approximately 200 mm square and 50 mm deep.

1.3.4.1.3.2 *A balance*, of 1 kg minimum capacity, readable to 0.5 g.

1.3.4.1.3.3 *A sand-bath*, containing clean sand to a depth of at least 25 mm and large enough to take the tray.

NOTE A larger bath may be used to heat several samples at once.

1.3.4.1.3.4 *A palette knife*, or other implement for stirring the test portion during drying.

NOTE A convenient size is one having a blade 100 mm long and 20 mm wide.

1.3.4.1.3.5 *A medium-sized scoop* (see Figure 2 of BS 1924-1:1990).

1.3.4.1.4 Apparatus for coarse-grained materials

1.3.4.1.4.1 *A heat-resistant tray*, approximately 250 mm square and 50 mm to 70 mm deep.

1.3.4.1.4.2 *A balance*, of 10 kg minimum capacity, readable to 1 g.

1.3.4.1.4.3 *A sand-bath*, containing clean sand to a depth of at least 25 mm and large enough to take the tray.

1.3.4.1.4.4 *A palette knife*, or other implement for stirring the test portion during drying.

NOTE A convenient size is one having a blade 200 mm long and 30 mm wide.

1.3.4.1.4.5 A *large-sized scoop* (see Figure 2 of BS 1924-1:1990).

1.3.4.2 Procedures

1.3.4.2.1 Procedure for fine-grained materials

1.3.4.2.1.1 Clean, dry and weigh the container to the nearest 0.1 g (m_1). Take the test portion of minimum mass 30 g prepared as described in **1.3.3.2** crumble and place loosely in the container, and replace the lid. Weigh the container and contents to the nearest 0.1 g (m_2).

1.3.4.2.1.2 Remove the lid and place the container and contents on the sand-bath, which shall be heated by one of the methods given in **1.3.4.1.1**, care being taken not to get the sand-bath too hot (see note). During heating disturb the sample frequently and thoroughly with the palette knife to assist the evaporation of the water.

NOTE A convenient method of detecting overheating is by the use of small white pieces of paper mixed with the material. Overheating is indicated if the paper turns brown.

1.3.4.2.1.3 When the container and contents have been heated long enough to dry the sample [1 h is usually sufficient (see note)], remove them from the sand-bath, replace the lid, and allow the whole to cool.

NOTE The drying period will vary with the type of material, the size of samples and the field conditions. It is suggested that when a large number of moisture content determinations are to be made with one material, several measurements should be made using different periods of drying to determine the minimum period required to effect adequate drying. The material shall be deemed to be dry if the additional loss of mass when it is heated for a further period of 15 min does not exceed 0.1 g for fine-grained, 0.5 g for medium-grained and 5 g for coarse-grained materials.

1.3.4.2.1.4 Weigh the container and contents to the nearest 0.1 g (m_3).

1.3.4.2.2 Procedure for medium and coarse-grained materials

1.3.4.2.2.1 Clean, dry and weigh the tray to the nearest 0.5 g (m_1). Take a test portion of minimum mass 300 g for medium-grained materials and 3 kg for coarse-grained materials, prepared as described in **1.3.3.2**, crumble and spread out evenly in the tray. Weigh the tray and contents to the nearest 0.5 g (m_2) for medium-grained materials, and to the nearest 5 g (m_2) for coarse-grained materials.

1.3.4.2.2.2 Place the tray on the sand-bath, which shall be heated by one of the methods given in **1.3.4.1.1**, care being taken not to get the sand-bath too hot (see note to **1.3.4.2.1.2**). During heating disturb the sample frequently and thoroughly with the palette knife to assist the evaporation of the water.

1.3.4.2.2.3 When the tray and contents have been heated long enough to dry the sample [1 h is usually sufficient (see note to **1.3.4.2.1.3**)], remove them from the sand-bath, replace the lid, and allow the whole to cool.

1.3.4.2.2.4 Immediately the tray is cool enough to handle, weigh the tray and contents to the nearest 0.5 g for medium-grained materials, and to the nearest 5 g for coarse materials (m_3).

1.3.4.3 Calculations and expression of results.

Calculate the moisture content (w) of the test portion as a percentage of the dry mass of solids from the equation:

$$w = 100(m_2 - m_3)/(m_3 - m_1)$$

where

m_1 is the mass of container (in g);

m_2 is the mass of container and wet material (in g);

m_3 is the mass of container and dry material (in g).

Express the value of moisture content to the nearest 0.1 % of the dry mass of solids.

1.3.5 Microwave oven method (Subsidiary method for fine-grained materials)

NOTE This method covers the determination of the moisture content of a test portion of a stabilized fine-grained material. In favourable circumstances it is a rapid alternative to the definitive method described in **1.3.3** but the range of materials for which it is suitable is restricted and it is confined to fine-grained materials because suitable containers of adequate size are not readily available to hold the required mass of medium and coarse-grained materials.

Most siliceous and calcareous aggregates can be dried satisfactorily in a microwave oven but flints, slag and some calcareous aggregates have a tendency to shatter. Materials such as pulverized fuel ash, colliery spoil (minestone) or aggregates derived from them are not suitable as any carbonaceous matter remaining in them will ignite in the microwave oven. Materials with a high proportion of iron compounds may also give rise to problems. For these reasons it is necessary to carry out preliminary trials to establish whether or not the material under test is adversely affected by microwave radiation.

1.3.5.1 Apparatus. The apparatus shall be as specified for fine-grained materials in **1.3.3.1** except that the oven and airtight corrosion-resistant containers shall be replaced respectively by a well ventilated microwave oven and nonmetal containers of sufficient capacity to hold the mass of the test portion.

NOTE Metal containers cannot be used as they reflect microwaves. Materials such as porcelain and borosilicate glass which heat up under the influence of microwaves and not just by conduction from the aggregate are preferable; this reduces the possibility of water vapour condensing on the cooler walls of the container before being carried away by air circulation. Silica and polypropylene containers may also be used.

1.3.5.2 Procedure

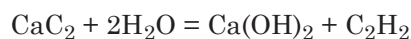
1.3.5.2.1 Carry out preliminary trials to ascertain the time required to dry the test portion and to establish whether or not the material under test is adversely affected by microwave radiation.

1.3.5.2.2 Follow the procedure described for fine-grained materials described in **1.3.3.2** except that microwave drying is used. Operate the microwave oven in accordance with the manufacturer's instructions.

1.3.5.3 Calculations and expression of results. Calculate the moisture content as described in **1.3.3.3** and express the value to the nearest 0.1 % of the dry mass of solids.

1.3.6 Calcium carbide method (Subsidiary method)

1.3.6.1 Principle. Calcium carbide will react with water in a material to produce acetylene according to the equation



If the reaction is allowed to occur under standardized conditions in a closed container the pressure of the acetylene generated in the container is a measure of the moisture content of the aggregate. The procedure given in this subclause describes how this can be used as a rapid method of determining moisture content of stabilized materials. The test results may not correspond exactly with the definitive oven-drying method.

1.3.6.2 Apparatus

1.3.6.2.1 A calcium carbide pressure moisture meter, calibrated in accordance with the manufacturer's instructions.

1.3.6.2.2 A balance, of 2 kg minimum capacity, readable to 0.1 g.

1.3.6.2.3 Steel balls, to aid the mixing process usually supplied with the apparatus.

1.3.6.2.4 A cleaning brush and a cloth.

1.3.6.2.5 A scoop, for measuring the calcium carbide reagent.

1.3.6.3 Reagent

1.3.6.3.1 Finely pulverized calcium carbide, of a grade capable of producing acetylene gas in the amount of at least 0.15 m³/kg of carbide.

1.3.6.4 Procedure

NOTE Only a general procedure is given as the test should always be carried out in accordance with the procedure recommended by the manufacturer.

1.3.6.4.1 Place the calcium carbide and the steel balls in the larger chamber of the moisture tester.

1.3.6.4.2 Take a test portion of the stabilized material of known mass (not less than 100 g) and place it in the cap of the tester. With the vessel in an approximately horizontal position, insert the cap in the pressure vessel and seal the unit by tightening the clamp, taking care that no carbide comes into contact with the material until a complete seal is achieved. Then raise the moisture tester to a vertical position so that the aggregate falls into the pressure vessel.

1.3.6.4.3 Shake the instrument vigorously in a rotary motion so that the calcium carbide can react with the available free water.

NOTE The shaking should continue for at least a minute and time should be permitted to allow dissipation of the heat generated by the chemical reaction.

1.3.6.4.4 When the needle of the pressure dial stops moving read the dial while holding the instrument in a horizontal position at eye level. Record the dial reading.

1.3.6.4.5 With the cap of the instrument pointed away from the operator slowly release the gas pressure. Empty the pressure vessel and examine the material for lumps. If the sample is not completely pulverized repeat the test using a new test portion.

1.3.6.5 Calculations and expression of results. The dial reading is the percentage of moisture by wet mass. Convert this to the percentage of moisture by dry mass from the equation

$$Y = X / \left(1 - \frac{X}{100}\right)$$

where

Y is the moisture content as a percentage of the dry mass;

X is the moisture content as a percentage of the wet mass;

and record the results to the nearest 0.1 % of the dry mass of solids.

1.3.7 Nuclear gauge method (for on site testing only)

For details of the measurement of the in-situ moisture content by nuclear gauges, see **3.7**.

1.3.8 Test report

The test report shall affirm that the moisture content was determined in accordance with **1.3** of BS 1924-2:1990 and whether or not a certificate of sampling is available. If available a copy of the certificate of sampling shall be provided. The test report shall contain the following additional information:

a) sample identification;

- b) the moisture content as a percentage of the dry mass of the stabilized material;
- c) the method used for the determination of moisture content, i.e. the definitive oven-drying method or whichever of the subsidiary methods was used.

NOTE Normally the subsidiary methods will be used for site control purposes where the need for a test report will not arise.

1.4 Determination of effect of the stabilizer on plasticity properties

1.4.1 Principle

Lime (and to a lesser extent cement) has a marked effect on the plasticity properties of materials containing clay minerals. This is brought about by two separate mechanisms; firstly, there is an immediate effect as a result of cation exchange at the surface of the clay particles and, secondly, there is a longer term effect as a result of the pozzolanic reaction between the lime (or lime liberated by hydrated cement) and the clay minerals. The cation exchange reactions have the most influence on the plasticity properties whilst the pozzolanic reaction is largely responsible for the increase in strength which occurs over a period of time.

The requirements of BS 1924-1 shall, where appropriate, apply to this test method.

1.4.2 Apparatus

1.4.2.1 General apparatus

1.4.2.1.1 *Apparatus for the determination of moisture content* by the oven-drying method given in 1.3.3.1.

1.4.2.1.2 *A 2 mm and a 425 μm test sieve* with receivers complying with 4.2.4.2 of BS 1924-1:1990.

1.4.2.1.3 *A sharp knife.*

1.4.2.1.4 *An implement for shredding cohesive material.*

1.4.2.1.5 *Two palette knives.*

NOTE A convenient size is one having a blade 200 mm long and 30 mm wide.

1.4.2.1.6 *Airtight containers*, such as polyethylene bags of suitable size and sheets of plastics sheeting.

1.4.2.1.7 *An evaporating dish*, 150 mm in diameter.

1.4.2.1.8 *A flat glass plate.*

NOTE 1 A convenient size is about 10 mm thick and 500 mm square.

NOTE 2 When determining the plastic limit, the condition of the surface of the glass plate may affect the behaviour of the rolled threads. Mixing of material containing silica particles inevitably scratches a glass surface so the plate used for mixing the material with water will not generally be suitable. Use of a separate unscratched glass plate for the rolling operation will reduce discrepancies due to this effect.

1.4.2.1.9 *A wash bottle*, containing distilled or demineralized water.

1.4.2.1.10 *Glass beakers*, of 1 L capacity and a plastic bucket of 5 L capacity.

1.4.2.1.11 *A glass stirring rod.*

1.4.2.1.12 *A length of rubber or plastic tubing*, for connection to the water supply, fitted at the other end with a spray nozzle.

1.4.2.2 *Additional apparatus for determination of the plastic limit*

1.4.2.2.1 *A length of rod*, 3 mm in diameter and about 100 mm long.

1.4.2.3 *Additional apparatus for determination of the liquid limit*

1.4.2.3.1 *A penetrometer*, as used in bituminous material testing complying with BS 2000-49.

1.4.2.3.2 *A cone of machined stainless steel* complying with the essential details shown in Figure 1(a). The surface of the cone shall be smooth, polished and dry (see note). To ensure that the point remains sufficiently sharp for the purpose of the test, the cone shall be replaced if after continued use the point can no longer be felt when brushed lightly with the tip of the finger when the tip of the cone is pushed through a hole 1.5 ± 0.02 mm in diameter, bored through a metal plate 1.75 ± 0.1 mm thick [Figure 1(b)].

NOTE The effect of surface roughness is more significant than small variations in cone angle or bluntness of the tip.

1.4.2.3.3 *One or more metal cups*, approximately 55 mm in diameter and 40 mm deep with the rim parallel to the flat base.

1.4.2.3.4 *A metal straightedge*, with bevelled edge, approximately 150 mm long.

1.4.3 Sample preparation

NOTE The procedure given assumes that laboratory trials are being made to find the effect of the addition of stabilizer on the plasticity properties of the material. If it is desired to find the plasticity properties of field-mixed material the sample preparation procedure is not applicable. However, if required the plasticity properties of field-mixed material may be determined with appropriate modifications by the procedure given in 1.4.5 and 1.4.6.

1.4.3.1 *Taking of sample.* The sample received at the laboratory shall be taken in accordance with clause 5 of BS 1924-1:1990.

1.4.3.2 *Reduction of sample.* Reduce the laboratory sample by the procedures described in 1.4.3.3 or 1.4.3.4. Wherever possible the tests shall be carried out on material in its natural state. With many fine-grained material, it is possible to remove the few coarse particles present, i.e. particles retained on a 425 μm sieve, by hand, otherwise these particles shall be removed as described in 1.4.3.4. Do not oven-dry the material and do not allow it to dry in air more than is necessary to prepare the test portions for test.

1.4.3.3 *Initial preparation of cohesive fine-grained materials*

1.4.3.3.1 From a laboratory sample of fine-grained material in its natural state, and which contains little or no material retained on a 425 µm test sieve, take a representative test portion weighing about 500 g. Cut it into small pieces using a knife or grater and remove any coarse particles by hand or with tweezers.

1.4.3.3.2 If coarse particles are present determine their mass and the mass of the sample used.

NOTE These weighings enable the approximate proportion of coarse material to be calculated if required.

1.4.3.3.3 Determine the moisture content of a 50 g sample of the test portion by the oven-drying method described in 1.3.3. Place the remainder of the test portion in an airtight container that is just large enough to hold the material and store until required.

1.4.3.4 *Initial preparation of all other materials*

1.4.3.4.1 From the laboratory sample take a representative test portion of the material to give a test specimen passing the 425 µm test sieve weighing at least 500 g.

1.4.3.4.2 From the test portion take a representative sample of mass about 10 % of the total mass for the determination of moisture content (w %) by the oven-drying method described in 1.3.3.

1.4.3.4.3 Weigh the remainder of the test portion to an accuracy of within 0.03 %. Record the mass (m_1).

1.4.3.4.4 Place the weighed test portion in a suitable container under just enough distilled or demineralized water to submerge it. Stir the mixture until it forms a slurry.

NOTE If practicable use distilled or demineralized water throughout the stages of washing; on no account should dispersants or flocculating agents be used in this or any subsequent stage.

1.4.3.4.5 Pour the slurry through a suitable guard sieve (or sieves) and the 425 µm test sieve, nested in a receiver. Use the minimum amount of water necessary to wash the fines through into the receiver (or into a larger container if necessary) until the water passing the 425 µm test sieve is virtually clear.

1.4.3.4.6 Collect together the washed material retained on the sieves, dry it at 105 °C to 110 °C and determine its mass to the same accuracy as before (m_2).

1.4.3.4.7 Allow the fine particles in the wash water to settle out and after a suitable interval carefully pour off the clear water above the suspension.

1.4.3.4.8 Allow the suspension to dry partially in a current of warm air, protected from dust, until it forms a stiff paste.

1.4.3.4.9 Determine the moisture content of a 50 g sample of the test portion by the oven-drying method described in 1.3.3. Place the remainder of the test portion in an airtight container that is just large enough to hold the material and store until required.

1.4.3.4.10 Calculate the dry mass (m_d , in g) of the initial test portion and the percentage of particles (p_a) passing the 425 µm sieve from the equation

$$m_d = 100m_1/(100 + w)$$

where

w is the moisture content (in %);

m_1 is the mass of the sample as determined in 1.4.3.4.3 (in g);

$p_a = 100 (m_d - m_2)/m_d$ (in %);

m_2 is the mass of the sample as determined in 1.4.3.4.6 (in g).

1.4.3.5 *Preparation of samples for plastic limit determination*

1.4.3.5.1 Two test samples are required for this determination, one of the material in its natural condition and the other of the material to which the stabilizer has been added.

1.4.3.5.2 Take two test samples each of mass about 25 g from the paste prepared as described in 1.4.3.3.3 or 1.4.3.4.9. Weigh each sample to 0.1 g and calculate its dry mass from the mass of the wet sample and the value of its moisture content.

1.4.3.5.3 To one sample add the required amount of stabilizer and mix thoroughly on the glass plate with palette knives. If the immediate effect of the stabilizer on the plastic limit is required determine the plastic limit of both samples as described in 1.4.4. If the change of plastic limit with time is being investigated roll each sample into a ball, wrap each in plastics sheeting and store in an airtight container until required.

1.4.3.6 *Preparation of samples for liquid limit determination*

1.4.3.6.1 Two test samples are required for this determination, one of the material in its natural condition and the other of the material to which the stabilizer has been added.

1.4.3.6.2 Take the material, prepared as described in 1.4.3.3.3 or 1.4.3.4.9, set aside about 50 g for the determination of the plastic limit, if this has not already been done. Split the remaining sample in half, weigh each test sample to 0.1 g and calculate its dry mass from the mass of the wet sample and the value of its moisture content.

1.4.3.6.3 To one sample add the required amount of stabilizer and mix thoroughly with the palette knives on the glass plate. Mix the paste for at least 10 min (see note) and if necessary add more distilled or demineralized water so that the first cone penetration, when tested as described in **1.4.5**, is about 15 mm. If the immediate effect of the stabilizer on the liquid limit is required determine the liquid limit of both samples as described in **1.4.5**. If the change of liquid limit with time is being investigated roll each sample into a ball, wrap each in plastics sheeting and store in an airtight container until required.

NOTE Some materials, e.g. clays of high plasticity, may require up to 40 min of continuous mixing immediately before testing to obtain reliable results.

1.4.4 Determination of the plastic limit

1.4.4.1 Procedure

1.4.4.1.1 For each test sample, allow the sample to dry on the glass plate (**1.4.3.5.3**) until it becomes plastic enough to be shaped into a ball. If the sample is too dry to start with mix it with water until it is in a plastic condition.

1.4.4.1.2 Mould the ball between the fingers and roll it between the palms of the hands until the heat of the hands has dried the sample sufficiently for cracks to appear on its surface. Divide this sample into two subsamples of approximately 10g each and carry out a separate determination on each portion. Divide each subsample into four approximately equal parts and treat each part as described in **1.4.4.1.3** to **1.4.4.1.7**.

1.4.4.1.3 Mould the sample in the fingers to equalize the distribution of moisture, then form it into a thread about 6 mm diameter between the first finger and thumb of each hand.

1.4.4.1.4 Roll the thread between the fingers (finger-tip to the second joint) of one hand and the surface of the glass roiling plate. Use enough pressure to reduce the diameter of the thread to about 3 mm in five to ten complete (forward and back) movements of the hand. (Some heavy clays will require 10 to 15 movements when the sample is near the plastic limit, because the material hardens at this stage). Maintain a uniform rolling pressure and do not reduce the pressure as the thread diameter approaches 3 mm.

1.4.4.1.5 Pick up the sample, mould it between the fingers to dry it further, form it into a thread and roll it out again as in **1.4.4.1.4**.

NOTE Gradual drying of the material is achieved by alternately rolling and moulding, not by continual rolling (either as a ball or threads) which produces a dry crust.

1.4.4.1.6 Repeat **1.4.4.1.5** until the thread shears both longitudinally and transversely when it has been rolled to about 3 mm diameter, as gauged by the metal rod (see note). Do not gather the pieces of material together after they have been crumbled, and re-form a thread. The first crumbling point is the plastic limit.

NOTE With materials that are only marginally plastic it is often difficult to obtain the correct crumbling condition.

1.4.4.1.7 Gather together the portions of the crumbled thread, transfer them to a suitable container and replace the lid immediately.

1.4.4.1.8 Repeat **1.4.4.1.3** to **1.4.4.1.7** on the other three portions of the sample, replacing them all in the same container, determine the moisture content of the material in the container as described in **1.3.3**.

1.4.4.1.9 Repeat **1.4.4.1.2** to **1.4.4.1.8** on the duplicate subsample formed in **1.4.4.1.2**.

1.4.4.2 Calculations and expression of results

NOTE A typical data and calculation form for the determination of the plastic limit is given in form B of Appendix A.

1.4.4.2.1 Calculate the moisture content of both subsamples tested, as described in **1.3.3**.

1.4.4.2.2 If the two results differ by more than 0.5 % moisture content repeat the whole test.

1.4.4.2.3 Calculate the average of the two moisture content values and report this as the plastic limit of the sample under test to the nearest whole number.

1.4.5 Determination of the liquid limit

1.4.5.1 Procedure

1.4.5.1.1 For each test sample, place the test sample on the glass plate and, if necessary, mix with more distilled or demineralized water so that the first cone penetration reading is about 150 mm.

1.4.5.1.2 Push a portion of the mixed material into the cup with a palette knife taking care not to trap air. Strike off excess material with the bevelled edge of the straightedge to give a smooth surface.

1.4.5.1.3 With the penetration cone locked in the raised position lower the supporting assembly so that the tip of the cone just touches the surface of the material. When the cone is in the correct position a slight movement of the cup will just mark the surface. Record the reading of the dial gauge to the nearest 0.1 mm.

1.4.5.1.4 Release the cone for a period of 5 ± 1 s. If the apparatus is not fitted with an automatic release and locking device take care not to jerk the apparatus during this operation. After locking the cone in position lower the dial gauge to the new position of the cone shaft and note the reading to the nearest 0.1 mm. Record the difference between the beginning and end of the drop as the cone penetration.

1.4.5.1.5 Lift out the cone and carefully clean it, taking care not to scratch the surface.

1.4.5.1.6 Add a little more wet material to the cup, taking care not to trap air, make the surface smooth as in **1.4.5.1.2** and repeat steps **1.4.5.1.3** to **1.4.5.1.5**.

1.4.5.1.7 Proceed as follows, as applicable:

- a) if the difference between the first and second penetration readings is less than 0.5 mm record the average of the two penetrations and proceed to **1.4.5.1.8**; or
- b) if the second penetration is more than 0.5 mm and less than 1 mm difference from the first, carry out a third test; if the overall range is not more than 1 mm continue at **1.4.5.1.8**; or
- c) if the overall range is more than 1 mm remove the material from the cup, re-mix and repeat **1.4.5.1.2** to **1.4.5.1.7** until constant results are obtained before proceeding to **1.4.5.1.8**.

1.4.5.1.8 Take a moisture content sample of about 10 g from the area penetrated by the cone and determine the moisture content as described in **1.3.3**.

1.4.5.1.9 Repeat steps **1.4.5.1.2** and **1.4.5.1.8** at least three more times using the same sample of material to which further increments of distilled water have been added. The test shall always proceed from the drier to the wetter condition of the material. The amount of water added shall be such that a range of penetration values of approximately 15 mm to 25 mm is covered by the four or more test runs and are evenly distributed. Each time material is removed from the cup for the addition of water the cup shall be washed and dried.

1.4.5.1.10 If at any time during the above procedure the material has to be left for a short time on the glass plate it shall be covered with the evaporating dish or damp cloth to prevent it drying out.

1.4.5.2 *Calculations and expression of results*

NOTE A typical data and calculation form for the determination of the liquid limit is given in form C of Appendix A.

1.4.5.2.1 Calculate the moisture content of each separate determination as described in **1.3.3**.

1.4.5.2.2 Plot the relationship between moisture content and cone penetration with the percentage moisture contents as abscissae and the cone penetrations as ordinates, both on linear scales.

1.4.5.2.3 Draw the best straight line fitting the plotted points.

1.4.5.2.4 From the linear graph read off the moisture content corresponding to a cone penetration of 20 mm as the liquid limit of the sample under test.

1.4.6 Derivation of the plasticity index

1.4.6.1 Determine the plastic limit (w_P) by the procedure given in **1.4.4** and the liquid limit (w_L) by the procedure given in **1.4.5**.

1.4.6.2 Calculate the plasticity index (i_P , in %) from the equation

$$i_P = w_L - w_P$$

1.4.7 Test report

The test report shall affirm that the effect of the stabilizer on the plasticity properties of the material were determined in accordance with **1.4** of BS 1924-2:1990 and whether or not a certificate of sampling is available. If available a copy of the certificate of sampling shall be provided. The test report shall contain the following additional information:

- a) sample identification;
- b) the amount and type of stabilizer used;
- c) the lapse in time (if more than 3 h) between the addition of the stabilizer and carrying out the test;
- d) the plastic limit and/or the liquid limit of the material with and without the addition of stabilizer;
- e) the proportion of material that was used, i.e. the amount that passes the 425 μm test sieve, and the method to be used to obtain the material to be tested, i.e. whether as described in **1.4.3.3** or **1.4.3.4**;
- f) if both the liquid limit and the plastic limit have been determined, the plasticity index.

1.5 Determination of degree of pulverization

1.5.1 Principle

The determination of the degree of pulverization is carried out on spot samples taken from small areas of the mixed material. It is essential that the individual lumps of material are not broken down during the sampling and sample reduction operations. For this reason it is better to take a sample of the mass required for the test rather than to obtain a larger sample and then to reduce this to the required mass by sample reduction.

The requirements of BS 1924-1 shall where appropriate apply to this test method.

1.5.2 Apparatus

1.5.2.1 A balance, of 5 kg minimum capacity, readable to 1 g.

1.5.2.2 A 5 mm test sieve, and receiver, complying with 4.2.4.2 of BS 1924-1:1990.

1.5.2.3 A scoop, e.g. as in Figure 2 of BS 1924-1:1990.

1.5.2.4 A tray, approximately 300 mm square.

1.5.3 Procedure

Take a sample of the material approximately 1 kg in mass and weigh to the nearest 1 g (m_1). Spread this on the sieve, taking care not to overload it, and shake it gently. Do not force material through the sieve and ensure that the lumps of material are broken as little as possible. Determine the mass of the material retained on the sieve to the nearest 1 g (m_2). Break any lumps of the material retained on the sieve until all individual particles finer than 5 mm are separated. Replace on the sieve and shake the sieve until all the material finer than 5 mm has passed through it. Determine the mass of the material that is still retained on the sieve to the nearest 1 g (m_3).

1.5.4 Calculations and expression of results

NOTE A typical data and calculation form for the determination of the degree of pulverization is given in form D of Appendix A.

1.5.4.1 Calculate the degree of pulverization (P , in %) from the equation:

$$P = 100 (m_1 - m_2)/(m_1 - m_3)$$

where

m_1 is the total mass of the sample (in g);

m_2 is the mass of the unbroken material retained on the sieve (in g);

m_3 is the mass of the material finally retained on the sieve (in g).

1.5.4.2 Report the degree of pulverization to the nearest 5 %.

1.5.5 Test report

Normally this test is used for site control purposes where the need for a test report will not arise. If a test report is required it shall affirm that the degree of pulverization was determined in accordance with 1.5 of BS 1924-2:1990. The test report shall contain the following additional information:

- a) sample identification;
- b) the degree of pulverization of the sample to the nearest 5 %.

Section 2. Compaction related tests

2.1 Determination of the dry density/moisture content relation

2.1.1 Principle

Compaction of stabilized material is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the stabilized material. The dry density which can be achieved depends on the degree of compaction applied and the amount of water present in the material. For a given degree of compaction of a given material there is usually an optimum moisture content at which the dry density obtained reaches a maximum value. With free-draining granular materials, however, the moisture/density relation may have little meaning. The requirements of BS 1924-1 shall where appropriate apply to this test method.

2.1.2 Types of test

2.1.2.1 Three types of compaction test are described each with procedural variations related to the nature of the material. The first of these is the “light” compaction test in which a 2.5 kg rammer is used (see 2.1.3). The second is the “heavy” compaction test which is similar but gives a much greater degree of compaction by using a 4.5 kg rammer with a larger drop on thinner layers of material (see 2.1.4).

2.1.2.2 For both these tests a 1 L capacity compaction mould is used for fine-grained materials and for medium-grained materials containing less than 5 % retained on a 20 mm test sieve. For other medium-grained materials and for coarse-grained materials the tests are carried out in the larger “CBR” mould (see notes 1 and 2).

2.1.2.3 The third type of test makes use of vibratory compaction and is intended mainly for granular (non-cohesive) materials. Two methods of vibratory compaction are given, the first (preferred) method uses the special apparatus described in 2.1.5. The second (subsidiary) method uses a hand-held vibrating hammer and a CBR mould (see 2.1.6).

NOTE 1 The requirements for compaction in the CBR mould are based on the same compactive effort per unit volume of material as in the standard 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 material, one size of mould should therefore be used throughout.

NOTE 2 If more than 15 % of material is retained on a 37.5 mm test sieve the material is too coarse to be tested.

2.1.3 Method using 2.5 kg rammer

2.1.3.1 Sampling. The sample received at the laboratory (the laboratory sample) shall be taken in accordance with clause 5 of BS 1924-1:1990.

Reduce the laboratory sample by the procedures described in 5.4 of BS 1924-1:1990 to produce at least five test portions each with an approximate mass of 2.5 kg in the case of fine and medium-grained materials to be compacted in the 1 L mould, or an approximate mass of 8 kg in the case of medium and coarse-grained materials to be compacted in a CBR mould.

2.1.3.2 Apparatus

2.1.3.2.1 A cylindrical metal mould (the 1 L compaction mould), having a nominal internal volume of 1 L (for fine-grained and medium-grained materials (see 2.1.2.2). The mould shall be fitted with a detachable baseplate and a removable extension. Its dimensions shall be as shown in Figure 2 which also indicates one suitable design of mould. The internal faces shall be smooth, clean and dry before each use.

2.1.3.2.2 A CBR mould (for medium and coarse-grained materials [see 2.1.2.2]) as used for the determination of the California Bearing Ratio and as specified in 4.5.

2.1.3.2.3 A metal rammer, having a 50 mm diameter circular face weighing 2.5 kg and complying with the essential dimensions shown in Figure 3. The rammer shall be equipped with a suitable arrangement for controlling the height of drop to 300 ± 3 mm. The machine shall be firmly supported on a heavy solid base such as concrete floor or plinth.

NOTE One suitable form of hand apparatus is shown in Figure 3. A motorized form of the apparatus may be used provided:

- a) that the essential dimensions of the rammer and mould are adhered to;
- b) that the rammer has a free vertical fall of the correct controlled height; and
- c) that the density achieved is within ± 2 % of the density achieved by using the hand rammer.

2.1.3.2.4 A balance of, either:

- a) 10 kg minimum capacity readable to 1 g, for tests carried out in a standard mould; or
- b) 25 kg minimum capacity readable to 5 g, for tests carried out in a CBR mould.

2.1.3.2.5 A palette knife.

NOTE A convenient size is one having a blade approximately 100 mm long and 20 mm wide.

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

2.1.3.2.7 A 20 mm and a 37.5 mm test sieve and receivers.

2.1.3.2.8 A large metal tray.

NOTE A convenient size is one about 600 mm $\times$ 500 mm with sides 80 mm deep.

2.1.3.2.9 Apparatus for determination of the moisture content, by the oven-drying method given in 1.3.3.

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

2.1.3.3 Preparation of the test portions

2.1.3.3.1 For fine and medium-grained materials compacted in the 1 L mould

2.1.3.3.1.1 Remove all stones retained on the 20 mm test sieve (see note) from each of the test portions, obtained as described in 2.1.3.1.

NOTE The removal of small amounts of stone (up to 5 % retained on a 20 mm test sieve) will affect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density. If more than 5 % of material is retained on the 20 mm test sieve the procedure for medium and coarse-grained materials should be followed.

2.1.3.3.1.2 Mix each of the test portions with the required amounts of water (see note 1) and stabilizer (see note 2) as described in clause 6 of BS 1924-1:1990. Mix the respective test portions with the different amounts of water to give a suitable range of moisture contents. The range of moisture contents shall be such that the optimum moisture content, at which the maximum dry density occurs, is within that range (see note 3). Do not mix any test portion with stabilizer until it is ready to be compacted.

NOTE 1 The choice of the range of moisture contents to use is inevitably one of trial-and-error and an unfortunate choice could lead to a large number of test portions being required. Consequently although five test portions may be sufficient it is usually necessary to be prepared to produce a larger number than this.

NOTE 2 If the amount of stabilizer required has not been determined at this stage, the amount may be estimated, but the test should be repeated with the required amount of stabilizer if this is found subsequently to be different from the estimated amount.

NOTE 3 The range of moisture contents obtained should include the optimum moisture content and the amounts of water to be added to the test portions will therefore vary with the type of stabilized material under test. In general with non-cohesive materials a minimum moisture content of 4 to 6 % would be suitable with additional increments of 1 to 2 % for each successive test portion tested. With cohesive materials a minimum moisture content of 8 to 10 % below the plastic limit of the material would usually be suitable with additional increments of 2 to 4 % for each successive sample tested. To increase the accuracy of the test it is often advisable to reduce the increments in the region of the optimum moisture content.

2.1.3.3.2 For medium and coarse-grained materials compacted in a CBR mould

2.1.3.3.2.1 Remove all stones retained on the 37.5 mm test sieve from each of the test portions, obtained as described in 2.1.3.1. If more than 15 % of material is removed the material is too coarse to be tested by the procedure given here.

2.1.3.3.2.2 Follow the procedure given in 2.1.3.3.1.2.

2.1.3.4 Compaction procedure for use with the 1 L mould

2.1.3.4.1 Weigh the mould with the baseplate attached to the nearest 1 g (m_1). Measure the internal dimensions to 0.1 mm to ensure that the mould complies with the specification.

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

2.1.3.4.3 Place a quantity of the first test portion in the mould such that when compacted it occupies a little over one-third of the height of the mould body.

2.1.3.4.4 Apply 27 blows from the rammer dropped from a height of 300 ± 3 mm above the material. Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed by the material in the guide tube. Allow the rammer to fall under its own mass and do not impart any momentum to it when it is released.

2.1.3.4.5 Repeat Steps 2.1.3.4.3 and 2.1.3.4.4 twice more, so that the amount of material 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). Complete the compaction of the test portion within 20 min of adding water to the mix.

NOTE It is necessary to control the total volume of material compacted since, if the amount of material struck off after removing the extension is too great, the result will be inaccurate.

2.1.3.4.6 Remove the extension, strike off the excess material and level off the surface of the compacted material 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.

2.1.3.4.7 Weigh the material and mould with baseplate to the nearest 1 g (m_2).

2.1.3.4.8 Remove the compacted specimen from the mould and place it on the large metal tray. Take a representative sample of the material for determination of its moisture content by the oven-drying method described in 1.3.3. Alternatively the whole specimen may be dried out.

2.1.3.4.9 Repeat steps 2.1.3.4.1 to 2.1.3.4.8 with the remaining test portions to give a total of at least five determinations.

2.1.3.5 Compaction procedure for use with the CBR mould. Follow the procedure given in 2.1.3.4 except for the following.

a) In 2.1.3.4.1, weigh the mould, with baseplate attached to the nearest 5 g (m_1).

b) In 2.1.3.4.4, apply 62 blows from the rammer dropped from a height of 300 ± 3 mm to each layer.

c) In 2.1.3.4.7, weigh the material and mould with baseplate to the nearest 5 g (m_2).

2.1.3.6 Calculations and expression of results

NOTE A typical data and calculation form for the determination of the dry density/moisture content relation is given in form E of Appendix A.

2.1.3.6.1 Calculations

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

$$\rho = (m_2 - m_1)/v$$

where

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

m_2 is the mass of the mould, base and compacted material (in g);

v is the volume of the mould (in mL).

where

$v = 1\,000$, for a mould having the dimensions shown in Figure 2;

$v = 2\,305$, for a CBR mould having the dimensions specified in 4.5.2.5.

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

$$\rho_d = 100\rho/(100 + w)$$

where

w is the moisture content of the relevant test portion.

2.1.3.6.1.3 Plot the dry densities, obtained from a series of determinations, as ordinates against the corresponding moisture contents as abscissae. Draw a smooth curve through the points and identify the position of the maximum on this curve (see note). Read off the values of dry density and moisture content to three significant figures corresponding to that point (see Figure 1 of BS 1924-1:1990).

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

2.1.3.6.1.4 To assist in drawing the curve, and for comparison on the same graph, plot the curves corresponding to zero, 5 % and 10 % air voids calculated from the equation:

$$\rho_d = \rho_w \left[\frac{1 - \frac{V_a}{100}}{\frac{1}{\rho_z} + \frac{w}{100}} \right]$$

where

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

ρ_w is the density of water assumed to be 1.000 (in Mg/m^3);

V_a is the volume of air voids in the compacted stabilized mixture expressed as a percentage of the total volume of the mixture;

w is the moisture content of the stabilized material (in %);

ρ_z is the combined particle density (in Mg/m^3) of the material plus stabilizer calculated from the equation:

$$\rho_z = \frac{1 + \frac{c}{100}}{\frac{1}{\rho_m} + \frac{c}{\rho_c}}$$

where

c is the stabilizer content expressed as a percentage of the dry material;

ρ_m is the particle density of the material (in Mg/m^3);

ρ_c is the particle density of the stabilizer;

where the following values may be assumed:

$\rho_c = 3.12 \text{ Mg/m}^3$ at 20 °C for cement;

$\rho_c = 2.13 \text{ Mg/m}^3$ at 20 °C for lime.

2.1.3.6.2 Reporting of results. Report the following information:

- the method used for obtaining the result, i.e. the 2.5 kg rammer method using the 1 L or the CBR mould;
- the amount of material retained on the 20 mm and 37.5 mm test sieves to the nearest 1 %;
- the experimental points and the smooth curve drawn through them (see note) showing the relation between moisture content and dry density;
- the dry density (in Mg/m^3) corresponding to the maximum dry density on the compaction curve to the nearest 0.01;
- the optimum moisture content at which the maximum dry density occurs. Report the values of moisture content to two significant figures.

NOTE For some highly permeable materials such as clean gravels, uniformly graded and coarse-clean sands the results of this test may provide only a poor guide to 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.

2.1.4 Method using 4.5 kg rammer

2.1.4.1 Principle. This method covers the determination of dry density measured as the mass of dry solids per m^3 when a stabilized material 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 that used for the 2.5 kg rammer method, the mass of the rammer being increased to 4.5 kg and the height of fall to 450 ± 4 mm. Otherwise the test procedure is broadly similar to that used in the previous test.

2.1.4.2 Sampling. The sample received at the laboratory (the laboratory sample) shall be taken in accordance with clause 5 of BS 1924-1:1990.

Reduce the laboratory sample by the procedures described in 5.4 of BS 1924-1:1990 to produce at least five test portions each with an approximate mass of 2.5 kg, in the case of fine and medium-grained materials to be compacted in a 1 L mould, or an approximate mass of 8 kg in the case of medium and coarse-grained materials to be compacted in a CBR mould.

2.1.4.3 Apparatus

NOTE The apparatus required for this test is identical to that given in 2.1.3.2 except that the rammer specified in 2.1.3.2.3 is replaced with a rammer as specified in 2.1.4.3.1.

2.1.4.3.1 A metal rammer, having a 50 mm diameter circular face, and weighing 4.5 kg. The rammer shall be equipped with a suitable arrangement for controlling the height of drop to 450 ± 4 mm. The machine shall be firmly supported on a heavy solid base such as concrete floor or plinth.

NOTE One suitable form of hand apparatus and the tolerances on the essential dimensions is shown in Figure 4. A motorized form of the apparatus may be used provided:

- a) that the essential dimensions of the rammer and mould are adhered to;
- b) that the rammer has a free vertical fall of the correct controlled height;
- c) that the density achieved is within $\pm 2\%$ of the density achieved by using the hand rammer.

2.1.4.4 Preparation of the test portions. Prepare the test portions of fine and medium-grained materials compacted in the 1 L mould in accordance with 2.1.3.3.1. Prepare the test portions of medium and coarse-grained materials compacted in the CBR mould in accordance with 2.1.3.3.2.

2.1.4.5 Compaction procedure for use with the 1 L mould

2.1.4.5.1 Weigh the mould with the baseplate attached to the nearest 1 g (m_1). Measure the internal dimensions to 0.1 mm to ensure that the mould complies with 2.1.3.2.1.

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

2.1.4.5.3 Place a quantity of the first test portion in the mould such that when compacted it occupies a little over one-fifth of the height of the mould body.

2.1.4.5.4 Apply 27 blows from the rammer dropped from a height of 450 ± 4 mm above the material. Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed by the material in the guide tube. Allow the rammer to fall under its own mass and do not impart any momentum to it when it is released.

2.1.4.5.5 Repeat steps 2.1.4.5.3 and 2.1.4.5.4 four more times, so that the amount of material 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). Complete the compaction of the test portion within 20 min of adding water to the mix.

NOTE It is necessary to control the total volume of material compacted since, if the amount of material struck off after removing the extension is too great, the result will be inaccurate.

2.1.4.5.6 Remove the extension, strike off the excess material and level off the surface of the compacted material 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.

2.1.4.5.7 Weigh the material and mould with baseplate to the nearest 1 g (m_2).

2.1.4.5.8 Remove the compacted specimen from the mould and place it on the large metal tray. Take a representative sample of the material for determination of its moisture content by the oven-drying method described in 1.3.3.

Alternatively the whole specimen may be dried out.

2.1.4.5.9 Repeat steps 2.1.4.5.1 to 2.1.4.5.8 with the remaining test portions to give a total of at least five determinations.

2.1.4.6 Compaction procedure for use with the CBR mould. Follow the procedure given in 2.1.4.5 except for the following.

a) In 2.1.4.5.1, weigh the mould, with baseplate attached to the nearest 5 g (m_1).

b) In 2.1.4.5.4 apply 62 blows from the rammer dropped from a height of 450 ± 4 mm to each layer.

c) In 2.1.4.5.7 weigh the material and mould with baseplate to the nearest 5 g (m_2).

2.1.4.7 Calculations and expression of results.

Calculate and express the results in accordance with 2.1.3.6.

2.1.4.8 Reporting of results. Report the results in accordance with **2.1.3.6.2**, except that in a) state that the 4.5 kg rammer method was used.

2.1.5 Method using vibratory compaction (Definitive method)

2.1.5.1 Principle. This method covers the determination of the dry density measured as the mass of dry solids per cubic metre when a stabilized granular material is compacted in a specified manner by vibratory compaction over a range of moisture contents. For most materials the range includes the optimum moisture content at which the maximum dry density for this degree of compaction is obtained but with some free-draining granular materials no such optimum can be identified (see **2.1.5.8.1.5**).

NOTE This method is recommended in preference to the methods given in **2.1.3** and **2.1.4** for highly permeable stabilized materials such as clean gravels, uniformly graded and coarse clean sands on which the tests described in **2.1.3** and **2.1.4** may provide only a poor guide for specifications on site compaction. Results given by this method provide a satisfactory guide to the optimum moisture content for site compaction and, generally, the maximum density given by the test is only slightly greater than that obtained on full-scale site operations.

2.1.5.2 Sampling. The sample received at the laboratory (the laboratory sample) shall be taken in accordance with clause 5 of BS 1924-1:1990.

Reduce the laboratory sample by the procedures described in **5.4** of BS 1924-1:1990 to produce at least 12 test portions each with an approximate mass of 2.5 kg.

NOTE The choice of the range of moisture contents to use is inevitably one of trial-and-error and an unfortunate choice could lead to a large number of test portions being required. Consequently although 12 test portions may be sufficient it is usually necessary to be prepared to produce a larger number than this.

2.1.5.3 Apparatus

NOTE The design of the apparatus required in **2.1.5.3.1**, **2.1.5.3.2** and **2.1.5.3.3** below 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, Old Wokingham Road, Crowthorne, Berkshire, RG11 6AU.

2.1.5.3.1 A standard compaction mould, comprising a body, a base, a filter assembly consisting of a geotextile membrane, having a pore-size of 70 to 100 μm and a permeability under a 100 mm head of water of 50 $\text{L/m}^2/\text{sec}^2$), placed between two perforated steel plates and an anvil (see note). Working dimensions of the standard mould are shown in Figure 5. The cylinder bore and external diameter of the anvil shall be parallel, the difference in diameter of the mould and the external surface of the anvil shall be more than 0.3 mm and less than 0.9 mm. The cross-sectional area of the bore of the mould, given to the nearest 10 mm^2 , shall be stamped on the side of the body.

NOTE The anvil is fitted with a pair of rubber O-rings which will suffer wear. In time this will allow fines to be forced past the O-rings during compaction. Replacement O-rings should therefore be kept and fitted after 50 uses or earlier if necessary. The O-rings should comply with BS 1806 or BS 4518.

2.1.5.3.2 An electric vibrating hammer, having a power consumption of not less than 900 W and capable of delivering about 2 000 blows/min to the anvil. It shall be equipped with a suitable shank which makes contact with the anvil (see Figure 5 and Figure 6). The hammer shall be calibrated as described in **2.1.5.5**.

NOTE 1 The power consumption and frequency requirements are given as a guide to the type of hammer required. To ensure good working order, overhauls and calibrations should be carried out not less frequently than every 50 h of operation, or every 6 months, whichever is shorter.

NOTE 2 As vibrating hammers of the type used in this test can emit noise levels of up to 100 dB (A), suitable noise-reduction precautions should be taken during use.

2.1.5.3.3 A suitable loading frame to permit the hammer to be brought into contact with the anvil in the mould (see Figure 6). The surcharge mass and the length of the lever arm shall be such that when the lever arm is in position the total dead-weight force under the anvil is $640 \pm 10 \text{ N}$ when the mould is not in position but the rest of the apparatus is assembled.

2.1.5.3.4 A depth gauge, clearly readable, to measure the distance between the top of the cylinder and the upper surface of the anvil to an accuracy of 0.1 mm or better.

2.1.5.3.5 A stopwatch or stopclock or an automatic timer, readable to 1 s to control the vibrating hammer.

2.1.5.3.6 Filter papers, 150 mm in diameter²⁾.

2.1.5.3.7 A square-holed perforated plate 37.5 mm test sieve complying with **4.2.4.2** of BS 1924-1:1990.

2.1.5.3.8 A balance of 10 kg minimum capacity, readable to 1 g.

²⁾ Further information may be obtained from Enquiry Section, BSI, Linford Wood, Milton Keynes MK14 6LE, enclosing a stamped addressed envelope for reply.

³⁾ Whatman grade 113 has been found to be suitable.

2.1.5.3.9 A ventilated-oven temperature-controlled to maintain a temperature of $105 \pm 50^\circ\text{C}$.

2.1.5.3.10 Corrosion-resistant, water-tight, containers, such as strong polythene bags which can be adequately sealed.

NOTE At least 16 containers having a minimum capacity of 2 L are required.

2.1.5.3.11 Apparatus for the determination of the moisture content by the oven drying method described in 1.3.3.

2.1.5.4 Material

2.1.5.4.1 Clean silica sand, from the Woburn Beds of the Lower Greensand in the Leighton Buzzard district⁴⁾. The grading shall be such that 100 % passes a 600 μm test sieve and 100 % is retained on a 63 μm test sieve. The sand shall be free from flakey particles, silt, clay and organic matter.

NOTE The sand is required for the calibration of the vibrating hammer; 5 kg is required for each calibration. The sand cannot be re-used (see 2.1.5.5).

2.1.5.5 Calibration of the vibrating hammer

2.1.5.5.1 Take a sample of the calibrating sand which has not been previously used. Oven-dry the sand, sieve through a 600 μm test sieve and discard the coarse fraction.

2.1.5.5.2 Weigh out two test portions each of mass 2.5 ± 0.1 kg. Mix each test portion with water to raise its moisture content to 2.5 ± 0.25 %.

2.1.5.5.3 Compact the sand in the mould in accordance with the procedure given in 2.1.5.7.

2.1.5.5.4 Carry out the test on each test portion and determine the mean density. Calculate the dry density values to the nearest 0.002 Mg/m^3 .

2.1.5.5.5 If the range of values in the two tests exceeds 0.01 Mg/m^3 repeat the whole procedure. Consider the vibrating hammer suitable for use in this test if the mean dry density exceeds 1.74 Mg/m^3 .

2.1.5.6 Preparation of test portions

2.1.5.6.1 Dry the test portions obtained as described in 2.1.5.2, at $105 \pm 5^\circ\text{C}$ (see note 1). Sieve the dried test portions on a 37.5 mm test sieve and reject the material retained after recording the percentage of oversize material (see note 2). Each test portion after removal of the oversize material shall have a dry mass in the range 2.4 kg to 2.6 kg.

NOTE 1 The properties of materials containing a large proportion of clay fines may be changed by oven-drying. If oven-drying is likely to affect the results dry the test portions in air and determine their air-dry moisture contents. Allowance must be made for the water already present in air-dried material when adding stabilizer and water to bring the material to a specified moisture and stabilizer content.

NOTE 2 If more than 15 % of material is removed the aggregate is too coarse to be tested.

2.1.5.6.2 Mix each of the test portions with the required amount of water and stabilizer (see note 1) as described in clause 4 of BS 1924-1:1990 to give suitable range of moisture contents (see note 2).

NOTE 1 If the amount of stabilizer required has not been determined at this stage, the amount may be estimated, but the test should be repeated with the required amount of stabilizer if this is found subsequently to be substantially different from the estimated amount.

NOTE 2 The range of moisture contents obtained should include the optimum moisture content (OMC) and the amounts of water to be added to the test portions will therefore vary with the type of stabilized material under test. Initially, tests should be carried out at moisture contents 2 % apart to find the approximate location of the optimum moisture content if this is known. The precise location of the optimum moisture content should then be determined from tests carried out at moisture contents 0.5 % apart. These should be chosen so that results are obtained at about the optimum and at two moisture contents each side of the optimum at this spacing. Two test portions should be tested at each moisture content.

Example. Initial tests with duplicate test portions at moisture contents of 2 %, 4 %, 6 % and 8 % suggest that the OMC is about 6.5 %. Further tests are then done at moisture contents of 5.5 %, 6.5 %, 7.0 % and 7.5 % to obtain a good definition of the optimum value. The initial test requires eight test portions and the supplementary test requires another eight test portions.

2.1.5.7 Compaction test procedure

2.1.5.7.1 Before each compaction test check the compaction mould to ensure that it is thoroughly clean and dry. Assemble the mould body, base, filter plates and fibre filter, taking care to ensure that the parts fit together properly. Tighten the clamps to full tightness.

2.1.5.7.2 Lay three filter papers flat on the bottom of the mould and insert the anvil into the mould so that it touches the upper filter paper. Apply the vibrating hammer to the anvil for about 5 s to ensure that it is properly bedded. Measure carefully and record, to an accuracy of 0.1 mm, the distance (e) between the bottom of the small hole within the half-ball in the anvil and the top of the mould. Remove the anvil and filter papers. Replace two of the filter papers flat on the bottom of the mould.

2.1.5.7.3 Remix thoroughly the appropriate test portion in its container. Record the mass of the container and test portion, and also that of the empty container. From these results calculate the initial mass of the test portion (m_1) to an accuracy of 0.1 %. Place the whole of the test portion in the mould in such a way as to form a single layer with minimum segregation. Roughly level off the top of the test portion, being careful not to remove any material from the mould, and cover it with the remaining filter paper.

⁴⁾ Further information may be obtained from Enquiries Section, BSI, Linford Wood, Milton Keynes MK14 6LE.

2.1.5.7.4 Locate the filled compaction mould assembly in the loading frame, insert the anvil into the mould so that it rests on the upper filter paper and place the vibrating hammer in position. Apply the surcharge load and operate the vibrating hammer for 180 ± 5 s to compact the test portion.

After compaction has ended remove the vibrating hammer from the frame and from the mould.

2.1.5.7.5 With the depth gauge measure carefully and record to an accuracy of 0.1 mm the distance (f) between the bottom of the small hole in the anvil and the top of the mould. Calculate the height ($h = e - f$) of the compacted portion. Take care not to disturb the anvil after compaction has ceased and before the depth measurement is made.

2.1.5.7.6 Extract the compacted test portion in its entirety from the mould, remove the filter papers and transfer the test portion to an appropriate container of known mass. Determine its moisture content by oven-drying the whole contents of the container following the oven-drying method described in 1.3.3. The moisture content so obtained is the residual moisture content (W_R), i.e. the moisture content after the compaction process has been completed.

NOTE The value of the residual moisture content usually differs from the initial moisture content because some water is squeezed out during compaction. If the value of the residual moisture content differs from the initial moisture content by more than 2 % ignore this particular result when estimating the optimum moisture content (see 2.1.5.8.1.4).

2.1.5.7.7 Repeat 2.1.5.7.1 to 2.1.5.7.6 until all the remaining test portions have been compacted.

2.1.5.8 Calculations and expression of results

2.1.5.8.1 Calculations

NOTE A typical data and calculation form for the determination of the dry density/moisture content relation by the vibrating hammer method is given in form F of Appendix A. A model form for one determination is shown in form G of Appendix A; this sets out the stages of the calculations.

2.1.5.8.1.1 Calculate the dry mass (m_2 , in g) of each test portion from the equation:

$$m_2 = \frac{100m_1}{W + 100}$$

where

m_1 is the initial mass of the test portion (solid particles and any contained water) placed in the mould (in g);

W is the initial moisture content of the test portion, i.e. a value in the range $W, W_1, \dots, W_n$ (in %).

2.1.5.8.1.2 Calculate the vibrated bulk density (ρ , in Mg/m^3) of each portion from the equation:

$$\rho = \frac{100m_2(100 + W_R)}{ah}$$

where

m_2 is the mass of dry material (in g);

W_R is the residual moisture content of each test portion (in %);

a is the cross-sectional area of the mould (in mm^2);

$h = e - f$

where

e is the depth gauge reading in the empty mould (in mm);

f is the depth gauge reading in the filled mould (in mm).

2.1.5.8.1.3 Calculate the vibrated dry density (ρ_d , in Mg/m^3) of each test portion from the equation:

$$\rho_d = \frac{1000m_2}{ah}$$

2.1.5.8.1.4 From the results obtained as described above, plot the vibrated dry density values against the corresponding residual moisture content values using the values obtained for the individual test portions with moisture content as the x axis of the graph and dry density as the y axis. In addition plot the three lines representing 0 %, 5 % and 10 % air voids.

NOTE Appropriate values of dry density for given moisture contents and air voids may be obtained from the formula given in 2.1.3.6.1.4.

2.1.5.8.1.5 Record the results as follows:

- where the curve approximates to a convex curve (see (1) of note), read the peak dry density and the corresponding optimum moisture content from the curve and record to the nearest 0.1 Mg/m^3 and 0.5 % respectively;
- where the curve approximates to a concave curve (see (2) of note), take the values for maximum dry density and optimum moisture content as the terminal values and record to the nearest 0.1 Mg/m^3 and 0.5 % respectively;
- where no curve can be drawn and the best line through the points is approximately horizontal (see (3) of note) report that no value for optimum moisture content exists and give the value for density for any moisture content.

NOTE Compaction curves for coarse-grained materials and free-draining medium-grained materials take three forms depending on the grading and porosity of the stabilized material under test, as follows:

- (1) **convex:** 
 (2) **concave:** 
 (3) **flat:** 

2.1.5.8.2 Reporting of results. Report the following information:

- the method used for obtaining the result, i.e. the definitive method of vibrating compaction;
- the amount of material retained on the 37.5 mm test sieve;
- the experimental points and, where possible, the smooth curve drawn through them showing the relationship between moisture content and dry density;
- where it can be identified, the dry density (in Mg/m^3) corresponding to the maximum dry density on the compaction curve to the nearest 0.01 Mg/m^3 ;
- where it can be identified, the optimum moisture content at which the maximum dry density occurs to the nearest 0.5 %.

2.1.6 Method using vibratory compaction (Subsidiary method)

2.1.6.1 Principle. This method covers the determination of the dry density measured as the mass of dry solids per m^3 when a stabilized granular material is compacted in a specified manner by vibratory compaction over a range of moisture contents. For most materials the range includes the optimum moisture content at which the maximum dry density for this degree of compaction is obtained but with some free-draining granular materials no such optimum can be identified (see **2.1.5.8.1.5**).

NOTE The test is an alternative to the definitive method given in **2.1.5**. Within the limits of experimental error of the test methods it gives the same results as the definitive method and has the same applicability. Where the apparatus is available the definitive method is preferred because it is easier to carry out and less dependent on the skill of the operator.

2.1.6.2 Sampling. The sample received at the laboratory (the laboratory sample) shall be taken in accordance with clause **5** of BS 1924-1:1990.

Reduce the laboratory sample by the procedures described in **5.4** of BS 1924-1:1990 to produce at least six test portions each with an approximate mass of 8 kg.

NOTE The choice of the range of moisture contents to use is inevitably one of trial-and-error and an unfortunate choice could lead to a large number of test portions being required. Consequently although six test portions may be sufficient it is usually necessary to be prepared to produce a larger number than this.

2.1.6.3 Apparatus

2.1.6.3.1 A cylindrical metal mould, such as a CBR mould, 152 mm diameter, with baseplate and extension, similar to that described in **4.5**. The internal faces shall be smooth, clean and dry before each use.

2.1.6.3.2 An electric vibrating hammer, having a power consumption between 600 W and 750 W and operating at a frequency between 25 Hz and 45 Hz. The hammer shall be calibrated as described in **2.1.6.5**.

NOTE 1 The power consumption and frequency requirements are given as a guide to the type of hammer required. To ensure good working order, overhauls and calibrations should be carried out not less frequently than every 50 hours of operation, or every 6 months, whichever is shorter.

NOTE 2 See note to **2.1.5.3**.

2.1.6.3.3 Steel tampers, for attachment to the vibrating hammer. Suitable designs of tampers are shown in Figure 7.

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

2.1.6.3.5 A balance, of 25 kg minimum capacity, readable to 5 g.

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

2.1.6.3.7 A 600 μm , 20 mm and 37.5 mm test sieve, and receivers complying with **4.2.4.2** of BS 1924-1:1990.

2.1.6.3.8 A large metal tray.

NOTE A convenient size is one about 600 mm $\times$ 500 mm with sides 80 mm deep.

2.1.6.3.9 Apparatus for the determination of moisture content, in accordance with the oven-drying method described in **1.3.3**.

2.1.6.3.10 A stopclock.

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

2.1.6.4 Material

2.1.6.4.1 Clean silica sand, from the Woburn Beds of the Lower Greensand in the Leighton Buzzard district⁵⁾. The grading shall be such that 100 % passes a 600 μm test sieve and 100 % is retained on a 63 μm test sieve. The sand shall be free from flakey particles, silt, clay and organic matter.

⁵⁾ Further information may be obtained from Enquiries Section, BSI, Linford Wood, Milton Keynes MK14 6LE.

NOTE The sand is required for the calibration of the vibrating hammer; 5 kg is required for each calibration. The sand cannot be re-used (see 2.1.6.5).

2.1.6.5 Calibration of the vibrating hammer

2.1.6.5.1 Calibration test

2.1.6.5.1.1 Take a sample of the calibrating sand which has not been previously used. Oven-dry the sand, sieve through a 600 μm test sieve and discard the coarse fraction.

2.1.6.5.1.2 Weigh out three test portions each of mass 5 ± 0.1 kg. Mix each test portion with water to raise its moisture content to 2.5 ± 0.25 %.

2.1.6.5.1.3 Compact the sand in the mould using the vibrating hammer in accordance with the procedure given in 2.1.6.7.

2.1.6.5.1.4 Carry out the test on each test portion and determine the mean density. Calculate the dry density values to the nearest 0.002 Mg/m^3 .

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

2.1.6.5.2 Pressure check. The application of pressure combined with vibration is essential to ensure the required degree of compaction. Therefore exert a downward force of 300 N to 400 N on the sample surface, this being greater than the force needed to prevent the hammer bouncing on the material.

NOTE The required pressure can be judged 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.

2.1.6.6 Preparation of test portions

2.1.6.6.1 Dry the test portions obtained as described in 2.1.6.2, at 105 ± 5 °C (see note 1). Sieve the dried test portions on a 37.5 mm test sieve and reject the material retained after recording the percentage of oversize material (see note 2). Each test portion after removal of the over size material shall have a dry mass in the range 6 kg to 8 kg.

NOTE 1 The properties of materials containing a large proportion of clay fines may be changed by oven-drying. If oven-drying is likely to affect the results dry the test portions in air and determine their air-dry moisture contents. Make allowance for the water already present in air-dried material when adding stabilizer and water to bring the material to a specified moisture and stabilizer content.

NOTE 2 If more than 15 % of material is removed the aggregate is too coarse to be tested.

2.1.6.6.2 Mix each of the test portions with the required amount of water and stabilizer (see note 1) as described in clause 6 of BS 1924-1:1990 to give a suitable range of moisture contents (see note 2). In the case of cement-stabilized materials do not mix any test portion with cement until it is ready to be compacted.

NOTE 1 If the amount of stabilizer required has not been determined at this stage, the amount may be estimated, but the test should be repeated with the required amount of stabilizer if this is found subsequently to be substantially different from the estimated amount.

NOTE 2 The range of moisture contents obtained should include the optimum moisture content and the amounts of water to be added to the test portions will therefore vary with the type of stabilized material under test. Initially, tests should be carried out at moisture contents 2 % apart to find the approximate location of the optimum moisture content if this is not known. The precise location of the optimum moisture content should then be determined from tests carried out at moisture contents 0.5 % apart. These should be chosen so that results are obtained at about the optimum and at two moisture contents each side of the optimum at this spacing.

2.1.6.7 Compaction test procedure

2.1.6.7.1 Weigh the mould with the baseplate attached to 5 g (m_1). Measure the internal dimensions of the mould to 0.1 mm to ensure that it is within specification.

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

2.1.6.7.3 Place a quantity of the first test portion to be tested in the mould such that when compacted it occupies a little over one-third of the height of the mould body.

2.1.6.7.4 Place the circular tamper on the material and compact with the vibrating hammer for 60 ± 5 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.

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

2.1.6.7.6 Repeat steps 2.1.6.7.3, 2.1.6.7.4 and 2.1.6.7.5 twice more.

2.1.6.7.7 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 2.1.6.7.3.

2.1.6.7.8 Weigh the material and mould with baseplate to 5 g (m_2).

2.1.6.7.9 Remove the compacted material from the mould and place it in the large metal tray. Take a representative sample of the material for determination of its moisture content by the oven-drying method described in 1.3.3. Alternatively the whole specimen may be dried out.

2.1.6.7.10 Repeat steps **2.1.6.7.3** to **2.1.6.7.9** with each of the remaining test portions.

2.1.6.8 *Calculations and expression of results*

2.1.6.8.1 *Calculations*

2.1.6.8.1.1 Calculate the bulk density (ρ , in Mg/m^3) of each compacted test portion from the equation:

$$\rho = \frac{1000(m_2 - m_1)}{ah}$$

where

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

m_2 is the mass of mould base and compacted material (in g);

h is the height of the compacted sample (in mm);

a is the cross-sectional area of the mould (in mm^2).

NOTE For a CBR mould having a diameter of 152 mm, $a = 18145.8 \text{ mm}^2$.

2.1.6.8.1.2 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 stabilized material.

2.1.6.8.1.3 From the results obtained as described above, plot the vibrated dry density values against the corresponding moisture content values with moisture content as the x axis of the graph and dry density as the y axis. The three lines representing 0 %, 5 % and 10 % air voids should also be plotted. Appropriate values of dry density for given moisture contents and air voids may be obtained from the formula given in **2.1.3.6.1.4** and the procedure for plotting the curves is described in **2.1.5.8.1.4** and **2.1.5.8.1.5**.

2.1.6.8.2 *Reporting of results.* Report the following information:

- the method used for obtaining the result, i.e. the vibrating hammer method;
- the amount of material retained on the 37.5 mm test sieve;
- the experimental points and, where possible, the smooth curve drawn through them showing the relationship between moisture content and dry density;
- where it can be identified, the dry density (in Mg/m^3) corresponding to the maximum dry density on the compaction curve to the nearest 0.01 Mg/m^3 ;

e) where it can be identified, the optimum moisture content at which the maximum dry density occurs to the nearest 0.5 %.

2.1.7 *Test report*

The test report shall affirm that the dry density/moisture content relationship was determined in accordance with **2.1** of BS 1924-2:1990 and whether or not a certificate of sampling is available. If available a copy of the certificate of sampling shall be provided. In addition the test report shall contain the following information:

- sample identification;
- the method used for the determination of the dry density/moisture content relationship;
- all the information in **2.1.3.6.2**, **2.1.4.8**, **2.1.5.8.2** or **2.1.6.8.2**, whichever is appropriate.

2.2 *Determination of the moisture condition value (MCV)*

2.2.1 *Principle*

The MCV test involves the determination of the compactive effort necessary in terms of the number of blows of a rammer to compact almost fully a sample of the material under test. It is based on the fact that relations between density and moisture content produced by different compactive efforts tend to converge as the moisture content increases. To determine the MCV, a sample of the material is placed in a mould and the penetration of the rammer into the mould is measured at various stages of compaction. The penetration of the rammer at any given number of blows is compared with the penetration for four times as many blows and the difference in penetration determined. The change in penetration is plotted against the logarithm (to the base 10) of the number of blows corresponding to a change in penetration of 5 mm in the plotted curve.

The requirements of BS 1924-1 shall, where appropriate, apply to this test method.

2.2.2 *Sampling*

2.2.2.1 The determination of the MCV is carried out on samples of the stabilized material at pre-determined intervals after it has been mixed and is about to be compacted. The samples for the determination of the MCV shall be taken in accordance with clause 5 of BS 1924-1:1990.

2.2.2.2 Reduce the sample by the procedures described in **5.4** of BS 1924-1:1990 to produce a test portion on which the MCV is to be determined that has a mass of 1.5 kg after any individual particles retained on a 20 mm test sieve have been removed. If particles larger than 20 mm have been removed weigh the material passing the sieve and take a representative portion for the determination of the moisture content.

NOTE If a moisture content determination proves to be necessary the initial mass of the test portion shall be such that 1.5 kg of material is available for the determination of the MCV. The aggregations of material need not be broken down any further after passing through the 20 mm sieve.

2.2.3 Procedure for determination of the MCV

Determine the MCV in accordance with clause **5** of BS 1377-4:1990.

2.2.4 Procedure for determination of the MCV/moisture content relation

Determine the MCV/moisture content relation in accordance with **5.5.1.2** of BS 1377-4:1990.

Section 3. In-situ density tests

NOTE This section describes the methods to be used for determining the in-situ density of a stabilized material. Several methods are included, the choice of which depends on the type of material, the circumstances in which the test is being made and on the equipment available. The applicability of the methods and their limitations are given under each test procedure.

Several of the methods included in this section are also to be found, with minor differences of detail, in BS 1377 and they use apparatus that is identical to that used for the corresponding methods in that standard.

3.1 Nuclear moisture/density gauges

For general definitions see clause 2 of BS 1924-1:1990.

Several models of nuclear moisture/density gauges are available commercially for the measurement of both density and moisture content. They measure density either by the back-scatter method as shown in Figure 8(a) or by the direct-transmission method shown in Figure 8(b). The principles on which the gauges work are described in 3.7.

3.2 Sampling

The determination of the in-situ density is carried out on small areas of compacted material so that the advice on sampling given in clause 5 of BS 1924-1:1990 is not generally applicable. It is impracticable to obtain a single sample that is representative of a given area of compacted material; selected locations of material therefore have to be tested to find the variability of the in-situ density within the area of compacted stabilized material.

3.3 Sand replacement method

3.3.1 Principle

A hole is dug in the compacted stabilized material to the full depth of the compacted layer and the mass and moisture content of the stabilized material removed from the hole are determined. The volume of the hole is then determined by finding the mass of sand of known bulk density that is required to fill it. From the mass of material removed from the hole and the volume of the hole, the bulk density of the stabilized material is calculated and, if required, the dry density is calculated from the results of the bulk density and moisture content determinations.

The requirements of BS 1924-1 shall where appropriate apply to this test method.

3.3.2 Apparatus

3.3.2.1 Apparatus for all materials

3.3.2.1.1 *Suitable tools for excavating holes in compacted stabilized material, e.g. bent spoon, chisel, hammer, dibber, large screwdriver and/or pointed steel rod about 250 mm long and 7 mm to 10 mm in diameter with a wooden handle.*

3.3.2.1.2 *A balance, of 10 kg minimum capacity, readable to 1 g (see note to 3.3.4.1.1).*

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

3.3.2.1.4 *Apparatus for moisture content determination by the oven-drying method described in 1.3.3.*

3.3.2.1.5 *A glass plate approximately 10 mm thick and approximately 500 mm square if the small pouring cylinder is used, and approximately 600 mm square if the large pouring cylinder is used.*

3.3.2.2 Additional apparatus for fine and medium-grained materials

NOTE This apparatus is for the determination of the in-situ density of compacted stabilized fine and medium-grained materials for which a 115 mm diameter sand pouring cylinder is used. The method is applicable to layers not exceeding 150 mm in thickness. For layers between 150 mm and 250 mm the apparatus described in 3.3.2.3 should be used.

3.3.2.2.1 *A small pouring cylinder similar in essential details to that shown in Figure 9.*

3.3.2.2.2 *A cylindrical metal calibrating container with an internal diameter of 100 ± 2 mm and an internal depth of 150 ± 3 mm (see note) of the type shown in Figure 10, fitted with a lip 50 mm wide and approximately 5 mm thick surrounding the open end.*

NOTE If for any reason it is necessary to excavate the holes to depths less than 150 mm, either the calibrating container should be replaced by one of the same depth as the hole excavated, or its effective depth should be reduced to that of the hole excavated.

3.3.2.2.3 *A metal tray approximately 300 mm square and 40 mm deep with a hole of approximately 100 mm diameter in the centre.*

3.3.2.3 Additional apparatus for coarse-grained materials

NOTE This apparatus is for the determination of the in-situ density of compacted stabilized materials containing stones which makes the test procedure with the apparatus described in 3.3.2.2 difficult to perform. It is an alternative to the apparatus described in 3.3.2.2 for fine and medium-grained stabilized materials and should be used instead for layers exceeding 250 mm in thickness.

3.3.2.3.1 *A large pouring cylinder, similar in essential details to that shown in Figure 11.*

3.3.2.3.2 *A cylindrical metal calibrating container, with an internal diameter of 200 ± 5 mm and an internal depth of 250 ± 5 mm (see note) of the type shown in Figure 12, fitted with a lip 75 mm wide and about 5 mm thick surrounding the open end.*

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

3.3.2.3.3 A metal tray, approximately 500 mm square and 50 mm deep with a hole of approximately 200 mm diameter in the centre.

3.3.3 Material

3.3.3.1 Clean closely graded sand.

NOTE 1 Material passing the 600 μm sieve and retained on the 200 μm test sieve, free from flakey particles, silt, clay and organic matter, which has been oven-dried and stored for a suitable period in an open container to allow its moisture content to reach equilibrium with atmospheric humidity, is suitable.

NOTE 2 Generally a storage period, after oven-drying, of about 7 days is sufficient for the moisture content of the sand to reach equilibrium with the atmospheric humidity. The sand should not be stored in an airtight container and should be mixed thoroughly before use. If sand is salvaged from the holes in compacted materials after carrying out this test, it is advisable to sieve, dry and store this sand again before it is used in further sand replacement tests.

3.3.4 Calibration

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

3.3.4.1.1 Fill the pouring cylinder so that the level of the sand in the cylinder is within about 15 mm of the top. Find its total initial mass (m_1) to the nearest 0.1 % (see note) and maintain this constant throughout the tests for which the calibration is used. Allow a volume of sand, equivalent to that of the excavated hole in the soil, or equal to that of the calibrating container, to run out. Close the shutter on the pouring cylinder and place the cylinder on a plane surface, e.g. the glass plate.

NOTE The total mass, when it is filled with sand, of the large pouring cylinder described in **3.3.2.3.1** exceeds the capacity of the balance so that the method of filling and weighing is to weigh the sand in two or three containers and tip it into the pouring cylinder before using. Take care to see that the same initial mass as is used in calibrating the apparatus is used for each density measurement. Enough sand should be used to ensure that 4 kg to 5 kg of sand is left in the pouring cylinder after the test is completed.

3.3.4.1.2 Open the shutter of the pouring cylinder and allow sand to run out. Do not tap or otherwise vibrate the cylinder during this period. When no further movement of sand takes place in the cylinder, close the shutter and carefully remove the cylinder.

3.3.4.1.3 Collect the sand, on the glass plate, that had filled the cone of the pouring cylinder and determine its mass (m_2) to the nearest 0.1 %.

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

3.3.4.2 Determination of the bulk density (ρ_s) of the sand

3.3.4.2.1 Determine the internal volume (v , in mL) of the calibrating container from the mass of water required to fill it (see note to **3.3.4.1.1**) as described in **3.3.4.2.2** below.

3.3.4.2.2 Place the empty container on the flat pan of the balance, ensuring that the upper rim of the container is horizontal, if necessary by embedding the base in plasticine or similar material. Note the mass of the container, together with any plasticine, to the nearest 1 g (m_5). Then fill the calibrating container almost to the brim with water, taking care not to spill any water on the pan of the balance or on the outside of the container. Lay a straightedge across the top of the container and add water slowly and carefully by means of a dropping rod until the water just touches the straightedge. Remove the straightedge and note the mass of the container plus water to the nearest 1 g (m_6). Repeat the measurement a number of times to obtain an accurate mean value for m_6 . For the repeat tests it is only necessary to remove a small amount of water by means of the dropping rod, and to refill the container to the level of the straightedge. The volume of the calibrating container (v , in mL) is given by the equation:

$$v = m_6 - m_5$$

3.3.4.2.3 Place the pouring cylinder, after it has been filled to the constant mass (m_1), concentrically on the top of the calibrating container as described in **3.3.4.1.1**. Keep the shutter on the pouring cylinder closed during this operation. Open the shutter and allow the sand to run out. Do not tap the pouring cylinder or otherwise vibrate it during this period. When no further movement of the sand takes place in the cylinder, close the shutter. Remove the pouring cylinder with the sand remaining in it and determine their combined mass (m_3) to the nearest 0.1 % of the initial mass.

NOTE Stand the calibration container on a tray during this part of the test procedure, to collect the sand overflowing when the cone of the cylinder is removed.

3.3.4.2.4 Repeat these measurements at least three times and calculate the mean value of m_3 .

NOTE Since variations in atmospheric humidity affect the moisture content of the sand, and hence its bulk density, the calibration should be made (or at least checked) during each day's work. To overcome the effects of slight variations in grading and particle shape between batches of sand, each batch should be sampled and calibrated.

3.3.5 Test procedure

3.3.5.1 Select as described in **3.2** a flat area approximately 450 mm square of the compacted material to be tested. Brush away any loose material lying on the surface and remove any surface dressing or curing membrane as far as it is possible without removing the surface layer of compacted material.

NOTE Erroneously high values of density can be obtained as a result of the excavated hole slumping before the volume is measured. In the case of cement-stabilized materials this problem can be overcome by delaying the test until the material has gained sufficient stability to prevent the slump. The delay is usually not more than a few hours.

3.3.5.2 Lay the metal tray on the prepared surface with the hole over the portion of the material to be tested. Using this hole as a pattern, excavate a round hole, approximately 100 mm in diameter and to the depth of the layer to be tested up to a maximum of 150 mm deep if the small pouring cylinder is used and up to 250 mm deep if the large pouring cylinder is used (see notes to **3.3.2.2**, **3.3.2.3** and note to this subclause). Do not leave loose material in the hole, and do not distort the immediate surround to the hole (see note). Carefully collect all the excavated material from the hole and determine its mass to the nearest 1 g (m_w). Remove the metal tray before placing the pouring cylinder in position over the excavated hole.

NOTE Do not enlarge the hole by levering the excavating tool against the side, as this will result in lower densities being recorded. The hammer and chisel should be used for loosening individual stones without disturbing the surrounding material. This is especially important in the case of weak materials or those tested at an early age.

3.3.5.3 Place a representative sample of the excavated material in a suitable airtight container and determine its moisture content (w) as described in **1.3** (see note). Alternatively the whole of the excavated material may be dried and weighed to give the mass (m_d) of the dry material removed from the hole.

NOTE The calcium carbide and nuclear gauge methods described respectively in **1.3.6** and **1.3.7** do not give results of sufficient accuracy to be used for the determination of the dry mass of material removed from the hole and/or the calculation of dry density. They should not therefore be used for this purpose. Any of the other methods described may be used, subject to their limitations which are given for the individual test procedures.

3.3.5.4 Place the pouring cylinder, filled to the constant mass (m_1) as in **3.3.4.1.1** so that the base of the cylinder covers the hole concentrically. Ensure the shutter on the pouring cylinder is closed during this operation. Open the shutter and allow sand to run out; during this period do not vibrate the cylinder or the surrounding area. When no further movement of the sand takes place close the shutter. Remove the cylinder and determine its mass (m_4) to the nearest 0.1 %.

3.3.6 Calculations and expression of results

NOTE A typical data and calculation form for the determination of the in-situ density by the sand replacement method is given in form H of Appendix A.

3.3.6.1 Calculate the mass (m_a , in g) required to fill the calibrating container from the equation:

$$m_a = m_1 - m_3 - m_2$$

where

- m_1 is the mass of the cylinder and sand before pouring into the calibrating container (in g);
- m_2 is the mass of sand in the cone (in g);

m_3 is the mean mass of cylinder and sand after pouring into the calibrating container (in g).

3.3.6.2 Calculate the bulk density of the sand (ρ_s , in Mg/m^3) from the equation:

$$\rho_s = m_a/v$$

where

v is the volume of the calibrating container (in mL).

3.3.6.3 Calculate the mass of sand (m_b , in g) required to fill the excavated hole from the equation:

$$m_b = m_1 - m_4 - m_2$$

where

m_1 is the mass of the cylinder and sand before pouring into the calibrating container (in g);

m_2 is the mass of sand in the cone (in g);

m_4 is the mass of the cylinder and sand after pouring into the hole (in g).

3.3.6.4 Calculate the bulk density (ρ , in Mg/m^3) of the stabilized material from the equation:

$$\rho = m_w \rho_s / m_b$$

where

m_w is the total mass of material excavated (in g);

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

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

3.3.6.5 If required, calculate the dry density (ρ_d , in Mg/m^3) of the stabilized material either from the equation:

$$\rho_d = 100\rho/100 + w$$

where:

w is the moisture content of the stabilized material (in %);

or from the equation:

$$\rho_d = \rho_s m_d / m_b$$

where

m_d is the mass of oven-dry material from the hole (in g).

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

3.3.6.6 Express the value of the bulk and/or dry density in Mg/m^3 to the nearest 0.01 Mg/m^3 .

3.3.7 Test report

Report the results in accordance with **3.8**.

3.4 Core-cutter method (for unhardened fine-grained materials)

NOTE This method covers the determination of the in-situ density of freshly laid compacted fine-grained stabilized materials. It is applicable only where the material is free from stones and sufficiently soft for the cutter to be driven easily into the compacted material. If required the dry density can be calculated from the results of the bulk density and moisture content determinations.

3.4.1 Principle

A core of stabilized material is removed by driving a cylindrical cutter of known volume into the compacted material. The in-situ bulk density is calculated from a knowledge of the mass and volume of the material removed. If required the dry density is calculated from the results of the bulk density and moisture content determinations.

The requirements of BS 1924-1 shall where appropriate apply to this test method.

3.4.2 Apparatus

3.4.2.1 A *cylindrical core-cutter*, of the type shown in Figure 13(c), 130 ± 2 mm long (see note) and of 100 ± 2 mm internal diameter, with a minimum wall thickness of 3 mm and bevelled at one end. This cutter shall be kept adequately greased.

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

3.4.2.2 *Steel dolly*, of the type shown in Figure 13(b), 25 mm high and of 100 mm internal diameter, with a wall thickness of 6 mm, fitted with a lip to enable it to be located on top of the core-cutter.

3.4.2.3 *Steel rammer*, of the type illustrated in Figure 13(a).

3.4.2.4 A *balance*, of 10 kg minimum capacity, readable to 1 g.

3.4.2.5 *Palette knife*.

NOTE A convenient size is one having a blade approximately 200 mm long and 30 mm wide.

3.4.2.6 *Steel rule*, approximately 300 mm long, graduated to 0.5 mm.

3.4.2.7 *Grafting tool*, or spade and pick-axe.

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

3.4.2.9 *Apparatus for the determination of moisture content*, by the oven-drying method described in 1.3.3.

3.4.2.10 *Apparatus for extracting samples from the cutter* (optional).

3.4.3 Test procedure

3.4.3.1 Calculate the internal volume (V_c , in mL) of the core-cutter from its dimensions which shall be measured to the nearest 0.5 mm.

3.4.3.2 Weigh the cutter and determine its mass (m_c) to the nearest 1 g.

3.4.3.3 Select, as described in 3.2, a flat area of approximately 300 mm square of the compacted material to be tested and, if necessary, trim down to a level surface. Remove loose extraneous material. Place the steel dolly on top of the cutter, and ram the latter into the compacted layer until 5 mm to 10 mm of the dolly protrudes above the surface, care being taken not to rock the cutter. Dig the cutter out of the surrounding stabilized material and trim both ends of the core flat to the ends of the cutter with a knife or a spatula and check for flatness with the straightedge.

3.4.3.4 Determine, to the nearest 1 g, the mass (m_a) of the cutter containing the core.

3.4.3.5 Remove the core from the cutter, crumble it and place a representative sample in an airtight container and determine its moisture content as described in 1.3.

NOTE The calcium carbide and nuclear gauge methods described respectively in 1.3.6 and 1.3.7 do not give results of sufficient accuracy to be used for the determination of the dry mass of material removed from the hole and/or the calculation of dry density. They should not therefore be used for this purpose. Any of the other methods described may be used, subject to their limitations which are given for the individual test procedures.

3.4.4 Calculations and expression of results

NOTE A typical data and calculation form for the determination of the in-situ density by the core-cutter method is given in form I of Appendix A.

3.4.4.1 Calculate the bulk density (ρ , in Mg/m^3) from the equation:

$$\rho = (m_a - m_c)/V_c$$

where

m_a is the mass of stabilized material together with the core-cutter (in g);

m_c is the mass of the core-cutter (in g);

V_c is the volume of the core-cutter (in mL).

3.4.4.2 If required calculate the dry density (ρ_d , in Mg/m^3) from the equation:

$$\rho_d = 100\rho/(100 + w)$$

where

w is the moisture content of the stabilized material (in %).

3.4.4.3 Express the value of the bulk and/or dry density in Mg/m^3 to the nearest 0.01 Mg/m^3 .

3.4.5 Test report

Report the results in accordance with 3.8.

3.5 Immersion in water method

NOTE This method covers the determination of the density of a sample of compacted stabilized material. The method can be employed whenever lumps of suitable size can be obtained; in particular it is a convenient method of determining the density of cores cut from hardened stabilized material. An acceptable alternative to this method is given in 3.6. Although the sample should preferably be cylindrical or cubical, the test can be carried out quite satisfactorily on specimens of other shapes providing no one dimension is very much smaller than the other two.

3.5.1 Principle

The method makes use of Archimedes' principle, i.e. the apparent loss in mass of the sample when it is immersed in water is equal to the mass, and hence the volume, of the water displaced. The mass of the sample is therefore determined first in air; its apparent mass when it is suspended in water is then determined. The density is calculated from the values thus determined for the mass and volume of the sample.

The requirements of BS 1924-1 shall where appropriate apply to this test method.

3.5.2 Apparatus

3.5.2.1 *A balance*, of 10 kg minimum capacity, readable to 1 g.

3.5.2.2 *A suitable metal or plastics watertight container*, such as a large bucket in which the samples can be immersed.

3.5.2.3 *A cradle and supporting frame*, similar in principle to that shown in Figure 14, with which the frame attached to the weighing system of the balance can support the cradle below the balance.

NOTE The arrangement of the cradle and supporting frame shown in Figure 14 has been found to be convenient but any other method which enables the specimen to be suspended in water supported by the weighing system of the balance above would also be satisfactory.

3.5.2.4 *Equipment for melting paraffin wax.*

3.5.2.5 *Apparatus for the determination of the moisture content* by the oven-drying method as described in 1.3.3 (see note to 3.5.6.4).

3.5.3 Materials

3.5.3.1 *Paraffin wax.*

3.5.3.2 *Modelling clay or putty.*

3.5.4 Preparation of apparatus

3.5.4.1 Support the balance with the scoop or platform over the cylindrical container and with at least 300 mm clear space between the underside of the supports and the top of the container. A suitable arrangement is shown in Figure 14.

3.5.4.2 Fill the watertight container with water to within approximately 80 mm of the top. Place it below the balance and adjust the cradle and supporting frame, so that the cradle is suspended in the water without touching either the bottom or the sides of the container. Ensure that the largest specimen to be tested will be immersed completely when on the cradle.

3.5.4.3 Place a counter mass on the scale pan to bring the reading on the balance back to zero.

3.5.5 Preparation of the test specimens

3.5.5.1 Trim the lumps of material to be tested to a suitable size and shape. Take care not to remove all the loosely bonded material if the specimen is honeycombed, and also to keep the specimen representative of the full depth of the layer. As the accuracy of the test depends upon the size of the specimen used, use the largest available specimen compatible with the capacity of the balance. If necessary reduce the size of the lumps to produce suitable specimens of regular shape and having minimum masses of 2 kg for fine- and medium-grained materials and 4 kg for coarse-grained materials. Weigh the specimens to the nearest 1 g (m_a).

3.5.5.2 Determine the densities of the prepared specimens using the procedure given in either 3.5.6 or 3.5.7 depending on the state of compaction of the material and the size and number of the voids.

3.5.6 Test procedure for dense specimens with no large voids

NOTE Only dense, well compacted specimens having a few small air voids should be tested by this procedure. Specimens with either a few large air voids due to poor local compaction, or many small air voids due to poor general compaction or bad grading of the material used, should be tested by the procedure given in 3.5.7.

3.5.6.1 Place the specimen, prepared as described in 3.5.5, under water in a container so that it is immersed completely and then left to soak for at least 24 h.

3.5.6.2 When the specimen is removed from the water allow the free water in the specimen to drain away and then weigh and record its mass (m_a) to the nearest 1 g.

3.5.6.3 Immediately after weighing the specimen place it in the cradle and suspend this cradle from the weighing system of the balance (see note). Measure the apparent mass (m_b) of the specimen while suspended in water to the nearest 1 g.

NOTE When the specimen is placed in the water, supported by the cradle, care should be taken to ensure that no air bubbles are trapped underneath the specimen. Also, while measuring the apparent mass of the specimen when suspended in water, it should be ensured that the specimen is immersed completely. If this is not the case, either the level of water in the container should be raised or the supporting frame should be adjusted until the specimen is immersed completely. The specimen should then be removed from the cradle and the apparatus adjusted as in 3.5.4.

3.5.6.4 Remove the specimen from the cradle and dry in the oven at a temperature of $105 \pm 5^\circ\text{C}$ (see note). The period required for drying will vary with the type of material and the size of the specimen. The specimen shall be deemed to be dry when successive weighings of the sample, carried out at intervals of 4 h, do not differ by more than 0.1 % of the original mass. After drying place the specimen in a container, replace the lid and allow to cool. When cool, weigh the specimen and record its mass (m_d) to the nearest 1 g.

NOTE If a suitable size of oven is not available break the sample into fragments and take a representative sample for the determination of the moisture content.

3.5.7 Test procedure for specimens with large voids

3.5.7.1 Dry the specimen, prepared as described in 3.5.5 in an oven at a temperature of $105 \pm 5^\circ\text{C}$ (see note). The period required for drying will vary with the type of material and the size of specimen. The specimen shall be deemed to be dry when successive weighings of the sample, carried out at intervals of 4 h, do not differ by more than 0.1 % of the original mass. After drying place the specimen in a container, replace the lid and allow to cool. When cool weigh the specimen and record its mass (m_d) to the nearest 1 g.

NOTE When a temperature-controlled drying oven is not available the specimen may be tested without drying in which case it becomes necessary to determine its moisture contents at a subsequent stage (see 3.5.7.5).

3.5.7.2 Fill all the surface voids in the specimen with a suitable material which is insoluble in water (see note). After filling the voids weigh the specimen to the nearest 1 g and record its mass (m_f).

NOTE Care should be taken to fill only air voids and not holes resulting from the loss of stone during collection and preparation of the specimen. In filling the voids the material used should be trimmed level with the surface of the specimen.

3.5.7.3 Coat the specimen completely by repeated dipping in molten paraffin wax (see note). Allow the waxed specimen to cool and then weigh and record its mass (m_w) to the nearest 1 g. Calculate the mass (m , in g) of the paraffin wax adhering to the specimen from the equation:

$$m = m_w - m_f$$

where

m_w is the mass of the specimen after coating with wax (in g);

m_f is the mass of the specimen after filling air voids with modelling clay or putty (in g).

NOTE Waxing of the specimens should be carried out very carefully. Surface depressions, including cavities left by stones, should be first coated with molten wax applied by brush, and allowed to set before dipping. Air bubbles should not be allowed to form under the wax. Cavities considered to be part of the existing voids should be made up with filler before waxing. To avoid shrinking and cracking of the wax coating, the wax should be only just molten when applied. In the absence of a temperature controlled waxpot, use of a carpenter's glue pot helps to avoid overheating.

3.5.7.4 Place the waxed specimen in the cradle and suspend the cradle from the weighing system of the balance (see note). Record the apparent mass (m_g) of the specimen, whilst it is suspended in water, to the nearest 1 g.

NOTE When the specimen is placed in water, supported by the cradle, care should be taken that no air bubbles become trapped beneath the specimen. Also, whilst measuring the apparent mass of the specimen when suspended in water, it should be ensured that the specimen is completely immersed. If this is not the case, either the level of water in the container should be raised or the supporting frame should be adjusted until the specimen is immersed completely. The specimen should then be removed from the cradle and the apparatus re-adjusted as described in 3.5.4.

3.5.7.5 Remove the specimen from the cradle. If the specimen was not dried as described in 3.5.7.1 remove the wax coating from the specimen and take a representative sample for the determination of the moisture content (w) by one or other of the methods given in 1.3.3 to 1.3.5. Make sure that the portion used for the determination of the moisture content is completely free from paraffin wax, modelling clay or putty.

3.5.8 Calculations and expression of results

NOTE A typical data and calculation form for the determination of the in-situ density by the immersion in water method is given in form J of Appendix A.

3.5.8.1 *Dense specimens with no large voids (not coated with wax)*

3.5.8.1.1 Calculate the volume (V_s , in mL) occupied by the specimen from the equation:

$$V_s = m_a - m_b$$

where

m_a is the mass of the soaked specimen immediately before weighing in water (in g);

m_b is the apparent mass of the specimen when suspended in water (in g).

3.5.8.1.2 Calculate the bulk density (ρ , in Mg/m^3) from the equation:

$$\rho = m_s/V_a$$

where

m_s is the mass of the specimen (in g), prepared as described in 3.5.5.

3.5.8.1.3 Calculate the dry density (ρ_d , in Mg/m^3) from the appropriate equation as follows:

- a) for specimens dried completely after weighing suspended in water, as in **3.5.6.4**:

$$\rho_d = m_d/V_s$$

where

m_d is the mass of the specimen after drying (in g);

- b) for specimens not dried after weighing suspended in water, as in **3.5.7.5**:

$$\rho_d = 100m_c/V_s(100 + w)$$

where

m_c is the mass of the specimen immediately before it is broken up for moisture content determination (in g);

w is the moisture content of the stabilized material (in %).

3.5.8.2 Specimens with large voids (coated with wax)

3.5.8.2.1 Calculate the volume (V_s , in mL) occupied by the specimen from the equation:

$$V_s = (m_w - m_g) - (m/\rho_p)$$

where

m_w is the mass of the specimen and wax coating (in g);

m_g is the apparent mass of the specimen and wax coating when suspended in water (in g);

m is the mass of the wax coating (in g);

ρ_p is the density of the paraffin wax (in g/mL).

3.5.8.2.2 Calculate the bulk density (ρ , in Mg/m^3) of the stabilized material from the equation:

$$\rho = m_s/V_s$$

where

m_s is the mass of the specimen, prepared as described in **3.5.5**, (in g).

3.5.8.2.3 Calculate the dry density (ρ_d , in Mg/m^3) of the stabilized material from the appropriate equation as follows:

- a) for specimens dried before filling air voids and coating with wax as in **3.5.7.1**:

$$\rho_d = m_d/V_s$$

where

m_d is the mass of the specimen before drying (in g).

- b) for specimens not dried before filling air voids and coating with wax:

$$\rho_d = 100\rho/(100 + W)$$

where

w is the moisture content of the stabilized material (in %).

3.5.8.3 Express the value of the bulk and/or dry density in Mg/m^3 to the nearest 0.01 Mg/m^3 .

3.5.9 Test report

Report the results in accordance with **3.8**.

3.6 Water displacement method

NOTE This method describes the determination of the density of a sample of compacted stabilized material. The method can be employed whenever lumps of suitable size can be obtained; in particular it is a convenient method of determining the density of cores cut from hardened stabilized material. An acceptable alternative to this method is given in **3.5** but it requires more specialized equipment. Although the sample should preferably be cylindrical or cubical, the test can be carried out quite satisfactorily on specimens of other shapes providing no one dimension is very much smaller than the other two. In obtaining the lumps of material and trimming them to a suitable size and shape for testing, care should be taken not to remove all the loosely bonded material if the specimen is honeycombed, and also to keep the specimen representative of the full depth of the layer. As the accuracy of the test depends upon the size of the specimen used, it is important that the largest available specimen compatible with the capacity of the apparatus should be used.

3.6.1 Principle

The volume of a specimen of known mass is determined by totally immersing the specimen in water and measuring the volume of water displaced. The density is then calculated from the values obtained for the mass and the volume.

The requirements of BS 1924-1 shall where appropriate apply to this test method.

3.6.2 Apparatus

3.6.2.1 A balance, of 10 kg minimum capacity, readable to 1 g.

3.6.2.2 A cylindrical metal container, fitted with a siphon tube, of the type shown in Figure 15 for fine- and medium-grained materials and Figure 16 for coarse-grained materials.

3.6.2.3 A watertight container, to act as a receiver for the water siphoning over from the container described in **3.6.2.2**.

NOTE A convenient size is one about 250 mm in diameter and 250 mm deep.

3.6.2.4 Equipment for melting paraffin wax.

3.6.2.5 Apparatus for determining the moisture content by the oven-drying method as described in **1.3.3** (see note to **3.6.6.1**).

3.6.3 Materials

3.6.3.1 Paraffin wax.

3.6.3.2 Modelling clay or putty.