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Methods of test for
Stabilized soils

British Standards Institution

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Foreword

This British Standard was first published under the authority of the Road Engineering Industry Standards Committee in 1953. The third edition was published in 1967 but the need for a metric edition soon became apparent and this new edition is basically a metric version of the third edition and very few other changes have been made.

In making the change SI units have been used and wherever possible the dimensions have been rationalized, e.g. a length specified formerly as 12 in has been changed to 300 mm and not to the exact equivalent of 304.8 mm. In the case of the bearing ratio test, however, the apparatus used is essentially the same as the California Bearing Ratio test. As the dimensions of this equipment cannot be rationalized without international agreement on the way it should be done the dimensions are given as exact conversions from the imperial units.

Where critical dimensions have been rationalized the equations in the standard relate, of course, only to these new dimensions. It is recognized that equipment made to the specifications in BS 1924 : 1967 may thus have been rendered obsolescent. Both sets of equipment give the same results but it is important when using equipment to the old specification to quote the final results in the same SI units that are used in this edition. Provided that care is taken to ensure that the correct factors are used in the equations and calculations, apparatus made to conform to BS 1924 : 1967 may therefore continue to be used up to 1 January 1980.

In several instances methods are termed 'standard method' and 'subsidiary method' respectively. The former are more accurate but may be unsatisfactory for use in the laboratory or on site owing to the time taken or the need for equipment which is not easily obtainable.

In each of the methods, the measurement of only one value of the quantity concerned is required. It is recognized that it is necessary in many practical applications to make a number of tests in order to obtain a mean value and an indication of its reliability. Guidance on the number of measurements required and the treatment of the results obtained is regarded as being beyond the scope of the present standard.

Typical forms are included for nearly all the test methods to illustrate how the results may conveniently be calculated and recorded. The layout of such forms is a matter of individual preference, but most of the typical layouts have been printed so that photographic reproduction and enlargement to about A4 size will provide a usable standard form. If there is likely to be a wide demand for these forms within industry, the British Standards Institution will be pleased to consider the printing of bulk supplies at the usual rates.

The term 'specific gravity' has been retained in this edition. The term recognized by the International Organization for standardization (ISO) for this concept is 'relative density' but the latter term is used in soils engineering with reference to the relationship between the voids ratio of the soil in its loosest state and the voids ratio of the soil in its densest state (see BS 1991 'Letter symbols, signs and abbreviations', Part 4 'Structures, materials and soil mechanics').

British Standard Methods of test for

Stabilized soils

1. General

1.1 Scope

This British Standard specifies methods of test for stabilized soils.

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

1.2 Definitions and symbols

1.2.1 Definitions. For the purposes of this British Standard the following definitions and those given in BS 892 apply:

- (1) *Particle size distribution*. The percentages of the various grain sizes present in a soil as determined by sieving, sedimentation, elutriation or other means.
- (2) *Cobbles*. Rounded or sub-angular stones of sizes between 200 mm and 60 mm.
- (3) *Gravel fraction*. The fraction of a soil composed of particles between the sizes of 60 mm and 2 mm. The gravel fraction may be subdivided as follows:

BS test sieve sizes to be used for separation*

Coarse gravel,	60 mm to 20 mm	63 mm to 20 mm
Medium gravel,	20 mm to 6 mm	20 mm to 6.3 mm
Fine gravel,	6 mm to 2 mm	6.3 mm to 2.0 mm

- (4) *Sand fraction*. The fraction of a soil composed of particles between the sizes 2.0 mm and 0.06 mm. The sand fraction may be subdivided as follows:

BS test sieve sizes to be used for separation*

Coarse sand,	2.0 mm to 0.6 mm	2.0 mm to 600 μ m
Medium sand,	0.6 mm to 0.2 mm	600 μ m to 212 μ m
Fine sand,	0.2 mm to 0.06 mm	212 μ m to 63 μ m

- (5) *Silt fraction*. The fraction of a soil composed of particles between the sizes 0.06 mm and 0.002 mm. The silt fraction may be subdivided as follows:

Coarse silt,	0.06 mm to 0.02 mm
Medium silt,	0.02 mm to 0.006 mm
Fine silt,	0.006 mm to 0.002 mm

- (6) *Clay fraction*. The fraction of a soil composed of particles smaller in size than 0.002 mm.
- (7) *Cohesive soil*. A soil which by virtue of its clay content will form a coherent mass.
- (8) *Non-cohesive soil, granular soil*. A soil which will not form a coherent mass.
- (9) *Sampling*. The selection of a representative portion of a material.
- (10) *Quartering*. The reduction in quantity of a large sample of material by dividing a circular heap into four approximately equal parts by diameters at right angles, removing two diagonally opposite quarters, and mixing the two remaining quarters intimately together so as to obtain a truly representative half of the original mass. The process is repeated until a sample of the required size is obtained.
- (11) *Riffling*. The reduction in quantity of a large sample of material by dividing the mass into two approximately equal halves by passing the sample through an appropriately sized riffle (or riffle box). The process is repeated until a sample of the required size is obtained.
- (12) *Compaction*[†]. The process of packing stabilized soil particles more closely together by rolling or other mechanical means, thus increasing the dry density of the stabilized soil.
- (13) *Bulk density*. The mass of a material (including solid particles, any contained water and any fluid stabilizer) per unit volume, including voids.

* These are the test sieve sizes nearest to the theoretical sizes. When the 2.0 mm and 63 μ m sieves are not available the 2.36 mm (No. 7) and 75 μ m (No. 200) sieves may be used without seriously affecting the result.

[†] This term should not be confused with consolidation, which is the process whereby soil particles are packed more closely together over a period of time by application of continued pressure.

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- (14) *Dry density*. The mass of the dry material after drying to constant mass at 105 °C and after removal of any fluid stabilizers contained in unit volume of undried material.
- (15) *Moisture content**. The mass of water which can be removed from the stabilized soil, usually by heating at 105 °C, expressed as a percentage of the dry mass.
- (16) *Optimum moisture content*. The moisture content at which a specified amount of compaction will produce the maximum dry density (see Fig. 1).
- (17) *Maximum dry density*. The dry density obtained using a specified amount of compaction at the optimum moisture content (see Fig. 1).
- (18) *Relative compaction*. The percentage ratio of the dry density of the stabilized soil to the maximum dry density of that stabilized soil as determined by a specified laboratory compaction test.
- (19) *Dry density/moisture content relationship*. The relationship between dry density and moisture content of a soil when a given compactive effort is employed.
- (20) *Percentage air voids*. The volume of air voids in the soil expressed as a percentage of the total volume of the soil.
- (21) *Air voids line*. A line showing the dry density/moisture content relationship for soil containing a constant percentage of air voids. (Air voids lines are shown in Fig. 1). The line can be calculated from the equation:

$$\rho_d = \rho_w \left(\frac{1 - \frac{V_a}{100}}{\frac{1}{G_s} + \frac{w}{100}} \right)$$

where

ρ_d is the dry density of the soil, Mg/m³;

ρ_w is the density of water, Mg/m³;

V_a is the volume of air voids in the soil, expressed as a percentage of the total volume of the soil;

G_s is the specific gravity of the soil particles;

w is the moisture content, expressed as a percentage of the mass of dry soil.

- (22) *Saturation line (zero air voids line)*. A line showing the dry density/moisture content relationship for soil containing no air voids. The saturation line is also shown on Fig. 1. It is obtained by putting $V_a = 0$ in the equation given in definition (21).

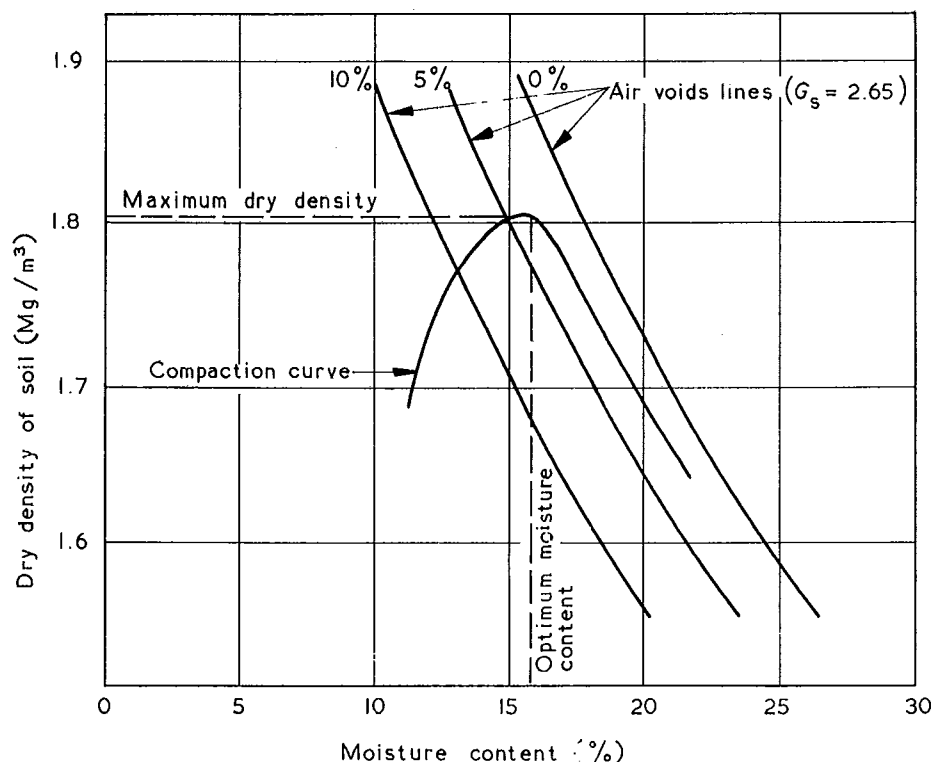


Fig. 1. Terms used in compaction tests

* Although the term moisture content has been used throughout this standard, the term water content is also widely used and either may be employed.

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1.2.2 Symbols. For the purposes of this British Standard, the following symbols and those given in BS 1991: Parts 1 and 4 are used.

Term	Symbol
Moisture content	w
Specific gravity of soil particles	G_s
Bulk density of soil	ρ
Dry density of soil	ρ_d
Non-aqueous fluid stabilizer content	s
Solid stabilizer content	c
Bearing ratio	BR
Percentage air voids	V_a

1.3 Apparatus

Apparatus shall comply with the requirements of British Standards where these are available. For example,

BS 410	Test sieves
BS 572	Interchangeable conical ground glass joints
BS 593	Laboratory thermometers
BS 604	Graduated measuring cylinders
BS 756	Dean and Stark apparatus
BS 805	Toluenes
BS 846	Burettes and bulb burettes
BS 1583	One-mark pipettes
BS 1610	Methods for the load verification of testing machines
BS 1739	Filter flasks
BS 1752	Laboratory sintered or fritted filters
BS 1792	One-mark volumetric flasks
BS 1796	Methods for the use of British Standard fine-mesh test sieves
BS 1923	Glass filter funnels
BS 2648	Performance requirements for electrically-heated laboratory drying ovens
BS 2734	Boiling flasks (narrow-necked) conical, flat bottom and round bottom

For the type of materials covered by this British Standard full tolerance sieves will be sufficiently accurate. Sieves with 5 mm aperture size and above shall be perforated plate square hole sieves. Below that size they shall be woven wire test sieves.

The essential details of the equipment illustrated in this standard have been indicated by an asterisk in the figures.

The manufacturing tolerances on the essential dimensions shall be as shown below unless other tolerances are shown in the figures.

- (1) ± 1.0 mm on dimensions greater than 300 mm;
- (2) ± 0.5 mm on dimensions between 100 mm and 300 mm;
- (3) ± 0.15 mm on dimensions up to and including 100 mm.

Where mass is an essential requirement the tolerance on the mass is shown in the figure.

NOTE 1. The following range of balances covers the requirements of all tests in this standard:

Capacity	100 g	250 g	1 kg	5 kg	10 kg	25 kg
Accuracy	0.001 g	0.01 g	0.1 g	0.5 g	1 g	5 g

NOTE 2. The following palette knives cover the requirements of all the tests in this standard:

Length	100 mm	200 mm
Breadth	20 mm	30 mm

1.4 Grouping of soils

For the purposes of the tests described in this British Standard, soils shall be grouped as follows:

- (1) *Fine-grained soils.* Soils containing not less than 90 % passing a 2 mm BS test sieve.
- (2) *Medium-grained soils.* Soils containing not less than 90 % passing a 20 mm BS test sieve.
- (3) *Coarse-grained soils.* Soils containing not less than 90 % passing a 37.5 mm BS test sieve.

The grouping of a soil thus depends on the result of a sieve analysis; any soil shall be regarded as belonging to the finest-grained group appropriate under the definitions given above.

Soils with a greater proportion of material than about 10 % retained on a 37.5 mm BS test sieve cannot be examined usefully by any of the tests in this standard. They would, of necessity, fall into the range of materials classed as aggregates which are covered by BS 812.

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1.5 Sampling and preparation of the sample for testing

1.5.1 Introduction. This describes the general principles to be observed in taking samples and the preparation and treatment of samples of material and stabilized soil which are to be subjected to the tests described in Clauses 2 to 7.

It is apparent that different approaches are often required in handling soils stabilized with different stabilizers. In particular, cement-stabilized soils become more difficult to compact to high densities with increase in elapsed time after mixing and for this reason their preparation and treatment have been separated in some instances from that of other types of stabilized soil.

Reference to the sampling and preparation of samples of stabilized soil is intended to refer particularly to the handling of site mixed material required for control tests, but in some instances it can equally well be applied to laboratory mixed material.

1.5.2 Sampling. The technique to be used for sampling will have to vary widely according to the material being sampled, site conditions, the facilities available, the size of sample required and its purpose. Nevertheless, certain general principles can be quoted which should be followed so far as circumstances allow. Only the obtaining of disturbed samples is considered here as the tests in this standard (apart from Tests 9(A) and 9(B)) do not require undisturbed samples. Samples for Tests 9(A) and 9(B) are considered under the respective test procedures.

The purpose for which a sample is required may be considered either as being to represent as large a body of material as possible in order to study its average properties, or as being one of a series representing a relatively small body of material in order to study the variability of its properties. The first class of samples will be referred to as representative; typical of these are samples taken in advance of construction to assess the suitability of a given source of soil. The second class of samples will be referred to as selected; typical of these are samples taken for control tests carried out during construction where the samples represent only a small proportion of the whole work.

Representative samples should be obtained by taking a number of subsamples from separate places in the material being sampled; these subsamples should be mixed thoroughly. It is desirable that the number of subsamples should be about ten, but the facilities available may be insufficient to make this practicable, and in such cases not less than four subsamples should be taken. If less than ten subsamples are taken the number shall be recorded and reported. If appropriate, the size of the resulting sample shall be reduced to that required for tests. If the size of the test sample is one-eighth or more of the total sample it shall be obtained by riffing or quartering. If the size of the test sample is less than one-eighth of the total sample it shall be obtained by taking six small samples of appropriate size from the newly mixed total sample. These six samples may be mixed, e.g. for moisture content determinations.

Where several subsamples are taken, each should normally be taken so as to eliminate as far as possible any segregation that occurred in the placing of the material being sampled. For example, the coarse material of a stock pile or lorry load will be concentrated normally at the base and edges and the apex will be deficient in it. Care should also be taken that the size of the sampling tool is not so small that the coarser material rolls off.

In some instances the whole of a selected sample may be taken from one place without subsampling. Often, however, selected samples will be required to be representative of quantities of material of perhaps 4 m³ in volume, and in such cases about ten subsamples should be taken from the selected material, and mixed. It is convenient if the size of subsample can be chosen such that no reduction in the size of this mixed sample is required. Selected samples will often be taken from soil mixed with a stabilizer, and in many such instances speed of treatment will be of greater importance than thoroughness of mixing of the subsamples. Indeed, the changes in uniformity brought about by mixing may be undesirable, because the selected sample may become better mixed than the material from which it was taken.

An assessment should then be made of whether the soil is to be classed as fine-grained, medium-grained or coarse-grained (see 1.4). In many cases this will be known or self evident but, in doubtful cases or where confirmation is required, a portion of the sample should be sieved. The size of sample used for this shall be in accordance with the following table:

Maximum size of material present in substantial proportion (more than 10 %)	Minimum mass of sample to be taken for sieving
mm	kg
> 20	15
< 20 but > 2	2
< 2	0.1

The sieving shall be done in accordance with Test 7(A) or 7(B) of BS 1377.

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The size of sample required will depend on the soil group and the purpose to which it is to be put. It can be assessed by multiplying the mass given in the table below (which includes some allowance for drying, wastage and rejection of stones where required) by the maximum number of tests envisaged.

Type of test	Soil group		
	Fine-grained	Medium-grained	Coarse-grained
Moisture content, Tests 1(A) and 1(B)	50 g	350 g	4 kg
Moisture content, Test 1(C)	50 g	350 g	—
Moisture content, Test 2	200 g	500 g	4 kg
Compaction tests, Tests 3 and 4	25 kg	25 kg	25 kg
Compaction test, Test 5	80 kg	80 kg	80 kg
Strength and durability tests, Test 10	600 g*	5 kg*	—
Test 11	—	9 kg*	9 kg*
Test 12	600 g*	5 kg* or 9 kg*	9 kg*
Test 13	6 kg*	6 kg*	—
Stabilizer content, Tests 14 and 15	400 g	4 kg	8 kg
Test 16	300 g	2 kg	8 kg
Degree of pulverization, Test 17	1.5 kg	1.5 kg	1.5 kg
Presence of organic matter, Test 18	100 g	250 g	1 kg

* Per specimen.

NOTE. Use of the same material for several tests in succession is generally not acceptable.

Where samples are being taken for moisture content determination or for testing without change of moisture content, the use of shallow trays for storing or carrying should be avoided as these expose the sample unnecessarily to evaporation or rainfall. Likewise, particularly at a site laboratory where much of the work may be carried out in the open, such samples should be kept covered if not sealed, except when material is actually being extracted.

1.5.3 Preparation of samples for testing

1.5.3.1 Apparatus. The following apparatus is required.

- (1) Containers with airtight lids, or bags capable of being sealed, suitable for samples of various sizes up to 100 kg in mass.
- (2) Non-corrodible metal trays of sizes ranging from 0.05 m² to 1 m².
- (3) The following test sieves: 37.5 mm, 20 mm, 10 mm, 5 mm, 2 mm complying with the requirements of BS 410.
- (4) Say, 150 mm cast iron mortar and, say, 80 mm porcelain mortar, each with a suitable pestle.
- (5) Rubber ended pestle complying with the requirements of BS 1377.
- (6) Balances capable of weighing up to 10 kg and 25 kg, readable and accurate to 1 g and 5 g respectively.
- (7) A thermostatically-controlled oven capable of maintaining a temperature of 45 °C to 50 °C and of 105 °C to 110 °C. (It will often be found convenient to have one about 0.2 m³ to 0.3 m³ capacity.)
- (8) Mechanical mixers of suitable capacities or suitable tools for hand mixing, e.g. a spatula, a trowel and a shovel.
- (9) Graduated glass or polyethylene cylinders of 100 ml and 1000 ml capacity.
- (10) Apparatus for the determination of moisture content in accordance with Test 1(A), 1(B) or 1(C) of this standard.

1.5.3.2 Procedure

1.5.3.2.1 General. Methods are described both for the processing of natural soils and their mixing in the laboratory with water and stabilizers, and for the processing of stabilized soils which have been mixed in situ or in full-scale mixing plant and are being sampled for control tests. It is visualized that on occasions the tests described in this standard will be used on natural soils for comparative purposes.

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1.5.3.2.2 Initial preparation of natural soils. The initial preparation varies according to the test(s) for which the sample is required.

(1) *For Tests 1(A), 1(B), 1(C) and 2 (moisture content determinations).* If the moisture content of the natural soil as received is required, a representative or selected portion of the material shall be obtained of the following minimum mass.

	Test 1(A)	Test 1(B)	Test 1(C)	Test 2
For fine-grained soils	30 g	30 g	30 g	200 g
For medium-grained soils	300 g	300 g	300 g	500 g
For coarse-grained soils	3 kg	2 kg	—	3 kg

Where one-eighth or more of the total sample is being used for the moisture content determination, the sample shall be obtained, if practicable, by riffing or quartering, but otherwise by combining not less than four subsamples taken from the main sample. Where a greater reduction in size is required it shall be obtained by combining ten subsamples taken from the main sample, as repeated riffing or quartering would in many cases reduce the moisture content of the sample. The main sample shall be mixed before such subsamples are taken, care being taken that the moisture content is not reduced appreciably during this process.

(2) *For the remaining tests.* The remainder of the main sample shall be air dried or oven dried at a temperature not exceeding 50 °C and its moisture content determined after such drying. Soils to which no irreversible changes occur in drying at 105 °C to 110 °C may be dried at this temperature (see Note 1).

a. *For Tests 3 and 4 (compaction tests using a rammer).* A portion large enough to provide about 15 kg of material passing the 20 mm BS test sieve shall be taken. This shall be sieved on a 20 mm BS test sieve and the coarse fraction rejected after the amount of coarse material present has been noted.

Aggregations of particles shall be broken down to pass a 5 mm BS test sieve using a method that is not more liable to break down individual particles than is the method of mixing envisaged. In general, the use of a hand roller or the gentle use of a normal pestle and mortar will be acceptable but in some cases the use of a rubber ended pestle with the mortar may be needed.

b. *For Test 5 (compaction test using a vibrating hammer).* A portion large enough to provide about 50 kg of material passing the 37.5 mm BS test sieve shall be taken and the material retained on this sieve shall be removed and its proportion to the total noted.

c. *For Tests 6, 7, 8, 9(A) and 9(B) (density determinations).* These are site tests for which no sample preparation is required.

d. *For Tests 10, 11, 12 and 13 (strength tests).* Soil for these tests has to be mixed with predetermined quantities of water and of stabilizer. (For mechanical stabilization the stabilizer may itself be a soil and in some cases the quantity of stabilizer used may be zero.) If the tests are to be carried out on a sample of natural soil, the preparation should be the same as that described in 1.5.3.2.4 for a sample of stabilized soil.

e. *For Tests 14, 15, 16, 17 and 18 (stabilizer content determinations and miscellaneous tests).* The preparation of the samples for these tests is given under the respective test procedures.

1.5.3.2.3 Mixing of natural soils with water and stabilizing agents. If it is desired to blend two or more soils, appropriate masses, i.e. with due allowance for moisture content, of the different soils shall be mixed thoroughly to a uniform condition in the mechanical mixer, or by hand using a spatula or trowel.

An appropriate quantity of the dried material shall be mixed with water and stabilizer in the manner indicated below.

(1) *Mechanical stabilization.* The required amount of water shall be incorporated with the soil, by mixing thoroughly to a uniform condition in a mechanical mixer or by hand, taking care to minimize loss of moisture. The moist soil shall then be allowed to stand for 24 h in an airtight container. This procedure applies either to soil which is inherently mechanically stable or to soils which are blended to achieve this result.

(2) *Stabilization with powders.* The total amount of water to be added, less an amount equal to about 3 % of the mass of dried soil, shall be incorporated with the soil by mixing thoroughly to a uniform condition in a mechanical mixer or by hand, taking care to minimize loss of moisture. In the case of heavy clays, the moist soil shall be allowed to stand for 24 h in an airtight container; with other soils the mixing with stabilizer may proceed at once.

The required quantity of stabilizer shall then be added to the soil and mixed to a uniform condition either by mixing in a mechanical mixer for about one to two minutes, or by hand using a spatula, trowel or other suitable tool. The remainder of the water shall then be added, and mixing continued for a further period of about 8 min.

When cement-stabilized soil is being mixed for compaction tests or for the manufacture of cylinder or cube specimens, no more soil than can be used within one hour of adding the cement to the soil shall be mixed. If any stabilized soil remains at the end of this period it shall be discarded.

(3) *Emulsified oil or emulsified asphaltic bitumen stabilization.* Sufficient water shall be incorporated with the soil to bring the soil mortar approximately to the plastic limit (see Test 3 of BS 1377 : 1975).

The material shall be mixed, either in a mechanical mixer, or by hand using a spatula or other suitable tool, for 10 min or until it is judged by visual inspection that adequate dispersion of the water has been obtained, care being taken to minimize loss of moisture in mixing. The moist soil shall be allowed to stand for 24 h in an airtight container.

The required quantity of emulsion, diluted with distilled water if it is considered necessary, shall then be added to the soil and mixing started. Additional water shall be added if necessary during the mixing, to ensure a uniform distribution of the emulsified stabilizer. Any other additive shall be incorporated in a manner appropriate to the process of stabilization under consideration (see Note 2).

The mixture shall then be allowed to dry uniformly in air until it has the moisture content required for the subsequent test.

(4) *Oil, asphaltic bitumen and other stabilizers.* The required amount of water shall be incorporated in the soil by mixing thoroughly to a uniform condition in a mechanical mixer, or by hand using a spatula or other suitable tool, care being taken to minimize loss of moisture. The moist soil shall be allowed to stand for 24 h in an airtight container. The required quantity of stabilizer and any other additive shall be incorporated in the soil in a manner appropriate to the process under consideration (see Note 2).

1.5.3.2.4 *Initial preparation of stabilized soils.* The procedures are as follows.

(1) *For Tests 1(A), 1(B), 1(C) and 2 (moisture content determinations).* If moisture contents of the stabilized soil as received are required by any of these methods, the procedure described in 1.5.3.2.2 (1) for natural soils shall be followed.

(2) *For Tests 3, 4 and 5 (compaction tests).* It is not regarded as being generally appropriate for compaction tests to be carried out on site mixed material as the optimum moisture content should usually be known before this stage of the work is reached.

(3) *For Tests 6, 7, 8, 9(A) and 9(B) (density determinations).* These are site tests for which no sample preparation is required.

(4) *For Tests 10, 11, 12 and 13 (strength tests).* For fine-grained cohesive soils the sample as received may have compacted aggregations that have been produced as a result of mixing. For mixes prepared in a laboratory mixer it is recommended that all the material shall be passed through a 20 mm BS test sieve by working material greater than 20 mm through the mesh. The material shall then be remixed thoroughly by hand before preparing the test specimens. This procedure will result in a more uniformly compacted specimen. For mixes taken from construction site work, the specimens shall be made from all the mixed material and the size of the specimen used shall be determined by the size of the aggregations of stabilized soil produced by the mixing plant.

For materials that are stabilized with cement it is essential that compaction takes place as quickly as possible after the mixing is completed, otherwise considerable loss in strength may occur as a result of the hydration of the cement meanwhile.

(5) *For Tests 14, 15, 16, 17 and 18 (stabilizer content determinations and miscellaneous tests).* The preparation of the samples for these tests is given under the respective test procedures.

NOTE 1. Air drying has been specified in the preparation of soil samples for testing since with some soils irreversible changes take place in the soil when it is oven dried at 105 °C to 110 °C. With many soils, however, this effect is of negligible practical significance. Organic soils and certain tropical soils are even affected by air drying and should be used in their natural state.

In the United Kingdom, samples may be air dried by leaving them spread out on trays in the laboratory with free access to air for three or four days. Some silts and clays without large particle sizes may be used in their natural state for certain tests instead of being air dried.

NOTE 2. The time of mixing cannot be specified in advance; guidance may be obtained from the suppliers of the stabilizer or by means of preliminary trials. It should be noted that in some instances, excessive mixing has been found to be deleterious.

2. Determination of the moisture content

2.1 Test 1(A). Determination of the moisture content of soils stabilized with non-volatile stabilizers: standard method (oven drying method)

2.1.1 *General.* This method covers the determination of the moisture content of stabilized soil as a percentage of the oven dry mass of solids (see Note 1). It is applicable to mechanically stabilized soils and to soils mixed with stabilizers which do not contain a significant proportion of volatile matter. With stabilizers containing a significant proportion of volatile matter, the distillation method described in Test 2 should be used. In cases of doubt, information should be sought from the manufacturer of the stabilizer.

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2.1.2 Apparatus. A thermostatically-controlled drying oven capable of maintaining a temperature of 105 °C to 110 °C (see Note 2) and the following items of apparatus.

For fine-grained soils.

- (1) A glass weighing bottle fitted with a ground glass stopper or cap, or a suitable airtight non-corrodible metal container (a convenient size is one 50 mm in diameter and 25 mm high).
- (2) A balance readable and accurate to 0.01 g.
- (3) A desiccator (a convenient size is one 200 mm to 250 mm in diameter) containing anhydrous silica gel (see Note 3).

For medium-grained soils.

- (1) An airtight non-corrodible container of about 500 g capacity.
- (2) A balance readable and accurate to 0.1 g.
- (3) A scoop (a convenient size is one about 200 mm long and 100 mm wide).

For coarse-grained soils.

- (1) An airtight non-corrodible container of about 3 kg capacity.
- (2) A balance readable and accurate to 1 g.
- (3) A scoop (a convenient size is one about 200 mm long and 100 mm wide).

2.1.3 Procedure

2.1.3.1 For fine-grained soils. The procedure is as follows.

- (1) The weighing bottle or container shall be cleaned, dried, and weighed to the nearest 0.01 g (m_1) (see Note 4). A sample of at least 30 g of stabilized soil shall be crumbled and placed loosely in the container or the weighing bottle, and the lid or stopper shall be replaced. The container or bottle and contents shall then be weighed to the nearest 0.01 g (m_2).
- (2) The lid or stopper shall then be removed, and the container or bottle with its lid and contents shall be placed in the oven and dried at 105 °C to 110 °C (see Note 5). The period required for drying will vary with the type of soil and the size of sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see operations (3) and (4)), carried out at intervals of 4 h, do not exceed about 0.1 % of the original mass of the sample (see Note 6). The lid or stopper shall not be replaced while the sample is in the oven.
- (3) After drying, the container or bottle and contents shall be removed from the oven and the whole placed in the desiccator to cool (see Note 7).
- (4) The lid shall be replaced and the container or bottle and contents shall then be weighed to the nearest 0.01 g (m_3).

2.1.3.2 For medium-grained soils. The procedure is as follows.

- (1) The container shall be cleaned, dried and weighed to the nearest 0.1 g (m_1). A sample of at least 300 g of stabilized soil shall be crumbled and placed loosely in the container and the lid shall be replaced. The container and contents shall then be weighed to the nearest 0.1 g (m_2).
- (2) The lid shall then be removed and the container and contents shall be placed in the oven and dried at 105 °C to 110 °C (see Note 5). The period required for drying will vary with the type of soil and the size of sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see operations (3) and (4)), carried out at intervals of 4 h, do not exceed about 0.1 % of the original mass of the sample (see Note 6). The lid shall not be replaced while the sample is in the oven.
- (3) After drying, the lid shall be replaced and the whole allowed to cool.
- (4) The container and contents shall then be weighed to the nearest 0.1 g (m_3).

2.1.3.3 For coarse-grained soils. The procedure is as follows.

- (1) The container shall be cleaned, dried, and weighed to the nearest 1 g (m_1). A sample of at least 3 kg of stabilized soil shall be crumbled and placed loosely in the container and the lid replaced. The container and contents shall then be weighed to the nearest 1 g (m_2).
- (2) The lid shall be removed and the container and contents shall be placed in the oven and dried at 105 °C to 110 °C (see Note 5). The period required for drying will vary with the type of soil and the size of sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see operations (3) and (4)), carried out at intervals of 4 h, do not exceed about 0.1 % of the original mass of the sample (see Note 6). The lid shall not be replaced while the sample is in the oven.
- (3) After drying, the lid shall be replaced and the whole allowed to cool.
- (4) The container and contents shall then be weighed to the nearest 1 g (m_3).

2.1.4 Calculations*. In the case of soil stabilized with a solid stabilizer the moisture content, w' , shall be calculated as a percentage of the dry soil plus stabilizer mass from the equation:

$$w' = \frac{(m_2 - m_3) \times 100}{m_3 - m_1} (\%)$$

where

m_1 is the mass of container (g);

m_2 is the mass of container and wet stabilized soil (g);

m_3 is the mass of container and dry stabilized soil (g).

In the case of soil stabilized with a fluid stabilizer, the moisture content, w , shall be calculated as a percentage of the dry soil mass from the equation:

$$w = \frac{(m_2 - m_3) \times (100 + s)}{m_3 - m_1}$$

where

s is the non-aqueous fluid stabilizer content of the stabilized soil (%).

2.1.5 Reporting of results. The moisture content of the stabilized soil, w' or w , shall be reported to two significant figures. The method used to obtain the result shall be stated.

Notes on Test 1(A)

NOTE 1. Soils stabilized with cement or lime. The measured moisture contents of cement- or lime-stabilized soil samples are misleadingly low because the water of hydration of the cement or of the lime-clay reaction cannot be removed by normal drying processes. The error in the result depends on a number of factors, the chief of which are the age of the sample and the speed with which the water is removed once the sample is placed in the oven. It may be as high as 20 % of the stabilizer content for samples that are older than 28 days, or in cases where because of the large size of sample taken or because of overloading of the oven, drying is very slow (see also Note 6).

NOTE 2. A microwave oven may be employed provided preliminary tests show that the soil does not exceed a temperature of 110 °C before all the water is driven off. If a microwave oven is used metal containers are not suitable and the soil should be dried in glass, silica or polytetrafluoroethylene (PTFE) evaporating dishes.

NOTE 3. It is preferable to use self-indicating silica gel as the desiccant. Calcium chloride should not be used as it is known that many clays when oven dry are capable of absorbing water from it.

NOTE 4. It is convenient when many containers are in use to bring them to a standard mass. In the case of 50 mm diameter tins, solder may be added to the lid to bring the mass to, say, 30.00 g.

NOTE 5. Soils containing gypsum. Certain soils contain gypsum which on heating 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 in the soil, the moisture content samples should be dried at not more than 80 °C, and possibly for a longer time. State in the test the drying conditions used if the standard conditions are not used.

NOTE 6. Drying time of soils. 16 h to 24 h is usually a sufficient length of time for drying most soils, but certain soil types and large or very wet samples will require longer. The drying time will also depend on the amount of material in the oven, the size of the oven and the efficiency of the ventilation system.

NOTE 7. If the lids of the containers fit well and it is unlikely that the samples are to be left for a considerable time before weighing, they need not be placed in the desiccator to cool unless glass weighing bottles with ground glass stoppers have been used.

2.2 Test 1(B). Determination of the moisture content of soils stabilized with non-volatile stabilizers: subsidiary method (sand bath method)

2.2.1 General. This method covers the determination of the moisture content of a stabilized soil as a percentage of the dry mass of solids. It is intended as a rapid alternative to Test 1(A) but is less accurate and is more suitable as a site test. The method shall not be used if the soil is stabilized with a fluid stabilizer nor shall it be used if the soil contains a large proportion of gypsum, calcareous matter or organic matter.

2.2.2 Apparatus. The following apparatus is required.

For fine-grained soils.

- (1) A suitable airtight, non-corrodible metal container, approximately 50 mm in diameter and 25 mm deep.
- (2) A balance readable and accurate to 0.1 g.
- (3) A sand bath approximately 200 mm in diameter containing clean sand to a depth of at least 25 mm. A larger bath may be used to heat several samples at once.
- (4) Equipment for heating the sand bath, e.g. a bottled gas or paraffin pressure stove.
- (5) A palette knife (a convenient size is one having a blade 100 mm long and 20 mm wide).

* See Form A, Appendix A.

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For medium-grained soils.

- (1) A balance readable and accurate to 0.5 g.
- (2) A heat-resistant tray about 200 mm square and about 50 mm deep.
- (3) A sand bath containing clean sand to a depth of at least 25 mm and large enough to take the tray. A larger bath may be used to heat several samples at once.
- (4) Equipment for heating the sand bath, e.g. a bottled gas or paraffin pressure stove.
- (5) A palette knife (a convenient size is one having a blade 100 mm long and 20 mm wide).
- (6) A scoop (a convenient size is one about 200 mm long and 100 mm wide).

For coarse-grained soils.

- (1) A balance readable and accurate to 5 g.
- (2) A heat-resistant tray about 250 mm square and 50 mm to 70 mm deep.
- (3) A sand bath containing sand to a depth of at least 25 mm and large enough to take the tray.
- (4) Equipment for heating the sand bath, e.g. a bottled gas or paraffin pressure stove.
- (5) A palette knife (a convenient size is one having a blade 200 mm long and 30 mm wide).
- (6) A scoop (a convenient size is one about 200 mm long and 100 mm wide).

2.2.3 Procedure. The procedure is as follows.

For fine-grained soils.

- (1) The container shall be cleaned, dried and weighed to the nearest 0.1 g (m_1) (see Note 1). A sample of at least 30 g of stabilized soil shall be crumbled and placed loosely in the container and the lid shall be replaced. The container and contents shall then be weighed to the nearest 0.1 g (m_2).
- (2) After the lid has been removed, the container and contents shall be placed on the sand bath which shall be heated by means of the stove, care being taken not to get the sand bath too hot (see Note 2). During heating, the sample shall be disturbed frequently and thoroughly with the palette knife to assist the evaporation of moisture.
- (3) When the container and contents have been heated for a period sufficient to dry out the sample (usually 1 h is sufficient, see Note 3) they shall be removed from the sand bath, the lid replaced and the whole allowed to cool.
- (4) The container and contents shall then be weighed to the nearest 0.1 g (m_3).

For medium- and coarse-grained soils.

- (1) The tray shall be cleaned, dried and weighed to the nearest 0.5 g (m_1). A sample of at least 300 g for medium-grained and 2 kg for coarse-grained stabilized soils shall be crumbled and spread out evenly in the tray and the tray and contents weighed to the nearest 0.5 g (m_2) for medium-grained soils, and to the nearest 5 g (m_2) for coarse-grained soils.
- (2) The tray shall be placed on the sand bath which shall be heated by the stove, care being taken not to get the sand bath too hot (see Note 2). During heating, the sample shall be disturbed frequently and thoroughly with the palette knife to assist the evaporation of moisture.
- (3) When the tray has been heated for a period sufficient to dry out the sample (usually 1 h is sufficient, see Note 3) it shall be removed from the sand bath and allowed to cool.
- (4) Immediately the tray is cool enough to handle, the tray and contents shall be weighed to the nearest 0.5 g for medium-grained soils and to the nearest 5 g for coarse-grained soils (m_3).

2.2.4 Calculations*. The moisture content of the stabilized soil, w' , shall be calculated as a percentage of the dry soil plus stabilizer mass from the equation:

$$w' = \frac{(m_2 - m_3) \times 100}{m_3 - m_1} \%$$

where

- m_1 is the mass of container (or tray) (g);
 m_2 is the mass of container (or tray) and wet stabilized soil (g);
 m_3 is the mass of container (or tray) and dry stabilized soil (g).

* See Form A, Appendix A.

2.2.5 Reporting of results. The moisture content of the stabilized soil, w' , shall be reported to the nearest whole number. The method used to obtain the result shall be stated.

Notes on Test 1(B)

NOTE 1. It is convenient when many containers are in use to bring them to a standard mass, e.g. solder may be added to the lid to bring the mass to, say, 30.0 g.

NOTE 2. *Avoidance of overheating.* A convenient method of detecting overheating of the stabilized soil is by the use of small pieces of white paper mixed with the soil. Overheating is indicated if the paper turns brown.

NOTE 3. *Period of drying.* The drying period will vary with the type of soil, the size of sample and field conditions and it is suggested that, when a large number of moisture determinations are to be made with one soil, 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 soils, 0.5 g for medium-grained soils and 5 g for coarse-grained soils.

2.3 Test 1(C). Determination of the moisture content of soils stabilized with non-volatile stabilizers: subsidiary method (alcohol method)

2.3.1 General. This method covers the determination of the moisture content of stabilized soil as a percentage of the dry mass of solids. It is intended as a rapid alternative to Test 1(A) but is less accurate, and is more suitable as a site test. Because of the large quantity of methylated spirit required and the consequent risk of fire, this method is not advised for use with coarse-grained soils. The method shall not be used if the soil is stabilized with a fluid stabilizer nor shall it be used if the soil contains a large proportion of clay, gypsum, calcareous matter or organic matter.

2.3.2 Apparatus. The following apparatus is required.

- (1) An evaporating dish preferably silica (a convenient size is one about 100 mm diameter for fine-grained soils and about 150 mm diameter for medium-grained soils).
- (2) A palette knife (a convenient size is one having a blade 100 mm long and 20 mm wide).
- (3) A length of about 200 mm to 250 mm of rod about 3 mm diameter (see Note).
- (4) A balance readable and accurate to 0.1 g for fine-grained soils and 0.5 g for medium-grained soils.
- (5) Methylated spirit.

2.3.3 Procedure. The procedure is as follows.

- (1) The evaporating dish shall be cleaned, dried and weighed to the nearest 0.1 g for fine-grained soils and the nearest 0.5 g for medium-grained soils (m_1).
- (2) A sample of stabilized soil of about 30 g for fine-grained soils and 300 g for medium-grained soils shall be placed in the evaporating dish, and the evaporating dish and its contents weighed to the nearest 0.1 g or 0.5 g respectively (m_2).
- (3) A quantity of methylated spirit, about 30 ml for fine-grained soils and 300 ml for medium-grained soils, shall be poured over the stabilized soil so that it is well covered. The methylated spirit shall be worked well into the stabilized soil with the palette knife and any large lumps of stabilized soil broken up.
- (4) The evaporating dish shall be placed on a surface unlikely to be affected by heat, and the methylated spirit ignited.
- (5) The stabilized soil shall be stirred constantly with the piece of rod, care being taken to see that none of the soil mixture is lost.
- (6) The dish of stabilized soil shall be allowed to cool after the methylated spirit has burnt away completely, and when cool enough to be handled the dish and contents shall be weighed to the nearest 0.1 g for fine-grained and the nearest 0.5 g for medium-grained soils (m_3).

NOTE. A piece of metal rod has been found to be the most useful means of stirring as the heat generated will soften the palette knife blade and crack a glass rod.

2.3.4 Calculations*. The moisture content of the stabilized soil, w' , shall be calculated as a percentage of the dry soil plus stabilizer mass from the equation:

$$w' = \frac{(m_2 - m_3) \times 100}{m_3 - m_1} (\%)$$

where

- m_1 is the mass of dish (g);
- m_2 is the mass of dish and wet stabilized soil (g);
- m_3 is the mass of dish and dry stabilized soil (g).

2.3.5 Reporting of results. The moisture content of the stabilized soil, w' , shall be reported to the nearest whole number. The method used to obtain the result shall be stated.

* See Form A, Appendix A.

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2.4 Test 2. Determination of the moisture content of soils stabilized with volatile stabilizers (distillation method)

2.4.1 General. This method covers the determination of the moisture content of stabilized soil as a percentage of the mass of the dry soil or mass of dry soil plus stabilizer. It is necessary to use this method when the stabilizer contains a significant proportion of volatile matter, e.g. in the case of certain bituminous materials. The method may also be used with other stabilizing agents.

2.4.2 Apparatus. The following apparatus is required.

For fine-grained soils

- (1) A distillation apparatus, as shown in Fig. 2, comprising:
 - A round-bottom glass flask of 500 ml capacity, the top of which shall be ground to form the socket of a size 24/29 joint, complying with the requirements of BS 572.
 - A glass reflux condenser, water cooled, 250 mm long.
 - A 25 ml glass receiver with ground glass joints.
- (2) A balance readable and accurate to 0.1 g.
- (3) A length of 1 mm diameter metal wire, approximately 600 mm long.
- (4) A carrier liquid which may be either toluene (nitration grade) complying with the requirements of BS 805 or petroleum spirit, boiling range 100 °C to 120 °C.

For medium-grained soils

- (1) A distillation apparatus, as shown in Figs. 3 to 5, comprising:
 - A metal still of approximately 90 mm internal diameter and 150 mm long, having a flange at the top, to which the head can be attached tightly by means of a clamp. The head is also of metal and a graphited asbestos gasket moistened with the water extraction spirit is provided for insertion between the flange and the head (see Fig. 4). The still head shall be joined by means of a flanged joint or, alternatively, by means of a cork fitting into an outlet tube of about 25 mm diameter (see Figs. 3 and 5).
 - A glass reflux condenser, water cooled, 250 mm long.
 - A 25 ml graduated receiver, with a stopcock.
- (2) A 100 ml measuring cylinder.
- (3) A balance readable and accurate to 1 g.
- (4) A length of 1 mm diameter metal wire, approximately 600 mm long.
- (5) A carrier liquid which may be either toluene (nitration grade) complying with the requirements of BS 805, or petroleum spirit, boiling range 100 °C to 120 °C.

For coarse-grained soils

- (1) A distillation apparatus, as shown in Figs. 6 and 7, comprising:
 - A metal still of approximately 180 mm internal diameter and 300 mm long, having a flanged face at the top to which the head can be attached tightly by means of nuts. The head is also of metal and a graphited asbestos gasket moistened with the water extraction spirit is provided for insertion between the flange and the head (see Fig. 7). The still head and receiver shall be joined by means of a flanged joint, or alternatively by means of a cork fitting into an outlet tube of about 45 mm diameter (see Figs. 5 and 6).
 - A glass reflux condenser, water cooled, 250 mm long.
 - A 100 ml graduated receiver, with a stopcock.
- (2) A 500 ml measuring cylinder.
- (3) A balance readable and accurate to 5 g.
- (4) A length of 1 mm diameter metal wire, approximately 600 mm long.
- (5) A carrier liquid which may be either toluene (nitration grade) complying with the requirements of BS 805, or petroleum spirit, boiling range 100 °C to 120 °C.

2.4.3 Procedure. The procedure is as follows.

- (1) A sample of stabilized soil, some 30 g to 200 g for fine-grained soils or 400 g to 500 g for medium-grained soils (depending upon their moisture content, but preferably yielding approximately 15 ml of water) shall be weighed out to the nearest 0.1 g (m_1) for fine-grained and 1 g (m_1) for medium-grained soils. The sample of coarse-grained soil of 2 kg to 3 kg (depending on the moisture content, but preferably yielding approximately 60 ml of water) shall be weighed out to the nearest 5 g (m_1). With soils stabilized with a fluid stabilizer, unless the fluid stabilizer content, s , is known, it shall be determined by a suitable method, e.g. the method outlined in Test 16.
- (2) Carrier liquid shall be placed in the flask or still with the sample in the proportion of 1 ml of the liquid to 1 g of the sample. The apparatus shall then be assembled by connecting the flask or still and the condenser to

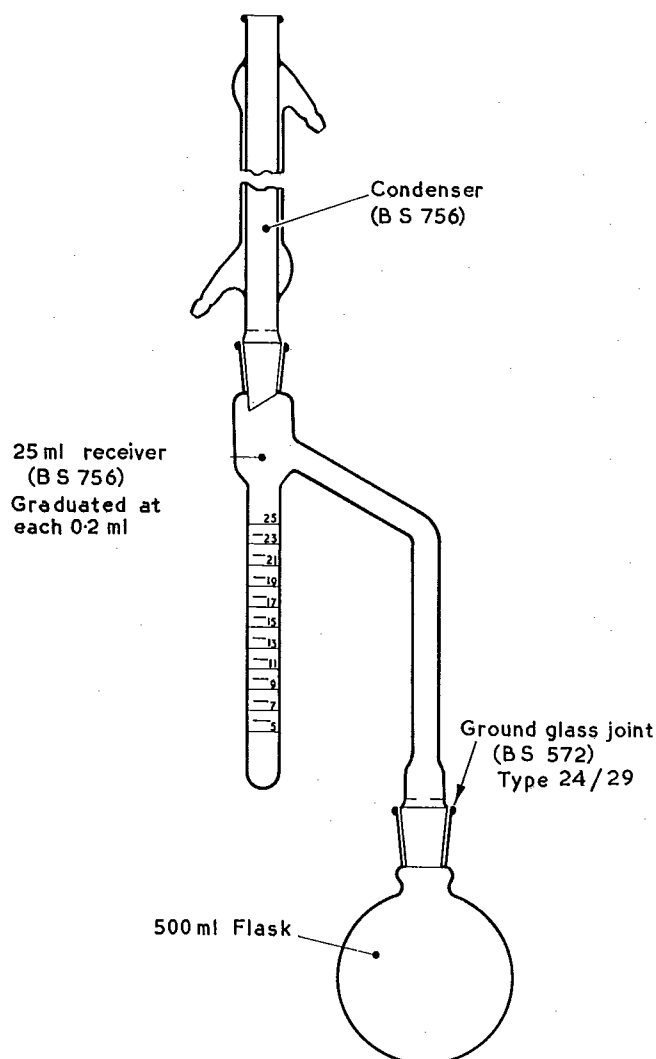
the receiver, care being taken that the lower end of the condenser is remote from the delivery tube of the receiver.

If with the sample of fine-grained soil there is any reason to suppose that the sample will yield less than 5 ml of water after distillation, 5 ml of distilled water shall be measured out with a pipette into the graduated receiver before the commencement of the test.

(3) Cold water shall be circulated through the water jacket of the condenser, and heat shall be applied to the flask or still and adjusted so as to avoid intense local heating, while providing a steady reflux action, so that the condensate falls from the end of the condenser at a rate of 2 to 5 drops per second. With medium- and coarse-grained soils, if more than 25 ml and 100 ml respectively collects in the receiver, it shall be drained off into the measuring cylinder, leaving about 2 ml and 10 ml respectively in the receiver on each occasion.

(4) Distillation shall be maintained until no condensed water accumulates in any part of the apparatus except at the bottom of the receiver. Any ring of condensed water at the top of the receiver shall be removed by agitation with the fine wire. When the volume of water in the receiver is constant, the source of heat shall be removed and the receiver and contents allowed to cool to room temperature. Any droplets of water adhering to the sides of the receiver shall be dislodged by means of the fine wire.

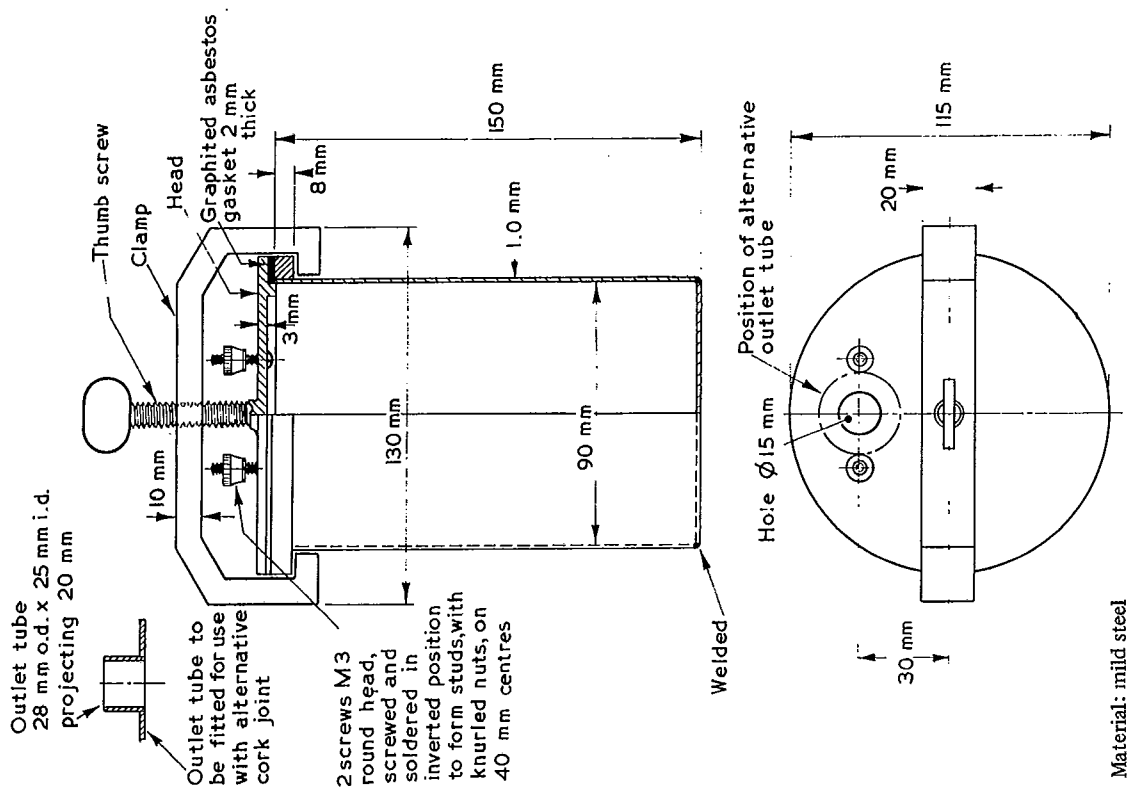
(5) The volume of condensed water, V in ml, measured in the graduated receiver and in any measuring cylinder used, at room temperature after subtracting the volume of water, if any, placed in the receiver before distillation was commenced, shall be noted.



This design has been found to be satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

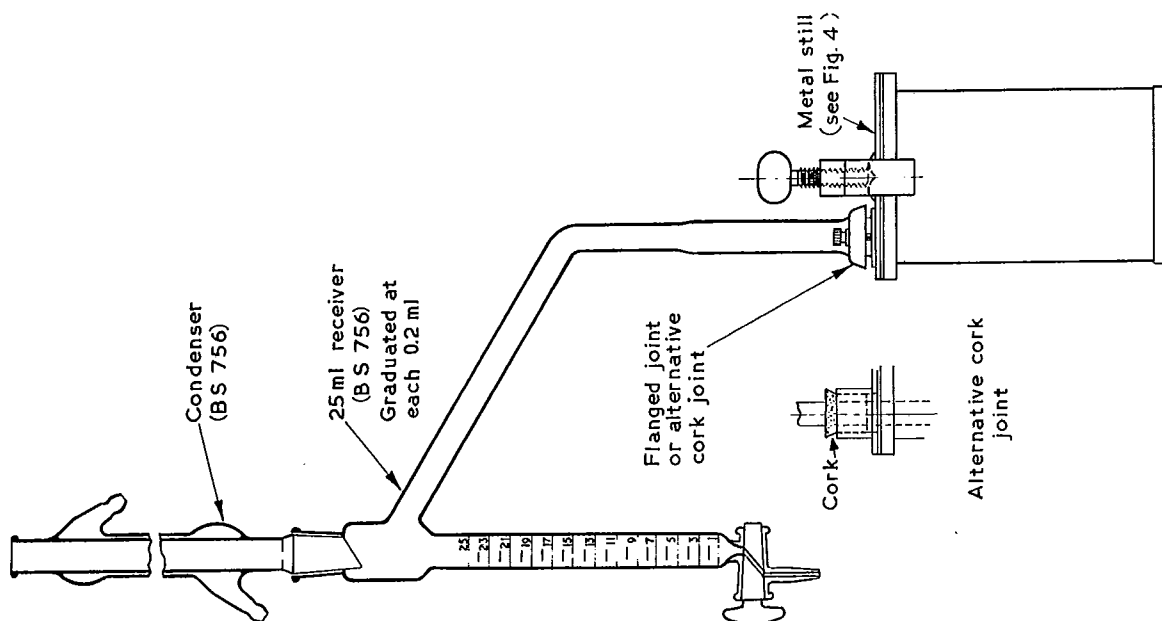
Fig. 2. Apparatus for the determination of moisture content by distillation (fine-grained soils)

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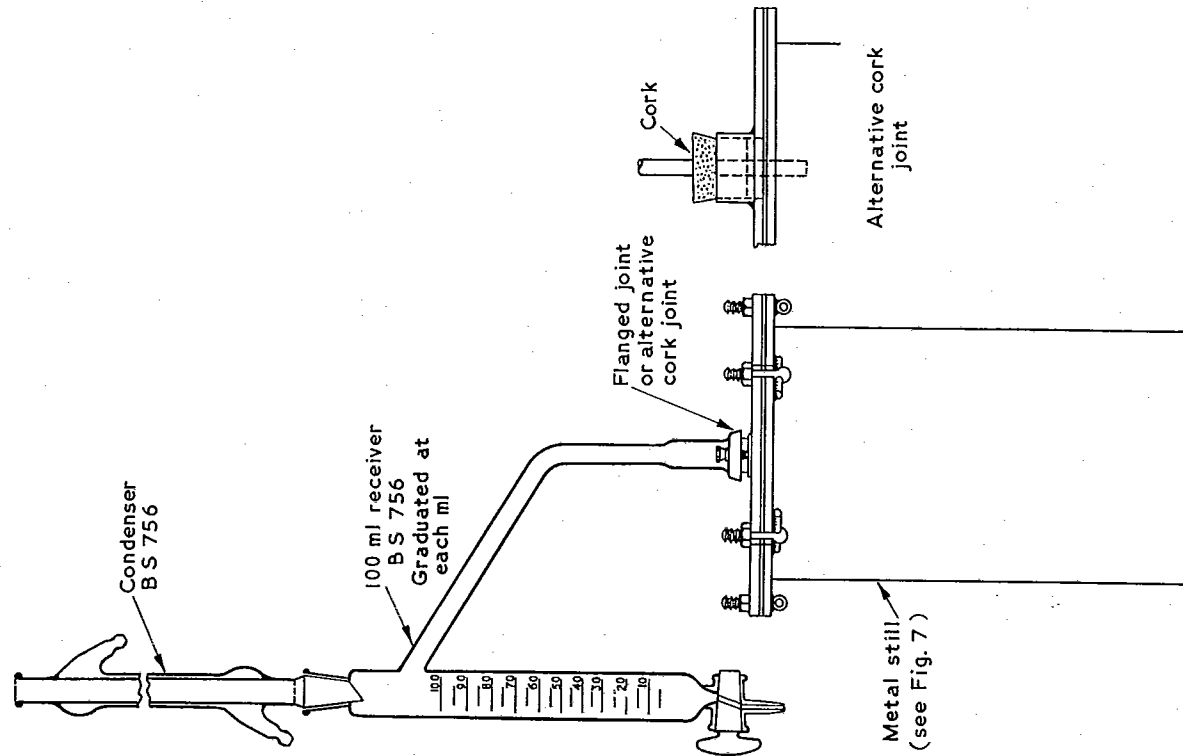
This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

Fig. 4. Metal still for the determination of moisture content by distillation (medium-grained soils)



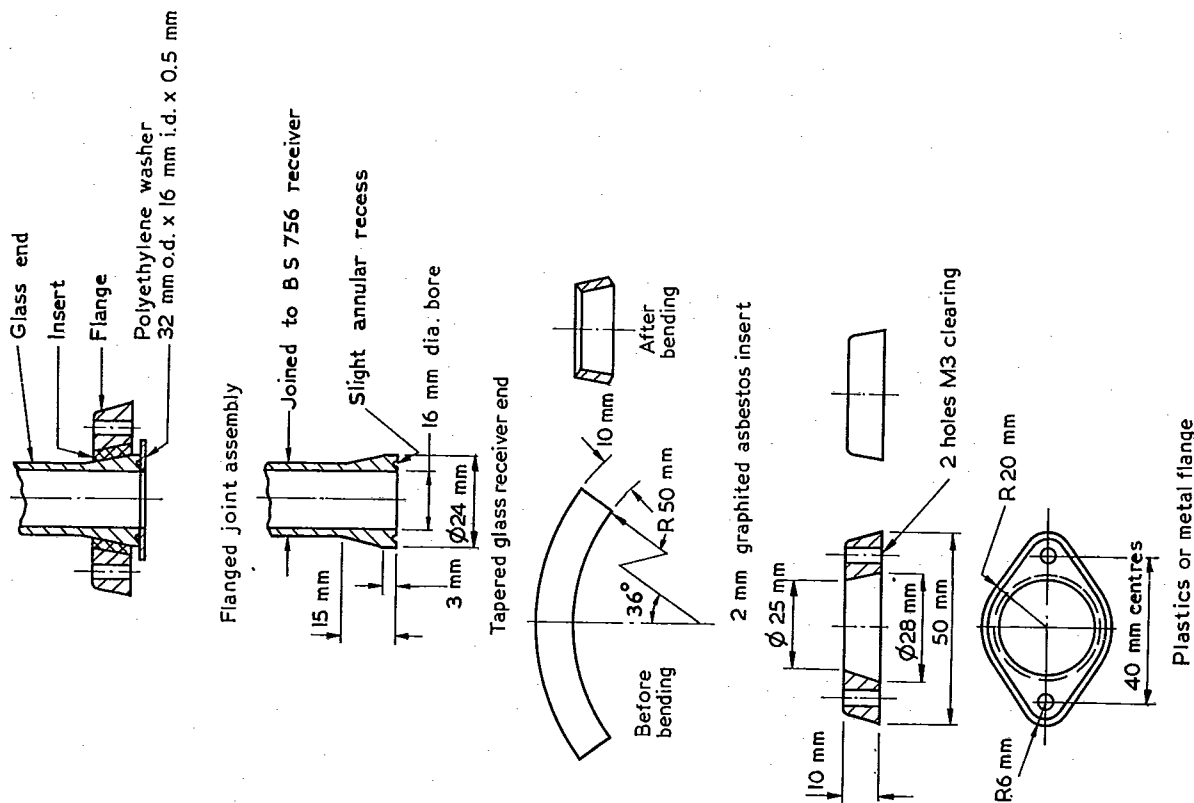
This design has been found to be satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

Fig. 3. Apparatus for the determination of moisture content by distillation (medium-grained soils)



This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

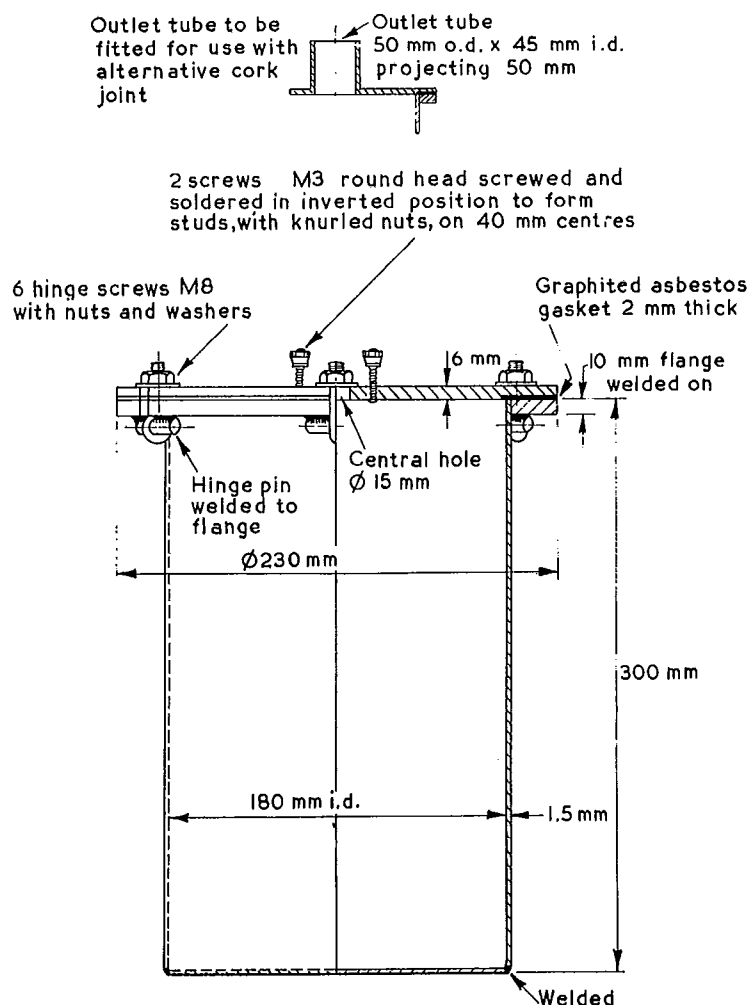
Fig. 6. Apparatus for the determination of moisture content by distillation (coarse-grained soils)



This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

Fig. 5. Assembly and details of flanged joint between receiver and metal still (medium- and coarse-grained soils)

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This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

Fig. 7. Metal still for the determination of moisture content by distillation (coarse-grained soils)

2.4.4 Calculations*. In the case of soil stabilized with a solid stabilizer, the moisture content, w' , shall be calculated as a percentage of the dry soil plus stabilizer mass from the equation:

$$w' = \frac{100 V}{m_1 - V} (\%)$$

where

V is the volume of water distilled (ml);

m_1 is the original mass of sample (g).

In the case of soil stabilized with a fluid stabilizer, the moisture content, w , shall be calculated as a percentage of the dry soil mass from the equation:

$$w = \frac{(100 + s) V}{m_1 - V} (\%)$$

where

s is the non-aqueous fluid stabilizer content of the stabilized soil expressed as a percentage of the dry soil mass.

In the case of unstabilized soil, the moisture content, w , shall be calculated as a percentage of the dry soil mass from the equation:

$$w = \frac{100 V}{m_1 - V} (\%)$$

2.4.5 Reporting of results. The moisture content of the stabilized or unstabilized soil shall be reported to the nearest whole number. The method used to obtain the result shall be stated.

* See Form B, Appendix A.

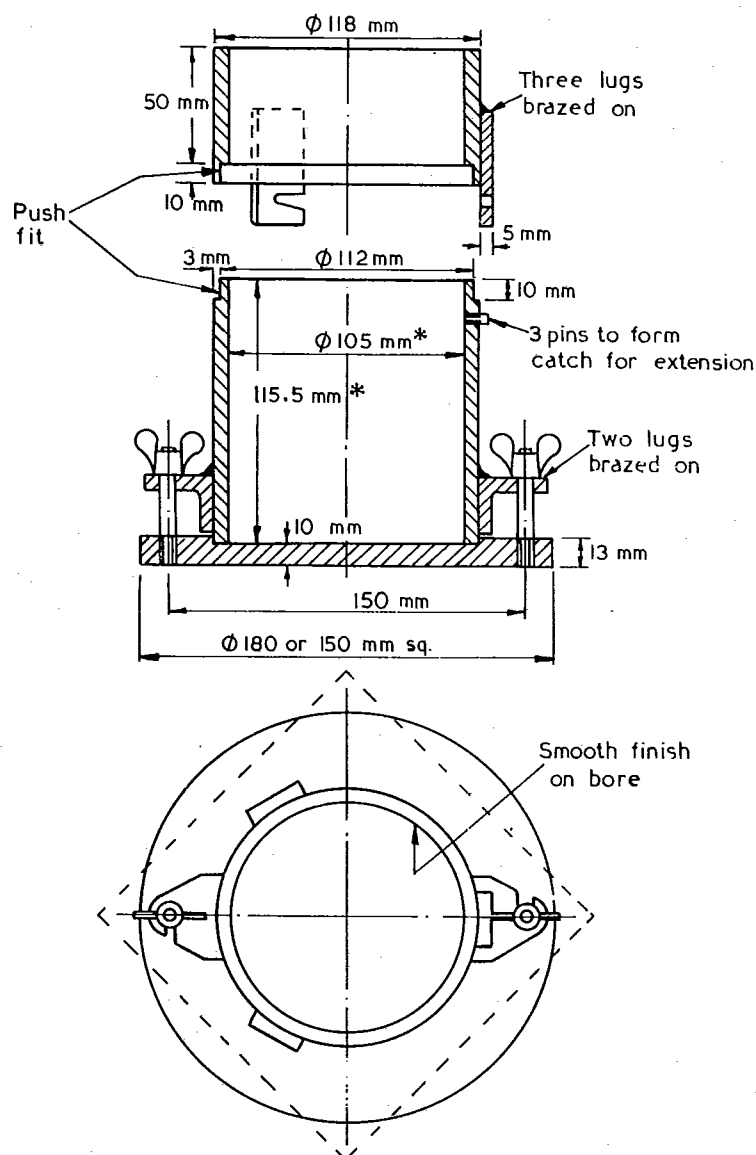
3. Compaction tests

3.1 Test 3. Determination of the dry density/moisture content relationship of stabilized soil (2.5 kg rammer method)

3.1.1 General. This method covers the determination of dry density measured as the mass of dry solids per cubic metre when a stabilized soil mixture is compacted in a specified manner over a range of moisture contents, including that giving the maximum mass of dry solids per cubic metre. In this test a 2.5 kg rammer falling through a height of 300 mm is used.

3.1.2 Apparatus. The following apparatus is required.

(1) A cylindrical metal mould, having an internal diameter of 105 mm, an internal height of 115.5 mm, and a volume of 1000 cm³. The mould shall be fitted with a detachable baseplate, and a removable extension approximately 50 mm high. One suitable design of mould is shown in Fig. 8.



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions are indicated by an asterisk.)

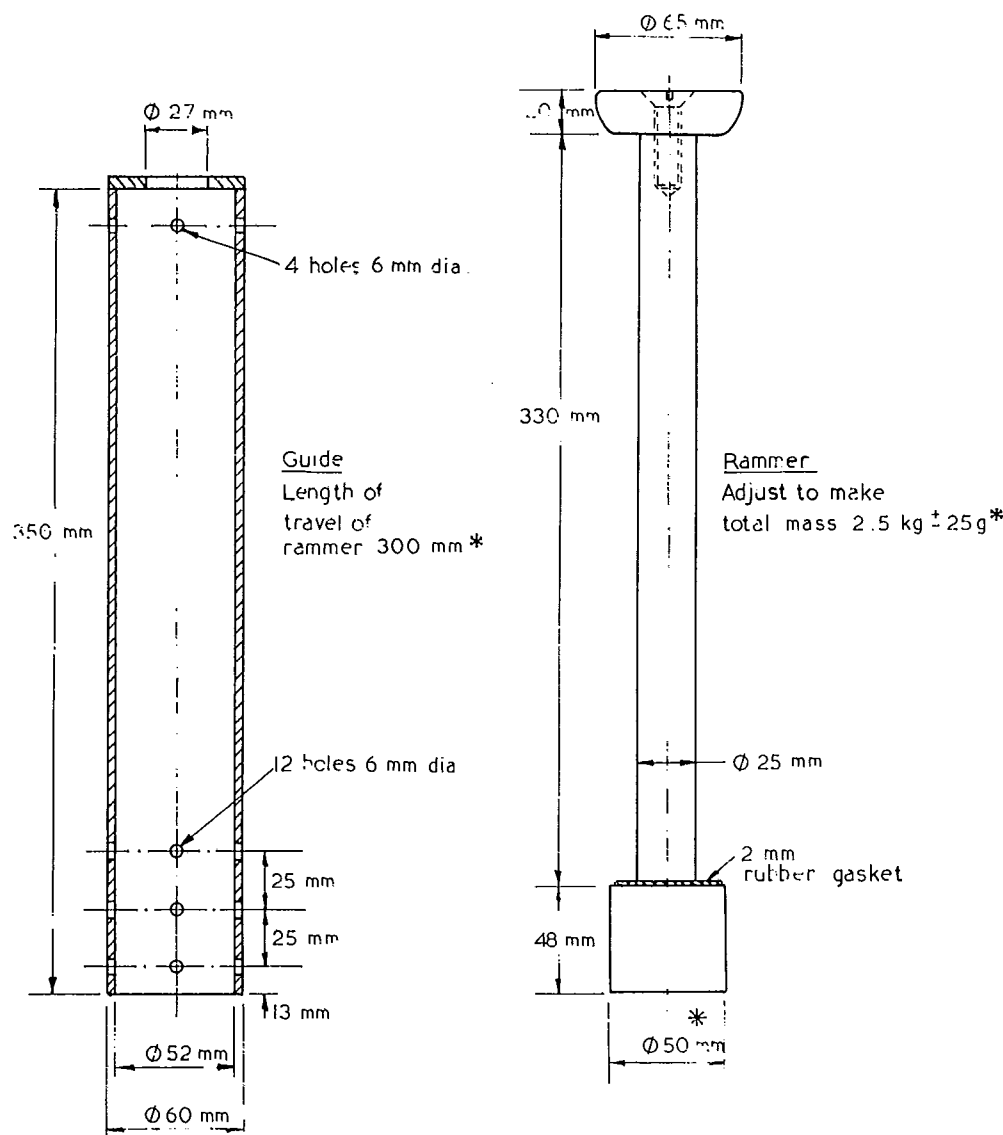
Fig. 8. Mould for compaction test

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- (2) A metal rammer having a 50 mm diameter circular face, and weighing 2.5 kg. The rammer shall be equipped with a suitable arrangement for controlling the height of drop to 300 mm. One suitable form of hand apparatus is shown in Fig. 9. A mechanical form of the apparatus may be used provided the essential dimensions of the rammer and mould are adhered to, and provided that the rammer has a free vertical fall of the correct controlled height. It is also essential that the design of the machine is such that the mould rests on a heavy solid base.
- (3) A balance readable and accurate to 1 g.
- (4) A palette knife (a convenient size is one having a blade approximately 100 mm long and 20 mm wide).
- (5) A straightedge, e.g. a steel strip 300 mm long, 25 mm wide, and 3 mm thick, with one bevelled edge.
- (6) A 20 mm BS test sieve and receiver.
- (7) A large metal tray (a convenient size is one about 600 mm × 500 mm, with sides 80 mm deep).
- (8) Apparatus for the determination of moisture content in accordance with Test 1 or 2.
- (9) Apparatus for extracting specimens from the mould (optional).

3.1.3 Procedure. The procedure is as follows.

- (1) Five or more 2.5 kg samples of stabilized soil shall be prepared in the manner described in 1.5, and all stones retained on the 20 mm BS test sieve removed (see Note 1). The samples shall each be mixed thoroughly with different amounts of water to give a suitable range of moisture contents. The range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range (see Notes 2 and 3).



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions are indicated by an asterisk.)

Fig. 9. 2.5 kg rammer for the compaction test

(2) The mould, with baseplate attached, shall be weighed to the nearest 1 g (m_1). Each sample shall be compacted into the mould and compaction on each sample shall be completed within 20 min of the completion of mixing. The mould shall be placed on a solid base, e.g. a concrete floor or plinth, and the moist stabilized soil mixture shall be compacted into the mould, with the extension attached, in three layers of approximately equal mass, each layer being given 27 blows from the rammer dropped from a height of 300 mm above the stabilized soil mixture. The blows shall be distributed uniformly over the surface of each layer. The operator shall ensure that the tube of the rammer is kept clear of soil so that the rammer always falls freely.

The amount of stabilized soil mixture used shall be sufficient to fill the mould, leaving not more than about 6 mm to be struck off when the extension is removed (see Note 4). The extension shall be removed and the compacted stabilized soil mixture shall be levelled off carefully to the top of the mould by means of the straightedge. The mould and stabilized soil mixture shall then be weighed to the nearest 1 g (m_2).

(3) The compacted specimen shall be removed from the mould and placed on the large metal tray. A representative sample of the specimen shall be taken and its moisture content determined in accordance with Test 1 or 2 of this standard. Alternatively, where Test 1 is used, the whole specimen shall be dried out. The moisture content shall be calculated as in Test 1 or 2 of this standard.

3.1.4 Calculations*. The calculations are as follows.

Soils stabilized with a solid stabilizer

(1) The bulk density, ρ in Mg/m^3 , of each compacted density specimen shall be calculated from the equation:

$$\rho = \frac{m_2 - m_1}{1000} \quad (\text{see Note 5})$$

where

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

m_2 is the mass of the mould, base and compacted specimen (g).

(2) The dry soil plus solid stabilizer density, ρ'_d in Mg/m^3 , shall be calculated from the equation:

$$\rho'_d = \frac{100 \rho}{100 + w'}$$

where

w' is the moisture content of the soil plus solid stabilizer (%).

(3) The dry soil plus solid stabilizer densities, ρ'_d , obtained in a series of determinations, shall be plotted against the corresponding moisture contents, w' . A smooth curve shall be drawn through the resulting points, the position of the maximum on this curve determined, and the zero, 5 % and 10 % air voids lines plotted for comparison. Air voids lines shall be calculated from the equation:

$$\rho'_d = \frac{\rho_w \left(1 - \frac{V_a}{100}\right)}{\frac{1}{G} + \frac{w'}{100}}$$

where

ρ'_d is the dry density of soil plus solid stabilizer (Mg/m^3);

ρ_w is the density of water (Mg/m^3);

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

w' is the moisture content of the soil plus solid stabilizer (%);

G is the combined specific gravity of the soil plus stabilizer, calculated from the equation:

$$G = \frac{1 + \frac{c}{100}}{\frac{1}{G_s} + \frac{c}{100 G_c}}$$

where

c is the stabilizer content, expressed as a percentage of the mass of dry soil;

G_s is the specific gravity of the soil particles, determined in accordance with the method given in Test 6(A) or 6(B) in BS 1377 : 1975;

G_c is the specific gravity of the solid stabilizer. The following values may be assumed:

for ordinary Portland cement, $G_c = 3.12$ at 20°C ;

for hydrated lime, $G_c = 2.23$ at 20°C .

* See Form C, Appendix A.

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Soils stabilized with a fluid stabilizer

(1) The bulk density, ρ in Mg/m^3 , of each compacted specimen shall be calculated from the equation:

$$\rho = \frac{m_2 - m_1}{1000} \quad (\text{see Note 5})$$

where

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

m_2 is the mass of the mould, base and compacted specimen (g).

(2) The dry soil density, ρ_d in Mg/m^3 , shall be calculated from the equation:

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

where

w is the moisture content of the soil (%);

s is the non-aqueous fluid stabilizer content of the soil (%).

(3) The dry soil densities, ρ_d , obtained in a series of determinations, shall be plotted against the corresponding moisture contents, w . A smooth curve shall be drawn through the resulting points, the position of the maximum on this curve determined, and the zero, 5 % and 10 % air voids lines plotted for comparison. Air voids lines shall be calculated from the equation:

$$\rho_d = \frac{\rho_w \left(1 - \frac{V_a}{100} \right)}{\left(\frac{1}{G_s} + \frac{w}{100} + \frac{s}{100} \right)}$$

where

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

ρ_w is the density of water (Mg/m^3);

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

w is the moisture content of the soil (%);

s is the non-aqueous fluid stabilizer content of the soil (%);

G_s is the specific gravity of the soil particles, determined in accordance with the method given in Test 6(A) or 6(B) in BS 1377 : 1975.

3.1.5 Reporting of results. The experimental points and the smooth curve drawn through them showing the relationship between moisture content and dry density shall be reported.

The dry density in Mg/m^3 corresponding to the maximum point on the moisture content/dry density curve shall be reported as the maximum dry density, to the nearest 0.01.

The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the optimum moisture content, and quoted to the nearest 0.2 for values below 5 %, to the nearest 0.5 for values from 5 % to 10 % and to the nearest whole number for values exceeding 10 % (see Note 6).

The amount of stone retained on the 20 mm BS test sieve shall be reported to the nearest 1 %.

The method of obtaining the result shall be stated, i.e. BS 2.5 kg rammer method, and the amount and type of stabilizer used shall also be stated.

Notes on Test 3

NOTE 1. The removal of small amounts of stone (up to 5 %) retained on a 20 mm BS test sieve will affect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density. The exclusion of a large proportion of stone coarser than 20 mm (such as is present, for example, in a gravel of 75 mm maximum size) may have a major effect on the density obtained compared with that obtainable with the soil as a whole, and on the optimum moisture content. There is at present no generally accepted method of testing or of calculation for dealing with this difficulty in comparing laboratory compaction test results with densities obtained in the field. The following comments may be of assistance in providing a basis for action which will avoid major errors; they are, however, not considered comprehensive and are not to be read as part of the standard method of test. (The term gravel should be taken to include rock fragments.)

(1) For soils containing up to about 20 % or 25 % of coarse gravel or cobbles, a correction may be calculated for the maximum dry density based on the displacement of a proportion of soil of given density by stone of known specific gravity. A check of the validity of this calculation may be obtained by replacing the coarse gravel in the soil by an equal quantity of 20 mm to 10 mm gravel of similar characteristics and carrying out a compaction test on this material. For soils containing little fine or medium gravel the proportion of coarse gravel permissible may be extended to 40 % or 50 %.

(2) For soils containing larger proportions of coarse gravel or cobbles, various methods have been advocated but it is not considered that any can be satisfactory which does not involve the use of a mould which is large compared with the maximum size of gravel or cobbles involved. California Bearing Ratio (CBR) moulds are sometimes used for this purpose but because of the difference in area and height, the number of blows per layer should be increased to 62.

NOTE 2. The range of moisture contents obtained should include the optimum moisture content, and the amount of water to be added to the samples will, therefore, vary with the type of stabilized soil under test. In general, with stabilized sandy and gravelly soils a minimum moisture content of 4 % to 6 % would be suitable, with additional increments of 1 % to 2 % for each successive sample tested. With stabilized cohesive soils a minimum moisture content about 8 % to 10 % below the plastic limit of the soil (PL-10 to PL-8) 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.

NOTE 3. 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 4. It is necessary to control the total volume of stabilized soil mixture compacted, since it has been found that if the amount of mixture struck off after removing the extension is too great, the test results will be inaccurate.

NOTE 5. The constant 1000 only applies when the dimensions of the mould are as given in 3.1.2(1).

NOTE 6. For mixtures prepared from some highly permeable soils, such as clean gravels, uniformly graded and coarse clean sands, the results of the laboratory compaction test (2.5 kg rammer method) may provide only a poor guide for specifications on field compaction. The laboratory test often indicates higher values of optimum moisture content than would be desirable for field compaction and the maximum dry density is often much lower than the state of compaction that can readily be obtained in the field.

3.2 Test 4. Determination of the dry density/moisture content relationship of stabilized soil (4.5 kg rammer method)

3.2.1 General. This method covers the determination of dry density measured as the mass of dry solids per cubic metre when a stabilized soil mixture is compacted in a specified manner over a range of moisture contents, including that giving the maximum mass of dry solids per cubic metre. In this test, the compactive effort is greater than that in Test 3, the mass of rammer being increased to 4.5 kg and the height of fall to 450 mm.

3.2.2 Apparatus. The following apparatus is required.

- (1) A cylindrical metal mould, having an internal diameter of 105 mm, an internal effective height of 115.5 mm and a volume of 1000 cm³. The mould shall be fitted with a detachable baseplate and a removable extension approximately 50 mm high. One suitable design of mould is shown in Fig. 8.
- (2) 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 mm (one suitable form of hand apparatus is shown in Fig. 10). A mechanical form of the apparatus may be used provided the essential dimensions of the rammer and mould are adhered to, and provided that the rammer has a free vertical fall of the correct controlled height. It is also essential that the design of the machine is such that the mould rests on a heavy solid base.
- (3) A balance readable and accurate to 1 g.
- (4) A palette knife (a convenient size is one having a blade approximately 100 mm long and 20 mm wide).
- (5) A straightedge, e.g. a steel strip 300 mm long, 25 mm wide and 3 mm thick, with one bevelled edge.
- (6) A 20 mm BS test sieve and receiver.
- (7) A large metal tray (a convenient size is one about 600 mm X 500 mm, with sides 80 mm deep).
- (8) Apparatus for the determination of moisture content in accordance with Test 1 or 2.
- (9) Apparatus for extracting specimens from the mould (optional).

3.2.3 Procedure. The procedure is as follows.

(1) Five or more 2.5 kg samples of stabilized soil shall be prepared in the manner described in 1.5, and all stones retained on the 20 mm BS test sieve removed (see Note 1). The samples shall each be mixed thoroughly with different amounts of water to give a suitable range of moisture contents. The range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range (see Notes 2 and 3).

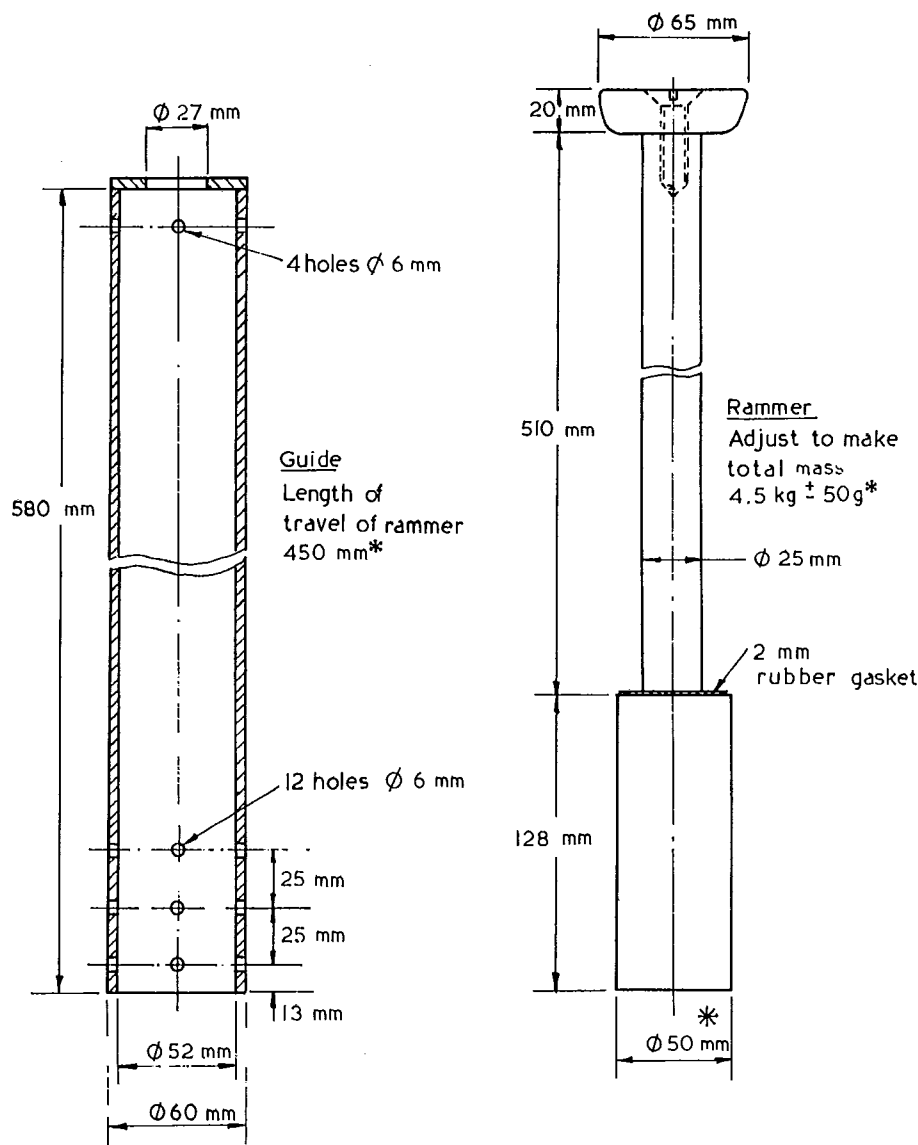
(2) The mould, with baseplate attached, shall be weighed to the nearest 1 g (m_1).

Each sample shall be compacted into the mould and compaction on each sample shall be completed within 20 min of the completion of mixing. The mould shall be placed on a solid base, e.g. a concrete floor or plinth, and the moist stabilized soil mixture shall be compacted into the mould, with the extension attached, in five layers of approximately equal mass, each layer being given 27 blows from the rammer dropped from a height of 450 mm above the stabilized soil mixture. The blows shall be distributed uniformly over the surface of each layer. The operator shall ensure that the tube of the rammer is kept clear of soil so that the rammer always falls freely.

The amount of stabilized soil mixture used shall be sufficient to fill the mould, leaving not more than about 6 mm to be struck off when the extension is removed (see Note 4). The extension shall be removed and the compacted stabilized soil mixture shall be levelled off carefully to the top of the mould by means of the straightedge. The mould and stabilized soil mixture shall then be weighed to the nearest 1 g (m_2).

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(3) The compacted specimen shall be removed from the mould and placed on the large metal tray. A representative sample of the specimen shall be taken and its moisture content determined in accordance with Test 1 or 2 of this standard. Alternatively, where Test 1 is used, the whole specimen shall be dried out. The moisture content shall be calculated as in Test 1 or 2 of this standard.



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions are indicated by an asterisk.)

Fig. 10. 4.5 kg rammer for the compaction test

3.2.4 Calculations*. The calculations are as follows.

Soils stabilized with a solid stabilizer

(1) The bulk density, ρ in Mg/m^3 , of each compacted specimen shall be calculated from the equation:

$$\rho = \frac{m_2 - m_1}{1000} \text{ (see Note 5)}$$

where

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

m_2 is the mass of the mould, base and compacted specimen (g).

* See Form C, Appendix A.

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- (2) The dry soil plus solid stabilizer density, ρ'_d , in Mg/m^3 , shall be calculated from the equation:

$$\rho'_d = \frac{100 \rho}{100 + w'}$$

where

w' is the moisture content of the soil plus solid stabilizer (%).

- (3) The dry soil plus solid stabilizer densities, ρ'_d , obtained in a series of determinations shall be plotted against the corresponding moisture contents, w' . A smooth curve shall be drawn through the resulting points, the position of the maximum on this curve determined, and the zero, 5 % and 10 % air voids lines plotted for comparison. Air voids lines shall be calculated from the equation:

$$\rho'_d = \frac{\rho_w \left(1 - \frac{V_a}{100}\right)}{\frac{1}{G} + \frac{w'}{100}}$$

where

ρ'_d is the dry density of soil plus solid stabilizer (Mg/m^3);

ρ_w is the density of water (Mg/m^3);

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

w' is the moisture content of the soil plus solid stabilizer (%);

G is the combined specific gravity of the soil plus stabilizer, calculated from the equation:

$$G = \frac{1 + \frac{c}{100}}{\frac{1}{G_s} + \frac{c}{100 G_c}}$$

where

c is the stabilizer content, expressed as a percentage of the mass of dry soil;

G_s is the specific gravity of the soil particles, determined in accordance with the method given in Test 6(A) or 6(B) in BS 1377 : 1975.

G_c is the specific gravity of the solid stabilizer. The following values may be assumed:

for ordinary Portland cement, $G_c = 3.12$ at 20°C ;

for hydrated lime, $G_c = 2.23$ at 20°C .

Soils stabilized with a fluid stabilizer

- (1) The bulk density, ρ in Mg/m^3 , of each compacted specimen shall be calculated from the equation:

$$\rho = \frac{m_2 - m_1}{1000} \text{ (see Note 5)}$$

where

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

m_2 is the mass of the mould, base and compacted specimen (g).

- (2) The dry soil density, ρ_d in Mg/m^3 , shall be calculated from the equation:

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

where

w is the moisture content of the soil (%);

s is the non-aqueous fluid stabilizer content of the soil (%).

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(3) The dry soil densities, ρ_d , obtained in a series of determinations shall be plotted against the corresponding moisture contents, w . A smooth curve shall be drawn through the resulting points, the position of the maximum on this curve determined, and the zero, 5 % and 10 % air voids lines plotted for comparison. Air voids lines shall be calculated from the equation:

$$\rho_d = \frac{\rho_w \left(1 - \frac{V_a}{100}\right)}{\left(\frac{1}{G_s} + \frac{w}{100} + \frac{s}{100}\right)}$$

where

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

ρ_w is the density of water (Mg/m^3);

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

w is the moisture content of the soil (%);

s is the non-aqueous fluid stabilizer content of the soil (%);

G_s is the specific gravity of the soil particles, determined in accordance with the method given in Test 6(A) or 6(B) in BS 1377 : 1975.

3.2.5 Reporting of results. The experimental points and the smooth curve drawn through them showing the relationship between moisture content and dry density shall be reported.

The dry density in Mg/m^3 corresponding to the maximum point on the moisture content/dry density curve shall be reported as the maximum dry density, to the nearest 0.01.

The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the optimum moisture content, and quoted to the nearest 0.2 for values below 5 %, to the nearest 0.5 for values from 5 % to 10 %, and to the nearest whole number for values exceeding 10 % (see Note 6).

The amount of stone retained on the 20 mm BS test sieve shall be reported to the nearest 1 %.

The method of obtaining the result shall be stated, i.e. BS 4.5 kg rammer method, and the amount and type of stabilizer used shall also be stated.

Notes on Test 4

NOTE 1. The removal of small amounts of stone (up to 5%) retained on a 20 mm BS test sieve will affect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density. The exclusion of a large proportion of stone coarser than 20 mm (such as is present, for example, in a gravel of 75 mm maximum size) may have a major effect on the density obtained compared with that obtainable with the soil as a whole, and on the optimum moisture content. There is at present no generally accepted method of testing or of calculation for dealing with this difficulty in comparing laboratory compaction test results with densities obtained in the field. The following comments may be of assistance in providing a basis for action which will avoid major errors; they are not considered comprehensive, however, and are not to be read as part of the standard method of test. (The term gravel should be taken to include rock fragments).

(1) For soils containing up to about 20 % or 25 % of coarse gravel or cobbles, a correction may be calculated for the maximum dry density based on the displacement of a proportion of soil of given density by stone of known specific gravity. A check of the validity of this calculation may be obtained by replacing the coarse gravel in the soil by an equal quantity of 20 mm to 10 mm gravel of similar characteristics and carrying out a compaction test on this material. For soils containing little fine or medium gravel the proportion of coarse gravel permissible may be extended to 40 % or 50 %.

(2) For soils containing larger proportions of coarse gravel or cobbles, various methods have been advocated, but it is not considered that any can be satisfactory which does not involve the use of a mould which is large compared with the maximum size of gravel or cobbles involved. California Bearing Ratio (CBR) moulds are sometimes used for this purpose but because of the difference in area and height, the number of blows per layer should be increased to 62.

NOTE 2. The range of moisture contents obtained should include the optimum moisture content, and the amount of water to be added to the samples will, therefore, vary with the type of stabilized soil under test. In general, with stabilized sandy and gravelly soils a minimum moisture content of 3 % to 5 % would be suitable, with additional increments of 1 % to 2 % for each successive sample tested. With stabilized cohesive soils a minimum moisture content about 12 % to 16 % below the plastic limit of the soil (PL-16 to PL-12) 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.

NOTE 3. 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 4. It is necessary to control the total volume of stabilized soil mixture compacted, since it has been found that if the amount of mixture struck off after removing the extension is too great, the test results will be inaccurate.

NOTE 5. The constant 1000 only applies when the dimensions of the mould are as given in 3.2.2(1).

NOTE 6. For mixtures prepared from some highly permeable soils, such as clean gravels, uniformly graded and coarse clean sands, the results of the laboratory compaction test (4.5 kg rammer method) may provide only a poor guide for specifications on field compaction. The laboratory test often indicates higher values of optimum moisture content than would be desirable for field compaction and the maximum dry density is often much lower than the state of compaction that can readily be obtained in the field.