British Standard

BRITISH STANDARD

BS 5835-1: 1980

Incorporating Amendment Nos. 1, 2 and 3

Recommendations for

Testing of aggregates —

Part 1: Compactibility test for graded aggregates

UDC 691.322:620.1:539.58

Cooperating organizations

The Cement, Gypsum, Aggregates Quarry Products Standards Committee, under whose direction this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

Association of Consulting Engineers*
Association of County Councils
Association of Metropolitan Authorities
Autoclaved Aerated Concrete Products Association
British Precast Concrete Federation Ltd.*
British Quarrying and Slag Federation*
British Railways Board
British Ready Mixed Concrete Association
British Steel Industry
Cement Admixtures Association
Cement and Concrete Association*
Cement Makers' Federation*
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Sand and Ballast Hauliers and Allied Trades Alliance
Sand and Gravel Association Limited*
Society of Chemical Industry

The organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

Asphalt and Coated Macadam Association
Association of Lightweight Aggregate Manufacturers
Brick Development Association
British Ceramic Research Association
British Civil Engineering Test Equipment Manufacturers' Association
Calcium Silicate Brick Association Limited
Concrete Block Association
County Surveyors' Society
Electricity Supply Industry in England and Wales
Greater London Council
Institute of Building
Institute of Concrete Technology
Mortar Producers' Association Ltd.

This British Standard, having been prepared under the direction of the Cement, Gypsum, Aggregates and Quarry Products Standards Committee, was published under the authority of the Executive Board and comes into effect on 30 June 1980.

The following BSI references relate to the work on this standard:
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Foreword

These recommendations supplement BS 812 "*Methods for sampling and testing of mineral aggregates, sands and fillers*", which at present includes neither a test that determines the bulk density of graded aggregates at high levels of compaction, nor a test for "optimum moisture content". Tests for these properties are included in BS 1377 "*Methods of test for soil for civil engineering purposes*", but these have been found to be unreliable when applied to the aggregates that are commonly used for road sub-bases and base materials.

The recommendations are based on work carried out at the Transport and Road Research Laboratory of the Department of the Environment and the Department of Transport, and the committee responsible felt that the publication of this document would encourage the wider use of a standardized approach to compactibility testing. Subject to minor changes that will be made if such wider use reveals a need to amend apparatus or procedure, it is intended that this standard will be superseded by an addition to BS 812 in due course.

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

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 14, an inside back cover and back cover.

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

1 Scope

This Part of BS 5835 makes recommendations for testing the compactibility of graded aggregates, particularly those used in roadbases and sub-bases.

2 References

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

3 Definitions

For the purposes of this Part of this British Standard, the definitions given in BS 892 and BS 2787 apply, with the following additions.

3.1
moisture content

the mass of water that can be removed from the aggregate by heating at 105 °C, expressed as a percentage of the mass of the dry aggregate

3.2
initial moisture content

the moisture content of the aggregate before compaction

3.3
residual moisture content, W_R

the moisture content of the aggregate after compaction

3.4
optimum moisture content

the moisture content at which the specified amount of compaction produces the peak value of (dry) bulk density (see Figure 4.)

NOTE The term "optimum moisture content" can be abbreviated to "OMC".

3.5
pessimum moisture content

the moisture content at which the specified amount of compaction produces the lowest value of (dry) bulk density (see Figure 4)

3.6
saturation

the condition when all air in the voids within and between the particles in an aggregate at a given level of bulk density is displaced by water

3.7
(dry) bulk density, B

the ratio of the mass of a sample of (dry) aggregate to the volume of a standard container required to contain that sample

NOTE Peak (dry) bulk density is the highest mean value found in any *complete* set of compactibility tests.

3.8
proportion of volume occupied by solids, V_s

the volumetric equivalent of (dry) bulk density

NOTE Peak proportion of volume occupied by solids is the highest mean value found in any *complete* set of compactibility tests.

3.9
particle density, P

the average mass per unit volume of a sample of individual particles of oven-dried aggregate as determined using the test methods described in clause **5** of BS 812-2:1975

NOTE This term is roughly synonymous with the term "specific gravity" used in BS 1377. The term "relative density" is now preferred.

3.10
water absorption value, W_A

the mass of water held in the voids within particles of aggregate. This, together with the free water around the particles, gives the total moisture content expressed as a percentage of the dry mass of the aggregate, as determined using the test methods described in clause **5** of BS 812-2:1975

4 General

Vibrating hammer compaction tests on graded aggregates give an indication of their packing properties. When such tests are carried out at moisture contents covering a sufficient range, they can give estimates of those levels of bulk density that are likely to be achieved in field conditions, and also of the effects of moisture content upon bulk density levels. It is usually, but not always, possible to identify optimum moisture contents.

The test described is suitable for aggregates having a nominal maximum size not exceeding 37.5 mm. Materials used as sub-bases may include particles as large as 50 mm. These should be removed during the sampling stage (see clause **5**).

5 Sampling

The bulk sample for this test should be taken in accordance with clause **5** of BS 812-1:1975, and the method used should be reported. Particles larger than 37.5 mm should be removed and discarded.

The proportion by mass of discarded material should be recorded, and given in the report.

6 Preparation of test material

Representative portions of aggregate for testing should be prepared from the bulk sample so that the mass of oven-dry aggregate in each portion lies in the range of 2.4 kg to 2.6 kg. Care should be taken to minimize variations in grading between these replicate portions.

If a decision has been made to test only the dry material, then only five oven-dry portions will usually be required. These should be stored in sealed containers until required for testing.

For each level of initial moisture content above zero, a set of five portions should be taken. Water should be added to, and mixed with, each of the five portions in each set, to raise their individual moisture contents to within 0.1 % of the required initial moisture content. Each of the wetted portions should be stored in a sealed, water-tight container for at least 12 h before testing, to ensure thorough wetting.

If compaction tests are to be carried out to define the relation between moisture content and (dry) bulk density over the whole range of moisture contents from zero to beyond optimum moisture content (see Figure 4), at least 25 portions should be prepared.

NOTE If the primary purpose is to measure optimum moisture content, it is usually best to select three levels of initial moisture content (e.g. 4 %,6 % and 8 %) to span the likely value of optimum moisture content. Tests on the 15 portions required by this procedure may be sufficient, but it may be necessary to carry out further tests at other moisture contents.

A guide to the usefulness of tests at any particular moisture content may be gained by plotting the results as they are obtained (see clause **9** and Figure 3, Figure 4 and Figure 5). Moreover, if residual moisture contents are significantly lower than initial moisture contents, there is an implication that saturation moisture content has been reached, and thus it would be pointless to make up portions at even higher initial moisture contents.

7 Apparatus

NOTE The design of the apparatus required in **7.1**, **7.2**, **7.3**, and **7.4** is subject to crown copyright. The Secretary of State for Transport has agreed with BSI to make available, through his Transport and Road Research Laboratory, licences to market and manufacture this apparatus on non-discriminatory terms in the form of royalty payments of 5 % of the net selling price of the apparatus. Applicants for licences should apply to the Director, Transport and Road Reasearch Laboratory, Department of Transport, Old Wokingham Road, Crowthorne, RG11 6AU.

The following apparatus is required.

7.1 *A standard compaction mould*, comprising a body, a base, filter assembly and an anvil. Details of the standard mould are shown in Figure 1. The cross-sectional area of the mould, given to the nearest 10 square millimetres, should 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 when necessary.

7.2 *An electric vibrating hammer*, having a power consumption of 900 W and operating at a frequency of about 33 Hz, and equipped with a special shank (see Figure 1 and Figure 2).

NOTE It is important that the vibrating hammer should be properly maintained in accordance with the manufacturer's instructions and that its working parts are not worn. To ensure good working order, overhauls should be carried out not less frequently than every 50 h of operation, or every six months, whichever is the shorter.

7.3 *A loading frame* to support the hammer and mould and to provide a steady downward force of 450 ± 10 N. The design for the frame is shown in Figure 2.

NOTE Because vibrating hammers of the type used in this test can emit noise levels of up to 100 dB(A), the compaction rig may be housed in a noise-reducing cabinet. A suitable design for a cabinet is also shown in Figure 2. Other, cheaper noise-reduction devices may be satisfactory, but at least some precautions should be taken.

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

NOTE It may be necessary to modify a standard depth gauge to fit into the hole in the anvil.

7.5 *A balance*, with a capacity of at least 4 kg, readable and accurate to 1 g.

7.6 *A stop-watch or stop-clock or an automatic timer* to control the vibrating hammer.

7.7 *A supply of filter papers, 150 mm in diameter*. "Whatman grade 113" has been found to be suitable.

7.8 *A supply of non-corrodible, watertight storage containers*, having a capacity of about two litres and with lids that can be sealed.

7.9 *Apparatus for the determination of particle density and water absorption*, in accordance with clause **5** of BS 812-2:1975.

7.10 *Apparatus for the determination of moisture content*, in accordance with clause **7** of BS 812-2:1975.

7.11 *Apparatus for the determination of particle size distribution*, in accordance with clause **7** of BS 812-1:1975. Washing and decantation will usually be appropriate (see **7.1.6** of BS 812-1:1975). (Alternatively apparatus for test 7a of BS 1377:1975 may be employed.)

8 Test procedure

NOTE A flow diagram showing the essential steps in the test is given in Figure 6.

8.1 Compaction test. 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 hand screws to full tightness.

Lay two 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 the depth between the bottom of the small hole within the half-ball in the anvil and the top of the mould. This should be recorded to an accuracy of 0.1 mm. The apparatus should then be dismantled. Repeat this process to obtain five consecutive values of the depth constant and calculate a mean value (ⓔ in Figure 3). This value should be used for not more than 25 single compactibility tests.

Reassemble the mould body, base, filter plates and fibre filter ensuring that the parts fit together properly. Lay one filter paper flat on the bottom of the mould.

Remix thoroughly one portion for test and introduce into the mould in such a way as to form a single layer with minimum segregation. The top of the loose portion should be levelled off roughly and should be covered with a filter paper. Insert the anvil into the mould so that it touches the upper filter paper.

Locate the whole compaction mould assembly in the loading frame and place the vibrating hammer in position. Apply the surcharge load. Operate the vibrating hammer for 180 ± 5 s to compact the portion. After compaction has ceased, remove the vibrating hammer from the frame and from the mould.

Care should be taken not to disturb the anvil after compaction has ceased, and before the depth measurement is made. The distance between the bottom of the small hole in the anvil and the top of the mould should be measured carefully with the depth gauge and recorded to an accuracy of 0.1 mm (ⓕ in Figure 3).

Extract the compacted portion carefully from the mould and discard the two filter papers. Measure the mass of the portion and record to an accuracy of 1 g (for a moist portion ⓑ, and for an oven-dry portion ⓒ: see Figure 3). Unless the portion is already dry, it should be dried at a temperature of 105 ± 5 °C to constant mass (ⓒ in Figure 3) which should be measured and recorded to an accuracy of 1 g.

Repeat this process until all the remaining portions have been compacted.

NOTE If the filter papers stick to wet portions, they should be weighed with the portions and the mass of the wet portions should be calculated by subtracting the mass of two similar filter papers previously saturated with water. When the portions are dried it is usually a simple matter to remove those filter papers that were stuck to them.

8.2 Determination of particle density and water absorption values. So that the results of the compaction tests may be expressed volumetrically, values of particle density and of water absorption should be obtained for the aggregate. This should be done in accordance with clause **5** of BS 812-2:1975. Allowance should be made for the various size fractions by weighting the results for the individual sizes according to their concentrations in the bulk sample, as illustrated below:

$$\text{weighted particle density} = \frac{100}{\frac{a_1}{P_1}+\frac{a_2}{P_2}+\frac{a_3}{P_3}+\frac{a_4}{P_4}}$$

where

a_1, a_2, etc. is the concentration of size fraction in the bulk sample (% by mass)

P_1, P_2, etc. is the particle density of size fraction

For example:

Size fraction	37.5 mm to 20 mm	20 mm to 10 mm	10 mm to 5 mm	Passing 5 mm
Concentration in bulk sample (%)	23	26	17	34
Particle density of size fraction	2.54	2.52	2.38	2.57

weighted particle density =

$$\frac{100}{\frac{23}{2.54}+\frac{26}{2.52}+\frac{17}{2.38}+\frac{34}{2.57}} = \frac{100}{39.74} = 2.52$$

A similar table may be used for calculating a weighted water absorption value. The weighting requirement implies a knowledge of the grading of the bulk sample. Sieving tests should be carried out according to the method given in clause **7** of BS 812-1:1975. Washing and decantation will usually be appropriate (see **7.1.6** of BS 812-1:1975). (Alternatively, the method stated in Test 7a of BS 1377:1975 may be employed.)

9 Calculations and reports of results

9.1 General. Depending upon the use to which they are to be put, the results of compactibility tests may be expressed either in gravimetric terms, or in volumetric terms, or in both. For example, it is useful to report values of (dry) bulk density and moisture contents in terms that include mass. Equally, it is useful to assess compactibility in volumetric units, so that the unwanted influence of particle density can be excluded.

A model test form is illustrated in Figure 3. This sets out the stages of calculation that are necessary for both gravimetric and volumetric values. (Each form deals with five replicate portions at a single moisture content, thus five or more forms may be needed for a complete set of tests).

The permitted ranges between the highest and lowest results obtained on the five individual portions within each set should be:

(dry) bulk density: 80 kg/m^3

proportion of volume occupied by solids: 3.0 %

total residual moisture content: 1.0 %

If one or more of the permitted ranges is exceeded, and one of the five seems to be markedly different from the other four, that result should be excluded and the averages derived from the other four should be used for plotting results, etc .

In all other cases in which the prescribed ranges are exceeded, the probable causes should be investigated. For example, more attention may have to be given to the preparation and mixing of portions. Then the tests should be repeated. If variability cannot be reduced satisfactorily, this should be reported.

9.2 Plotting of results on graphs. When it is seen from the calculated mean values of (dry) bulk density and residual moisture content that there is a relationship between these two variables, the mean values should be plotted graphically as a means of estimating optimum moisture content (see note at end of **9.3**). This can be done in two ways, as given in **9.2.1** and **9.2.2**.

9.2.1 *By plotting gravimetric results*. The mean values (from each set of five replicate portions) of (dry) bulk density and of residual moisture content (e.g. see Figure 3) should be plotted on a graph with appropriate scales (e.g. see Figure 4). The three lines representing zero, 5 % and 10 % air voids, should also be plotted. Appropriate values of (dry) bulk density for given contents of moisture and air voids may be obtained from the relation:

$$B = \frac{(100 - V_A)}{\left(\frac{1}{10P} + \frac{W_R - W_A}{1000}\right)}$$

where

B is the (dry) bulk density (in kg/m^3)

V_A is the air void content (% by volume)

P is the particle density (in t/m^3)

W_R is the residual moisture content total (%)

W_A is the water absorption value (%)

NOTE B is given in units of kg/m^3 so that typical values will have four digits (e.g. 2180 kg/m^3 and *not* 2.18 mg/m^3. Test 14 of BS 1377:1975 uses units of Mg/m^3 for "dry density" and thus care will be needed to ensure that users of the results are made aware of this difference, if reference is made to test 14 in BS 1377:1975.)

If points fall on the right hand side of the zero air voids line of the plot illustrated in Figure 4, this implies that the particle density chosen for the aggregate may be too low, and it may be worthwhile to recheck the value of P.

Levels of *initial* moisture content that plot to the right of the zero air voids line (e.g. see Figure 5) indicate that saturation of the relevant portions will occur during compaction. Thus significant losses of moisture from these portions can be expected to occur. This will be manifested by a significant difference between *initial* and *residual* moisture contents. However, significant losses of water may be caused by other factors as well.

The calculation of the values for plotting of voids lines for gravimetric results is a tiresome task and can be eliminated by the use of volumetric plots (see **9.2.2**).

9.2.2 *By plotting volumetric results*. The mean values (from each set of five replicate portions) of proportion of volume occupied by free, residual moisture, should be plotted on a graph with appropriate scales (e.g. see Figure 6).

NOTE The term "free" in relation to moisture content means "that fraction of total moisture not accounted for by the water absorption value". On this definition it is clear that, when an aggregate is saturated and surface-dry, its free residual moisture content (in both gravimetric and volumetric terms) is zero. It follows that, at total moisture contents between absolute dryness and water absorption value, negative values of free residual moisture content (and its volumetric equivalent) are calculated. This explains the position of the origin in Figure 5. The advantage of this apparently complicated system of presentation is that the voids lines are in exactly the same, easily calculated positions, regardless of particle density and water absorption value. Hence the tester can use a single standard chart for plotting.

9.3 Determination of peak (dry) bulk density and optimum moisture content; and of their volumetric equivalents. Where possible, a smoothly curved line should be drawn through the points plotted by the methods described in **9.2**. The position at which peak (dry) bulk density, or its volumetric equivalent, peak proportion of volume occupied by solids, occurs, should be noted.

These values are related as follows:

$$\hat{V}_s = \frac{\hat{B}}{10P}$$

where

$\hat{V}_s$ is the peak proportion of volume occupied by solids (%)

$\hat{B}$ is the peak (dry) bulk density (kg/m^3)

P is the particle density (weighted value: see **8.2**)

The moisture content at which peak (dry) bulk density occurs should be selected as that indicating optimum moisture content. This can be extracted directly from gravimetric plots. It can be obtained from volumetric plots by the use of the relations:

$$W_f = \frac{1000\, V_{\mathrm{wf}}}{B}$$

where

W_f is the free moisture content (%)

V_{wf} is the proportion of volume occupied by free, residual moisture (%)

B is the appropriate value of (dry) bulk density,e.g. peak value when estimating optimum moisture content.

and $W_\mathrm{R} = W_\mathrm{f} + W_\mathrm{A}$

where

W_R is the residual moisture content (total) (%)

W_A is the water absorption value (%)

NOTE Many well graded aggregates exhibit peak values of (dry) bulk density when they are dry, and similar values when they are nearly saturated, but it may be possible to achieve a curve that turns over near the zero air voids line. Other aggregates, especially if they contain less than about 35 % of material finer than 5 mm (if the nominal maximum size is 37.5 mm), exhibit peak values of density at air void contents higher than 5 %. In extreme cases it is impossible to identify a peak at all. In some other cases the tester may have reservations about selecting a value of optimum moisture content because it may seem to be inappropriate to use *residual* values of moisture content. If the difference between initial and residual moisture contents is less than about 0.5 % by mass (or about 1.0 % by volume), it is usually satisfactory to ignore the initial moisture content. However, if the difference is greater than 0.5 %, it may be desirable to retest at a different (usually lower) value of initial moisture content. Values of density obtained on portions with initial moisture contents more than 2.0 % higher than residual moisture content should be ignored for the purpose of curve plotting.

9.4 Reporting results. When optimum moisture contents can be measured, they should be reported to the nearest 0.1 %. Values of (dry) bulk density, including peak values, should be reported to the nearest 10 kg/m^3. Volumetric values should be reported to the nearest 0.1 %.

If tests are carried out at several moisture contents, the graphical plot, or plots, of the results (see **9.2**) should be reported. If tests are carried out on oven-dry aggregates only, the values of B and V_s should be reported as "estimated from oven-dried portions only".

The method of sample reduction and proportion of material larger than 37.5 mm excluded from the test should also be reported.

The values for particle density, water absorption value and results of sieving tests should be reported in accordance with the relevant clauses of BS 812 (or BS 1377).

9.5 Repeatability and reproducibility. A limited reproducibility trial, coupled with a much larger number of replicate tests within a single laboratory, has given the following estimates:

	Repeatability	**Reproducibility**
Optimum moisture content %	0.5	1.0
$\hat{V}_s$ %	1.0	3.0
$\hat{B}$ kg/m3	30	80

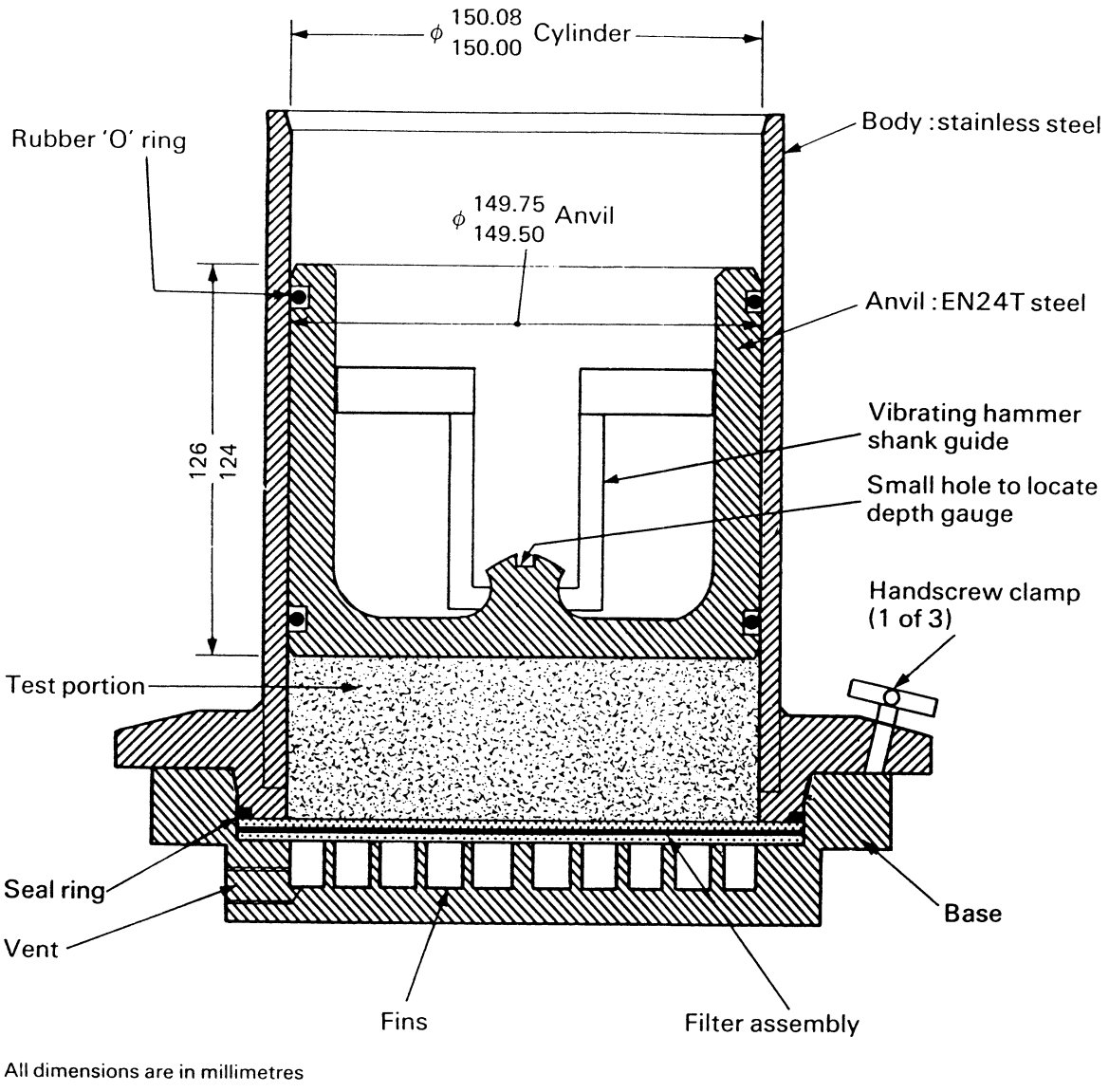


Figure 1 — Compaction mould apparatus

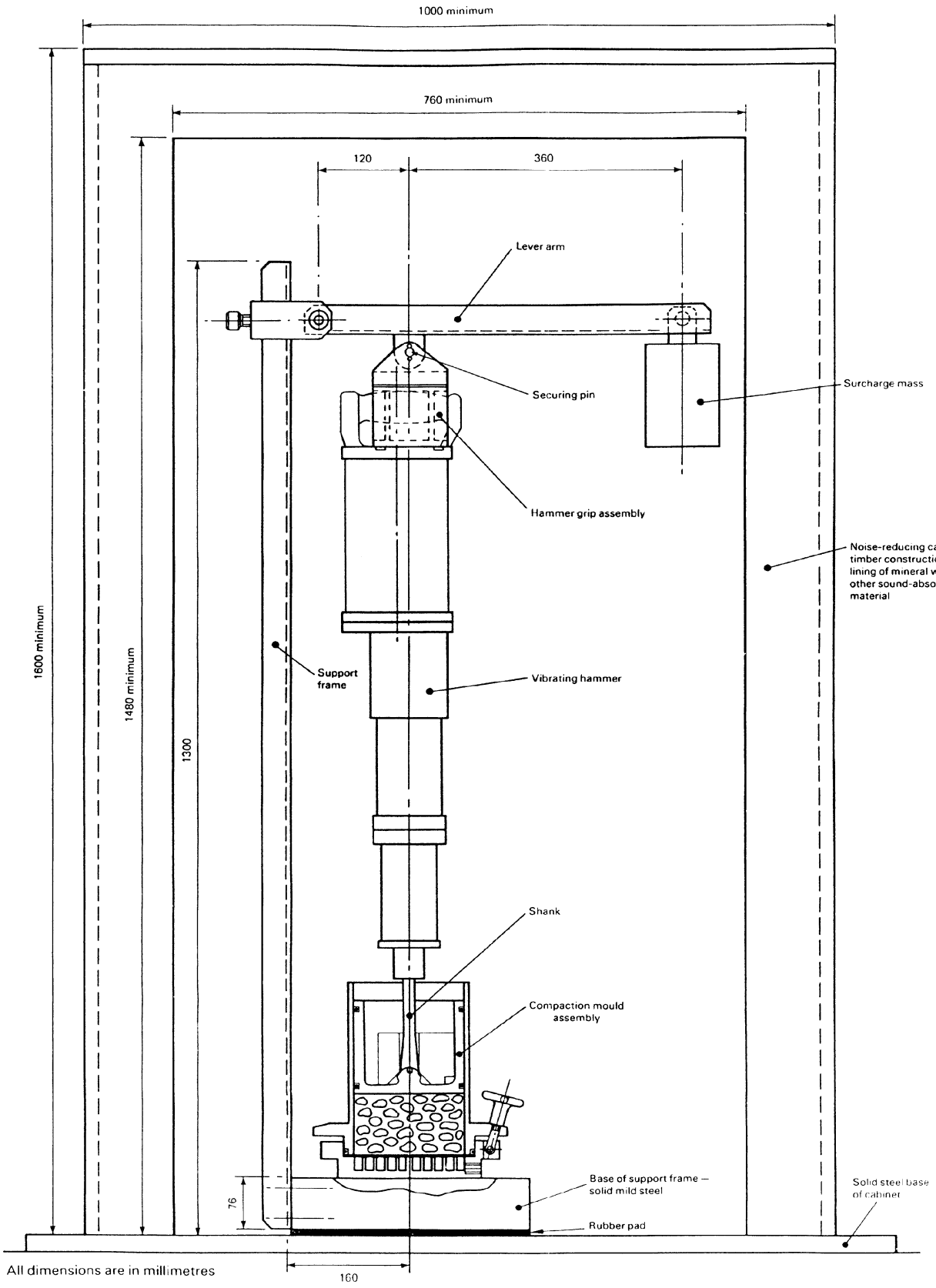


Figure 2 — Compaction rig assembly

SAMPLE REFERENCE No. SPECIMEN ONLY	ⓐ Cross sectional area of mould = 17730 mm2
Particle density on an oven-dried basis P (weighted for grading used) = 2.53	Water absorption value W_A (weighted for grading used) = 1.9 %

Calculations	Observations	Precision						Mean values
	Total initial moisture content (%)	Nearest 0.1	6·0	6·0	6·0	6·0	6·0	6·0
ⓑ	Mass of portion at residual moisture content (g)	Nearest 1.0	2666	2664	2684	2673	2648	
ⓒ	Mass of oven-dry portion (g)	Nearest 1.0	2537	2538	2556	2540	2519	
ⓓ = ⓑ − ⓒ	Mass of residual moisture (g)	Nearest 1.0	129	126	128	133	129	
ⓔ	Depth gauge reading on empty mould (mm)	Nearest 0.1	278·7	278·7	278·7	278·7	278·7	
ⓕ	Depth gauge reading on filled mould (mm)	Nearest 0.1	207·6	211·1	208·7	210·3	213·2	
ⓖ = ⓔ − ⓕ	Height of compacted portion (mm)	Nearest 0.1	71·1	67·6	70·0	68·4	65·5	
$B = 10^6$ ⓒ / (ⓐ × ⓖ)	Dry bulk density (kg/m3)	Nearest 10	2010	2120	2060	2100	2170	2090
$W = 100$ ⓓ/ ⓒ	Total residual moisture content (%)	Nearest 0.1	5·1	5·0	5·0	5·2	5·1	5·1
Results expressed in volumetric terms								
$V_S = B / 10P$	Proportion of volume occupied by solids (%)	Nearest 0.1	79·4	83·8	81·4	83·0	85·8	82·7
$V_{WF} = B(W - W_A)/1000$	Proportion of volume occupied by free residual moisture (%)	Nearest 0.1	6·4	6·6	6·4	6·9	6·9	6·6

NOTE Negative values for V_{wf} indicate that these portions contain less moisture that their water-absorption values.

Figure 3 — A suitable test sheet, with worked examples

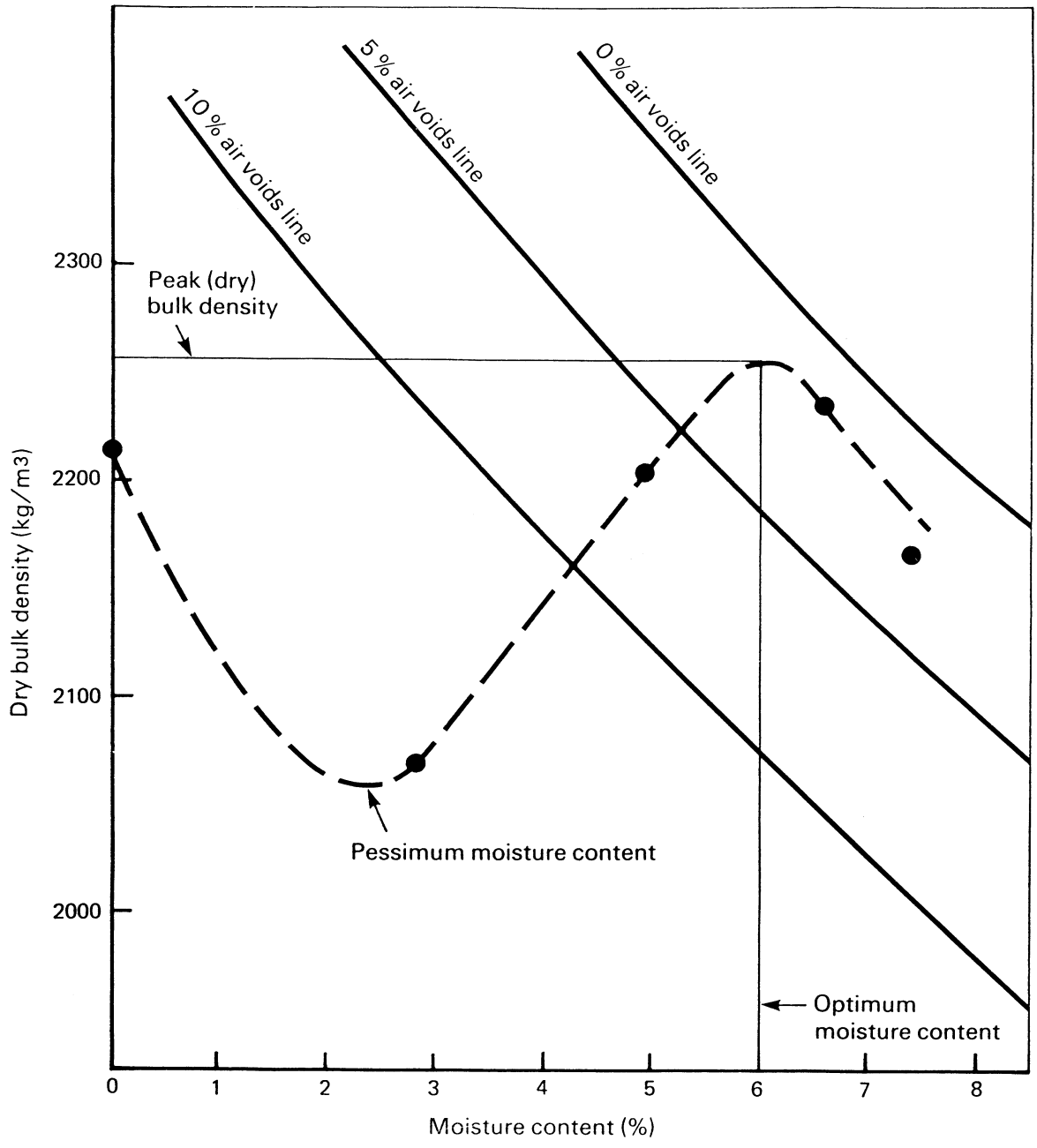


Figure 4 — Idealized plot of test results on a mass basis (see also Figure 5)

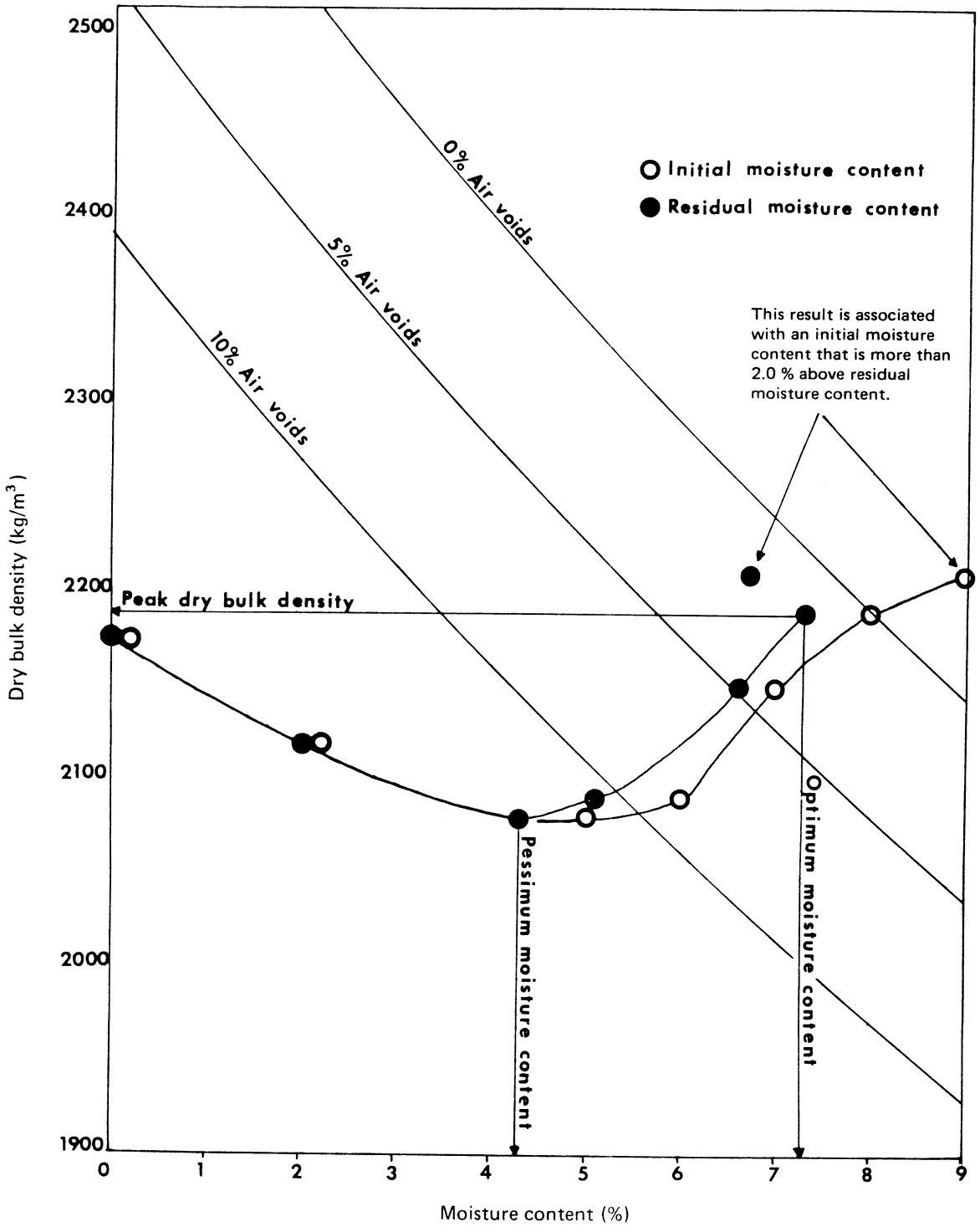


Figure 5 — Typical test results, plotted on a mass basis

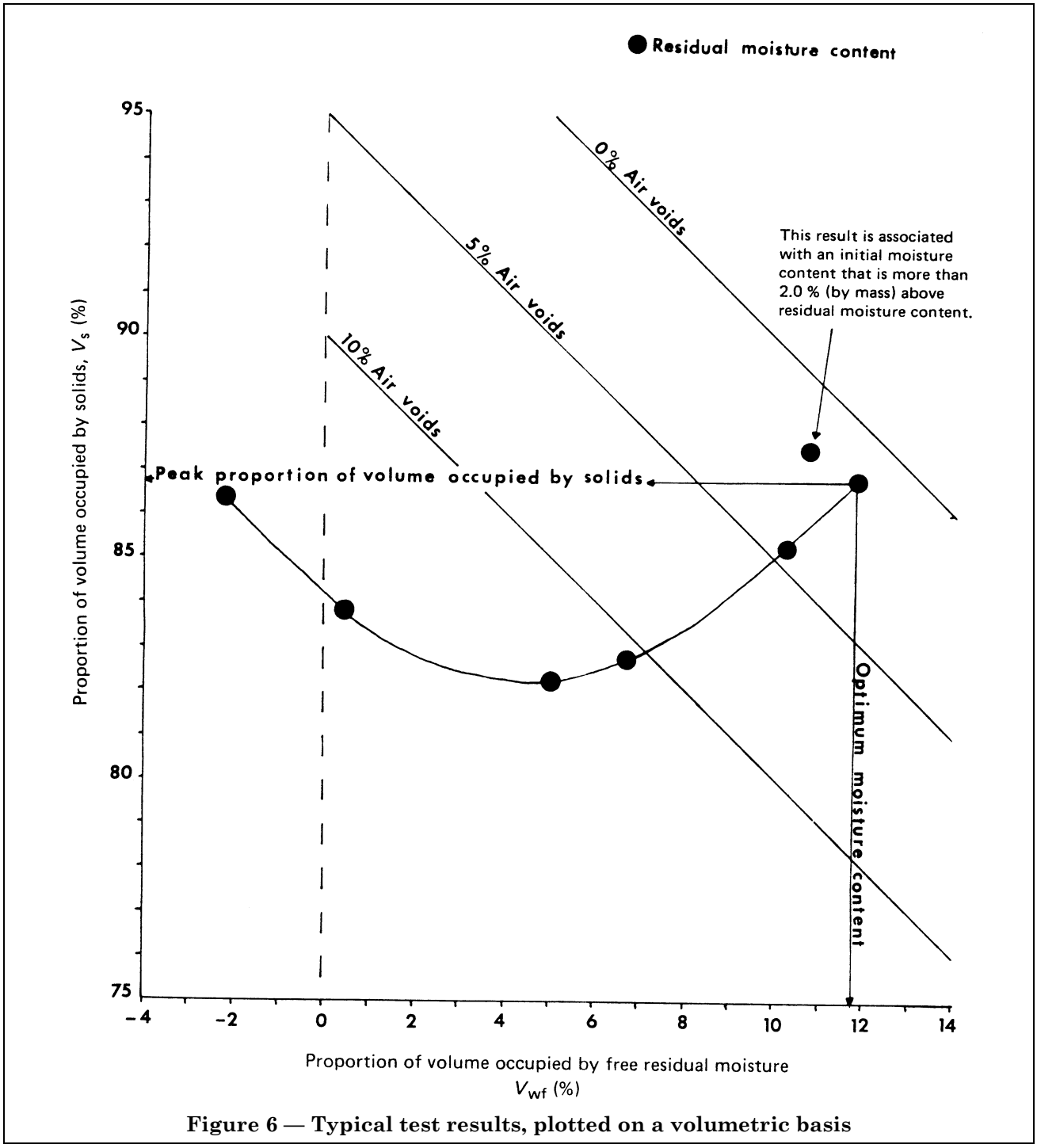
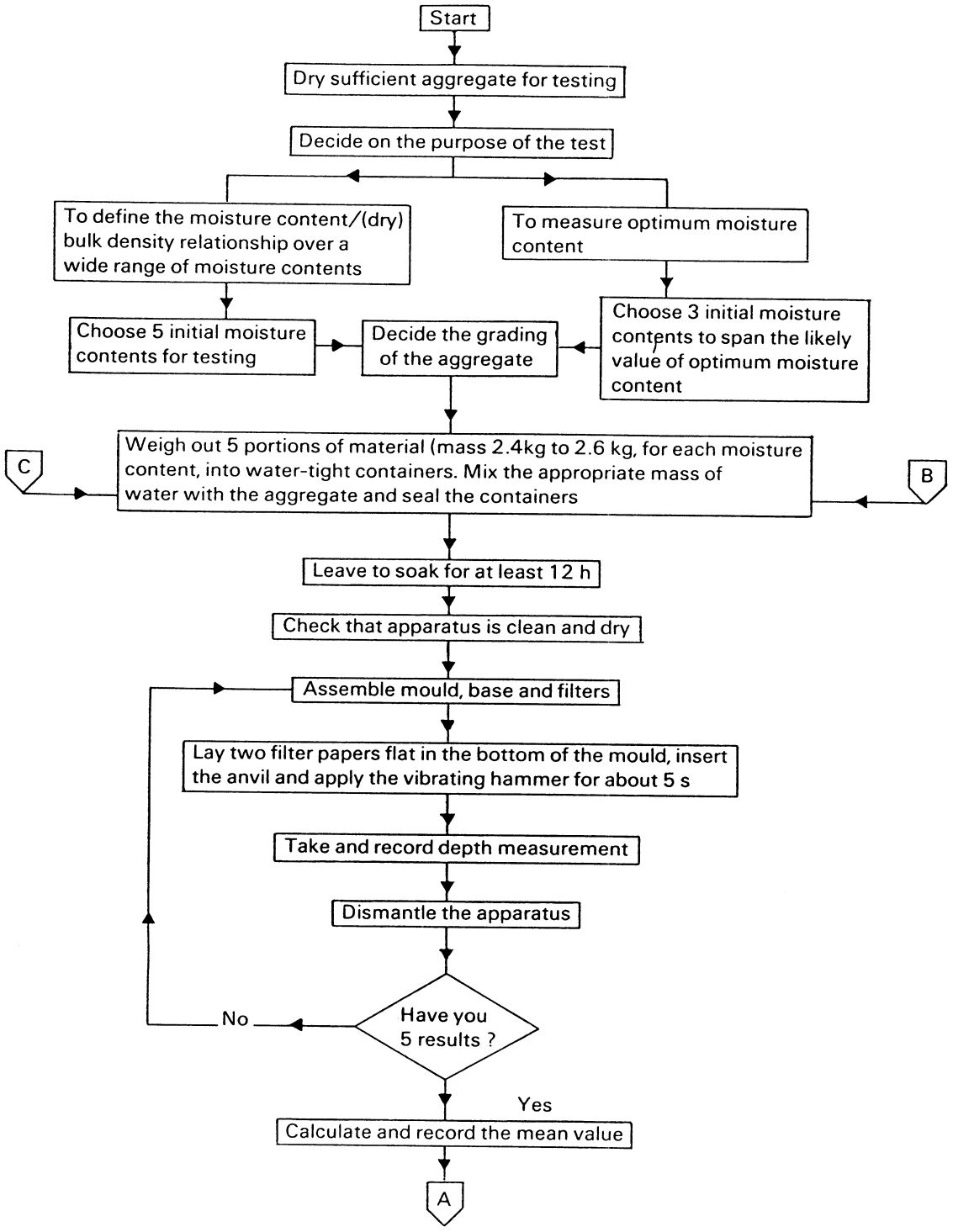
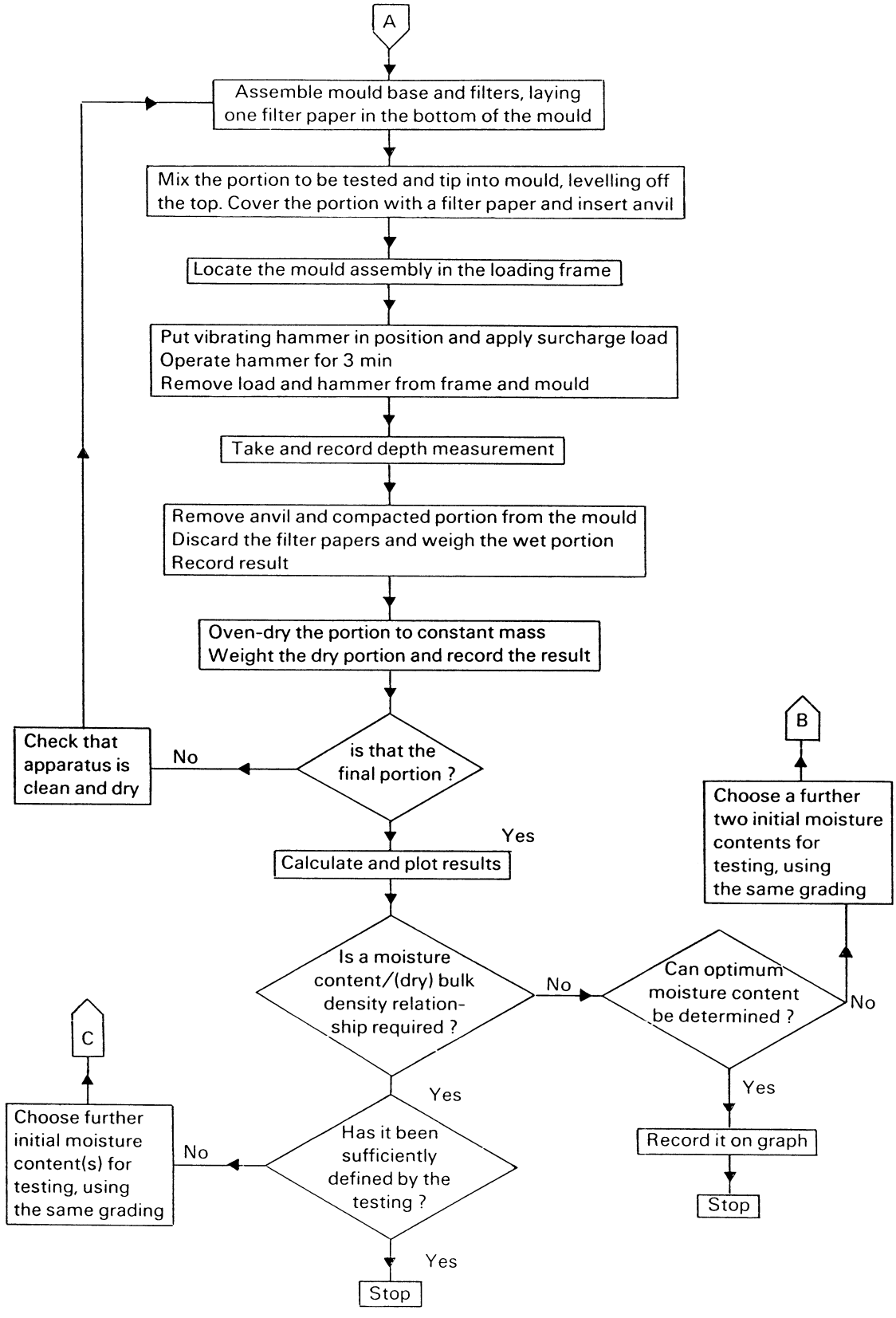


Figure 6 — Typical test results, plotted on a volumetric basis



(a) Calibration

Figure 7 — A flow diagram showing the test procedure



(b) Testing

Figure 7 — A flow diagram showing the test procedure

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Publications referred to

BS 812, *Methods for sampling and testing of mineral aggregates, sands and fillers.*
BS 812-1, *Sampling, size, shape and classification.*
BS 812-2, *Physical properties.*
BS 892, *Glossary of highway engineering terms.*
BS 1377, *Methods of test for soil for civil engineering purposes.*
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