BRITISH STANDARD

BS 3921:1985

Incorporating amendment No. 1

Specification for

Clay bricks

UDC 666.71/.72:691.421.2

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Clay Products Standards Committee (CLB/-) to Technical Committee CLB/7 upon which the following bodies were represented:

Brick Development Association
British Aggregate Construction Materials Industries
British Ceramic Research Association
British Engineering Brick Association
Building Employers' Confederation
Calcium Silicate Brick Association Limited
Consumer Standards Advisory Committee of BSI
Department of Education and Science
Department of the Environment (Building Research Establishment)
Department of the Environment (Housing and Construction Industries)
Department of the Environment (Property Services Agency)
Department of Finance Northern Ireland
Greater London Council
Institution of Civil Engineers
Institution of Structural Engineers
National House-building Council
North of Ireland Brickmakers' Association
Royal Institute of British Architects
Scottish Employers' Council for the Clay Industries
Society of Chemical Industry
Society of Chief Architects of Local Authorities

The following were also represented in the drafting of the standard, through sub-committees and panels:

Coopted members

This British Standard, having been prepared under the direction of the Clay Products Standards Committee, was published under the authority of the Board of BSI and comes into effect on 29 November 1985

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

Foreword

This revision of BS 3921 has been prepared under the direction of the Clay Products Standards Committee and supersedes BS 3921:1974 which is therefore withdrawn.

In this revision the committee have attempted to specify more closely, and to quantify where possible, those properties of fired-clay bricks which are most critical in use, with particular regard to durability.

The main changes from the previous edition are as follows.

Requirements for clay blocks have not been included, since they are no longer manufactured.

The anomaly whereby bricks with holes forming up to 25 % of the gross volume were designated "solid" has been removed.

NOTE This does not affect recommendations in other documents that a perforated brick should be treated as solid, for example in respect of its behaviour under compressive loading and in fire resistance tables.

The method of overall measurement of 24 bricks has been retained. However, a limit on the maximum size of any brick has been added to ensure that the limits of tolerance have been met.

The 225 mm × 112.5 mm × 75 mm format has been retained as the only format in this standard. However, a new standard, BS 6649, has been published which specifies a single format, namely 200 mm × 100 mm × 75 mm, selected by the Department of Education and Science, Royal Institute of British Architects and Society of Chief Architects of Local Authorities as the most promising of the four formats listed in DD 34 and DD 59 which are withdrawn. It is intended for users requiring bricks having dimensionally coordinated sizes.

The decision to cover these two brick formats in separate standards was taken to allow for any possible future development and to obviate confusion when ordering bricks. Other formats are available and will be covered in the forthcoming revision of BS 4729. (At present BS 4729 covers only special shapes.)

Limits for the soluble salts content for all bricks have now been specified. Accordingly the liability to efflorescence test has been deleted as its function was to safeguard against the use of bricks with excessive quantities of very soluble salts. The test was originally intended to predict the liability of the bricks to damage from magnesium sulphate and to a lesser extent potassium sulphate crystallisation. It was not intended to indicate the liability of brickwork to exhibit the visual effects to water soluble efflorescence as is commonly supposed. It has proved difficult to relate the result of the test to the liability of the brickwork to produce efflorescence, although this is in part explained by the fact that some efflorescence arises from causes other than the water soluble salts content of the bricks. Alkalies derived from the mortar constituents and salts present in ground water are typical examples.

Experience also suggests that efflorescence is mainly a short term problem and the risk is minimized where the brickwork is constructed in accordance with the recommendations in BS 5628 *Code of Practice for Use of Masonry Part 3. Materials and Components, Design and Workmanship.*

Pending further research, it is now a requirement to state the frost resistance of bricks, classifying them into one of three categories (see clause **5**). As a consequence, the distinction between ordinary and special quality is no longer required. As soon as sufficient evidence is available to set appropriate performance levels, a test method for frost resistance will be included in the standard. It is also the intention to develop some form of index for assessing the effect of sulphate content on performance of brickwork in buildings.

It has not yet been found possible to specify an overall limit for soluble salt content for all bricks. In the meantime, a requirement that bricks do not show an efflorescence worse than Moderate has been included to exclude bricks that have excessive quantities of very soluble salts.

The loadbearing classification of bricks in BS 3921:1974 has been omitted from this standard.

It is now a requirement to state the water absorption of bricks. Experimental work has shown that there is no simple relationship between the values for the water absorption determined by the 5 h boil and vacuum methods. Only the 5 h boil method is, therefore, now specified in the standard, although the vacuum or the 24 h soak methods still may be used for works quality control.

The committee has been unable to recommend a satisfactory test for the irreversible moisture expansion which affects all fired-clay products, especially in their early life. However, research in this field is continuing.

In view of the wide range of appearance which gives the many varieties of bricks or individual facing bricks their aesthetic appeal, it is not practicable to establish a numerical system of classification. However, a guide to assessment of visual acceptability for facing bricks has been included (see appendix F).

A check-list for ordering bricks has been added (see appendix G).

A suction rate test has been added (see appendix H) because in highly stressed masonry structures the initial rate of suction of the bricks may need to be specified or adjusted by wetting to some predetermined level.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 22, an inside back cover and a back cover.

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

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0 Introduction

0.1 Water absorption

As a consequence of extensive research into the structural performance of fired-clay masonry, the importance of water absorption as a determinant of its behaviour in flexure is now recognized. BS 5628-1 relates three levels of water absorption (less than 7 %; between 7 % and 12 %; over 12 %) to the characteristic flexural strengths to be used in design.

A low water absorption figure is used to classify engineering bricks and bricks for damp-proof courses but water absorption, like strength, is not a general index of durability. With many clays, the more durable bricks of a given type absorb less water than those of the same type that are not so durable.

0.2 Durability

Much research has been carried out to develop a reliable test for frost resistance. The British Ceramic Research Association has devised a panel freezing test[1] for testing samples of clay brickwork rather than individual bricks, which has the merit of reproducing the type of failure found in practice. In this test the brickwork panel is maintained in a saturated condition and subjected to 100 cycles of freezing and thawing. It is thus a very severe test and bricks which withstand 100 cycles may be expected to be frost resistant (class F as defined in **5.1**). Work is in progress to develop a single pan-European frost resistance test for clay masonry units. Natural exposure tests are being carried out to get more information. Where the test is not appropriate, the manufacturer should provide evidence that bricks of the quality to be offered have been in service under conditions of exposure at least as severe as those proposed for not less than 3 years in the situation in which their use is to be considered and that their performance has been shown by inspection to be satisfactory.

It should be noted that the durability of fired-clay brickwork depends not only upon the properties of the bricks but also on other material in contact with them, the exposure conditions and the degree of protection from the effects of weather, particularly moisture penetration. For guidance see BS 5628-3.

0.3 Tolerances

The average size of the bricks in a batch should not vary greatly from the average size in the sample of 24 bricks tested, although average size may occasionally alter sufficiently from one batch to the next for the effect to be noticeable in the finished brickwork. Individual bricks, on the other hand, may show a greater deviation due to differences cancelling one another in the test. These variabilities are a natural characteristic of fired clay bricks.

Accuracy can become critical where very short lengths of brickwork are involved and insufficient joints are available to absorb variability in the individual bricks without excessive variation in joint width. It is also important where, in a larger area of work, a poor appearance might result from a change in the average size (and hence joint width) due to differences between batches. In such cases the designer should consider carefully the character of the particular bricks specified.

At any one time, variations in the manufacturing, drying and firing conditions will cause variations in the size of the bricks. This is the usual cause of variation in the batch (consignment). The magnitude of the variation in the batch is influenced by the type of clay and the manufacturing process.

In addition, the batch average can deviate from the target or work size due to gradual changes in raw materials. This is the usual cause of variation between batches, for which the manufacturer has to make periodic adjustment.

It is the combined effect of the variations in and between batches which affects the user. The method of overall measurement of 24 bricks takes into account both variations but is influenced more by the latter.

It is however, the deviation from the work size which is of concern to the user. The overall measurement of 24 bricks is based on the prediction that individual brick dimensions should not differ from the work size by more than 6.4 mm on length and 4 mm on width and height. This is a compromise between the requirements of the manufacturer and the user. Batches with less than 1 % of individual brick dimensions outside these tolerances have a chance of rejection of approximately 1 in 1 000 whilst batches containing more than 12 % of individual brick dimensions outside these tolerances have a chance of acceptance of approximately 1 in 200.

[1] See *Transactions and Journal of the British Ceramic Society,* Vol. 83 (1984), available from the British Ceramic Research Association, Queens Road, Penkhull, Stoke-on-Trent ST4 7LQ.

It was apparent from the evidence of control charts made available to the committee responsible for drafting BS 3921:1974 that some types of brick (e.g. handmade and stock bricks) had some difficulty in meeting the dimensional requirement. Other types of brick could meet a more stringent requirement, although not consistently; manufacturers have sometimes supplied these bricks with smaller tolerances by special arrangement with the user. The committee has therefore felt it desirable to retain tolerances similar to those in BS 657[2], and to suggest that smaller tolerances should be agreed between the manufacturer and the user.

1 Scope

This British Standard specifies requirements for dimensions, compressive strength, water absorption, soluble salts content, efflorescence and sampling for bricks manufactured from clay for use in walling. It also gives methods of classification. The bricks are intended to be laid on a bed of mortar, following the recommendations in BS 5628-3.

Sizes and tolerances given in this standard apply only to the 225 mm × 125 mm × 75 mm format (see **0.3**). Requirements for a 200 mm × 100 mm × 75 mm format are given in BS 6649 and requirements for special bricks are given in BS 4729.

NOTE 1 In view of the wide variety of bricks available, there are no requirements for appearance, but general guidance is given in appendix F as well as a guide to the assessment of the visual acceptability of consignments of facing bricks using a reference panel.

NOTE 2 Some types of bricks may also be suitable for use in paving.

NOTE 3 A check-list for ordering bricks is given in appendix G. A suction rate test is given in appendix H.

NOTE 4 The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard the definitions given in BS 6100-5.3 apply, together with the following.

2.1
compressive strength

the average value of the crushing strengths of ten bricks sampled in accordance with clause **9** and tested in accordance with appendix D

2.2
water absorption

the average value of the water absorptions of ten bricks sampled in accordance with clause **9** and tested in accordance with appendix E

2.3 coordinating size

the size of a coordinating space allocated to a brick, including allowances for joints and tolerances

2.4
work size

the size of a brick specified for its manufacture, to which its actual size should conform within specified permissible deviations

3 Sizes

3.1 External sizes

Bricks shall be designated in terms of their coordinating sizes. The coordinating sizes and work sizes for bricks shall be as given in Table 1.

Table 1 — Sizes

Coordinating size			Work size		
Length	Width	Height	Length	Width	Height
mm	mm	mm	mm	mm	mm
225	112.5	75	215	102.5	65
NOTE The work sizes are derived from the corresponding coordinating sizes by the subtraction of a nominal thickness of 10 mm for the mortar joint.					

[2] BS 657:1950 "Dimensions of common clay building bricks" was withdrawn in 1974 when the previous edition of BS 3921 superseded it.

3.2 Sizes of voids

Solid bricks shall not have holes, cavities[3] or depressions.

Cellular bricks shall not have holes, but may have frogs or cavities[3] exceeding 20 % of the gross volume of the brick.

Perforated bricks shall have holes not exceeding 25 % of the gross volume of the brick. The holes shall be so disposed that the aggregate thickness of solid material, measured horizontally across the width of the unit at right angles to the face, is nowhere less than 30 % of the overall width of the brick. The area of any one hole shall not exceed 10 % of the gross area of the brick.

Frogged bricks shall have depressions in one or more bed faces but their total volume shall not exceed 20 % of the gross volume of the brick.

4 Dimensional deviations

The overall measurements of 24 bricks sampled in accordance with clause **9** and measured as described in appendix A shall not fall outside the limits given in Table 2. In addition, the size of any individual brick in the sample shall not exceed the coordinating size given in Table 1.

Table 2 — Limits of size

Work size (see Table 1)	**Overall measurement of 24 bricks**	
	Maximum	**Minimum**
mm	mm	mm
215	5235	5085
102.5	2505	2415
65	1605	1515
NOTE Where for special reasons closer limits of size are required, this can best be achieved by agreement between the specifier and the supplier.		

5 Durability

NOTE The classification of bricks by frost resistance (see **5.1**) and by soluble salts content (see **5.2**) may be used to distinguish different designations of durability as given in Table 3.

The word “designation” has been used rather than “level” to avoid any implication that bricks of one particular frost resistance and soluble salts content are of better quality than bricks of any other frost resistance and/or soluble salts content.

5.1 Frost resistance

The bricks shall be classified into one of the following categories.

Frost resistant (F). Bricks durable in all building situations including those where they are in a saturated condition and subjected to repeated freezing and thawing.

Moderately frost resistant (M). Bricks durable except when in a saturated condition and subjected to repeated freezing and thawing.

Not frost resistant (O). Bricks liable to be damaged by freezing and thawing if not protected as recommended in BS 5628-3 during construction and afterwards, e.g. by an impermeable cladding. Such units may be suitable for internal use.

5.2 Soluble salts content

The bricks shall be classified into one of the following categories.

Low (L). The percentage by mass of soluble ions, measured as described in appendix B, shall not exceed the following.

magnesium 0.030 %
potassium 0.030 %

[3] A cavity is a hole closed at one end.

sodium 0.030 %
sulphate 0.500 %

Normal (N). The percentage by mass of soluble ions, measured as described in annex B, shall not exceed the following.

The sum of the contents of sodium, potassium and magnesium	0.25 %
Sulphate	1.6 %

Table 3 — Durability designations

Designation	Frost resistance (see 5.1)	Soluble salt content (see 5.2)
FL	Frost resistant (F)	Low (L)
FN	Frost resistant (F)	Normal (N)
ML	Moderately frost resistant (M)	Low (L)
MN	Moderately frost resistant (M)	Normal (N)
OL	Not frost resistant (O)	Low (L)
ON	Not frost resistant (O)	Normal (N)
NOTE Guidance on the selection of bricks and mortars for use in a variety of environments, particularly where brickwork might be subjected to frequent freezing and thawing when saturated, is given in BS 5628-3. For a particular exposure category, a frost resistant facing brick with a low soluble salts content may be specified, whilst for rendered brickwork in the same exposure category, a not frost resistant brick with a normal soluble salts content may be satisfactory.		

6 *Text deleted*

7 Compressive strength

The compressive strength (see **2.1**) of the bricks, sampled in accordance with clause **9** and tested as described in appendix D, shall be stated. The compressive strength shall be not less than the stated strength and in no case less than the strength for the appropriate class of brick given in Table 4.

NOTE Clay bricks are available with compressive strengths ranging from about 7 N/mm^2 to more than 100 N/mm^2.

8 Water absorption

The water absorption (see **2.2**) of the bricks, sampled in accordance with clause **9** and tested as described in appendix E, shall be stated. The water absorption shall meet the stated water absorption and shall in no case be greater than the water absorption for the appropriate class of brick given in Table 4.

9 Sampling for tests

9.1 General

The required number of bricks shall be sampled from a consignment of not more than 15 000 bricks, as specified in **9.2** and Table 5.

9.2 Sampling procedure

NOTE The choice of the method of sampling will normally be dictated by the physical form of the consignment in question.

9.2.1 *Random sampling*. Whenever possible, the random sampling method shall be used, in which every brick in the consignment has an equal chance of being selected for the sample. The appropriate number of bricks shall be selected at random from positions throughout the consignment without any consideration being given to the condition or quality of the selected bricks.

Table 4 — Classification of bricks by compressive strength and water absorption

Class	Compressive strength (see **2.1**)	Water absorption (see **2.2**)
	N/mm^2	% by mass
Engineering A	≥ 70	≤ 4.5
Engineering B	≥ 50	≤ 7.0
Damp-proof course 1	≥ 5	≤ 4.5
Damp-proof course 2	≥ 5	≤ 7.0
All others	≥ 5	No limits

NOTE 1 There is no direct relationship between compressive strength and water absorption as given in this table and durability.

NOTE 2 Damp-proof course 1 bricks are recommended for use in buildings whilst damp-proof course 2 bricks are recommended for use in external works (see Table 13 of BS 5628-3:1985).

NOTE In practice, random sampling is normally only convenient either when the bricks forming the consignment are being moved in a loose (unpacked) form from one place to another or when they have been split into a large number of small stacks, e.g. on scaffolding awaiting laying.

9.2.2 ***Representative sampling***

9.2.2.1 *General.* When random sampling is impracticable or not convenient, e.g. when the bricks form a large stack or stacks with ready access to only a limited number of bricks, a representative sampling procedure shall be used.

9.2.2.2 *Sampling from a stack.* The consignment shall be divided into at least six real or imaginary sections, each of a similar size. An equal number of not more than four bricks shall be selected at random from within each section in order to give the required number of samples without any consideration being given to the condition or quality of the selected bricks.

NOTE 1 It will be necessary to remove some sections of the stack or stacks in order to gain access to bricks within the body of such stacks when taking samples.

NOTE 2 Sampling from a stack may not be satisfactory when testing for soluble salts because contamination from the ground or other sources may occur.

Table 5 — Number of bricks required for testing

Purpose	Appendix reference	Number of bricks required for sample
Dimensional checks	A	24 (available for subsequent tests)
Determination of soluble salts content	B	10
Determination of compressive strength	D	10
Determination of water absorption	E	10 (available for subsequent compressive strength tests)

9.2.2.3 *Sampling from a consignment formed of banded packs.* At least six packs shall be selected at random from the consignment. The band around one blade or slice in each pack shall be removed and an equal number of not more than four bricks shall be sampled at random from within each of the broken slices or blades in order to give the required number of samples without any consideration being given to the condition or quality of the selected bricks.

9.2.3 *Dividing the sample.* When the sample is to provide bricks for more than one test, the total number shall be collected together and then divided by taking bricks at random from within the total sample to form each successive sub-sample.

NOTE 1 Sampling and testing of isolated batches is unsatisfactory for routine quality control because the properties of clay products are liable to vary as a result of changes in the raw material as well as process variations. Products should be sampled and tested regularly and the results recorded on control charts. This recommendation does not preclude users from taking samples for testing in accordance with clause **9**. All such samples should be taken before the bricks are used for building.

NOTE 2 Where bricks are supplied to the special category of manufacturing control (see appendix J), lower partial safety factors may be used, allowing structural brickwork to be designed to finer limits (see BS 5628-1 or BS 5628-2). Appendix J is included for information only and is outside the scope of this standard.

10 Marking

The following particulars shall be clearly indicated on the delivery note, invoice or supplier's certificate supplied with a consignment of bricks:

a) the name, trade mark or other means of identification of the manufacturer;

b) the number and date of this British Standard, i.e. BS 3921:1985[4)];

c) the type of brick, i.e. solid, cellular, hollow or perforated;

d) the name of the brick, e.g. Red Multi.

NOTE It is desirable to repeat the same details on any wrapping supplied with the consignment of units.

[4)] Marking BS 3921:1985 on or in relation to a product is a claim by the manufacturer that the product has been manufactured in accordance with the requirements of the standard. The accuracy of such a claim is therefore solely the manufacturer's responsibility.

Appendix A Measurement of dimensions

Take 24 bricks sampled as described in clause **9**. Remove any blisters, small projections or loose particles of clay adhering to each brick. Place the bricks in contact with each other in a straight line upon a level surface, using the appropriate arrangement for each work size shown in Figure 1.

Measure the overall dimension (length, width or height) to the nearest millimetre, using an inextensible measure long enough to measure the whole row at one time, e.g. a steel tape. Record each result.

Alternatively, divide the sample in half and form two rows of 12 bricks. Measure each row separately and record the sum of the results for the two rows.

Using a gauge box or similar means, check that the size of any brick in the sample does not exceed the coordinating size given in Table 1

Appendix B Determination of soluble salts content

B.1 Principle

The method adopted is based on water extraction from a crushed representative sample, and determines the soluble magnesium, sodium and potassium ions, together with the sulphate content.

B.2 Symbols

M_{Mg} is the number of milligrams of Mg equivalent to 1 ml of EDTA,

x,y is the volume of EDTA titrated, in ml,

m_o is the mass of crucible, in grams,

m_i is the mass of crucible and contents, in grams.

B.3 Reagents

B.3.1 *General.*

All reagents shall be of analytical quality.

NOTE Materials for the rapid test method of **B.6.4.3** are given in **B.6.4.3.1**.

B.3.2 *Distilled or deionized water,* is for extraction of soluble salts from the sample, and for preparation of analytical test solutions.

B.3.3 *Hydrochloric acid* (relative density 1.18).

B.3.4 *Magnesium metal.*

B.3.5 *Ethylenediaminetetra acetic acid (EDTA)* (disodium salt dihydrated).

B.3.6 *Indicators.*

a) calcein;

b) methyl thymol blue complexone;

c) methyl red.

B.3.7 *Potassium hydroxide.*

B.3.8 *Ammonia solution* (relative density 0,88).

B.3.9 *Potassium nitrate.*

B.3.10 *Bromine water* (saturated).

B.3.11 *Barium chloride.*

B.4 Apparatus

B.4.1 *Test sieves,* complying with the requirements of BS 410.

B.4.2 *Mortar,* or other suitable grinding equipment capable of producing particles to pass a 150 µm test sieve.

B.4.3 *Masonry drill*

B.4.4 *Beaker,* capacity 250 ml

B.4.5 *Platinum crucible.*

B.4.6 *Polyethylene bottle,* capacity 250 ml.

B.4.7 *Rotary shaker or magnetic stirrer.*

NOTE Apparatus for the rapid test method of **B.6.4.3** are given in **B.6.4.3.2**

B.5 Preparation of sample

B.5.1 *Sampling*

The method of sampling shall be stated in the test report.

NOTE No specific method of sampling is given but the method and the number of specimens chosen should be such that the sample is representative of the batch to be tested.

The number of specimens for determination of soluble salts content shall be a minimum of six and shall comprise whole units. They shall be sampled in such a manner that they have not been exposed to water which would lead to leaching of soluble salts from the units.

From the bulk sample of units prepare a representative sample of 25 g to 250 g of material, ground to pass a 150 µm test sieve, using either the crushing method described in **B.5.2** or the drilling method described in **B.5.3**. Determine the soluble salts content of two sub-samples as described in **B.6**.

B.5.2 *Crushing method*

Either crush all the units and reduce by quartering about 5 000 g of material or crush fragments representative of the interior and exterior of the units and amounting to at least one-tenth of each unit to produce about 5 000 g of material. Such material should pass through a test sieve having an aperture not greater than 3.35 mm.

Mix this material and reduce it by coning and quartering (or any other suitable method) to about 250 g to 500 g of material, which shall then be ground so as to pass through a test sieve with an aperture not greater than 710 µm. (Alternatively all the 5 000 g may be reduced to a particular size less than 710 µm, followed by coning and quartering).
Finally reduce the prepared sample to 25 g to 250 g using the same method as before, and grind to pass a 150 µm test sieve. Dry the sample at 70 °C ± 5 °C[5].

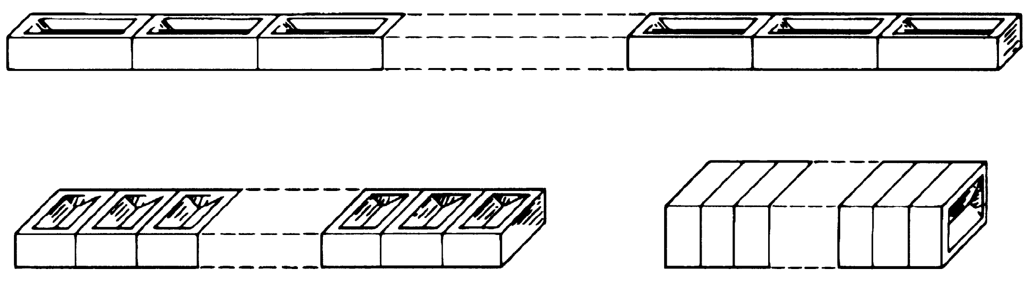


Figure 1 — Arrangement of bricks for measurement of dimensions

B.5.3 *Drilling method*

Drill holes in the units not larger than 7 mm in diameter, using a masonry drill. Space the holes approximately equally over the bed faces of each unit and drill them to a depth approximately equal to half the depth of the unit.

The number of holes shall be such as to give a sample of at least 25 g of powder passing a 150 µm test sieve.

Grind material from the drillings which does not pass a 150 µm test sieve, until the whole sample passes through. Dry the sample at 110 °C.

B.6 Determination of water-soluble salts

B.6.1 *Extraction procedure*

Weigh 20 g ± 0.05 g of the sample at room temperature and transfer it to a polyethylene bottle.

[5] In the case of newly produced bricks, a drying temperature of 110 °C ± 5 °C may be used.

Add 200 ml of cold distilled or deionized water, close the bottle with a screw-on polyethylene top and shake the bottle for 60 min, using a rotary shaker revolving at 30 r/min ± 3 r/min or a magnetic stirrer using a polyethylene covered follower to achieve a similar dispersion.

Filter the suspended sample and collect the filtrate in a clean dry flask. Do not wash the residue on the filter. Alternatively use a centrifuge. It is essential that the filtrate shall be clear. (If required, sample weight may be proportionately increased to 100 g for 1 000 ml of cold distilled or deionized water).

B.6.2 ***Preparation of reagents for calcium and magnesium determination***

B.6.2.1 *Magnesium test solution, 1.0 mg/ml of Mg*

Dissolve 1 000 g of magnesium metal in a slight excess of hydrochloric acid solution consisting of one part hydrochloric acid (relative density 1.18) to three parts distilled or deionized water, and dilute to 1 l with distilled or deionized water in a calibrated flask. Before weighing, etch the metal ribbon or foil in dilute hydrochloric acid and then dry it with alcohol followed by ether. Adjust the mass with scissors.

B.6.2.2 *Preparation of EDTA test solution, (0,5 %)*

Dissolve 5 g of ethylenediaminetetra acetic acid (EDTA) (disodium salt, dihydrated) in warm distilled or deionized water, filter if necessary, cool and dilute to 1 l. Store in a polyethylene bottle. Standardize against the magnesium test solution described in **B.6.2.1** using methyl thymol blue complexone as an indicator, where M_{Mg} is the number of milligrams of Mg equivalent to 1 ml of EDTA.

B.6.3 ***Determination of metal ions***

B.6.3.1 *General*

The metal ion content will normally be determined using an established instrumental method, e.g. inductively coupled plasma spectrometry or atomic absorption spectroscopy which shall have been validated by comparison with the reference methods described in **B.6.3.2**, **B.6.3.3** and **B.6.3.5**.

B.6.3.2 *First titration (calcium)*

Pipette a 10 ml aliquot of the soluble salts extract into a 500 ml conical flask. Add 20 drops of hydrochloric acid (relative density 1.18), followed by 10 ml of potassium hydroxide solution (approximately 250 g/l), and dilute to about 200 ml with distilled or deionized water. Add about 0.015 g of calcein indicator prepared by grinding together 0.1 g of calcein with 10 g of potassium chloride. Titrate with EDTA test solution, prepared as described in **B.6.2.2** from a 10 ml semi-micro burette, the colour change being from fluorescent green to pink. Measure the volume titrated *(x)*.

B.6.3.3 *Second titration (calcium plus magnesium)*

Pipette a 10 ml aliquot of the soluble salts extract into a 500 ml conical flask. Add 20 drops of hydrochloric acid (relative density 1.18), followed by 10 ml of ammonia solution (relative density 0.88) and dilute with distilled or deionized water to about 200 ml. Add about 0.04 g of methyl blue complexone indicator, prepared by grinding together 0.2 g of methyl thymol blue complexone with 20 g of potassium nitrate. Titrate with EDTA test solution, prepared as described in **B.6.2.3** from a 10 ml semi-micro burette, the colour change being from blue to colourless. Measure the volume titrated *(y)*.

B.6.3.4 *Magnesium*

Calculate the mass of water soluble magnesium as a percentage of the mass of the original sample from the equation

$$\%\ Mg = (y - x)\ M_{Mg}/10$$

where x is the volume of the EDTA used in the titration described in **B.6.3.2** and y is the volume of EDTA described in **B.6.3.3**.

B.6.3.5 *Sodium and potassium*

Compare a portion of the soluble salts extract with test solutions containing 5 p.p.m. by mass of sodium and 10 p.p.m. by mass of potassium in a suitable flame photometer or by atomic absorption spectroscopy. Calculate the sodium and potassium contents by reference to previously prepared calibration graphs.

B.6.4 ***Determination of sulphate ions***

B.6.4.1 *General*

The sulphate content of the soluble salts extract will normally be determined using an established instrumental method, e.g. inductively-coupled plasma spectrometry or ion chromatography which shall have been validated by comparison with the reference method described in **B.6.4.2**. The resin column method given in **B.6.4.3** will give a measure by a rapid test method of the tonal anion concentration. In most aqueous extracts of powdered clay masonry unit this will be virtually all sulphate and use of this method may be satisfactory. In cases of doubt about meeting the specification an instrumental method or the reference method shall be used.

B.6.4.2 *Method*

Pipette a 50 ml aliquot of the soluble salts extract into a 250 ml beaker, add 100 ml of distilled or deionized water and 1 or 2 spots of methyl red indicator. Add hydrochloric acid (relative density 1.18) dropwise until acid (1 or 2 drops will normally suffice) then add a further 25 drops of the acid followed by 5 ml of bromine water (saturated).

Cover the beaker with a clock glass and heat to boiling.

Boil for 2 min and, while boiling, slowly add from a pipette 10 ml of barium chloride solution (100 g/l). Continue boiling for about 2 min, transfer to a steam bath for 1 h and allow to cool. Standard overnight filter through a slow ashless filter paper. Wash with hot water until free of chlorides.

Weigh a platinum crucible and record the mass m_0 in grams, to the nearest 0.0001 g. Transfer the precipitate and paper to the crucible and heat gently to dry the residue and char the paper. Ignite the precipitate and paper at 1 000 °C for 30 min, cool and weigh. Record the mass, m_i, in grams to the nearest 0.0001 g.

Calculate the mass of water-soluble sulphate M (in g), using the equation:

$$M = 0.4115\ (m_i - m_0)$$

Calculate the water-soluble sulphate content as a percentage of the mass of the original sample (i.e. 5 g) and report it to the nearest 0.01 %.

B.6.4.3 *Rapid test method (for total anions) using resin column*

B.6.4.3.1 *Reagents*

B.6.4.3.1.1 *Distilled or deionized water.*

B.6.4.3.1.2 *Amberlite IR 120 ion-exchange resin beads,* (hydrogen form).

B.6.4.3.1.3 *Indicator,* a mixed pH indicator covering the pH range 3.5 to 6.0 e.g. BDH 4,5 indicator.

B.6.4.3.1.4 *Sodium borate solution* (N/100).

B.6.4.3.2 *Apparatus*

B.6.4.3.2.1 *A 25 ml burette,* modified by joining a glass reservoir (100mm × 25mm) at the top.

B.6.4.3.2.2 *Silica wool.*

B.6.4.3.3 *Method*

Place a small plug of silica wool in the bottom of the burette (to retain the resin packing) and fill the burette and reservoir with distilled or deionized water. Add Amberlite IR 120 ion-exchange resin beads (hydrogen form) by slowly allowing the beads to fall through the water to fill the burette.

Care is necessary to avoid trapping of air bubbles. A second plug of silica wool is then used to retain the resin beads just below the top of the burette.

Run distilled or deionized water through the column until a sample of the eluate gives a neutral or alkaline reaction when tested with BDH 4.5 indicator or equivalent.

NOTE Care should be taken to avoid draining the reservoir below the top surface of the resin column, to prevent air from entering the column.

Now place a 10 ml aliquot of the soluble salts extract in the reservoir, and open the top of the burette slightly to allow a slow percolation through the column (about 2 drops per second is satisfactory).

Collect the now acid eluate in a clean titration flask and as soon as the sample aliquot has drained to the top of the column immediately add a 20 ml washing of distilled or deoinized water.

Repeat washings until a few drops of eluate give a neutral or alkaline reaction with the 4.5 indicator (the eluate should be caught in a small receiver for testing), then added to the main titration flask.

When all the free acid generated from dissolved anions (primarily sulphate) has been flushed from the column, titrate the eluate and washing against N/100 sodium borate solution, using BDH 4,5 indicator or equivalent.

For a 10 ml aliquot of the soluble salts extract (equivalent to 1 g of powdered clay masonry unit)

Titre × 0.048 = SO_4 m %

B.7 Test report

The test report shall contain the following information:

a) the name, title and date of issue of this British Standard;

b) a description of the masonry unit to this British Standard;

c) the method of sampling and by which organization;

d) the date of delivery of the specimens;

e) the date of testing;

f) the name of the testing laboratory;

g) the number of specimens in the sample;

h) the method of analysis, detailing whether chemical or alternative instrumental methods were used;

i) the soluble salts content of the sample, expressed as a percentage to the nearest 0.01 % for the radicals of magnesium, sodium, potassium and water-soluble sulphate;

j) remarks.

Appendix C *Text deleted.*

Figure 2. *Figure deleted.*

Appendix D Determination of compressive strength

D.1 Apparatus

D.1.1 *Testing machine,* equipped with a means of providing the rate of loading specified in **D.3.3** and with a pacing device. The capacity of the machine shall be such that the expected ultimate load on a specimen is greater than one-fifth of the machine scale range. The accuracy of the machine shall comply with the requirements for grade A or B of BS 1610:1964.

The machine shall be equipped with two permanent ferrous bearing platens which shall be at least as large as any plywood packing or, where such packing is not being used, the bedding faces of the specimen being tested.

The upper machine platen shall be able to align freely with the specimens as contact is made but the platens shall be restrained by friction or other means from tilting with respect to each other during loading.

The lower compression platen shall be a plain, non-tilting bearing block.

The testing face of the platens shall be hardened and shall have:

a) a flatness tolerance of ± 0.05 mm;

b) a parallelism tolerance for one face of each platen with respect to the other of ± 0.10 mm;

c) a surface texture not greater than 3.2 µm R_a measured in accordance with BS 1134.

The testing faces, where case-hardened, shall have a Vickers hardness of at least 600 HV when tested in accordance with BS 427-1.

Where the platens are through-hardened, the steel shall be in condition Y of grade 826M40 as specified in BS 970-1 or any equivalent grade of steel.

D.2 Preparation of specimens

D.2.1 *General*

Prepare ten bricks sampled in accordance with clause **9**, using the method described in **D.2.2**, **D.2.3** or **D.2.4** as appropriate.

Measure the overall dimensions of each bed face and calculate the area of the smaller bed face of the specimen.

D.2.2 ***Solid bricks: bricks with a frog intended to be laid downwards: perforated bricks; cellular bricks***

Immerse the brick in water for 24 h or saturate the brick by boiling as described in **E.4**.

D.2.3 ***Bricks with a single frog intended to be laid frog upwards***

Immerse the brick in water at ambient temperature for not less than 24 h or saturate the brick by boiling. Remove the brick and allow to drain for not less than 5 min. Wipe off the surplus moisture and fill the frog with mortar (see note). Make cubes of side 70.7 mm or 75 mm from the mortar and test for compressive strength in accordance with the procedure given in BS 4551. Store the bricks under damp sacking, polyethylene or similar material until the mortar has hardened (approximately 24 h for Portland cement mixes or 3 h for high alumina cement mixes) and then immerse in water.

NOTE The strength of mortar required [see **D.3.1** a)] may be obtained within a reasonable time (3 days to 7 days) by using a 1 : 1½ mix of ordinary Portland cement or rapid-hardening Portland cement complying with BS 12, with clean well-graded sand, 2.8 mm down. The water: cement ratio will not usually be greater than 0.35 and, if the bricks are of an open texture so that water drains from them readily, it may be necessary to use a lower water: cement ratio. Alternatively a 1 : 3 mix with a high alumina cement complying with BS 915-2 can be used. This will produce the required mortar strength in about 24 h.

If the sand available is relatively fine and/or contaminated with silt or clay, a higher water: cement ratio will be required to obtain satisfactory workability. It will then be difficult to attain the required strength within a reasonable time when using a 1 : 1½ mix with Portland cement. A 1 : 1 mix with ordinary Portland cement or rapid-hardening Portland cement, or a 1 : 3 mix with high alumina cement will then be found more satisfactory.

D.2.4 ***Bricks with double frogs***

Prepare the brick and fill the first frog with mortar as described in **D.2.3**. After 4 h to 8 h, fill the second frog in the same way as the first frog, using the same mortar composition. Store the bricks under damp sacking, polyethylene or similar material until the mortar has hardened (approximately 24 h for Portland cement mixes or 3 h for high alumina cement mixes) and then immerse in water.

D.3 Test procedure

D.3.1 Remove each specimen from the water. For mortar filled or capped specimens (see **D.2.3** or **D.2.4**):

a) the compressive strength of the mortar, as determined from three cubes, shall be not less than 28 N/mm^2 and not greater than 42 N/mm^2;

b) there shall be no concavity in the mortar filling.

If either of these conditions is not satisfied, use another specimen.

D.3.2 Wipe clean the bearing surfaces of all the platens and remove any loose grit or other material from the surfaces of the specimen which are to be in contact with the platens.

To ensure a uniform bearing for any specimen that is not capped, place the specimen between plywood sheets to take up irregularities. The plywood shall be three-ply, normally 4 mm thick, of European birch or softwood and free from knots. Ensure that the plywood exceeds the work size dimensions by 5 mm to 15 mm. Use a fresh pair of plywood sheets for each test.

D.3.3 Apply the load without shock and increase it at a convenient rate not exceeding 35.0 N/(mm^2 min) up to half the anticipated maximum load. Thereafter, smoothly change the rate of loading to 15.0 N/(mm^2 min) and maintain this rate until failure, i.e. when the indicator needle falls back in spite of progressively adjusting the machine controls or the specimen undergoes explosive collapse.

NOTE 1 A higher rate of loading up to half the maximum load reduces the time for testing the specimen and may be used because the rate of loading during this stage does not influence the ultimate strength.

NOTE 2 It is necessary to adjust the controls of the machine continuously and smoothly to maintain a constant rate of loading because of the non-linearity of the yield of the specimen with load. This becomes increasingly necessary as failure is approached.

D.3.4 Record the maximum load (in N) carried by the specimen during the test.

D.4 Calculation of compressive strength

Obtain the strength of each specimen by dividing the maximum load obtained in **D.3.4** by the appropriate area of the bed face determined in **D.2.1**.

Record the strength in N/mm^2 to the nearest 0.1 N/mm^2.

Calculate the compressive strength, i.e. the average of the strengths of the ten specimens (see **2.1**) of the sample to the nearest 0.1 N/mm^2.

Appendix E Determination of Water absorption

NOTE The method for the determination of water absorption specified in this standard is the 5 h boiling test. Methods of test by 24 h cold immersion and absorption under vacuum are also used as works control tests only. The results obtained from these tests are generally lower than, and are not proportional to, those obtained using the method given in this standard, nor are they equivalent to each other.

E.1 Apparatus

E.1.1 *Ventilated drying oven,* complying with the requirements of BS 2648.

E.1.2 *Tank,* provided with a grid to ensure free circulation of water between masonry units and the bottom of the tank.

E.1.3 *Laboratory balance,* capable of weighing to an accuracy of 0.1 % of the mass of the specimen.

E.2 Test specimens

Use ten whole bricks, sampled in accordance with clause **9**, as test specimens.

Carry out the test using either dry bricks or bricks that have been subjected to a 24-hour cold immersion test, provided that they were dried and weighed as described in **E.3**.

E.3 Preparation of specimens

Dry the specimens to constant mass in the oven (**E.1.1**) at a temperature between 110 °C and 115 °C. When cool, weigh each specimen to an accuracy of 0.1 %.

NOTE It can be assumed that heating for at least 48 h at 110 °C will assure constant mass, but it should be noted that several hours may be required before the specimens reach 110 °C if they are wet when put into the oven. The 48 h should be reckoned from the time the specimens reach 110 °C. Storage of bricks, unstacked, with spaces between them, in a ventilated room for a period of 4 h, with a current of air from an electric fan passing over them continuously for at least 2 h, will cool the specimens to approximately room temperature.

E.4 Test procedure

Place the specimens in a single layer in a tank of water (**E.1.2**) immediately after weighing so that water can circulate freely on all sides of them. Leave a space of at least 10 mm between adjacent bricks and between bricks and the side of the tank. Heat the water to boiling point in approximately 1 h, boil continuously for 5 h, and then allow to cool to room temperature by natural loss of heat for not less than 16 h or more than 19 h. Remove the specimens, wipe off the surface water with a damp cloth and weigh. When wiping perforated bricks, shake them to displace water that might otherwise be left in the perforations.

Complete weighing of any one specimen within 2 min after its removal from the water.

E.5 Calculation of water absorption

Calculate the water absorbed by each specimen, *A*, expressed as a percentage of the dry mass, using the following equation

$$A = 100\,\frac{(\text{Wet mass} - \text{dry mass})}{\text{dry mass}}$$

Calculate the water absorption of the sample, i.e. the average of the water absorptions for the ten specimens (see **2.2**), to the nearest 0.1 %.

Appendix F Appearance

F.1 *General guidance on the appearance of bricks*

The appearance of bricks is always a matter of agreement between the specifier or user and the manufacturer or supplier. The requirement will vary according to the use to which the bricks are to be put, and the inherent characteristics of the bricks, e.g. common, facing, handmade, stock, should be taken into account. As a guide bricks should be reasonably free from deep or extensive cracks and from damage to edges and corners, from pebbles and from expansive particles of lime.

F.2 Assessment of the visual acceptability of facing bricks

F.2.1 ***Introduction***

This appendix describes one way of assessing the acceptability of minor defects such as cracks, chips, surface blemishes or irregularity of shape of facing bricks when delivered to site, which cannot be judged by examining individual bricks. Sample panels from the brick deliveries are compared with a previously constructed reference panel which is representative of what may reasonably be expected to be delivered and is large enough to encompass known and acceptable variations in bricks.

This method cannot cover possible future visual defects, e.g. due to lime blowing or frost attack. It may be used to assess consistency of supply in respect of colour and texture; however, the actual colour and texture has to be agreed between the supplier and the specifier.

When making an assessment, it is essential to recognize that different types of brick, e.g. handmade, stock, machine-made, textured faced, smooth faced, will have different acceptance criteria.

F.2.2 ***Construction of the reference panel***

The reference panel should be erected on a level firm foundation in a dry location, having good natural daylight. It should be so sited that it can be retained for further inspection and reference and should, therefore, be protected from damage and the weather. If necessary, provision should be made for ensuring lateral stability.

The reference panel should be constructed to expose not less than 100 brick faces, selected as follows:

a) supplied by the manufacturer or supplier so that they are reasonably representative of the average quality of the whole order to be delivered; or

b) randomly sampled in accordance with clause **9**.

It is essential to build the reference panel so that it reasonably represents the finished work and exposes for assessment those faces which will be visible in the finished work. In particular, bricks should be laid in the bond selected for the finished work, using mortar of the same class and colour. If colour and texture are to be included in the assessment, the joints should be tooled in the same manner as the finished work.

F.2.3 ***Construction of the sample panels***

Sample panels representing individual batches should be constructed in the same way as the reference panel (see **F.2.2**).

The 100 bricks used for each panel should be randomly sampled from the batch delivered to the site in accordance with clause **9**, prior to subsequent handling on site.

F.2.4 ***Assessment***

Inspection should be carried out at any time prior to subsequent handling on site. When the sample panel is viewed at the same distance as the reference panel, without close scrutiny of individual bricks, the two panels should not differ significantly.

NOTE A viewing distance of 3 m is normally satisfactory for the purposes of this assessment. This distance may be varied by prior agreement between the supplier and the specifier.

It should be noted that there may be differences in the incidence of minor visual defects in any one batch when compared with the reference panel but the reference panel should be indicative of the average quality of the bricks.

Appendix G Check-list for ordering bricks

When enquiring about or ordering bricks, specifiers should consider carefully which of the physical properties will be of significance in the finished brickwork and specify only these. Specification of qualities which are not essential may restrict the choice of bricks offered. In using the following check-list specifiers should pay particular attention to the referenced clauses in order to assess the significance of each property and the need to specify it.

a) Type of brick.

b) Durability requirements (see clause **5** and BS 5628-3).

c) Requirements for structural use.

1) Compressive strength (see clause **7** and BS 5628-1 or BS 5628-2).

2) Water absorption (see clause **8** and BS 5628-1 or BS 5628-2).

3) Category of manufacturing control (see appendix J and BS 5628-1).

d) Any special requirements for tolerances (see **0.3**).

e) Any additional requirements not covered by the standard, e.g. colour, texture, acid resistance.

f) Quantity, including type and number of special bricks.

g) Handling requirements, e.g. pallet-loading, strapping, mechanical off-loading.

Appendix H Determination of initial rate of suction

H.1 Apparatus

H.1.1 *Large shallow dish,* e.g. a photographic dish.

H.1.2 *Two pieces of metal of equal size,* either angle sections or rods.

H.2 Test procedure

Place the dish (**H.1.1**) on a level table and position the two pieces of metal (**H.1.2**) 75 mm to 100 mm apart in the bottom of the dish.

Fill the dish with water until the pieces of metal are covered to a depth of about 3 mm.

Weigh a dry brick to the nearest gram and record the mass m_1, in grams.

Where double-frogged bricks are being tested, place the brick stretcher face downwards on the pieces of metal. Where other types of brick are being tested, place the brick bed face downwards on the pieces of metal. Ensure that the depth of immersion of the face of the brick is maintained at 3 ± 1 mm.

After 60 s, remove the brick, quickly wipe off the surplus water with a damp cloth and reweigh the brick to the nearest gram. Record the mass m_2, in grams.

Measure the length and width of immersed face of the brick in mm and calculate its gross area A, in mm^2.

Calculate the initial rate of suction, I, in kg/(m^2.min), using the following equation

$$I = \frac{1000\,(m_2 - m_1)}{A}$$

where

m_1 is the mass of the dry brick (in g);

m_2 is the mass of the wet brick (in g);

A is the area of the immersed face of the brick (in mm^2).

Appendix J Recommendations for quality control

NOTE 1 This appendix is included for information only and is outside the scope of this standard.

NOTE 2 Throughout this appendix the following symbols are used for specific statistical quantities:

$\bar{X}$ is the arithmetic mean of a population (consignment);

$\bar{x}$ is the arithmetic mean of a sample;

σ is the standard deviation of a population (consignment);

s is the standard deviation of a sample;

$\bar{X}_{10}$ is the average of 10 sample means;

σ_{10} is the standard deviation obtained from the averaging of the standard deviation of 10 samples.

J.1 Recommendations for special category of manufacturing control

Where the specifier requires masonry units to be subject to the special category of manufacturing control described in **27.2.1** of BS 5628-1:1978, he should specify the following.

a) The manufacturer should operate a quality control scheme, the results of which can be made available to demonstrate to the satisfaction of the specifier that the acceptance limit is being consistently met in practice.

b) Such a quality control scheme should be available for inspection by prospective specifiers and/or their representatives, provided a prior appointment is made.

A suitable quality control scheme for compressive strength is described in **J.2** and one for dimensions in **J.3**.

J.2 Quality control scheme for compressive strength

NOTE All the quantities used in this clause have the units N/mm^2.

J.2.1 *Introduction*

The scheme is designed to enable the manufacturer to supply consignments with a probability of not more than 1 in 40 of non-compliance with the requirements of this standard in respect of compressive strength, i.e. when any consignment is sampled and tested according to clauses **9** and **7**, there is a probability of not more than 1 in 40 that the arithmetic mean strength of the sample will be below some agreed acceptance limit, G. For this to be the case the compressive strength of the consignment $\bar{X}$, should be not less than

$$\bar{X} = G + (1.96/\sqrt{10})\sigma$$
$$\bar{X} = G + 0.62\,\sigma \qquad (1)$$

where σ is the standard deviation for the consignment, assumed to be a reasonably stable quantity equal to the short term standard deviation estimated by methods given in **J.2.3**.

For example, if bricks of stated compressive strength 40 N/mm^2 are supplied by a manufacturer the value of the acceptance limit, G, is 40 N/mm^2. If the estimated standard deviation, σ, is 7 N/mm^2, the manufacturer should aim to achieve a minimum compressive strength $\bar{X}$, of 40.0 + (0.62 × 7) = 44.34 N/mm^2.

The mean strength of acceptable consignments is kept above the minimum strength by action based on mean strength results obtained from tests on small samples, moving averages and ranges, the results being plotted on control charts. Control limits for these charts are calculated for values of G and σ (see Figure 3).

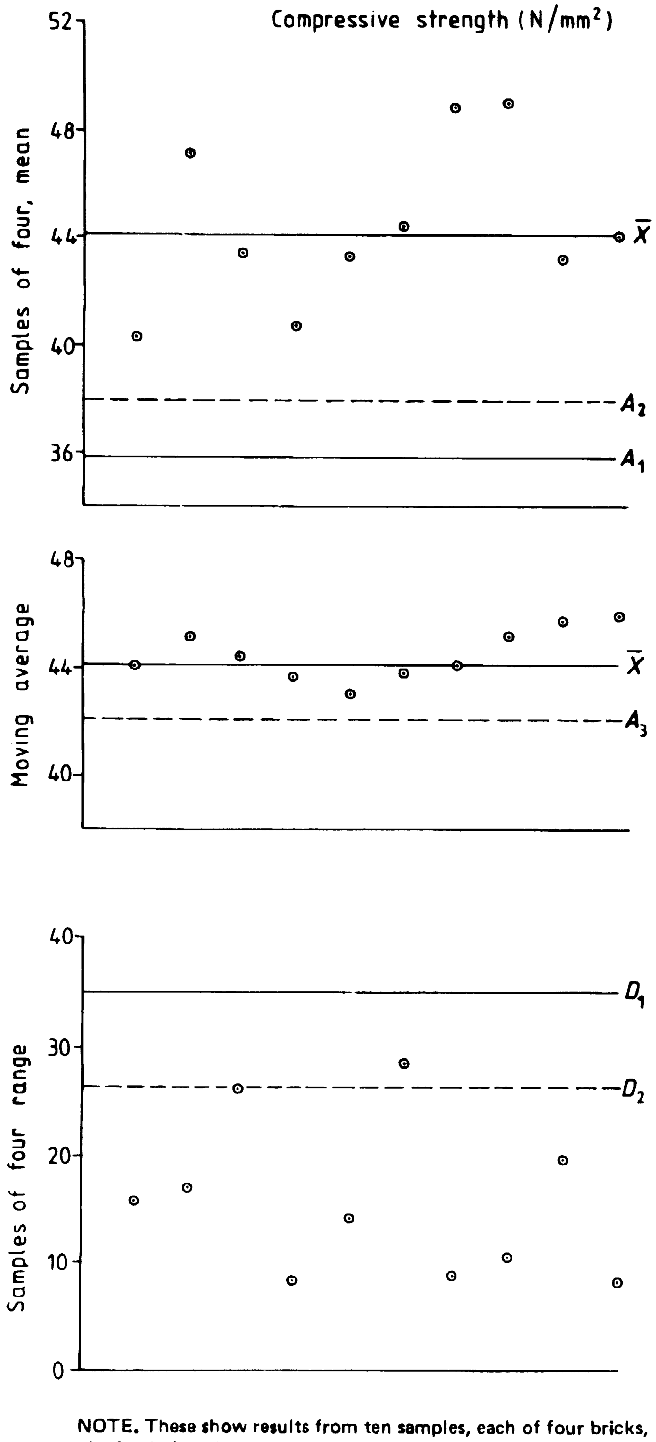
J.2.2 *Procedure*

Take samples of four bricks from the sorted output of the production unit over a short period of time. At least one sample should be taken per working day. Measure the crushing strengths and calculate the mean value x, and range $x_{max} - x_{min}$, of the sample, using the methods given in **J.2.5**. As soon as five samples have been taken, calculate the average of the last five sample means and continue this throughout the operation of the scheme, giving a series of moving averages. Plot sample means, moving averages and ranges on separate charts in sequential order with dates identified. The scales on the sample mean and moving average charts should be the same and all scales should be chosen so that fluctuations are clearly visible but not unduly pronounced. On the sample mean chart draw horizontal full lines at values $\bar{X}$ and A_1 where

$$A_1 = 2G - \bar{X} \qquad (2)$$

and a horizontal broken line at value A_2 where

$$A_2 = \frac{3G - \bar{X}}{2} \qquad (3)$$



NOTE. These show results from ten samples, each of four bricks, obtained after the scheme was well established.

Figure 3 — Example of control charts for the quality control scheme for compressive strength

On the moving average chart draw a horizontal full line at value $\bar{X}$ and a horizontal broken line at value A_3 where

$$A_3 = \frac{G + \bar{X}}{2} \quad (4)$$

On the range charts draw a horizontal full line at value D_1 and a horizontal broken line at value D_2 where

$$D_1 = 5.30\sigma \quad (5)$$

$$D_2 = 3.98\sigma \quad (6)$$

An example of a portion of such control charts is shown in Figure 3, using the values from the worked example described in **J.2.1**.

Take action in the following cases, where decreased strength or an underestimate of the standard deviation is suspected.

a) *Sample mean chart:*

1) point is below A_1;

2) point is below A_2 and corresponding moving average or one of two subsequent moving averages is below A_3;

3) two consecutive points are below A_2.

b) *Moving average chart:*

1) point is below A_3, depending on trends in all charts;

2) two consecutive points are below A_3.

NOTE The action taken will depend on individual circumstances. It may involve testing of samples from consignments according to clause **9** and/or downgrading of consignments. Subsequently, more frequent sampling may be necessary to re-establish the mean and appropriate limits and/or attention may need to be given to the manufacturing process to enable the existing limits to be maintained.

c) *Range chart:*

1) point is above D_1, depending on trends in average range;

2) frequent points are above D_2, depending on trends in average range.

Take the mean of every 25 values of the range and multiply this by 0.486 to give an estimate of the current standard deviation. If this estimate exceeds σ by more than 10 % or falls short of σ by more than 20 %, recalculate the limit on the mean, moving average, and range charts by using the new estimate as σ in the formulae. The margins of 10 % and 20 % are allowed to take account of the sampling error in estimating σ from the average range; a smaller margin is allowed when the estimate exceeds σ because in general the consequences of underestimating the standard deviation are more serious.

J.2.3 *Preparation for scheme*

The most important parameter in the scheme, as it affects the user, is the acceptance limit, G. The appropriate value may be decided by previous experience, i.e. successful working to that particular limit. If sufficiently extensive records of compressive strength measurements on samples of the brick are available, they may be used to provide estimates of the standard deviation, σ, and of the appropriate value of G. If records indicate that a long term drift of consignment mean may be expected to occur in normal working, the value of G selected should allow for this. It is advisable to err on the high side when estimating σ, as the consequences of overestimation are in general less serious than those of underestimation.

If adequate records are not available, determine the average strength and short term variation over a period of normal working, preferably not exceeding one week.

NOTE This first estimate is intended only to allow the quality control scheme to be started and it will be necessary to note the results over the period of likely long term variation before basing marketing on a particular mean strength.

Take ten samples, each consisting of ten bricks, at random from the sorted output of the production unit and set aside for the determination of compressive strength. To ensure that the variation within each sample may be regarded as short term, take each sample of ten as described in clause **9**. If two such samples are taken each day for 5 days, the required samples are obtained.

Calculate the compressive strength $\bar{x}$, and standard deviation s, for each sample as described in **J.2.5**.

Obtain the grand mean, $\bar{X}_{10}$, by taking the mean of the ten sample means.

$$\bar{X}_{10} = \frac{(\bar{x}_1 + \bar{x}_2 + \ldots + \bar{x}_{10})}{10} \qquad (7)$$

Estimate the short term standard deviation, σ_{10}, by taking the mean of the sample standard deviations s, for ten samples and multiplying by 1.03 to correct for a slight tendency of the sample value to be an underestimate.

$$\sigma_{10} = 1.03\,(s_1 + s_2 + \ldots + s_9 + s_{10})/10 \qquad (8)$$

If the value of G has not already been decided on other grounds, test a number of possible values by substituting $\bar{X}_{10}$ for $\bar{X}$ and σ_{10} for σ in equation (1)

$$X_{10} = G + 0.62\sigma_{10} \qquad (9)$$

The value of G finally chosen should be such that the corresponding value of $\bar{X}$ is either:

a) not higher than that estimated to be easily attainable on the evidence of past records; or

not greater than the value of the grand mean, $\bar{X}_{10}$.

In case (b) it is desirable to allow some margin of safety, because conditions may possibly have been unusually good when the samples were taken and so the value of $\bar{X}_{10}$ may be higher than some of the values of $\bar{X}$ likely to be obtained.

Calculate the other limits (A_1, A_2, A_3 and D_2) using equations (2) to (6).

It should be noted that if it is found to be necessary to revise the value of σ_{10} or σ because of changed conditions, the distance between the levels G and $\bar{X}$ is affected and the other limits are altered too.

J.2.4 ***Interpretation of limits***

If the true value of the consignment mean is $\bar{X}$ and the standard deviation is σ the probabilities of the mean crushing strengths of samples of four bricks being below the calculated limits are approximately as follows:

Single mean below A_1	1 in 150
Single mean below A_2	1 in 32
Two consecutive means below A_2	1 in 1000

The probability of a single moving average being below A_3 is about 1 in 12.

Successive moving averages are not independent and it is difficult to calculate the probability of two successive averages below A_3, but an approximate calculation gives a probability of the order of 1 in 20.

The probability of the sample range exceeding the calculated limits is:

Range above D_1	1 in 1 000
Range above D_1	1 in 40

Quality control charts are intended to give evidence that the situation is under control. It is therefore advisable to reinforce the strict rules regarding compliance with the limits by a careful appraisal of the trend of the moving averages so as to anticipate possible trouble. The scheme works best if G is so chosen that a substantial majority of sample means and moving averages is above $\bar{X}$, so ensuring that there is some margin between normal performance and strict requirements. If the product only just complies with the level of $\bar{X}$ calculated, there will be fairly frequent need to decide whether or not to take corrective action on the basis of the control charts; this may lead to uncertainty and disruption of normal procedures and is best avoided.

J.2.5 ***Calculation of mean and standard deviation***

If a sample of n values of compressive strength has been obtained and they are x_1, x_2, $x_3 \ldots x_n$, the following statistical parameters may be calculated:

Mean = $\bar{x} = (x_1 + x_2 + x_3 + \ldots + x_n)/n$

Range = $x_{max} - x_{min}$

where x_{max} and x_{min} are the maximum and minimum values in the sample.

$$\text{Standard deviation} = \sqrt{\frac{\left(x_1^2 + x_2^2 + \ldots + x_n^2\right) - \frac{(x_1 + x_2 + \ldots + x_n)^2}{n}}{n - 1}}$$

For the purpose of these calculations, individual strengths should be stated to the nearest 0.1 N/mm^2 irrespective of the magnitude of the values.

J.3 Quality control scheme for dimensions

NOTE All the quantities used in this clause have the units mm.

J.3.1 *Introduction*

The scheme is intended to ensure that batches of bricks will be unlikely to fail to comply with the dimensional requirements of clause **4**.

The scheme assumes that when production is stable the standard deviation within a batch of bricks is roughly constant and can be estimated. Batches may not comply because:

a) the batch mean has drifted too far from the target value; or,

b) there is a sudden change of the batch mean to an unacceptable value; or,

c) the batch standard deviation has increased appreciably.

The scheme is aimed chiefly at controlling a gradual drift, as described in a). The control limits are set so that when a batch has a 1 in 75 chance of rejection it has approximately a 1 in 17 chance of giving a point outside the limit for means. Similarly, when the chance of rejection is 1 in 20 there is approximately a 1 in 8 chance of a point being outside the limit. Hence, if the mean is drifting, the drift can be detected before it causes serious trouble.

The occurrence of a point outside the limit is not a cause for rejection of a batch. When a point is outside the limit, the process should be examined, action taken if necessary, and subsequent points should be watched.

It is possible to choose warning limits that will give more advanced warning of a drift in the mean, but it is important not to make them so stringent that they frequently give false alarms. A batch with a 1 in 75 chance of rejection would have a 1 in 5 chance of giving a point outside a warning limit. When the frequency of points outside the warning limits is 1 in 20, the mean has already drifted a high proportion of the way towards producing unsatisfactory material.

J.3.2 *Procedure*

J.3.2.1 *General.* Measure the total length, width and height of a group of six bricks as described in appendix A or by means of a gauge board (see **J.3.2.2**).

Take two random samples, each of six bricks, from each batch that is sampled; a number of batches should be sampled daily. For each sample of six, measure the total length, width and height, and plot the average of the two total lengths for each batch, and the range, or difference, between the two total lengths on average and range charts. Plot similar charts for width and height. After a period of reasonably stable production, covering at least 20 measured batches, calculate the average range. Revise this figure from time to time as more results become available.

Control limits for the range charts are 2.81 $\overline{(X_{max} - X_{min})}$ for the 1 in 40 limit and 4.12 $\overline{(X_{max} - X_{min})}$ for the 1 in 1 000 limit. Provided that the points are not above the 1 in 40 limit, it is customary to assume that the variability is reasonably stable. The occurrence of an undue proportion of points above the 1 in 40 limit may indicate that the average range figure needs to be revised or that the variability is unstable.

If the variability is stable, calculate the standard deviation within the batch *s*, for each dimension, using the formula

$$s = \frac{\overline{(x_{max} - x_{min})}}{2.76}$$

Insert limits on the average charts and take action when points occur outside these limits as indicated in **J.3.1**. It is convenient to give limits to the nearest 1 mm; if this is done the probability levels given in **J.3.1** are no longer strictly accurate, but are sufficiently close for practical purposes. In any case it is difficult to achieve an accuracy better than 2 mm in actual measurement of the totals. The control limits (in millimetres) are as follows.

Length	1271 and 1309
Width	604 and 626
Height	379 and 401

The algebraic expressions for the warning limits, based on the appropriate standard deviations *s*, are as follows.

Length	1271.25 + 1.27 *s* and 1308.75 – 1.27 *s*
Width	603.75 + 1.27 *s* and 626.25 – 1.27 *s*
Height	378.75 + 1.27 *s* and 401.25 – 1.27 *s*

The position of these limits is not very sensitive to small changes in the value of *s*. It is possible to use fixed warning limits calculated by giving *s* the values assumed in deriving clause **4**, namely 1.9 mm for length and 1.27 mm for width and height. The fixed warning limits (in millimetres) are as follows.

Length	1274 and 1306
Width	605 and 625
Height	380 and 400

J.3.2.2 *Use of gauge board.* Measure each sample of six bricks by packing them together, end to end, side to side, etc. on a gauge board having graduated metal plates, e.g. brass or stainless steel, set into the frame and flush with the surface. Each metal plate is graduated in a convenient unit, such as 2 mm, the graduations running from, say, + 15 to – 15.

Position the plates so that the zero mark on the scale is at a distance 1290 mm for length, 615 mm for width and 390 mm for height, from a reference stop at the end of the board corresponding to the target total for six bricks.

Although the limits are calculated to the nearest half unit, it is quite sufficient to read each total for six bricks to the nearest unit.

Record the measurements directly in terms of gauge units.

NOTE 1 Care should be taken when manipulating negative values. For example, if the two totals for samples of six bricks are + 1 and –4 units, the average total is (1 – 4)/2 = – 1½ units and the range is 1 – (– 4) = 5 units. If the totals are – 1 and – 4 units, the average is (– 1 – 4)/2 = – 2 ½ units and the range is – 1 – (– 4) = – 1 + 4 = 3 units. The range is always positive.

To calculate the standard deviation *s*, in millimetres, divide the average range in gauge units by 1.38. The control charts can be plotted in terms of gauge units and the limits may be determined from the average range $(\overline{X_{max} - X_{min}})$ also in gauge units. The control limits for the range charts are 2.81 $(\overline{X_{max} - X_{min}})$ for the 1 in 40 limit and 4.12 $(\overline{X_{max} - X_{min}})$ for the 1 in 1 000 limit.

The appropriate values for the various limits rounded off to the nearest half unit are given in Table 6.

NOTE 2 There is no reason why the gauge unit should necessarily be 2 mm. If an alternative gauge unit were adopted, it would be necessary to recalculate the limits using similar statistical principles, and works quality control charts may then be kept in a similar manner.

NOTE 3 It is possible to avoid the use of negative numbers and the slight complications involved in their manipulation, by graduating the scale from 0 to 30 instead of – 15 to + 15. Here the target average dimension will be 15. The disadvantage is that the values to be recorded for the average are usually double-figure numbers.

Table 6 — Limits for the dimensions measured when using the gauge board

Limit	Dimensions	Lower limit	Upper limit
		1 mm units	1 mm units
Control	Length	– 19	+ 19
	Width	– 11	+ 11
	Height	– 11	+ 11
Warning	Length	$-18.8 + 0.92\,(\overline{X_{max} - X_{min}})$	$+18.8 - 0.92\,(\overline{X_{max} - X_{min}})$
	Width	$-11.2 + 0.92\,(\overline{X_{max} - X_{min}})$	$+18.8 - 0.92\,(\overline{X_{max} - X_{min}})$
	Height	$-11.2 + 0.92\,(\overline{X_{max} - X_{min}})$	$+18.8 - 0.92\,(\overline{X_{max} - X_{min}})$
Fixed warning	Length	– 16	+ 16
	Width	– 10	+ 10
	Height	– 10	+ 10

Publications referred to

BS 12, *Specification for ordinary and rapid-hardening Portland cement.*

BS 410, *Specification for test sieves.*

BS 427, *Method for Vickers hardness test.*

BS 427-1, *Testing of metals.*

BS 915, *High alumina cement.*

BS 915-2, *Metric units.*

BS 970, *Specification for wrought steels for mechanical and allied engineering purposes.*

BS 970-1, *General inspection and testing procedures and specific requirements for carbon, carbon manganese and stainless steels.*

BS 1134, *Method for the assessment of surface texture.*

BS 1610, *Methods for the load verification of testing machines.*

BS 2648, *Performance requirements for electrically-heated laboratory drying ovens.*

BS 4551, *Methods of testing mortars, screeds and plasters.*

BS 4729, *Shapes and dimensions of special bricks.*

BS 5628, *Code of practice for use of masonry.*

BS 5628-1, *Structural use of unreinforced masonry.*

BS5628-2, *Structural use of reinforced and prestressed masonry.*

BS5628-3, *Materials and components, design and workmanship.*

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

BS 6100-5, *Masonry.*

BS 6100-5.3, *Bricks and blocks.*

BS 6649, *Specification for clay and calcium silicate modular bricks.*

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