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FOREWORD

This Standard has been prepared to replace the various parts and editions of BS1881 hitherto used, which are not entirely suitable for Hong Kong conditions. It provides methods for sampling and testing concrete and it covers the procedures to be adopted both on site and in the laboratory.

The contents of the Standard are based primarily on the following British Standards, with modifications to suit local conditions and practices:

BS 1881 : Part 1 to 6 :1970
BS 1881 : Part 101 : 1983
BS 1881 : Part 102 : 1983
BS 1881 : Part 103 : 1983
BS 1881 : Part 104 : 1983
BS 1881 : Part 106 : 1983
BS 1881 : Part 107 : 1983
BS 1881 : Part 108 : 1983
BS 1881 : Part 109 : 1983
BS 1881 : Part 110 : 1983
BS 1881 : Part 111 : 1983
BS 1881 : Part 114 : 1983
BS 1881 : Part 115 : 1986
BS 1881 : Part 116 : 1983
BS 1881 : Part 117 : 1983
BS 1881 : Part 118 : 1983
BS 1881 : Part 120 : 1983
BS 1881 : Part 121 : 1983
BS 1881 : Part 124 : 1983
BS 1881 : Part 125 : 1986

The Standard comprises two volumes. Volume 1 generally covers site operations, including methods of sampling fresh concrete, testing of fresh concrete and making and curing test specimens. Volume 2 is intended to be used by laboratory staff and covers sampling of fresh concrete in the laboratory, methods of determining the physical properties of hardened concrete and the sampling and chemical analysis of hardened concrete. This division of the contents is purely for convenience and has no other implications.

The permission of the British Standards Institution to reproduce and modify its publications is gratefully acknowledged.

Any comments on the contents of this Standard should be addressed to the Chairman, Standing Committee on Concrete Technology, Works Branch, Hong Kong Government.

DRAFTING COMMITTEE

The preparation of this Standard was undertaken by a sub-committee of the Hong Kong Government, Works Branch, Standing Committee on Concrete Technology. The organisations represented on the sub-committee and the names of the persons who contributed to the drafting of the Standard are listed below:

Works Branch	R H Pilling	(Chairman)
Civil Engineering Services Department	T K Cheung	
	C J Chivers	
	P W C Leung	(Secretary)
	K C Sin	
	W L Tse	
	E K C Pang	
Buildings and Lands Department	P J Osborne	
Highways Department	T K Lee	
	W F Ho	
	K T Li	
	S M Wong	
Housing Department	G Waterton	
	J V Schembri	
	S C Yeung	
	H W Pang	
	T T Kam	
	S Y Cheung	
The Concrete Producers Association of Hong Kong Ltd	P R Jones	
	P E Halstead	
Hong Kong Association of Certification Laboratories Ltd	A P Jeary	
	D S C Chiu	
Hong Kong Construction Association Ltd	D T Riley	
	H Y Lam	
Hong Kong Institution of Engineers	K Francis	

CONTENTS

Page

VOLUME 1

VOLUME 2

LIST OF TABLES

Table **Page**

VOLUME 1

VOLUME 2

LIST OF FIGURES

Figure **Page**

VOLUME 1

VOLUME 2

GENERAL NOTES

The following notes are relevant, where applicable, to all the sections of this Standard.

1. Reports

(a) It is a mandatory requirement for all reports to contain the name and signature of the person responsible for the sampling or the test. The person responsible for the test is not necessarily the same as the person actually carrying out the test. For HOKLAS accredited laboratories the person responsible should be an authorised signatory.

(b) The person responsible for the test must ensure that all the information listed for the inclusion in a Report is fully and accurately stated. However, some of the information listed for inclusion in a Report may not be known to the person responsible for the test. In such a case the words `not known' should be entered in the Report.

(c) If any test is performed on a specimen which does not fully comply with this Standard (e.g. a cube which has not been cured in accordance with Section 10) or if the test itself does not fully conform to the requirements of this Standard, the test result, although it may have some indicative value, will be invalid and this must be stated in the Report.

2. Apparatus

In general the lists of required apparatus in the Standard do not include standard items of equipment and consumables which are normally found in a well equipped testing facility.

3. Tolerances

The tolerances stated in various sections of this Standard shall be interpreted as follows:

(a) **Flatness.** The surface specified as having a flatness tolerance shall lie between two parallel planes. The perpendicular distance between the planes is the flatness tolerance quoted.

(b) **Squareness.** Where a surface is specified as having a squareness tolerance relative to another surface, it shall lie between two parallel planes perpendicular to the reference surface. The perpendicular distance between the planes is the squareness tolerance quoted. Where a surface is specified as having a squareness tolerance relative to a datum line (e.g. the axis of a cylinder), it shall lie between parallel planes perpendicular to the datum line. The perpendicular distance between the two planes shall be the squareness tolerance quoted.

(c) **Parallelism.** Where is a surface is specified as having a parallelism tolerance relative to another surface, it shall lie between two planes parallel to the reference surface. The perpendicular distance between the planes shall be the parallelism tolerance quoted.

(d) **Cylindricity.** Where a surface is specified as having a cylindricity tolerance, the surface shall lie between two coaxial cylindrical surfaces. The radial distance between the two coaxial surfaces shall be the cylindricity tolerance quoted.

4. Singular and plural

Words importing the singular only also include the plural and vice versa where the content requires.

SECTION 11

MIXING AND SAMPLING FRESH CONCRETE IN THE LABORATORY

11.1 SCOPE

This Section describes the methods for the preparation of materials and the batching, mixing and sampling of concrete in the laboratory.

11.2 DEFINITIONS

Batch is the quantity of concrete mixed in one cycle of operations of a mixer or the quantity mixed by hand in one cycle of operations.

11.3 APPARATUS

The following apparatus is required:

(a) Mixer (see C1. C1).
(b) Sample container (see C1. C2).
(c) Sample tray (see C1. C3).
(d) Scoop (see C1. C4).
(e) Square-mouthed shovel.

Further details of the apparatus are given in Appendix C.

11.4 CONSTITUENT MATERIALS

11.4.1 Sampling

If bulk samples are supplied, subsamples for the test portions shall be taken in accordance with the relevant Standard and shall be representative of the bulk materials. Where required, samples shall be accompanied by a certificate of sampling in accordance with the relevant Standard. Otherwise, the materials in the proportions supplied or specified for the mix shall be used.

11.4.2 Cement and pulverized-fuel ash (PFA)

Upon their arrival at the laboratory, the materials shall be stored in separate airtight containers of appropriate size in a dry place. Before use, each separate material shall be stirred thoroughly either with a hand tool or in a suitable mixer, in such a manner as to ensure the greatest possible uniformity. Care shall be taken to avoid the intrusion of foreign matter or loss of material.

11.4.3 Aggregates

The moisture content (as a percentage of the oven dry mass) of the aggregates shall be determined in accordance with BS812 : Part 2.

The aggregates shall be in one of the following conditions:

(a) Oven dried as described in BS812: Part 2.
(b) Air dried at 25 ± 5^0C.
(c) Saturated surface dry as described in BS812: Part 2.
(d) Saturated by soaking in water for at least 24 hours.

The aggregate for each batch may be used either in separate size fractions or with an all-in grading. Care shall be taken to prevent loss of fines during the saturation process.

Note. *The easiest way to standardise the condition of aggregate is by saturation.*

11.4.4 Temperature

All materials shall be at a temperature of 25 ± 5^0C before mixing.

11.5 BATCHING

The quantity of concrete in each batch shall be at least 10% more than that required for the proposed test.

For each batch, the cement, PFA, aggregate and water shall be weighed to an accuracy of 0.5% or better.

If an admixture is to be incorporated, the amount shall be measured to within 0.5% of the specified dosage and the manufacture's instructions for use shall be followed.

11.6 MIXING

11.6.1 General

The concrete shall be mixed in a room having an ambient temperature of 25 ± 5^0C and a relative humidity of not less than 50%.

If the aggregate is dry, it shall be soaked with some of the mixing water before adding other materials. Loss of water by evaporation shall be avoided.

After the dry aggregate has been allowed to soak, admixtures if required may be added together with the remaining portion of the mixing water, except in the case of admixtures that need to be added shortly before using the concrete.

The concrete shall be mixed, preferably by machine or alternatively by hand, in such a manner as to avoid loss of water or other materials.

Note. *Different methods of mixing may lead to different results.*

11.6.2 Machine mixing

The size of the batch shall be of sufficient volume to allow thorough mixing.

Before using the mixer, any fresh concrete remaining from a previous batch shall be cleaned out. No free water shall remain in the mixer. If the mixer is dry it shall be wiped with a damp cloth. When using a tilting drum mixer, a small preliminary batch, of similar proportions to the main batch, shall be mixed and discharged immediately before the main batch in order to coat the mixer.

The mixer shall be charged with about one half of the coarse aggregate, then with the fine aggregate, then with the cement and finally with the remaining coarse aggregate. The water shall be added immediately before the rotation of the drum or pan is started. The period of mixing shall be not less than two minutes and mixing shall continue until the concrete appears to be uniform and homogeneous. When using a pan mixer not fitted with a discharging gate the concrete shall be heaped together before sampling. When using other types of mixer the discharged concrete shall be remixed on a sample tray in such a manner as to ensure uniformity.

11.6.3 Hand mixing

The concrete batch shall be mixed on a sample tray with a square-mouthed shovel or similar suitable implement, using the following procedure:

The cement and fine aggregate shall be mixed dry until the mixture is uniform. The coarse aggregate shall be added and mixed dry with the cement and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch. The water shall then be added and the whole mixed for at least three minutes and until the concrete appears to be homogeneous.

11.7 SAMPLING AND TESTING THE CONCRETE

Tests on fresh concrete and the preparation of specimens for tests on hardened concrete shall start as soon as possible after completion of mixing. The required operations shall be carried out during a period of not more than one hour from the addition of the water to the cement. The fresh concrete shall be protected against gaining or losing water.

Provided that care is taken to ensure that no water or other material is lost, the concrete used in workability and density tests may be remixed with the remainder of the batch before making any specimen for testing hardened concrete. The period of remixing should be as short as possible but sufficient to produce a homogeneous mass.

11.8 REPORT

The report shall affirm that the preparation of materials, batching, mixing and sampling were carried out in accordance with this Standard. The report shall be include the following:

(a) Name and address of laboratory.
(b) Name of project, if any.
(c) Batch identity number.
(d) Date and time of adding water to the mix.
(e) Description of materials, including moisture content and condition of the aggregates.
(f) Particle size of aggregates.
(g) Grade of concrete.
(h) Actual quantities or proportions of material batched and admixtures added.
(i) Method of mixing, type and rated capacity of mixer.
(j) Any observations on the appearance of the fresh concrete, e.g. segregation and bleeding.
(k) Name and signature of person responsible for mixing and samplig and sampling.

SECTION 12

DETERMINATION OF COMPRESSIVE STRENGTH OF CONCRETE CUBES

12.1 SCOPE

This Section describes the method of determining the compressive strength of concrete cubes.

12.2 APPARATUS

The following apparatus is required:

(a)	Compression testing machine	(see C1. C5).
(b)	Cube checking jig	(see C1. C6).
(c)	Calliper	(see C1. C7).
(d)	Weighing equipment Type 2	(see C1. C8).
(e)	Feeler gauges	(see C1. C9).

Further details of the apparatus are given in Appendix C.

12.3 PROCEDURE

12.3.1 Preparation

Cubes stored in water or a mist room shall be tested within one hour of removal from the water or mist room, whilst they are still wet. Surface water and grit on the cube shall be wiped off and projecting fins removed.

12.3.2 Measurement of cubes

All cubes shall be visually inspected. Any cube which was unprotected on delivery or has unsatisfactory features shall be recorded as such. A cube having an edge broken for 20 mm or more in any direction shall be recorded as ‘a cube with damaged edge’.

All cubes shall be checked to ensure that they satisfy the squareness requirement given in Section 7 of this Standard. Each cube shall be placed in the cube checking jig with the trowelled surface upwards, and the contact between the cube and jig shall be checked with the feeler gauges. The cube shall then be turned through 90^0 and the check repeated. Should the squareness of the cube not be within 1 % of the cube dimension, the amount of out of squareness shall be recorded and the cube described as irregular.

The cube dimensions between the three pairs of opposing faces shall be measured with a calliper. A cube whose dimensions differ from the nominal dimensions by more than 1 mm on width or 2 mm on height as cast shall be recorded as ‘oversize’ or ‘undersize’ as appropriate.

Each cube shall be weighed to the nearest 5 g and the as-received or saturated density determined in accordance with Section 16 of this Standard.

12.3.3 Placing the cube in the testing machine

The bearing surfaces of the testing machine shall be wiped clean and any loose grit or other extraneous material shall be removed from the surfaces of the cube which are to be in contact with the platens. No packing other than the spacing blocks shall be used between the cube and platens. The cube shall be carefully centred on the lower platen. The trowelled surface shall be vertical.

12.3.4 Loading

The load shall be applied steadily and without shock such that the stress is increased at a rate within the range of 0.2 MPa/s to 0.4 MPa/s until no greater load can be sustained. On manually controlled machines as failure is approached the loading rate will decrease; at this stage the specified loading rate shall be maintained as nearly as possible. The maximum load applied to the cube shall be recorded.

12.4 TYPE OF FAILURE

Any unusual features in the type of failure shall be recorded. Examples of satisfactory failures and of some unsatisfactory failures as shown in Figure 6.

12.5 CALCULATION AND EXPRESSION OF RESULTS

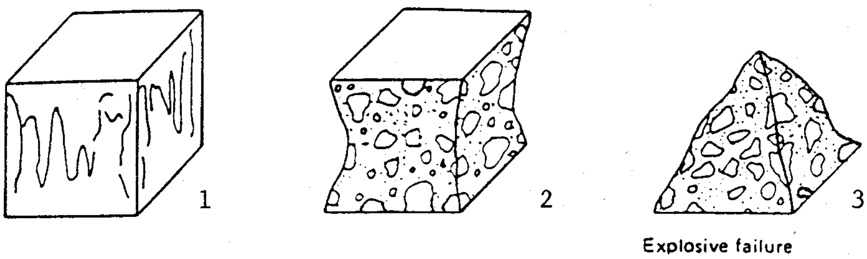
The cross-sectional area of the cube shall be calculated from the measured dimensions. The compressive strength of the cube shall be calculated by dividing the maximum load by the cross-sectional area. The result shall be expressed to the nearest 0.5 MPa. The density of the specimen shall be calculated using the measured dimensions or the volume obtained from the water displacement method.

12.6 TEST REPORT

The report shall affirm that the test was carried out in accordance with this Standard and shall include the following:

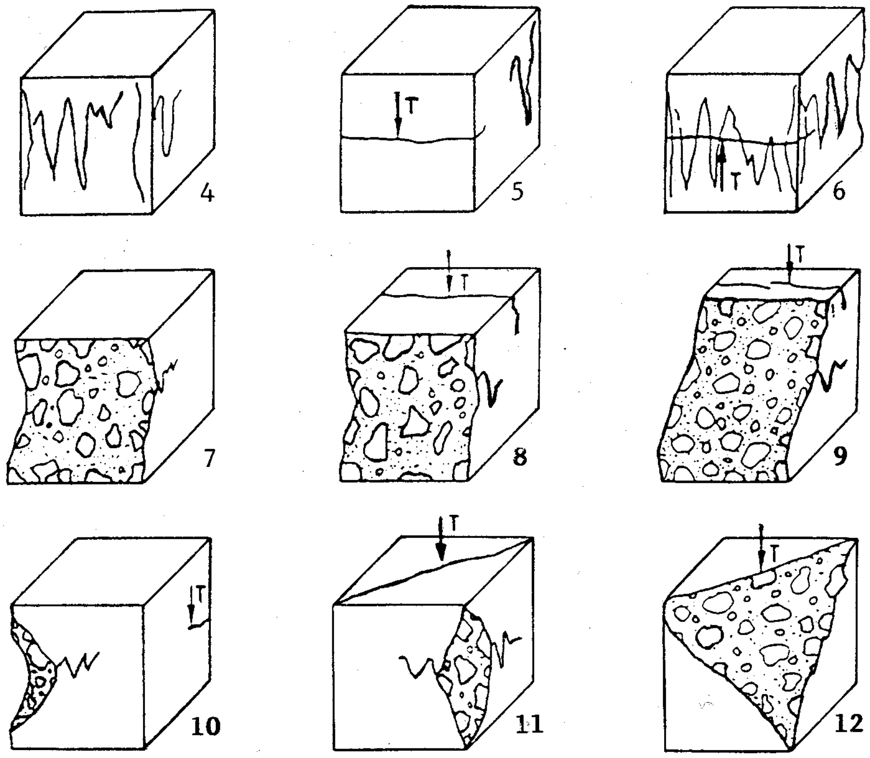
(a) Identification number of the specimen.
(b) Date of receipt of the cube at the laboratory.
(c) Date of test.
(d) Age of the specimen at test.
(e) Condition of the specimen when received (including poor compaction, honeycombing, incorrect dimensions or out of squareness).
(f) Curing report, if cured in laboratory.
(g) Measured dimensions of specimen.
(h) Mass of the specimen (as-received or saturated).
(i) Density of the specimen (as-received or saturated, and the method of determining the volume).
(j) Maximum load at failure.
(k) Compressive strength.
(l) Appearance of the concrete and type of fracture if these are unusual.
(m) Other remarks if any.
(n) Name and signature of person responsible for testing.

Note. *The reports on the production and curing of the test specimen (see Sections 7 and 10) may conveniently be added to this report.*



Note. *All four exposed faces are cracked approximately equally, generally with little damage to faces in contact with the platens.*

Satisfactory Failures



Note. *T = tensile crack*

Unsatisfactory Failures

Figure 6 - Failure Patterns of Cubes

SECTION 13

DETERMINATION OF TENSILE SPLITTIG STRENGTH

13.1 SCOPE

This Section describes the method of determining the Tensile Splitting Strength of cylindrical concrete test specimens.

13.2 DEFINITIONS

Tensile Splitting Strength is the theoretical maximum indirect tensile stress obtained by splitting the specimen under a concentrated compressive line load.

13.3 APPARATUS

The following apparatus is required:

(a) Compression testing machine(see C1. C5).
(b) Jig for splitting strength test (see C1. C10).
(c) Packing strips (see C1. C11).
(d) Steel loading pieces (see C1. C12).

Further details of the apparatus are given in Appendix C.

13.4 TEST SPECIMENS

13.4.1 Specimen size

The test specimen shall be a 150 mm diameter by 300 mm long cylinder made, cured and stored in accordance with Sections 9 and 10 of this Standard.

13.4.2 Dimensions

The dimensions of each specimen shall be measured in accordance with Section 16 of this Standard.

13.4.3 Mass and density

Each specimen shall be weighed to the nearest 10 g and the as-received or saturated density determined in accordance with Section 16 of this Standard.

13.5 PROCEDURE

Mist room or water cured specimens shall be tested within one hour of removal from the water or mist room, whilst they are still wet.

13.5.1 Preparation for testing

The bearing surfaces of the testing machine, the steel loading pieces and the packing strips shall be wiped clean; any loose material on the surfaces of the test specimen which are to be in contact with the packing strips shall be removed.

13.5.2 Positioning of the test specimen

The test specimen shall be placed in the centering jig with packing strips and loading pieces carefully positioned along the top and bottom of the plane of loading of the specimen. The jig shall then be placed in the machine so that the specimen is located centrally. The upper platen shall be parallel to the lower platen (see Figure 11 of Appendix C).

13.5.3 Loading

The load shall be applied steadily and without shock such that the stress is increased at a rate within the range of 0.02 MPa/s to 0.04 MPa/s. Once adjusted, the rate shall be maintained until failure. On manually controlled machines as failure is approached the loading rate will decrease; at this stage the specified loading rate shall be maintained as nearly as possible. The maximum load applied to the specimen shall be recorded. The rate of increase of load may be calculated from the following expression:

$$(0.02 \text{ to } 0.04) \times \frac{\pi}{2} \times L \times d \quad \text{N/s} \qquad \textbf{(13-1)}$$

where

L is the average measured length of the specimen (in mm)
d is the average measured length of the specimen (in mm)

13.6 CALCULATION AND EXPRESSION OF RESULTS

The Tensile Splitting Strength f_{ct} in MPa is given by the equation:

$$f_{ct} = \frac{2F}{\pi \times L \times d} \qquad \textbf{(13-2)}$$

where

F is the maximum load (in N)
L is the average measured length (in mm)
d is the average measured diameter (in mm)

The Tensile Splitting Strength shall be expressed to the nearest 0.05 MPa.

13.7 TEST REPORT

The report shall affirm that the test was carried out in accordance with this Standard and shall include the following:

(a) Identification number of the specimen.
(b) Date of receipt of the specimen at the laboratory.
(c) Date of test.
(d) Age of the specimen at test.
(e) Condition of the specimen when received (include poor compaction, honeycombing or incorrect dimensions).
(f) Curing report, if cured in laboratory.
(g) Mass of the specimen (as-received or saturated).
(h) Measured dimensions of the specimen.
(i) Density of the specimen (as-received or saturated and the method of determining the volume).
(j) Maximum load at failure.
(k) Tensile Splitting Strength.
(l) Appearance of concrete and type of fracture if these are unusual.
(m) Other remarks if any.
(n) Name and signature of person responsible for testing.

Note. *The reports on the production and curing of the test specimen (see Sections 7 to 10) may conveniently be added to this report.*

SECTION 14

DETERMINATION OF FLEXURAL STRENGTH

14.1 SCOPE

This Section describes the method of determining the Flexural Strength of a test specimen of hardened concrete.

14.2 DEFINITIONS

Flexural Strength is the theoretical maximum tensile stress reached in the bottom fibre of a test beam during a flexural strength test.

14.3 APPARATUS

The following apparatus is required:

(a) Compression testing machine	(see C1. C5).
(b) Flexural loading device	(see Figure 7 and C1. C13).

Further details of the apparatus are given in Appendix C.

14.4 TEST SPECIMENS

14.4.1 Specimen size

Test specimens shall be 150 mm x 150 mm x 750 mm long moulded concrete beams made in accordance with Section 8 and cured in accordance with Section 10 of this Standard.

14.4.2 Tolerances

The specimen shall be checked with a try-square, straight edge and calliper to ensure that it satisfies the tolerance requirements of Section 8.

In addition, the flatness tolerance for the bearing surfaces at the four positions of the rollers shall be 0.25 mm.

14.4.3 Mass and density

The specimen shall be weighed to the nearest 10g and the as-received or saturated density determined in accordance with Section 16 of this Standard.

14.5 PROCEDURE

Specimens stored in water or a mist room shall be tested within one hour or removal from the water or mist room, whilst they are still wet.

The bearing surfaces of the supporting and loading rollers shall be wiped clean and loose grit or other extraneous material shall be removed from the specimen.

The test specimen shall be correctly centred in the machine with the trowelled surface vertical (see Figure 7). The rollers shall be placed at right angles to the longitudinal axis of the specimen.

There shall be no packing between the specimen and the rollers. All loading and supporting rollers shall be in even contact with the test specimen before load is applied. The load shall be applied steadily and without shock such that the stress is increased at a rate within the range of 0.03 to 0.06 MPa/s.

Once adjusted, the rate of loading shall be maintained without change until failure occurs. The maximum load applied shall be recorded.

Note. *A rate of increase of loading of 450 N/s is equivalent to an increase of stress of 0.06 MPa/s for a 150 mm specimen.*

Failures outside the middle one-third of the distance between the supporting rollers shall render the test invalid.

14.6 CALCULATION AND EXPRESSION OF RESULTS

The Flexural Strength f_{cf} (in MPa) is given by the equation

$$f_{cf} = \frac{450 \times F}{d_1 \times d_2^2} \qquad \textbf{(14-1)}$$

where

F	is the maximum load (in N)
d_1 & d_2	are the width and depth of the specimen respectively (in mm) (see Figure 7).

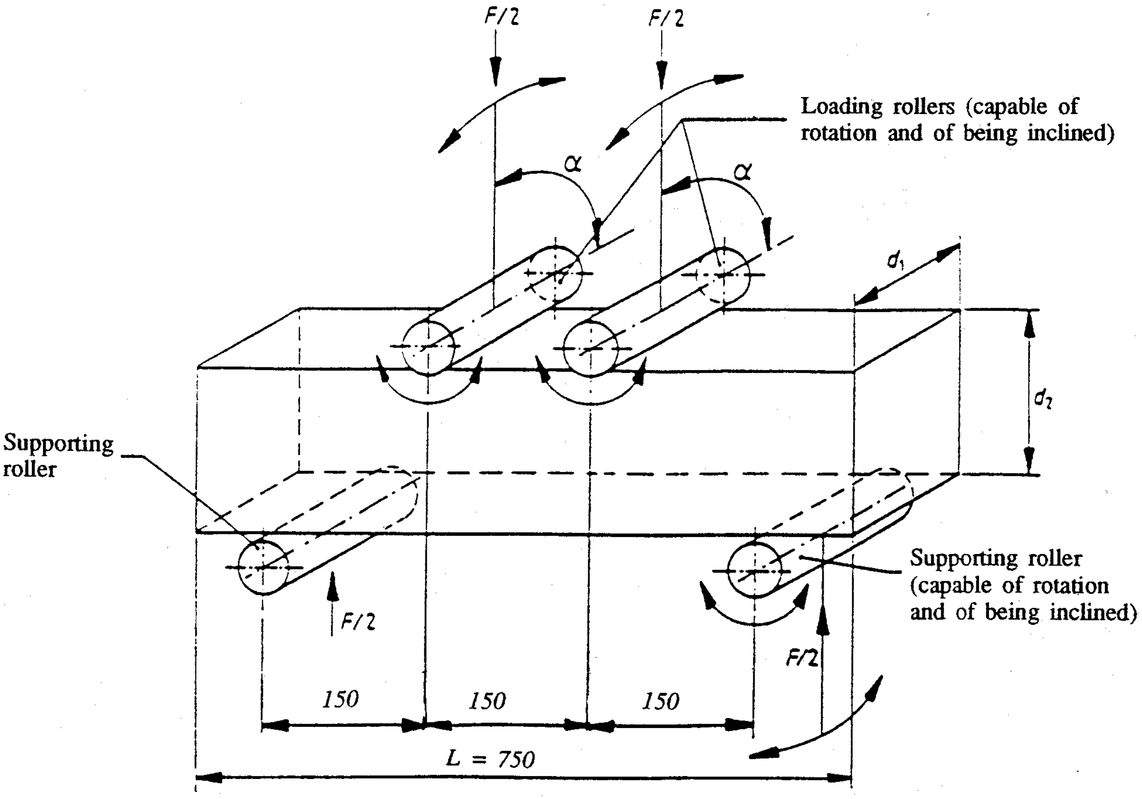
The Flexural Strength shall be expressed to the nearest 0.1 MPa.

14.7 TEST REPORT

The report shall affirm that the test was carried out in accordance with this Standard and shall include the following:

(a) Identification number of the specimen.
(b) Date of receipt of the specimen.
(c) Date of test.
(d) Age of the specimen at the time of testing.
(e) Condition of specimen when received (include poor compaction, honeycombing or incorrect dimensions).
(f) Curing report, if cured in the laboratory.
(g) Mass of the specimen (as-received or saturated).
(h) Measured dimensions of the specimen.
(i) Density of the specimen (as-received or saturated, and the method of determining the volume).
(j) Rate of loading.
(k) Maximum load at failure.
(l) Flexural Strength.
(m) Appearance of concrete and type of fracture if these are unusual.
(n) Other remarks if any.
(o) Name and signature of person responsible for testing.

Note. *The reports on the production and curing of the test specimen (see Sections 8 and 10) may conveniently be added to this report.*



d_1, d_2 = actual dimensions of the beam.

Figure 7 - Loading Arrangement of Flexural Strength Test

SECTION 15

OBTAINING CORE SAMPLES AND DETERMINATION OF THE COMPRESSIVE STRENGTH OF CONCRETE CORES

15.1 SCOPE

This Section describes the method of taking a core from concrete, preparing if for testing, determining its compressive strength and calculating the estimated in-situ cube strength.

Note. *Before deciding to drill cores for compressive testing, it is essential that full consideration be given to the necessity for the test, its aims and the value of the results which will be obtained. Specialist literature, e.g. BS6089 or the Concrete Society Technical Report No. 11 should be consulted for advice on the number of cores necessary, on the need for trimming and for the assessment of results. It is recommended that before coring full agreement should be reached by all parties on the need for core testing and on how the results should be interpreted.*

15.2 APPARATUS

The following apparatus is required:

(a)	Coring machine	(see C1. C14).
(b)	Grinding equipment	(see C1. C15).
(c)	Steel plate	(see C1. C16).
(d)	Compression testing machine	(see C1. C5).

Further details of the apparatus are given in Appendix C.

15.3 TEST SPECIMENS

15.3.1 Size of cores

The test specimen shall preferably be of 150 mm diameter and in no case shall it be less than 75 mm diameter. The ratio of diameter to the maximum aggregate size shall be not less than 3. The length of core shall be sufficient to give the required length/diameter ratio after end preparation.

15.3.2 Drilling

Unless specifically required otherwise, cores shall be drilled perpendicular to the surface using a diamond core drilling bit and in such a manner as not to damage the cores. The drill shall be kept rigidly positioned during coring. Drilling through reinforcement shall be avoided wherever possible.

15.3.3 Identification

Immediately after cutting, each core shall be clearly and indelibly marked, indicating its location and orientation within the member. The direction of drilling relative to the direction of casting shall be recorded.

The core shall be marked to indicate distances in millimetres from the drilling surfaces so that the location in the element from which the test core came can be determined when the ends have been trimmed.

15.4 EXAMINATION OF CORES

15.4.1 Compaction

Each core shall be examined for the presence of voids and cracks, and the position at which any honeycombing occurs shall be noted. In describing the compaction of the concrete in a core the following terms shall be used:

Small void.
A void measuring not less than 0.5 mm and not more than 3 mm across in any direction.

Medium void.
A void having a dimension greater than 3 mm but not greater than 6 mm.

Large void.
A void having a dimension greater than 6 mm.

Honeycombing.
Interconnected voids arising from, for example, inadequate compaction or lack of mortar.

In referring to the extent to which voids occur, the number should be related to the area of the curved surface of the core and may be described as ‘negligible’, ‘few’, ‘considerable’ or ‘numerous’ in accordance with the values shown in Table 4.

As an alternative to the above method of assessing the extent of voids, electronically based image processing procedures may be used. In such cases, resolution of voidage should be to a precision of at least 0.5%.

A set of four photographs of the curved surface of the core shall be taken at 90^0 intervals.

15.4.2 Description of aggregate

When required, pieces of coarse aggregate shall be examined for general type, particle shape and size.

15.4.3 Distribution of materials

Each core shall be examined for evidence of segregation of the individual materials by visually comparing the approximate coarse aggregate/mortar ratio at different planes in the core.

15.4.4 Measurement of dimensions

The diameter and length shall be measured with a calliper in accordance with C1. 16.6.1 of this Standard before and after end preparation. The average length and diameter shall be calculated and the volume V_1 of the specimen (in m^3) obtained.

15.4.5 Measurement of mass and density

The mass and saturated density of each specimen shall be determined in accordance with Section 16 of this Standard before end preparation.

15.4.6 Measurement of reinforcement

The size and, if possible, spacing of any reinforcing bars shall be measured. The position of any reinforcement shall be determined by measuring from the centre of the exposed bars to the drilling surface as received and after end preparation.

15.4.7 Cylindricity

The cylindricity tolerance for the core shall be 3% of the core diameter.

Table 4 - Classification of the Extent of Voids

Extents of Voids	Number of voids per 100 000 mm^2 of curved face (approx. 150 mm dia.x 200 mm long core)		
	Small voids	**Medium voids**	**Large voids**
Negligible	**Less than 40**	**Less than 4**	**---------**
Few	**40-150**	**4-15**	**Less than 2**
Considerable	**50-400**	**15-75**	**2-15**
Numerous	**More than 400**	**More than 75**	**More than 15**

15.5 PREPARATION OF CORES

15.5.1 End preparation

For compressive strength testing the length/diameter ratio shall be between 1.0 and 1.2. For static modulus testing, the length/diameter ratio shall be between 2 and 5. When it is necessary to reduce the length of core, the core shall be sawn perpendicular to its longitudinal axis. Wherever possible, inclusion of reinforcement in the specimen shall be avoided.

Grinding is the preferred method of end preparation but if this is impracticable, the ends shall be capped in accordance with C1. 15.5.2. The ground or capped ends shall comply with the tolerances given in C1. 15.5.3 of this Standard.

15.5.2 Capping

Caps shall be made as thin as possible and shall not exceed 10 mm thickness at any point.

The capping material may be a suitable proprietary capping compound, a mixture of sulphur and fine siliceous sand or a mixture of sulphur and pulverized-fuel ash.

If a mixture of sulphur and fine siliceous sand is used, it shall consist of a mixture of equal parts by weight of sulphur and fine siliceous sand (most of which passes a 300 µm woven wire sieve and is retained on a 150 µm woven wire sieve) together with a small proportion (1% to 2%) of carbon black or a small proportion (2% to 4%) of polysulphide rubber. The mixture shall be heated to a temperature of 130^0C to 150^0C and then allowed to cool slightly while being stirred continuously. The mixture shall be poured onto a level machined steel plate that has been slightly warmed and thinly coated with kerosene. Using a guide, the specimen shall be placed into this layer with its axis vertical. After a few seconds, the surplus material around the specimen shall be cut away with a sharp knife and the specimen lifted off the plate. The cap shall not flow or fracture before the concrete fails.

15.5.3 Tolerances

The tolerances of the prepared specimen shall be as follows:

(a) **Flatness**. The flatness tolerance for the prepared end surfaces shall be 0.06 mm.

(b) **Squareness**. The squareness tolerance for the prepared end with respect to the axis of the specimen as datum axis shall be 2.0 mm.

(c) **Parallelism**. The parallelism tolerance for the prepared top surface with respect to the bottom surface of the specimen as datum face shall be 2.0 mm.

15.5.4 Storage

After end preparation, all specimens shall be stored in water or a mist room at 27 ± 3^0C until saturated.

15.6 TESTING PROCEDURE

15.6.1 General

Specimens with cracked or loose caps shall not be tested. The specimens shall be tested within one hour of removal from the water or mist room, whilst they are still wet.

15.6.2 Placing the specimen in the testing machine

The bearing surfaces and the auxiliary platens of the testing machine shall be wiped clean and any water, loose grit or other material shall be removed from the ends of the specimen. The specimen shall be carefully centred on the lower platen of the machine. No packing other than auxiliary steel platens shall be used between the ends of the specimen and the platens of the testing machine.

15.6.3 Loading

The load shall be applied steadily such that the stress is increased at a rate within the range of 0.2 MPa/s to 0.4 MPa/s until no greater load can be sustained. On manually controlled machines as failure is approached the loading rate will decrease; at this stage the specified loading rate shall be maintained as nearly as possible. The maximum load shall be recorded.

Normal failures are reasonably symmetrical. The appearance of the concrete and any unusual failure shall be noted.

15.7 CALCULATION AND EXPRESSION OF RESULTS

15.7.1 Compressive strength of core

The compressive strength of the core shall be calculated by dividing the maximum load by the cross-sectional area as calculated from the average diameter. The results shall be expressed to the nearest 0.5 MPa.

Note. *The presence of reinforcement in a core cut from reinforced concrete may affect the result.*

15.7.2 Estimated in-situ cube strength

For cores free of reinforcement, the estimated in-situ cube strength, F_{ce} shall be calculated to the nearest 0.5 MPa from the equation:

$$F_{ce} = \frac{D}{1.5 + \dfrac{1}{\alpha}} \text{ x } \begin{array}{l}\text{measured} \\ \text{compressive} \\ \text{strength of core (to} \\ \text{nearest 0.1 MPa)}\end{array} \qquad \textbf{(15-1)}$$

where

F_{ce} is the estimated in-situ cube strength

D is 2.5 for cores drilled horizontally (for precast units perpendicular to height when cast) or 2.3 for cores drilled vertically (for precast units parallel to height when cast)

α is the length (after end preparation)/diameter ratio

Note. ***It should be noted that in-situ strengths estimated from the above formula cannot be equated to standard cube strengths.***

For cores with reinforcement perpendicular to the core axis, the estimated in-situ cube strength shall be calculated by multiplying the strength of core obtained from equation (15-1) by the following factors:

(a) for cores containing a single bar:

$$1.0 + 1.5 \frac{\phi_r d}{\phi_c L} \qquad \textbf{(15-2)}$$

(b) for specimens containing two bars no further apart at their closest point than the diameter of the larger bar, only the bar corresponding to the higher value or $_r$d need be considered. If the bars are further apart, their combined effect should be assessed by using the factor:

$$1.0 + 1.5 \frac{\Sigma\phi_r d}{\phi_c L} \qquad \textbf{(15-3)}$$

where

ϕ_r is the diameter of reinforcement

ϕ_c is the diameter of specimen

d end of the uncapped specimen is the distance of axis of bar from nearer

L is the length of uncapped specimen

15.8 TEST REPORT

The report shall affirm that the specimens were prepared and tested in accordance with this Standard.

15.8.1 Information to be provided by the producer of the test specimens for inclusion in the test report

The following information shall be provided:

(a) Name of project and place where core was taken.
(b) Specified concrete strength, if known.
(c) Concrete mid details, if known.
(d) Admixtures used, if known.
(e) Identification number of the core.
(f) Date of drilling.
(g) Direction of drilling relative to the direction of casting e.g. vertically, horizontally or diagonally.
(h) Conditions of storage.
(i) Age of concrete at time of coring, if known.
(j) Name and signature of person responsible for taking cores.

15.8.2 Information to be provided by the test laboratory for inclusion in the test report

The following information shall be provided:

(a) Identification number of the specimen.
(b) Date of receipt of the specimen.
(c) Condition of specimen when received (including poor compaction, honeycombing or incorrect dimensions).
(d) Average diameter.
(e) Saturated density of the specimen.
(f) Length after preparation, and location in relation to the length received.
(g) Compaction of concrete, distribution of materials, classification of voids and presence of cracks.
(h) Size, position and spacing of any reinforcement.
(i) Description of aggregate, including maximum size and particle shape.
(j) A set of four photographs of the core taken at 90^0 intervals before testing.
(k) Date of test
(l) Age of specimen at date of test, if known.
(m) Maximum load at failure.
(n) Measured compressive strength and estimated in-situ cube strength.
(o) Appearance of concrete and type of fracture.
(p) Other remarks if any.
(q) Name and signature of person responsible for testing.

SECTION 16

DETERMINATION OF DENSITY OF HARDENED CONCRETE

16.1 SCOPE

This Section describes the methods of determining the density of hardened concrete.

16.2 APPLICATION

The as-received density generally applies to specimens cut from a structure and tested on arrival in the laboratory or to moulded specimens which have not been cured to a saturated state.

The as-received density may be required in the following tests:

(a) Compressive strength of cubes	(Section 12).
(b) Tensile splitting strength	(Section 13).
(c) Flexural strength	(Section 14).

The saturated and oven-dried densities provide a convenient basis for comparison as the conditions are reproducible, but may not be representative of the in-situ condition.

Saturated density may be required in the following tests:

(a) Compressive strength of cube	(Section 12).
(b) Tensile splitting strength	(Section 13).
(c) Flexural strength	(Section 14).
(d) Compressive strength of cores	(Section 15).
(e) Modulus of Elasticity	(Section 17).

16.3 DEFINITIONS

Density (ρ) is the mass of a unit volume of hardened concrete expressed in kilograms per cubic metre.

$$\rho = \frac{m}{V} \tag{16-1}$$

where

m can be m_1 = mass of the as-received specimen in air (in kg)
or m_2 = mass of the saturated specimen in air (in kg)
or m_3 = mass of the oven-dried specimen in air (in kg)

V can be V_1 = the volume of the specimen calculated from its measured dimensions (in m^3)
V_2 = the volume of the specimen determined by the displacement of water (in m^3)

Note. *Determination of the volume by water displacement is to be preferred, especially for cut or cored specimens.*

16.4 APPARATUS

The following apparatus is required:

(a) Calliper	(see C1. C7).
(b) Balance with stirrup	(see C1. C17).
(c) Water container	(see C1. C18).
(d) Ventilated oven	(see C1. C19).

Further details of the apparatus are given in Appendix C.

16.5 TEST SPECIMENS

The volume of the specimen shall be not less than 40 d^3, where d is the nominal maximum size of the aggregate. If the shape or size of the sample is such that it is not possible to use all of it, a smaller specimen may be taken from the original, provided that the prepared specimen is representative of the as-received sample.

16.6 PROCEDURE FOR DETERMINATION OF THE VOLUME BY CALCULATION

Only specimens of regular shape shall be measured. All measurements of dimensions shall be recorded to the nearest millimetre.

16.6.1 Cylindrical specimens

The length of the specimen parallel to the axis shall be measured at four evenly distributed positions and a pair of measurements of the diameter shall be taken right angles to each other at each one-third point along the length. The average length and diameter shall be calculated and the volume V_1 of the specimen (in m^3) determined.

16.6.2 Rectilinear specimens

The length parallel to the axis of the specimen shall be measured at the centre of the four edges. The width shall be measured with a calliper at two points across each pair of opposite faces. The average width shall be calculated and the volume V_1 of the specimen (in m^3) determined.

16.7 PROCEDURE FOR DETERMINATION OF THE VOLUME BY WATER DISPLACEMENT

Note. *The water displacement method is not applicable to specimens of no-fines concrete or samples where the moisture content is not to be altered.*

16.7.1 Procedure

If the specimen is not saturated, it shall first be immersed in water for 30 minutes. The specimen shall then be placed on the stirrup and fully immersed in water. The stirrup shall not touch the bottom of the tank and air bubbles shall not be allowed to be trapped on the surfaces of the specimen or the stirrup. The completely immersed specimen shall be weighed and its apparent mass m_w recorded after correcting for the apparent mass of the empty stirrup. The apparent mass of the empty stirrup shall be determined by weighing it in water to the same depth as when holding the specimen.

The specimen shall be wiped to remove surface water and then weighed in air and its mass m_a recorded.

16.7.2 Calculation

Taking the density of water as 1000 kg/m^3, the volume V_2 of the specimen shall be calculated from the following equation:

$$V_2 = \frac{m_a - m_w}{1000} \qquad \textbf{(16-2)}$$

16.8 PROCEDURE FOR DETERMINATION OF AS-RECEIVED DENSITY

16.8.1 Procedure

The specimen as-received shall be weighed in air and its mass m_1 recorded. The volume of the specimen may be determined in accordance with C1.16.6 or C1.16.7.

16.8.2 Calculation

The as-received density shall be calculated using the appropriate equation:

(a) for volume calculated in accordance with C1. 16.6

$$r_1 = \frac{m_1}{V_1} \qquad \textbf{(16-3)}$$

(b) for volume obtained by water displacement in accordance with C1. 16.7

$$r_2 = \frac{m_1}{V_2} \qquad \textbf{(16-4)}$$

16.9 PROCEDURE FOR DETERMINATION OF SATURATED DENSITY

16.9.1 Procedure

The specimen shall be fully immersed in water at

27 ± 3^0C until constant mass is achieved. This state shall be regarded as having been reached when two measurements taken 24 hours apart give a difference of less than 0.2% in the mass of the wet specimen in air. Before each weighing, surplus water from the surface shall be removed with a moist cloth. The constant mass m_2 shall be recorded. Specimens cured in water in accordance with Section 10 of this Standard for more than three days immediately prior to testing may be assumed to be saturated to a constant mass for this test. The volume of the specimen shall be determined in accordance with C1. 16.6 or 16.7.

16.9.2 Calculation

The saturated density shall be calculated using the appropriate equation:

(a) for volume calculated in accordance with C1. 16.6

$$r_3 = \frac{m_2}{V_1} \tag{16-5}$$

(b) for volume obtained by water displacement in accordance with C1. 16.6

$$r_4 = \frac{m_2}{V_2} \tag{16-6}$$

16.10 PROCEDURE FOR DETERMINATION OF OVEN-DRIED DENSITY

16.10.1 Procedure

The specimen shall be placed in a ventilated oven and dried at 105 ± 5^0C until constant mass is achieved. This state shall be regarded as having been reached when two measurements taken 24 hours apart give a difference of less than 0.2% in the mass of the dry specimen. Before each weighing, the specimen shall be cooled to near room temperature in a dry airtight vessel or desiccator. The constant mass m_3 shall be recorded. The volume of the specimen shall be determined in accordance with C1. 16.6 or 16.7.

16.10.2 Calculation

The oven-dried density shall be calculated using the appropriate equation:

(a) for volume calculated in accordance with C1. 16.6

$$r_5 = \frac{m_3}{V_1} \tag{16-7}$$

(b) for volume obtained by water displacement in accordance with C1. 16.7

$$r_6 = \frac{m_3}{V_2} \tag{16-8}$$

16.11 CALCULATION AND EXPRESSION OF RESULTS

The density of each specimen shall be calculated using the appropriate equation given in C1. 16.7, 16.8, 16.9 or 16.10 and shall be expressed to the nearest to 10 kg/m^3.

16.12 TEST REPORT

The report shall affirm that the test was carried out in accordance with this Standard and shall include the following:

(a) Identification number of the specimen.
(b) Date of receipt of the specimen at the laboratory.
(c) Condition of the specimen when received (including poor compaction, honeycombing and incorrect dimensions).
(d) Date of test.
(e) Method of determination of volume.
(f) Measured dimensions and shape of the specimen.
(g) Mass of specimen (as-received, saturated or oven-dried).
(h) Type of density measured, (i.e. as-received, saturated or oven-dried) and values obtained.
(i) Name and signature of person responsible for testing.

SECTION 17

DETERMINATION OF STATIC MODULUS OF ELASTICITY IN COMPRESSION

17.1 SCOPE

This Section describes the method of determining the static modulus of elasticity in compression of hardened concrete, on test specimens which may be cast or taken from a structure.

17.2 DEFINITION

Static modulus of elasticity in compression is the ratio between compressive stress and strain, expressed in terms of the secant modulus. The secant modulus in MPa is calculated from the equation:

$$E_c = \frac{\Delta_\sigma}{\Delta_\varepsilon} \qquad \textbf{(17-1)}$$

Where Δ_σ and Δ_ε are the differences in stress and strain respectively, between a basic loading level of 0.5 MPa and an upper loading level of one-third of the compressive strength of the concrete.

17.3 APPARATUS

The following apparatus is required:

(a) Compression testing machine (see C1. C5).
(b) Strain measuring apparatus (see C1. C20).

Further details of the apparatus are given in Appendix C.

17.4 TEST SPECIMENS

17.4.1 Moulded specimens

Moulded specimens shall be 150 mm diameter by 300 mm long cylinders, made, cured and stored in accordance with Sections 9 and 10 of this Standard. Two standard 150 mm cubes shall also be made from concrete of the same batch and cured under same condition as the specimen. If the upper surface of the cylinder has not been prepared whilst it is still workable, it shall be allowed to harden and the upper surface prepared by grinding or capping. After grinding or capping, the specimen shall be stored in water or a mist room until saturated.

17.4.1.1 Grinding of hardened cylinder

After the concrete has hardened, the upper surface shall be ground until it complies with the tolerances stated in C1. 17.4.1.3. Only water shall be used as a coolant during grinding.

17.4.1.2 Sulphur capping of hardened cylinder

Caps shall be made as thin as possible and shall not exceed 10 mm thickness at any point.

The capping material shall consist of a mixture of equal parts by weight of sulphur and fine siliceous sand (most of which passes a 300 μm woven wire sieve and is retained on a 150 μm woven wire sieve) together with a small proportion (1% to 2%) of carbon black or a small proportion (2% to 4%) of polysulphide rubber. The mixture shall be heated to a temperature of 130^0C to 150^0C and then allowed to cool slightly while being stirred continuously. The mixture shall be poured onto a level machined steel plate that has been slightly warmed and thinly coated with kerosene. Using a guide, the specimen shall be placed into this layer with its axis vertical. After a few seconds, the surplus material around the specimen shall be cut away with a sharp knife and the specimen lifted off the plate. The cap shall not flow or fracture before the concrete fails.

17.4.1.3 Tolerances

If the upper end is ground or capped when hardened, the end shall comply with the following limits:

(a) **Flatness.** The flatness tolerance for the prepared surface shall be 0.06 mm.

(b) **Parallelism.** The parallelism tolerance for the prepared surface with respect to the lower surface of the cylinder as datum face shall be 2.0 mm.

17.4.2 Cores

Specimens drilled out of a structure shall be drilled, stored and capped in accordance with Section 15 of this Standard. The minimum dimension of the core shall be not less than three times the nominal maximum size of aggregates in the concrete not less than 100 mm. An extra core shall be taken for the determination of the concrete strength.

17.4.3 Measurement of mass and density

The mass and saturated density of each specimen shall be determined in accordance with Section 16 of this Standard.

17.5 PROCEDURE

17.5.1 Determination of compressive strength

All specimens shall be tested within one hour of removal from the water or mist room, whilst they are still wet.

Just before commencing the static modulus of elasticity test, the compressive strength of the moulded specimen shall be determined from the two standard 150 mm cubes of the same batch, made and cured under similar conditions as the specimen. The cubes shall be crushed and the concrete strength converted to an equivalent cylinder strength by multiplying the cube strength by a factor of 0.8.

For concrete cores, the compressive strength shall be determined in accordance with the procedure given in Section 15 of this Standard.

The mean value of the compressive strength (i.e. equivalent cylinder strength), f_c, determines the stress to be applied in the determination of static modulus of elasticity.

17.5.2 Measuring instruments or fixing points

Measuring instruments or fixing points shall be attached to the test specimen axially in such a way that the gauge points are equidistant from the two ends of the specimen and at a distance not less than one-quarter of the length of the test specimen ($L/4$) from its ends. At least one pair of measurements shall be taken on opposite sides of the specimen.

Note. *Where fixing points for extensometer are required, threaded inserts cast into the specimen are preferred.*

If adhesives are used for the fixing points they should be rapid setting and set hard. The specimen shall be removed from the curing tank or the mist room for as short a time as possible to allow the surface to be dried for the application of adhesive. Specimens shall not be less than seven days old when removed for this purpose. Specimens shall be placed back in the water or mist room for a minimum of two days before testing.

17.5.3 Loading

The test specimen, with the measuring instruments or fixing points attached axially, shall be placed centrally in the machine. The basic stress of 0.5 MPa (σ_b) shall be applied, and the strain gauge readings at each measurement line shall be recorded.

The load shall be applied steadily and without shock such that the stress is increased at a constant rate within the range 0.5 to 0.7 MPa/s until the stress is equal to one-third of the compressive strength of the concrete ($\sigma_a = f_c/3$).

Note. *The preferred rate is 0.6 MPa/s.*

The stress shall be maintained for 60 seconds and the strain readings at each measurement line during the succeeding 30 seconds shall be recorded. If the individual strains are not within a range of ± 10% of their mean value at σ_a, the test specimen shall be recentred and the test repeated. If it is not possible to reduce the differences to within this range, the test shall be stopped.

When the centering is sufficiently accurate, the load shall be reduced to the level of the basic stress at the same rate as during loading. At least two additional loading cycles, using the same loading and unloading rate, shall be carried out and the stresses (σ_a *and* σ_b) maintained constant for a period of 60 seconds. After completion of the last loading cycle and a waiting period of 60 seconds under the stress σ_b = 0.5 MPa, the strain reading at the various measurement lines ε_b, during the succeeding 30 seconds shall be recorded.

The specimen shall be reloaded to stress σ_a at the specified rate, and the strain reading ε_a at the various measurement lines taken within 30 seconds shall be recorded.

When all elasticity measurements have been completed, the load on the test specimen shall be increased, at the specified rate, until failure of the specimen occurs. If the compressive strength of the specimen differs from f_c by more than 20%, this shall be noted in the test report.

17.6 CALCULATION AND EXPRESSION OF RESULTS

The mean strain ε_a and ε_b respectively shall be calculated.

The static modulus of elasticity in compression E_c (in MPa) is given by the equation:

$$\frac{\Delta\sigma}{\Delta\varepsilon} = \frac{\sigma_a - \sigma_b}{\varepsilon_a - \varepsilon_b} \qquad \textbf{(17-2)}$$

where

σ_a is the upper loading stress (in MPa) ($\sigma_a = f_c/3$)

σ_b is the basic stress (0.5 MPa)

ε_a is the mean strain under the upper loading stress

ε_b is the mean strain under the basic stress

The result shall be expressed to the nearest 500 MPa for values over 10 000 MPa, and to the nearest 100 MPa for values below 10 000 MPa.

17.7 TEST REPORT

The report shall affirm that the tests were carried out in accordance with this Standard and shall include the following:

(a) Identification number of the specimen.
(b) Date of receipt of the specimen.
(c) Condition of the specimen when received, and any surface treatment.
(d) Curing and storage report.
(e) Date of test.
(f) Saturated density.
(g) Concrete cube strength or core strength at date of testing.
(h) Maximum applied stress during test (f_c/3).
(i) Compressive strength of test specimen.
(j) Static modulus of elasticity.
(k) Appearance of the concrete and type of fracture.
(l) Name and signature of person responsible for testing.

Note. *The report on the production and curing of the test specimen may conveniently be included as part of the testing report.*

SECTION 21

CHEMICAL ANALYSIS OF HARDENED CONCRETE

Contents **Page**

SECTION 21

CHEMICAL ANALYSIS OF HARDENED CONCRETE

21.1 SCOPE

The Section describes the sampling procedures, treatment of samples, and analytical methods of determine the cement content, aggregate content, original water content, type of cement, type of aggregate, chloride content, sulphate content and carbonate content of a sample of hardened concrete.

The procedures apply to concrete made with Portland cement. The analysis of concrete made with other cements and the determination of PFA content are outside the scope of this Standard. At present, there is no reliable method of determining the cement or PFA content of hardened concrete containing PFA.

21.2 GENERAL

21.2.1 Reagents

All reagents shall be of analytical reagent quality, and water shall be distilled or deionized.

Dilutions of acids and other liquid reagents are given as (1 + n) which indicates that one volume of the concentrated reagent is diluted with n volumes of water.

Solutions of solid reagents shall be filtered if the solution is not clear.

Proprietary reagents of equal quality to those described in the Standard may be used as alternatives.

21.2.2 Apparatus

It is assumed that a laboratory carrying out these tests will be equipped with basic apparatus such as analytical balances, beakers, volumetric flasks, pipettes, burettes, filtration apparatus, magnetic and mechanical stirrer, etc. Only apparatus special to the determinations necessary to analyse hardened concrete is therefore listed.

All volumetric glassware shall have an accuracy of class B or better as given in the appropriate British Standard. Analytical balances shall have an accuracy of 0.2 mg.

The filter papers used in gravimetric analysis using ignition shall be ashless.

21.3 SAMPLING

21.3.1 General

It is usual for the tests described in this Section to be applied only when there is some doubt about the quality of the concrete. For example, the average quality of a mass of concrete, or the quality of a particular part of this mass may be in question. The size of the mass can vary greatly and the sampling techniques necessary to provide information on the quality of a concrete will be determined by the form of the concrete. For example, the requirements for a concrete retaining wall and for a concrete backing to a decorative panel can be quite different. For such reasons it is extremely difficult to specify how a sample should be taken and no requirements can be given.

Note. *It is strongly advised that no sample be taken for testing without agreement between the interested parties about the method of taking the sample and the quantity of material that is considered to be represented by the sample (see Cl. 21.3.3).*

21.3.2 Section of Sample

The following general requirements shall be observed in selecting the concrete sample:

(a) No linear dimension of the sample shall be less than five times the nominal maximum size of the largest aggregate.

(b) If original water content is to be determined, the sample shall be in a single piece with no cracks visible to the naked eye.

(c) The minimum mass of the sample will be determined by testing requirements but a mass of at least 1 kg is necessary, or at least 2 kg if the original water content is to be determined.

(d) All foreign matter and reinforcement shall be avoided unless they are subject to test.

The sample shall be clearly and indelibly labelled with full particulars, including the date, exact position from which the sample was taken, the method of sampling and any other relevant information. The sample shall be enclosed in a heavy-duty polyethylene bag and sealed or tied securely.

21.3.3 Number of samples

When information about the composition of concrete with a volume of up to 10 m^3 is required, at least two and preferably four representative samples shall be taken from different locations and analysed separately.

When a very large volume of concrete or a large number of concrete units are to be examined, at least ten samples shall be taken from different locations and analysed separately. The results can then be used to identify locations requiring more extensive investigation.

21.3.4 Additional material

Information on the composition of the cement and aggregate used in the concrete will enable more accurate results to be obtained. Where available, representative samples of all the constituents of the concrete used shall be taken and enclosed in heavy-duty polyethylene bags, clearly labelled and sealed or tied securely. Where such samples are not available, information on the source and nature of these materials should be given.

21.3.5 Report on sampling

Each sample of concrete and additional material shall be accompanied by a report from the person responsible for taking the sample stating that sampling was carried out in accordance with this Standard. The report shall include the following:

(a) Name and location of building, structure etc.
(b) A description of the structure or component under investigation.
(c) The location from which the concrete sample was taken and its orientation relative to direction of casting.
(d) The method of sampling.
(e) Details of the concrete, in particular its age, if known.
(f) The identification number of the sample.
(g) The date and time of sampling.
(h) The name and signature of the person responsible for sampling.

21.4 TREATMENTS OF SAMPLES

21.4.1 Apparatus

The following apparatus is required:

(a) Ventilated oven (see C1. C19).
(b) Crushing and grinding equipment (see C1. C21).
(c) Test sieves (see C1. C22).
(d) Airtight bottles (see C1. C23).
(e) Concrete saw (see C1. C24).
(f) Device for sample reduction, such as a riffle box.
(g) Bar magnet.

Further details of the apparatus are given in Appendix C.

21.4.2 Density

If the content of constituents determined as percentages by mass of the oven-dried concrete is to be converted to kilograms per cubic metre of concrete, the oven-dried density of a single sound piece of concrete shall first determined before any work involving breakdown of the sample.

21.4.3 Original water content

If the original water content is to be determined, a slice of approximately 20 mm thick and having a single face area of not less than 7500 mm^2 shall be obtained by making two parallel cuts in the sample, preferably with a diamond saw. Care shall be taken to avoid the loss of material out of the cut faces.

The reduce carbonation of the concrete, a specimen for water content determination shall be stored in an airtight container until ready for testing.

21.4.4 Nature of aggregate

The concrete sample shall be examined (see C1. 21.9.2), and the coarse and fine aggregate broadly classified under the following headings:

type I :	natural aggregates essentially insoluble in dilute hydrochloric acid.
type S :	natural aggregates largely soluble in dilute hydrochloric acid.
type O :	other aggregates.

21.4.5 Preparation of test samples

21.4.5.1 Initial treatment

The sample shall be broken into lumps not larger than about 50 mm in size, avoiding as far as possible fracture of the aggregate. The lumps shall be dried in the oven at 105 ± 5^0C for 15 hours to 24 hours and allowed to cool to room temperature.

The dried sample shall be divided into two portions, A and B, with portion A approximately three-quarters of the bulk. Each portion shall remain as nearly as possible representative of the whole.

21.4.5.2 Determination of the presence of PFA

Since there is no reliable method at present available to determine the cement content of hardened concrete containing PFA, it is necessary to establish whether or not PFA is present in the concrete prior to the analysis for cement content.

The method of determining whether PFA is present in the concrete is given in Clause 21.5. If PFA is found to be present, the determination of cement content is not possible and the further preparation of the portion A of the sample need not be carried out unless it is required in other tests such as the determination of chloride content.

21.4.5.3 Treatment of portion A

A major source of error in the analysis of hardened concrete is inadequate sample preparation. It is essential to avoid loss of material, particularly dust, during the crushing and grinding operations. Excessive particle size reduction shall be avoided during the preparation of the analytical sample. The crushing, grinding and following operations shall be carried out as quickly as possible so that the sample is exposed to atmospheric carbon dioxide for the minimum time. The procedure to provide a representative analytical sample of not less than 30 g of ground material, all passing a 150 µm sieve shall be as follows:

Using the crushing and grinding equipment, portion A shall be crushed until it all passes a 5.0 mm sieve. It shall then be subdivided, using a riffle box or by equivalent means, to produce a sub-sample of 500 g to 1000 g. This sub-sample shall be crushed to pass a 2.36 mm sieve and reduced by two separate subdividing operations, discarding one half on each occasion. The whole of the remaining part shall be ground to pass a 600 µm sieve and again reduced by two separate subdividing operations, discarding one half on each occasion. The whole of the remaining part shall be ground to pass a 150 µm sieve.

When mechanical means of crushing and grinding are used some of these stages may be by-passed. For example, the initial crushing of portion A may yield a product passing a 1.18 mm sieve. In this case the subdivision before the next stage should provide a sub-sample of 100 g to 200 g. This can then be ground in a suitable grinder to pass a 150 µm sieve.

Before the final grinding operation, it is recommended that material in the sub-sample which passes a 150 µm sieve is removed by sieving, reserved and recombined with the ground fraction. If a number of passes through the grinding apparatus is required, this removal of fine material should be done each time.

The analytical sample so obtained shall be placed in a porcelain evaporating basin or similar container and the metallic iron removed by stirring the sample with a bar magnet. The analytical sample shall then be transferred to a clean dry bottle with an airtight closure and thoroughly mixed by tumbling, rolling or shaking for at least two minutes.

When aggregate control samples are available, they shall be dried and ground by the same method as that used for the concrete.

21.4.5.4 Treatment of portion B

Portion B shall be retained in an airtight container for use in the test described in clauses 21.8, 21.9 and 21.10.

21.5 DETECTION OF PFA

21.5.1 General

As PFA contains characteristic spherical particles, its presence in hardened concrete may be detected by microscopic examination of the residue after treatment of the concrete with dilute acid.

21.5.2 Reagents

The following reagent is required:

- Dilute hydrochloric acid (1 + 9)

21.5.3 Apparatus

The following apparatus is required:

(a)	Centrifuge	(see C1. C25).
(b)	Transmitted-light microscope	(see C1. C26).
(c)	Microsieve set with replaceable 75 μm sieve	(see C1. C27).

Further details of the apparatus are given in Appendix C.

21.5.4 Preparation of sample

Approximately 400 g of portion B prepared in accordance with C1 21.4.5.1 shall be obtained using a riffle box. The sample shall then be broken down in the crushing equipment, and aggregate removed as far as possible to ensure an adequate concentration of the cement matrix.

About 5 g of this cement-rich portion of size 3 to 5 mm shall be randomly selected from the bulk and transferred to a 200 mL beaker, 100 mL of the hydrochloric acid shall be added and stirred for 20 minutes with occasional breakdown of any remaining lumps using a plastic rod. The contents of the beaker shall be transferred to a centrifuge bottle which shall then be stoppered and allowed to spin in the centrifuge for five minutes. The supernatant shall be removed by decantation and the bottle containing the residue shall be refilled with 100 mL of water and then centrifuged for another five minutes.

The above process of decantation of the supernatant, washing of the residue by water and spinning shall be repeated twice before the contents of the bottle are emptied through a 75 μm microsieve set into a dry slow filter paper.

21.5.5 Microscopic examination

A speck of the sample residue retained on the filter paper shall be spread evenly over the centre of a microscope slide with the aid of a drop of dispersal agent and then covered by a glass cover. A second slide shall be prepared in the same manner with a speck of the sample residue taken from a different part of the filter paper.

The slides shall be examined using the transmitted-light microscope with a magnification of 200 to 400. The whole area of the sample being scanned in each case. The presence of spherical particles in either slide indicates that the concrete with and without PFA are reproduced in Figure 8.

Note. *To avoid possible contamination, the microsieve set should be washed, cleaned and the 75 mm sieve insert replaced by a new one prior to each test.*

21.6 CEMENT AND AGGREGATE CONTENTS

21.6.1 General

The closeness of agreement between the cement and aggregate contents, determined by the methods described in this Section, and the actual values depends on a knowledge of the chemical composition of these constituents of the concrete. Wherever possible, therefore, representative samples of the cement and aggregate used in making the concrete shall be obtained and chemical analyses carried out on them in a similar manner to that described for the concrete sample.

In cases where samples of the original constituents of the concrete are not available for analysis, the agreement between observed and actual contents of cement and aggregate depends on the validity of the assumptions made on the composition of the materials present in the concrete sample (see C1. 21.6.6 and Table 5). For example, an error of 1% in the assumed calcium oxide content of an aggregate is equivalent to an error of about 35 kg/m^3 in the calculated cement content. Similarly, a 1% error in the assumed soluble silica content of the aggregate is equivalent to an error of about 110 kg/m^3 in the calculated cement content.

One or more of the methods detailed in this Section may be used as appropriate. In C1. 21.6.5.1 a method for the extraction of soluble silica is described, and it is essential that this method is followed exactly. Methods of proven accuracy are given for other determinations. It is permissible to use alternative methods for the determination of the following, provided evidence is presented that such methods give equivalent results:

(a) Calcium oxide e.g. by atomic absorption.
(b) Soluble silica e.g. by atomic absorption.
(c) Loss-on-ignition e.g. by thermogravimetry.
(d) Carbon dioxide e.g. by instrumental methods.

21.6.2 Reagents

The following reagents are required:

(a) Ammonium chloride solution, 1g/L

1 g of ammonium chloride shall be dissolved in 1 L of water.

(b) Calcein (screened) indicator

The indicator shall be obtained by mixing and grinding together 0.2 g of calcein, 0.12 g of thymolphthalein and 20 g of potassium chloride.

(c) Calcium standard solution

A quantity of 1.78 g to 1.79 g of pure calcium carbonate shall be dried at a temperature in the range 150^{0}C to 200^{0}C and its mass recorded to the nearest 0.0001 g. It shall then be dissolved in a slight excess of dilute hydrochloric acid (1 + 4), boiled to expel carbon dioxide, cooled and diluted to 1 L in a volumetric flask.

The concentration of CaO shall be expressed in g/L to four significant figures as mass of $CaCO_3$ /1.7848.

(d) Triethanolamine solution (1 + 4)

(c) Sodium hydroxide solution, 200 g/L

(f) EDTA standard solution

The solution shall be obtained by dissolving 6.67 g of EDTA (ethylenediamine-tetra-acetic acid, disodium dihydrate salt) in warm water, filtering if necessary, cooling and diluting to 1 L. The solution shall be stored in a polyethylene bottle. The solution shall be standardized against the calcium standard solution as follows:

20 mL of the calcium standard solution shall be pipetted into a 250 mL beaker or flask. 10 mL of triethanolamine solution and 10 mL of sodium hydroxide solution shall be added and the solution shall be made up to a about 150 mL with water. About 0.15 g calcein indicator shall be added and the solution titrated with the EDTA standard solution until the fluorescent green of the indicator completely changes to pink-purple with no residual fluorescence. The end-point is more easily seen if observed against a black background. The CaO equivalent of the

EDTA, *E*, (in mg CaO/mL) shall be calculated from the expression:

$$E = \frac{20\ h}{V} \qquad \textbf{(21-1)}$$

where

h is the concentration of CaO in the calcium standard solution (in g/L)
V in the volume of EDTA required in the titration, to the nearest 0.02 mL.

(g) Concentrated hydrochloric acid, relative density 1.18.

(h) Dilute hydrochloric acid

(1+1), (1+4), (1+9) and (1+49).

(i) Polyacrylamide solution, 1 g/L

0.1 g of polyacrylamide, molecular weight about 5 x 10^6 shall be added to 100 mL of water and stirred using a mechanical stirrer until dissolved.

(j) Polyethylene oxide solution, 2.5 g/L

The solution shall be obtained by slowly adding 0.5 g of polyethylene oxide, molecular weight less than 1 x 10^6, to 200 mL of water and stirring using a mechanical stirrer until dissolved. The solution shall be discarded after two weeks.

(k) Sodium carbonate solution, 50 g/L
The solution shall be obtained by dissolving 50 g of anhydrous sodium carbonate in 1 L of water.

21.6.3 Apparatus

The following apparatus is required:

(a)	Furnace	(see C1. C28).
(b)	Desiccator	(see C1. C29).
(c)	250 mL polypropylene beakers.	
(d)	Plastic stirring rods.	
(e)	Water or steam bath.	

Further details of the apparatus are given in Appendix C.

21.6.4 Determination of calcium oxide when insoluble residue and soluble silica are not to be determined

A quantity of 5 ± 0.1 g of the analytical sample prepared as in C1. 21.4.5.3 shall be weighed accurately to the nearest 1 mg and transferred into a 500 mL beaker and dispersed with 50 mL to 100 mL of cold water. 10 mL of concentrated hydrochloric acid shall be added, swirled and immediately made up with hot water to about 150 mL. The solution shall be brought to the boil and kept hot for five minutes. After cooling, the entire content of the beaker shall be transferred to a 500 mL volumetric flask, diluted to the mark with water and mixed thoroughly. A portion of the solution shall be filtered through a dry medium filter paper or, alternatively, a centrifuge shall be used to obtain a clear solution.

25 mL aliquot of the clear solution shall be pipetted into a 250 mL beaker or flask and diluted to about 150 mL. 10 mL of the triethanolamine solution, 10 mL of the sodium hydroxide solution and about 0.15 g of screened calcein indicator shall be added. The solution shall then be titrated with EDTA standard solution using the magnetic stirrer until the fluorescent green of the indicator completely changes to pink-purple with no residual fluorescence (see C1. 21.6.2 (f)). The volume, *V*, of EDTA used in the titration shall be recorded to the nearest 0.02 mL.

Note. *The EDTA solution and the use of potassium hydroxide, as described in Cl. 6.3.2.4 of BS 4551 : 1980 and Cl. 6.2 of BS 4550 : Part 2 : 1970 are acceptable alternatives when determining calcium oxide. Other indicators which give clear end-points, e.g. HSN, may be used.*

The calcium oxide content *D* as a percentage by mass of the analytical sample shall be calculated to the nearest 0.1%, from the expression:

$$D = \frac{2\,V\,E}{m} \quad \text{(in \%)} \qquad \textbf{(21-2)}$$

where

V is the volume of EDTA solution used in the titration (in mL)
E is the calcium oxide equivalent of the EDTA solution (in mg CaO/mL)
m is the mass of the analytical sample (in g)

21.6.5 Determination of insoluble residue, soluble silica and calcium oxide

21.6.5.1 Extraction of soluble silica and preparation of stock test solution

A quantity of 5 ± 0.1 g of the analytical sample prepared as in C1. 21.4.5.3 shall be weighed accurately and transferred into a 250 mL polypropylene beaker and 100 mL of dilute hydrochloric acid (1+9) carefully added. When a limestone aggregate is known to be present or when vigorous effervescence on adding the acid indicates its likely presence, a further 10 mL of concentrated hydrochloric acid shall be added to the stirred suspension. Using a magnetic stirrer with a plastic covered magnetic follower, or other suitable mechanical stirrer, the suspension shall be stirred at room temperature for 20 minutes. It shall then be allowed to settle and the liquid decanted through either a medium filter paper or a paper pulp pad supported on a perforated cone or similar, with or without suction. The residue in the beaker shall be washed with three 25 mL portions of dilute hydrochloric acid (1+49) and the washings poured through the same filter paper. This first filtrate shall be retained.

Note. *The rate of filtration is improved by adding 1 mL of polyacrylamide solution to the acid extraction just before the completion of the 20 minutes stirring. The subsequent determinations based on the filtered extract are not affected. A coarser filter paper may be used.*

The filter paper plus any residue it contains shall be placed into the beaker containing the residue and 100 mL of the sodium carbonate solution shall be added. The beaker shall be placed on a boiling water or steam bath for 15 minutes stirring occasionally with a plastic rod to break up the filter paper.

The contents of the beaker shall be transferred on to a medium hardened ashless filter paper or a paper pulp pad supported on a perforated cone or similar, taking particular care to recover all the residue adhering to the sides of the beaker and the stirrer blade or magnet. It shall be washed six times with the hot ammonium chloride solution, twice with hot dilute hydrochloric acid (1+49) and twice with hot water, the volume of each of the washings being about 25 mL. Each washing shall be allowed to drain before continuing with the next. The second filtrate and the washings shall be retained.

To reduce the possibility of silica being introduced into the solution the filtrate should be collected in a plastic beaker.

10 mL of concentrated hydrochloric acid shall be added to the first filtrate which shall then be carefully combined with the second filtrate and washings, stirring frequently to avoid the formation of a precipitate that is difficult to dissolve again. The combined filtrates shall be reserved for treatment as described in C1. 21.6.5.3.

21.6.5.2 Determination of insoluble residue

To determine the insoluble residue, the filter paper containing the residue shall be placed in a weighed crucible and ignited, at first slowly until the carbon of the paper is completely consumed without flaming and finally at 925 ± 25^{0}C until constant mass is achieved (see C1. 21.8.3). The crucible and residue shall be allowed to cool to room temperature in the desiccator and weighed. The insoluble residue content of the analytical sample shall be calculated to the nearest 0.1% from the expression:

$$\text{Insoluble residue} = \frac{\text{mass of ignited residue}}{\text{mass of analytical sample}} \times 100\% \qquad \textbf{(21-3)}$$

21.6.5.3 Determination of soluble silica

The combined filtrates and washings shall be evaporated on a boiling water or steam bath until not more than approximately 5 mL remain. 10 mL of dilute hydrochloric acid (1+1), half of an ashless filter tablet and 5 mL of the polyethylene oxide solution shall be added stirring thoroughly during and after each addition. It shall be allowed to stand for five minutes and then filtered through a medium filter paper. All the solids shall be transferred to the filter, rinsing it if necessary, and washed thoroughly with not water. The volume of the filtrate and washings shall be adjusted to 500 mL in a volumetric flask, and mixed thoroughly to give the stock test solution for treatment as described in C1. 21.6.5.4.

The filter paper containing the precipitate shall be placed in a weighed platinum crucible and ignited, at first slowly until the carbon of the paper is completely consumed without flaming and finally at 1200 ± 50^{0}C until constant mass is achieved (see C1. 21.8.3). The crucible and residue shall be allowed to cool to room temperature in the desiccator and then weighed. The soluble silica content of the analytical sample shall be calculated to the nearest 0.1% from the expression:

$$\text{Soluble silica} = \frac{\text{mass of ignited residue}}{\text{mass of analytical sample}} \times 100\% \qquad \textbf{(21-4)}$$

The purity of the ignited silica precipitate shall be checked by evaporating it in the crucible with 10 mL of hydrofluoric acid containing five drops of sulphuric acid (1+1) in a fume cupboard. The residue shall be ignited and weighed as before. The loss in mass after evaporation and ignition equals the mass of silica in the original ignited residue. When the two masses differ by more than 0.005 g it is recommended that the determination (C1. 21.6.5) be repeated. If the discrepancy persists, the mass of silica found by evaporation with hydrofluoric acid shall be used to calculate the soluble silica content of the analytical sample.

21.6.5.4 Determination of calcium oxide

25 mL aliquot of the stock test solution from C1. 21.6.5.3 shall be pipetted into a 250 mL beaker or flask and diluted to about 150 mL. 10 mL of the diluted triethanolamine solution, 10 mL of the sodium hydroxide solution and about 0.15 g of screened calcein indicator shall be added. The solution shall then be titrated with the EDTA standard solution and the calcium oxide content of the analytical sample calculated as described in C1. 21.6.4.

21.6.6 Calculation of cement content

By assuming the combined water of hydration of the concrete to be 0.23 x C_1 and the total mass of oven dried concrete to be C_1 % cement + F% aggregate + 0.23 C_1 % combined water of hydration, the cement content as a percentage by mass of the concrete shall be calculated to the nearest 0.1% from the following expression using first the calcium oxide determinations and then the soluble silica determinations:

$$C_1 = \frac{c - b}{(a - 1.23b)} \times 100\% \qquad \textbf{(21-5)}$$

where

a is the calcium oxide or soluble silica content of the cement (in %)
b is the calcium oxide or soluble silica content of the aggregate (in %)
c is the calcium oxide or soluble silica content of the analytical sample (in %)

Note 1. *The range of values found for the combined water of hydration of Portland cements complying with BS 12, BS 146, BS 1370 or BS 4027 is between 0.20 and 0.25 of the cement, for fully hydration. For very young concrete (less than 28 days) special considerations may apply.*

If the calcium oxide and/or the silica contents of the cement and aggregate have not been determined, the best estimate based on the values listed in Table 5 shall be used. The assumed values as well as their justification shall be reported. For Portland cements complying with BS 12 there will be little loss in accuracy in assuming the calcium oxide content but rather greater loss in accuracy in assuming the silica content as stated in Table 5. For those aggregates essentially insoluble in hydrochloric acid it may be possible to assume that the calcium oxide content is zero. For local aggregates, it may be possible to assume the calcium oxide content to be 0.2% and the silica content as 0.4%.

When the two cement contents thus obtained are within 1% (m/m) of each other, the mean value shall be reported. When the two cement contents differ by more than this amount, the reasons for the discrepancy shall be investigated. If no reason can be found both results shall be reported and the preferred result highlighted.

This preference should be based on the analyst's experience, the age and exposure of the concrete and the nature of the aggregate, etc. Analysis of the sample for other constituents, such as insoluble residue, carbon dioxide, magnesium oxide, etc. may prove helpful in making the assessment. If such an assessment is not possible, the lower cement content is to be preferred.

Where it is known that the aggregate has a calcium oxide content of less than 0.5%, the determination of cement content by way of the soluble silica content is not obligatory, but nevertheless recommended, and the cement content can be based on the result of the determination of the calcium oxide content alone.

Conversely, where the calcium oxide content of the aggregate is 35% or more, calculations based on calcium oxide content are not recommended.

Where the calcium oxide content of the aggregate is 35% or more and the soluble silica content of the aggregate is 10% or more, the analytical sample shall be analysed for another constituent known to be present in substantially different amounts in the cement and in the aggregate and the cement content calculated by an appropriate modification of the equation (21-5). If possible, the constituent chosen shall generally form a greater proportion of the cement than of the aggregate.

When samples of the aggregate are available, petrographic methods may be applicable and reference can be made to ASTM C856.

21.6.7 Calculation of aggregate content

The aggregate content F as a percentage by mass of the concrete may be calculated to the nearest 0.1% by using either Method 1 or 2 below:

21.6.7.1 Method 1

$$F = \frac{a - 1.23c}{a - 1.23b} \times 100\% \qquad \textbf{(21-6)}$$

where

a is the calcium oxide or soluble silica content of the cement (in %)
b is the calcium oxide or soluble silica content of the aggregate (in %)
c is the calcium oxide or soluble silica content of the analytical sample (in %)

21.6.7.2 Method 2

Note. *This test cannot to used if a composite cement, e.g. Portland pozzolana cement having a significant insoluble residue has been used.*

The aggregate content may be obtained from the following expression, which is based on the insoluble residue values of the analytical sample:

$$\text{aggregate content} = \frac{\text{insoluble residue of analytical sample}}{\text{insoluble residue of aggregate}} \times 100\% \qquad \textbf{(21-7)}$$

Note. *When samples of the aggregate are not available for analysis there may be little loss of accuracy in assuming that with essentially insoluble aggregate the percentage insoluble residue of the analytical sample (see Cl. 21.6.5.2) corresponds to the percentage aggregate content.*

21.7 ORIGINAL WATER CONTENT

21.7.1 Applicability

21.7.1.1 General

The test described in this clause will only give acceptable results if the concrete is sound and in no way damaged, either physically or chemically. The method is not suitable for poorly compacted concrete, for semi-dry compacted concrete, for air-entrained concrete or for aerated concrete. With some aggregates, often manufactured, which are exceptionally porous or contain appreciable amounts of combined water, the corrections to be applied are so great as to render the results of doubtful value.

Unreliable results may be obtained when concrete older than five years is tested owing to changes in the pore structure of such concretes.

The original water contents refer to the water present in the concrete mix at the time of setting.

The procedure involves the determination of following:

(a) The capillary pores of the concrete originally filled with water at the time of setting.

(b) The combined water of hydration present in the prepared concrete sample.

The sum of these two represents the original water content of the concrete. It is usually expressed as water/cement ratio and this entails the determination of the cement content of the prepared sample.

Note. *It should be noted that the prepared sample, while representative for the water/cement ratio of the whole sample, will not necessarily be representative for the cement content.*

The water/cement ratio is expressed in two ways:

(a) as total water/cement ratio, which includes the water absorbed by the aggregates at the time of setting.
(b) as free water/cement ratio, which excludes the water absorbed by the aggregates at the time of setting.

The values for capillary porosity and combined water content will include contributions from the aggregates present and these shall be taken into account.

21.7.1.2 When aggregate control samples are available

The correction for the combined water content of the aggregate shall be made.

Correcting for aggregate porosity (see C1. 21.7.5.4) will give the original free water/cement ratio, while not making the correction will give the original total water/cement ratio, provided that the aggregate pores were filled with water at the time of setting. When there is some doubt about the condition of saturation of the aggregate in the set concrete, correction for aggregate porosity shall be made and only the original free water/cement ratio shall be reported. When there is no doubt, both free and total water/cement ratios shall be reported.

21.7.1.3 When aggregate control samples are not available

The combined water of hydration of the concrete shall be assumed to be:

$0.23 \times C_1$

where

C_1 is the cement content of the concrete (in %) (see note 1 to C1. 21.6.6)

The capillary porosity of the aggregate shall be taken to be equivalent to the water absorption value of the aggregate when this is reliably known (see C1. 21.7.6.2) to give the original free water/cement ratio. Otherwise no correction for aggregate porosity shall be made and only the total water/cement ratio shall be reported on the assumption that the aggregate pores were filled with water when the concrete had set.

21.7.2 Reagent

The following reagent is required:

. 1, 1, 1-trichloroethane

21.7.3 Apparatus

The following apparatus is required:

(a)	Vacuum desiccator	(see C1. C30).
(b)	Water pump or vacuum pump	(see C1. C31).
(c)	Apparatus for the determination of combined water content	(see C1. C32).

Further details of the apparatus are given in Appendix C.

21.7.4 Determination of capillary porosity

The sample shall be prepared by cutting a slice as described in C1. 21.4.3, drying it at 105 ± 5^{0}C for not less than 16 hours and allowed it to cool to room temperature in the desiccator.

The dried slice shall be weighed and immersed in 1,1,1-trichloroethane contained in the vacuum desiccator.

CAUTION. *Inhalation of the vapour and contact of the liquid with the skin and eyes should be avoided. Polyethylene gloves shall be worn when handling the sample.*

The absolute pressure in the vessel shall be reduced to less than 13.5 KPa (100 mmHg) by means of the water pump or vacuum pump.

Note 1. *It may be necessary to protect the vacuum pump against the effects of solvent vapour by fitting a cold trap or similar device.*

The air will then evolve from the capillaries in the concrete, rapidly at first and then more slowly. The removal of the capillary air is complete if no further air is released even when the evacuated vessel is cautiously given a sharp tap.

Note 2. *The time required to remove the air may be several hours. Boiling of the 1,1,1-trichloroethane induced by low pressure with continued evacuation should not be confused with air evolution and is normally recognizable by the tendency of large bubbles to appear at a few points on the concrete surface.*

When the air evolution has ceased, the pressure shall be released and the sample kept immersed at atmospheric pressure for a further five minutes. The sample shall then be removed from the 1,1,1-trichloroethane. Excess superficial liquid shall be allowed to drain away and excess solvent on the surface of the sample shall be quickly wiped off. The saturated sample shall be placed in a weighed polyethylene bag immediately, sealed to prevent loss of liquid by evaporation, and weighed. The mass of 1,1,1-trichloroethane required to fill the pores of the concrete shall be calculated and the equivalent mass of water derived assuming the relative density of the 1,1,1-trichloroethane to be 1.33.

The capillary porosity Q shall be calculated to the nearest 0.1% (m/m) from the expression:

$$Q = \frac{\text{mass of solvent absorbed}}{1.33 \times \text{mass of dried concrete sample}} \times 100\% \quad \textbf{(21-8)}$$

21.7.5 Determination of combined water and cement content

21.7.5.1 Sample preparation

The slice shall be removed from the polyethylene bag and heated to constant mass, i.e. until successive weighings after heating and cooling do not differ by more than 0.1 g, at 105 ± 5^{0}C. The slice shall be treated in accordance with the procedures described in C1. 21.4.5.3 to produce a representative analytical sample of not less than 30 g all passing a 150 µm sieve and the combined water and cement contents of the analytical sample shall be determined by the procedures detailed in C1. 21.7.5.2 to 21.7.5.5.

21.7.5.2 Determination of combined water content

Using the apparatus detailed in C1. 21.7.3, the combined water shall be determined by igniting the powdered sample at 1000 ± 25^{0}C in a stream of dried air or nitrogen and weighing the evolved water after absorption on dried magnesium perchlorate.

Note. *This determination is only made when reliable control samples of the aggregates are available.*

Residual moisture in the apparatus shall be purged by passing dried gas through the combustion tube, heated to 1000^{0}C, for 30 minutes with an empty absorption tube in position for the first 15 minutes, replacing it by the filled tubes for the rest of the time. After 30 minutes, the source of heat shall be removed and the air flow continued for a further 15 minutes. The absorption tubes shall be removed from the apparatus and transferred to the balance case.

When the combustion tube has cooled to below 100^{0}C, the absorption tubes shall be weighed and fitted into the train. Approximately 1 g of the sample shall be weighed accurately and placed into a combustion boat previously ignited to constant mass at 1000^{0}C and then promptly inserted into the combustion tube from the air inlet end. The connection shall be replaced and the gas flow adjusted to about three bubbles per second at the bubbler. The sample shall be heated cautiously at first and the temperature maintained at 1000^{0}C for 30 minutes. The source of heat shall be removed and the gas continued to pass for a further 15 minutes. The absorption tube shall be disconnected and transferred to the balance case and weighed after 15 minutes.

In order to determine the `blank' of the apparatus, which should be less than 1 mg, the procedure shall be carried out form the beginning with no sample in the combustion boat. If the blank is greater than 1 mg, the joints shall be checked to ensure that they are free of leaks. Then the blank determination shall be repeated. If a value greater than 1 mg is still obtained, the absorbents shall be replaced and the whole procedure repeated.

The combined water content X shall be calculated to the nearest 0.1% (m/m) from the expression:

$$X = \frac{\text{gain in mass of absorption tubes} - \text{blank}}{\text{mass of sample}} \times 100\% \qquad \textbf{(21-9)}$$

21.7.5.3 Determination of cement content

The cement content of the prepared sample shall be determined by the appropriate method as used for the analytical sample (see C1. 21.6.6).

21.7.5.4 Determination of aggregate porosity

About 1 kg of the dried coarse aggregate shall be weighed and the capillary porosity determined by the procedure given in C1. 21.7.4 but calculating it as a percentage q. For convenience, the aggregate shall be contained in a plastic mesh bag or supported on a sieve. The surface of the aggregate shall be dried before reweighing by shaking off the excess liquid and rapidly rubbing in a cloth.

21.7.5.5 Determination of aggregate combined water content

The solvent-saturated aggregate shall be heated to constant mass (as in C1. 21.7.5.1) at 105 ± 5^{0}C and crushed to pass a 150 µm sieve. The combined water content shall be determined by the procedure given in C1. 21.7.5.2 but calculated as a percentage Y.

21.7.6 Calculation of the original water/cement ratio

21.7.6.1 Aggregate control samples available

In the absence of contrary information, the values for porosity and combined water content found for the coarse aggregate may be assumed to be valid for the whole aggregate content of the sample.

Assuming that none of the water of hydration has been replaced by carbon dioxide, then the original free water content = corrected capillary porosity + corrected combined water content or

$$W_f = \left(Q - \frac{qF}{100}\right) + \left(X - \frac{YF}{100}\right) \quad \text{(in \%)} \qquad \textbf{(21-10)}$$

$$W_f = Q + X - \frac{F}{100}(q + Y) \quad \text{(in \%)} \qquad \textbf{(21-11)}$$

$$\text{original free water/cement ratio} = \frac{W_f}{C_1} \qquad \textbf{(21-12)}$$

original total water content = uncorrected capillary porosity + corrected combined water content or

$$W_f = Q + X - \frac{YF}{100} \quad \text{(in \%)} \qquad \textbf{(21-13)}$$

$$\text{original total water/cement ratio} = \frac{W_t}{C_1} \qquad \textbf{(21-14)}$$

where

Q	is the capillary porosity of the sample (in %) (see C1. 21.7.4)
q	is the capillary porosity of the aggregate (in %) (see C1. 21.7.5.4)
X	is the combined water content of the sample (in %) (see C1. 21.7.5.2)
Y	is the combined water content of the aggregate (in %) (see C1. 21.7.5.5)
C_1	is the cement content of the concrete (in %) (see C1. 21.7.5.3)
F	is the aggregate content of the concrete (in %) (see C1. 21.6.7)

Assuming the capillary porosity of the aggregate q' (in %) has the same value as its water absorption, then the concreted capillary porosity is

$$Q - \frac{q'F}{100} \quad \text{(in \%)} \qquad \textbf{(21-15)}$$

and the combined water content of the concrete is 0.23 C_1 so that the

$$\text{original free water/cement ratio} = \frac{Q}{C_1} - \frac{q'F}{100\, C_1} + 0.23 \qquad \textbf{(2-16)}$$

Note. *If q' is not reliably known then only the original total water/cement ratio can be reported.*

$$\text{The original total water/cement ratio} = \frac{Q}{C_1} + 0.23 \qquad \textbf{(2-17)}$$

21.8. IDENTIFICATION OF TYPE OF CEMENT

21.8.1 General

Differentiation between the various types of cement that may have been used in a concrete presents problems of varying complexity. In favourable circumstances it may be possible to differentiate between various cements by analysing for an element or elements peculiar to the cement in question after careful separation of the cement matrix. The results of typical analyses of various type of cement is given in Table 5.

It is strongly recommended that the results thus obtained should be supplemented by examination under a microscope of a polished specimen containing cement particles still unhydrated.

The test cannot be used to confirm that the cement used in the concrete did or did not comply with a cement specification. However, the test may help to determine compliance or otherwise with any requirement referring to general cement type in a concrete specification.

Table 5 - Typical Analyses of Types of Cement Currently Available in HK

	Ordinary and Rapid Hardening BS 12 %	Sulphate Resisting BS 4027 %	Portland-PFA BS 6588 (see note 3) %
CaO	64.2	64.5	48.4
SiO_2	20.4	20.9	-
MgO	2.0	0.9	2.0
Al_2O_3	5.9	4.3	-
Fe_2O_3	3.5	5.3	-
SO_3	2.3	2.1	2.6

Note 1. *These values are subject to a variation of at least ± 10%, with the exception of CaO content in ordinary Portland cement or sulphate resisting Portland cement which are subject to a variation of approximately ± 3.5%*

Note 2. *Variations in the clinkers used and in their relative proportions may cause large deviations from these values.*

Note 3. *Variations in the clinker and pulverized-fuel ash (PFA) used and in their relative proportions may cause large deviations from these values. The conditions of extraction may not bring all the other oxides into solution from the pozzolana although it may be expected that all the calcium will dissolve.*

21.8.2 Separation and analysis of matrix

A solid piece of the concrete sample shall be carefully broken down, for example by a compressive strength testing machine, and fine material shall be obtained by sieving using a 75 µm sieve. If insufficient sample is obtained, further breakdown is necessary.

The fine material so obtained shall be analysed for insoluble residue and loss-on-ignition (see C1. 1.8.3) and, or example, soluble silica (see C1. 21.6.5.3), calcium oxide (see C1. 21.6.5.4), alumina, ferric oxide, magnesium oxide, sulphuric anhydride, etc. It may be assumed that the insoluble residue represents aggregate in the fine material and the loss-on-ignition represents hydration and carbonation of the cement and the other analytical results shall be corrected by multiplying them by

$$\frac{100}{100 - (\text{loss-on-ignition} + \text{insoluble residue})}$$

The results shall be compared with typical analyses of various types of cement (see Table 5).

Note. *Any aggregate material in the separated fines can also contribute oxides, particularly ferric oxide, alumina and silica.*

21.8.3 Determination of loss-on-ignition

One to two grams of the analytical sample as prepared in C1. 21.4.5.3 shall be weighed accurately into a crucible which has been previously ignited and weighed accurately. The crucible shall be covered with a lid and placed in a furnace, the temperature of which shall be raised slowly to 925 ± 25^{0}C. After five minutes at this temperature, the lid shall be removed and the crucible left in the furnace at 925 ±25^{0}C for a further 30 minutes. The crucible shall be allowed to cool in the desiccator to room temperature and weighed. This process of ignition, cooling and weighing shall be repeated until constant mass is achieved as shown by successive weighings giving a difference in mass of less than 0.5 mg. The loss-on-ignition of the analytical sample shall be calculated to the nearest 0.1% from the following expression:

$$L_i = \frac{\text{mass of analytical sample} - \text{mass of ignited sample}}{\text{mass of analytical sample}} \times 100\% \qquad \textbf{(21-18)}$$

where

L_i is the loss-on-ignition

21.8.4 Examination under a microscope

21.8.4.1 General

To establish whether ordinary Portland cement or sulphate resisting Portland cement has been used in the concrete, the usual method is examination under a microscope. To do this, at least ten anhydrous relics of cement grains greater than 40 µm in size, or at least 20 grains greater than 20 µm in size shall be examined.

In older concretes which have been kept wet, e.g. foundations, it may prove impossible to find sufficient anhydrous grains.

21.8.4.2 Materials

The following materials are required:

(a) **Mounting resin**

An epoxy or polyester resin which sets rigidly when mixed with an appropriate hardener.

(b) **Silicon carbide powder,** medium grade, e.g. 26 µm

(c) **Non-aqueous liquid,** e.g. kerosene

(d) **Diamond paste,** of grades 14 µm, 6 µm, 3 µm, 1 µm and 0.25 µm

(e) **Non-aqueous solvent,** e.g. acetone

(f) **Potassium hydroxide solution,** 10%

10 g of potassium hydroxide shall be dissolved in 100 mL of water.

(g) **Methylated spirits or ethanol**

(h) **Hydrofluoric acid,** 40% relative density 1.13

21.8.4.3 Apparatus

The following apparatus is required:

(a)	Vacuum desiccator	(see C1. C30).
(b)	Rotary lap-plate	(see C1. C33).
(c)	Reflected-light microscope	(see C1. C34).
(d)	Cylindrical mould	(see C1. C35).

Further details of the apparatus are given in Appendix C.

21.8.4.4 Preparation of the sample

The sample shall be the portion B, obtained in accordance with C1. 21.4.5.1.

The concrete sample shall be broken up and at least ten nominal 5 mm sized pieces of cement-rich matrix shall be selected as the test portion. The test portion shall be dried at a temperature not exceeding 105^{0}C, allowed to cool and then embedded in a low viscosity mounting resin by casting into a cylindrical mould and curing in the vacuum desiccator at the temperature recommended by the resin manufacturer.

Note 1. *A cylindrical cast specimen of approximately 25 mm diameter is usually found to be suitable but larger or multiple specimens are also acceptable.*

The cylindrical casting shall be sectioned with a diamond saw lubricated with a non-aqueous liquid so that cut surfaces of the pieces are exposed on the sawn surface, and washed immediately using a non-aqueous solvent, e.g. acetone. The sawn surface shall be ground with silicon carbide powder lubricated with a non-aqueous liquid such as kerosene, or other suitable oil, to remove saw marks. All traces of grinding powder shall be removed.

Note 2. *Treatment with kerosene or industrial methylated spirits in an ultrasonic bath is effective.*

The sample shall be polished carefully with progressively finer diamond paste in an oil soluble base on a rotary lap-plate with a suitable surface. After a final polish with 0.25 μm diamond compound, the surface shall be cleaned using a non-aqueous cleaning agent and dried with tissue. The grinding and polishing routine shall be adjusted, particularly in terms of speed and duration of lapping, to minimize the plucking of cement particles out of the polished surface.

Note 3. *It is recommended that control samples of known cement types should be prepared at the same time so that the polishing, etching and microscopical examination stages can be monitored.*

21.8.4.5 Cement grain identification

The polished surface shall be examined through a reflected-light microscope using magnifications up to 800. If insufficient grains of anhydrous cement are found either further polished samples as described in C1. 21.8.4.4 shall be prepared so that the required number of grains can be assessed, or the method shall be reported as not applicable.

Note 1. *Anhydrous relics of cement grains smaller than 20 mm may be examined in addition, but the mineralogical composition of such small particles may not be representative.*

Note 2. *Anhydrous relics of cement grains apparently exhibiting selective hydration throughout the grains, e.g. patches of hydrated matrix should be discounted.*

Chemical etching of the grains reveals mineral phases characteristic of the type of cement present. It is permissible to use two alternative etchants:

(a) The polished surface shall be immersed in the potassium hydroxide solution at 30^{0}C for 10 to 20 seconds, then washed immediately in industrial methylated spirits or ethanol. The etching shall be controlled to give a bluish-grey colour to the tricalcium aluminate, the silicates remain grey, and the ferrite appears white.

(b) The polished surface shall be exposed to hydrofluoric acid vapour for two to five seconds until the hexagonal alite is coloured straw-brown; the rounded belite will appear in a variety of colours from blue to pink. In the interstitial phase, the tricalcium aluminate appears light grey and the ferrite appears white.

> **Note 3.** *It is sometimes difficult to distinguish these two compounds particularly at low magnification, i.e. less than 500.*

CAUTION. *Hydrofluoric acid is extremely dangerous and great care is required in its use, even in small quantities. Hydrofluoric acid vapour etching shall be performed in a fume cupboard. The vapour can damage microscope lenses and excess vapour shall be permitted to disperse completely from the specimen surface before examination is commenced. The vapour can be removed more quickly by placing a glass slide on top of the specimen after etching.*

With the use of the compositional information given in C1. 21.8.4.6, and making reference to the control specimens if prepared, the apparent type of cement represented shall be identified by examining each anhydrous grain. The cement type present in the concrete sample will be that represented by at least 80% of the anhydrous grains examined.

If the dominant cement type represents fewer than 80% of the grains examined, the whole procedure shall be repeated and the combined findings considered. If the dominant cement type represents fewer that 80% of the grains examined overall, the cement type shall be reported as `uncertain'.

Note 4. *A mixture os cement types could be one explanation of such uncertainty, but mixtures are extremely unusual and such an interpretation should not be regarded as conclusive.*

Photomicrographs of ordinary Portland cement and sulphate resisting Portland cement are reproduced in Figure 9.

21.8.4.6 Mineral phase compositions of different types of cement

Portland cements not having a specification limit for tricalcium aluminate content, e.g. ordinary and rapid hardening Portland cements complying with BS 12, generally have a volume ratio of ferrite to tricalcium aluminate of less than 2:1. For sulphate resisting Portland cement complying with BS 4027, the volume ratio of ferrite to tricalcium aluminate is generally more than 5:1. However, this ratio may not apply to sulphate resisting Portland cements with a high silicate content, such that the total volume of ferrite and tricalcium aluminate is very low.

Up to 20% of the unhydrated cement grains examined, may display an apparently anomalous phase composition. For this reason a concrete made with sulphate resisting Portland cement complying with BS 4027, for example, may contain a significant number of grains showing larger than expected amounts of tricalcium aluminate and thus having the appearance of ordinary Portland cement. Finding a few apparently anomalous grains in the examination is therefore not necessarily an indication of adulteration of the cement used.

21.9 IDENTIFICATION OF TYPE OF AGGREGATE

21.9.1 General

The identification of the type of aggregate is intended to aid the interpretation of the results of the chemical analysis. If more precise identification and classification of the aggregates are required, it shall be referred to a petrographer. The petrographical procedures required are outside the scope of this Standard.

Note. *Guidance notes for the petrographic examination of hardened concrete have been published in ASTM C856.*

21.9.2 Procedure

A broken, or preferably a sawn surface of the sample shall be prepared (see C1. 21.4.5.3). The general character of the aggregate shall be identified and the aggregate exposed shall be compared with known samples whenever possible.

Note 1. *Most carbonate aggregates may be identified by treating with dilute hydrochloric acid (1+9) and observing the presence (or absence) of effervescence. Even when a carbonate aggregate was not used in the concrete, there may nevertheless be some carbonate particles, or particles containing carbonate which will react with dilute acid, e.g. shell debris. Some dolomites do not react rapidly with cold dilute hydrochloric acid but will effervesce with warm dilute hydrochloric acid.*

Note 2. *Examination of the aggregates and of their reaction with acids may be aided by observation under a low-power binocular microscope.*

21.10 OTHER CONSTITUENTS

21.10.1 General

The analytical sample prepared as in C1. 21.4.5.3 may be used for the determinations of chloride, sulphate and carbonate contents. Since the chloride and sulphate contents are usually reported in relation to the cement content of the concrete, such a sample, in which the cement matrix has been concentrated, may present some advantage in all these tests.

A suitable procedure is to break the concrete sample and to obtain fine material by sieving through a 150 μm sieve. Further breaking and sieving is carried out until a sufficient quantity of fines has been produced. The less the aggregate is damaged the higher the cement content of the fine materials. The cement content of this separated sample has to be determined using the procedure described in C1. 21.6.6.

21.10.2 Determination of chloride content

Alternative methods based on potentiometric titration are acceptable.

21.10.2.1 Reagents

The following reagents are required:

(a) **Nitric acid,** relative density 1.4

(b) **Silver nitrate standard solution**, 0.1 mol/L

Powdered silver nitrate shall be dried at 150°C for two hours, cooled in a desiccator and a quantity of 16.989 g shall be dissolved in water and diluted to 1 L. The solution shall be stored in an opaque glass bottle and protected from prolonged exposure to light.

(c) **Thiocyanate standard solution,** approximately 0.1 mol/L

7.6 g of ammonium thiocyanate or 9.7 g of potassium thiocyanate shall be dissolved in water and diluted to 1 L. The solution shall be standardized against the silver nitrate standard solution using iron III indicator, once a week or each time a determination of chloride content is made, if less frequent.

(d) **Iron III indicator solution**

50 g of ammonium ferric sulphate shall be dissolved in 60 ml of warm water. 10 mL of nitric acid shall be added to the solution, which is then cooled and stored in a glass bottle.

(e) **3,5,5-trimethylhexanol (nonyl alcohol)**

21.10.2.2 Procedure

5 ± 0.1 g of the analytical (see C1.21.4.5.3) or separated (see C1. 21.10.1) sample shall be weighed accurately into a stoppered 500 mL conical flask. It shall be dispersed with 50 mL of water and 10mL of the nitric acid shall be added. 50 mL of hot water shall be added, boiled for four to five minutes and kept warm for 10 to 15 minutes. (If the supernatant liquid is turbid, it shall be filtered through a fast hardened ashless filter paper and washed with hot water.) The solution shall be cooled to room temperature and a measured excess of the silver nitrate standard solution added. 2 mL to 3 mL of 3,5,5-trimethylhexanol shall be added to the solution, the flask shall be stoppered and shaken vigorously to coagulate the precipitate. 1 mL of iron III indicator solution shall be added and titrated with the thiocyanate solution to the first permanent red colour.

The chloride ion content J of the cement shall be calculated to the nearest 0.01% (m/m) from the expression:

$$J = \left(V_1 - \frac{V_2 M}{0.1}\right) \times \frac{0.3545}{m} \times \frac{100}{C_1} \% \qquad \textbf{(21-19)}$$

Where

m is the mass of sample used (in g)
V_1 is the volume of 0.1M silver nitrate solution added (in mL)
V_2 is the volume of thiocyanate solution used (in mL)
M is the molarity of the thiocyanate solution (in mol/L)
C_1 is the cement content of the sample used (in %)

Note. *Other concentrations of silver nitrate solution and thiocyanate solution may be used and the equation modified accordingly.*

21.10.3 Determination of sulphate content

21.10.3.1 Reagents

The following reagents are required:

(a) **Concentrated hydrochloric acid,** relative density 1.18

(b) **Dilute hydrochloric acid (1+49)**

(c) **Ammonium hydroxide solution (1+1)**

(d) **Barium chloride solution, 100 g/L**

21.10.3.2 Procedure

5 ± 0.1 g of the analytical (see C1. 21.4.5.3) or separated (see C1. 21.10.1) sample shall be weighed accurately into a 400 mL beaker, dispersed with 50 mL or water and 10 mL of concentrated hydrochloric acid added. If effervescence is considerable, the beaker shall be covered immediately. 50 mL of hot water shall be added, the beaker covered and the solution boiled gently for 5 to 10 minutes. The content of the beaker shall then be filtered through a medium ashless filter paper and the residue thoroughly washed with hot dilute hydrochloric acid (1+49). Three drops of the methyl red indicator shall be added to the filtrate which shall then be heated to boiling and just neutralized to yellow with the dilute ammonium hydroxide solution. 1 mL of concentrated hydrochloric acid shall be added immediately and then 10 mL of the barium chloride solution shall be added dropwise. If excess ammonium hydroxide was added, 1 mL of concentrated hydrochloric acid may not be sufficient to obtain the required acid solution and the barium sulphate precipitate will then be contaminated. In this case the test shall be repeated.

The solution shall be boiled gently for five minutes, kept as just below boiling for 30 minutes and allowed to stand at room temperature for 12 to 24 hours. It shall then be filtered through a slow ashless filter paper and washed free from chlorides with hot water. The paper and contents shall be transferred to a weighed silica or platinum crucible and the paper burnt off without flaming. The precipitate shall be ignited at 800^0C to 900^0C until constant mass is achieved (see C1. 21.8.3).

The sulphate content G, expressed as SO_3 shall be calculated, as a percentage of the cement to the nearest 0.1% (m/m) from the expression:

$$G = \frac{B}{m} \times 34.3 \times \frac{100}{C_1} \% \qquad \textbf{(21-20)}$$

Where

B is the mass of ignited barium sulphate (in g)
m is the mass of the sample used (in g)
C_1 is the cement content of the sample used (in %)

Note. *The stock test solution (see Cl. 21.6.5.3) may be used for this determination. A 200 mL aliquot shall be used and the procedure as above followed from the heating stage to boiling and neutralizing with dilute ammonium hydroxide solution.*

21.10.4 Determination of carbonate

The carbonate content of the concrete may be calculated from its carbon dioxide content, two methods of determining which are given below:

21.10.4.1 Method 1

21.10.4.1.1 Reagents

(a) Orthophosphoric acid, relative density 1.7

(b) Concentrated sulphuric acid, relative density 1.8

(c) Anhydrous copper sulphate on pumice

50 g of pumice stone (particle size of about 1 mm) shall be added to 50 mL of 30% copper sulphate solution (15 gm copper sulphate pentahydrate dissolved in 50 mL distilled water). The mixture shall be heated on top of a boiling water bath to near dryness with constant stirring. The mixture shall be dried in an oven at 105^0C for two hours and kept in an air-tight bottle.

(d) Dried magnesium perchlorate, particle size 0.7-1.18 mm (10-16 mesh)

(e) Granular absorbent for CO_2 , soda lime, particle size 1.0-1.7 mm (10-16 mesh)

21.10.4.1.2 Procedure

The apparatus as shown in Figure 14 (see C1. C36 of Appendix C) shall be assembled without the weighable tubes and flushed with gas free from carbon dioxide at a rate of approximately three bubbles per second for 15 minutes. The tap funnel shall be acid-free. Approximately 0.2 g of the analytical sample prepared as in C1. 21.4.5.3 shall be accurately weighed into a duplicate reaction flask, the empty reaction flask shall be replaced by the one containing the sample and the passing of gas free from carbon dioxide continued. The two absorption tubes shall be weighed and connected to the apparatus. The gas inlet shall be disconnected and 30 mL of orthophosphoric acid shall be placed into the tap funnel. The tap shall be opened and the gas inlet reconnected; the gas pressure will force the acid into the reaction flask. After effervescence has ceased, the contents of the flask shall be slowly heated to boiling and boiled for five minutes. It shall then be allowed to cool for 15 minutes while maintaining the gas flow. The absorption tubes shall be detached, transferred to the balance case and weighed after 30 minutes.

To determine the ‘blank' of the apparatus, which should be less than 1 mg, the procedure described above shall be carried out with no sample in place. If the blank is greater than 1 mg, the joints shall be checked to ensure that they are free of leaks. The blank determination shall then be repeated. If a value greater than 1 mg is still obtained, the absorbents shall be replaced and the whole procedure repeated.

The carbon dioxide content, *C* of the analytical sample shall be calculated to the nearest 0.1% from the expression:

$$C = \frac{\begin{array}{c}\text{gain in mass of}\\ \text{absorption tubes} \quad - \quad \text{blank}\end{array}}{\text{mass of analytical sample}} \quad \text{x } 100\% \qquad \textbf{(21-21)}$$

21.10.4.2 Method 2 (see Figure 15 of Appendix C)

This method is based on a manometric measurement of the volume of carbon dioxide evolved upon acid treatment of a weighed powered concrete sample. The carbonate content is calculated from the volume of the gas after being corrected for temperature and atmospheric pressure.

21.10.4.2.1 Reagents

The following reagents are required:

(a) dilute hydrochloric acid solution (1+1)

(b) Methyl red indicator solution

1 g of methyl red shall be dissolved in 600 mL of methylated spirits and 400 mL of water added.

21.10.4.2.2 Apparatus

The following apparatus is required:

(a) A graduated burette
(b) A plastic measuring cylinder
(c) A levelling tube
(d) A thermometer
(e) A barometer

Further details of the apparatus are given in C1. C37 of Appendix C.

21.10.4.2.3 Procedure

The apparatus shall be set up as shown in Figure 15 (see C1. C37 of Appendix C). The graduated burette and levelling tube shall be filled with water to which two drops of the hydrochloric acid and a few drops of methyl red solution have been previously added.

The quantity of the analytical sample required is such as to give off 30-60 mL of carbon dioxide gas upon acid treatment. As a guide, this amount will range from 0.5 - 1.0 g for a heavily carbonated sample to about 3 - 5 g for one having a low carbonate content. The sample shall be weighed to an accuracy of 0.5 mg, placed in the reaction flask and about 20 mL of water shall then be added.

10 mL of the hydrochloric acid shall be put in the plastic measuring cylinder which shall then be carefully placed in the reaction flask without spilling the acid. The reaction flask shall be connected to the apparatus by inserting the rubber stopper.

With the 3-way tap opened to atmosphere, the level of the coloured solution in the graduated burette shall be adjusted until it coincides with the zero mark by raising or lowering the levelling tube. The tap shall then be closed and the reaction flask tilted so that the acid in the measuring cylinder spills over the sample. The flask shall be shaken well to ensure the sample and the acid are mixed thoroughly. The tap shall be set to the position in which the burette is connected to the flask.

The height of the levelling tube shall be adjusted until the levels of the solution in the burette and levelling tubes are equal. The tap shall then be closed and the volume displaced by the gas in the burette noted.

The flask shall be reshaken and the procedure repeated until there is no further increase in the gas volume indicated by the burette. The final volume shall be recorded as the volume of carbon dioxide evolved.

The ambient temperature and the barometric pressure at the time of the test shall be recorded.

21.10.4.3 Calculation of carbon dioxide content

The carbon dioxide content C of the analytical sample shall be calculated to the nearest 0.1% from the expression:

$$C = \frac{0.0705 \text{ x } V(P - W)}{(273 + T)\, m} \qquad \textbf{(21-22)}$$

where

V is the final gas volume in mL.
P is the barometric pressure in mmHg, see Table 6
W is the water vapour pressure (mmHg) at T^0C
T is the ambient temperature in ^{0}C
m is the mass of sample of g

The carbonate content C' in percentage by mass of the sample may be obtained from the following expression:

$$C' = \frac{15C}{11} \qquad \textbf{(21-23)}$$

When the carbonate content is calculated as calcium carbonate content, the following expression may be used:

$$CaCO_3 = \frac{25C}{11} \qquad \textbf{(21-24)}$$

The results shall be reported to the nearest 0.1%.

Note 1. *Correction for the volume of acid solution should be made to the final gas volume if the acid solution is added externally to the reaction flask.*

Note 2. *The value of water vapour pressure W at various temperatures is shown in Table 6.*

Table 6 - Vapour Pressure of Water at Temperatures between 20^{0}C to 30^{0}C

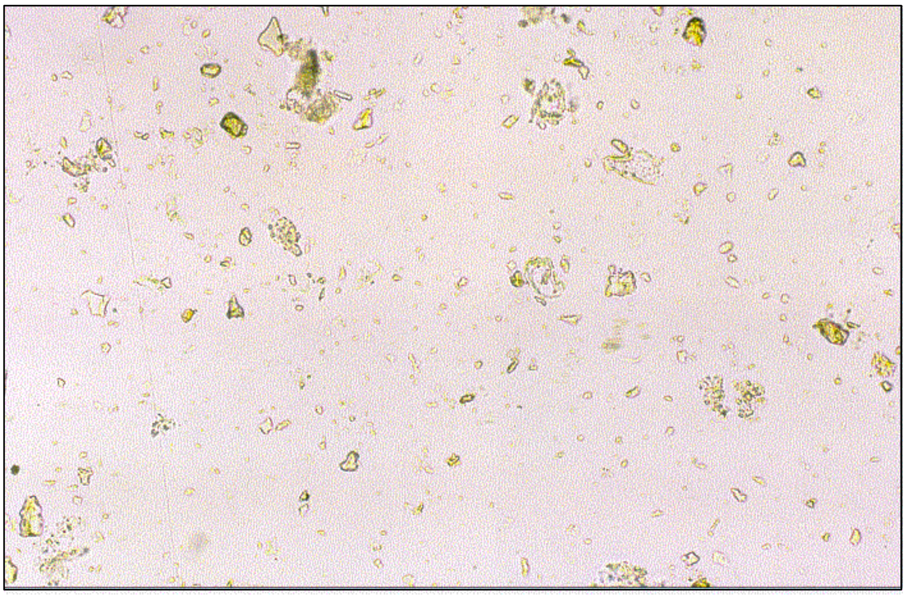
Temperature ^{0}C	Vapour Pressure mm Hg
20	17.53
20.5	18.085
21	18.650
21.5	19.231
22	19.827
22.5	20.440
23	21.068
23.5	21.714
24	22.377
24.5	23.060
25	23.756
25.5	24.471
26	25.209
26.5	25.964
27	26.739
27.5	27.535
28	28.349
28.5	29.184
29	30.043
29.5	30.923
30	31.824

21.11 REPORT

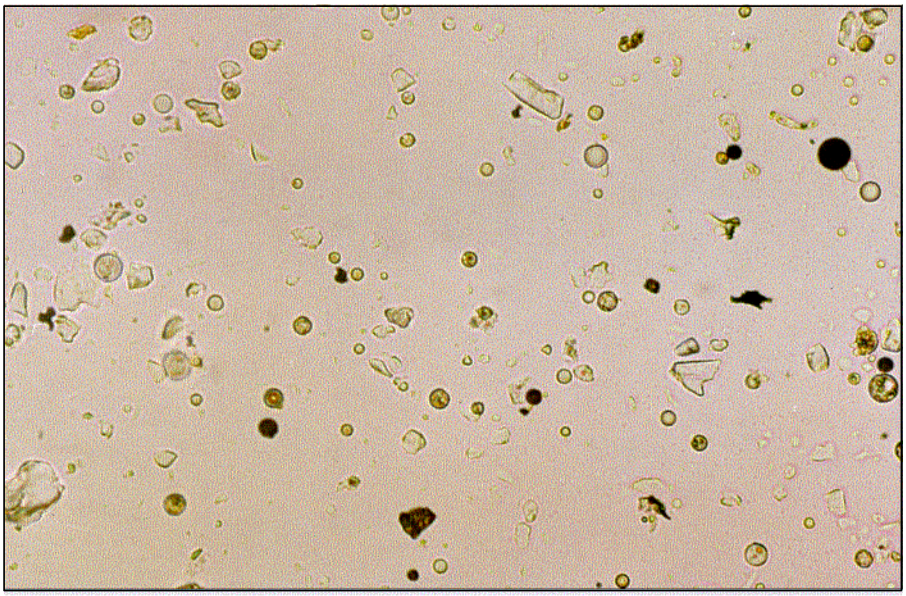
The report shall affirm that the analysis was made in accordance with this Standard. When alternative methods are used, the report shall include reference to evidence held by the laboratory showing that the alternative methods are capable of producing results which do not differ significantly from those obtained used the Standard method. A copy of the sampling report shall be provided with this report.

The report shall include the following information:

(a) Date and place of sampling and identification marks and other relevant details supplied with the sample.
(b) Full qualitative description of the sample, including the type of aggregate, with particular reference to factors likely to reduce the accuracy of the results.
(c) Date and place of the analysis.
(d) Any assumptions made in the analysis, e.g. type of aggregate, cement analysis, aggregate analysis, etc..
(e) Results of the analysis with the estimated magnitude of probable errors for comparative results.
(f) Any other results obtained coincidentally to the tests required.
(g) The results of any additional tests done at the analyst' s discretion.
(h) Name and signature of person responsible for testing.

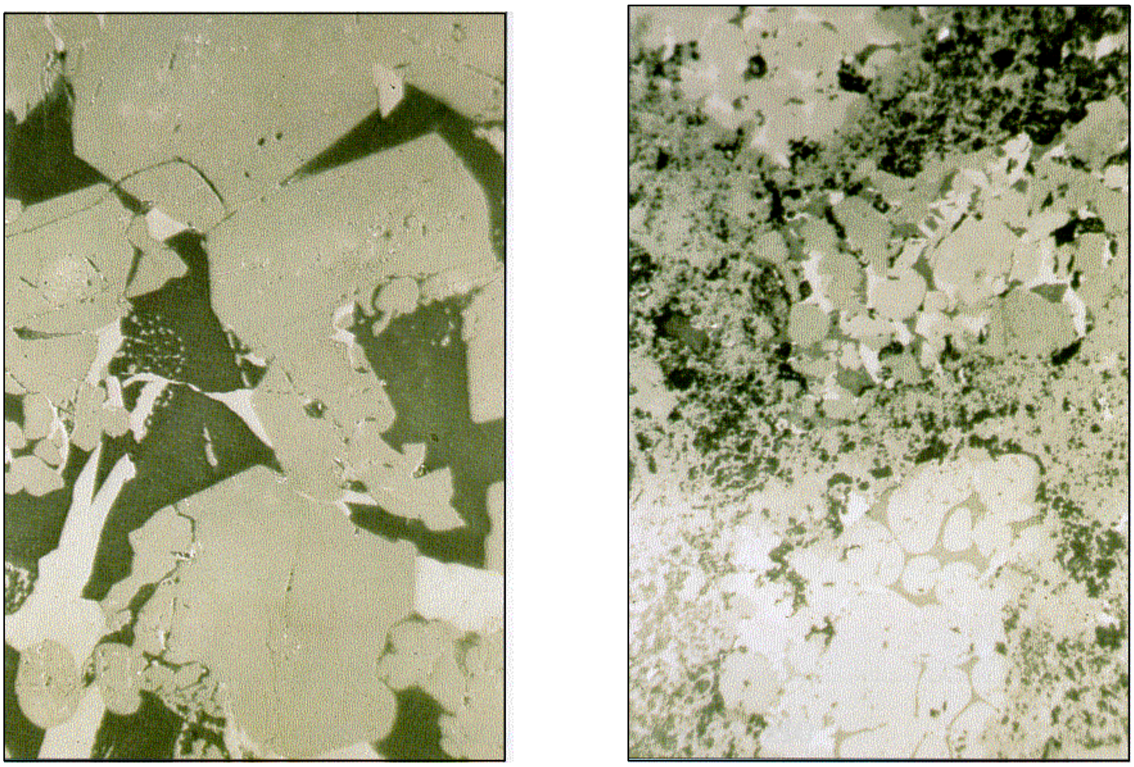


OPC Concrete (Magnification: 200X)



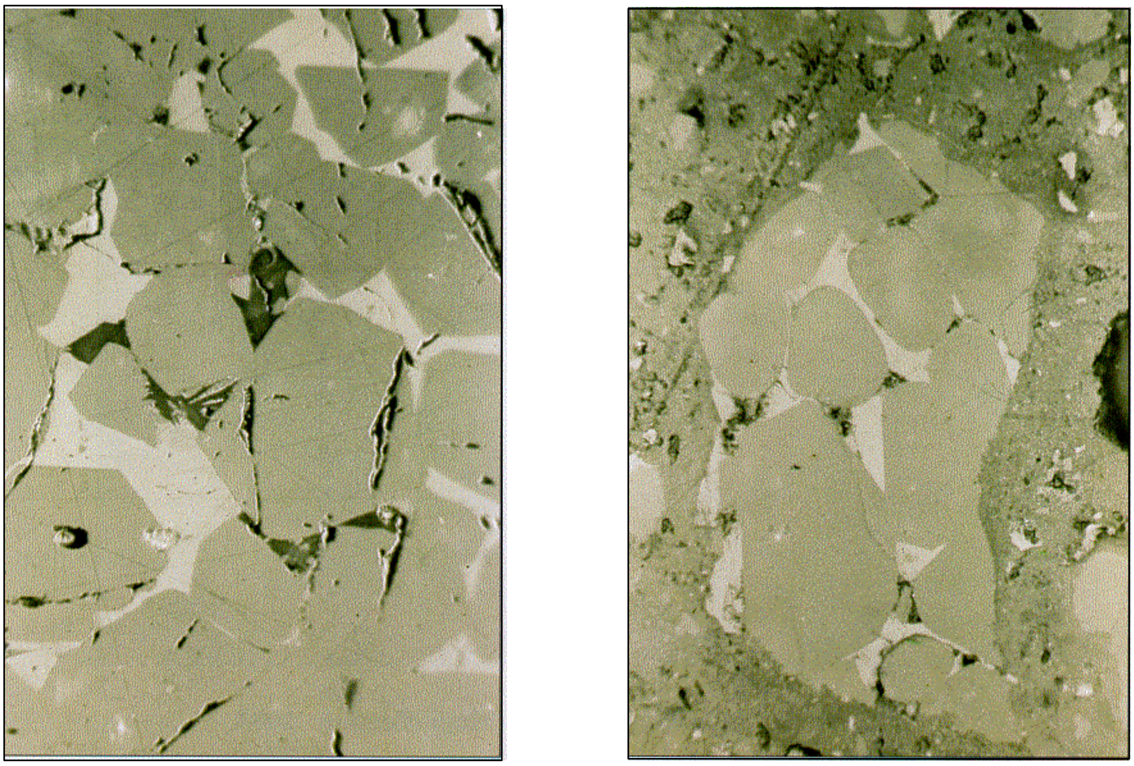
Concrete Containing PFA (Magnification: 200X)

Figure 8 - Photomicrographs of OPC and PFA Concrete



Ordinary Portland Cement (OPC)

OPC Concrete



Sulphate Resisting Portland Cement (SRPC)

SRPC Concrete

Figure 9 - Photomicrographs of OPC and SRPC Cement/Concrete

APPENDIX C

APPARATUS

CONTENTS

APPENDIX C - APPARATUS

C1 Mixer

The mixer shall be rotating pan or tilting drum type of capacity sufficient to mix batches large enough to provide samples for the tests to be carried out.

C2 Sample container

A bucket or other suitable container made of plastic or metal, of minimum 8-litre capacity.

C3 Sample tray

The sample tray shall be 1.2m x 1.2m in area, made of metal and have sufficient capacity to contain the concrete sample. It shall have sides to prevent the loss of water or cement paste.

C4 Scoop

The scoop should be made of metal of a size suitable for sampling concrete. The scoop shall not allow water to escape from concrete contained in it.

C5 Compression testing machine

The compression testing machine shall be suited to the size of the specimen and the expected load, and shall comply with BS 1610 : Part 1 and Clauses C5.1 to C5.5 of this Standard. The performance of the machine shall be verified in accordance with Appendix D of this Standard.

C5.1 Loading

C5.1.1 Load control

The machine shall be capable of applying the load at the specified rate, uniformly, without shock, using manual or automatic control.

C5.1.2 Load pacer

If the machine is not equipment with an automatic load control, a load pacer shall be fitted to enable the operator to manipulate the machine controls to maintain the specified rate.

If the pacer has a scale, this scale shall be basically linear such that 1 mm represents not more than 100 N/s. Over the operating range of the scale the accuracy shall be within ±5%.

If the pacer is fitted with a variable speed control or has pre-set speeds, then once the variable speed control has been set, or a preset speed has been chosen, the pacer speed shall remain within ± 5% of specified speed over the operating range.

C5.1.3 Load scale indicators or digital displays

The machine shall be provided with the following:

(a) Either easily read dials or scales or electrical load indicators, with a visual display.

(b) A resettable device which registers the maximum load sustained by the specimen.

Note. *The visual display may be supplemented by recording devices e.g. punched tape or print-out recorders, that are calibrated to the same accuracy as the display.*

(c) The machine scale range shall be chosen so that the specimens can be expected to fracture in the part of the range which is certified to be accurate to ±1% or ±2% of the indicated load (i.e. normally the upper four-fifths of the range).

The grading of the machine in accordance with BS 1610: Part 1 shall not be affected by variations in mains supply voltage or frequency of ±10% from the nominal value supplied to the machine.

Note 1. *Machines accurate to ±1% are preferred.*

Note 2. *Where electrical or other interference exists this may affect the accuracy of load indication, and special provisions to overcome this interference may be necessary.*

C5.1.4 Means of applying the load

The machine shall apply the load to the specimen either in direct contact with the machine platens, or spacing blocks, or with auxiliary platens interposed between each machine platen, or spacing blocks, and the specimen.

C5.2 Machine platens

In order to avoid excessive platen deformation during loading, the machine platens shall be adequately supported over the area in contact with the specimens.

The platens shall be made of a material which, when tested in accordance with BS 427, shall have a hardness value of at least 550HV30. Also the material shall not deform irreversibly when the machine is used.

The flatness tolerance for the area of each platen in contact with the specimen or auxiliary platen shall be 0.03 mm. The contact areas of the platens shall be checked for flatness at annual intervals.

The R_a value for the surface texture of the contact area of each platen shall be between 0.4 µm and 3.2 µm when assessed in accordance with BS 1134 : Part 1.

Note. *Roughness values of finishes by common manufacturing processes are given in Table 1 of BS 1134: Part 2 : 1972.*

C5.3 Auxiliary platens

Auxiliary platens should be used in order to save wear on the machine platens and to minimize the effect or overfilled sample on strength measurement. The top auxiliary platen shall rest on and be aligned with the cube. It shall not be fixed to the upper machine platen.

The auxiliary platens shall be made of a material which, when tested in accordance with BS 427, shall have a hardness value of at least 550HV30. Also the material shall not deform irreversibly when the machine is used.

The distance between either pair of opposite edges of a square auxiliary platen, or the diameter of a circular platen, shall be the nominal size of the specimen (i.e. 100 mm or 150 mm) $^{+0.2}_{-0.0}$ mm thickness of the platen shall be at least 23 mm.

The flatness tolerance for each contact face of the platens shall be 0.03 mm. The contact face of the auxiliary platens shall be checked for flatness at annual intervals. If auxiliary platens, worn by direct contact with the test specimens, are resurfaced they shall then be checked for size, squareness, parallelism, flatness, surface texture and hardness to ensure compliance with this clause. If case-hardened auxiliary platens are resurfaced they shall be re-hardened and checked for hardness before checking for the dimensional requirements of this case.

The squareness tolerance for each edge of the auxiliary platen with respect to the adjacent edge as datum shall be 0.2 mm.

The parallelism tolerance for one contact face of the auxiliary platen with respect to the other contact face as datum shall be 0.06 mm.

The R_a value for the surface texture of the contact faces of the auxiliary platen shall be between 0.4 µm and 3.2 µm when assessed in accordance with BS 1134 : Part 1.

Note. *Roughness values of finishes produced by common manufacturing processes are given in Table 1 of BS 1134 : Part 2 : 1972.*

C5.4 Spacing blocks

If it is required to reduce the distance between the machine platens, up to four spacing blocks may be located either beneath or upon the lower machine platen. Spacing blocks shall be either circular or square in section and shall comply with the flatness and parallelism tolerances required for auxiliary platens. Spacing blocks shall be positively located in the horizontal plane.

Spacing blocks used

(a) beneath the lower machine platen shall be nominally 200 mm in diameter or, if square, at least 210 mm x 210 mm;

(b) upon the lower machine platen shall be at least as large as any auxiliary platen to be used and shall not be larger than the machine platen or less than 23 mm thick;

(c) upon the lower machine platen and in contact with concrete specimens or proving devices shall be made of a material which has a hardness value of a least 550HV30 and which will not deform irreversibly when the machine is used. They shall have an R_a value for the surface texture of the contact faces of between 0.4 μm and 3.2 μm when assessed in accordance with BS1134 : Part 1. The contact faces of these spacing blocks shall be checked for flatness at annual intervals.

C5.5 Loading of specimen

Provision shall be made for positive and accurate location in the horizontal plane of the specimen or auxiliary platen on the lower machine platen or spacing block. Positive location shall be provided by the use of pegs, jigs or dowelled joints. Visual location alone is unacceptable.

C6 Cube checking jig

The jig shall be made of steel an consist of a base plate and two vertical side plates all at right angles to each other assembled so that the internal vertical surfaces are $150\,^{+0.2}_{-0.0}$ mm square. The tolerance for squareness shall be ± 0.2 mm between each pair of faces. The tolerance for flatness of each face shall be 0.03 mm. Provided that these tolerances are met it may be convenient to use half a standard cube mould securely fixed to a base plate.

C7 Calliper

The vernier calliper shall be capable of measuring specimen dimensions to an accuracy of 0.1 mm.

C8 Weighing equipment Type 2

The weighing equipment shall be capable of weighing up to 20 kg to an accuracy of 5 g or better.

C9 Feeler gauges

The feeler gauges shall be capable of measuring a gap up to 2 mm.

C10 Jig for tensile splitting strength test

A suitable jig is shown in Figure 11. The jig and/or the machine shall have a device to position the jig correctly on the lower platen, with the specimen central.

C11 Packing strips

The packing strips between the specimen and jig or steel loading pieces shall be of oil tempered grade hardboard and shall be used only once.

The length of the hardboard packing strips shall be greater than the line of contact of the test specimens. The width of the hardboard packing strips shall be 15 ± 2 mm and the thickness shall be 4 ± 1 mm.

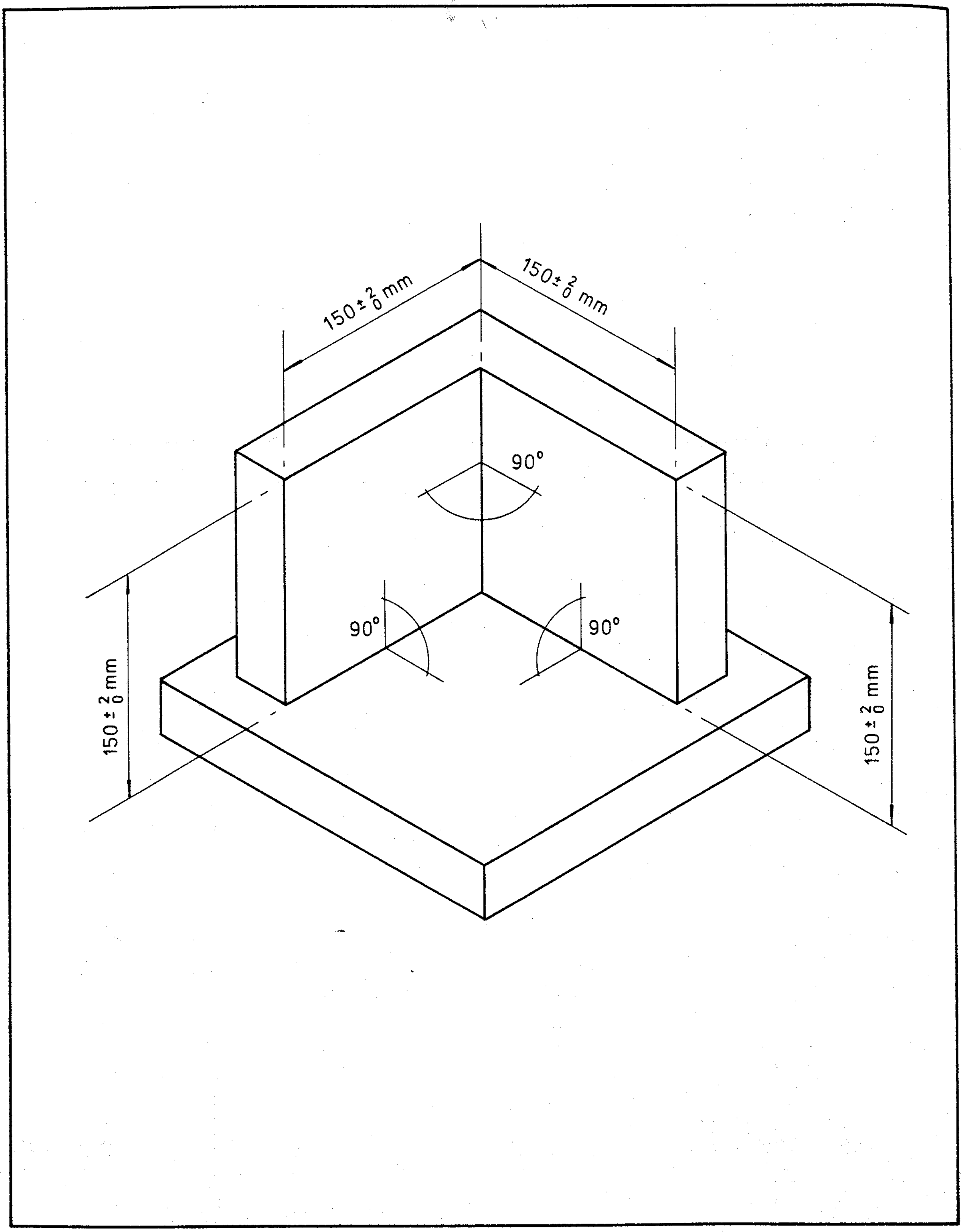


Figure 10 - Cube Checking Jig

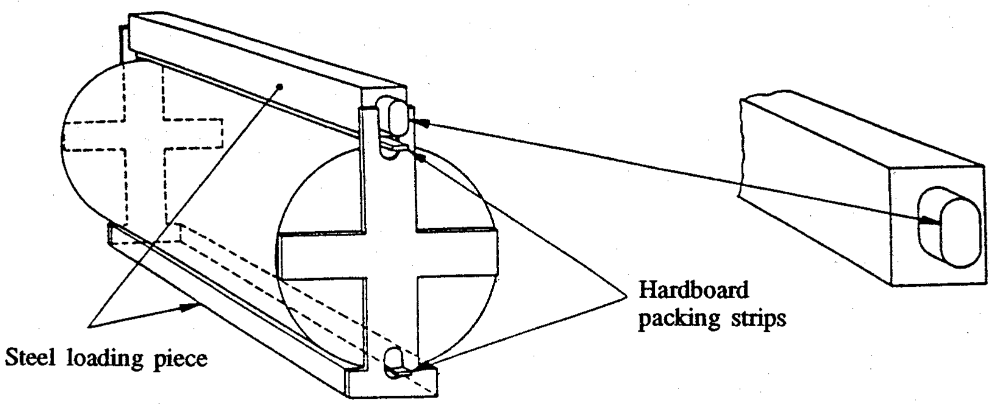


Figure 11 - Jig for Tensile Splitting Strength Test

C12 Steel loading pieces

A steel loading piece shall be placed between the platen of the machine and the hardboard packing strip. This piece shall not be shorter than the specimen. For cylindrical specimens it shall be of rectangular cross-section. This loading piece can be incorporated within the jig.

The flatness, parallelism and surface requirements of the steel loading pieces along the length of the strips shall be within the tolerances for auxiliary platens given in C1. 5.3 of this Appendix.

The steel loading pieces shall be replaced when the dimensions are out of tolerance or they are seriously damaged or pitted along the contact face.

C13 Flexural loading device

The device for applying the loads shall consist of two supporting rollers and two load-applying rollers (see Figure 7). All rollers shall be manufactured from steel and shall have a circular cross-section with a diameter of 20 mm to 40 mm; they shall be at least 10 mm longer than the width of the test specimen. All rollers except one shall be capable of rotating about their axes and of being inclined in a plane normal to the longitudinal axis of the test specimen.

Note. *Although the test method describes a method of loading above the specimen on two inner rollers, the load can be applied by the supporting rollers. Also the upper and lower roller positions relative to each other may be reversed.*

C14 Coring machine

The coring machine shall have a diamond drilling bit capable of cutting a core to a cylindrical tolerance of 3 % of the core diameter.

C15 Grinding equipment

The grinding equipment shall be capable of producing a surface to the required tolerances.

C16 Steel plate

A horizontal steel plate with an upper surface having a flatness tolerance of 0.03 mm, a surface texture not exceeding 3.2 µm Ra when determined in accordance with BS 1134 and a Rockwell (Scale B) Hardness Value of at least 95 when tested in accordance with BS 891 : Part 1.

C17 Balance with stirrup

The balance shall be equipped with a stirrup for weighing the specimen in both air and water to an accuracy of 0.1% of the mass. Some suitable types of stirrup are shown in Figure 12.

C18 Water container

The water container shall be fitted with a device to maintain the water level constant, and be of sufficient size to allow the specimen on the stirrup to be fully immersed to constant depth.

C19 Ventilated oven

The oven shall comply with BS 2648 and shall be of sufficient size to enable the specimens to be placed in the oven in the manner specified. The temperature of the oven shall be maintained at 105 ± 5^{0}C.

C20 Strain measuring apparatus

The strain measuring apparatus shall have an accuracy of ± 5 micro-strain.

Instruments for measuring strain (for example mirror or dial gauge extensometer, resistance strain gauges, inductance gauges, vibrating wire strain gauges) shall have a gauge length of not less than two-thirds of the width or diameter of the test specimen (2/3*d*).

C21 Crushing and grinding equipment

Jaw crushers, hammer mills, disc grinders, gyratory mills and mechanical or hand-operated mortars and pestles are among the types which have proved to be satisfactory.

C22 Test sieves

All sieves shall comply with BS 410 and be complete with the appropriate size of lids and receivers. If mechanical crushing and grinding is used, sieves with apertures of 150 µm and 1.18 mm will be required. If mechanical crushing and grinding is not used, other test sieves with apertures of 5.0 mm, 2.36 mm and 600 µm will be required.

C23 Airtight bottles

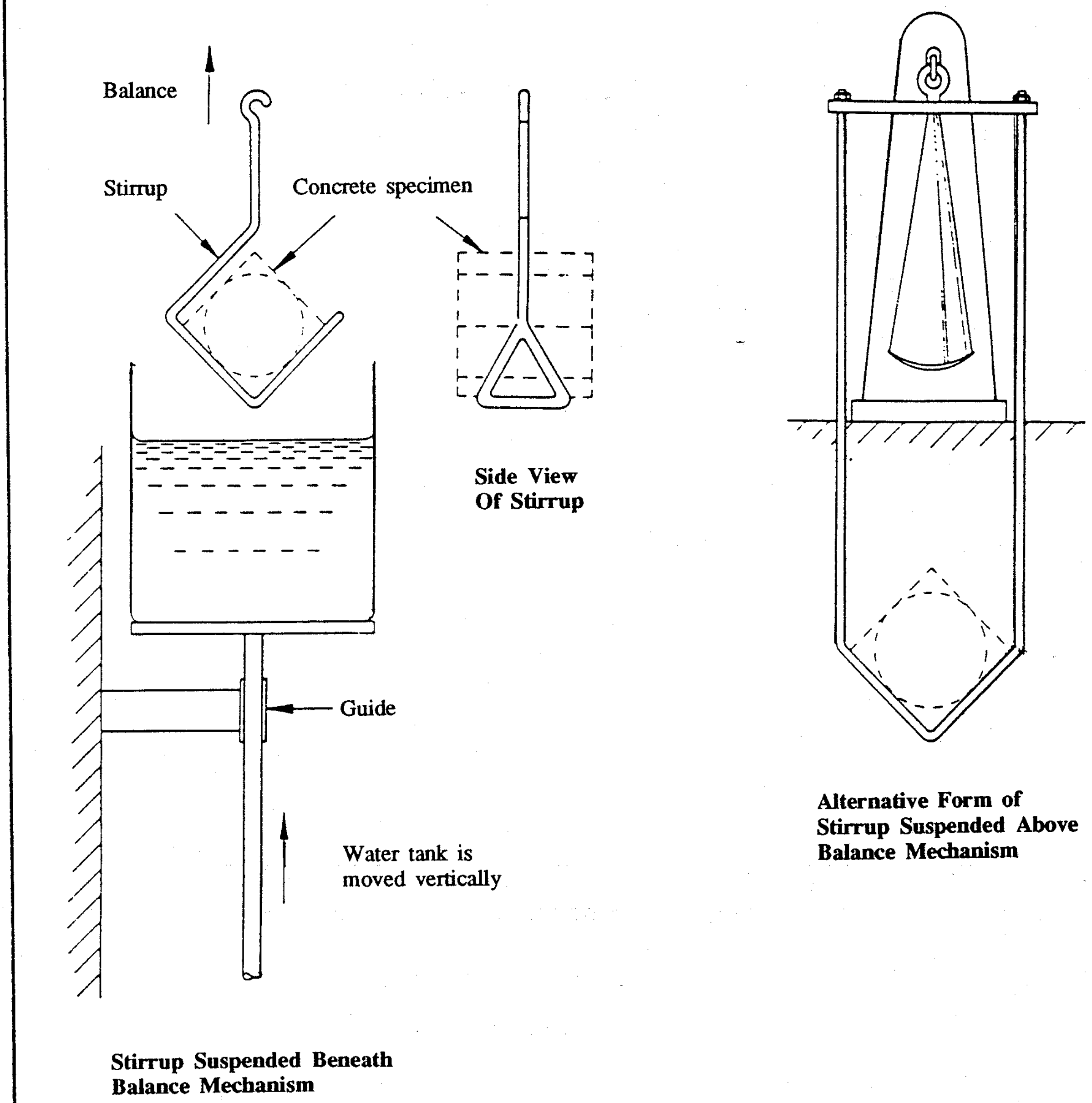
The bottle shall be made of glass or plastic and with a capacity of between 100 mL to 500 mL.

C24 Concrete saw

The saw shall be fitted with a diamond or carborundum blade.

C25 Centrifuge

The centrifuge shall be capable of operating at a speed 2500 - 3000 rpm and include sample bottles of capacity 150 - 200 mL with sealed caps.



Side View Of Stirrup

Stirrup Suspended Beneath Balance Mechanism

Alternative Form of Stirrup Suspended Above Balance Mechanism

Figure 12 - Typical Stirrup Arrangements for the Determination of the Volume of Concrete by Water Displacement

C26 Transmitted-light microscope

The transmitted-light microscope shall have a magnification of 200-400.

C27 Microsieve set with replaceable 75 μm sieve

The sieve shall comply with BS 410 and be complete with the appropriate size of lid and receiver.

C28 Furnace

The furnace or furnaces shall be capable of maintaining temperatures of 925 ± 25^0C and 1200 ± 50^0C.

C29 Desiccator

The desiccator shall contain dried magnesium perchlorate.

C30 Vacuum desiccator

The vacuum desiccator shall obtain dried magnesium perchlorate and be capable of maintaining a pressure of less than 13.5 kPa.

C31 Water pump or vacuum pump

The pump shall be capable of reducing the pressure in the vacuum desiccator to less than 13.5 kPa (100 mmHg).

C32 Apparatus for the determination of combined water content

The apparatus shall consist of a small absorption vessel, containing dried magnesium perchlorate, through which air, nitrogen or other suitable gas is passed before entering a silica combustion tube that is heated in furnace capable of reaching 1000^0C, bright red heat. The exit from the combustion tube shall be packed with silver wool to remove any hydrogen sulphide evolved. If silicon rubber connections are used it is advisable to protect them with heat reflectors. The gas leaving the combustion tube is passed through two weighable absorption tubes. The first quarter of each absorption tube is packed with silica gel and the remainder with dried magnesium perchlorate. A bubbler containing sulphuric acid is fitted after the exit end of the second absorption tube to allow the gas flow to be observed. A typical apparatus is shown in Figure 13.

C33 Rotary lap-plate

The lap-plate shall use a non-aqueous polishing medium and diamond pastes.

C34 Reflected-light microscope

A reflected-light microscope using magnifications up to x 800.

C35 Cylindrical mould

The mould shall be at least 25 mm in diameter, e.g. a plastic tube.

C36 Apparatus for the determination of carbon dioxide (Method 1)

The apparatus shall consist of a reaction flask fitted with a tap funnel through which carbon dioxide-free air or nitrogen can be passed at a controlled rate. The gas leaving the flask shall pass through a water-cooled condenser, then through a bubbler containing concentrated sulphuric acid and then through a series of absorption tubes which successively contain pumice coated with anhydrous copper sulphate, dried magnesium perchlorate and then two weighable tubes both three-quarters filled with a granular absorbent for carbon dioxide and one-quarter filled with dried magnesium perchlorate. A typical apparatus is shown in Figure 14.

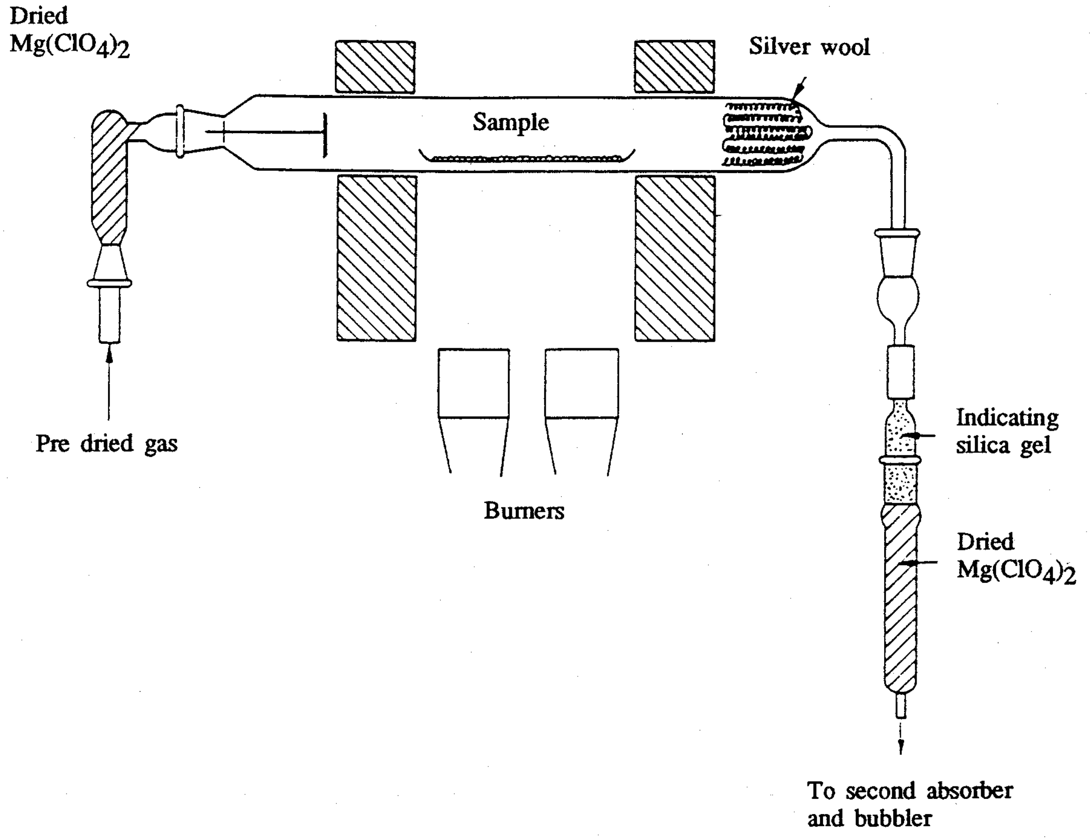


Figure 13 - Apparatus for the Determination of Water Content

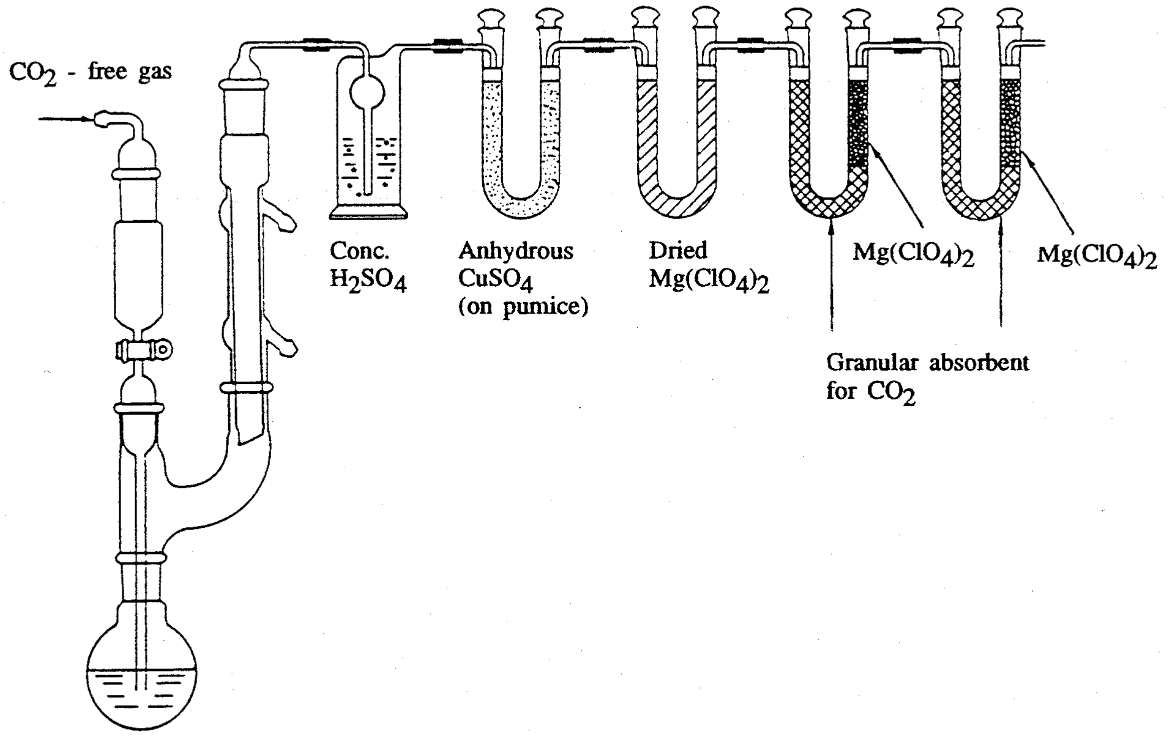


Figure 14 - Apparatus for the Determination of Carbon Dioxide (Method 1)

C37 Apparatus for the determination of carbon dioxide (Method 2)

The apparatus shall consist of the following :

(a) A graduated burette of 200-250 mL capacity and reading to 0.5 mL or better.

(b) A plastic measuring cylinder of 20 mL capacity.

(c) A levelling tube which can be raised and lowered on a mounting panel.

(d) A thermometer of range 0-40^{0}C and accurate to 0.2^{0}C.

(e) A barometer.

The apparatus shall be set up as shown in Figure 15.

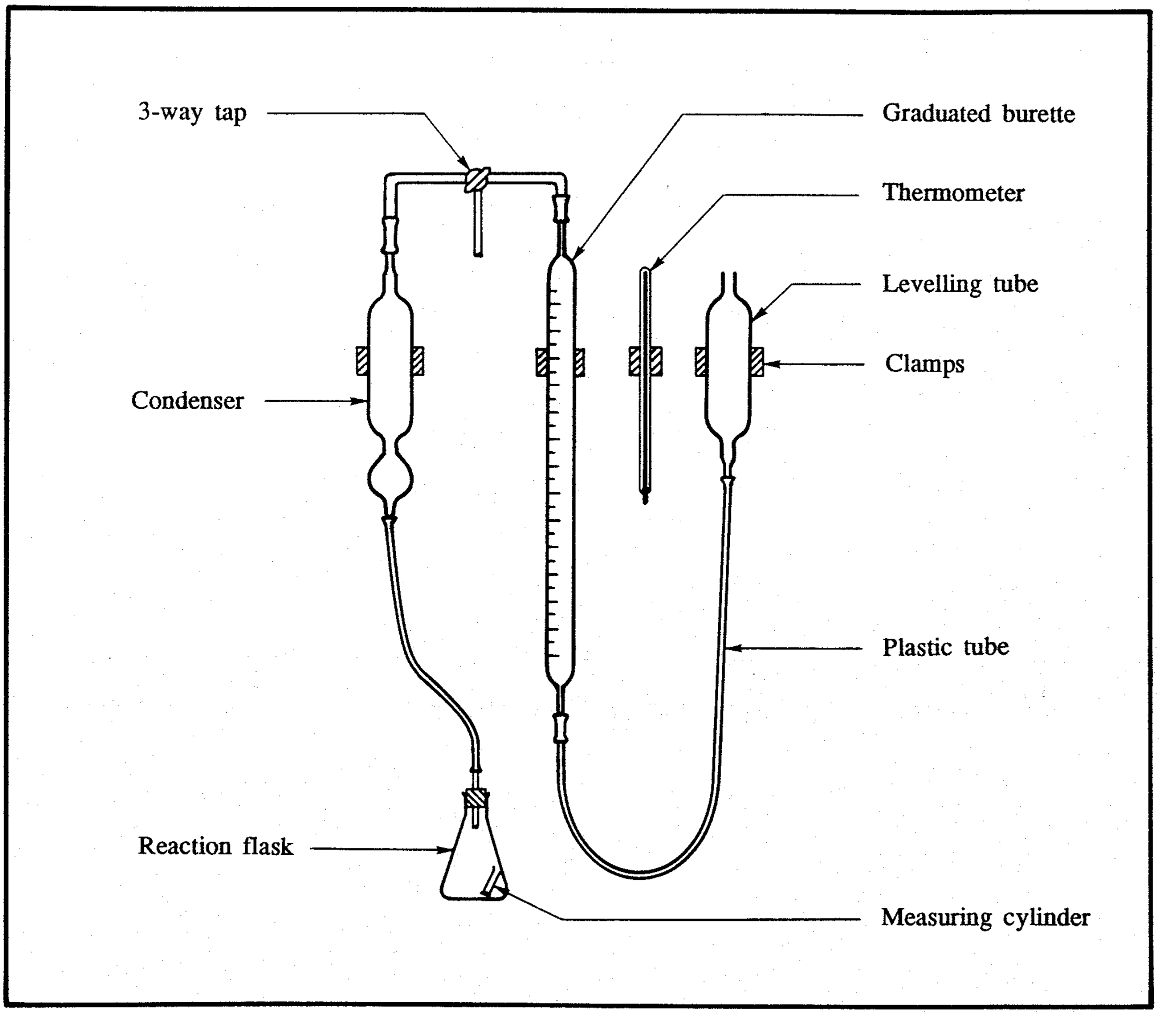


Figure 15 - Apparatus for the Determination of Carbon Dioxide (Method 2)

APPENDIX D

VERIFICATION OF PERFORMANCE OF COMPRESSION TESTING MACHINE

CONTENTS

APPENDIX D - VERIFICATION OF PERFORMANCE OF COMPRESSION TESTING MACHINE

D1 Load verification

The machine scales or digital displays shall be verified at intervals of not more than six months, when a machine is moved to a new location or is subject to disturbance, major repairs or adjustments. The verification shall be in accordance with BS1610: Part 1 to ensure compliance with C1. C5 of this Standard.

D2 Performance

When testing concrete cubes or vertical cylinders in compression:

(a) the component parts of the machine shall be aligned accurately;

(b) the upper machine platen shall align freely with the upper face of a correctly located specimen or upper auxiliary platen as initial contact is made; and

(c) the upper machine platen shall then be restrained from tilting with respect to the lower machine platen during loading.

Compliance with these requirements shall be checked on initial commissioning, after subsequent relocation or disturbance, and at intervals of not more than six months by meeting the compliance requirements of C1. D3.3, D3.4 and D3.6.

D3 Proving device and procedure

D3.1 The proving device

The proving device shall be a cylinder of steel 826M40, condition W, of BS970 : Part 1. It shall be 100 ± 1 mm in diameter and 200 ± 1 mm high. The flatness tolerance for the ends shall be 0.03 mm but the surfaces shall not be convex. The parallelism tolerance shall be 0.06 mm. The squareness tolerance of the cylinder with respect to one end as datum face shall be 0.03 mm. The roundness tolerance (b in Table 4 of BS308 : Part 3 : 1972) of the ends of the cylinder shall be 0.02 mm, and the whole cylinder shall be within a cylindricity tolerance of 0.04 mm. Centre holes of maximum size 15 mm diameter by 15 mm deep are permitted in the ends of the cylinder.

The device shall be gauged using matched temperature-compensated electrical resistance strain gauges. Four complete bridges, each centred at one of the ends of a pair of orthogonal diameters half way up the cylinder shall be used. Each bridge shall consist of two elements measuring axial strain and two measuring circumferential strain as shown in Figure 16. Each bridge shall be electrically and thermally balanced.

The device shall be supported in a carrying box by circumferential shoulders near the ends of the cylinder. The edge of each shoulder nearest the centre of the cylinder shall be no further than 15 mm from the nearest end of the cylinder. Vertical lines shall be inscribed on the cylinder walls so that they are visible outside the carrying case to indicate the position of the centre lines of the bridges. These lines shall not extend further than 20 mm from the lower end of the cylinder.

The device shall be used with a switch and balance unit which enables the outputs of each of the four bridges to be balanced in the unloaded condition and the bridge outputs to be selected thereafter by operation of a switch.

Note. *Alternatively, simultaneous display of the four bridge outputs may be used if means are provided to enable the sensitivity of the four channels to be checked and, if necessary, equalized immediately prior to the taking of a series of readings.*

The maximum limit of error for the strain-measuring equipment shall be ±0.1% or five microstrain, whichever is greater.

D3.2 Procedure for proving the self-alignment of the upper machine platen and the machine component parts

A 150 mm square auxiliary platen which complies with C1. C5.3 and is not convex shall be located on the lower machine platen or spacing block.

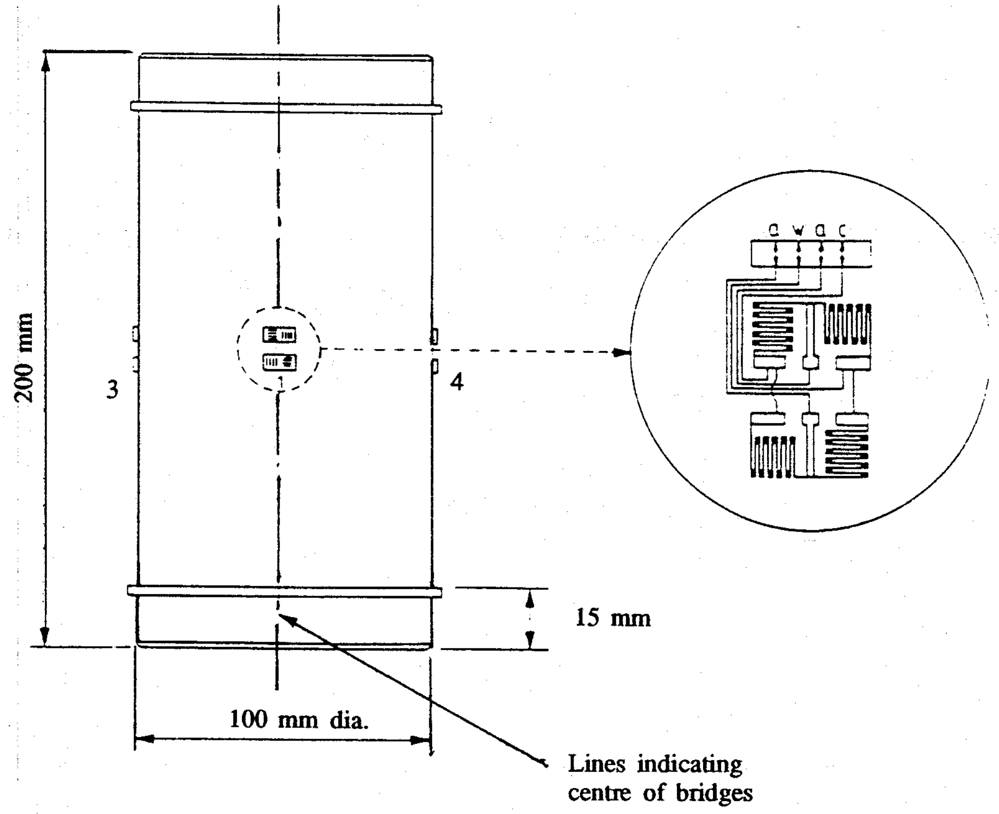


Figure 16 - Gauging of Proving Device

The proving device shall be placed centrally on the square auxiliary platen. The mid-points of the edges of the auxiliary platen shall be designated by A, B, C and D and the four bridge positions on the device designated by 1, 2, 3 and 4. The device shall be positioned by eye as shown in Figure 17.

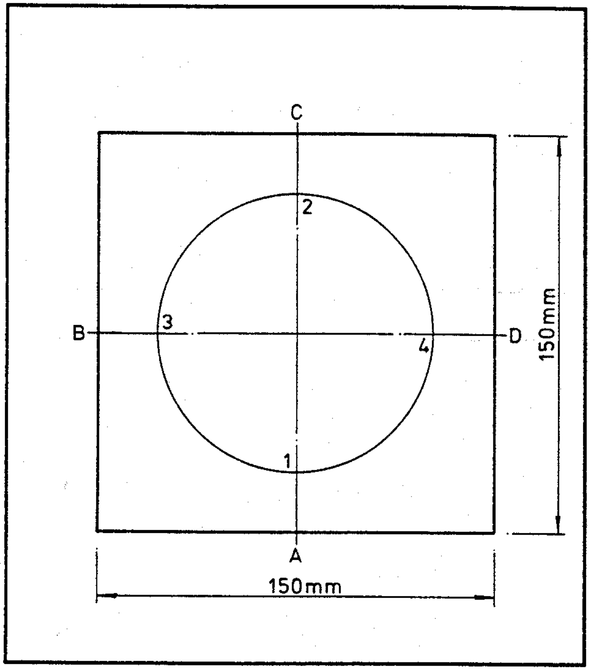


Figure 17 - Positioning of proving device on auxiliary platen

The distances from the centre of each top edge of the lower auxiliary platen to the nearest point on the bottom edge of the device shall be measured and the position of the device adjusted until the differences between the pairs of measurements from opposite edges of the platen to the device do not exceed 0.1 mm.

Note. *This may be conveniently achieved by fitting a stop to the edge of the platen and providing accurately machined spacers to centralize the device.*

The upper machine platen shall be brought to no closer than 5 mm to the top of the device. It shall then be tilted towards A about axis BD either to its fullest extent or until it touches the device. The upper machine platen shall be gently released and the machine operated so that the upper machine platen aligns with the device. The indicated load on the device shall be increased slowly up to a nominal value of at least 200 kN. The load shall be held constant and the outputs of the four bridges recorded. If the load exceeds 200 kN but does not exceed 220 kN before it can be held constant, the load shall not be reduced before taking the readings. If the load exceeds 220 kN the test shall be restarted.

Using the mean e_m of the four bridge outputs e_1, e_2, e_3 and e_4, the strain ratio $(e_n - e_m)/e_m$ for each bridge shall be calculated, where e_n is the strain at the bridge position under consideration.

The test shall be repeated first with the upper machine platen tilted down towards C about an axis BD, secondly with the upper machine platen tilted down towards B about an axis AC and thirdly with the upper machine platen tilted down towards D about an axis AC.

If the device is correctly machined and gauged, the sensitivity of the four bridges will be equal. However, if this is in doubt, the readings shall be repeated first with bridge 1 adjacent to B, then with bridge 1 adjacent to C and finally with bridge 1 adjacent to D (see Figure 16).

The readings so obtained, together with those obtained with bridge 1 opposite A should be averaged to eliminate differences in bridge sensitivity on the device. This should be done for the readings on all four bridges.

D 3.3 Self-alignment of the upper machine platen

The strain ratios at 200 kN for the four different directions of initial platen tilt shall be obtained and compared. The difference between the highest and lowest values for any bridge shall not exceed 0.10.

D 3.4 Alignment of the component parts of the machine

If the self-alignment is correct (see C1, D3.3), the mean strain ratios for each of the four bridges shall be calculated. For each bridge, this value shall lie within the range ± 0.10.

D3.5 Procedure for proving restraint on movement of the upper platen

If the self-alignment and alignment are correct (see C1. D3.3 and D3.4) the device shall be displaced by 6 ± 0.05 mm from the central position along AC towards A. Without further adjustment of the upper machine platen, the machine shall be operated to bring it into contact with the device and the load applied smoothly. The outputs of the four bridges at nominal loads of 200 kN and 2000 kN shall be recorded. If the machine capacity is less than 2000 kN, the readings at 200 kN and at maximum capacity shall be taken. Care shall be taken to ensure that the output of each of the four bridges is read while the load is held constant. If either nominal load is exceeded by not more than 10% before it can be held constant, the load shall not be reduced and the readings shall be taken. If either nominal load is exceeded by more than 10%, the test shall be restarted.

These readings shall be repeated with the device displaced 6 ± 0.05 mm from the central position, firstly along AC towards C, secondly along BD towards B and thirdly along BD towards D. The change in strain ratio per mm offset for displacement along AC and for displacement along BD for each load shall be calculated. If r_1, r_2, r_3 and r_4 represents strain ratios for bridges at positions A, C, B and D and *a, c, b* and *d* denotes ratio for displacement towards A, C, B and D respectively then for each load the value for displacement along AC shall be calculated as:

$$\frac{(r_{1c} - r_{2c}) - (r_{1a} - r_{2a})}{24} \qquad \textbf{(D-1)}$$

and for displacement along BD as :

$$\frac{(r_{3d} - r_{4d}) - (r_{3b} - r_{4b})}{24} \qquad \textbf{(D-2)}$$

D3.6 Restraint on tilt of the upper platen

The change in strain ratio per mm offset in each of the two directions shall not exceed 0.06 at 200 kN or 0.04 at 2000 kN or at the maximum capacity of the machine if this is less than 2000 kN.