BRITISH STANDARD

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1992

Testing concrete —

Part 207: Recommendations for the assessment of concrete strength by near-to-surface tests

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Technical Sector Board for Building and Civil Engineering (B/-) to Technical Committee CAB/4, upon which the following bodies were represented:

Association of Lightweight Aggregate Manufacturers
Association of Metropolitan Authorities
Association of Quality Pulverised Fuel Ash Suppliers
British Aggregate Construction Materials Industries
British Cement Association
British Civil Engineering Test Equipment Manufacturers Association
British Precast Concrete Federation
British Ready Mixed Concrete Association
Building Employers Confederation
Cement Admixtures Association
Cementitious Slag Makers Association
Concrete Society
County Surveyors' Society
Department of the Environment (Building Research Establishment)
Department of the Environment (Property Services Agency)
Department of Transport
Department of Transport (Transport and Road Research Laboratory)
Electricity Industry in United Kingdom
Federation of Civil Engineering Contractors
Institute of Concrete Technology
Institution of Civil Engineers
Institution of Highways and Transportation
Institution of Structural Engineers
Institution of Water and Environmental Management
National House-Building Council
Sand and Gravel Association
Society of Chemical Industry

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British Nuclear Fuels plc
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Contents

Foreword

This Part of BS 1881 has been prepared under the direction of the Technical Sector Board for Building and Civil Engineering. All aspects of testing concrete are being included as Parts of BS 1881 from sampling fresh concrete to assessing concrete in structures. Part 201 gives general guidance on the choice of non-destructive test methods, including a bibliography, and should be consulted for advice on methods which complement the use of near-to-surface strength tests or are useful as alternatives.

In recent years, several tests and devices have been developed which give a measure of the insitu strength of concrete near to the surface. Carrying out near-to-surface tests requires only one face of the concrete to be available and this face need not be as smooth as that required for some alternative tests. Although most of these tests measure a property of concrete related to its strength, correlation with compressive strength has to be established experimentally. The results obtained may be used to estimate the strength of the body of the concrete. However, placing, compacting and curing may make the concrete in the surface zone unrepresentative of the concrete at deeper levels. For some methods the same correlation can be used over a wide range of concrete types but this is not universally true. Care should be taken to ensure that the correlations adopted are relevant to the circumstances of use.

Guidance on planning and interpreting tests to assess the strength of concrete in structures is given in BS 6089, which refers to the use of near-to-surface methods. The tests described in this Part of BS 1881 are those for which there is most experience at present. Other near-to-surface techniques may be proposed, usually to meet some particular need, and their use is not precluded by this Part. The recommendations of clauses **3**, **4**, **5** and **11** to **13** may usefully be applied to such methods.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 12, an inside back cover and a back cover.

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

1 Scope

This Part of BS 1881 gives recommendations on tests that are designed to assess the strength of concrete by causing localized failure in a small zone, typically up to 75 mm from the surface, according to the method. The recommendations cover the following test methods:

a) internal fracture;

b) pull-out;

c) pull-off;

d) penetration resistance;

e) break-off.

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

2 Definitions

For the purposes of this Part of BS 1881 the definitions given in BS 1881-201 and BS 6100-6 apply.

3 General

It should be recognized that an individual test result indicates the quality of the concrete only in the immediate vicinity of the test point. The mean result from a number of tests is needed to estimate the average quality of the surface zone.

Near-to-surface tests should not be carried out where the surface concrete is known to be unrepresentative of the concrete in the structure, unless the purpose of the investigation is to assess the condition of this surface zone. In both cases, any correlation obtained as described in clause **11** will not be valid. The surface concrete can be damaged by aggressive agents such as fire, frost, corrosive liquids, etc. Tests should not be made on frozen concrete. The surface layer can also comprise a topping added subsequent to the compaction of the main body of concrete.

All the test methods described in this Part of BS 1881 produce a localized zone of surface damage. The need for localized repairs following testing, and the implications for the appearance and durability of exposed concrete surfaces, especially if the test is carried out adjacent to reinforcing steel, should therefore be considered.

It is important that tests should be performed by trained and experienced staff if worthwhile results are to be achieved and it is recommended that two persons should normally be involved during testing on site.

4 Applications

4.1 Comparative testing of concrete

Near-to-surface test values may be laid down so that tests can indicate when handling and transport of precast units, application of prestress and the removal of formwork or temporary supports for structural members may commence.

More detailed guidance on the use of near-to-surface tests for assessing formwork striking times may be found in CIRIA Report No. 73. These values should take due account of the limitations on accuracy of strength estimations for the particular test method used and the normal variations in properties within cast concrete.

The critical values for the near-to-surface test results should be established on the basis of laboratory calibration or past experience of performance. In acceptance testing or quality control procedures a small number of cores or destructive tests can be supplemented by a larger number of near-to-surface tests which are quicker to carry out and less damaging.

4.2 Estimation of in situ concrete strength

Near-to-surface tests can be correlated with strength tests on standard concrete specimens or on drilled cores. The estimation of strength in a concrete structure by near-to-surface testing should be made with considerable care and estimated values should be given only to the nearest 1 N/mm^2. In particular it should be remembered that the strength of the concrete near the surface may differ from that of the interior of a large mass and strength variations are likely to exist over the depth of a member. It is essential that test locations selected should be representative of the concrete under investigation. General guidance on the assessment of concrete strength in structures is given in BS 6089. Guidance on relating near-to-surface test results and strength is given in clause **11** of this Part. Although the most common correlation is with compressive strength, results may also be related to tensile strength.

4.3 Checking the uniformity of concrete

Near-to-surface tests can be used to define areas of different quality in a structural member and to locate areas appropriate for testing by other methods. The tests should be carried out at similar concrete maturity and ambient conditions. This approach can be applied to precast and in situ concrete.

4.4 Testing repairs to concrete

Some near-to-surface tests are also an effective means of checking the quality of repairs to concrete structures. When the bond between a substrate and a repair material is to be determined, either a pull-off test or break-off test should be used.

4.5 Long-term monitoring

Near-to-surface tests should be considered for use in situations where future deterioration of the surface concrete is expected and monitoring is required.

5 Choice of test method

Selection of the most appropriate method should take account of the purpose of the testing and practical factors relating to the nature and position of the concrete under investigation. These will include the availability and reliability of strength correlations, the acceptability of surface damage, size of member to be tested, test complexity and preparation, access requirements and test positions. Experience with all the methods described is based primarily on testing concrete containing aggregate of nominal size 20 mm or less. Caution should be exercised in interpreting results on concrete containing larger aggregates. More detailed guidance on planning an investigation is provided in BS 1881-201.

Some relevant details for each of the methods in this Part are given in Table 1.

6 Internal fracture test

6.1 General

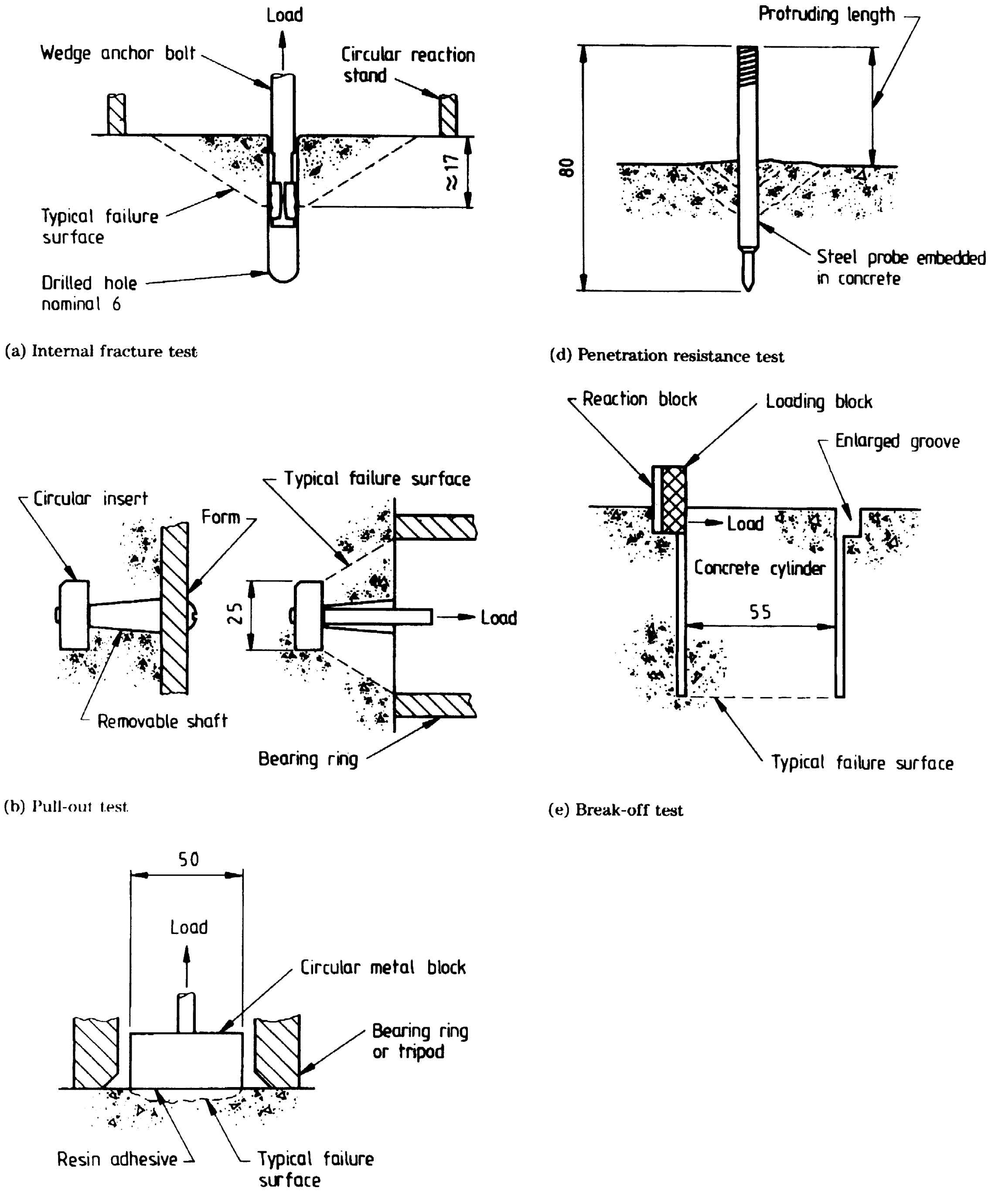
The internal fracture test is based on the concept that a measurement of the tensile force required for a wedge anchor bolt to cause failure of the concrete can be related to the concrete compressive strength. Apparatus has been developed in which a bolt is inserted into a predrilled hole and loaded in tension through a reaction stand by means of a torquemeter acting on a greased nut. More consistent results are obtained using apparatus in which a direct axial load is applied to the bolt. See Figure 1(a).

A 6 mm diameter bolt set at 20 mm depth as described in **6.3** has been found to be suitable for use in concrete of compressive strength up to 40 MPa.

The recommendations in **6.2** and **6.3** are based on these sizes. If other sizes are used, different apparatus and criteria are required.

Table 1 — Summary of near-to-surface test methods

Test method	Number of valid tests required at a location	95 % confidence limits for strength estimate of in situ concrete	Correlation requirements	Preparation requirements
Internal fracture (clause **6**)	6	± 30 %	Specific to loading method and concrete mix	Hole drilling with masonry drill
Pull-out (clause **7**)	4	± 20 %	General for natural aggregates	Either (a) cast-in insert or (b) drilling and under-reaming with specialist equipment
Pull-off (clause **8**)	6	(± 15 % in laboratory conditions)	Specific to concrete mix	Providing a dry flat concrete surface Partial coring if required
Penetration resistance (clause **9**)	3	± 20 %	Specific to aggregate	No power supply or complex access required but safety precautions necessary
Break-off (clause **10**)	5	± 20 %	Specific to concrete mix	Test cylinder formed either (a) during casting or (b) by partial coring with specialist equipment



(a) Internal fracture test

(b) Pull-out test

(c) Pull-off test

(d) Penetration resistance test

(e) Break-off test

All dimensions are in millimetres.

Figure 1 — Principal features of near-to-surface tests using commercially available apparatus

6.2 Apparatus

6.2.1 *Roto-hammer drill*, fitted with a nominal 6 mm hard-tipped bit.

NOTE It is important for the consistency of test results that the drilled holes have straight parallel sides and are uniform in diameter. Electropneumatic drills have been found to be suitable for this purpose.

6.2.2 *Drill tip diameter gauge*, to check that the drill bit has a diameter in the range 6.1 mm to 6.4 mm.

6.2.3 *Air blower*, capable of clearing drilled holes of debris.

6.2.4 *Wedge anchor bolts*, nominally identical, compatible with the loading system, with an ISO metric screw thread designation M6-6e complying with BS 3643-1.

Nuts and washers to fit these bolts are required if the load is to be applied by a torquemeter.

6.2.5 *Gauge*, or other device, for checking the normality to the concrete surface of each inserted wedge anchor bolt prior to testing, allowing a maximum deviation of 5° from the normal.

6.2.6 *Reaction stand*, consisting of a steel ring of internal diameter of at least 80 mm with three supports to bear on the concrete surface that can be placed symmetrically around a bolt to transmit to the concrete the reactive load from the tension applied to the anchor bolt.

6.2.7 *Loading system*, capable of applying a tensile force to the bolt against the reaction onto the concrete surface through the reaction stand (see **6.2.6**). The loading system should be designed to allow the reaction stand to be placed symmetrically about the bolt and should include a means for allowing for any slight deviation of the axis of the bolt from the normal to the concrete surface. The loading system should indicate either tensile force or torque to an accuracy of ± 3 % in the anticipated working range. It should include a maximum value indicator that retains the reading when fracture and force release occur.

The loading system should be calibrated by equipment, the accuracy of which is traceable to national standards, at yearly intervals or following adjustment or repair.

6.3 Test procedure

6.3.1 *Test positions*

Test holes should be drilled (**6.2.1**) more than 150 mm apart and no closer than 75 mm to an edge. They should be positioned so that all reinforcement is outside the expected conic fracture surface by at least one bar diameter or the maximum aggregate size, whichever is greater. For this purpose the conic fracture surface may be taken as about 17 mm deep at the apex and 75 mm in diameter at the surface of the concrete. Where possible, test positions should also be chosen in locations not subjected to high compressive stresses or possessing cracks. At least six tests should be performed in each location.

6.3.2 *Drilling and fitting the bolt*

Each hole should be drilled normal to the concrete surface 30 mm to 35 mm deep. The hole should be cleaned of debris using an air blower (**6.2.3**) immediately before insertion of the bolt (**6.2.4**). The bolt should be marked so that it can be fitted into the hole with the lower edge of the expanding sleeve 20 mm below the concrete surface. The bolt should be tapped into the hole to the marked depth without damaging the thread which should be checked by running a nut over its full length. The gauge (**6.2.5**) should be used to check that each protruding bolt section satisfies the normality requirement. If the axis of the bolt is not within 5° of the normal, that test position should not be used.

NOTE The normality of the drilled hole can be checked with a plain steel rod of the same diameter as the test bolt.

6.3.3 *Loading*

The loading system (**6.2.7**) should be connected to the bolt and load applied steadily, or in a series of smoothly applied increments without jerking, and at such a rate as to cause failure in approximately 1 min to 2 min. This occurs when the maximum reading is indicated. The precise loading method and rate may vary according to the apparatus employed but a consistent procedure should be adopted throughout a series of tests and the same procedure should be used when establishing correlations.

6.4 Test results

Test results should be reported as the failure value in newton metres for torque or kilonewtons for tensile force and the mean rounded off to the nearest 0.1 N m or 0.1 kN respectively.

6.5 Relationship between internal fracture force and strength of concrete

The internal fracture force generally increases with the strength of the concrete. However, the stress distribution in the concrete is complex and incompletely understood. Correlations between internal fracture force and strength should therefore be established experimentally. For guidance, see clause **11**. Evidence suggests that, although similar relationships between internal fracture force and strength may be obtained for a wide range of mix compositions, the use of a universal correlation can give serious errors. Factors which may influence the relationship between internal fracture force and strength include mix constituents, curing, hole size (which may be influenced by the precise size of the bit and the efficiency of the drill), operator effects and loading method.

The coefficient of variation of a set of measured values at one location under site conditions is typically about 15 %. However, in assessing compressive strength the accuracy of the correlation with torque or tensile force should also be considered as an additional factor. Experience suggests that a well-prepared correlation using a torquemeter will allow strength estimates to within ± 30 % at the 95 % confidence level from the mean of six valid results. Improved accuracy has been obtained in the laboratory by the use of a direct tensile loading system.

7 Pull-out test

7.1 General

The pull-out test is based on the concept that the strength of the concrete is related to the maximum tensile load that can be applied to an embedded insert before the concrete fails. Commercially available apparatus has been developed for this purpose. Other equipment may be used but the user should ensure that it will give reliable results and that it is in accordance with this Part of BS 1881. See Figure 1(b). Experiments show that this pull-out test gives more reliable results at lower strengths than other near-to-surface tests and so is useful for the estimation of early age strength.

7.2 Apparatus

7.2.1 *Insert*, of metal not readily attacked by fresh concrete, of sufficient thickness and strength to avoid yielding during the test. The insert may be cast into the concrete or positioned in hardened concrete in an under-reamed groove from a drilled hole. Inserts for casting-in should have a circular head and tapered shaft to minimize side friction during subsequent testing. The shaft, which may be removable, should have a diameter not more than 0.6 of the diameter of the head and a length such that the outer surface of the head is the same depth below the concrete surface as its diameter. The inserts may be coated with a release agent to prevent bonding to the concrete and may be notched to prevent their rotation in the concrete if the shafts are to be unscrewed. Inserts for use in drilled holes should have means for expanding them to fit into the groove, such as a split ring on a tapered rod.

7.2.2 *Drilling and under-reaming equipment*, specialized equipment for drilling and then enlarging the base of the hole when the insert is not cast into the concrete.

7.2.3 *Bearing ring*, that can be placed on the concrete surface symmetrically around the insert axis, having an inside diameter 2.0 to 2.4 times the insert head diameter and an outside diameter at least 1.25 times the inside diameter.

7.2.4 *Loading system*, capable of applying a tensile force to the insert with the reaction being transmitted to the concrete surface through the bearing ring (see **7.2.3**). The loading system should ensure that the bearing ring is concentric with the insert shaft and that the load is applied perpendicular to the plane of the insert. The loading system should include a means of indicating the maximum applied force to an accuracy of 2 % in the anticipated working range.

The loading system should be calibrated by equipment, the accuracy of which is traceable to national standards, at yearly intervals or following adjustment or repair.

NOTE Suitable apparatus is commercially available for a 25 mm insert depth.

7.3 Test procedure

7.3.1 *Test positions*

The centres of test positions should be separated by at least eight times the insert head diameter. The centres should be at least four times the head diameter from the edge of the concrete. The inserts should be placed so that all reinforcement is outside the expected conic fracture surface by at least one bar diameter or the maximum aggregate size whichever is greater. The thickness of the concrete to be tested should be at least four times the insert head diameter.

At least four pull-out tests should be performed in each location.

7.3.2 *Installation of inserts*

Cast-in inserts (**7.2.1**) should be securely fixed to the formwork or locating device at the required test positions. A small separately removable panel may be incorporated in the formwork when the test is being used to determine the formwork stripping time. It is important to ensure that the shafts are disconnected from the formwork before its removal. Holes for other inserts should be drilled and under-reamed (**7.2.2**) and the inserts assembled according to the manufacturer's instructions.

7.3.3 *Loading*

The tapered shaft of a cast-in insert should first be removed and then the loading system (**7.2.4**) connected to the insert in accordance with the manufacturer's instructions. The load should be applied and increased at a steady rate without jerking to cause failure. For a 25 mm diameter insert a loading rate of (0.5 ± 0.2) kN/s should be used.

The insert may be loaded to rupture the concrete if the strength is to be estimated or a proof load may be applied to check that the concrete has achieved a minimum strength.

7.4 Test results

Test results should be reported as the failure value in kilonewtons and the mean rounded off to the nearest 0.5 kN.

7.5 Relationship between pull-out force and strength of concrete

The pull-out force can be empirically related to the compressive strength of the concrete as determined by standard tests in accordance with BS 1881-116 and BS 1881-120. The correlation between strength and pull-out force for the apparatus being used should be established experimentally. The manufacturer may provide this information for specific concretes.

It has been shown that for a given type of apparatus the relationship between pull-out force and compressive strength is similar over a wide range of concrete mixes and that a general correlation can be used with reasonable accuracy. Greater accuracy can, however, be achieved if a specific correlation is obtained for the type of concrete under investigation. Special correlations are required for lightweight concretes or other mixes with less common constituents.

The coefficient of variation of a set of measured values at one location under site conditions is likely to be about 7 %. However, in assessing compressive strength, the accuracy of the correlation with pull-out force should also be considered as an additional factor. When a general correlation is used, estimates of compressive strength are unlikely to have 95 % confidence limits better than ± 20 % of the mean of four valid results. When a specially prepared correlation for the type of concrete is available, estimates can be within ± 10 %.

8 Pull-off test

8.1 General

The pull-off test is based on the concept that the force required to pull a metal block, together with a layer of concrete or mortar, from the surface to which it has been attached, is related to the strength of the concrete.

The technique may be applied in two forms. If a block is attached directly to the surface then the stressed volume of concrete lies close to the face of the block and the results may be less related to the strength of the body of the concrete than with some other near-to-surface tests. See Figure 1(c). Alternatively the test may be carried out by partially coring the concrete and bonding a block of the same nominal diameter to the top of the cylinder of concrete thus isolated. This allows the fracture surface to occur deeper into the concrete.

8.2 Apparatus

8.2.1 *Cylindrical metal blocks*, having a flat surface prepared for bonding to the surface of the concrete using a suitable resin adhesive and which can be connected to the loading system so that a tensile force can be applied perpendicular to the interface between the block and the concrete. The thickness of the block should not be less than 40 % of its diameter.

NOTE Current work indicates that a greater thickness/diameter ratio may be desirable to ensure uniform stress distribution in the concrete. A ratio of 60 % would be appropriate for aluminium blocks.

8.2.2 *Bearing ring or tripod*, that can be placed on the concrete surface concentric with the axis of the block, having dimensions such that the block can move freely and that will distribute the reaction force to the surface of the surrounding concrete.

8.2.3 *Loading system*, capable of applying a force to the block normal to the concrete surface through the bearing ring or tripod (see **8.2.2**). It should include a load measuring device capable of recording the maximum load after force release has occurred. The accuracy of load measurement should be to 2 % of the working range.

The loading system should be calibrated by equipment, the accuracy of which is traceable to national standards, at yearly intervals or following adjustment or repair.

NOTE Apparatus is commercially available for 50 mm and 75 mm diameter blocks.

8.3 Test procedure

8.3.1 *Test positions*

The centres of test positions should be at least two block or core hole diameters apart and one diameter from an edge. If the test is carried out on a plain flat surface, reinforcing steel at normal covers will not affect the results. If the test is carried out after partial coring, reinforcing steel should neither lie within the annulus nor within a depth equal to the maximum aggregate size from the base of the annulus. Six valid tests are usually sufficient in each location.

8.3.2 *Preparation*

The metal block (**8.2.1**) and the concrete surface should be carefully prepared to give a good bond. Clean off any laitance to expose the top of the coarse aggregate by abrasion to produce a flat surface with a texture suitable for bonding. Remove all grease and dust from the surface of the metal block liable to impair bonding of the two surfaces. A thin uniform layer of adhesive should be applied over the entire contact area and any excess adhesive squeezed out round the edges of the block should be removed before it sets. Sufficient time should be allowed to enable the adhesive to cure prior to load application. The time required will vary according to the type of adhesive and the temperature and may range from 1.5 h to 24 h. Difficulties may be met with damp surfaces. Where the partial coring technique is to be used a core of diameter equal to that of the block should be cut to the required depth before surface preparation. Care should be taken to ensure that the axis of the core is perpendicular to the concrete surface.

8.3.3 *Loading*

The loading system (**8.2.3**) should be connected to the block and tensile load applied and increased at a steady rate without jerking to cause failure. A loading rate to provide an increase of stress at $(0.05 \pm 0.03)\ \mathrm{N/mm^2 \cdot s}$ should be used. Both the maximum load and mode of failure (concrete or adhesive) should be recorded. If there is any failure in the adhesive, the strength indicated can only be a lower limit to the concrete strength. Such a value should be discounted when calculating the mean strength and tests should be repeated as necessary. The pull-off stress can be calculated as the maximum load divided by the cross-sectional area of the block in the case of surface tests or the measured cross-sectional area of the cylinder in the case of subsurface tests.

8.4 Test results

Test results should be reported as the failure stress in newtons per square millimetre and the mean rounded off to the nearest 0.1 $\mathrm{N/mm^2}$.

8.5 Relationship between pull-off stress and strength of concrete

The pull-off test causes tensile failure of the concrete. However, the results cannot be directly equated to the tensile strength measured in accordance with BS 1881-117. If pull-off tests are to be used to estimate strength in terms of standard test methods, correlations should be established experimentally. Correlations between pull-off stress and compressive strength are influenced by the aggregate type, block material and thickness. A correlation should therefore be established for the particular concrete under investigation and the apparatus being used. In some circumstances, use of a general correlation may be adequate. It should be noted that surface tests and subsurface tests using partial coring are unlikely to give the same results.

The coefficient of variation of a set of measured values at one location under site conditions is likely to be about 10 %. However, in assessing compressive strength, the accuracy of the correlation with pull-off strength should also be considered as an additional factor. Tests under laboratory conditions indicate that estimates of compressive strength are unlikely to have 95 % confidence limits better than ± 15 % of the mean of six valid results but there is currently insufficient evidence to suggest the likely accuracy under site conditions.

9 Penetration resistance test

9.1 General

The penetration resistance test is based on the concept that the depth of penetration of a metal probe fired into a concrete surface depends on the strength of the concrete. The depth of concrete that affects the test result may be up to about 75 mm for the equipment described in **9.2**. Some slender or flexible members may be unsuitable for testing by this method. A simple test to ascertain whether the concrete is too strong or too weak to be tested by this method is described in appendix A of BS 4078-1:1987.

Commercially available equipment has been developed in which the probe is propelled by a powder charge and this clause describes only this method of driving the probe.

9.2 Apparatus

9.2.1 *Probe*, of hardened alloy steel with a blunt conical nose which can be fired into the concrete in such a way that it remains firmly embedded. The tail end is threaded to facilitate firing, measurement and withdrawal. Probes should be of uniform length to within ± 0.5 %. Different probes are used for normal weight and lightweight aggregate concretes. The probes are typically about 80 mm long and can be expected to penetrate up to 40 mm into the concrete.

9.2.2 *Driver unit*, for firing probes into the concrete with an accurately controlled amount of energy. Different energies should be used for different concrete strength ranges. The driver unit has to incorporate features to prevent firing when the unit is not properly placed in a positioning device held against the concrete surface and incorporate a splinter guard to protect against flying particles.

The driver unit should be checked by the manufacturer at least annually.

CAUTION. Powder-actuated driving units should only be operated by trained personnel in accordance with the recommendations of BS 4078-1. Attention is drawn to the need to comply with statutory requirements such as the Health and Safety at Work etc. Act 1974, Factories Act 1961, Explosives Act 1875 as amended, Protection of Eyes Regulations 1974. Guidance can also be found in the Health and Safety Executive's Guidance Note PM 14[1)].

9.2.3 *Length-measuring device*, for measuring the length of the probe exposed above the original surface to an accuracy, traceable to national standards, of ± 0.25 mm.

9.3 Test method

9.3.1 *Test positions*

Test positions should be chosen to minimize the risk of structural cracking or movement of the member under test and should be at least 200 mm apart and 150 mm from an edge. The thickness of the concrete element should be not less than 150 mm. Tests should not be conducted within 50 mm of a reinforcing bar. Three valid measurements of penetration are required to give a result for a location. If the probe is not firmly embedded or if the range of depth of penetration for three tests is more than 5 mm the test is not valid and repeat tests should be made.

9.3.2 *Procedure*

Probes (**9.2.1**) should be fired into concrete using the driver unit (**9.2.2**) in accordance with the manufacturer's instructions and taking all necessary safety precautions. The protruding length of each probe which is firmly held in the concrete should be measured (**9.2.3**). The length should be measured relative to the original surface of the concrete as shown in Figure 1(d). It may be necessary to remove concrete which has been raised round the base of the probe to provide a suitable reference surface. On rough surfaces more sophisticated measurement techniques will be necessary or the surface may be ground smooth before testing.

9.4 Test report

The protruding probe length should be reported in millimetres and the mean rounded off to the nearest 0.5 mm. The depth of penetration may be calculated from this value and the length of the probe.

[1)] Available from the addresses given in the footnote on the inside back cover.

9.5 Relationship between penetration and strength of concrete

The depth of penetration of a probe can be empirically related to the strength of the concrete. This relationship is significantly influenced by the properties and proportions of the coarse and fine aggregates. An individual correlation should therefore be prepared for each different concrete to be tested. Reliance on published "universal" correlations may well lead to significant error in strength estimation. The use alone of Mohs' scale of hardness to determine corrections for aggregate type is unlikely to give satisfactory results.

The coefficient of variation of a set of measured values at one location under site conditions is not likely to be more than 5 %. However, in assessing compressive strength, the accuracy of the correlation with depth of penetration should also be considered as an additional factor. Experience suggests that a well-prepared correlation will allow strength estimates to be within ± 20 % at the 95 % confidence level from the mean of three valid results.

10 Break-off test

10.1 General

The break-off test determines directly a flexural tensile strength in a plane parallel to the concrete surface at a predetermined distance below the surface. A transverse force is applied to the top of a cylinder of concrete made either by partial coring of the hardened concrete or formed in fresh concrete during casting. See Figure 1(e). The force required to break this cylinder of concrete at its base from the parent material is measured, and known as the break-off force. In some circumstances it may be more convenient to measure and record the pressure required in the loading equipment to provide this force. Equipment for this purpose is commercially available and forms the basis for the sizes given in this clause. Other equipment may be used but the user should ensure that it will give reliable results.

10.2 Apparatus

NOTE The core cutter (see **10.2.1**) and hole former (see **10.2.2**) are alternatives for use with hardened or fresh concrete respectively.

10.2.1 *Core cutter*, diamond-tipped, capable of drilling an annulus at least 1 mm wide to form a concrete cylinder (55 ± 1) mm diameter and (70 ± 3) mm deep and then enlarging the annulus into a groove at the surface approximately 10 mm wide and 10 mm deep to accommodate the loading apparatus.

10.2.2 *Hole former*, of material not readily attacked by fresh concrete and sufficiently rigid to retain its shape during insertion into fresh concrete. This should be shaped as a hollow tube of internal diameter (55 ± 1) mm, overall length (70 ± 1) mm and wall thickness at least 1 mm incorporating a collar to form the groove at the surface required for the loading apparatus. The collar should enable a manual extractive device to be attached.

10.2.3 *Loading system*, to apply a transverse force to the concrete cylinder centred at (5 ± 1) mm below the surface of the concrete. The load should be applied through a loading block over a 25 mm to 30 mm length of the cylinder circumference. The reaction force is transmitted to the concrete around the annulus over an approximately 10 mm length on either side of this. Commercially available equipment provides a pressure reading in megapascals that may be converted to force by an appropriate calibration curve for the apparatus. The apparatus should be capable of increasing the load smoothly at a mean rate of (0.1 ± 0.05) kN/s and of measuring and recording the maximum reading at fracture. The accuracy of load measurement should be to 2 % of the working range.

The loading system should be calibrated by equipment, the accuracy of which is traceable to national standards, at yearly intervals or following adjustment or repair.

10.3 Test procedure

10.3.1 ***Test positions***

Test positions should be chosen to minimize the risk of structural damage. The thickness of the concrete member should be not less than 100 mm.

The outer circumference of the surface grooves should have a clear spacing or distance to the edge of the member of not less than four times the maximum aggregate size and in no case less than 50 mm. The intended fracture surface should not be crossed by any reinforcing bars. At least five valid tests should be carried out at a given location.

10.3.2 ***Preparation***

If formers (**10.2.2**) are used these should be well greased and placed in the surface of the concrete after it has been compacted and before it stiffens. Formers should not be used when the maximum aggregate size exceeds 20 mm. Concrete surrounding the formers should be compacted by lightly tapping on the surface to ensure that they are completely embedded. The formers should be extracted slowly by hand when the concrete has reached sufficient strength to ensure that it will not be damaged and preferably immediately before testing. Care should be taken to ensure that the concrete at prepared test positions receives similar curing to that of the surrounding body of concrete.

10.3.3 ***Loading***

A transverse force is applied by the loading system (**10.2.3**) near to the top of the cored (**10.2.1**) or formed cylinder until it breaks off. The minimum depth of the fracture measured at the cylinder face should be recorded. If the fracture does not take place within 20 mm of the base of the annulus the result is not valid for estimating strength.

10.4 Test results

Test results should be reported as either the break-off pressure in megapascals or the break-off force in kilonewtons and the mean rounded off to the nearest 0.2 MPa or 0.05 kN respectively. Force values can only be reported when an appropriate calibration is available for the equipment in use.

10.5 Relationship between break-off force and strength of concrete

The break-off force will increase with concrete strength and is related to the modulus of rupture measured on prism specimens.

Correlations may be developed experimentally between break-off force and strength. Confidence limits for compressive strength correlation may be expected to be wider than for tensile strength or modulus of rupture correlations. While a correlation for the particular type of concrete under test is recommended, a general correlation with compressive strength covering a wide range of mixes may be useful.

The coefficient of variation of a set of measured values at one location under site conditions is typically about 10 %. However, in assessing compressive strength, the accuracy of the correlation with break-off force should also be considered as an additional factor. Limited experience suggests that a well-prepared correlation will allow strength estimates to be within ± 20 % at the 95 % confidence level from the mean of five valid results.

11 Methods of establishing correlations between near-to-surface tests and strength

11.1 Introduction

All the tests described in this Part may be used to estimate strength. The extent to which each test method requires separate correlation for different types of concrete has been outlined in clauses **6** to **10**. It should be noted that all tests measure properties of concrete near to the surface and will only allow estimation of strength of concrete in the interior of the mass if there is a known relationship between the concrete properties near to and away from the surface. This relationship will be influenced by the curing conditions and will be particularly sensitive to temperature gradients at early ages and any segregation in the plastic concrete.

To prepare a correlation between a near-to-surface test and strength, a number of specimens should be tested which encompasses the likely range of strength to be expected in the structure. The reliability of the correlation will be increased by increasing the number of specimens and the range of strengths. The near-to-surface tests should be carried out in accordance with the relevant clauses of this Part of BS 1881.

A correlation curve should be drawn through the points plotted from the mean near-to-surface test results and the mean strength of each corresponding set of nominally identical specimens. The equation of this curve can be determined by any standard curve fitting procedure.

11.2 Laboratory correlation

A correlation between a near-to-surface test and strength should be obtained by carrying out the near-to-surface tests on a series of concrete specimens and measuring strength on a companion series cast from the same concrete batch and cured under identical conditions. The form and number of companion specimens will depend on the type of strength correlation required. These companion specimens should be made and tested in accordance with the relevant Parts of this standard. Some near-to-surface tests can be carried out on cubes but for others, larger specimens will be required to satisfy the requirements for minimum edge distances. Ideally the correlation specimens should represent the structure to be tested as closely as possible in manufacture and curing.

The method of varying the strength should be chosen in relation to the purpose for which the correlation is to be used. For example, if it is intended to monitor the development of strength in a structure then it would be appropriate to test correlation specimens of the same mix at different ages. If it is proposed to monitor the quality of the concrete in a structure it would be appropriate to vary the mix proportions of the concrete. At least the number of near-to-surface tests given in Table 1 should be made on the relevant specimens and the mean value related to the mean strength obtained from three companion strength test specimens of the same age. At least eight points at different strengths should be used to establish a correlation unless the general form of the relationship is available, in which case a smaller number of points may be acceptable. Different tests are influenced by different factors and the degree to which the correlation specimens may differ from the structure without unduly affecting the validity of the correlation will depend on the particular test involved (see **6.5**, **7.5**, **8.5**, **9.5** and **10.5**). Caution may be required when establishing correlations at early ages to allow for maturity differences between the near-to-surface test specimens and the strength test specimens.

11.3 Site correlation

It is difficult to ensure that laboratory specimens accurately represent the concrete in the structure to be tested and more reliable results may be obtained if a correlation is made using cores. In this case cores should be cut close to the positions of the near-to-surface tests but sufficiently far away to avoid the possibility of the tests interfering with one another. Results should be obtained from at least three cores cut from each of at least two locations within the test area selected to be likely to provide extreme values of the strength range involved based on the results of the near-to-surface or other tests. It may be necessary to establish the general form of the relationship by tests on laboratory-cast specimens to enable the correlation to apply over an adequate range of strength values but unjustifiable extrapolation should be avoided.

12 Assessment of structures

The near-to-surface test appropriate to the type of concrete and the purpose of the investigation should be selected taking account of the factors identified in clause **5**.

Suitable test locations should be chosen in relation to the purpose of the investigation and the factors which limit the applicability of a particular test method. Anticipated strength variations which are likely to exist within members should be considered at this stage. When testing a number of similar elements they should be tested at similar positions to reduce any possible effects due to segregation. If test results on a structure are to be compared with a reference value or in situ strength is to be estimated using a correlation, the structure should be tested under conditions as close as possible to those used when obtaining the reference value or preparing the correlation. When testing existing structures for which no correlation is available the use of cores may be necessary.

The correct operation of the apparatus should be checked and the apparatus should be used in accordance with the relevant clauses of this Part of BS 1881 and those sections of the manufacturer's instructions which refer to its physical operation.

Differences between the results of tests at different locations will give a measure of the variability of the concrete within that structure or unit. In assessing such variability the precision of the test method should be taken into account.

13 Report

13.1 General

The report should affirm that near-to-surface testing was carried out in accordance with this Part of BS 1881.

13.2 Information to be included in the test report

13.2.1 *Obligatory information*

The following information should be included in the test report:

a) date, time and place of test;

b) description of the structure and locations of test positions (give sketches if necessary);

c) details of concrete and conditions of test;

d) details of test, including make, type and identifying number of apparatus and the date of its last calibration;

e) individual test results and their mean value and coefficient of variation for each location.

13.2.2 *Additional information*

Where appropriate, the following information also should be included in the test report:

a) test results expressed in terms of a correlated property (e.g. strength) and an estimate of their accuracy; the source and details of the correlation should be provided;

b) results of complementary tests by other methods;

c) where applicable, the appearance of the fracture surface and of the adjacent concrete.

Publication(s) referred to

BS 1881, *Testing concrete*.
BS 1881-116, *Method for determination of compressive strength of concrete cubes*.
BS 1881-117, *Method for determination of tensile splitting strength*.
BS 1881-120, *Method for determination of the compressive strength of concrete cores*.
BS 1881-201, *Guide to the use of non-destructive methods of test for hardened concrete*.
BS 3643, *ISO metric screw threads*.
BS 3643-1, *Principles and basic data*.
BS 4078, *Powder actuated fixing systems*.
BS 4078-1, *Code of practice for safe use*.
BS 6089, *Guide to assessment of concrete strength in existing structures*.
BS 6100, *Glossary of building and civil engineering terms*.
BS 6100-6, *Concrete and plaster*.
CIRIA Report 73 "Formwork striking times. Method of assessment" T.A. Harrison, 2nd edition 1987[2)].
Health and Safety Executive Guidance Note, PM 14 "Safety in the use of cartridge operated fixing tools"[3)].

[2)] Available from Construction Industry Research and Information Association, 6 Storey's Gate, London SW1P 3AU.
[3)] Available from HMSO, 49 High Holborn, London WC1V 6HB for personal callers, or by post from HMSO, PO 276, London SW 18 5DT.

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