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British Standard

Testing concrete

Part 201. Guide to the use of non-destructive methods of test for hardened concrete

Essais du béton
Partie 201. Guide pour l'utilisation des méthodes d'essai non destructifs sur le béton durci

Prtifverfahren für Beton
Teil 201. Leitfaden für die Anwendung zerstörungsfreier Prtifverfahren für Festbeton

British Standards institution

Foreword

This Part of BS 1881 has been prepared under the direction of the Cement, Gypsum, Aggregates and Quarry Products Standards Committee. All aspects of testing concrete are being included as Parts of BS 1881 and this Part forms a general introduction to those on nondestructive testing.

Nondestructive testing of a body of hardened concrete as cast, whether in a structure or as a component, offers advantages of speed, cost and lack of damage in comparison with test methods which require the removal of a sample. The range of properties that can be measured in this way is considerable, and much valuable information may be obtained if the available methods are used with an understanding of what they can, and cannot, achieve.

This guide presents information on test methods of this type which will assist with the planning of investigations and the selection of methods which are most appropriate to the circumstances. It summarizes the principal features of currently available techniques together with their advantages, limitations and most reliable applications. Many of the methods will be described in detail in other Parts of BS 1881, Parts 202 onwards*, while other techniques which are not yet so well established are also included with appropriate references. Additional guidance is given concerning the value of combinations of test methods.

The use of tests to assess strength is covered in greater detail in BS 6089. Strain gauges suitable for monitoring the behaviour of concrete structures in service, or under test load conditions, will be dealt with in Part 206' of this standard. For details of methods which are not covered in these British Standards, reference should be made to specialist literature as indicated.

It is hoped that the guidance given in this Part will encourage the wider use of nondestructive testing in a worthwhile and economical manner; it is not intended to supplant engineering judgement or to inhibit the development and use of other test methods.

NOTE. The numbers in parentheses in the text of this Part refer to the numbered bibliographic references given in appendix A.

* In preparation.

Contents

Section one. General

1.1 scope

This Part of BS 1881 gives guidance on the tests that are available for nondestructive testing of hardened concrete which forms a laboratory specimen or part of a structure, structural component or other type of engineering construction. Some tests cause varying degrees of localized damage or defacement and may therefore be considered partially destructive; these methods are all defined as nondestructive. All the tests can be performed on the concrete as cast and do not require the removal of samples for subsequent analysis or testing.

Methods of testing hardened concrete which require sample extraction are either dealt with in other Parts of BS 1881 or elsewhere (1, 2).

NOTE 1. Damage caused by the extraction of small-diameter cores may not be significantly greater than that due to some of the near-to-surface methods included here, provided that reinforcement is not cut during extraction. In cases where strength determination is required they may offer similar or better accuracy with fewer calibration problems (3).

NOTE 2. The titles of the publications referred to in this standard are listed on the inside back cover.

1.2 Definitions

For the purposes of this Part of BS 1881, the definitions given in BS 2787 and BS 6100 : Part 6 apply, together with the following.

1.2.1 non-dertructivr test. A test that does not impair the Intended performance of the element or member under investigation.

1.2.2 location. A region of concrete that is being assessed and that, for practical purposes, is assumed to be of unlform quality.

1.2.3 near-to-surface test. A test that measures some property of the concrete near to, but below, the surface.

1.2.4 standard cube strength. The measured compressive strength of a cube made, cured and tested in accordance with BS 1881 : Parts 108,111 and 116 respectively.

1.2.5 estimated in situ cube strength. The strength of concrete at a location in a structural member estimated by indirect means and expressed as the compressive strength of specimens of cubic shape.

1.3 Principal considerations

1.3.1 Advantages of nondestructive testing

Nondestructive testing offers significant advantages of speed, cost and lack of damage in comparison with test methods which require the removal of a sample for subsequent examination. These factors will permit more extensive testing and thus enable an investigation to be wider ranging with respect to the concrete structure under examination than would otherwise be possible. The immediate availability of results may also be an important advantage of this type of testing.

1.3.2 Properties measured

The range of properties that can be assessed using non-destructive techniques is large and includes fundamental parameters of the concrete such as density and elastic modulus in addition to strength. Other properties which can be assessed include concrete surface hardness, surface absorption and moisture condition as well as reinforcement location, cover and corrosion risk. The quality of workmanship and structural integrity may also be checked by the ability to identify and locate voids, cracking and delamination.

The required property is not measured directly by a number of the available methods and precise correlations are not always easy to achieve. In some instances estimates of the required property can only be achieved by comparative means.

1.3.3 I mportence of trained steff

Skill and care by the operator will generally be necessary, while the results obtained by some methods are particularly sensitive to variations in testing procedure. It is important that tests are performed by trained and reliable staff if worthwhile results are to be achieved, end it is recommended that two persons should normally be involved during testing on site.

1.3.4 Situations in which non-destructive testing may be valuable

Nondestructive testing may be applied to both new and existing structures. For new structures, the principal applications are likely to be for quality control or resolution of doubts about the quality of materials or construction. Testing of existing structures will usually be related to an assessment of structural integrity or adequacy. In either case, a small number of tests on a large structure, for example tests on a few cores, can be misleading, while nondestructive testing is often a valuable indicator, either on its own or es a preliminary to some other form of testing.

Nondestructive tests are useful for the following purposes:

(a) quality control of precast units or construction in situ;

(b) removing uncertainties about the acceptability of the materiel supplied owing to apparent non-compliance with specifications;

(c) confirming or negating doubt concerning the workmanship involved in batching, mixing, placing, compacting or curing of concrete;

(d) monitoring of strength development in relation to formwork removal, cessation of curing, pre-stressing, load application or similar purposes;

(e) location and determination of the extent of cracks, voids, honeycombing end similar defects within a concrete structure;

(f) determlning the position, quantities or condition of reinforcement;

(g) determlnlng the concrete uniformlty, possibly es a preliminary to core cutting, load testing or other more expansive or disruptive tests;

(h) increasing the confidence level of a smaller number of destructive tests;

(i) determining the extent of concrete variability in order to help in the selection of sample locations representative of the quality to be assessed;

(j) confirming or locating suspected deterioration of concrete resulting from such factors as

(1) overloading,
(2) fatigue,
(3) external or internal chemical attack or change,
(4) fire,
(5) explosion,
(6) environmental effects;

(k) assessing the potential durability of the concrete;

(l) monitoring long term changes in concrete properties;

(m) providing information for any proposed change of use of a structure, for insurance or for change of ownership.

1.4 Planning an investigation

1.4.1 Reasons for testing

The situations in which non-destructive testing may be useful have been indicated in 1.3.4, and the reasons for testing should be clearly established before the details of a test programme are planned. These will establish the information that is required, e.g. strength, uniformity and density, and whether this should relate to the surface, near to the surface, or to the body of a member.

1.4.2 Acceptance of test data

Before any programme commences, it is essential that there is agreement between the interested parties on the validity of the proposed testing procedures, the criteria for acceptance and the appointment of a person and/or laboratory to take responsibility for the testing and interpretation of the results.

It is essential, despite the apparent simplicity of some test methods, that testing is performed only by skilled operators who are familiar with the methods and that the interpretation of results is entrusted to a suitably experienced engineer.

1.4.3 Selecting a test programme

1.4.3.1 *General.* The test programme will be determined by the objectives of the investigation coupled with the suitability of the available methods in relation to the site conditions and economic factors as outlined in 1.4.3.2 to 1.4.3.5.

The objective may be to investigate the overall quality of the fabric, in which instance a random choice of test locations will be appropriate. Where the objective is to investigate suspect material, the test locations will be selected for this purpose and the test results will only apply to this suspect material. In both cases, a sufficient number of test locations should be chosen to establish a satisfactory confidence level for the results.

Visual inspection should also be regarded as an essential preliminary to the planning of a programme of testing since observation of features such as deflection, cracking and colour may yield valuable information affecting the choice of methods and location of test points.

In some instances, calibration is necessary to relate thr measured values or properties to those which are required, The availability and reliability of such calibrations are thus important.

1.4.3.2 *Choice of test methods.* The methods recommended in table 1 an likely to be most suitable for the general circumstances indicated. Practical limitations may preclude the use of particular methods in some situations, while in other cases it may be appropriate or necessary to consider the use of methods other than those recommended. For example, surface treatments, such as those to reduce moisture permeability, or decorative coatings may prevent the use of some methods. The principal features of the methods, including their most important limitations and most reliable applications, are described in section two and summarized in table 2.

The equipment required to perform the tests is easily portable in most cases, and all tests can be rapidly carried out, although extensive preparation may sometimes be necessary.

Important considerations affecting the choice of test method include the following.

(a) *Test locations,* Some factors to be considered are:

(1) the position within the member or structure;

(2) the variations of concrete properties through depth of lift;

(3) the position of reinforcement;

(4) the presence of local defects or influences, e.g. surface carbonation;

(5) the depth below the surface of the zone to which results apply.

(b) *Effect of damage.* The choice of method may be influenced by:

(1) the effects of testing on the surface appearance of the members;

(2) the possibility of structural damage resulting from the testing of small section members.

(c) *Size of member.* The size of the member may restrict the use of some test methods as a result of limitations on minimum edge distances, minimum or maximum thicknesses, or similar considerations.

(d) *Testing accuracy required* The testing accuracy required will depend upon the purpose of the investigation. The level that can be achieved will depend on:

(1) the test method;

(2) the number and location of measurements;

(3) the accuracy and reliability of available calibrations.

In determining the necessary number of measurements, it should be remembered that an individual result relates only to the immediate test position and does not necessarily reflect the proparties of the concrete In general.

1.4.3.3 *Combination of methods.* In some circumstances, the accuracy achieved may be improved by the use of two or more test methods. A combination of different test methods may be used for the following reasons.

(a) The use of one method as a preliminary to another. The most common situations of this type are:

(1) the location of reinforcement prior to core cutting or use of other nondestructive testing methods;

(2) the use of a nondestructive method to provide comparative data on concrete uniformity prior to core cutting or use of other nondestructive methods involving greater expense or damage.

(b) To obtain enhanced reliability of results on the basis of:

(1) the confirmation of observed patterns of concrete quality;

(2) the correlation of combinations of measured values with a desired property.

Suitable combinations of methods are discussed in section three.

1.4.3.4 *Site conditions.* The principal site conditions that should be considered include:

(a) the geographic location and ease of transport of test equipment;

(b) the accessibility of test locations;

(c) the environment;

(d) the safety of personnel and the general public during testing.

1.4.3.5 *Economic end social factors.* The test programme will be influenced by factors such as the value of the project and costs arising from:

(a) delays in construction, or restriction on usage or occupancy, while testing is conducted and decisions are made;

(b) remedial works that may be necessary;

(c) the features of different test methods, including time, materials and equipment, temporary works and making good;

(d) the need to select an adequate number of tests for an appropriate reliability of assessment;

(e) the need for a higher level of confidence in the assessment of structures where public safety is involved.

Table 1. Suitability of non-destructive test methods

Methods*	Test situation					
	Quality control	Investigation of standard of workmanship	Control of formwork removal, pre-stress release or load application	Comparative survey of quality of concrete in the structure	Investigation of potential durability	Investigation of fire, frost, chemical attack or similar
Pull-out test (cast-in insert)	X		X			
Pull-out test (drilled hole)	X		x	X		X
Internal fracture	X		X	X		X
Break-off test	X		X			
Pull-off test	X		X	X		
Penetration resistance	X		X	X		
Surface hardness	X		X	X	X	
Screed test	X			X	X	
Dynamic response	x	x		X		
Ultrasonic pulse velocity measurement	X	X	X	X	X	X
Acoustic emission		X			X	
Electromagnetic cover measurement	X	X			X	
Radar		X		X		
Radiography		X				X
Radiometry	X	X		X		
Neutron moisture measurement				X	X	
Depth of carbonation				X	X	X
Initial surface absorption				X	X	
Surface permeability					X	
Resistivity measurements				X	X	
Half-call potential measurements					X	
Strain measurements		X	X	X	X	X
Thermography					X	X
Maturity measurements			X			
Resonant f requency	X					

* Subject to the practical limitations outlined in section two.

Table 2. Summary of principal test methods

Method	Clause number	Principal reference	Principal applications	Principal properties assessed	Surface damage	Type of equipment	Remarks
Pull-out test (cut-in insert)	2.18	BS 1881 : Part 207*	Quality control (in situ strength)	Strength related	Moderato/ minor	Mechanical	Preplanned usage, surface zone test
Pull-out tat (drilled hole)	2.18	BS 1881 : Part 207*	In situ strength measurement	Strength related	Moderate/ minor	Mechanical	Drilling difficulties on vertical surfaces or roffits, surface zone tnt
Internal fracture	2.17	BS 1881 : Put 207*	In situ strength measurement	Strength related	Moderate/ minor	Mechanical	High test variability. surface zone test
Break-off test	2.20	BS 1881 : Part 207*	In situ strength measurement	Flexural tensile strength	Substantial/ moderate	Mechanical	High test variability, substantial damage
Pull-off test	2.19	BS 1881 : Part 207*	In situ strength measurement	Direct tensile strength	Moderate/ minor	Mechanical	Care needed with adhesive, surface zone tast
Penetration resistance	2.21	BS 1881 : Part 207*	In situ strength measurement	Strength related	Moderate/ minor	Mechanical	Specific calibrations required, limits on minimum member size, surface zone test
Surface hardness	216	BS 1881 : Part 202 (supersedes BS 4408 : Part 4)	Comparative surveys	Surface hardness	Very minor	Mechanical	Greatly affected by surface texture end moisture, surface mat unrepresentative on concrete more than 3 months dd, strength calibration affected by mix properties
Initial surface absorption	2.8	BS 1881: Part 208* (supersedes BS 1881 : Part 5)	Surface permeability - t	Surface absorption	Minor	Hydraulic	Difficult to standardize in situ moisture conditions and to obtain watertight seal to surface, comparative test
Surface permeability	2.9	(11)	Surface permeability assessment	Surface permeability	Minor	Hydraulic	Surface zone test, water or gas
Resistivity measurements	2.3	(6)	Durability survey	Resistivity	Minor	Electrical	Surface zone test, related to moisture content, indicates probability of reinforcement corrosion in zones of high risk
Half-cell potential measurements	2.4	(9)	Survey of reinforcement corrosion risk	Electrode potential of reinforcement	Very minor	Electro-chemical	Cannot indicate corrosion rate
Thermography	2.11	(16)	Structural integrity survey and void location	Surface temperature differences	NOM	Intro-rod radiation detection	Extraneous temperature effects have to be excluded, temperature differentials small, shortage of data ● d development
Maturity measurements	2.10	(14)	In situ strength development monitoring	Maturity	Minor	Thermo-sensitive chemical or dactronic	Preplanned usage, specific calibration required

• In preparation.

Table 2 *(continued)*

Method	Clause number	Principal reference	Principal applications	Principal properties assessed	surface damage	Type of equipment	Remarks
Screed test	2.18	(21)	Quality control of screeds	Surface soundness	Minor	Mechanical	Sand/cement screeds only. cannot be used if screed over soft material
Ultrasonic pulse velocity measurement	2.13	BS 1881 : Part 203* (supersedes BS 4408 : Part 5)	Comparative surveys	Elastic modulus	None	Electronic	Two opposite smooth faces preferably needed, strength calibration affected by moisture and mix properties, some surface staining possible
Acoustic emission	2.23	(34)	Monitoring during load testing	Internal crack development	None	Electronic	Increasing load required, not fully developed for site use
Dynamic response techniques	2.14	(20)	Pile integrity	Dynamic response	None	Mechanical/ electronic	Cannot yield bearing capacity
Electromagnetic cover measurement	2.2	BS 1881 : Part 204* (supersedes BS 4408 : Part 1)	Location of reinforcement	Presence of embedded steel	None	Electro-magnetic	Affected by magnetic aggregates and unreliable for congested steel
Radar	2.12	(19)	Location of voids or reinforcement	Internal interfaces	None	Electronic	Experience limited, procedures under development
Radiography	2.6	BS 1881 : Part 205* (supersedes BS 4408 : Part 3)	Location of voids or reinforcement	Relative density	None	Radioactive source or generator	Extensive safety precautions, limit on member thickness
Radiometry	2.8	(3)	Quality control	Density	None	Radioactive source or generator	Safety precautions and limit on member thickness for 'direct' method, 'backscatter' method is surface zone test
Neutron moisture measurement	2.7	(3)	Comparative moisture content	Moisture content	None	Nuclear	Surface zone test, calibration difficult

* In preparation.

Table 2 *(concluded)*

Method	Clause number	Principal reference	Principal applications	Principal properties assessed	Surface damage	Type of equipment	Remarks
Depth of carbonation	2.22	(33)	Durability survey	Concrete alkalinity	Moderate/ minor	Chemical	Approximate indication of extent of carbonation
Resonant frequency	2.1	BS 1881 : Part 209* (supersedes BS 1881 : Part 5)	Quality control	Dynamic elastic modulus	None	Electronic	Specially cast specimen required
Strain measurements	2.24	BS 1881 : Part 206* (supersedes BS 4408 : Part 2)	Monitoring movements in structures	Changes in strain	Minor	Optical/ mechanical/ electronic	Attachment and reading requires skill, can only indicate changes in strain

* In preparation.

Section two. Test methods

20 Introduction

The test methods described here are in varying stages of development. Those which are well established are detailed in other Parts of BS 1881, as indicated. Methods which are not fully developed are described in technical literature referred to in the bibliography in appendix A, as indicated by the numbers in parentheses.

21 Resonant frequency

NOTE. This method is currently described in BS 1681 : Part 5, but will eventually be revised as BS 1881 : Part 209.

2.1.1 General

Measurement of the resonant frequency of a prismatic specimen and the determination of its density may be used to yield a value for the dynamic elastic modulus of the concrete of which the specimen is formed.

2.1.2 Advantages

This procedure is quick, does not damage the specimen in any way and is reliable. The influence of operator technique is small and other testing errors are low.

2.1.3 Limitations

This test has to be performed on a standard specimen of hardened concrete and is usually associated with laboratory-cast samples. The method as described is not applicable to in situ usage.

2.1.4 Principal application

The principal application Is to provide a valua of dynamic elastic modulus ot concrete. I he test may also be valuable as a technique for monitoring changes of concrete properties as a result of various influences during laboratory investigations. A modified form of this test may be adapted for site use.

2.2 Electromagnetic cover measurement

NOTE. This method is currently described in BS 4406 : Part 1, but will eventually be rwisad as BS 1681 : Part 204.

2.2.1 General

Portable devices are available which are operated by rechargeable or dry batteries and are based upon measurement of the change of an electromagnetic field caused by steel embedded in the concrete. Such equipment is calibrated to indicate the distance of the steel below the surface, and in some cases may also indicate the diameters of reinforcing bars. When reinforcement is parallel to the surface, rotation of the search head will enable the alignment of the bar to be identified. Non-calibrated metal detectors are available which may detect metals (ferrous or non-ferrous) at depths outside the range of the above equipment.

2.22 Advantages

This method for locating reinforcing steel within a concrete member is truly nondestructive.

Under reasonable conditions, a site accuracy of estimated cover of ± 5 mm within the working range of the instrument may be expected.

Techniques are available to permit estimates of both bar size and depth of cover when neither is known.

2.2.3 Limitations

The effect of bar size is important if this is lass than 10 mm or greater than 32 mm.

Calibrations are sansitive to steel type, bar diameter and deformity, and aggregate and cement type, and have to take these factors into account. Most commercially available equipment is calibrated for medium-sized mild steel round bars in ordinary Portland cement concrete.

The range of the equipment is limited according to type, but care and experience in interpretation of data are required in the following cases:

(a) multiple bars, e.g. laps, transverse steel or closely spaced parallel bars;

(b) light wire mesh, buried nails or other metals batween the reinforcing bars and the surface;

(c) metal tie wires;

(d) aggregates with magnetic properties;

(e) stability of calibration, which may ba particularly important in relation to temperature changes within the magnetic field;

(f) stray magnetic fields.

2.2.4 Principal applications

The principal application8 are the location of reinforcement and estimation of cover, orientation and, in some cases, diameter of reinforcing bars. The technique is most reliable for lightly reinforced members, and may be used for the following:

(a) quality control checking, to ensure correct location and cover of reinforcing bars;

(b) investigation of concrete members for which records are not available;

(c) location of reinforcement as a preliminary to some other form of testing in which reinforcement should be avoided, e.g. taking cores, ultrasonic pulse velocity measurement or near to surface methods.

2 3 Resistivity measurements ,

NOTE. This method Is discussad In rafarancas 4. 5 and 6 of appendix A.

2.3.1 Generd

The electrolytic resistivity of concrete is known to be influenced by many factors induding moisture, salt content and temperature, as well as mix proportions and the water/cement ratio. The presence of reinforcement may also influence measurements. In situ measurements may be made using a Wenner four-probe technique in which four electrodes are placed in a straight line on or just below the concrete surface at equal spacings. An electrical current is passed through the outer electrodes while the voltage drop between the inner electrodes is measured. The apparent resistivity of the concrete may be calculated from a knowledge of the current, voltage drop and electrode spacing. For practical purposes, the depth of the zone of concrete affecting the measurement may be taken as equal to the electrode spacing.

2.3.2 Advantages

This technique can provide a simple nondestructive indication of the electrical resistivity of the concrete at the test location. This can be related, principally by experience, to the corrosion hazard of embedded reinforcement or other features of the concrete.

2.3.3 Limitations

Correlation of resistivity measurements to properties such as mix proportions are at present only possible under laboratory conditions. The use of in situ measurements for this purpose is hindered by the sensitivity of readings to the factors outlined above. Practical application is thus generally restricted at present to comparative measurements. Limited damage to the concrete surface may sometimes be necessary.

2.3.4 Principal applications

Experienced investigators have used the method to assess or monitor the durability of concrete exposed to severe environments. In some circumstances, the likelihood of corrosion of embedded reinforcement may be predicted by this method where half-cell potential measurements show that corrosion is possible (5, 6). Other possible applications of the method include comparative assessment of moisture conditions and estimation of the thickness of a concrete pavement slab by varying the electrode spacings (7). Resistivity measurements may also be used to assist the integrity testing of reinforced concrete piles (8).

24 Half-cell potential measurements

NOTE. This method is discussed in references 6, 6 and 9 of appendix A.

2.4.1 General

The method of half-cell potential measurements normally involves measuring the potential of an embedded reinforcing bar relative to a reference half-cell placed on the concrete surface. This is usually a copper/copper sulphate or silver/silver chloride cell but other combinations are used. The concrete functions as an electrolyte and the risk of corrosion of the reinforcement in the immediate region of the test location may be related empirically to the measured potential difference (5). In some circumstances, useful measurements can be obtained between two half-calls on the concrete surface (6).

2.4.2 Advantages

The equipment is simple and enables an almost non destructive survey to produce isopotential contour maps of the surface of a concrete member. Zones of varying degrees of corrosion risk may be identified from these maps.

2.4.3 Limitations

This method cannot indicate the actual corrosion rate. It may require a small hole to be drilled to enable electrical contact to be made with the reinforcement in the member under examination, and surface preparation may also be required. It is important to *recognize* that the use and interpretation of the results obtained from the test require an experienced operator who will be aware of other limitations such as the effect of protective or decorative coatings applied to the concrete.

2.4.4 Principal applications

This technique is most likely to be used for assessment or monitoring of the durability of reinforced concrete members where reinforcement corrosion is suspected. Reported uses include the location of areas of high reinforcement corrosion risk in marine structures, bridge decks and abutments. Used in conjunction with other tests, it has been found helpful when investigating concrete contaminated by salts.

25 Radiography

NOTE. This method is currently described in BS 4408 : Part 3, but will eventually be revised as BS 1881 : Part 205.

2.5.1 General

Radiography provides a method of obtaining a photograph of the interior of a concrete member from which variations of density may be identified. This is produced on a suitable film held against the rear face of the concrete, while a beam of gamma rays or high-energy X-rays is directed at the front face. The presence of high density materials, such as reinforcement, or low density areas caused by voids will produce light and dark areas on the film.

2.5.2 Advantages

This non-destructive method is the most direct means of providing pictorial evidence of the interior of a body of concrete.

2.6.3 Limitations

This technique requires extensive safety precautions and utilizes highly specialized equipment. It is therefore essential that this type of work is only performed by radiographers with experience of working with concrete. Gamma ray sources may ba used for member thicknesses of up to 500 mm; high-energy X-rays are *more* suitable for greater thicknesses up to 1.6 m.

2.5.4 Principal applications

The principal applications are as follows.

(a) The method is particularly valuable for locating areas of variable compaction or of voids in the concrete, or in the grouting of post-tensioned constructions.

(b) The general location of reinforcing bars can be determined. In favourable conditions, the location and sizing of reinforcing bars may be determined fairly precisely by photogrammetric analysis of the radiograph. The accuracy of measurements dedines in adverse radiographic conditions.

26 Radiometry

NOTE. This method is discussed in references 3 and 10 of appendix A.

2.6.1 General

A narrow beam of gamma rays is directed into the concrete and the intensity of radiation emerging Is measured by means of either a Geiger counter or a scintillation detector. Measurements may be made either of radiation passing through a body of concrete (direct method) or of radiation reflected back to the same surface by collision with electrons within the concrete (backscatter method).

In either case, the mass per unit area of the concrete is the property which has the greatest influence on the attenuation of the beam of rays and hence the measured value of radiation. Steel reinforcement has about three times the effect of normal concrete and its presence will thus influence measured values.

2.6.2 Advantages

This method provides a truly non-destructive method of assessing in situ density. The direct method permits examination of the interior of a concrete member. Portable equipment, which can provide either backscatter or direct readings and incorporates a microprocessor to compute results, is commercially available.

2.6.3 Limitations

Direct methods across the full thickness of a concrete element require extensive precautions, skilled personnel and highly specialized equipment. Calibration may be obtained by cutting cores in the path of radiation after test and using these as samples for physical density measurement. Otherwise, results are restricted to comparative use. Concrete up to at least 1.2 m thick can be tested.

For larger bodies of concrete or ground supported slabs, it may be necessary to lower the source and/or detector into predrilled or formed holes.

Direct readings may only be made at depths of up to 300 mm below the surface using the commercially available portable equipment, while backscatter results relate to a surface zone approximately 100 mm thick. Although equipment of this type is calibrated, difficulties may be caused by the lack of uniformity of the radiation absorption characteristics of concrete or density gradients near the surface. Backscatter results will generally be more variable than direct measurements (10).

2.6.4 Principal applications

The principal applications are as follows.

(a) Measurements of density where large numbers of repetitive measurements are required, e.g. for specialized in situ locations such as cement bound road bases or for quality control of precast units.

(b) The direct method may be used to detect member thickness or reinforcement in addition to density measurements.

(c) The backscatter method may be used to measure the density of the surface zone.

27 Neutron moisture measurement

NOTE. This method is discussed in reference 3 of appendix A.

2.7.1 General

The energy of fast or high-energy neutrons is rapidly reduced by the presence of elements of low atomic weight. The resulting slow or low-energy neutrons may be counted by a detector designed for this purpose. Few elements of low atomic mass are found in concrete other than hydrogen contained in water, and the counts may be used to provide an indication of moisture content

Measurements may either be made of the scattered neutrons reflected back to the same surface as the source (the backscatter technique) or a direct transmission value may be obtained by lowering the source into a pre-drilled hole. Best results are obtained using the direct technique when the moisture content is high.

2.7.2 Advantages

Portable equipment, which can provide either backscatter or direct readings end incorporates a microprocessor to compute results, is commercially available. This provides a truly nondestructive assessment of in situ moisture content when using the backscatter method.

2.7.3 Limitations

The results will only relate to a surface zone of the concrete a few millimetres deep when using the backscatter method. Direct measurements may be made at depths of up to 300 mm using the equipment currently available. Calibration of the instrument may not be straightforward end in situ measurements may be influenced by moisture gradients near to the surface and the presence of other neutron absorbers. The accuracy of the method is poor for concrete of low moisture content.

27.4 Principal application

The principal application is the estimation of the moisture content of the surface zone.

2.8 Initial surface absorption

NOTE. This method is currently described in BS 1881 : Pert 5, but will eventually be revised as BS 1881 : Pert 208.

2.8.1 General

Initial surface absorption involves measurement of the rate of flow of water per unit area into a concrete surface subjected to a constant applied head.

The equipment consists of a cap which is clamped and sealed to the concrete surface, with an inlet connected to a reservoir and an outlet connected to a horizontal calibrated capillary tube and scale. Measurements are made of the movement of the water in the capillary tube over a fixed period of time following closure of a tap between the cap and the reservoir.

The absorption of water by a dry surface is initially high but decreases as the water-filled length of capillaries increases, thus measurements have to be taken at specified time intervals from the start of the test.

2.8.2 Advantages

This method provides a practical non-destructive method of in situ measurement of the rate of water penetration of a concrete surface. It may be used on exposed aggregate or profiled surfaces provided a water-tight seal is obtained.

2.8.3 Limitations

It is essential to provide a water-tight seal between the cap and the concrete surface and difficulties are likely to be encountered. Sometimes it will be necessary to drill the surface for fixings.

Results are affected by variations in moisture content of the concrete, and samples for laboratory testing should preferably be oven dry or at least have been in a dry atmosphere for 48 h. It is virtually impossible to achieve comparable conditions with in situ concrete and this will reduce the reliability of quantitative results in this application. In these circumstances, use will be restricted to comparative measurements. The standardited pressure used in the test, created by the 200 mm head of water, is low and although results may be related to surface weather exposure they are of little relevance to behaviour under higher water pressures.

The internal permeability characteristics of a body of concrete cannot be assessed by this method.

2.8.4 Principal application

The most reliable application is as a quality control test for precast units which can be tested when dry. The test has been shown to he sensitive to changes in quality and weathering performance, and thus may also be used comparatively on in situ concrete for the purposes of quality contro! and assessment of potential durability.

2.9 Surface permeability

NOTE. There methods are discussed in references 11, 12 end 13 of appendix A.

2.9.1 General

Several methods are available, or under development, which permit an assessment of the permeability of concrete in the surface zone to water, air, carbon dioxide or other gases under pressure. These techniques, which vary in detail, all require a hole to be drilled into the surface of the concrete.

2.9.2 Advantages

These methods provide practical ways of assessing the permeability of surface zone concrete under in situ conditions. Information of this type may be particularly valuable as an indicator of potential durability.

2.9.3 Limitations

Some surface damage will be caused by these methods. The results will relate only to the particular test points and it will generally be necessary to perform tests at a numbar of points to obtain a representative value for each location. Although use of tests of this type is increasing, experience in the interpretation of site results is still limited.

The internal permeability characteristics of a body of concrete cannot be assessed by these methods.

2.9.4 Principal application

The main application is the assessment of the permeability of surface zone concrete in relation to durability surveys.

210 Maturity measurements

NOTE. This method is discussed in references 14 and 15 of appendix A

2.10.1 General

Maturity is an arbitrary parameter based on measurements of the internal temperature of a body of concrete throughout the setting, hardening and subsequent strength development stages.

Equipment for these measurements may be constructed in many forms. Two commercially available types are:

(a) disposable maturity meters, which are based on a temperature-dependent chemical reaction and are embedded in the concrete surface at the time of casting;

(b) electrically-operated integrating maturity meters, consisting of a microprocessor coupled to a reusable temperature sensor inserted into a metal tube which is cast into the concrete.

Maturity measurements may be related to strength development for a particular concrete mix and are especially valuable when combined with other non-destructive methods for monitoring strength development.

2.10.2 Advantages

The measurement of maturity is a simple nondestructive technique which takes account of the temperature history within the concrete during hydration. This is particularly valuable for construction during adverse weather conditions when a knowledge of strength development is important.

2.10.3 Limitations

Measurements relate only to the individual test points, and for a major pour it will thus be necessary to take measurements at several points simultaneously to account for variations within the concrete. This can involve considerable expense if used on a regular basis.

Correlations between maturity and strength will only apply to the particular mix and circumstances for which they have been developed.

2.10.4 Principal application

The principal application is the monitoring of in situ strength development in relation to stripping of formwork, removol'of props or the application of load.

211 Thermography

NOTE. This method is discussed in references 16 and 17 of appendix A

2.11.1 General

Thermography involves the recording of surface temperature differentials on a concrete member undergoing heating or cooling. Hidden features, including voids or cracks, will influence the local rate of heating *or* cooling and may be detected by examination of temperature contour plots. Infrared measurement techniques are necessary to detect and record the temperature differentials involved, which are very small. The following alternative types of equipment are available:

(a) a *quantitative temperature measuring gun*, which will yield a digital reading of the surface temperature at the point at which it is aimed;

(b) a *qualitative thermal imager,* which will indicate relative temperature differentials within the field of view; the image may be recorded photographically;

(c) *a scanner and cathode-fey monitor,* which will produce a colour display of calibrated isotherms which may be video-recorded or photographed.

Experience suggests that observations are best made during cooling, for example in the afternoon when the surface has been exposed to sunlight.

2.11.2 Advantages

This method is non-destructive, non-contacting, requires only one exposed surface and does not require the safety precautions necessary for radiography. Thermography may be carried out with the apparatus near to, or at a considerable distance from, the concrete surface.

2.11.3 Limitations

For large-scale structural surveys, it may be necessary to use the relatively expansive scanner in conjunction with a cathode ray tube. Precautions have to be taken to avoid interference from extraneous heat sources. Experience of the use of these techniques for inspection of concrete is limited.

2.11.4 Principal applications

The principal reported applications are from North America, where the technique has been used for the detection of delamination within reinforced concrete bridge decks. The method has also been used successfully for the location of Ingress of moistum and of reinforcement (18), ducts, voids or similar features within concrete walls or slabs, although published information is limited.

2.12 Radar

NOTE. This method is discussed in reference 19 of appendix A

2.12.1 General

A surface-penetrating radar system may be used to examine the reflections of short duration pulses from interfaces between materials with different dielectric constants lying below the surface. Reinforcing bars, voids, ducts and similar features may be identified and the thickness of slabs may also be determined. The equipment, which consists of transmitting and receiving antennae together with a control unit and recorder, is available commercially.

2.12.2 Advantages

This method, which is nondestructive and may be non-contacting, provides a rapid method of locating and recording features lying below the surface of a concrete element.

2.12.3 Limitations

Many factors contribute to the characteristics of the results, which require skilled specialist interpretation. The resolution that can be obtained will depend upon the frequency used, which will in turn influence the depth of penetration possible. When high speed testing of large areas is involved, as in highway surveys, data handling and presentation may present particular problems. Applications of this technique to concrete are at an early stage, and available data and experience am limited.

2.12.4 Principal applications

The principal areas of application are likely to be the identification and location of voids, cracks, delamination, and reinforcing bars. The thickness of slabs and location of voids beneath ground slabs can also be determined (17).

2.13 Ultrasonic pulse velocity measurement

NOTE. This method is currently described in BS 4408 : Part 6, but will eventually be revised as BS 1881 : Part 203.

2.13.1 General

Ultrasonic pulse velocity equipment measures the transit time of a pulse between transducers placed on the surface of a body of concrete. The pulse velocity can then be calculated using the measured path length through the concrete.

The pulse velocity depends upon the dynamic Young's modulus, dynamic Poisson's ratio and density of the medium.

2.13.2 Advantages

The principal advantages of ultrasonic pulse velocity measurement are that it is totally nondestructive, quick to use and reflects the properties of the interior of a body of concrete. It is particularly valuable in circumstances where a considerable number of readings is required for the assessment of uniformity of hardened concrete.

2.13.3 Limitations

Although non-destructive, it is essential not to overlook surface staining from the use of some couplants. The pulse velocities for most practical concrete mixes lie within a narrow range and it is therefore necessary to measure both the transit time and path length to an accuracy of the order of ± 1 % if the results are to be of greatest value.

Measured values may be affected by surface texture, moisture content, temperature, specimen size, reinforcement and stress. Correlations with strength are difficult to make and will be influenced considerably by the types and proportions of mix constituents and maturity. For comparative surveys, readings may be made with both transducers placed on the same surface but when it is necessary to measure pulse velocity accurately, e.g. for strength estimation, it will be necessary to place the transducers on opposite faces of the concrete element.

2.13.4 Principal applications

The principal applications are as follows.

(a) Determination of concrete uniformity, which is most reliably achieved by taking measurements on a regular grid on a member, or at comparable locations on similar members.

(b) Detection of cracking and honeycombing, which will increase the effective path length resulting in a higher measured transit time. If such defects lie between the transducers, a higher measured transit time will not necessarily occur if the crack or voids are water filled or bridged by reinforcement. The depth of surface cracks may be estimated by placing transducers on either side. Honeycombing or voids may be identified by taking a series of measurements through a member on a regular grid. The minimum size of detectable defect depends upon the transducer size and the distance between them.

(c) In situ strength estimations, which are unlikely to have 95 % confidence limits of better than ± 7 MPa* given ideal testing conditions and a specifically prepared calibration chart for the concrete mix in use. It may be possible to improve this value if the density is known, or by combination with measured rebound numbers.

(d) Strength development monitoring, which is possible if appropriate calibration charts can be obtained. Where results can be compared with predetermined limits for acceptance, the method may be used for quality control, formwork removal, stressing operations, etc.

(e) Assessment of concrete deterioration, using a general comparative survey to locate suspect areas. Techniques are also available to estimate the depth of surface fire damage or chemical attack. Long term performance of concrete may also ba monitored by conducting repetitive tests at a location.

NOTE. Although this method of test may be used on both in situ concrete and laboratory specimens, for purely laboratory investigations resonance tests may be more suitable owing to their greater sensitivity. One test of this type is outlined in 2.1.

(f) Estimation of layer thickness, which may be possible where there is a surface layer of inferior quality to the body of the concrete due to construction, weathering or other damage such as fire.

2.14 Dynamic response techniques

NOTE. Some of these methods are discussed in reference 20 of appendix A

2.14.1 General

Several techniques are available that measure the response of a structural member to an imposed dynamic load. They may be used to deduce stiffness and other structural properties. A wide range of methods may be applied to entire structures or individual members of a structure, but the approach is most fully developed for integrity testing of piles. Applications to other types of structural member are under development.

Techniques for pile testing include single blow and continuous vibration methods (20). The simplest and most widely used of these is the pulse echo method in which the reflected shock waves, resulting from a single hammer blow, are monitored by a hand-held accelerometer coupled to a signal processor. The wave form is then generally displayed visually.

2.14.2 Advantages

These methods are fast to use and nondestructive. A wide range of specialist equipment is commercially available, which is especially suitable for testing of piles.

* 1 MPa 10^6 N/m^2 10 bar.

2.14.3 Limitations

The equipment is often very specialized in nature and expensive, and considerable skill and experience are necessary for the interpretation of results. Tests on piles cannot directly assess the cross-sectional area or bearing capacity, and limited preparation of the pile head may sometimes be necessary.

2.14.4 Principal applications

The principal applications are as follows:

(a) assessment of structural integrity and remaining service life;

(b) fault finding;

(c) assessment of the need for and effectiveness of repairs;

(d) identification of defects, varying support conditions and lengths of piles.

2.15 Surface hardness

NOTE. This method is published as BS 1881 : Part 202 (previously described in BS 4408 : Part 4).

2.15.1 General

The surface hardness test is based on the principle that the rebound of an elastic mass depends upon the hardness of the surface which it strikes. A number of different hand-held spring-loaded steel rebound hammers are available to suit a variety of concrete types. The results are expressed in terms of the rebound number which is affected by conditions near to the surface. The test is particularly suited to comparative surveys but the results may also be correlated with other properties of the concrete. In this case a specific calibration for the type of concrete under investigation should be established as the use of universal calibrations can give seriously erroneous results.

2.15.2 Advantages

The principal advantages of surface hardness tests are the speed and low cost of testing.

2.15.3 Limitations

Results relate only to a surface zone of up to 30 mm depth and may be greatly affected by localized hardening due to carbonation when the concrete is more than 3 months old. Although tests are easy to carry out, the results are influenced by many factors including surface texture, moisture conditions of the surface, cement type, mix characteristics and type and rigidity of the structure. Concrete made with high alumina cement develops a surface layer considerably stronger than the underlying material, so results can be misleading. Minor surface indentations may be caused, particularly with young or weak concreta.

2.15.4 Principal applications

The principal applications are as follows.

(a) Determination of concrete uniformity, which is most reliably achieved by taking measurements on a regular grid on a mambar, or at comparable locations on similar members.

(b) Strength development monitoring, which is possible if appropriate calibration charts can be obtained. Where results can ba compared with predetermined limits for acceptance, the method may be used for quality control, formwork removal, etc.

(c) In situ strength estimations, which era unlikely to have 95 % confidence limits of better than ± 7 MPa given ideal tasting conditions and a specifically prepared calibration chart for the concrete mix in use.

(d) Assessment of abrasion resistance of concrete floor slabs, which may be correlated with rebound number.

This test is often combined with ultrasonic pulse velocity testing (see 3.4 and 3.5).

216 Screed test

NOTE. This method is discussad in references 21 and 22 of appendix A.

2.16.1 General

Measurement of the surface indentation caused by a defined number of repeated controlled hammer blows at a point on a sand/cement screed may be empirically related to the soundness of the scraad. Equipment is available in which a mass of 4 kg is dropped 1 m down a vertical rod onto a foot which impacts the surface over a 500 mm' area. The indentation caused by a specified number of blows may be measured with a simple dial gauge device. This test has been specifically developed as a performance test for assessing the soundness of sand/cement floor sawds, soundness being used to describe that property required of a screed to withstand the imposed loads and traffic in service.

2.16.2 Advantages

This method provides a simple and quick approach which involves self-contained hand-held equipment. The damage to sound screeds is vary small.

2.16.3 Limitations

This test is not suitable for use on concrete. Experience is restricted to sand/cement mortar screeds. On sound screeds, minor surface indentations up to 5 mm may be caused. The test cannot be used if the screed is laid over a weak or soft insulating layer,and the test area has to be flat and free from all loose dirt and grit. The screed should normally be at least 14 days old, and measured indentations have to ba related to predetermined acceptability limits (22). The interpretation of results requires experience and common sense.

2.16.4 Principal application

The principal application is the assessment of durability and quality of floor screeds.

217 Internal fracture

NOTE. This method is discussed in reference 23 of appendix A and will eventually be published in BS 1661 : Pert 207.

2.17.1 General

A 6 mm diameter expanding wedge anchor bolt is fixed into a drilled hole in the concrete surface and the peak force is recorded when this bolt is pulled against a reaction tripod on the surface. The force may be calibrated against compressive strength for the particular load application technique employed, since failure is initiated by a combination of tensile and shear stresses for the standardized configuration of bolt depth and reaction tripod dimensions.

The most common technique for loading involves the use of a torquemeter on a greased nut bearing on the reaction tripod through a washer, but the twisting applied to the bolt increases the scatter of results compared with hydraulic or mechanical direct-pull methods (24, 25).

2.17.2 Advantages.

This strength determination method is simple and cheap, requires only one exposed surface and is suitable for slender members. Strength calibrations are effectively independent of water/cement ratio, cement type and curing.

2.17.3 Limitations

The test depth is small (about 17 mm) and test variability is very high, especially using the torquemeter loading method. The maximum acceptable aggregate size is 20 mm and an average of six readings is required at any location. The loading rate and method are critical in relation to strength calibrations, and the 95 % confidence limits are unlikely to be closer to the mean than ± 28 % using a torquemeter. Testing technique and aggregate type influence the correlation with compressive strength, and specific calibrations are recommended if reliance is to be placed on strength estimates.

Surface damage may be limited to the drill holes if the test is stopped when the peak force is reached, but there remains the possibility that further surface damage may be caused by frost attack. If the bolt is pulled out of the concrete a crater approximately 80 mm in diameter will be formed.

2.17.4 Principal applications

The principal applications are as follows.

(a) Strength estimation of in situ concrete in situations where other methods are not practicable. This is particularly likely in the case of slender members or for concrete where specific calibrations for other methods are impossible to obtain because of the large number of variables involved.

(b) Comparative surveys of in situ concrete.

(c) Quality control or strength monitoring purposes, which are possible if a suitable calibration chart is available.

218 Pull-out test

NOTE. This method is discussed in references 26 and 27 of appendix A and will eventually be published in BS 1661 : Part 207.

2.18.1 General

Pull-out tests involve measurement of the force required to pull a metal insert from within the concrete against a reaction ring. The shape and location of the insert and the reaction ring are designed and standardized to give a force which can be related to the compressive strength of the concrete. This calibration is relatively independent of mix characteristics for natural aggregates up to 36 mm maximum size.

The insert may be cast in the concrete or may be positioned in an underreamed groove from a drilled hole. Load is applied at a steady predetermined rate by hand-operated hydraulic equipment on to a removable bolt which is connected to the insert. The peak value obtained is known as the pull force and may be correlated against compressive strength. If the load is reduced at this stage, surface damage is small and the bolt can be removed, but if loading is continued, a cone of concrete will be pulled from the surface. Experience of these methods in the UK is limited but they are in increasing use in Scandinavia and North America.

2.18.2 Advantages

This method is quick and requires only one exposed surface. Cast-in inserts may be fixed to soff it or side forms or on the top surface, and tests may be made through cutouts in forms if required.

2.18.3 Limitations

The depth of test is small (25 mm) and the scatter of individual results is high, requiring an average of six readings to be used. Estimated compressive strengths are unlikely to have 95 % confidence limits of better than ± 20 % of the mean when a general calibration is used or ± 10 % when a specially prepared calibration for the aggregate type in use is available. A minimum edge distance of 100 mm is required and reinforcement has to be avoided. Although testing is quick and the equipment simple to use, either pre-planning is required or drilling and underreaming are necessary. This operation is basically straightforward but may present some practical difficulties in situ, involving the use of a hand-held electric core cutter with water supply. The extent of surface damage will depend upon the test procedures adopted.

2.18.4 Principal applications

Cast-in inserts are most likely to be used for quality control or strength monitoring purposes, especially related to acceptance, formwork stripping, post-tensioning or termination of winter curing or protection. Values of pull force should be compared with previously established limiting velues for the particular circumstances. In some circumstances, it may be appropriate to apply proof loads to such inserts.

Inserts fixed into drilled holes may be used for the following:

(a) comparative surveys of in situ concrete;

(b) in situ strength estimation based on an appropriate calibration.

219 Pull-off test

NOTE 1. This method is discussed in references 28 end 29 of appendix A and will eventually be. published in BS 1881 : Part 207.

2.19.1 General

The pull-off test is a near-to-surface method in which a circular steel disc is glued to the surface of the concrete with an epoxy or polyester resin. The force required to pull this from the surface, together with an attached layer of concrete, is measured. Simple mechanical hand-operated loading equipment has been developed for this purpose. Partial coring may be used, if necessary, to eliminate surface skin effects.

NOTE 2. Attention is drawn to the fact that it is claimed that the pull-off test is the subject of British Patent No. 1549842, copies of which can be obtained from the Patent Office, 25 Southampton Buildings, London WC2A 1AY. BSI takes no position as lo the validity of the patent or whether it is still in force. The patent is endorsed 'licences of right' under Section 46 of the Patents Act 1977, which states:

'(3) Where such an entry is made in respect of a patent –

(a) any person shall, at any time after the entry is made, be entitled as of right to a licence under the patent on such terms as may be settled by agreement or, in default of agreement, by the Comptroller on the application of the proprietor of the patent or the person requiring the licence'.

Licence details may be obtained from the registered proprietor of the patent.

2.19.2 Advantages

This method directly measures a strength-related property, requires only one exposed surface and is suitable for use on small-section members.

2.19.3 Limitations

Considerable care has to be given to surface preparation prior to fixing the steel disc. Sufficient time has to be allowed to enable the resin adhesive to cure prior to load application. Results may be correlated to strength properties measured on standard specimens. Correlation with compressive strength is likely, however, to be influenced by aggregate type and it will probably be necessary to derive a calibration with strength for a particular type of concrete to be investigated.

Laboratory tests on concrete cubes indicate that an accuracy of strength prediction, based on the mean of three readings, of ± 15 % is possible. However, there is insufficient evidence available to enable detailed guidance to be given on the accuracy of the method under site conditions, although a greater variability is to be expected. Localized surface damage will be caused, and test results are limited to the surface zone of the concrete with fracture occurring approximately 5 mm below the surface unless partial coring is used.

2.19.4 Principal applications

The principal applications are quality control, long term monitoring and in situ strength assessment (particularly of high alumina cement concrete and carbonated concrete made with ordinary Portland cement using partial coring). These all require a suitable correlation to be available. In some circumstances proof loads may be applied to a series of permanent probes. The method also provides a useful means of testing repairs to concrete surfaces.

220 Break-off test

NOTE. This method is discussed in references 30 and 31 of appendix A and will eventually be published in *ES* 1681 : Part 207.

2.20.1 General

The break-off test has been developad in Scandinavia and determines directly the flexural tensile strength in a plane parallel to the concrete surface at a specified distance below the surface. A 65 mm diameter core is effectively formed within the concrete to a depth of 70 mm either by means of a disposable tubular form, which is cast into the concrete and then removed, or by cutting. An enlarged slot is formed near to the surface into which a hydraulically-operated jack with a load all is inserted to provide a transverse force to the top of the core. Measured values may be correlated to strength tests on standard laboratory specimens; the most reliable relationship is with flexural tests on prisms.

2.20.2 Advantages

This method directly measures a strength-related property and requires only one exposed surface. It is claimed to be especially suitable for young concretes and is quicker than conventional core testing.

2.20.3 Limitations

This method will leave a sizable damage zone and will either require pre-planning or the use of core-cutting equipment. The test variability is high and it is recommended that the mean of five tests should be used to represent the concrete at a given location. Insufficient evidence is available to permit guidance to be given on the accuracy of in situ strength estimates obtained by this method.

220.4 Principd applications

Principal applications are likely to be situations in which the tensile strength of the concrete is of importance, as follows:

(a) quality control of concrete pavements where results can be compared with predetermined limits for acceptance;

(b) in situ strength assessment in situations where a suitable correlation is available.

221 Penetration resistance

NOTE. This method is discussed in references 3, 25 and 32 of appendix A and will eventually be published in BS 1861 : Part 207.

2.21.1 General

Penetration resistance involves firing a steel bolt (probe) into the surface of the concrete. A standardized charge is used and the depth of penetration is measured. This may be calibrated against compressive strength, with the relationship principally affected by aggregate characteristics. Two power levels are available according to the concrete strength and the mean of three individual test results is normally required at any location.

2.21.2 Advantages

This strength determination method is quick and relatively insensitive to operator techniques and factors such as moisture content, cement type and curing. This may ba particularly valuable in situations where access is poor. The method may be used with up to 50 mm aggregate size and with rough or lightly textured surfaces or through timber forms. The test depth is uncertain but results are likely to represent concrete between 25 mm to 75 mm from the surface.

2.21.3 Limitations

Damage in the form of cracking may be caused to slender members, and a minimum edge distance and member thickness of 150 mm are required. Reinforcement has to be avoided and simple safety precautions are necessary. Calibration for the aggregate in use is essential if results are to be used to assess compressive strength, and estimated values are unlikely to have 95 % confidence limits of better than ± 20 %.

After measurement, the probe may be pulled from the surface leaving a conical surface damage zone approximately 75 mm in diameter.

2.21.4 Principal applications

The principal applications are as follows:

(a) comparative strength estimation in situations where truly nondestructive methods are unsuitable or impracticable;

(b) quality control or strength development monitoring, where results can be compared with predetermined limits for acceptance, formwork removel, etc.;

(c) strength estimation of in situ concrete in cases where an appropriate calibration is available.

2.22 Depth of carbonation

NOTE. This method is discussed in reference 33 of appendix A,

2.22.1 General

Carbonation of surface zone concrete will be accompanied by a loss of alkalinity of the concrete affected. This may be detected by the use of a suitable indicator, e.g. phenolphthalein, which can be sprayed on to a freshly exposed cut or broken surface of the concrete.

2.22.2 Advantages

This method is quick and simple and gives an immediate visual indication.

2.22.3 Limitations

A suitable surface has to be provided by cutting or breaking and testing immediately. This procedure will cause localized surface damage. This method provides only an indication of the extent of carbonation.

2.22.4 Principal applications

A knowledge of the depth of carbonation combined with the age of the concrete may be useful when assessing potential durability and the likelihood of corrosion of reinforcement. This test may also be useful in conjunction with some of the near-to-surface test methods to ensure that the depth of carbonation is insufficient to influence results.

2.23 Acoustic emission

NOTE. This method is discussed in references 3 and 34 of appendix A.

2.23.1 General

This method involves the detection of small amplitude elastic stress waves which are propagated throughout a material as localized crushing or microcracking occurs under load. This emission is generally not in the audible range and may be monitored by transducers positioned on the concrete surface and connected to electronic processing and recording equipment. As the load level on a concrete element increases, both the emission rate and signal level increase steadily. A rapid increase in both parameters precedes failure.

2.23.2 Advantages

Crack initiation and propagation can be monitored nondestructively during a period of increasing stress within a concrete element. It may also be possible to identify the location of crack initiation and propagation by the use of multiple detectors.

2.23.3 Limitations

Concrete may recover some aspects of its pre-cracking internal structure, and reloading over a particular stress range may again generate emissions. Consequently, it is not always possible to establish a history of past stress levels, contrary to the behaviour of many other materials.

This method would not normally be used for either individual or comparative measurements under static load conditions.

The propagation of acoustic waves in concrete is limited to low ultrasonic frequencies where the noise background is often high. The method is not, therefore, suitable for use on most building sites nor for the precise location of propagation cracks even in quiet areas.

Specialist equipment is required, and applications of the technique to concrete outside of the laboratory have not yet been fully developed.

2.23.4 Principal application

The principal application is likely to be monitoring of the initiation, origin and development of internal cracking and local breakdown during load testing, and to provide a warning of impending failure.

2.24 Strain measurements

NOTE. This method is currently described in BS 4408 : Part 2, but will eventually be revised as BS 1881 : Part 206.

2.24.1 General

Useful deductions concerning the suitability of concrete elements can be made by measuring strain. Strain gauges can measure strain, or apparent strain, caused by crack propagation, thermal changes, etc. They use one or more of the following to amplify and display the movement:

(a) levers;

(b) optics;

(c) electrical resistance;

(d) frequency of vibration;

(e) other means.

2.24.2 Advantages

The movement of structures can be monitored over long periods. The relationship between design parameters and the performance of the finished structure can be checked.

2.24.3 Limitations

The attachment and reading of many of these devices require skill. Not all strain gauges are suitable for use with concrete.

2.24.4 Principal applications

Principal applications include the following:

(a) monitoring of movements in structures at all ages;

(b) assessing elasticity of structural members;

(c) research work and model testing;

(d) load testing.

Section three. Combinations of methods

3.1 General

Situations in which it may be worthwhile to use combinations of test methods are outlined in 1.4.3.3. The most suitable methods will vary according to the circumstances but the following suggestions may be considered as typical.

3.2 Electromagnetic cover measurement or radiography to locate reinforcement

Electromagnetic cover measuring devices will frequently be valuable in conjunction with the near-to-surface test methods to ensure that reinforcement is avoided at test locations. The limited depth range of such equipment will not normally be a problem in this situation. This approach may similarly be valuable in relation to core drilling and ultrasonic pulse velocity measurements.

If the reinforcement is embedded at a depth beyond the range of this equipment, it may be necessary to use radiography to provide an indication of location, but this is only likely to be justified in particularly critical situations.

3.3 Non-destructive methods as preliminary to partially-destructive methods

It may often be worthwhile to perform an extensive survey quickly and cheaply with a rebound hammer or ultrasonic pulse velocity equipment prior to the use of other methods involving greater expense or damage but which give a more reliable indication of the required property of the concrete. This approach will enable suspect zones to be identified and can provide a calibration datum, thereby reducing the time and cost of examining a large body of concrete. The choice of a preliminary method has to be determined, taking account of the practical circumstances and the limitations of the test methods, and may also include radiography, radiometry or thermography. The subsequent testing will depend largely upon the property required but may include core cutting, pullout, internal fracture, break-off or penetration resistance, where strength is important. When in situ strength development is to be monitored, maturity measurements may provide useful preliminary data prior to confirmation by more disruptive strength assessment tests, such as pull-outs 115, 35).

3.4 Increasing the confidence level of test results

As a general rule, the cheapest and quickest suitable test methods will have been chosen. The observed patterns of variation of quality may be confirmed by the use of additional methods. For example, on recently cast concrete the use of rebound hammer and ultrasonic pulse velocity may be the most appropriate combination. In other circumstances it may be necessary to combine one or the other of these with near-to-surface testing or radiometry. The patterns of results obtained should be compared directly, and results should not be converted to some other property before comparison. Confidence will be much increased if similar patterns emerge.

In situations where the volume of concrete is relatively small, and where a specific property, e.g. strength, is of primary interest, it may be worthwhile to compare two or more estimates of that property using different methods.

3.5 Improvement of calibration accuracy

In some cases where the correlation between measured values and required property is sensitive to a number of variables, it may be possible to achieve an improved accuracy of estimated property by mathematical combination of results.

The accuracy of strength prediction from ultrasonic pulse velocity may be improved by combination with values of density (36) obtained from the same specimens or sections, provided sufficiently accurate measurements can be made. Ideally, a velocity/strength relationship should be derived for each value of density, However, rebound hammer readings, which are surface-density related, have most often been used in combination with ultrasonic pulse velocity measurements.

In cases where strength calibrations are available for both methods relating to the concrete in use, multiple regression equations can be developed with compressive strength as the dependent variable (37, 38). This is likely to be of particular value for quality control applications. Correlation graphs may also be produced involving coefficients relating to various properties (39).

3.6 Half-cell potential and resistivity tests to indicate likelihood of reinforcement corrosion

Half-ceil potential surveys will usually indicate the level of possibility of the occurrence of reinforcement corrosion as a result of electrochemical action. Subsequent resistivity measurements in zones which are demonstrated to be at risk may sometimes indicate the likelihood of corrosion actually occurring. While combination of these methods cannot positively confirm that corrosion has occurred or is occurring, or assess the extent of any corrosion, they represent the most effective nondestructive approach currently available (6.40). Other tests of a chemical nature are available for the concrete, e.g. chloride content analysis and carbonation depth, while steel monitoring tests, e.g. electrical resistance probes and linear polarization probes, may have to be incorporated at the time of construction (5). Tests of this type may be valuable in conjunction with half-cell potential and resistivity measurements, but are outside the scope of this standard.

Appendix

Appendix A. Bibliography

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- Part 111 Method of normal curing of test specimens (20 °C method)
- Part 116 Method for determination of compressive strength of concrete cubes
- Part 202 Recommendations for surface hardness testing by rebound hemmer
- Part 203' Recommendations for the meesurement of velocity of ultrasonic pulses in concmte
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NOTE. See also bibliography in appendix *A*

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