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Testing of concrete —

Part 7:
Non-destructive tests on hardened concrete

Essais du béton —

Partie 7: Essais non destructifs du béton durci

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 1920-7 was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 1, *Test methods for concrete*.

ISO 1920 consists of the following parts under the general title *Testing of concrete*:

— *Part 1: Sampling of fresh concrete*

— *Part 2: Properties of fresh concrete*

— *Part 3: Making and curing test specimens*

— *Part 4: Strength of hardened concrete*

— *Part 5: Properties of hardened concrete other than strength*

— *Part 6: Sampling, preparing and testing concrete cores*

— *Part 7: Non-destructive tests on hardened concrete*

Testing of concrete —

Part 7:
Non-destructive tests on hardened concrete

1 Scope

This part of ISO 1920 specifies non-destructive test methods for use on hardened concrete.

The methods included are

a) determination of rebound number,

b) determination of ultrasonic pulse velocity, and

c) determination of pull-out force.

NOTE These test methods are not intended to be an alternative for the determination of compressive strength of concrete, but with suitable correlations they can provide an estimate of *in-situ* strength.

2 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

NOTE Additional terms are defined in other parts of ISO 1920.

2.1
rebound number
⟨rebound number test⟩ reading on a rebound hammer, which is related to the proportion of the energy returned to the hammer after striking the surface of the concrete

2.2
test area
⟨rebound number test⟩ region of concrete that is being assessed and which, for practical purposes, is assumed to be of uniform quality

2.3
median
⟨rebound number test⟩ middle value of a set of numbers when arranged in size order

NOTE If the set has an even number of items, the median is taken as the mean of the middle two.

2.4
transit time
⟨ultrasonic pulse velocity test⟩ time taken for an ultrasonic pulse to travel from the transmitting transducer to the receiving transducer, passing through the interposed concrete

2.5
onset
⟨ultrasonic pulse velocity test⟩ leading edge of the pulse detected by the measuring apparatus

2.6
rise time
⟨ultrasonic pulse velocity test⟩ time for the leading edge of the first pulse to rise from 10 % to 90 % of its maximum amplitude

3 Determination of rebound number

3.1 Principle

A mass propelled by a spring strikes a plunger in contact with the surface. The test result is expressed in terms of the rebound distance of the mass.

NOTE Annex A describes a method of obtaining a correlation between strength and rebound number.

3.2 Apparatus

3.2.1 Rebound hammer, hammer comprising a spring-loaded steel hammer that, when released, strikes a steel plunger in contact with the concrete surface.

The spring-loaded hammer shall travel with a fixed and repeatable velocity. The rebound distance of the steel hammer from the steel plunger shall be measured on a linear scale attached to the frame of the instrument.

The rebound hammer shall be calibrated twice a year to validate the calibration curve. It shall also be calibrated whenever there is a reason to question its proper operation.

NOTE Several types and sizes of rebound hammers are commercially available for testing various strengths and types of concrete. Each type and size of hammer should be used only with the strength and type of concrete for which it is intended. For testing concretes with a low surface hardness, such as lightweight concrete, a pendulum-type rebound hammer of low impact energy is suitable.

3.2.2 Steel reference anvil, for verification of the hammer, defined with a hardness of minimum 52 HRC and a mass of 16 kg ± 1 kg and a diameter of approximately 150 mm, except where the annex in a national standard defines a different mass.

NOTE Verification on an anvil will not guarantee that different hammers will yield the same results at other points on the rebound scale.

3.2.3 Abrasive stone, medium-grain texture silicon carbide stone or equivalent material.

3.3 Test area

3.3.1 Selection

If the concrete elements to be tested are not at least 100 mm thick and fixed within a structure, they shall be rigidly supported during testing. Areas exhibiting honeycombing, scaling, rough texture, or high porosity should be avoided.

In selecting an area to be tested, the factors described in Annex B should be taken into account.

A test area shall be approximately 300 mm × 300 mm.

NOTE It is normally better to confine the readings to a limited test area, rather than take random readings over the whole structure or element.

3.3.2 Preparation

Heavily textured or soft surfaces and surfaces with loose mortar shall be ground smooth using the abrasive stone (3.2.3).

Smooth-formed or trowelled surfaces may be tested without grinding.

Remove any water present on the surface of the concrete.

3.4 Procedure

3.4.1 Preliminaries

Use the rebound hammer (3.2.1) in accordance with the manufacturer's instructions for its operation. Activate it at least three times before taking any readings, to ensure that it is working correctly.

Before a sequence of tests on a concrete surface, take and record readings using the steel reference anvil (3.2.2) and ensure that they are within the range recommended by the manufacturer. If they are not, then clean and/or adjust the hammer.

The hammer should normally be operated at a temperature within the range of 10 °C to 35 °C.

3.4.2 Determination

Hold the hammer firmly in a position that allows the plunger to impact perpendicularly to the surface being tested. Gradually increase the pressure on the plunger until the hammer impacts.

After impact, record the rebound number.

NOTE There are hammers with automatic writing equipment and, in these cases, the rebound number is recorded automatically.

Use a minimum of nine readings to obtain a reliable estimate of the rebound number for a test area.

Record the position and orientation of the hammer for each set of readings.

No two impact points shall be closer together than 25 mm and none shall be within 50 mm from an edge.

NOTE It is preferable to draw a regular grid of lines 25 mm to 50 mm apart and take the intersections of the lines as the test points.

Examine each impression made on the surface after impact. If the impact has crushed or broken through a near-to-surface void, the result shall be discounted.

3.4.3 Reference checking

After testing the concrete, take readings using the steel anvil (3.2.2). Record and compare these with those taken prior to the test (see 3.4.1). If the results differ, clean and/or adjust the hammer and repeat the test.

3.5 Test results

The result for the test area shall be taken as the mean of all the readings, adjusted if necessary to take into account the orientation of the hammer in accordance with the manufacturer's instructions, and expressed as a whole number.

If more than one hammer is to be used, a sufficient number of tests should be made on similar concrete surfaces so as to determine the magnitude of the differences to be expected.

NOTE 1 A method for obtaining a correlation between strength and rebound number is given in Annex A.

NOTE 2 For factors influencing the rebound number, see Annex B.

If more than 20 % of all the readings differ from the mean value by more than 6 units, the entire set of readings shall be discarded.

3.6 Test report

An example of a test report is given in Annex C.

In addition to the details required by Clause 6, the report shall include the following:

a) identification of the rebound hammer;

b) reference anvil readings, before and after tests;

c) test result (mean value) and hammer orientation for each test area;

d) individual rebound hammer readings (when specified);

e) test result adjusted for hammer orientation (if appropriate).

4 Determination of ultrasonic pulse velocity

4.1 Principle

A pulse of longitudinal vibrations is produced by an electro-acoustical transducer held in contact with one surface of the concrete under test. After traversing a known path length in the concrete, the pulse of vibrations is converted into an electrical signal by a second transducer and electronic timing circuits enable the transit time of the pulse to be measured.

4.2 Apparatus

The apparatus comprises the following.

4.2.1 Electrical pulse generator

The pulse velocity of the apparatus should be calibrated against a standard calibration bar, generally supplied by the manufacturer of the apparatus.

4.2.2 Pair of transducers

The natural frequency of the transducers should normally be within the range 20 kHz to 150 kHz.

NOTE Frequencies as low as 10 kHz and as high as 200 kHz can sometimes be used. High-frequency pulses have a well-defined onset but, as they pass through the concrete, they become attenuated more rapidly than pulses of lower frequency. It is therefore preferable to use high-frequency transducers (60 kHz to 200 kHz) for short path lengths (down to 50 mm) and low frequency transducers (10 kHz to 40 kHz) for long path lengths (up to a maximum of 15 m). Transducers with a frequency of 40 kHz to 60 kHz are found to be useful for most applications.

4.2.3 Amplifier

4.2.4 Electronic timing device, for measuring the time interval elapsing between the onset of a pulse generated at the transmitting transducer and the onset of its arrival at the receiving transducer.

Two forms of the electronic timing apparatus are available:

— an oscilloscope on which the first front of the pulse is displayed in relation to a suitable time scale;

— an interval timer with a direct reading digital display.

NOTE An oscilloscope provides the facility for examining the wave form, which can be advantageous in complex situations.

4.2.5 Apparatus for determination of arrival time of the pulse

The apparatus shall be capable of determining, in microseconds, the time of arrival of the first front of the pulse, even though this may be of small amplitude compared with that of the first half wave of the pulse.

4.3 Performance requirements of apparatus

The apparatus shall conform to the following performance requirements:

a) it shall be capable of measuring transit times in the calibration bar to an accuracy of $\pm$ 0,1 µs;

b) the electronic excitation pulse applied to the transmitting transducer shall have a rise time of not greater than one-quarter of its natural period; this is to ensure a sharp pulse onset;

c) the pulse repetition frequency shall be low enough to ensure that the onset of the received signal is free from interference by reverberations;

d) the apparatus shall be used within the operating conditions stated by the manufacturer;

e) the apparatus shall be in calibration at the time of the test.

4.4 Procedure

4.4.1 Factors influencing pulse velocity measurements

In order to provide a measurement of pulse velocity that is repeatable, it is necessary to take into account the various factors that influence the measurements. These are set out in Annex E.

4.4.2 Transducer arrangement

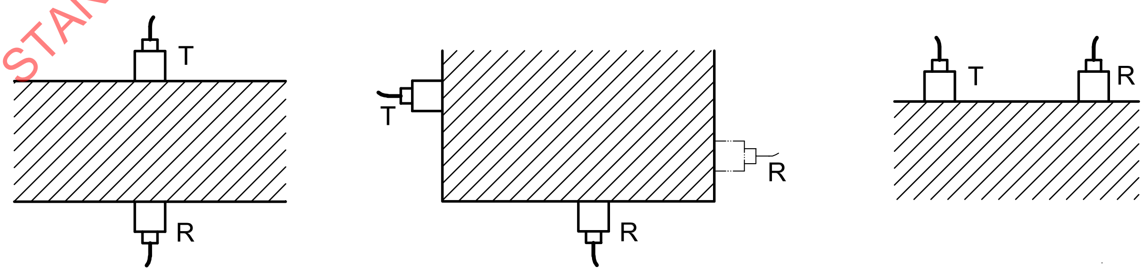
Place the two transducers on opposite faces (direct transmission), or on adjacent faces (semi-direct transmission), or on the same face (indirect or surface transmission) (see Figure 1). Although the direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer, it is possible to detect pulses that have travelled through the concrete in some other direction.

It may be necessary to place the transducers on opposite faces but not directly opposite each other. Such arrangements shall be regarded as a semi-direct transmission [see Figure 1 b)].

The indirect transmission arrangement is the least sensitive and should be used when only one face of the concrete is accessible, or when the quality of the surface concrete relative to the overall quality is of interest.

See Annex D for the method of determining the ultrasonic pulse velocity by indirect transmission.

The semi-direct transmission arrangement has a sensitivity intermediate between the other two arrangements and should only be used when the direct arrangement cannot be used.



a) Direct transmission **b) Semi-direct transmission** **c) Indirect transmission**

Key

T is the transmitter

R is the receiver

Figure 1 — Positioning of transducers

4.5 Expression of results

For direct and semi-direct transmissions the pulse velocity shall be calculated from the formula:

$$V = \frac{L}{T}$$

where

V is the pulse velocity, in kilometres per second;

L is the path length, in millimetres;

T is the time taken by the pulse to traverse the length, in microseconds.

For indirect transmission, the pulse velocity shall be calculated in accordance with Annex D.

The resultant determination of the pulse velocity shall be expressed to the nearest 0,01 km/s or to three significant figures.

NOTE For a method of determining a correlation between pulse velocity and strength, see Annex F.

4.6 Test report

An example of a test report is given in Annex G.

In addition to the details required by Clause 6, the report shall include the following:

a) type and make of apparatus used, including: dimensions of contact area transducers, natural pulse frequency of transducers, and any special characteristics;

b) arrangements of transducers and transmission method (including a sketch, where appropriate);

c) details of reinforcing steel or ducts in the vicinity of the test areas (if known);

d) surface conditions and preparation at test points;

e) measured values of path length (for direct and semi-direct transmission), including method of measurement and accuracy of measurement;

f) pulse velocity.

5 Determination of pull-out force

5.1 Principle

The force required to pull out a disc installed a fixed distance below the surface of the concrete is measured.

5.2 Apparatus

The apparatus shall be as follows [see Figure 2 c)].

5.2.1 Insert, made of metal not readily attacked by fresh concrete, of sufficient thickness and strength to avoid deformation during the test.

The diameter of the head of the pull-out insert shall be 25 mm ± 0,1 mm. The sides of the insert shall be smooth.

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 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 [see Figure 2 a) and b)].

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 to 25 mm ± 0,1 mm.

5.2.2 Drilling and under-reaming equipment

Specialized equipment shall be used for drilling and then enlarging the base of the hole, when the insert is not cast into the concrete.

5.2.3 Bearing ring, that can be placed on the concrete surface symmetrically around the insert axis, having an inside diameter of 55 mm ± 0,1 mm and an outside diameter of 70 mm ± 1 mm.

The width of the bearing ring shall not be less than 0,4 of the diameter of the head of the pull-out insert.

5.2.4 Loading system, capable of applying a tensile force to the insert with the reaction being transmitted to the concrete surface through the bearing ring.

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 dial, scale or display shall have a resettable device that records the maximum applied force.

The loading system shall be calibrated twice a year and whenever there is a reason to question its proper operation.

5.3 Test area

5.3.1 Specimen location

The centres of test positions shall be at least 200 mm apart.

The centres shall be at least 100 mm from the edge of the concrete.

The inserts shall be placed so that all reinforcement is outside the expected conic failure surface by at least one bar diameter, or the maximum aggregate size, whichever is the greater.

The minimum thickness of the concrete to be tested shall be 100 mm.

5.3.2 Number of tests

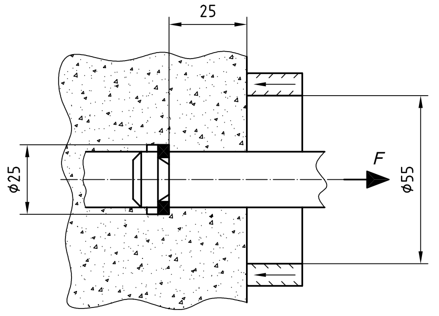
The number of tests required to represent an area or part of a structure shall be specified and will depend upon

a) the variability of the concrete, and

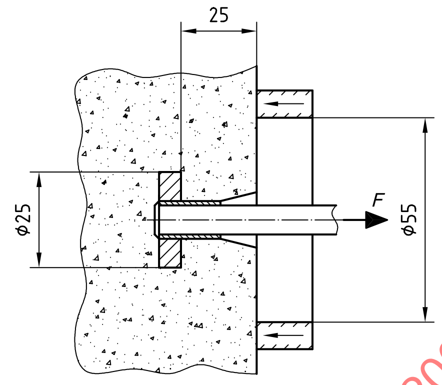
b) the purpose of the test and the accuracy required.

Care should be exercised to avoid averaging individual results if the differences between them reflect real differences in strength due to factors such as variations in curing conditions or batches of concrete.

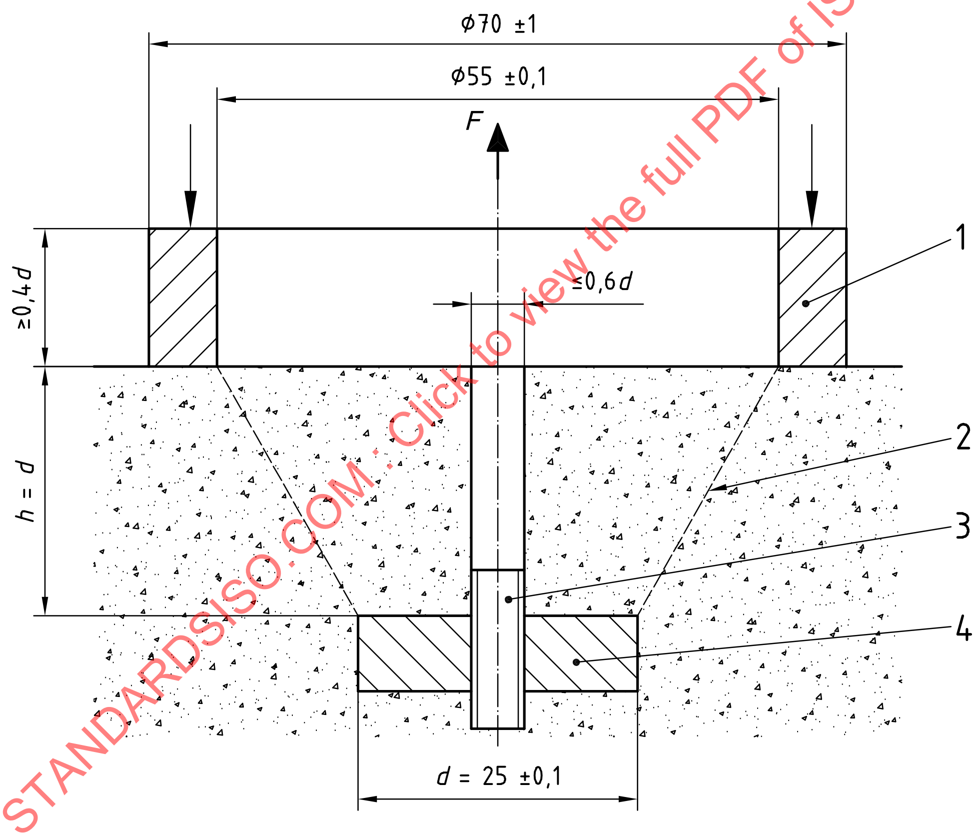
Dimensions in millimetres



a) Insert installed before casting



b) Insert installed after casting



c) Apparatus

Key

1 bearing ring

2 assured conic fracture

3 removable pull-out insert shaft

4 pull-out insert head

F is the pull-out force

d is the diameter of the insert head

h is the distance from the pull-out insert head to the concrete surface

Figure 2 — Schematic representation of pull-out test arrangement

5.4 Procedure

5.4.1 Installation of inserts

Securely fix the cast-in inserts to the formwork or locating device at the required test positions.

NOTE 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.

Drill holes for other types of inserts, under-reamed, and assemble the inserts according to the manufacturer's instructions.

5.4.2 Loading

Do not apply the test to frozen concrete.

First remove the tapered shaft of a cast-in insert and then connect the loading system to the insert in accordance with the manufacturer's instructions.

Apply the load and increase at a steady rate of 0,5 kN/s ± 0,2 kN/s, without shock, until either the concrete is fractured (if the strength is to be estimated) or to the specified proof load (if the purpose of the test is to verify that the concrete has achieved a required minimum strength).

Record the maximum indicated force.

5.5 Expression of results

The maximum indicated force shall be expressed to the nearest 0,05 kN or to three significant figures.

If there is a requirement to determine the pull-out strength, then the procedures given in Annex H should be followed.

5.6 Test report

An example of a test report is given in Annex I.

In addition to the details required by Clause 6, the report shall include the following:

a) type of apparatus (inserted or drilled);

b) whether the concrete was loaded to rupture or proof loaded;

c) individual force measurement(s).

6 General requirements for test reports

Test reports shall include the following:

a) identification of the concrete structure/element;

b) location of the test area;

c) date of the test;

d) description of the concrete tested; where known, include mix design, age of concrete, details of curing of the concrete, temperature of the concrete at time of the test, surface moisture condition of the concrete at the time of the test, description of the preparation of the test area;

e) any deviation from the methods set out in this International Standard;

f) declaration by the person technically responsible for the test, that the test was carried out according to this International Standard, except as detailed in e).

Annex A
(informative)

Method of obtaining a correlation between strength and rebound number

A.1 The most convenient method of producing a correlation between strength and rebound number is by tests in which both measurements are made on cast specimens. However, it is difficult to ensure that cast specimens represent *in-situ* concrete in all respects. More reliable results may be obtained, either by using cores taken from *in-situ* concrete to establish a correlation between strength and rebound number, or by using data obtained from impact tests and core strengths to 'calibrate' correlations based on cast specimens. In this case, rebound number tests should be made on the concrete *in situ* at proposed core positions and cores subsequently cut and tested for strength.

NOTE Correlations between rebound number and compressive strength are unlikely to be valid if the concrete has been damaged, for example by freeze-thaw attack, fire or attack by sulfates.

A.2 For convenience and to ensure rigidity, cast specimens maybe held in a compression testing machine, at load corresponding to about 2 MPa, whilst the rebound hammer readings are taken.

A.3 To prepare a correlation between rebound number and strength, it is necessary to test a number of specimens encompassing the likely range of strength expected in the structure. The reliability of the correlation is increased by increasing the number of specimens. The method of varying the strength should be chosen in relation to the purpose for which the correlation is to be used. If it is intended to monitor the development of strength in a structure, then it would be appropriate to test correlation specimens 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.

A.4 Correlation specimens should represent the structure to be tested as closely as possible; all the factors given in Annex B should be taken into account.

A.5 A correlation curve can be constructed from the rebound number and strength test results. The precision of the correlation can be judged by a correlation coefficient from the data.

Annex B
(informative)

Factors influencing the rebound of a concrete surface

B.1 General

The empirical relationship between the strength of concrete and its rebound number described in Annex A is influenced by the factors described in B.2 to B.9.

B.2 Concrete strength

Type of cement: Different types of cement may give substantially different correlations between rebound number and strength.

Cement content: Concrete with a high cement content will give lower rebound number readings than concrete of the same strength but a lower cement content. However, the error in strength estimation resulting from a change in cement content is unlikely to exceed 10 %.

Type of aggregate: Although many normal-weight aggregates give similar correlations between concrete strength and hardness, these should not be assumed unless supporting test evidence is available. Lightweight aggregates and aggregates with unusual properties require special calibrations.

Type of curing and age of concrete: The relationship between hardness and strength varies as a function of time. Variations in initial rate of hardening, subsequent curing and conditions of exposure also influence the relationship. Separate calibration curves are required for different curing regimes but the effect of age can generally be ignored for concrete between 3 days and 3 months old (see B.5).

Compaction: Rebound hammers are unsuitable for detecting strength variations caused by different degrees of compaction. If the concrete is not fully compacted, this technique is not applicable.

B.3 Type of surface

Only smooth surfaces should be tested. Surfaces obtained by casting against different formwork materials respond differently to rebound number tests. Trowelled surfaces are generally harder than those cast against formwork and may also give more variable results. (See also the Note to A.1.)

Tests on cut surfaces are likely to give more variable results and the results may differ significantly from those obtained from a cast surface.

Tests on moulded surfaces are generally to be preferred. Lack of quantitative evidence on how different surfaces behave under a rebound number test can lead to considerable errors if results are compared. In such cases, separate calibrations are necessary.

B.4 Type of concrete

Rebound number test methods are only suitable for close textured concrete. These tests are unsuitable for open textured concrete typical of masonry blocks, honeycombed concrete, or no-fines concrete.

B.5 Moisture condition of the surface

A wet surface gives lower rebound hammer readings than a dry surface. This effect can be considerable and a reduction in rebound number of 20 % is typical for structural concrete, although some types of concrete can give greater differences.

B.6 Carbonation

The effect of carbonation is to increase the hardness of concrete. Normal rates of carbonation do not significantly affect the measured rebound number when the concrete is less than 3 months old. In some conditions of high temperature and high carbon dioxide concentration, carbonation may have a significant effect at earlier ages. Carbonation affects the surface layer, which ceases to be representative of the concrete within an element. If required, the carbonated layer may be removed by grinding.

B.7 Movement of concrete under test

The impact from the rebound hammer should not be allowed to cause noticeable vibration or movement of the concrete being tested. Consequently, small concrete specimens have to be rigidly mounted (e.g. by clamping them firmly in a heavy testing machine). For some structural members (e.g. a console of a structure) the slenderness or mass may be such that this criterion is not fully satisfied and, in such cases, strength prediction is difficult, although comparisons between or within individual members may be made by conducting tests at points of similar rigidity.

B.8 Direction of test

The direction of test will influence the measured rebound number. The usual directions of test are either horizontal or vertically down, but any direction of test may be used provided that it is consistent and normal to the surface. Corrections for a given direction are usually supplied with the hardness tester. It is desirable that they should be checked experimentally.

B.9 Other factors

Other factors that are known to influence rebound hammer readings are proximity of the test area to a discontinuity, the state of stress of the concrete, and the temperature of both the concrete and the hardness tester. Provided that points of impact are at least 25 mm from any edge or sharp discontinuity and extreme conditions are avoided, these effects are likely to be small in normal practical situations. Normal sizes and covers of reinforcing steel in concrete are unlikely to have a significant effect on hammer readings when measured as described in this International Standard.

Different rebound hammers of the same nominal design may give different rebound numbers and all tests should be made with the same device if results are to be compared. If the use of more than one rebound hammer is unavoidable, a sufficient number of tests should be made on typical concrete surfaces with all of the hammers to determine the magnitude of the differences to be expected between them. Rebound numbers obtained by using any rebound hammer should be converted to strength values using only the correlation experimentally established for that device.

Annex C
(informative)

Example of a test report of the rebound number of hardened concrete

Client

Test organization

Accreditation test report ref.

Test location

Identification of rebound hammer:

Concrete/structure
Identification:
Location of test areas:
Details of preparation of test areas:
Details of the concrete and its condition:

Test preliminaries
Number of times hammer activated before taking readings:
Initial reference anvil readings:
Date and time of test:

Test results

Test area	Hammer orientation	Rebound number median & individual rebound hammer readings (if required)	Adjusted rebound number (if appropriate)

Reference check
Final anvil reference readings:

Any deviations from ISO 1920-7:
Except as detailed above, the specimens were tested in accordance with ISO 1920-7.

Technical responsibility
Responsible person: Name: Position:
Signature:

Test report identification
Test report No: Date issued:

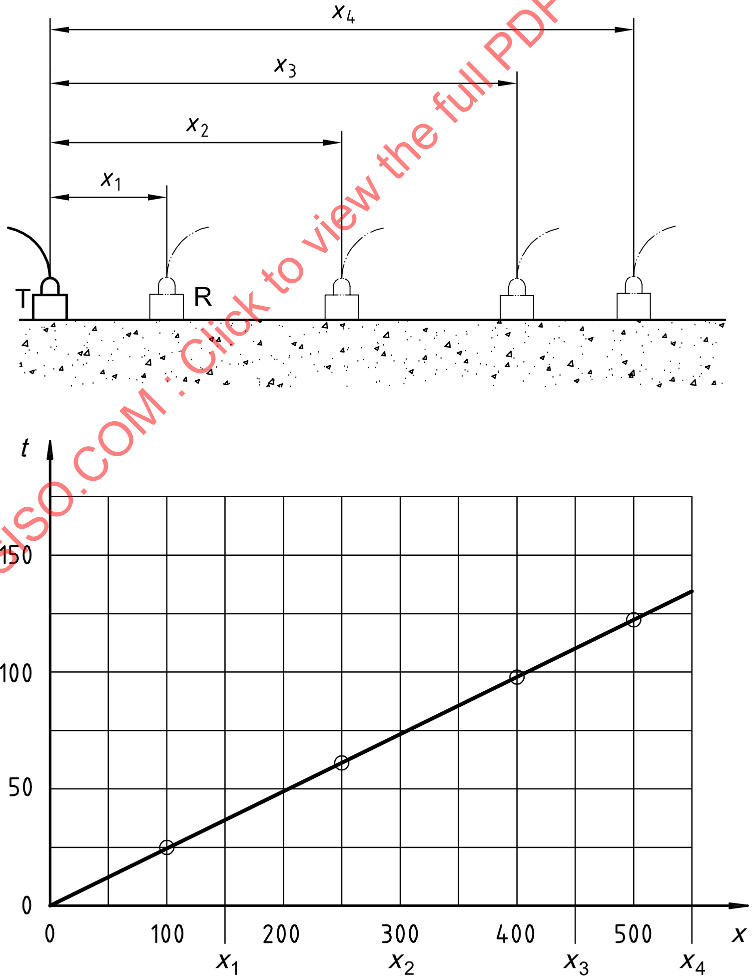
Annex D
(normative)

Determination of pulse velocity — Indirect transmission

D.1 With indirect transmission, there is some uncertainty regarding the exact length of the transmission path because of the significant size of the areas of contact between the transducers and the concrete. It is therefore preferable to make a series of measurements with the transducers at different distances apart to eliminate this uncertainty.

D.2 To do this, the transmitting transducer shall be placed in contact with the concrete surface at a fixed point x and the receiving transducer shall be placed at fixed increments x_n along a chosen line on the surface. The transmission times recorded should be plotted as points on a graph showing their relation to the distance separating the transducers. An example of such a plot is shown in Figure D.1.

D.3 The slope of the best straight line drawn through the points (tan ϕ) shall be measured and recorded as the mean pulse velocity along the chosen line on the concrete surface. Where the points measured and recorded in this way indicate a discontinuity, it is likely that a surface crack or surface layer of inferior quality is present and a velocity measured in such an instance is unreliable.



Key

x is the distance, in millimetres

t is the transit time, in microseconds

T is the transmitter

R is the receiver

NOTE Results from homogeneous concrete (see D.2).

Figure D.1 — Pulse velocity determination by indirect (surface) transmission

Annex E
(informative)

Factors influencing pulse velocity measurements

E.1 General

In order to provide a measurement of pulse velocity that is repeatable and which depends essentially on the properties of the concrete under test, it is necessary to take account of the various factors that influence pulse velocity and its correlation with various physical properties of the concrete.

E.2 Contact between transducer and concrete

Poor contact will affect the reading. It is essential to use grease to improve the contact between the transducer and the concrete, according to the manufacturer's recommendation.

E.3 Moisture content

The moisture content has two effects on the pulse velocity, one chemical, the other physical. These effects are important in the production of correlations for the estimation of concrete strength. Between a properly cured standard cubical or cylindrical specimen and a structural element made from the same concrete, there may be a significant pulse velocity difference. Much of the difference is accounted for by the effect of different curing conditions on the hydration of the cement, while some of the difference is due to the presence of free water in the voids. It is important that these effects be carefully considered when estimating strength.

E.4 Temperature of the concrete

Variations of the concrete temperature between 10 °C and 30 °C have been found to cause no significant change without the occurrence of corresponding changes in strength or elastic properties. The corrections to pulse velocity measurements given in Table E.1 should be made for temperatures outside this range.

Table E.1 — Effect of temperature on pulse transmission

Temperature °C	Correction to the measured pulse velocity Air-dried concrete %	 Water-saturated concrete %
60	+ 5	+ 4
40	+ 2	+ 1,7
10 to 30	0	0
0	− 0,5	− 1
− 4	− 1,5	− 7,5

E.5 Path length

The path length over which the pulse velocity is measured should be long enough not to be significantly influenced by the heterogeneous nature of the concrete. It is recommended that, except for the conditions stated in 4.2, the minimum path length should be 100 mm for concrete in which the nominal maximum size of aggregate is 20 mm or less and 150 mm for concrete in which the nominal maximum size of aggregate is between 20 mm and 40 mm. The pulse velocity is not generally influenced by changes in path length, although the electronic timing apparatus may indicate a tendency for velocity to reduce slightly with increasing path length. This is because the higher frequency components of the pulse are attenuated more than the lower frequency components, and the shape of the onset of the pulse becomes more rounded with increased distance travelled. Thus, the apparent reduction in pulse velocity arises from the difficulty of defining exactly the onset of the pulse and this depends on the particular method used for its definition. This apparent reduction in velocity is usually small and well within the tolerance of time measurement accuracy given in 4.2, but particular care needs to be taken when transmitting over long path lengths.

E.6 Shape and size of specimen

The velocity of short pulses of vibrations is independent of the size and shape of the specimen in which they travel, unless its least lateral dimension is less than a certain minimum value. Below this value, the pulse velocity may be reduced appreciably. The extent of this reduction depends mainly on the ratio of the wave length of the pulse vibrations to the least lateral dimension of the specimen but is insignificant if the ratio is less than unity. Table E.2 gives the relationship between the pulse velocity in the concrete, the transducer frequency and the minimum permissible lateral dimension of the specimen.

If the minimum lateral dimension is less than the wavelength or if the indirect transmission arrangement is used, the mode of propagation changes and, therefore, the measured velocity will be different. This is particularly important in cases where concrete elements of significantly different sizes are being compared.

Table E.2 — Minimum specimen dimensions

Transducer frequency	**Pulse velocity in concrete**		
	3,50 km/s	4,00 km/s	4,50 km/s
kHz	**Minimum permissible lateral specimen dimension**, in mm		
24	146	167	188
54	65	74	83
82	43	49	55
150	23	27	30

E.7 Effect of reinforcing bars

When possible, measurements in close proximity to steel reinforcing bars, parallel to the direction of pulse propagation, should be avoided.

E.8 Cracks and voids

When an ultrasonic pulse travelling through concrete meets a concrete-air interface, there is negligible transmission of energy across this interface. Thus, any air-filled crack or void lying immediately between two transducers will obstruct the direct ultrasonic beam when the projected length of the void is greater than the width of the transducers and the wavelength of sound used. When this happens, the first pulse to arrive at the receiving transducer will have been diffracted around the periphery of the defect and the transit time will be longer than in similar concrete with no defect.

It is possible to make use of this effect for locating flaws, voids or other defects greater than about 100 mm in diameter or depth. Relatively small defects have little or no effect on transmission times, but equally are probably of minor engineering importance. Plotting contours of equal velocity often gives significant information regarding the quality of a concrete unit.

In cracked members, where the broken faces of the members are held tightly together in close contact by compression forces, the pulse energy may pass unimpeded across the crack. As an example, this may occur in cracked vertical bearing piles. If the crack is filled with liquid which transmits the ultrasonic energy (e.g. in marine structures), the crack is undetectable using digital reading equipment. Measurements of attenuation may give valuable information in these cases.

A grid should be drawn on the concrete member with its points of intersection spaced to correspond to the size of void that would significantly affect its performance. A large survey of measurements at the grid points enables a large cavity to be investigated by measuring the transit times of pulses passing between the transducers when they are placed so that the cavity lies in the direct path between them.

The size of such cavities may be estimated by assuming that the pulses pass along the shortest path between the transducers and around the cavity. Such estimates are valid only when the concrete around the cavity is uniformly dense and the pulse velocity can be measured in that concrete.

Annex F
(informative)

Correlation of pulse velocity and strength

F.1 General

The important physical properties of materials that influence pulse velocity are the elastic modulus and the density. In concrete, these properties are related to the type of aggregate, its proportion (in the mix) and its physical properties and the physical properties of the cement paste, which relate, mainly, to the original water/cement ratio (of the mix) and the maturity of the concrete. On the other hand, the strength of concrete is more related to the water/cement ratio than to aggregate type and the proportions of aggregate and paste. Thus correlations between the pulse velocity and strength of concrete are physically indirect and have to be established for the specific concrete mix. For an unknown concrete, the estimation of strength on the basis of pulse velocity alone is not reliable.

F.2 Correlation using moulded specimens

The method used for varying the strength of the specimens influences the correlation. It is therefore essential that only one method of strength variation be used for a particular correlation and that it be appropriate to the application required. The correlation of pulse velocity with strength is less reliable as the strength of concrete increases. A correlation obtained by varying the age of the concrete is appropriate when monitoring strength development, but for quality control purposes a correlation obtained by varying the water/cement ratio is preferable.

The appropriate test specimens should be in accordance with the requirements described in ISO 1920-3. At least three specimens should be cast from each batch. The pulse velocity should be measured across a specimen between moulded faces. In the case of beams, it is preferable to measure the pulse velocity along their length to obtain greater accuracy. For each specimen there should be at least three measurements spaced between its top and bottom. The variation between the measured transit times on single test specimens should be within ± 1 % of the mean value of these three measurements, otherwise the specimen should be rejected as abnormal. The specimens should then be tested for strength according to the methods described in ISO 1920-4.

The mean pulse velocity and mean strength obtained from each set of three nominally identical test specimens provide the data to construct a correlation curve. A correlation curve produced in this way relates only to specimens produced, cured and tested in a similar way; different correlation curves will be obtained for the same mixes if air curing is substituted for water curing.

F.3 Correlation by tests on cores

When making a correlation from tests on cores, it will not generally be possible to vary the strength of the concrete deliberately. Pulse velocity tests should, therefore, be used to locate areas of different quality and cores taken from these areas will give a range of strengths. The pulse velocity through the concrete at proposed core locations should be used for preparing the correlation. Pulse velocities taken from cores after cutting and soaking will generally be higher than those in the structure and should not be used for direct correlation.

The cores should be cut and tested for strength in accordance with the method described in ISO 1920-6.

The shape of the correlation is sensibly the same for any given concrete notwithstanding the curing conditions. It is therefore possible to use the curve derived from reference specimens to extrapolate from the limited range that will normally be obtained from core samples.

F.4 Correlation with the strength of precast units

When precast components are required to conform to strength requirements, it may be possible to establish correlations between the pulse velocity measurements and the particular types of strength tests. This should be done by making pulse velocity measurements on the components in the appropriate regions where the concrete would be expected to fail under the test loading conditions.

For conformity purposes, a safe relationship between the UPV reading and strength should be used (e.g. the 90 % confidence limit).

The procedure for obtaining a graphical correlation in such cases should be as described in F.2