IS 13311 (Part 1) : 1992

(Reaffirmed 1999)

भारतीय मानक

कंकरीट का अविनाशी परीक्षण – परीक्षण पद्धतियां

भाग 1 पराश्रव्यी स्पन्द वेग

Indian Standard

NON-DESTRUCTIVE TESTING OF CONCRETE – METHODS OF TEST

PART 1 ULTRASONIC PULSE VELOCITY

First Reprint SEPTEMBER 1996

UDC 666·972·620·179·16

BUREAU OF INDIAN STANDARDS

MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG

NEW DELHI 110002

January 1992 **Price Group 4**

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

There are occasions when the various performance characteristics of concrete in a structure are required to be assessed. In most of the cases, an estimate of strength of concrete in the structure is needed, although parameters like overall quality, uniformity, etc, also become important in others. The various methods that can be adopted for *in-situ* assessment of strength properties of concrete depend upon the particular aspect of the strength in question. For example, if the load-carrying capacity of a structural ensemble is to be assessed, carrying out a full-scale load test as per IS 456 : 1978 'Code of practice for plain and reinforced concrete (*third revision*)' or IS 1343 : 1980 'Code of practice for prestressed concrete (*first revision*)' is the most direct way; on the other hand when the actual compressive strength of concrete in the structure is to be measured, core testing as per IS 516 : 1959 'Method of test for strength of concrete' is more reliable. However, both these methods are relatively cumbersome and the latter method may leave the structure damaged locally in some cases. Use is, therefore, made of suitable non-destructive tests, which not only provide an estimate of the relative strength and overall quality of concrete in the structure but also help in deciding whether more rigorous tests like load testing or core drilling at selected locations are required.

There are various such non-destructive testing methods which can be broadly classified as those which measure the overall quality of concrete, for example dynamic or vibration methods like resonance frequency and ultrasonic pulse velocity tests and those which involve measurement of parameters like surface hardness, rebound, penetration, pull-out strength, etc, and are believed to be indirectly related to the compressive strength of concrete. In addition, radiographic, radiometric, nuclear, magnetic and electrical methods are also available. Since such non-destructive tests are at best indirect methods of monitoring the particulars, characteristic of concrete and the measurements are influenced by materials, mix and environmental factors, proper interpretation of the results calls for certain degree of expertise. It is more so, when the data on the materials and mix proportions used in the construction are not available, as is often the case.

In view of the limitations of the methods for predicting the strength of concrete in the structure it is preferable that both ultrasonic pulse velocity and rebound hammer methods given in Part 2 of the standard are used in combination to alleviate the errors arising out of influence of material, mix and environmental parameters on the respective measurements. Relationships between pulse velocity, rebound number and compressive strength of concrete are obtained by multiple regression of the measured values on laboratory test specimens. However, this approach has the limitation that the correlations are valid only for the materials and mix proportions used in trials. The intrinsic difference between the laboratory test specimens and *in-situ* concrete, for example, surface texture, moisture condition, presence of reinforcement, etc, also affect the accuracy of results. The correlation is valid only within the range of values of pulse velocity rebound number and compressive strength employed and any extrapolation beyond these is open to question.

Because of the above limitations, the combined use of these two methods is made in another way. In this, if the quality of concrete is assessed to be 'excellent or good' by pulse velocity method, only then the compressive strength is assessed from the rebound manner indices and this is taken as indicative of strength of concrete in the entire cross-section of the concrete member. When the quality assessed is 'medium', the estimation of compressive strength by rebound indices is extended to the entire mass only on the basis of other colateral measurements, for example, strength of site concrete cubes, cement content in the concrete or core testing. When the quality of concrete is doubtful, no assessment of concrete strength is made from rebound indices.

(*Continued on third Cover*)

Indian Standard

NON-DESTRUCTIVE TESTING OF CONCRETE — METHODS OF TEST

PART 1 ULTRASONIC PULSE VELOCITY

1 SCOPE

1.1 This standard covers the object, principle, apparatus and test procedure of ultrasonic pulse velocity test method. In addition, influence of test conditions and some general guidance on the interpretation of test results are also given.

NOTE — In view of the limitations of each method of non-destructive testing of concrete, it is essential that the results of tests obtained by one method should be complimented by other tests and each method should be adopted very carefully.

2 OBJECT

2.1 The ultrasonic pulse velocity method could be used to establish:

a) the homogeneity of the concrete,

b) the presence of cracks, voids and other imperfections,

c) changes in the structure of the concrete which may occur with time,

d) the quality of the concrete in relation to standard requirements,

e) the quality of one element of concrete in relation to another, and

f) the values of dynamic elastic modulus of the concrete.

3 PRINCIPLE

3.1 The ultrasonic pulse is generated by an electroacoustical transducer. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (compressional), shear (transverse) and surface (rayleigh) waves. The receiving transducer detects the onset of the longitudinal waves, which is the fastest.

Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic properties, pulse velocity method is a convenient technique for investigating structural concrete.

The underlying principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete. Density and modulus of elasticity of aggregate also significantly affect the pulse velocity.

4 APPARATUS

4.1 The apparatus for ultrasonic pulse velocity measurement shall consist of the following:

a) Electrical pulse generator,

b) Transducer — one pair,

c) Amplifier, and

d) Electronic timing device.

4.1.1 *Transducer*

Any suitable type of transducer operating within the frequency range of 20 kHz to 150 kHz (*see* Table 1) may be used. Piezoelectric and magneto-strictive types of transducers may be used, the latter being more suitable for the lower part of the frequency range.

Table 1 Natural Frequency of Transducers for Different Path Lengths

Path Length (mm)	Natural Frequency of Transducer (kHz)	Minimum Transverse Dimensions of Members (mm)
Up to 500	150	25
500-700	> 60	70
700-1 500	> 40	150
above 1 500	> 20	300

4.1.2 *Electronic Timing Device*

It shall be capable of 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 possible, one of which uses a cathode ray tube on which the leading edge of the pulse is displayed in relation to the suitable time scale, the other uses an interval timer with a direct reading digital display. If both the forms of timing apparatus are available, the interpretation of results becomes more reliable.

4.2 Performance of the Assembly of Apparatus

The apparatus should be capable of measuring transit times to an accuracy of $\pm$ 1 percent over a range of 20 microseconds to 10 milliseconds. For this, it is necessary to check the overall performance by making measurements on two standard reference specimens in which the pulse transit times are known accurately. The two reference specimens (usually steel bars) should have pulse transit times of about 25 microseconds to 100 microseconds respectively; these times being specified by the supplier of the equipment to an accuracy of $\pm$0·2 microsecond. The shorter of the reference specimens should be used to set the zero for the apparatus and the longer one should be used to check the accuracy of transit time measurement of the apparatus. The measurement obtained should not differ from the known value for the reference specimen by more than $\pm$0·5 percent.

4.2.1 The electronic excitation pulse applied to the transmitting transducer should have a rise time of not greater than one quarter of its natural period. This is to ensure a sharp pulse onset.

4.2.2 The interval between pulses should be low enough to ensure that the onset of the received signal in small concrete test specimens is free from interference by reverberations produced within the preceding working cycle.

4.2.3 The apparatus should maintain its performance over the range of ambient temperature, humidity and power supply voltage stated by the supplier.

5 PROCEDURE

5.1 In this test method, the ultrasonic pulse is produced by the transducer which is held in contact with one surface of the concrete member under test. After traversing a known path length (L) in the concrete, the pulse of vibrations is converted into an electrical signal by the second transducer held in contact with the other surface of the concrete member and an electronic timing circuit enables the transit time (T) of the pulse to be measured. The pulse velocity (V) is given by:

$$V = L/T$$

Once the ultrasonic pulse impinges on the surface of the material, the maximum energy is propagated at right angles to the face of the transmitting transducer and best results are, therefore, obtained when the receiving transducer is placed on the opposite face of the concrete member (direct transmission or cross probing). However, in many situations two opposite faces of the structural member may not be accessible for measurements. In such cases, the receiving transducer is also placed on the same face of the concrete members (surface probing). Surface probing is not so efficient as cross probing, because the signal produced at the receiving transducer has an amplitude of only 2 to 3 percent of that produced by cross probing and the test results are greatly influenced by the surface layers of concrete which may have different properties from that of concrete inside the structural member. The indirect velocity is invariably lower than the direct velocity on the same concrete element. This difference may vary from 5 to 20 percent depending largely on the quality of the concrete under test. For good quality concrete, a difference of about 0·5 km/sec may generally be encountered.

To ensure that the ultrasonic pulses generated at the transmitting transducer pass into the concrete and are then detected by the receiving transducer, it is essential that there be adequate acoustical coupling between the concrete and the face of each transducer. Typical couplants are petroleum jelly, grease, liquid soap and kaolin glycerol paste. If there is very rough concrete surface, it is required to smoothen and level an area of the surface where the transducer is to be placed. If it is necessary to work on concrete surfaces formed by other means, for example trowelling, it is desirable to measure pulse velocity over a longer path length than would normally be used. A minimum path length of 150 mm is recommended for the direct transmission method involving one unmoulded surface and a minimum of 400 mm for the surface probing method along an unmoulded surface.

5.2 The natural frequency of transducers should preferably be within the range of 20 to 150 kHz (*see* Table 1). Generally, high frequency transducers are preferable for short path lengths and low frequency transducers for long path lengths. Transducers with a frequency of 50 to 60 kHz are useful for most all-round applications.

5.3 Since size of aggregates influences the pulse velocity measurement, it is recommended that 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 to 40 mm.

5.4 In view of the inherent variability in the test results, sufficient number of readings are taken by dividing the entire structure in suitable grid markings of 30×30 cm or even smaller. Each junction point of the grid becomes a point of observation.

Transducers are held on corresponding points of observation on opposite faces of a structural element to measure the ultrasonic pulse velocity by direct transmission, i.e., cross probing. If one of the faces is not accessible, ultrasonic pulse velocity is measured on one face of the structural member by surface probing.

5.4.1 Surface probing in general gives lower pulse velocity than in case of cross probing and depending on number of parameters, the difference could be of the order of about 1 km/sec.

6 INFLUENCE OF TEST CONDITIONS

6.1 Influence of Surface Conditions and Moisture Content of Concrete

Smoothness of contact surface under test affects the measurement of ultrasonic pulse velocity. For most concrete surfaces, the finish is usually sufficiently smooth to ensure good acoustical contact by the use of a coupling medium and by pressing the transducer against the concrete surface. When the concrete surface is rough and uneven, it is necessary to smoothen the surface to make the pulse velocity measurement possible.

In general, pulse velocity through concrete increases with increased moisture content of concrete. This influence is more for low strength concrete than high strength concrete. The pulse velocity of saturated concrete may be up to 2 percent higher than that of similar dry concrete. In general, drying of concrete may result in somewhat lower pulse velocity.

6.2 Influence of Path Length, Shape and Size of the Concrete Member

As concrete is inherently heterogeneous, it is essential that path lengths be sufficiently long so as to avoid any error introduced due to its heterogeneity. In field work, this does not pose any difficulty as the pulse velocity measurements are carried out on thick structural concrete members. However, in the laboratory where generally small specimens are used, the path length can affect the pulse velocity readings.

The shape and size of the concrete member do not influence the pulse velocity unless the least lateral dimension is less than a certain minimum value, for example the minimum lateral dimension of about 80 mm for 50 kHz natural frequency of the transducer. Table 1 gives the guidance on the choice of the transducer natural frequency for different path lengths and minimum transverse dimensions of the concrete members.

6.3 Influence of Temperature of Concrete

Variations of the concrete temperature between 5 and 30°C do not significantly affect the pulse velocity measurements in concrete. At temperatures between 30 to 60°C, there can be reduction in pulse velocity up to 5 percent. Below freezing temperature, the free water freezes within concrete, resulting in an increase in pulse velocity up to 7·5 percent.

6.4 Influence of Stress

When concrete is subjected to a stress which is abnormally high for the quality of the concrete, the pulse velocity may be reduced due to the development of micro-cracks. This influence is likely to be the greatest when the pulse path is normal to the predominent direction of the planes of such micro-cracks. This occurs when the pulse path is perpendicular to the direction of a uniaxial compressive stress in a member.

This influence is generally insignificant unless the stress is greater than about 60 percent of the ultimate strength of the concrete.

6.5 Effect of Reinforcing Bars

The pulse velocity measured in reinforced concrete in the vicinity of reinforcing bars is usually higher than in plain concrete of the same composition. This is because, the pulse velocity in steel is 1·2 to 1·9 times the velocity in plain concrete and, under certain conditions, the first pulse to arrive at the receiving transducer travels partly in concrete and partly in steel.

The apparent increase in pulse velocity depends upon the proximity of the measurements to the reinforcing bar, the diameter and number of the bars and their orientation with respect to the path of propagation.

7 INTERPRETATION OF RESULTS

7.1 The ultrasonic pulse velocity of concrete is mainly related to its density and modulus of elasticity. This in turn, depends upon the materials and mix proportions used in making concrete as well as the method of placing, compaction and curing of concrete.

For example, if the concrete is not compacted as thoroughly as possible, or if there is segregation of concrete during placing or there are internal cracks or flaws, the pulse velocity will be lower, although the same materials and mix proportions are used.

7.1.1 The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc, indicative of the level of workmanship employed, can thus be assessed using the guidelines given in Table 2, which have been evolved for characterising the quality of concrete in structures in terms of the ultrasonic pulse velocity.

Table 2 Velocity Criterion for Concrete Quality Grading

Sl No.	Pulse Velocity by Cross Probing (km/sec)	Concrete Quality Grading
1.	Above 4·5	Excellent
2.	3·5 to 4·5	Good
3.	3·0 to 3·5	Medium
4.	Below 3·0	Doubtful

NOTE — In case of "doubtful" quality it may be necessary to carry out further tests.

7.2 Since actual values of the pulse velocity obtained, depend on a number of parameters, any criterion for assessing the quality of concrete on the basis of pulse velocity as given in Table 2 can be held as satisfactory only to a general extent. However, when the comparison is made amongst different parts of a structure, which have been built at the same time with supposedly similar materials, construction practices and supervision, the assessment of quality becomes more meaningful and reliable.

7.3 The assessment of compressive strength of concrete from ultrasonic pulse velocity values is not adequate because the statistical confidence of the correlation between ultrasonic pulse velocity and the compressive strength of concrete is not very high. The reason is that a large number of parameters are involved, which influence the pulse velocity and compressive strength of concrete to different extents. However, if actual concrete materials and mix proportions adopted in a particular structure are available, then estimate of concrete strength can be made by establishing suitable correlation between the pulse velocity and the compressive strength of concrete specimens made with such materials and mix proportions, under environmental conditions similar to that in the structure. The estimated strength may vary from the actual strength by $\pm$ 20 percent. The correlation so obtained may not be applicable for concrete of another grade or made with different types of materials.

7.4 The dynamic Young's modulus of elasticity (E) of the concrete may be determined from the pulse velocity and the dynamic Poisson's ratio (μ), using the following relationship:

$$E = \frac{\rho\ (1+\mu)\ (1-2\mu)}{1-\mu} V^2$$

where

E = dynamic Young's Modulus of elasticity in MPa

ρ = density in kg/m^3, and

V = pulse velocity in m/second.

The above relationship may be expressed as:

$$E = \rho f\ (\mu)\ V^2$$

where

$$f(\mu) = \frac{(1+\mu)\ (1-2\mu)}{1-\mu}$$

The value of the dynamic Poisson's ratio varies from 0·20 to 0·35, with 0·24 as average. However, it is desirable to have an independent measure of it for the particular type of concrete under test. The dynamic Poisson's ratio may be obtained from measurements on concrete test-beams of the pulse velocity (V) alongwith length (l) of the beam and the fundamental resonant frequency (n) of the beam in longitudinal mode of vibration. From these measurements, the factor $f(\mu)$ is calculated by the relation:

$$f(\mu) = \frac{(2nl)^2}{V^2}$$

where

n = fundamental resonant frequency in cycles per second, and

l = length of specimen in m.

ANNEX A

(*Foreword*)

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(*Continued from second Cover*)

In most of the situations, the records of the original materials or mix proportions used in the structure are not available. Therefore, considerable improvisation has to be done in evolving the testing scheme and use is made of comparative measurements made on adjoining portions of the structure or even other structures in the vicinity of the one in question. In doing so, an approach is taken that if the same materials and similar mix proportions and level of workmanship were employed for the two situations, any significant difference in the ultrasonic pulse velocity or rebound indices between them must be due to some inherent differences in the overall quality. If the nominal grades of concrete or mix proportions are known to be different in either case, suitable allowance is made for the same in interpretation of results.

The test results on ultrasonic pulse velocity and rebound indices are analysed statistically and plotted as histograms and the lower fractiles of results are taken for assessing the quality or 'characteristic' strength of concrete, in line with the current limit state concepts of design.

The composition of the technical committee responsible for the formulation of this standard is given in Annex A.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Review of Indian Standards

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This Indian Standard has been developed from Doc: No. **CED 2 (3889)**

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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Printed at Dee Kay Printers, New Delhi-110015, India.