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Nondestructive Evaluation of Concrete Structures

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Abstract- Non-Destructive testing is unique approach to check the soundness and feasibility of the structure. It is a type of testing which is carried out to the different members of the structure with-out causing any damage to the structure, NDT is effectively used to assess the structural feasibility and it has been proved best for RC structures. Nondestructive testing is normally used to evaluate the strength of the structure. Aging and defects in the concrete structures leads to failure of the RC members. Deterioration observed in concrete structures has clearly highlighted the need for periodic inspection and maintenance. Normally NDT is carried out in two types: surface testing techniques and through testing techniques. Also the concrete evaluation is necessary for the proper diagnosis of successful rehabilitation work. The paper present case study includes the use of various Non Destructive Tests (NDT), to evaluate the concrete quality of components of a RC structure.

Keywords Non destructive testing and evaluation (NDT&E), RC Structures, Non destructive tests

1.**Introduction**

It is sometime necessary to test concrete structures after the concrete has hardened to determine whether the structure is feasible enough to with stand its designed load. Ideally such testing should be done without damaging the concrete structures. Non- Destructive Testing is a form of testing to be carried out on various Building and RC members without causing any damage to the structure. Concrete is a complex material and has been used in construction industry for its compressive strength and NDT is a one of the technique to assess its behavior. This paper covers evaluation of NDT on RC structural members. NDT application to concrete can be broadly divided into two methods i.e. surface testing and through testing

A. Surface Testing Technique:

In this technique generally Schmidt Rebound Hammer, Windsor Probe test, Half Cell Electrical Potential Method, Carbonation Depth Measurement Test, Permeability Test, Carbonation Depth Measurement Test. These tests are practically used to determine the compressive strength, corrosion, carbonation depth, durability of concrete. NDT can measure the compressive strength of in situ concrete directly but all the tests measure some other property of concrete like surface hardness, toughness, penetration resistance etc. and the compressive strength is deduced based on empirical formulae. In this paper apart from other properties we evaluate majorly compressive strength with the help of Schmidt Rebound Hammer.

B. Through Testing Technique:

In this technique generally including Ultrasonic Pulse Velocity, Impact Echo, Electromagnetic methods, Infrared Thermo graphic methods, Ground Penetrating Radar, Radiographic Testing, GPR technique. All these techniques have a common theory of passing some form of waves, either high frequency sound or electromagnetic or mechanical or light etc., through the body of concrete to assess the quality of the same. Non-destructive testing can be applied to both old and new structures. For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. In present case, a study on Ultrasonic pulse velocity is carried out to find uniformity of concrete, modulus of elasticity and dynamic Poisson's ratio of the concrete.

The correlation between pulse velocity and strength as a measure of concrete quality.

Situations where NDT may be useful

The following are the situations where NDT technique can be adopted.

- To know the quality of concrete in precast or cast in-situ structural members
- To check the workmanship involved in batching, mixing, placing, compacting and curing of concrete
- To check the strength of existing structure
- To know the quantity and position of reinforcement in structural members
- To check the long term changes in the concrete properties

To check the durability of the concrete

2. METHODOLOGY

2.1 SCHMIDT REBOUND HAMMER TEST

Rebound hammer is the oldest technique used to assess the compressive strength of concrete indirectly and also to compare the various parts of structure. Schmidt rebound hammer is the instrument for this test. Schmidt rebound hammer shown in Fig1 is a simple, handy tool, which can be used to provide a convenient and rapid indication of the compressive strength of concrete. It consists of a spring controlled mass that slides on a plunger within a tubular housing. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against

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Fig 1. Rebound hammer

which the mass impinges. The correlation of compressive strength of concrete and rebound hammer numbers./indices can be obtained by calibration charts.

2.1.1 Calibration of Rebound hammer

Calibration chart can be obtained by conducting rebound hammer test on concrete cubes of different grades or different mix proportions and the compressive strength of cubes can be determined by testing the in Compression testing machine. The calibration chart obtained is used to know the compressive strength or grade of concrete with respect to rebound hammer number.

Calibration graph is obtained as shown below:

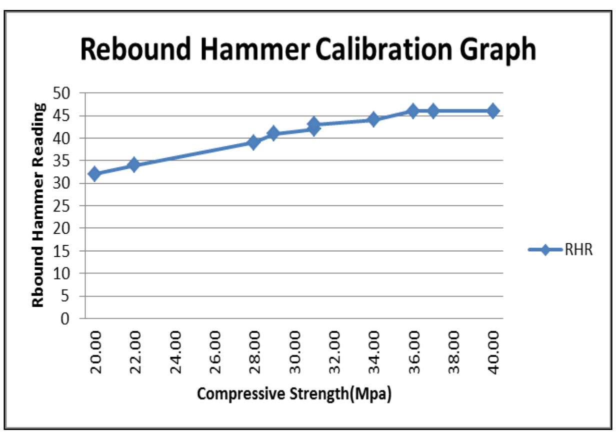

Fig2: Correlation between compressive strength of concrete and rebound hammer number

2.2 ULTRASONIC PULSE VELOCITY (UPV) TEST

The method consists of measuring velocity of a pulse through concrete with transducer and receiver. A pulse of longitudinal vibrations is produced by an electro-acoustical transducer, which is held in contact with one surface of the concrete under test. When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves develops, which include both longitudinal and shear waves, and propagates through the concrete. The first waves to reach the receiving transducer are the longitudinal waves, which are converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time T of the pulse to be measured. Longitudinal pulse velocity (in km/s or m/s) is given by:

$$V = L/T \qquad (1)$$

where,

V is the longitudinal pulse velocity,

L is the path length,

T is the time taken by the pulse to traverse that length.

Fig 3. Ultrasonic pulse velocity testing instrument

2.2.1 Calibration chart for UPV test

The calibration chart between compressive strength of concrete and ultrasonic pulse velocity can be obtained by testing the concrete cubes different grades by ultrasonic pulse velocity testing machine and compressive testing machine. The calibration chart is as shown below. The calibration chart obtained is used to know the compressive strength or grade of concrete with respect to Ultra sonic pulse velocity readings.

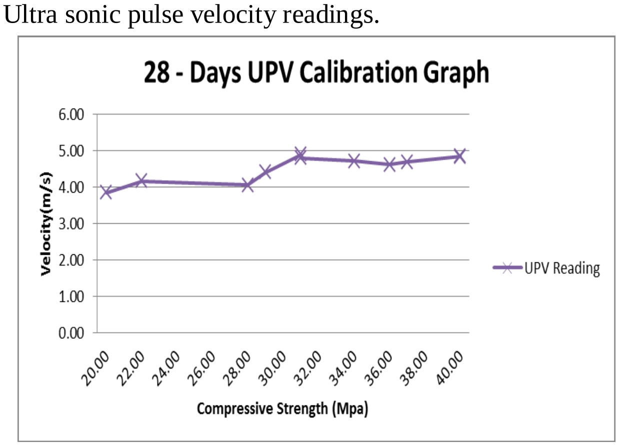

Fig.4 the calibration chart for compressive strength and ultrasonic pulse velocity

2.2.2 Applications:

- Determination of the uniformity of concrete in and between members
- Measurement of changes occurring with time in the properties of concrete
- Correlation of pulse velocity and strength as a measure

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of concrete quality.

- Determination of the modulus of elasticity and dynamic Poisson's ratio of the concrete.

2.2.3 Determination of pulse velocity:

Transducer arrangement ï

- Opposite faces (direct transmission)
- Adjacent faces (semi-direct transmission) or
- On the same face (indirect or surface transmission).

These three arrangements are shown in Figs. 5(A), 5(B) and 5(C).

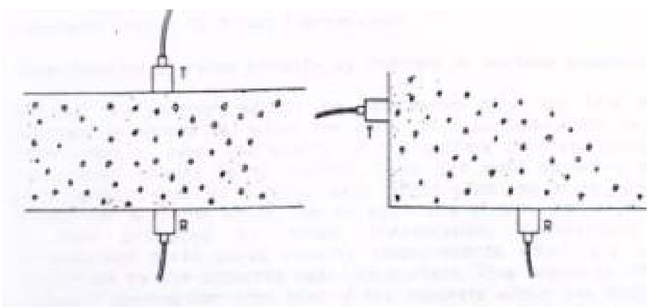


Fig.5 (A): Direct transmission.(opposite faces)
Fig. 5(B): Semi-direct transmission.(adjacent faces)

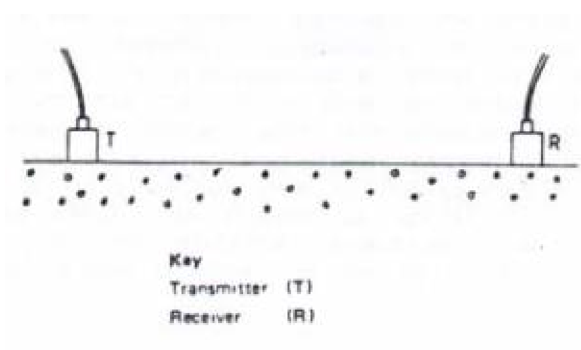


Fig.5(C): Indirect or surface transmission

A. Determination of pulse velocity by direct transmission:

In the direct transmission, the transfer of energy between transducers is at its maximum and the accuracy of velocity determination is therefore governed principally by the accuracy of the path length measurement. The couplant used should be spread as thinly as possible to avoid any end effects resulting from the different velocities in couplant and concrete.

Determination of pulse velocity by semi direct transmission:

It has a sensitivity intermediate between those of the other two arrangements. Although there may be some reduction in the accuracy of measurement of the path length, it is generally found to be sufficiently accurate to take this as the distance measured from centre to centre of the transducer faces.

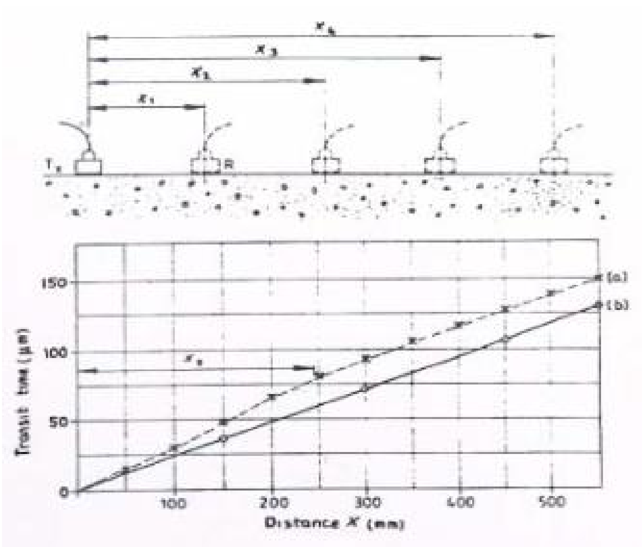
Determination of pulse velocity by indirect or surface transmission:

Indirect transmission should be used when only one face of the concrete is accessible, when the depth of a surface crack is to be determined or when the quality of the surface concrete relative to the overall quality is of interest. It is the least sensitive of the arrangements and, for a given path length, produces at the receiving transducer a signal which has an amplitude of only about 2% or 3% of that produced by direct transmission. The indirect velocity is invariably lower than the direct velocity on the same concrete element. 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. To do this, the transmitting transducer should be placed in contact with the concrete surface at a fixed point x and the receiving transducer should be placed at fixed increments xn 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 as line (b).The slope of the best straight line drawn through the points should 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.

2.2.4 Coupling the transducer onto the concrete

To ensure that the ultrasonic pulses generated at the transmitting transducers pass into the concrete and are then detected by the receiving transducer, it is essential that there is adequate acoustical coupling between the concrete and the face of each transducer. For many concrete surfaces, the finish is sufficiently smooth to ensure good acoustical contact by the use of a coupling medium and by pressing the transducer against the concrete surface. Typical couplings are petroleum jelly, grease, soft soap and kaolin/glycerol paste. If it is necessary to work on such a surface, measurements should be made over a longer path length than would normally be used. A minimum path length of 150 mm is recommended for direct transmission involving one unmolded surface and a minimum of 400 mm for indirect transmission along one unmolded surface. When the concrete surface is very rough and uneven, the area of the surface where the transducer is to be applied should be smoothed and leveled. Alternately, a smoothing medium such as quick setting epoxy resin or plaster may be used, but good adhesion between the concrete surface and the smoothing medium has to be ensured so that the pulse propagates correctly into the concrete under test.



a) Results for concrete with the top 50 mm of inferior quality
(b) Results for homogeneous concrete.
Fig.6 Pulse velocity determination by indirect (surface) transmission.

2.2.5 Factors influencing pulse velocity measurements:

- Moisture content
- Temperature of the concrete
- Path length
- Effect of reinforcing bars
- Determination of concrete uniformity
- Shape and size of specimen

2.2.6 Detection of Effects

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 void lying immediately between 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 void and the transit time will be longer than in similar concrete with no void. 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.

The method is not very successful when applied to structures with cracks because the cracked faces are usually sufficiently in contact with each other to allow the pulse energy to pass unimpeded across the crack.

A.**Estimating the thickness of a layer of inferior quality concrete.**

If concrete is suspected of having a surface layer of poor quality because of poor manufacture, or damage by fire, frost or sulphate attack, the thickness of the layer can be estimated from ultrasonic measurements of transit times along the surface. The technique used is to place the transmitting transducer on the surface and the receiving transducer a distance ñx1ò from the transmitting transducer. The transit time is measured and then measured again at distances of ñx2ò, ñx3ò, etc. The transit times are plotted against distance as in Fig.6 in which x is 50 mm. At the shorter distance of separation of the pulse travels through the surface layer and the slope of the experimental line gives the pulse velocity in this surface layer.

The distance xo at which the change of slope occurs together with the measured pulse velocities in the two different layers of concrete, enables an estimate of the thickness t (in mm) of the surface layer to be made using the equation below.

$$t = \frac{x_0}{2}\sqrt{\frac{v_s - v_d}{v_s + v_d}} \qquad (2)$$

where
vd is the pulse velocity in the damaged concrete (in km/s),
vs is the pulse velocity in the underlying sound concrete (in km/s),
x0 is the distance from the transmitter at which the slope changes (in mm).

B. Determination of changes in concrete properties

Pulse velocity measurements are particularly useful to follow the hardening process, especially during the first 36 h. Here, rapid changes in pulse velocity are associated with physiochemical changes in the cement paste structure, and it is necessary to make measurements at intervals of 1 h or 2 h if these changes are to be followed closely. As the concrete hardens these intervals may be lengthened to 1 day or more after the initial period of 36 h has elapsed. The relationship between ultrasonic pulse velocity and strength is affected by a number of factors including age, curing conditions, moisture condition, mix proportions, type of aggregate and type of cement.

Table 1. CLASSIFICATION OF THE QUALITY OF CONCRETE ON THE BASIS OF PULSE VELOCITY (IS 13311-Part-1-1992)

Sr. No.	Pulse Velocity (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.	2.0 to 3.0	Poor
5.	Below 2.0	Very poor

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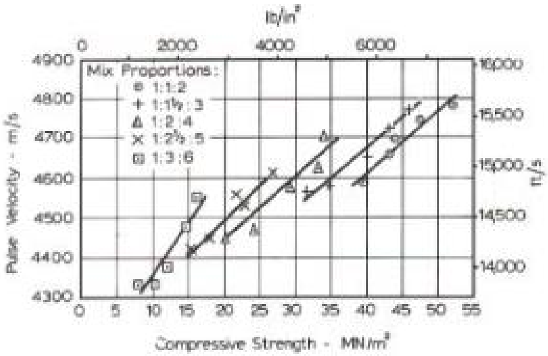

Fig.7. Relation between ultrasonic pulse velocity and compressive strength for concretes of different mix proportion

A. Determination of the modulus of elasticity and dynamic Poisson's ratio:

The relationship between these elastic constants and the velocity of an ultrasonic pulse travelling in an isotropic elastic medium of infinite dimensions is given below:

$$\mathbf{E_d = \rho v^2[(1+\upsilon)+(1-\upsilon)] / (1-\upsilon)} \qquad \textbf{(3)}$$

where
Ed is the dynamic elastic modulus (in MN/m2),
g is the dynamic Poisson's ratio,
ɟ is the density (in kg/m3),
v is the pulse velocity (in km/s).
If the values of g and ɟ are known, it helps to determine the value of Ed in concrete samples for a wide range of shapes or sizes.

2.2.7 Velocity versus rebound number curves

Using a series of correction coefficients developed for the specific concrete grade and type being investigated and, knowing the pulse velocity and the rebound number, a more accurate prediction can be made of the compressive strength of concrete. In an ordinary concrete, between 60% and 70% of the absolute volume is taken up by aggregate and the rest by cement paste, consisting of hydrated and unhydrated cement grains, chemically bound and free water, and entrained (small voids) or entrapped (larger voids) air. Thus, even in concrete of suspect quality and unknown composition, there are two variables which can be identified with a reasonable degree of accuracy, namely, petrological type of the aggregate and approximate age of the concrete.

Establishment of a series of specific correlations between the combination of rebound hammer number (R) and ultrasonic pulse velocity (V) and the compressive strength (S) of concretes, each containing a particular aggregate type and being of a particular age group which can find by SONREB method. Thus the general equation for the rebound hammer correlation relationship is given below:

$$S = a_0 + a_1R \qquad \textbf{(4)}$$

where
S is the compressive strength,
V is the ultrasonic pulse velocity,
and b_0 and b_1 are constants.

The universally accepted empirical relationship between the elastic modulus of concrete and the compressive strength of concrete is of the following general form:

$$E = AS^{0.5} \qquad \textbf{(6)}$$

where
E is the elastic modulus of concrete,
S is the compressive strength of concrete,
and A is a constant, depending on concrete density, statistical evaluation of strength and the selected system of measures.

At the same time, the theory of propagation of stress waves through elastic medium states that for a compression wave the following functional relationship is valid:

$$E = BV^2 \qquad \textbf{(7)}$$

where
E is the elastic modulus of concrete,
V is the ultrasonic pulse velocity,
and B is a constant, depending on density and Poissonôs ratio.

In the work of Samarin and Meynink, The compressive strength is determined by:

$$S = k_0 + k_1R + k_2V^4 \qquad \textbf{(8)}$$

where
$k_{0,}k_1$ and k_2 are constants.

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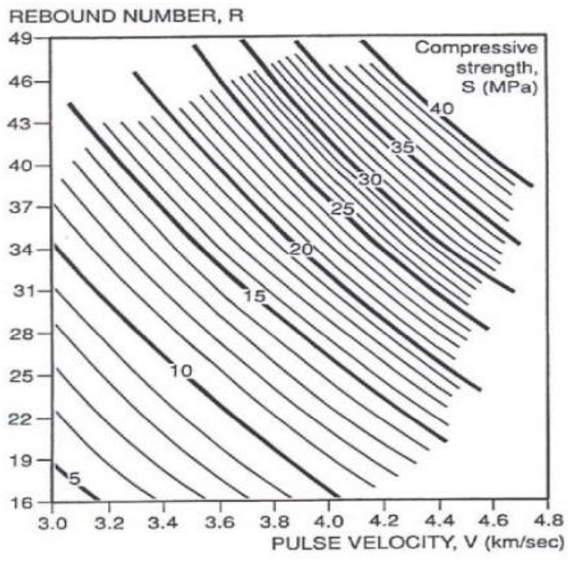


Fig.8 ISO-Strength curves concrete for reference in SONREB method

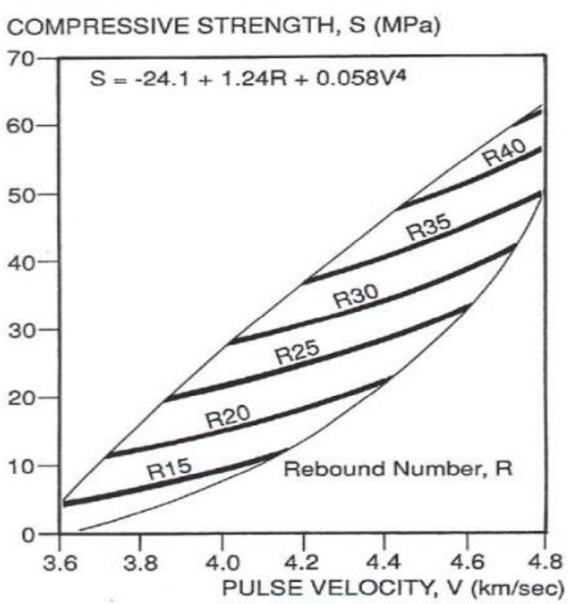
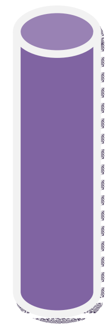


Fig.9 Nomogram for concrete of a particular aggregate type and age

3. CASE STUDY

In a T-beam girder bridge, constructed across a river in India, it was reported that the strength of concrete in one of the piers could not be achieved in the testing of corresponding concrete cubes. After the grouting carried out in accordance with required procedure the Non destructive test was carried-out using Rebound hammer and Ultrasonic pulse velocity tester. The diameter and height of the pier is 1.8m and 3.35 m measured from base to the bottom of the pier cap, respectively. For testing the pier, a grid of 0.71 m x 0.8 m has been marked (Fig.10). with this the total number of NDT testing location points became 40. The core samples for conducting the destructive test were collected from three locations (1C, 3D and 5D).

1	2	3	4	5	6	7	8
O							
A							
B							
C							
D							
O							



Perimeter 5.65 m

Pier- 5

Grid size: 0.71 m along Perimeter, 0.8m along Height

Diameter = 1.80m

Height = 3.35 m

Fig.10 Grid Points Marked On the Pier

Fig.11 Testing of Bridge Pier using Rebound Hammer

Fig.12 Testing of Bridge Pier using Ultrasonic Tester

4. OBSERVATIONS AND RESULTS:

A. The average Ultrasonic Pulse velocity obtained is 3.942 km/sec. Further none of the USP value is less than 3 km/sec. Also the variation in individual USP values is within ±10% of average. This indicate, as per the guidelines laid in IS-13311-Part

1- 1992, that the quality of concrete in terms of uniformity, incidence or absence of flaws, cracks and segregation, the level of workmanship employed may be categorized as medium. The analysis is done by considering wave path, length (mm), ultrasonic time UST (µs), and ultrasonic pulse velocity USP (km/s).

Average Ultrasonic Pulse (USP) Wave Velocity
= (3.63 + 4.76 + 3.48 + 3.78 + 4.06) / 5 = 3.942 km/sec
(The variation is within ±10%)

B.The Average Rebound value is 34.58 and the variation in individual values is within ±10%. The Concrete compressive strength as interpreted from the rebound value is 24.865 MPa, which satisfies the requirement of M20 grade concrete. .The analysis is done by considering location, rebound values and average rebound value.

Combined Average Rebound Value
= (38.26 + 34.00 + 36.14 + 34.40 + 33.18 + 31.60 + 33.74 + 35.32) /8 = 34.58 (Variations within ±10%)

From the above investigation it can be concluded that the Concrete used in the construction of RCC Pier of the Bridge the River confirms to M20 grade concrete as per IS-456-2000 and the quality and uniformity of concrete can be categorized as ôMediumö as per IS 13311-Part-1-1992.

CONCLUSION:

1. The various NDT techniques are very useful in evaluating the quality and strength of existing concrete structures.
2. Apart from other methods, theoretically evaluation of compressive strength, dynamic elastic modulus and Poissonös ratio from Schmidt rebound hammer test and ultrasonic pulse velocity method presented in this paper.
3. Practically, with the help of case study on existing bridge pier, evaluating the quality of RC pier. The results obtained from USP and Schmidt rebound hammer test were found to be satisfactory and the quality of concrete can be categorized as ô**Medium**ö.
4. From the theoretical analysis and design verification it is found that the existing pier of a bridge has enough strength to bare the proposed loading conditions

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