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Non Destructive Testing of Bridge Pier - a Case Study

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Abstract

This paper reviews various NDT methods available and presents a case study related to the strength evaluation of existing bridge pier. The assessment of quality and strength is made by correlating the NDT observations with core tests. The assessment involves the core tests, Rebound hammer tests and Ultrasonic pulse velocity tests.

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1. Introduction

It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delamination. Non-destructive

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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. The testing of existing structures is usually related to an assessment of structural integrity or adequacy. In either case, if destructive testing alone is used, for instance, by removing cores for compression testing, the cost of coring and testing may only allow a relatively small number of tests to be carried out on a large structure which may be misleading. Non-destructive testing can be used in those situations as a preliminary to subsequent coring.

Typical situations where non-destructive testing may be useful are, as follows:

1. Quality control of pre-cast units or construction *in situ*
2. Removing uncertainties about the acceptability of the material supplied owing to apparent non-compliance with specification
3. Confirming or negating doubt concerning the workmanship involved in batching,
4. mixing, placing, compacting or curing of concrete
5. Monitoring of strength development in relation to formwork removal, cessation of
6. curing, prestressing, load application or similar purpose
7. Location and determination of the extent of cracks, voids, honeycombing and similar defects within a concrete structure
8. Determining the concrete uniformity, possibly preliminary to core cutting, load testing or other more expensive or disruptive tests
9. Determining the position, quantity or condition of reinforcement
10. Increasing the confidence level of a smaller number of destructive tests

2. Basic Methods for NDT of Concrete Structures

The following methods, with some typical applications, have been used for the NDT of concrete (Shetty, 2010):

- Visual inspection, which is an essential precursor to any intended non-destructive test to establish the possible cause(s) of damage to a concrete structure and hence identify which of the various NDT methods available could be most useful for any further investigation of the problem.
- Half-cell electrical potential method, used to detect the corrosion potential of reinforcing bars in concrete.
- Schmidt/rebound hammer test, used to evaluate the surface hardness of concrete.
- Carbonation depth measurement test, used to determine whether moisture has reached the depth of the reinforcing bars and hence corrosion may be occurring.
- Permeability test, used to measure the flow of water through the concrete.

- Penetration resistance or Windsor probe test, used to measure the surface hardness and hence the strength of the surface and near surface layers of the concrete.
- Covermeter testing, used to measure the distance of steel reinforcing bars beneath the surface of the concrete and also possibly to measure the diameter of the reinforcing bars.
- Radiographic testing, used to detect voids in the concrete and the position of stressing ducts.
- Ultrasonic pulse velocity testing, mainly used to measure the sound velocity of the concrete and hence the compressive strength of the concrete.
- Sonic methods using an instrumented hammer providing both sonic echo and transmission methods.
- Impact echo testing, used to detect voids, delamination and other anomalies in concrete.
- Ground penetrating radar or impulse radar testing, used to detect the position of reinforcing bars or stressing ducts.
- Infrared thermography, used to detect voids, delamination and other anomalies in concrete and also detect water entry points in buildings.

2.2 Schmidt Rebound Hammer Test

The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges (IS 13311 (Part-2) 1992). There is little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. However, within limits, empirical correlations have been established between strength properties and the rebound number.

2.3 Ultrosonic Pulse Velocity Test

A pulse of longitudinal vibrations is produced by an electro-acoustical transducer, whichis 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:

$$v = L / T \tag{1}$$

where v is the longitudinal pulse velocity, L is the path length, T is the time taken by the pulse to traverse that length.

The equipment consists essentially of an electrical pulse generator, a pair of transducers, an amplifier and an electronic timing device for measuring the time interval between the initiation of a pulse generated at the transmitting transducer and its arrival at the receiving transducer. Two forms of electronic timing apparatus and display are available, one of which uses a cathode ray tube on which the received pulse is displayed in relation to a suitable time scale, the other uses an interval timer with a direct reading digital display. The equipment should have the following characteristics. It should be capable of measuring transit time over path lengths ranging from about 100 mm to the maximum thickness to be inspected to an accuracy of ±1%. Generally the transducers used should be in the range of 20 to 150 kHz although frequencies as low as 10 kHz may be used for very long concrete path lengths and as high as 1 MHz for mortars and grouts or for short path lengths. High frequency pulses have a well defined onset but, as they pass through the concrete, become attenuated more rapidly than pulses of lower frequency. It is therefore preferable to use high frequency transducers for short path lengths and low frequency transducers for long path lengths. Transducers with a frequency of 50 kHz to 60 kHz are suitable for most common applications.

Pulse velocity measurements made on concrete structures may be used for quality control purposes. In comparison with mechanical tests on control samples such as cubes or cylinders, pulse velocity measurements have the advantage that they relate directly to the concrete in the structure rather than to samples, which may not be always truly representative of the concrete *in situ*.

The typical classification of the quality of concrete on the basis of Ultrasonic pulse velocity is given the Table.1

Table1. Classification of the Quality of Concrete on the Basis of Pulse Velocity
(IS 13311-Part-1-1992)

Longitudinal pulse velocity km/s	Quality of concrete
>4.5	Excellent
3.5-4.5	Good
3.0-3.5	Medium
2.0-3.0	Poor
< 2.0	Very poor

2.4 Core Test

In most structural investigations or diagnoses extraction of core samples is unavoidableand often essential. Cores are usually extracted by drilling using a diamond tipped core cutter cooled with water. Broken samples, for example, due to popping, spalling and delamination, are also commonly retrieved for further analysis as these samples may provide additional evidence as to the cause of distress. The selection of the locations for extraction of core samples is made after non-destructive testing which can give guidance on the most suitable sampling areas. For instance, a covermeter can be used to ensure there are no reinforcing bars where the core is to be taken; or the ultrasonic pulse velocity test can be used to establish the areas of maximum and minimum pulse velocity that could indicate the highest and lowest compressive strength areas in the structure.

Moreover, using non-destructive tests, the number of cores that need to be taken can be reduced or minimized. This is often an advantage since coring is frequently viewed as being destructive. Also the cost of extracting cores is quite high and the damage to the concrete is severe. The extracted cores can be subjected to a series of tests and serve multiple functions such as:

- confirming the findings of the non-destructive test
- identifying the presence of deleterious matter in the concrete
- ascertaining the strength of the concrete for design purposes
- predicting the potential durability of the concrete
- confirming the mix composition of the concrete for dispute resolution

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. Further the core samples collected gave different strength values. In this connection it was recommended to have the grouting of the pier. 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. Further to quantify the strength of concrete three core samples were also collected for testing.

The testing was conducted in the presence of concerned Engineering personal. 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.1). 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). The test results are presented in Table.2-4. Some of the photographs (Fig.2-4) taken during the test are also enclosed.

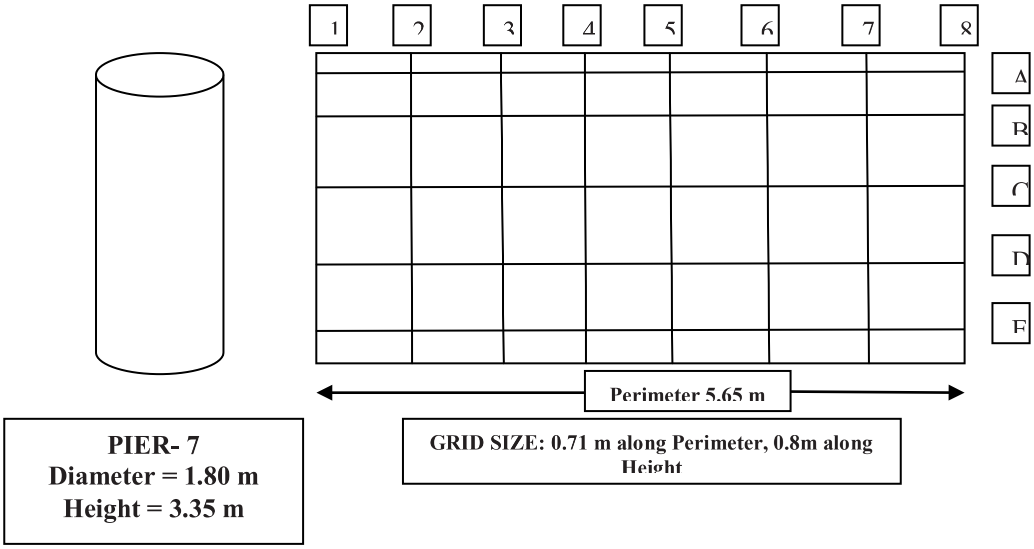

Figure 1. Grid Points Marked On The Pier

Figure 2. Testing of Bridge Pier using Rebound Hammer

Figure 3. Testing of Bridge Pier using Ultrasonic Tester

Figure 4. Extraction of Concrete core from the Bridge Pier

The following are the observations made out of the test report

3.2 Observations

1. The Concrete Core test results indicate that the Average Compressive Strength of Concrete is 32.91MPa. Also it is observed that individual core test values (which are within ±20% of average value) are above 20MPa and satisfy the strength requirement of M20 grade concrete.
2. The average Ultrasonic Pulse velocity obtained is 3.942 kM/sec. Further none of the USP value is less than 3kM/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 categorised as 'Medium'.
3. 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.

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 categorized as 'Medium' as per IS 13311-Part-1-1992.

4. Analysis of Test Results

Table 2. Concrete core test results

Core No.	Dia. (mm)	Cross Sectional Area (Sq.mm)	Height (mm)	Rebound Values	Average Rebound Value	UST (μs)	USP Velocity kM/Sec (4)/(7)	Measured Ultimateload In Compression (KN)	Compressive Strength (MPa)	Equivalent Comp. Strength of Concrete Cube (MPa)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1C	143	16060.61	288	42,48,46	45.33	65	4.43	500	31.132	38.983
5D	144	16286.02	295	40,44,46	43.33	67	4.40	380	22.911	28.809
3D	142	15836.77	290	50,48,48	48.67	58	5.00	390	24.626	30.942
		Average			**45.77**	**--**	**4.61**	**--**	**--**	**32.911**

Note: μs = Micro Seconds

Average Rebound Value = 45.77, USP Velocity= 4.61 kM/sec

Compressive Strength= 32.911 MPa (The variation is within ±20%)

As per Table 11 of IS 456-2000 (2000) the requirement of M20 grade concrete are as follows:

The mean of the test results shall be :

i) 20 + 4 = 24 MPaor ii) 20 + 0.825 x 4 = 23.3 MPa, whichever is greater. Since the mean compressive strength (i.e 32.911 MPa) is well above 24 MPa, it can be inferred that the concrete used in the pier confirms to M20 grade concrete.

Table.3. Ultrasonic pulse velocity test results

Diameter of the Pier-7 = 1.8 m, Height of Pier = 3.35 m (from Base to the Cap bottom)

Wave Path.	Length (mm)	UST (μs)	USP Velocity (kM/Sec)	Wave Path.	Length (mm)	UST (μs)	USP Velocity (kM/Sec)	Wave Path.	Length (mm)	UST (μs)	USP Velocity (kM/Sec)
1A-2A	688	210	3.28	1C-2C	688	220	3.13	1E-2E	688	161	4.27
1A-3A	1273	295	4.32	1C-3C	1273	421	3.02	1E-3E	1273	270	4.71
1A-4A	1663	545	3.05	1C-4C	1663	548	3.03	1E-4E	1663	421	3.95
1A-5A	1800	462	3.90	1C-5C	1800	589	3.06	1E-5E	1800	383	4.70
1A-6A	1663	550	3.02	1C-6C	1663	383	4.34	1E-6E	1663	360	4.62
1A-7A	1273	287	4.44	1C-7C	1273	422	3.02	1E-7E	1273	415	3.07
1A-8A	688	201	3.42	1C-8C	688	144	4.78	1E-8E	688	222	3.10
Ave.USP@ A Level			**3.63**	Ave.USP@ C Level			**3.48**	Ave.USP@ E Level			**4.06**
1B-2B	688	148	4.65	1D-2D	688	223	3.09				
1B-3B	1273	268	4.75	1D-3D	1273	289	4.40				
1B-4B	1663	350	4.75	1D-4D	1663	386	4.31	**Ave.USP Velocity**		=	**3.942 kM/Sec**
1B-5B	1800	371	4.85	1D-5D	1800	419	4.30				
1B-6B	1663	347	4.79	1D-6D	1663	391	4.25				
1B-7B	1273	266	4.79	1D-7D	1273	418	3.05				
1B-8B	688	146	4.71	1D-8D	688	223	3.09				
Ave.USP@ B Level			**4.76**	Ave.USP@ D Level			**3.78**				

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%)

The Ultrasonic pulse velocity represents *the quality of concrete in terms of uniformity, incidence or absence of flaws, cracks and segregation, the level of workmanship employed in concrete structure. As per the guidelines laid in IS-13311-Part 1-1992, since the USP velocity is greater than 3 kM/sec, the concrete quality may be categorised as '**Medium**'.*

Compressive Strength of Concrete (as interpreted from the USP Velocity) = 28.142 MPa**.** Since the compressive strength (i.e 28.142 MPa) is well above 24 MPa, it can be inferred that the concrete used in the pier confirms to M20 grade concrete.

Table.4. Rebound hammer test results

Location	Rebound Values	Average Rebound Value		Location	Rebound Values	Average Rebound Value		Location	Rebound Values	Average Rebound Value
1A	29,26,24	26.3		4A	36,36,30	34.0		7A	30,30,26	28.7
1B	46,46,46	46.0		4B	46,36,36	39.3		7B	28,36,30	31.3
1C	42,40,38	40.0		4C	30,34,36	33.3		7C	36,32,42	36.7
1D	42,44,44	42.3		4D	32,28,32	30.7		7D	38,36,36	36.7
1E	50,30,30	36.7		4E	34,36,34	34.7		7E	38,38,30	35.3
		38.26				**34.40**				**33.74**
2A	30,28,30	29.3		5A	38,26,30	31.3		8A	30,30,30	30.0
2B	34,40,34	36.0		5B	28,26,28	27.3		8B	40,44,38	40.7
2C	34,36,32	34.0		5C	40,40,34	38.0		8C	34,28,38	33.3
2D	42,36,30	36.0		5D	32,36,34	34.0		8D	38,28,28	31.3
2E	38,30,36	34.7		5E	40,40,26	35.3		8E	40,40,44	41.3
		34.00				**33.18**				**35.32**
3A	30,30,32	30.7		6A	28,28,28	28.0				
3B	44,44,44	44.0		6B	40,28,36	34.7				
3C	38,34,32	34.7		6C	28,28,38	31.3				
3D	40,40,38	39.3		6D	26,38,34	32.7				
3E	30,30,36	32.0		6E	30,30,34	31.3				
		36.14				**31.6**				

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

Compressive Strength of Concrete (as interpreted from the Rebound value) = 24.865 MPa**.** Since the compressive strength (i.e 24.865 MPa) is above 24 MPa, it can be inferred that the concrete used in the pier confirms to M20 grade concrete.

5. Concluding Remarks

The various NDT techniques are very useful in estimating the quality and strength of existing concrete structures. The case study presented here illustrates the correlation of destructive and NDT results in the comprehensive assessment of structure condition.

Acknowlegement

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