Strength Assessment of Recycled Aggregate Concrete by Ultrasonic Pulse Velocity Test

Yati R. Tank[1], Maulik R. Joshi[2], Hitesh K. Dhameliya[3]

Abstract—**Ultrasonic Pulse Velocity Test is one of the best known techniques which can be used for the measurement of concrete uniformity, its elastic modulus, layer thickness and presence of honeycombing in concrete. There are three methods adopted for Ultrasonic pulse velocity testing on concrete i.e. direct, indirect & semidirect method. In the present paper, an overview on Ultrasonic Pulse Velocity (UPV), its application and limitation is discussed. Also, an attempt has been made to study an influence of recycled concrete aggregate on concrete replaced by normal aggregate on UPV results. At the same time, various case studies have been studied which may include an effect of concrete age on UPV and an effect of obstruction made along the path inside concrete on UPV results.**

Keywords- **Recycled Concrete Aggregate (RCA), ultrasonic pulse velocity (UPV), direct, semidirect**

I. INTRODUCTION

In the last few decades, the application of Nondestructive Testing (NDT) in civil engineering has becoming a subject of interest in various countries. The concrete cannot be considered as an eternal material once maintenance is needed to guarantee its life-time. The lack of maintenance observed in some structures leads to some pathological manifestations with significant intensity (1). NDT do not only allow the evaluation of aged and spoiled structures; they also can be used in quality control of new structures. Also, the generation of construction and demolition (C &D) waste is upto the tune of 23.75 million tones annually and these figures are likely to double fold in the next 7 years, in developing countries like India.[] Using the demolished concrete debris as recycled concrete aggregate conserves natural aggregates, reduces the impact on landfills, decreases energy consumption and can provide cost savings. The use of recycled aggregates in concrete results in significant economical and environmental benefits.Using the UPV, it was possible to collect results of concrete specimens, leading to an opportunity to analyze how the cure process of concrete affects the readings. This analysis is important for concrete durability prognostics and can be useful considering the economic aspect.

This method is explained in IS 13311 (part 1):1992, which involves measurement of the time of travel of electronically generated mechanical pulses through the concrete. The ultrasonic pulse velocity method could be used to establish: a) Homogeneity of concrete b) Presence of cracks & voids c) Changes in structures of the concrete d) The quality of the concrete in relation to standard requirement e) The values of dynamic elastic modulus of the concrete.

The principle behind the Ultrasonic Pulse Velocity is that the pulses are generated by an electro-acoustical transducer, when pulse is induced into the concrete from a transducer; it undergoes multiple reflections at the boundaries of different material phase within the concrete. A complex system of waves is developed which include longitudinal, shear and surface waves. The receiving transducer detects the onset of longitudinal waves which is the fastest.

Because the velocity of the pulses is independent of the geometry of the material through which they pass and depends only on its elastic properties. When quality of concrete in terms of density , homogeneity and uniformity is good, higher velocities are obtained. In case of poorer quality of concrete lower velocities are obtained. In general the velocity criterions are as shown in table No.1.

Table: 1 Criteria for Velocity

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	Below 3.0	Doubtful

A. Factors affecting the pulse velocity

- Surface condition and moisture content
- Temperature of concrete
- Micro cracks in concrete
- Water cement ratio
- Age of concrete
- Presence of steel reinforcement

B. Applications of Ultrasonic Pulse Velocity test

- Measurement of concrete uniformity
- Strength estimation
- Identifying Honeycombing and cracks
- Assessment of concrete deterioration
- Measurement of layer thickness
- Measurement of elastic modulus
- Strength development monitoring

C. Limitations of Ultrasonic Pulse Velocity test

It can't be overemphasized that administrators must be overall prepared and mindful of the components influencing the readings. It is correspondingly fundamental that comes about are appropriately assessed and deciphered by accomplished Engineers who are acquainted with the method. It should be noted that allowances for tolerances on measurement of transit time and path length combine to

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mean that a change in calculated pulse velocity of at least 2% will be needed to reject a significant change in properties. If wet concrete is noted than Flaw detection of concrete should not reliable.

D. Aim & Objective

- To understand the basic concepts of NDT testing.
- To study the various methods of UPV testing in detail and understand its application and limitations.
- To study various case studies related to effect of concrete age, effect of obstruction made along the path inside concrete and effect of recycled aggregate replaced by normal aggregate on UPV results for different methods of UPV test.
- To study the quality of concrete bridge girder by UPV.

II. RELATED WORK

Many studies have been conducted on direct pulse velocity determination and factors that affect it. Standards are available for measuring velocity using direct transmission (ASTM 1999a,b; RILEM 1972; BS 1997). Less information, however, is available on indirect transmission. In general, indirect transmission is used when only one face of the concrete structure is accessible, and it is often stated that indirect measurements are not reliable (ASTM 1999a; RILEM 1972; BS 1997). Moreover, indirect transmission is described as the least sensitive testing arrangement. British Standards (BS 1881) state that the indirect velocity is 5 to 20% lower than direct velocity, depending mostly on the concrete quality. Jones (1962) explained the discrepancy between the direct and indirect velocity as being due to wave dispersion. Popovics et al. (1998) verified Jones's (1962) finding by demonstrating that accurate algorithms for determining the time of flight reduce the difference between direct and indirect velocities. British Standards (BS 1881) recommends an indirect velocity measurement procedure using a relationship between transducer spacing and time of flight, obtained by repeating time-of-flight measurements with increasing distance between the transducers. Indirect measurements are not recommended in ASTM C 597 except when only one surface of a material is accessible. Furthermore, it is stated that measurements on the surface are indicative of properties of only the layers that are close to the surface. At present, ASTM standards for indirect DPV measurements do not exist.

Dr. Kulkarni D. K. et al. presented the field investigation for strength assessment and hence resolved the doubts of quality of construction of an existing structure based upon nondestructive testing. It was concluded by the authors that, health assessment work may be performed on new structures if concrete fails to attain the desired strength at 28 days age. This case study deals with the health assessment work where the strength of the concrete existing in a new structure was ascertained by developing statistical correlation between NDT properties and compressive strength of concrete as per IS: 13311.

Savaliya K. D. et al. investigated the relationship between velocities of Ultrasonic waves propagating along direct, semi-direct and indirect method. Simple cement concrete beams of M 25 grade and fabricated anomalies namely rubber pieces and re-bars are casted for experimentation. The comparisons of UPV results between direct, indirect and semi-direct methods also described in brief.

Savaliya K. D. et al. studied the variation of Ultrasonic Pulse Velocity versus Age. Series of Experimental were conducted on CC Cubes, Beams of Concrete as well as mortar, to evaluate the effect of Age. Experiments were carried on 7, 28 and 56 days after casting. Results were analyzed to evaluate the Variation in Ultrasonic Pulse Velocity diff. Methods namely Direct, Indirect & Semi-direct employed for the experimentation. Ultrasonic pulse velocity is observed to increase from 7 day to 28 days of casting. The UP Velocity continuously increasing 56 days however much slower rate that observed between 7 and 28 days of casting. At the same time, it has been observed that on a same element of concrete, UP Velocity when measured by keeping transducers either on top and bottom surface in case of semi-direct method, gives different results.

Jaggerwal H. et. al. estimated the quality of concrete bridge girder and attempted to increase the accuracy of calculating the strength by UPV test. It was concluded that UPV method is very useful for predicting the service life of structures and deterioration of the structures provided the periodical monitoring of the same member of the structure. The experimental investigations showed that a good co- relation exists between compressive strength and UPV.

Yaman I. O. et. al. investigated the relationship between velocities of ultrasonic stress waves transmitted along direct and indirect paths. Tests were conducted on plain concrete slabs of dimensions 1000 x 1500 mm, with a thickness of 250 mm. Direct ultrasonic wave transmission tests were conducted between rop and bottom surfaces of the slabs and indirect tests were conducted along the slab surface. The statistical analysis revealed that direct and indirect wave velocities could be used interchangeably in evaluating the properties of the concrete. The minimum number of test poil1ls required for a reliable estimate of indirect wave velocity was studied and recommendations are provided.

III. EXPERIMENTAL WORK

Experimental procedure consists of 9 nos. cement concrete cube. M25 grade concrete with Ordinary Portland Cement is used. Locally available 10 and 20 mm aggregates and river sand is used. And the concrete proportions are as follows:

Table: 2 Mix Proportion

Cement	375 kg/m^3
Water	167.45 kg/m^3
Fine aggregate (sand)	709.48 kg/m^3
Coarse aggregate (10 down)	473.33 kg/m^3
Coarse aggregate (20 down)	780.80 kg/m^3
Chemical admixture	3.75 kg/m^3
Water/Cement	0.45

A. Material Used:

- ***Cement***: In concrete mix, Ordinary Portland Cement of 53 grade was used in this project.
- ***Fine Aggregate***: The fractions for 4.75 mm to 150 micron are term as fine aggregate. Sand and crushed sand is used in combination as fine aggregate conforming to the requirements of IS: 383 of grading zone II.
- ***Coarse Aggregate:*** The fraction from 20 mm to 4.75 mm is used for coarse aggregate in this project. Generally there

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are 2 types of coarse aggregate is used coarse aggregate I (grit, which is 10 mm down) and coarse aggregate II (20 mm down).

- ***Recycled Concrete Aggregate***: The C&D waste was collected from Varachha Road near old Gitanjali Cinema at Surat. The demolished structure named "Shree Ram hospital" was mainly used for public and residential purpose. It was old about 25-30 years. Water:
- ***Water:*** It is an important ingredient of concrete as its actually participate in chemical reaction with cement since it helps to form the strength quality and quantity of water is required to be looked in to very carefully therefore. Potable water was used in preparation of M25 grade concrete.
- ***Chemical Admixture***: A super plasticizer named FAIRFLO-333 of company named FAIRMATE CHEMICAL PVT. LTD. has been used in the present work.

Figure 1: Concrete debris collected from site

Figure 2: Generated RCA from debris

B. Methodology Adopted :

Casting of concrete specimens was done in drum mixture. The purpose of casting of specimens with different anomalies is to know wave behavior in different media having different acoustic medium. Total 9 nos. of concrete cubes were casted. Among of those 3 beams were normal concrete cubes, 3 cubes were composed with 25% of recycled aggregate replaced by normal aggregate and 3 cubes were composed with 50% of recycled aggregate replaced by normal aggregate. Size of the Beam element is 150X150X150 mm. All specimens of concrete are subjected to same condition. Specimens are compacted and cured at ambient temperature until the date of testing.

A) *Experimental Study and Test Set-up* :

Ultrasonic testing equipment includes a pulse generation circuit, consisting of electronic circuit for generating pulses and a transducer for transforming electronic pulse into mechanical pulse having an oscillation frequency in range of 40kHz to 50kHz, and a pulse reception circuit that receives the signal. The transducer, clock, oscillation circuit, and power source are assembled for use. After calibration to a standard sample of material with known properties, the transducers are places on opposite sides of the material. Pulse velocity is measured by a simple formula:

$$Pulse\ Velocity = \frac{Width\ of\ Structure}{Time\ taken\ by\ pulse\ to\ go\ through}$$

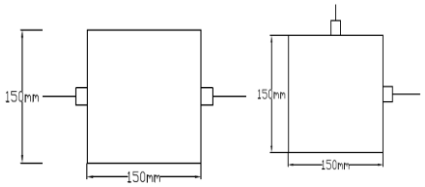
Ultrasonic stress (compression or shear) waves are produced by electro acoustic transducers made up of piezoelectric material. Transducers convert electric energy to the mechanical energy in form of stress wave which may be surface, compressive or shear waves.

PUNDIT 7 is shown in Fig 3 is used for UPV testing of specimens. From Fig 4 Piezoelectric Transducers having 54 kHz frequency are employed. As a coupling agent petroleum gel is used. Gel facilitates an airtight bond between concrete or mortar specimen and Transducers.

The Testing Procedure is consisting of UPV test by Direct and Semi-direct method at ages of 7, 28 and days interval.

In Direct method, Transmitting and Receiving Transducers are kept on its opposite faces. While in Semi direct method, Transmitting and Receiving Transducers are kept on adjacent faces. And in Indirect method, Transducers are kept on the same face. All three methods are shown in Fig 5. The readings are taken by putting transmitter and receiving transducer on opposite faces in case of direct method. While In semi direct method, the readings are taken by putting transmitter on top and bottom faces sequentially and by varying receiver transducers on adjacent faces. In Indirect method, the receiving and transmitting Transducers are kept on same face with different interval. And it has been varied by 150 mm distance on same face.

Figure: 3 PUNDIT Equipment



(a) (b)

Figure: 4 UPV measurements on concrete Cube by (a) Direct Method (b) Semidirect Method

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IV. RESULTS AND DISCUSSION

UPV results by different 2 methods i.e. direct and semidirect at different age of concrete were evaluated. The results are taken at 7, 28 and 56 days on different cube specimens for 3 different case of concrete mix i.e. for normal concrete (0% replacement of RCA), 25% replacement of RCA replaced by normal aggregates and 50% replacement of RCA replaced by normal aggregates. And the results of UPV are shown in graphical form as follows:

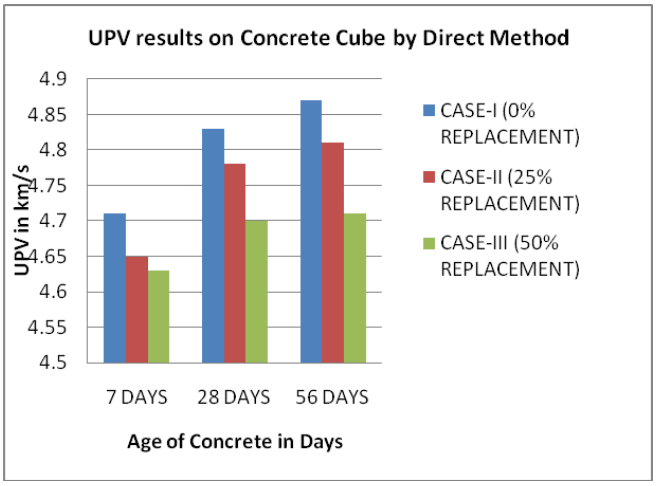

Figure: 5 UPV results on Concrete Cube by Direct Method

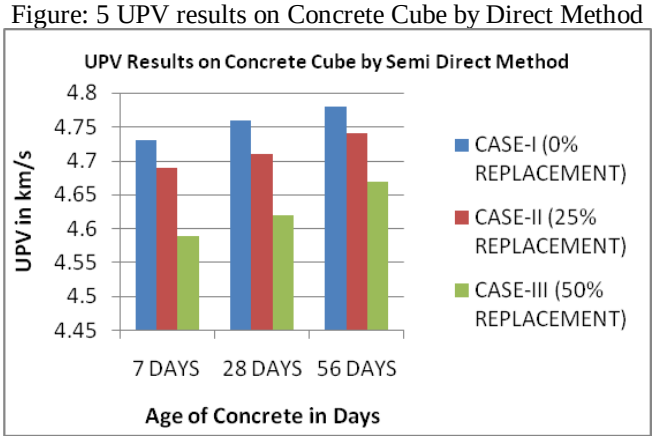

Figure: 6 UPV results on Concrete Cube by Semidirect Method

IV. CONCLUDING REMARKS

Following concluding remarks have been made on basis of the work conducted in the major project:

- Standard cube size of 150x150x150 mm has been used of concrete grade M25. UPV results have been taken at the age of 7, 28 and 56 days by direct and semi-direct method. Scatter plot has been plotted for UPV results of concrete cube versus age of concrete by direct and semi-direct method.
- Ultrasonic pulse velocity increases with the age of concrete from 7 days to 28 days. The rate of increment of Pulse Velocity decreases gradually from 28 days to 56 days.
- At the same time, for normal concrete the UPV results are more, as compared to Recycled Aggregate because of the cement paste attached to the recycled aggregate. Also, the water absorption and bulk density of recycled aggregate are more as compared to normal aggregate. Therefore, the results of 50% replacement are less as compared to 25 % replacement case. And the results of 25% replacement are less as compared to normal concrete in both cases i.e. direct and semi direct method.

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