

Correlation between Pulse Velocity and Compressive Strength of Concrete

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ABSTRACT: Aging of dams necessitates their health monitoring. For this purpose different destructive techniques involve extraction of cores for finding the strength. Puncturing the body of dams is not advisable as it would unnecessarily result in damaging the structure and the procedure is also too expensive to be used. Therefore in order to monitor the post construction performance of concrete investigations were carried out for developing the relationship between the ultrasonic pulse velocity (UPV) and the compressive strength of concrete. The specimens used in the studies were made of concrete with varied cement content, water-cement ratios (w/c) and coarse aggregate contents by weigh batching. The UPV measurement and compressive strength tests were carried out on concrete cubes at the age of 7 and 28 days. The relationship developed in the study is case specific as the UPV and the compressive strength of concrete depends on various factors such as cement-mortar paste content, water-cement ratio and coarse aggregate content and its quality, admixtures. Hardened concrete (at an age of 28 days) was selected as the subject for analysis in the current study. It is found that with the same grade of concrete, a clear relationship curve can be drawn to describe the UPV and compressive strength of hardened concrete. This paper proposes the UPV and strength relationship curves for different concrete mixes/grades used in concrete structures of Tehri Hydro Electric Project, Uttarakhand. The estimated correlation curves are verified to be suitable for prediction of hardened concrete strength with a measured UPV value in the health monitoring of structures under reference during its service period.

KEYWORDS: Concrete strength; Grades of concrete; Nondestructive evaluation; Ultrasonic pulse velocity.

INTRODUCTION

The ultrasonic pulse velocity technique first introduced by Long, Kurtz and Sandenaw (1945) for evaluating the non destructive method of testing for quality of concrete by transmitting a irrational pulse to travel a known distance through a concrete. Some work in previous literature made use of the ultrasonic pulse velocity (UPV) of concrete to predict compressive strength and it is fundamental in such research work to study the relationship between UPV and compressive strength (Sturup et al. 1984 and Lin et al. 1998). Pulse velocity is influenced by many variables such as mixture proportions, aggregate type, age of concrete, moisture content, and others (Popovics et al. 1990). The factors significantly affecting the concrete strength might have little influence on UPV. As a result, a strength estimate made with the pulse velocity method is not a broad spectrum technique. Therefore, the relations derived can be used for structures made with same materials at any time during its service period.

The previous studies concluded that, for concrete with a particular mixture proportion, there is a good correlation between UPV and the compressive strength. No clear rules have been presented to describe how the relationship between UPV and the compressive strength of concrete changes with its mixture proportion. Therefore, there exists a high uncertainty when one tries to make use of UPV to predict the strength of concrete in different mixture proportions.

Previous it has been established that UPV of hardened concrete is predictable based on its mixture proportion. In addition, it has been known that the compressive strength of concrete corresponds with the mixture proportion. Thus, this study tries to adopt the same mixture proportion and grade of concrete as a medium to investigate the relationship between UPV and the compressive strength of hardened concrete. The study in this paper uses various grades of concrete i.e. M15, M20 and M35 with cement content 257kg/m^3 , 314kg/m^3 and 425kg/m^3 respectively to make cubes of concrete specimens with different water/cement ratio (w/c) and coarse aggregate/fine aggregate content by weigh batching. The UPV measurement and compressive strength tests were carried out at the age of 7 and 28 days.

Nondestructive methods of testing concrete may be used with greater confidence when the objective is only comparative & qualitative assessment from the known quantitative state or standard. The correlation between UPV and compressive strength is influenced by number of factors stated above which would have to be taken in to account if a reasonable prediction of compressive strength has to be made from pulse velocity measurements.

RESEARCH SIGNIFICANCE

This study carried out on different concrete mix proportions and different grades of concrete. The true concrete cube specimen from Tehri Hydro Electric Project, Uttarakhand are taken for interpretation of relationship between UPV and the compressive strength of concrete. Furthermore, this paper proposes to establish a clear relationship curve between UPV and the compressive strength of concrete to improve the application of the UPV method for performance analysis during entire service period of structures.

Salient Features of Tehri Hydro Electric Project

The Project (Lat. $30^{\circ}28'N$ Long. $78^{\circ}30'E$) is constructed in head reaches of Ganga basin in Uttar Pradesh State now in Uttarakhand, to generate 2000 MW of hydropower, to provide additional irrigation to an area of about 2.70 lakh hectares and to provide drinking water of about $10 \text{ m}^3/\text{s}$ or 86 ha m every day for million of souls residing in metropolis of Delhi. The project comprises construction of 260.5 m high rock fill dam downstream of Tehri township after confluence of Bhagirathi and Nilangna. Catchment area at Tehri Dam is 7511 sq.km. The concrete spillway is constructed to take care of inflow Probable Maximum Flood (PMF) of $5380 \text{ m}^3/\text{s}$. The underground power house, inspection galleries and drainage gallery of the dam have been constructed using concrete linings of different grades.

EXPERIMENTAL DETAILS

Materials

Materials used for making specimens include cement, fine aggregate (FA), CA, and water-reducing admixture. The cement used was Ordinary Portland cement (43 grade) with fineness $290 \text{ m}^2/\text{kg}$, specific gravity 3.16 and 28 days compressive strength 48-50 MPa. Crushed sand (fine aggregate) used having the specific gravity of 2.62, fineness modulus of 2.68 to 2.81 and silt content 1.50%. Coarse aggregate used is having the specific gravity of 2.66 and passed for non-wearing surfaces as per accepted BIS criterion. Both sand and coarse aggregate used in different grades of concrete were from the same source.

Experimental Specimens

Cubes of different grades of concrete viz. M15, M20, and M35 were cast out of the concrete matrix used during construction at different locations. The w/c ratio ranges from 0.42 to 0.60. The cement mortar occupies 43% to 45% of the total concrete volume. The volume ratios of FA: CA (Fine Aggregate : Coarse Aggregate) are 38 : 62, 35 : 65 and 37 : 63 respectively for each grade of concrete. To improve workability of concrete, water-reducing admixture was added into each grade of concrete to control the slump and to prevent the occurrence of bleeding and segregation.

125 Nos. of concrete specimens for M15 grade of concrete, 200 Nos. for M20 grade of concrete and 45 Nos. for M35 grade of concrete were cast and tested for both UPV and compressive strength. All the specimens were cast in steel cubic molds of 150 mm and kept in molds for approximately 24 hours in the laboratory. After removing the moulds, all

concrete cubes were cured in water at $27^{\circ} \pm 2^{\circ}\text{C}$ for 7 and 28 days. The ultrasonic pulse velocity tests were carried out using PUNDIT before they are tested in a compression testing machine. At each age, the pulse velocity and compressive strength of these specimens were measured according to the specification of IS:13313 Part I and IS:516, respectively.

Experimental Equipment

Through a direct transmission mode, as illustrated in Fig. 1, ultrasonic pulse velocities were measured by a commercially available Portable Ultrasound Nondestructive Digital Indicator Tester (PUNDIT) with an associated transducer pair. The nominal frequency of the transducers used for testing concrete cubes is 54 kHz. The principle of ultrasonic pulse velocity measurement involves sending a wave pulse into concrete by an electro-acoustical transducer and measuring the travel time for the pulse to propagate through the concrete. The pulse is generated by a transmitter and received by a similar type of receiver in contact with the other surface. In the experimental studies, the transmitter and receiver were placed at the opposite ends of specimens. As a result, the traveling length of the ultrasonic pulse was the length of the specimen. The concrete surface must be prepared in advance for a proper acoustic coupling by applying grease. Light pressure is needed to ensure firm contact of the transducers against the concrete surface. Knowing the path length (L), the measured travel time between the transducers (T) can be used to calculate the pulse velocity (V) using the formula $V = L/T$.

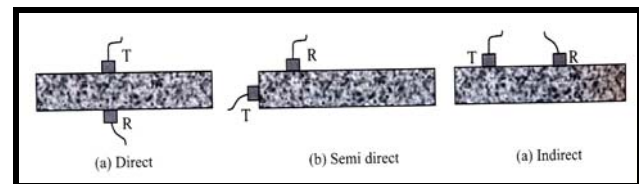


Figure 1: Various Transmission Modes
(T: Transducer, R: Receiver)

EXPERIMENTAL RESULTS

The experimental data discussed in this paper and presented in the figures is generated from various grades of concrete i.e. M15, M20 and M35 based on the UPV and compressive strength at 28 days.

Relationship between UPV and Strength of Hardened Concrete

Using 125 data points for M15 grade of concrete, 200 data points for M20 grade of concrete and 45 data points for M35 grade of concrete were plotted for establishing relation between UPV and compressive strength. The linear regression was applied to establish the UPV-strength relationship. Fig. 2, Fig. 3 and Fig. 4 shows the relationships between UPV and strength at the age of 28 days of concrete having M15, M20 and M35 grades of concrete respectively. From the data, it has been observed that for M15 grade of concrete, the pulse velocity ranges from 4.00 to 4.40 km/sec

for which the values of compressive strength ranges from 19 to 23 MPa, for M20 grade of concrete, the pulse velocity ranges from 4.00 to 4.60 km/sec for which the values of compressive strength ranges from 28 to 30 MPa and for M35 grade of concrete the pulse velocity ranges from 4.12 to 5.06 km/sec for which the values of compressive strength ranges from 35 to 39 MPa. Their corresponding coefficients of determination R^2 are 0.244, 0.027, and 0.025 indicating good relevance between data points and the regression curves.

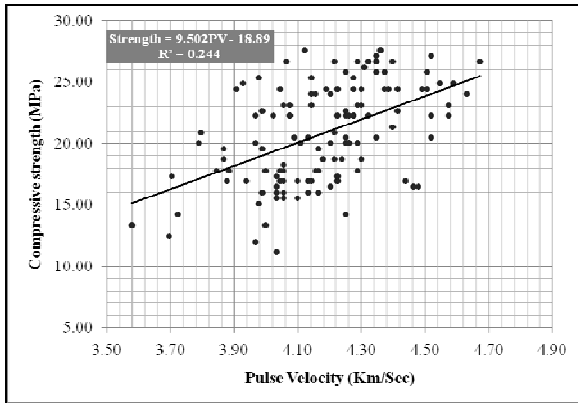


Figure 2: Correlation between compressive strength in MPa Vs pulse velocity in km/sec for M15 Grade at 28days age of concrete used in Tehri H. E. Project, Uttarakhand

The correlation factors/equations for the simulation curves for M15, M20 and M35 grades of concrete are given below as eq.1, eq.2 and eq.3 respectively:

$$CS = 9.502PV - 18.89 \quad (1)$$

$$CS = 2.701PV + 17.15 \quad (2)$$

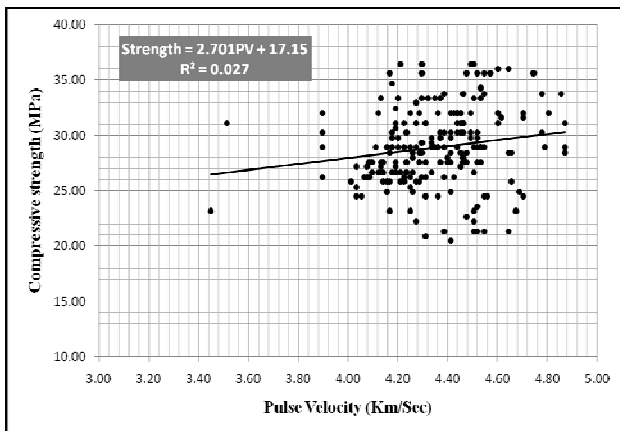


Figure 3: Correlation between compressive strength in MPa Vs pulse velocity in km/sec for M20 Grade at 28days age of concrete used in Tehri H. E. Project, Uttarakhand

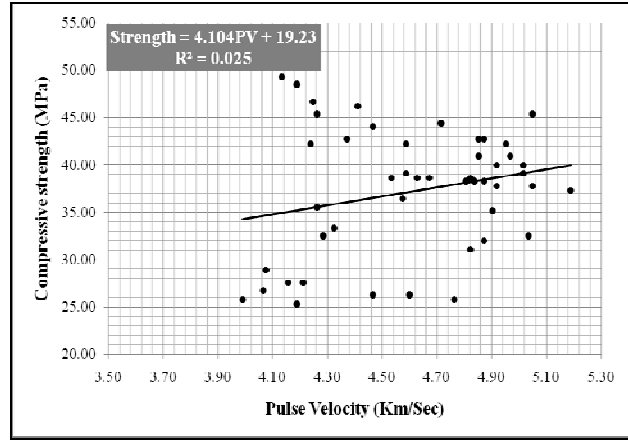


Figure 4: Correlation between compressive strength in MPa Vs pulse velocity in km/sec for M35 Grade at 28days age of concrete used in Tehri H. E. Project, Uttarakhand

$$CS = 4.104PV + 19.23 \quad (3)$$

where CS and PV represent the compressive strength (MPa) and the ultrasonic pulse velocity (km/s), respectively.

Verification of Proposed UPV-Strength Relationship Curves

To verify the validity of the proposed UPV-strength relationship, additional specimens were prepared with concrete having same grades of concrete i.e. M15, M20 and M35. A total of 15 concrete specimens (5 for each grade of concrete) were prepared and cured in water and then tested at the age of 28 days. The measured pulse velocity PV of each saturated-surface dry specimen was used to predict its compressive strength by using a suitable UPV-strength equation that is representative of different grades of the specimen. For example, Eq. (1), (2) and (3) were used to predict the strengths of concretes having M15, M20 and M35 grades respectively. The predicted strength was compared with the measured strength obtained from a compressive test on the specimen. The comparison results were given in Table 1. The results show that almost all the comparison results are between 5.96% and -4.33%. This verifies the suitability of the proposed relationship curves for prediction of hardened concrete strength with a measured UPV value.

Table 1: Shows the predicted strength from UPV and actual strength of concrete

Sl. No	Pulse Velocity (km/sec)	Predicted Compressive Strength (MPa)	Actual Compressive Strength (MPa)	Percent Variation [(3-4)/4]
1	2	3	4	5
Data for M15 Grade of Concrete				
1	4.21	21.11	20.89	1.05%
2	4.40	22.92	21.63	5.96%

3	4.09	19.97	20.44	-2.30%
4	3.99	19.02	19.56	-2.76%
5	4.25	21.49	20.45	5.09%
Data for M20 Grade of Concrete				
6	4.18	28.44	26.97	5.45%
7	4.13	28.31	27.56	2.72%
8	4.17	28.41	28.44	-0.11%
9	4.20	28.49	29.78	-4.33%
10	3.90	27.68	28.89	-4.19%
Data for M35 Grade of Concrete				
11	4.90	39.34	37.82	4.02%
12	4.26	36.71	35.56	3.23%
13	4.57	37.99	36.44	4.25%
14	4.82	39.01	38.67	0.88%
15	4.59	38.07	39.11	-2.66%

Further Research

In this paper, a new approach to establishing the relationship between UPV and the strength of hardened concrete was presented and verified to be suitable for particular application. To extend the application of the relationship, further studies are under way to investigate how the changes in the volume fraction of cement paste and the type of coarse aggregate affect the UPV-strength relationship. It is also to be investigated whether the use of pozzolanic materials such as fly ash and slag in concrete influences the relationship between UPV and strength of hardened concrete.

CONCLUSIONS

The objective of this paper is to investigate the relationship between the ultrasonic pulse velocity (UPV) and the compressive strength of concrete. The attempts are made towards either developing new procedures of estimating the strength and other properties of concrete or towards using the existing methods for getting more reliable and dependable information of the quality of concrete of the structures under reference in the years to come without disturbing the structure. Based on the extensive experimental works and studies, the following conclusions are drawn:

- When the above equations are used for mixes with same concrete grades but different materials from different projects i.e. CA, FA and varying cement paste content, the predicted strength of concrete shows more variation from the actual strength of the specimens.

- These curves were verified to be suitable for estimation of concrete strength with a measured UPV value for the concrete with same materials and cement paste content only.
- The derived correlation curves can be used for prediction of concrete strength in the health monitoring of structures under reference during its service period.

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