# EVALUATION OF COMPRESSIVE STRENGTH OF CONCRETE FROM ULTRASONIC PULSE VELOCITY FOR EXISTING CONCRETE STRUCTURE

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**ABSTRACT.** Health assessment of aging concrete structures has become a necessity especially where they exhibit visible signs of distress. For this purpose, the non-destructive testing techniques such as ultrasonic pulse velocity, rebound hammer, and acoustic emission have become extremely popular. Subsequently, the concrete strength would be required to be estimated from these non-destructive test results. This could be performed by empirical correlation equations. In this paper, the compressive strength of concrete of an existing structure is evaluated by using ultrasonic pulse velocity. For this purpose, empirical equations available in literature have been utilized. Further, utilizing the results of core test conducted at a few locations, the suitability of the empirical expressions is evaluated and the best suited equation is selected. Using this best suited equation, the characteristic strength evaluation of concrete for the building would be performed.

**Keywords:** Non-destructive Testing, Partially Destructive Testing, Ultrasonic Pulse Velocity, Concrete, Compressive Strength, Characteristic Strength

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# INTRODUCTION

Concrete has been a popular building material in last few decades mainly because of the flexibility in the geometry offered by concrete, the resistance to the environment and fire as compared to steel, and the cost effectiveness. However, over the life of the structure the concrete undergoes deterioration depending upon the various factors like the environments exposure conditions, the loading and stress history, and the accidental impact or fire, among others. Most of the concrete structures survive their design life and still are serviceable. For life extension, health assessment of the structure then becomes essential. In other cases, if the structure displays visible signs of distress during a scheduled / emergency survey, health assessment would be suggested for further analysis of the worthiness of the structure. In certain cases of accidental loading or fire, the evaluation of the structural health becomes mandatory before further use of the facility. For important infrastructure facilities as well as critical structures, health assessment might be a periodic activity as stipulated by the prevailing standards.

For health assessment of existing concrete structures, the non-destructive testing techniques such as ultrasonic pulse velocity (USPV), rebound hammer, and acoustic emission have become extremely popular. They are especially useful in cases where the structure is sensitive or would be distressed by the partially destructive tests such as core tests, which could give a direct estimate of the compressive strength of concrete. In such cases, the concrete strength would be required to be estimated from the non-destructive test results. This could be performed by empirical correlation equations describing the relationship between the variable obtained from the non-destructive test, say, USPV and the compressive strength of concrete. The empirical equation may be developed for the particular structure according to the guidelines in national standards [IS 13311: 1992] with the data from the structure.

In literature there have been efforts to arrive at correlation expressions for the USPV and compressive strength of concrete, where the grade of concrete or its age have been taken as unknown [Turgut, 2004]. Such expressions provide the advantage that the local variations in the structure due to the factors like the materials, placement, compaction, curing, and position with respect to the lift height would be already accounted for, at least to a certain extent. Further, the distress on the old concrete structures could be avoided by using correlation expressions from literature, as the core specimens need not be taken for the estimation of the compressive strength and establishment of correlation equations.

Whereas the utilization of correlation expressions from literature have their inherent advantages, their applicability for the present application needs verification. The error margins of the estimated compressive strength from correlation equations and USPV is indicated as $\pm$ 20% [IS 13311: 1992] when the equations are developed for the particular structure. The error margins associated with the use of correlation equations between USPV and compressive strength from literature could be different for different groups of structure. In a large facility, there were several buildings which needed health assessment and non-destructive (USPV) and partially destructive test (core test) were carried out on one of them. It was intended to use the non-destructive results for estimation of compressive strength for all the structures and the suitable expression with the knowledge of associated error margins was required. This could be accomplished by evaluation of the errors arising from the expressions from literature.

In this paper, the compressive strength of concrete of an existing structure is evaluated by using ultrasonic pulse velocity. For this purpose, empirical equations available in literature have been utilized. Further, utilizing the results of core test conducted at a few locations, the suitability of the empirical expressions is evaluated and the best suited equation is selected. Using this best suited equation, the evaluation of characteristic strength of concrete for the building would be performed, and the associated error margins are indicated. This selected equation and the error margins would be useful in estimation of characteristic strength from USPV for all the other structures. The characteristic strength would be an important input for the re-evaluation analysis and design checks for the structures.

## DATA AND METHODOLOGY

### The Structure

The data taken for this study originated from the non-destructive and partially destructive testing on an existing reinforced concrete structure located in northern coastal Maharashtra. The construction of the structure was performed with strict quality control in all stages and periodic inspection, minor plaster repair and painting had been conducted for its service life. The structure comprises of concrete beams, columns, slabs and thick concrete walls. The plan dimensions are approximately 120 m X 65 m and the overall height of the structure is 25 m above ground, in 6 storeys of 3 m each over the high-bay of 7 m at ground floor. The structure is resting on raft foundation.

### Non-destructive and Partially Destructive Tests

The non-destructive tests carried out included USPV and the partially destructive tests carried out included core test. The USPV data from the core locations are used in conjunction with the empirical correlation equations available in literature (described later) for the USPV and compressive strength of concrete and the accuracy is evaluated with the results of the core tests. Subsequently, the USPV from the entire structure is used to evaluate the corresponding equivalent compressive strength values and the characteristic strength is evaluated according to the stipulations in standards.

### Correlation Equations from Literature

For estimating the compressive strength of concrete from the non-destructive tests like USPV, correlation equations should be developed for the structure and subsequently used [IS 13311 (Part 1): 1992]. The accuracy of the strength estimates are suggested to be $\pm$ 20% [IS 13311 (Part 1): 1992]. The reasons for the variations are indicated as the involvement of a large number of parameters, some of which influence the USPV and the compressive strength to different extents [IS 13311 (Part 1): 1992].The various factors influencing the USPV are the in-situ moisture content, the in-site temperature of concrete, the stress condition, the proximity and direction of reinforcement, among others. The compressive strength could be affected by the age of the structure, the deterioration of concrete due to factors like carbonation or chemical attack, the stress history etc. Detailed information regarding the nature of influence of various factors on the USPV and compressive strength may be obtained from literature [IS 13311 (Part 1): 1992; Neville, 2011]

An alternate to development of site-specific correlation curves could be the use of generalized correlation expressions from literature. In a paper by Turgut (2004) in which the author performed extensive analysis with USPV and corresponding compressive strength data from various sources with different concrete mixes (considered unknown for existing structures), three expressions were given: for laboratory test data (Eq. 1), for field test data (Eq. 2) and for combined data (Eq. 3). They are reproduced below:

$$S_{lab} = 0.0872\ e^{1.29\ V_{lab}} \qquad \text{Eq. 1}$$

$$S_{site} = 1.146\ e^{0.77\ V_{site}} \qquad \text{Eq. 2}$$

$$S_{comb} = 0.316\ e^{1.03\ V_{comb}} \qquad \text{Eq. 3}$$

where, $S_{lab}$: compressive strength of laboratory specimens (MPa),
$S_{site}$: compressive strength of specimens from actual structure (MPa),
$S_{comb}$: combined set of compressive strength of specimens from laboratory and actual structure (MPa),
$V_{lab}$: USPV of laboratory specimens (m/sec),
$S_{site}$: compressive strength of specimens from actual structure (m/sec),
$S_{comb}$: combined set of compressive strength of specimens from laboratory and actual structure (m/sec).

**Characteristic strength of concrete from core test results**

According to Indian standard [IS 456: 2000] the characteristic strength of concrete in existing structure represented by a core test can be acceptable under the following conditions:

i. The average equivalent cube strength of the cores is equal to at least 85 percent of the characteristic strength of concrete.
ii. No individual core has a strength less than 75 percent of the characteristic strength of concrete.

## RESULTS AND DISCUSSIONS

**Data Statistics**

The statistical descriptors of the dataset from USPV and the core test results are presented in Table 1 for the core locations.

Table 1 Statistical Properties of the USPV and Core Test Results: Core Locations

| STATISTICS | USPV (KM/SEC) | CORE (MPA) |
|---|---|---|
| Mean | 4.07 | 30.31 |
| Median | 4.10 | 28.95 |
| Standard Deviation | 0.42 | 7.42 |
| Coefficient of Variation | 0.10 | 0.24 |
| Minimum | 3.13 | 17.23 |
| Maximum | 4.82 | 45.55 |

### Compressive Strength from Correlation Expression from Literature

The compressive strength of concrete is estimated from the three expressions discussed above for all the core test location. The statistical descriptors for the estimates of compressive strength from the correlation expressions and the core test results are presented in Fig. 1. The mean and median from all estimates from correlation equations are lower than the core strength, whereas the corresponding standard deviations are higher than the core strengths. The range of the estimates from correlation equations are higher than the core strength, mainly due to the low estimate for the lower values of the USPV.

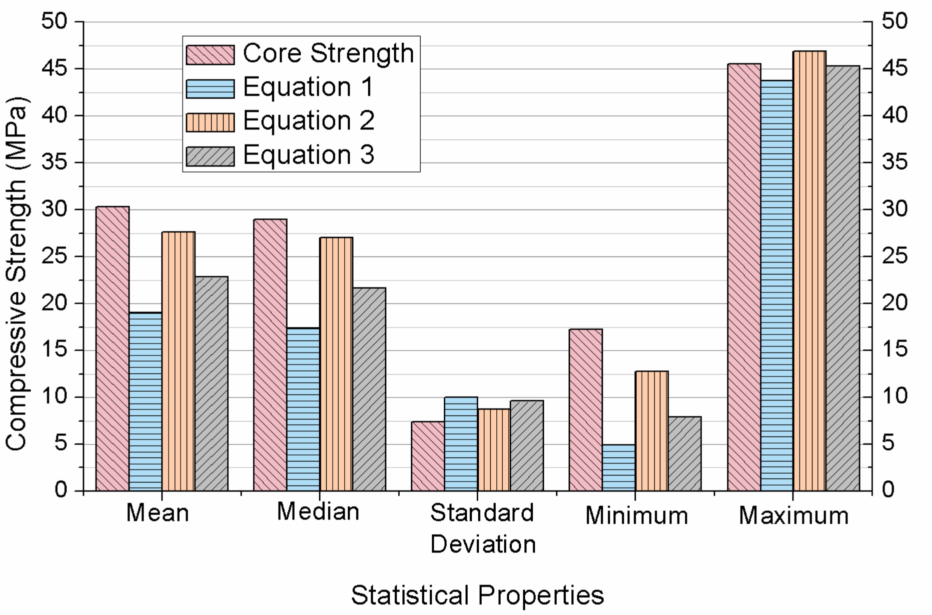


Figure 1 Estimates of Compressive Strength from Correlation Equations and Core Strength

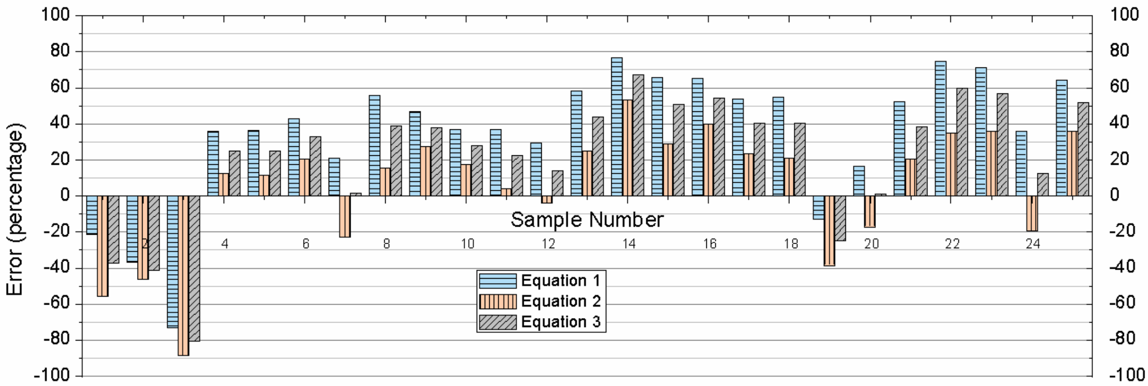


Figure 2 Errors in Estimates of Compressive Strength from Correlation Equations with respect to Core Strength

The errors associated with the individual estimates from the three correlation equations are depicted in Fig. 2. The statistical descriptors for the errors associated with the estimates of compressive strength from the correlation expressions are given in Fig. 3. It is noted that the mean, median, maximum and the standard deviation are all minimum for the equation no. 2, which was given for the site USPV measurements. Particularly because the standard deviation is least, the equation no. 2 appears to be the most appropriate for this structure. Further, the overall error estimates, namely, root mean squared error (RMSE) and mean absolute error (MAE), as listed in Table 2, indicate that the equation no. 2 is having the minimum values for both, thereby being the most suitable one for this particular case.

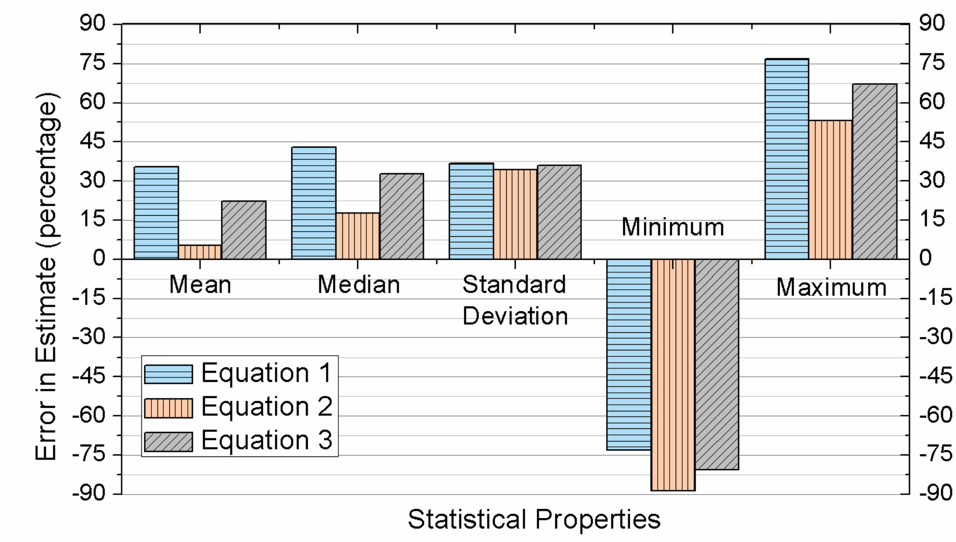


Figure 3 Statistical Properties of Errors in Estimates of Compressive Strength with respect to Core Strength

Table 2 Overall Errors in Estimates of Compressive Strength with respect to Core Strength

| OVERALL ERRORS | EQ. 1 | EQ. 2 | EQ. 3 |
|---|---|---|---|
| RMSE | 15.73 | 8.59 | 11.37 |
| MAE | 14.32 | 10.09 | 12.90 |

From assessment of the errors associated estimates of compressive strength with the three correlation expressions, is may be concluded that the expression in equation no. 2 gives the minimum positive error, the error margin being + 53% and – 89%. As conservative estimate of the characteristic strength of concrete in the structure is desired for the re-evaluation studies, the lower positive errors would be deemed better. From this consideration also, the equation no. 2 is better suited for the case. Hence, this expression is recommended for estimation of compressive strength of the structure from the USPV results, the exercise reported in the next section. The error range varies from that suggested in literature on the higher side, which could be attributed to the fact that the correlation expression used (Eq. 2) was developed from the results from a number of structures of different mix design, age and the state of health whereas this study was for a single structure.

**Characteristic Strength of Concrete for Structure from USPV**

From the most suitable correlation expression from literature (Eq. 2) identified in the earlier section, the equivalent compressive strength of concrete for the entire structure is estimated from all USPV reading and the statistical descriptors are presented in Table 3.

Table 3 Statistical properties of the USPV and Estimated Compressive Strength of Concrete for the Entire Structure

| STATISTICS | USPV (KM/SEC) | ESTIMATED COMPRESSIVE STRENGTH (MPA) |
|---|---|---|
| Mean | 4.33 | 34.10 |
| Median | 4.36 | 32.97 |
| Standard Deviation | 0.47 | 12.01 |
| Coefficient of Variation | 0.11 | 0.35 |
| Minimum | 3.13 | 12.74 |
| Maximum | 5.28 | 66.66 |

In accordance with the stipulations of the Indian Standard [IS 456: 2000], the characteristic strength of concrete is evaluated as follows:

i. Characteristic strength from average core strength: 40 MPa.
ii. Characteristic strength from minimum core strength: 17 MPa.

The final characteristic strength is equal to the minimum of the two above, which is equal to 17 MPa. This strength may be used in further analysis of the structure for health assessment studies with the knowledge that the strength might have a variation of around ± 20% according to the IS stipulations [IS 13311: 1992] or + 55% & - 90% according to the evaluation in the present study.

## SUMMARY AND CONCLUSIONS

In this study, the compressive strength of an existing concrete structure has been evaluated from the USPV and the correlation equations between USPC and compressive strength from literature. The estimates from three equations have been compared with the results of the core tests at the same location to evaluate the errors associated with the three equations. The most suitable expression is selected on the basis of the error study and the corresponding error margins have been noted. From the USPV for the entire structure, the compressive strength have been thereafter estimated, followed by estimation of the characteristic strength of concrete for the structure according to the national standard [IS 456: 2000]. From the study, the following conclusions are drawn:

- For the given structure, equation no. 2 (suggested for site USPV measurements) would be most suitable for estimation of compressive strength from USPV, as it yields minimum positive error, thus is the most conservative.
- The errors associated with the estimate of compressive strength of concrete in the structure from USPV using equation no. 2 would be around + 55% and – 90%.
- The characteristic strength of concrete evaluated from the compressive strength estimated from correlation with USPV for the structure is 17 MPa according to the national standard [IS 456: 2000].

The expression identified in this study could be used to evaluate the characteristic strength of concrete for the other structures in the facility, with the possible error margins indicated in this study.

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