A Review on Research into the Correlation between Concrete Strength and UPV Values

Naved Siddiqui *1, Rajat Palya*2, Dr. Arun Patel*3
M.Tech.Scholar*1, Asst. Professor*2, Professor*3,
Department of Civil Engineering, RKDF, University Bhopal, (M.P.) India.
Email id:- rajatpalya90@gmail.com*1 dreamsanchi@gmail.com*2

Abstract: *In this study, a relationship is determined between concrete strength and UPV (Ultrasonic Pulse Velocity) by using the data obtained from many cores taken from different reinforced concrete structures having different ages and unknown ratios of concrete mixtures. Also, a correlation is set up so as to find concrete strength-UPV relationship between the data obtained from the earlier laboratory researches on the concrete specimens with various mixture ratios. By processing correlation between these data sets, the best fit formula for the concrete strength- UPV relationship is obtained. Therefore, with this study, a general concrete strength-UPV formula is developed without taking the concrete mixture ratios into consideration. This new formula enables to find concrete strengths practically in existing concrete structures that their records of concrete mixture ratios are not available or not present. It can also be used in conditions that the number of the structures is too many and the time of the examination of them is too restricted.*

Keywords: *Ultrasounds; Non-destructive testing; Concrete*

I. Introduction

This template, modified in MS Word 2003 and saved as "Word 97-2003 & 6.0/95 – RTF" for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers [1, 2] and [3-5] The non-destructive testing (NDT) of concrete is of great scientific and practical importance. The subject has received growing attention during recent years, especially the need for quality characterisation of damaged constructions made of concrete, using NDT methods. Malhotra [1] presented a comprehensive literature survey for the nondestructive methods normally used for concrete testing and evaluation. Leshchinsky [2] summarized the advantages of nondestructive tests as reduction in the labor consumption of testing, a decrease in labor consumption of preparatory work, a smaller amount of structural damage, a possibility of testing concrete strength in structures where cores cannot be drilled and application of less expensive testing equipment, as compared to core testing. These advantages are of no value if the results are not reliable, representative, and as close as possible to the actual strength of the tested part of the structure.

Longitudinal ultrasonic waves are an attractive tool for investigating concrete. Such waves have the highest velocity so it is simple to separate them from the other wave modes. The equipment is portable, usable in the field for in situ testing, is truly nondestructive and has been successful for testing materials other than concrete. In addition, none of the available nondestructive methods for testing concrete strength is better. Nevertheless, there are intrinsic and practical factors that may interfere with the determination of concrete strength by ultrasonic means. Concrete is a mixture of four materials: portland cement, mineral aggregate, water and air. This complexity makes the behavior of ultrasonic waves in concrete highly irregular, which, in turn hinders nondestructive testing. In the view of the complexities of the problem it would appear to be overly optimistic to attempt to formulate an ultrasonic test method for the determination of concrete strength. However, considering the seriousness of the infrastructure problem and the magnitude of the cost of rehabilitation, major advancement is desperately needed to improve the current situation. For instance, it has been demonstrated

repeatedly that the standard ultrasonic method using longitudinal waves for testing concrete can estimate the concrete strength only with ± 20 percent accuracy under laboratory conditions [3]. Earlier researches [4-21] on finding the correlation between concrete strengths and UPV were generally limited to the specimens prepared in laboratory conditions. In these researches different correlation formulas were found for different concrete mixture ratios.

Furthermore, a general expression of a concrete strength and UPV correlation by not taking the ratio of concrete mixture and its age into consideration does not exits in these earlier researches [4-21]. In this research, a new correlation is found by comparing the strength-UPV relationship of concrete cores taken from existing reinforced concrete structures and the data obtained from specimens in laboratory condition which consist of different concrete mixture ratios. In earlier researches [4-21] the concrete mixture ratios were variable and the ages of the specimens were generally 28 days. Only one research [4] used a restricted amount of specimens with 28 years old. In this research, the ages of existing reinforced concrete structures taken cores ranges between 28 days to 36 years and their concrete mixture ratios are not known.

Unknown concrete mixture ratios in existing reinforced concrete structures are one of the most common issues that cause difficulties so as to determinate the strength-UPV relationship. In this respect, because of variability in the concrete mixture ratio findings obtained from laboratory researches [4-21] do not have a general pattern, the strength of concrete can not be determined appropriately. Thus, these findings can not represent a general way of analysis as well. In this research, a general best fit formula is developed by comparing the values obtained from existing reinforced concrete structures and the findings of earlier researches [4- 21]. Namely, a new general strength-UPV correlation formula is developed via analyzing the relationship between the curves obtained from laboratory experiments [4-21] and the curves obtained from existing reinforced concrete structures.

II. NDT testing of concrete using ultrasound

Among the available nondestructive methods, the ultrasonic pulse velocity tester is the most commonly used ones in practice. Test is described in ASTM C597 [22] and BS 1881-203 [23]. The principle of test is that the velocity of sound in a solid material, V, is a function of the square root of the ratio of its modulus of elasticity, E, to its density,.

$$V = f(gE/\rho)^{1/2} \quad (1)$$

where g is the gravity acceleration. Relationships among the pulse velocity of concrete, the strength of concrete and the modulus of elasticity of concrete are given in references [24-27]. In the test, the time the pulses take to travel through concrete is recorded. Then, the velocity is calculated as:

$$V = L/T \quad (2)$$

where V= pulse velocity (m/s), L= length (m), and T= effective time (s), which is the measured time minus the zero time correction. Numerous experimental data and the correlation relationship between strength and pulse velocity of concrete have been presented and proposed. Some figures suggested by Whitehurst[28] for concrete with a density of approximately 2400 kg/m3 are given as excellent, good, doubtful, poor and very poor for 4500 m/s and above, 3500-4500, 3000-3500 and 2000 m/s and below UPV values, respectively.

Based on experimental results, Tharmaratnam and Tan [29] gave the relationship between the ultrasonic pulse velocity in a concrete Vc and concrete compressive strength fc as:

$$fc = aebV \quad (3)$$

where a and b are parameters dependent upon the material properties.

Findings of different researchers' studies [4-21] on the relationships between the concrete strengths and UPV are shown in Figure 1. The specimens used in these researches were cube or cylinder shapes. Whole values of cylinder concrete strengths were given by converting them into standard cube of 15 cm length. These researches [4-21] have been processed on the different specimens prepared in laboratory conditions and have different concrete mixture ratios. As it is shown in Figure 1, strength-UPV curves of these values are different from each other.

Table 1: **Velocity Criteria For Concrete Quality Grading As per Table 2 of IS 13311 (Part 1) : 1992**

Sr. No.	Pulse Velocity by Cross Probing (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

III -Objectives Of The Study:

Objectives of the present work are summarized as following –

1. To find suitability of different non-destructive testing methods for evaluating the compressive strength of concrete.
2. To evaluate the advantages of UPV method over other non-destructive methods.
3. To compare the compressive strength of concrete by measuring UPV and density of concrete.
4. To find out a correlation between UPV and compressive strength of concrete.

IV- The method and discussion

A correlation is set up and showed in Figure 1 with the data obtained from earlier experimental studies [4-21] which are produced on specimens having dissimilar concrete mixture ratios. Because developing a correlation by ignoring concrete mixture ratios is the aim of this study, the ages and concrete mixture ratios of each specimens used in laboratory studies are not given.

So as to develop a new correlation on concrete strength-

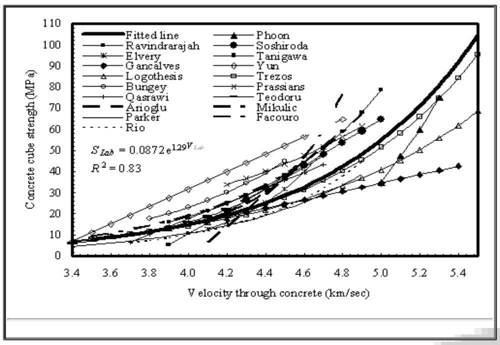

FIG. UPV relationship, the curve obtained from correlation

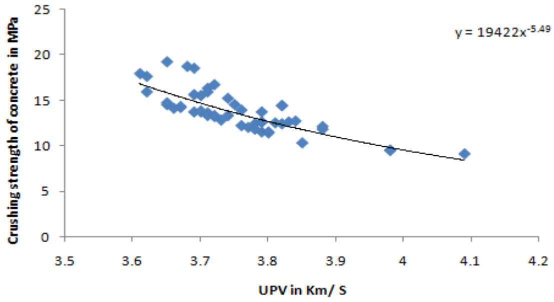

FIG. **Relation between UPV and crushing strength:-**

which represents the data produced in laboratories and the curve obtained from the correlation which represents the data produced from existing reinforced concrete structures are compared. For this process, from 30 reinforced structures which their ages vary between 28 days to 36 years old 82 cores were obtained. The densities of concrete cores vary between 1.88 and 2.60 gr/cm^3 . Records containing the aggregate proportions, the water- cement ratio and strength value for tested concretes were no available in structures tested for this study. The cores were obtained from columns, shear or retained walls in the concrete structures. The size of cores was 100x200 mm. There was no reinforcement present in the cores.

All cores were drilled horizontally through the thickness of the concrete elements. For determining of the compressive strength of cores BS 1881: Part 120: 1983 [29] and ASTM C 42-90 [30] procedures were used. Before the execution of destructive compressive test, the cores were tested, using ultrasound for the determination of the velocities of the longitudinal ultrasonic waves. The velocity of the propagation of ultrasound pulses was measured by direct transmission using a Controls E48 ultrasound device. This measured the time of propagation of ultrasound pulses with a precision of 0.1 s. The transducers used were 50 mm in diameter, and had maximum

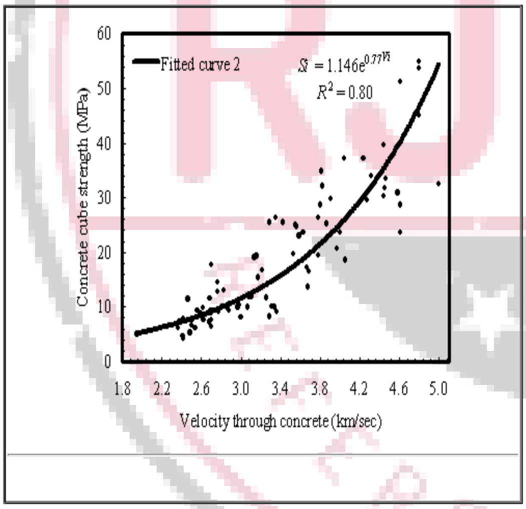

Fig. – Relation between UPV and crushing strength

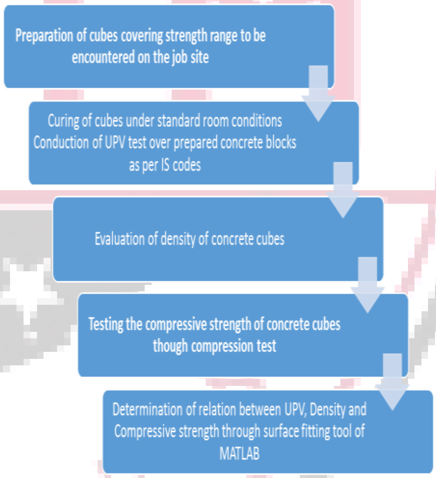

FIG. Following is the Flow chart of present study

resonant frequencies, as measured in our laboratory, of 54 kHz. The compressive strengths of the concrete cores were converted to cube with 15 mm side length.

The values of the ultrasonic pulse velocities lay within 1.8 and 5.0 km/s. The concrete cube strengths varied between 5.0 and 55.0 MPa.

A correlation is set up so as to find strength-UPV relationship between the data from the earlier laboratory researches and the best fit-curve representing the relationship is given as:

SLab = 0.0872e1.29VLab

Where, SLab and VLab respectively represent the strength and velocity obtained in laboratories. R2 value was found to be 0.83. In Figure 2 the strength-UPV relation that reflects the test results obtained from the cores obtained from existing reinforced concrete structures is shown. In here, the differences in strength and UPV values of cores stem from having different concrete ages and mixture ratios. Variation in tested cores' mixture ratios result in obtaining different strength-

UPV correlations. In this respect, these data can be used in terms of controlling the reliability of the curves which show the correlation studies held in laboratories [4-21].

The correlation set up the data shown in Figure 2, represents the most appropriate strength- UPV relationship as:

Si = 1.146e0.77Vi

where, Si and Vi respectively represent the strength and velocity obtained from existing reinforced concrete structures. R2 value was found to be 0.80. Although their standard variations and strengths are different at the beginning, curves obtained from earlier researches and existing reinforced concrete structures increase parallel as it seen in the Figure 3.

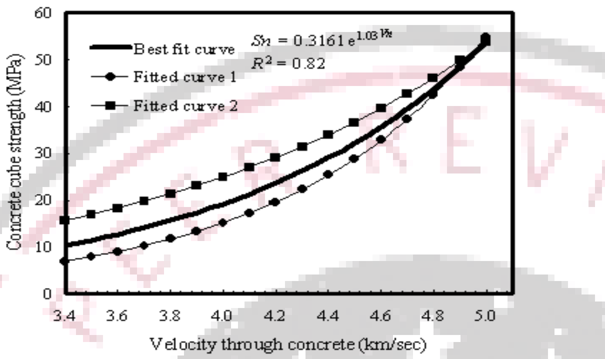

Fig.3. Comparison of results from earlier works [4-21] and existing reinforced

The behind this should be depends on two reasons. First, most of the cores having up to 4,3 km/sec velocity were collected from comparatively old aged existing reinforced structures.
However, earlier researches [4-21] are depended on specimens which are 28 days old. Namely, it is thought that the difference between this study and earlier ones' [4-21] core strengths up to 4,3 km/sec is because of differences in the ages of the specimens used. Secondly, the compressive strength tests and UVP tests of cores from existing reinforced structures are measured with their natural humidity. However, specimens tested in laboratories have more humidity as content. As it is known, compressive strength of wet concretes is less than dry ones but their UPV values are high [5,32]. As a consequence, difference between values of cores taken from existing reinforced structures and values of specimens prepared in laboratories is inevitable.

In Figure 3 the most appropriate curve is found and shown depending on the correlation between the curve obtained from existing reinforced structures and the curve obtained from studies on laboratory originated specimens. Depending on these curves the best fit formula is found as:

Sn = 0.3161e1.03Vn

where, Sn and Vn respectively represent the new strength and velocity values. R2 value was found to be 0.80. As shown in Figure 3, the curve obtained from existing reinforced structures and the curve obtained from laboratory originated specimens lay and increase parallel between the values of 3.4 km/s and 4.3 km/sec. Between 4.3 km/s and 5.0 km/s these curves begin to approach as the velocity increase. They converge at the value of 5,00 km/sec. This shows that high strength concretes are more uniform than the less strength concretes. As a consequence, it can be claimed that in concrete strength-UPV test increasing velocity decreases the error.
Thus, the curve obtained from the correlation of existing reinforced structure and laboratory originated specimens can be used in terms of finding the approximate value of concrete strength.

V. Conclusions

From this study it can be concluded that:

In earlier researches [4-21] there is not a general formula representing the concrete strength by using UPV test. Although the studies made with UPV test, until now, have depended mainly on materials which were concrete, each study found different strength-

UPV correlations. This variation, shown in Figure 1, comes in to being because specimens used in laboratory experiments have different concrete mixture ratio. Difference in their wetness and dryness causes a variation as well.

In this research it is verified that, shown in Figure 3, both tests on concrete specimens used in earlier researches [4-21] and on existing reinforced concrete structures represent that value of UPV increases as the concrete strength increases.

Depending on Figure 3 it may be claimed that using UPV tests on high strength concretes is more reliable.

Strength-UPV relationship obtained from laboratory originated specimens is calibrated with the test results of the cores from existing reinforced concrete structures.

With the formula Sn = 0.3161e1.03Vn, obtained with the correlation of earlier researches' findings and this study's findings, approximate value of compressive strength in any point of concrete can be practically found with ignoring the mixture ratio of concrete through using only longitudinal velocity variable (Vn).

V REFERENCES-

Malhotra V. M. (Ed.), Testing Hardened Concrete: Non-destructive Methods, ACI, monograph No. 9, Detroit, US, 1976.

Leshchinsky A., Non-destructive methods instead of specimens and cores, quality control of concrete structures, In: Proceedings of the International Symposium Held by RILEM. Belgium, E FN SPON, U.K., 1991, pp.377-386.

Popovics S., Strength and related properties of concrete: a quantitative approach, New York: John Wiley Sons Inc., 1998.

Prassianakis I.N., Giokas P., Mechanical properties of old concrete using destructive and ultrasonic non-destructive testing methods, Magazine of Concrete Research, 55 (2003) 171-176.

Bungey J.H., The validity of ultrasonic pulse velocity testing of in-place concrete for strength, N.D.T. International 13(6) (1980) 296-300.

Facaoaru I., Contribution à i'étude de la relation entre la résistance du béton à la compression et de la vitesse de propagation longitudinale des ultrasons, RILEM 22 (1961) 125-154.

Trezos K.G., Georgiou K., Marebelias C., Determination of the in situ strength of concrete using the indirect methods of impact and the ultrasounds, Technika Chronika-Scientific Edition TCG 13 (1993) 27-41.

Mikulic D., Pause Z., Ukrainc V., Determination of concrete quality in a structure by combination of destructive and non-destructive methods, Materials and Structures 25 (1992) 65-69.

Logothetis L., Combination of three non-destructive methods for the determination of the strength of concrete, PhD Thesis:Athens, 1979.

Qasrawi H.Y., Concrete strength by combined non-destructive methods simply and reliably predicted, Cem Concr Res 30 (2000) 739-746.

Ravindrarajah R.S., Loo Y.H. and Tam C.T., Recycled concrete as fine and coarse aggregates in concrete, Magazine of Concrete Research 39 (1987) 214-220.

Goncalves A., In situ concrete strength estimation. Simultaneous use of cores, rebound hammer and pulse velocity, In: International Symposium NDT in Civil Engineering. Germany, 1995, pp.977-984.

Soshiroda T., Voraputhaporn K., Recommended method for earlier inspection of concrete quality by non-destructive testing, Concrete Durability and Repair Technology (1999) 27-36.

Phoon K.K., Wee T.H., Loi C.S., Development of statistical quality assurance criterion for concrete using ultrasonic pulse velocity method, ACI Material Journal 96 (5) (1999) 568-573.

Elvery R.H, Ibrahim LAM., Ultrasonic assessment of concrete strength at early ages, Magazine of Concrete Research (1976) 181-190.

Teodoru, G.V., The use of simultaneous nondestructive tests to predict the compressive strength of concrete, ACI SP-112 ,1998,137-152.

Tanigawa Y, Baba K, Mori H., Estimation of concrete strength by combined nondestructive testing method, ACI SP-82, 1984, pp.57-76.

Parker W.E., Pulse velocity testing of concrete, Proc Am Soc Test Mater 53 (1953) 1033-1042.

Yun CH, Choi KR, Kim SY, Song YC., Comparative evaluation of nondestructive test Methods for in-place strength determination, ACI SP 112-6 1988.

Rio, L.M., Jimenez, A., Lopez, F., Rosa, F.J., Rufo, M.M., Paniagua, J.M., Characterization and hardening of concrete with ultrasonic testing, Ultrasonics 42 (2004) 527-530.

Arioglu, E., Arioglu, N., Testing of concrete core samples and evaluations, Evrim Publisher, Istanbul, 1998.

ASTM C 597-83, Test for pulse velocity through concrete, ASTM, U.S.A., 1991.

BS 1881-203, Recommendations for measurement of velocity of ultrasonic pulses in concrete, BSI, U.K., 1986.

A. Nilsen, P. Aitcin, Static modulus of elasticity of high strength concrete from pulse velocity tests, Cem Concr Aggr 14 (1) (1992) 64-66.

R. Philleo, Comparison of results of three methods for determining Young's modulus of elasticity of concrete, J Am Concr Inst 51 (1955) 461-469.

M. Sharma, B. Gupta, Sonic modulus as related to strength and static modulus of high strength concrete, Indian Concr J 34 (4) (1960) 139-141.

ACI 318-95, Building Code Requirements for structural concrete, (ACI 318-95) and commentary-ACI 318R-95, ACI, U.S., 1995.

E. Whitehurst, Soniscope tests concrete structures, J Am Concr Inst 47 (1951) 433- 444.

K. Tharmaratnam, B.S. Tan, Attenuation of ultrasonic pulse in cement mortar, Cem. Concr. Res. 20 (1990) 335-345.

BS 1881: Part 120: 1983, Method for Determination of Compressive Strength of Concrete Cores, BSI, U.K., 1983.

ASTM C 42-90, Standard test method for obtaining and testing drilled cores and sawed beams of concrete, ASTM, U.S.A., 1992.

Popovics, S., Effect of curing method and final moisture condition on compressive strength of concrete, ACI Journal 83 (4) (1986) 650-657.