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Full Length Research Paper

Application of Schmidt rebound hammer and ultrasonic pulse velocity techniques for structural health monitoring

Mohammadreza Hamidian, Ali Shariati, M. M. Arabnejad Khanouki, Hamid Sinaei, Ali Toghroli and Karim Nouri

Department of Civil Engineering, Kerman Branch, Islamic Azad University, Kerman, Iran.

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The concept of nondestructive testing (NDT) is to obtain material properties of "in place" specimens without the destruction of the specimens and to do the structural health monitoring. Ultrasonic pulse velocity (UPV) used together with Schmidt Rebound Hammer (SRH) tests give a combined test method for health assessment by a suitable correlation between these two tests along with test by compressive testing machine. The structural health monitoring by NDT methods comprised of UPV and RSH were carried out in laboratory and site. The experimental investigation using NDT methods showed that a good correlation exists between compressive strength, SRH and UPV. The SRH offers method of achieving concrete strength with accuracy of ±15 to ±20 parent and the UPV method is a perfect instrument for both existing structures and those under construction with accuracy within ±20%.

Key words: Ultrasonic pulse velocity, Schmidt rebound hammer, laboratory, site, experimental investigation.

INTRODUCTION

Since the beginning of the 20th century, concrete became the main building material for most construction. Studying many buildings made with concrete showed that the concrete can be sensitive to the deterioration in different situation so the assessment and rehabilitation of concrete buildings is of important issues. Assessment can be very useful for the recognition of potential damage to structures and to identify the causes of its probability (Shariati et al., 2011; Hamidian et al., 2011). The purpose of this investigation based on non-destructive testing (NDT) is to access information and the structural health monitoring for concrete structures especially in the case of historic structures. The benefit of the NDT investigation which avoids damage of structure is of an important issue of this investigation. The ultrasonic pulse velocity and Schmidt rebound hammer were being used for this investigation. These methods are used quite a long time for damage analysis, cracks, voids and other deterioration of concrete structures. However, in an extreme environment having higher humid in the atmosphere, high level of pollution, presence of CO_2 and chloride contents in the atmosphere, NDT by ultrasonic pulse velocity or rebound hammer can be effectively used to predict the service life of the structure apart from quality control for new or old structures as structural health monitoring as well. Also, another important factor which can be tested by NDT methods is to find out the homogeneity of the concrete.

Concrete is a heterogeneous material with cement, fine and coarse aggregate along with super plasticizers which influences the properties of the concrete by variation of elastic stiffness and mechanical strength (Mirmiran and Wei, 2001). With so much of variable factors, NDT methods become quite helpful to establish a correlation between UPV and SRH readings to measure the quality of the concrete. The test results were used to draw a correlation between NDT methods and studying the effects of variable factors such as admixtures on strength and homogeneity of the concrete. Comparison between compressive strength by SRH, UPV and compressive

*Corresponding author. E-mail: mhamidian1390@gmail.com.

testing machine and also establishment of a combined test method of both NDT methods to assess the strength and quality of the concrete were conducted.

TEST METHODOLOGY

Investigations were carried out in two phases by designing various mix proportions for concrete cubes in laboratory and also testing of the columns, beams and slabs of an existing building using one of concrete mix properties for accurate comparison. Tests on cube specimens were made of concrete cube with 150 × 150 × 150 mm dimensions. The concrete mix proportion was made for different mix design of concrete. The materials used for the mix were OPC cement, river sand, crusher broken granite coarse aggregates of 10 and 20 mm size, superplasticizer of poly carboxyl (PC) based for water reducing of concrete mix. All details of concrete mixes are given in Table 1. The NDT tests were carried out according to ASTM (ASTM C: 597). The age of 7, 28 and 90 days for concrete cubes were chosen by compressive testing machine, SRH and UPV. These time periods were chosen since the UPV and SRH tests were unaffected between 3 days to 3 months (Mirmiran and Wei, 2001).

Comparison of compressive strength between ultrasonic pulse velocity, rebound hammer and compressive testing machine in laboratory

In the first phase of testing, the compressive strength of cubes were tested by RSH and UPV tests and correlated with compressive strength in compressive testing machine. A comparison of compressive strength between SRH, UPV and compressive testing machine for concrete with age of 7, 28 and 90 days is given in Figure 1. It shows that compressive strength by SRH is higher than compressive testing machine in all the samples. As SRH is based upon surface hardness, the compressive strength becomes higher in all the cases. SRH test results give a conservative value. On the other hand the compressive strength by UPV is near to compressive testing machine. Hence SRH strength can be used for general quality assurance purposes but due to age of the structures, the carbonation of concrete structures becomes more and at this state the SRH readings of carbonated concrete may become more (Qasrawi, 2000).

Comparison of compressive strength between ultrasonic pulse velocity, rebound hammer and compressive testing machine in site

In the second phase of testing, two double stories building were used for investigation by both NDT methods. The readings of SRH and UPV were obtained for each member of building, at different locations on the surfaces of members which have the same mix properties of sample 1 in Table 1. The cubes for comparison with this phase made from same quality of same concrete mix to be used in compression testing machine. The cubes were then loaded up to their ultimate stress and the strength was obtained. Figure 2 is a graph that is obtained between the predicted compressive strength by actual compressive strength of concrete and against SRH and UPV readings. The cubes were tested for compressive strength by compressive testing machine to develop a correlation with UPV for structural health monitoring. The correlation is shown in Figure 2 and the best fitted curve in this case is linear and having wider variations. However this correlation may not agree with the compressive strength obtained from SRH test. This is because the tests were carried out in laboratory control conditions whereas SRH for structural health monitoring at site may not have the same ideal conditions.

Theses graphs can be used to approximately predict the compressive strength of concrete. Although it gives fairly approximate results but it should be verified with some other tests.

Correlation between rebound hammer readings and UPV

Although SRH gives the compressive strength but UPV helps to determine the density, uniformity and modulus of elasticity of the concrete structures which are the factors for durability of the structures and also predicting the service life of the structures but compressive strength is one of the parameter which always has a prime importance for determining the quality of the structure (Aydin and Saribiyik, 2010; Oz and Turkmen, 2010). SRH gives the surface hardness in turn being correlated to the compressive strength by the best fitted curve equation as given in the digital rebound hammer instrument but this curve needs to be standardized as local conditions. As SRH is very much handy for determining the compressive strength, a correlation with UPV will be very much helpful for establishing the standardization of both NDT methods for better accuracy. A correlation showed in Figure 3 between compressive strength by SRH and UPV where a best fitted curve is drawn to show the relation between these two values. There is no much variation in the best fitted linear curve which shows that for the same UPV reading, there is a wide variation of compressive strengths which may not be true. Hence, result of SRH cannot be reliable only. It has to be further tested with UPV which gives the actual quality of the concrete.

TEST RESULTS AND DISCUSSION

The NDT readings were obtained during the investigations used for different concrete grades and different physical conditions. The corresponding actual cube strengths were reported and exponential expressions have been tried to correlate the NDT values and the cube strength to best fit through regression analysis. The best-fit expression is obviously the one which has correlation coefficient value nearly equal to 1.0. It was found that the correlation between UPV values and the concrete strength for any measurement made did not improve when such correlations were developed separately for different grades of concrete. It was then thought advisable to determine expressions, which would be identical for all grades of concrete as considered in the present investigation. Separate expressions were, however, determined for different measurement modes and physical conditions.

Conclusion

The structural health monitoring by use of nondestructive testing such as ‘ultrasonic pulse velocity’ and Schmidt Rebound Hammer were being carried out. The experimental investigation showed that a good correlation exists between compressive strength, Schmidt Rebound Hammer and ‘ultrasonic pulse velocity’. The Schmidt

Table 1. Concrete mix proportions.

Specimens	Ages (days)	Cement	Fine aggregate	Coarse aggregate	Water	Rebound hammer compressive strength (mpa)	Pulse velocity (m/s)	Concrete compressive strength (MPa)
1	07	1	2	4.6	0.5	25.3	4010	25.54
2	07	1	1.75	2.62	0.44	39.8	4154	35.87
3	28	1	1.75	2.62	0.44	41.7	4476	44.62
4	07	1	2	2.85	0.44	34.1	4285	31.64
5	28	1	1.85	3.99	0.54	27.3	4411	48.0
6	90	1	1.85	3.99	0.54	8477	4411	50.0
7	07	1	1.85	3.99	0.54	8138	4050	31.32
8	28	1	1.85	3.99	0.54	8300	4054	33.10
9	90	1	1.85	3.99	0.54	8022	4545	30.68

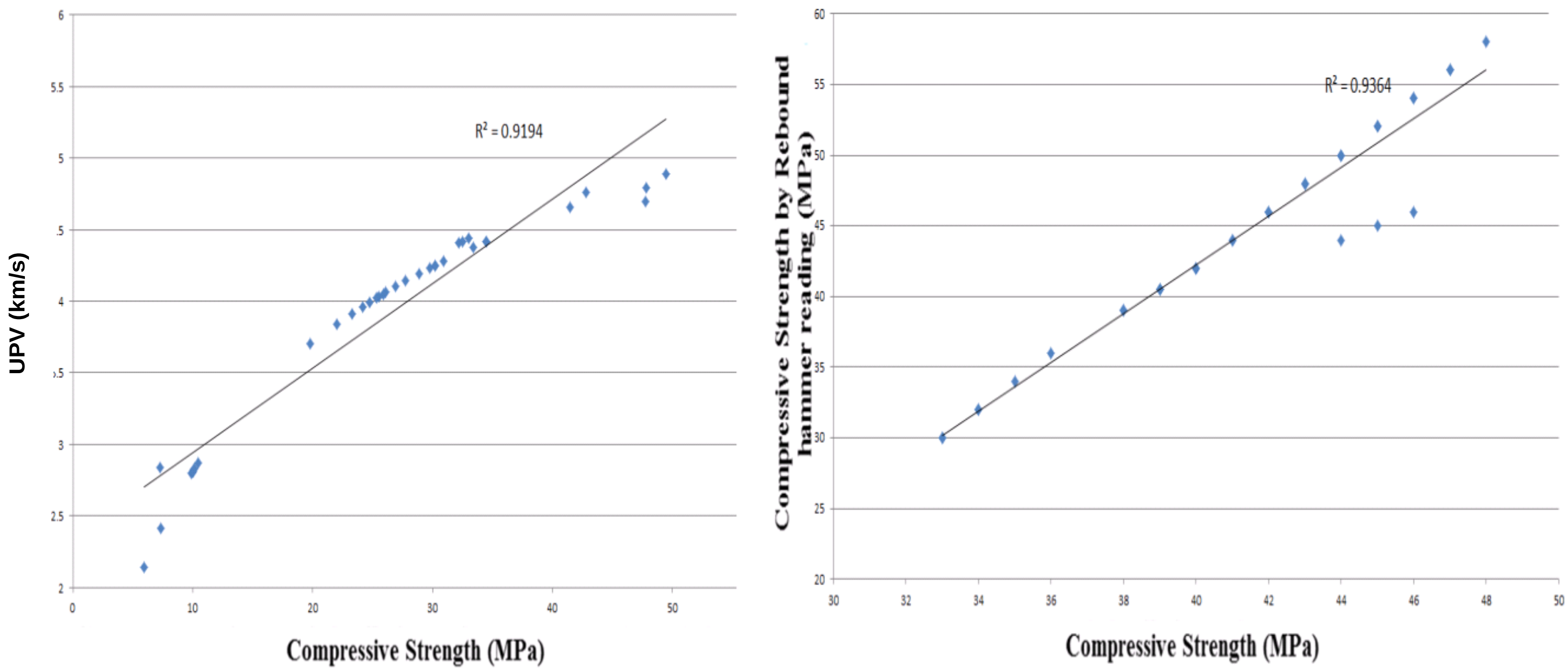

Figure 1. Laboratory comparison of test results between SRH, UPV and compressive strength testing machine.

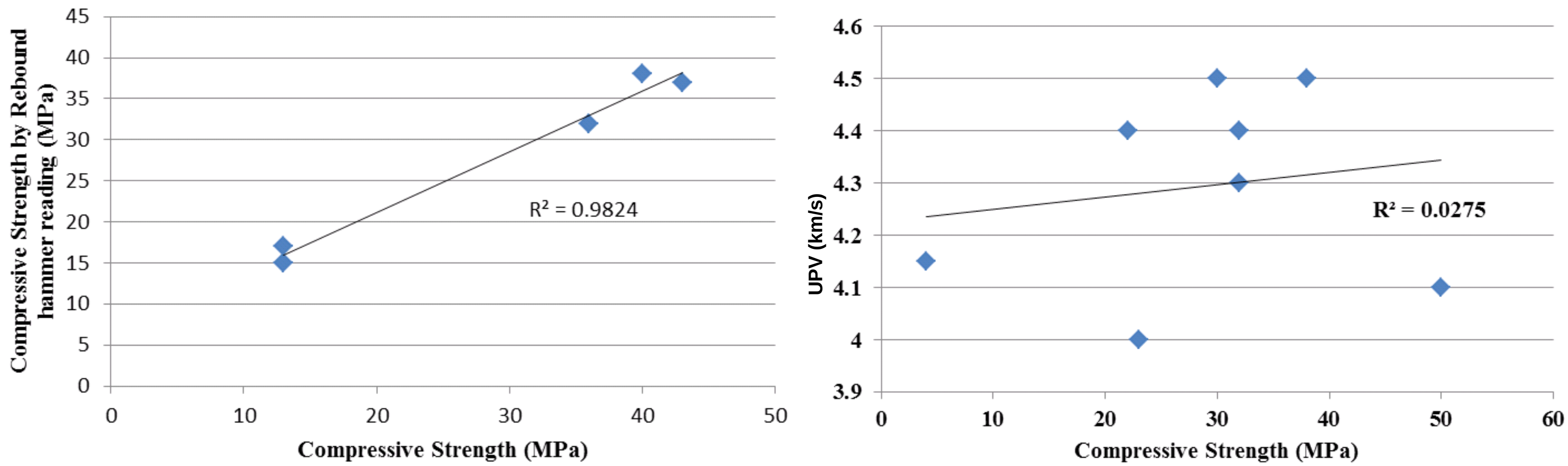

Figure 2. In site comparison of test results between SRH, UPV and compressive strength testing machine.

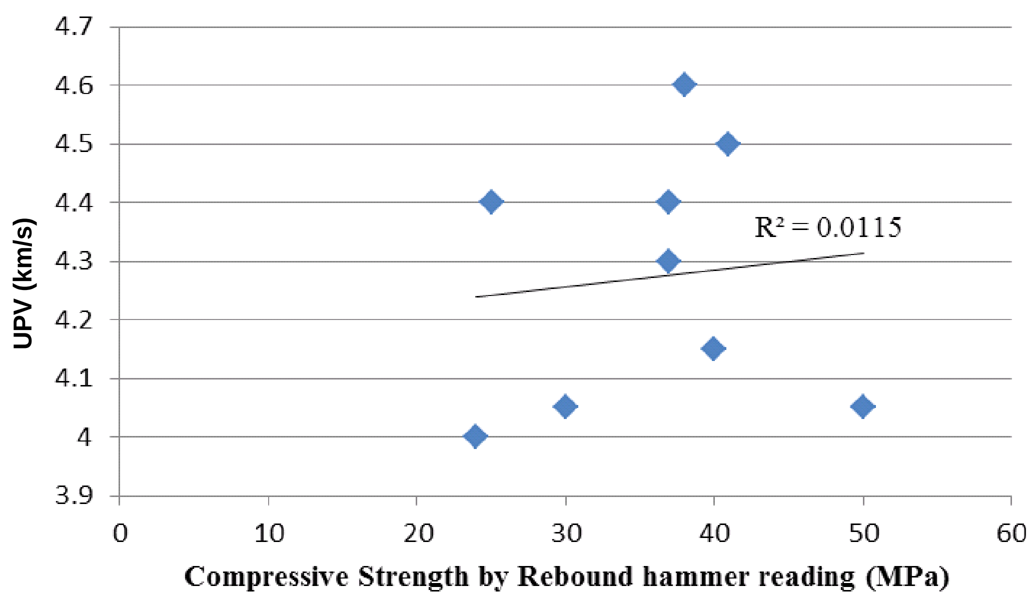

Figure 3. Correlation curve between UPV, SRH and actual compressive strength.

Rebound Hammer offers a cheap, simple and fast method of achieving concrete strength with accuracy of ±15 to ±20%. The 'ultrasonic pulse velocity method' is a perfect instrument for launching whether concrete is uniform. It can be used on both existing structures and those under construction. These relations enable the strength of structural concrete to be predicted within ±20% in this case. The deviation between actual results and predicted results may be attributed to the fact that samples from existing structures are cores and the crushing compressive cube strength was obtained by using various corrections. Also, measurements were not accurate and representative when compared to the cubes used for construction designs. The method can be extended to test existing structures by taking direct measurements on concrete elements.

The methods presented are simple, quick, reliable and covers wide ranges of concrete strengths and these methods can be easily applied to concrete specimens as well as existing concrete structures.

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