ULTRASONIC PULSE VELOCITY AND REBOUND HAMMER AS NDT TOOLS FOR STRUCTURAL HEALTH MONITORING

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[Paper published in the conference proceedings of International Conference NUiCONE 2010 at Institute of Technology, Nirma University, Ahmedabad from December 09-11, 2010]

Abstract
Structural Health monitoring with Rebound Hammer is being widely used by many consultants. But the rebound hammer should not be used alone for any old structures for predicting the service life or damage assessment. However Ultrasonic pulse velocity is more reliable for such purposes and can be used together with Rebound hammer tests. The present paper gives a combined test method for health assessment by a suitable correlation between these two tests along with test by compressive testing machine. A correction factor can be used for quick assessment of quality of the concrete by rebound hammer. Since concrete is a heterogeneous and affected by many factors any standard curve or established correlation can not be used while conducting these non-destructive tests.The co-relation has to be established between each pair of NDT instruments for structural health monitoring.

Keywords
Ultrasonic pulse velocity, Rebound hammer, Structural health monitoring, Service life

1.0 INTRODUCTION

The ultrasonic pulse velocity is being used for 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(Non Destructive Testing) by UPV(Ultrasonic Pulse Velocity) can be effectively used for changes in the structures occurring with time to predict the service life of the structure apart from quality control for new structures. Also, another important factor which can be tested by UPV is to find out the homogeneity of the concrete. As concrete is a heterogeneous material with cement, fine aggregate and coarse aggregate along with super plasticizers which influences the properties of the concrete by variation of elastic stiffness and mechanical strength. This variation is caused due to nature and proportions of materials, dosages of superplastisizer, water-cement ratio, cement aggregate ratio, method of compaction and curing and age of concrete. With so much of variable factors, NDT methods become quite helpful to establish a co-relation between pulse velocity and rebound hammer test to measure the quality of the concrete.

2.0 USE OF NDT FOR EVALUATION OF CONCRETE STRUCTURES

Concrete structures can be evaluated by UPV meter for quality control during construction of new structure and also periodical evaluation of the same member to

assess the deterioration of the structures to measure the changes occurring with time in the properties of the concrete and taking a remedial measure immediately without damaging the structure further by which service life of the member is extended. For quality control, results of UPV can be more reliable than usual procedure of sample testing by cubes or cylinders which is basically done in a controlled manner and may not give a true value of the quality of the concrete rather than giving the compressive strength which is only a single factor of quality control. There are so many factors which can not be found out from a cube or cylinder compressive test. Hence, UPV plays an important role for assessing the quality control of new structure and predicting the deterioration of the structure with time in an extreme environment [1]. However, there are so many variables which influence the matrix of materials of a heterogeneous concrete for strength, density which are important factors of a durable concrete. To study the influences of few variables which affects the concrete characteristics a laboratory investigation was made.

- The variables which were considered were water-cement ratio, cement-aggregate ratio, different types of super plasticizers and their varying percentage dosages, different mix proportions, and different methods of testing.
- The fixed parameters were type of cement, fine aggregate, water, curing condition, temperature and humidity, molding procedure, type of compaction etc.
- Mixes of different types of samples of cubes 150mmx150mmx150mm were casted [2].
- Different Non destructive testing methods such as compressive strength by Digital Rebound Hammer (PROCEQ), UPV (Pundit Plus) were tested [3,4] and Compressive strength was also tested by compressive strength testing machine (CTM) on same cubes.

The test results were used for following evaluations.

- To draw a correlation between UPV and RH tests.
- To study the effects of variable factors such as admixtures on strength and homogeneity of the concrete.
- To draw a comparison between compressive strength by Rebound Hammer & Compressive Testing machine.
- To establish a combined test method of RH and UPV to assess the strength and quality of the concrete.

3.0 EXPERIMENTAL INVESTIGATION

Laboratory investigations were carried out to establish the above results by designing various Mix Proportions and casting cubes samples of 150x150x150 mm with some variables and fixed parameters as explained earlier.

- The variables such as water/cement ratio were taken for 0.44, 0.50 and 0.54 with superplasticizers as water-cement ratio is the main factor governing the strength of the concrete.
- Cement-aggregate ratio variation was for 2.62, 2.85 and 3.99 because the cement aggregate ratio is responsible of pore structure of concrete and compacity of concrete.
- Two different types of superplasticizers which were used were SNF and Poly Carboxylic (PC) based because it helped to reduce to water-cement ratio which

helped to achieve higher compressive strength, homogeneity and higher density using variable dosages based upon type of superplasticizer to attain a minimum slump.

- The age of concrete cubes were considered for standard 7 days, 28days and 90 days for compressive strength by Compressive Testing Machine, Rebound Hammer and Ultrasonic Pulse Velocity meter. These time period was chosen as UPV and Rebound hammer Tests were unaffected between 3 days to 3months.

3.1Test Specimens

Test specimens were made of concrete cube of 150mmx150mmx150mm. The details of specimens along with their Mix proportions and showing W/C ratio and type of superplasticizer along with their percentage of dosages are provided in Table 1.The NDT tests were carried out as per IS 13311(Part1) and (Part2) [3,4].

3.2 Concrete Mix Proportion

The concrete mix proportion was made for Mix Design of M30 & M40 Grade of concrete as per IS 10262[2].The materials used for the mix were 43 Grade OPC Cement, Baitaran river sand, local available crusher broken black hard granite coarse aggregates of 10 & 20 mm size, superplasticizer of Dr.Fixit Hyper CF a Poly Carboxyl (PC) based water reducing admixture and Dr.Fixit Pidicrete CF 111 a modified Sulfonated Naphthalene Formaldehyde(SNF) based water reducing admixture along with their proportions are given in Table 1.

4.0 TEST RESULTS

Table: 1 Compressive strength Vs. Ultra Sonic Pulse Velocity of Cubes

Sl. No.	Days	Mix Design Cement: Fine Aggregate: Coarse Aggregate: Water (Admixture)	Weight of sample in(gm)	Digital Rebound Hammer Compressive Strength (MPa)	CTM Compressive Strength (MPa)	Pulse velocity m/s
1	07	1:2:4.6:0.50 (1.5%PC Based)	8340	25.3	25.54	4010
2	07	1:1.75:2.62:0.44 (0.84%PC Based)	8155	39.8	35.87	4154
3	28	1:1.75:2.62:0.44 (0.84%PC Based)	7966	41.7	44.62	4476
4	07	1:2:2.85:0.44 (0.7%PC Based)	8346	34.1	31.64	4285
5	28	1:2:2.85:0.44 (0.7%PC Based)	8025	27.3	48.0	4411

6	90	1:2:2.85:0.44 (0.7%PC Based)	8477	34.1	50.0	4411
7	07	1:1.85:3.99:0.54 (1%SNF Based)	8138	49.3	31.32	4050
8	28	1:1.85:3.99:0.54 (1%SNF Based)	8300	30.5	33.10	4054
9	90	1:1.85:3.99:0.54 (1%SNF Based)	8022	37.9	30.68	4545

5.0 ANALYSIS OF TEST RESULTS

5.1 Effect of admixture varying dosages on compressive strength and UPV

All the samples tested for ultrasonic pulse velocity ranges between 4000 m/s to 4600m/s which can be termed as very good concrete. Optimum dosage of PC based admixture was 0.7% for higher compressive strength. However, compressive strength increased by 24.4%from 7 days to 28 days with 0.84% PC based admixture and increased 50% with 0.7% from 7-days to 28-days.Also an increase of only 4.2% was noted from 28-days to 90 days strength which shows that there is no much strength improvement beyond 28-days as maximum hydration of cement paste takes place by 28 days which confirms the general property of the OPC cement of hydration (Fig.1).

However in terms of UPV with 0.84% PC there is an increase of compressive strength of 7.75% from 7-days to 28-days.Similarily with 0.7% PC based admixture, UPV results shows an increase of 2.94%from 7-days to 28-days.But after that there was no increase in UPV test results from 28days to 90 days.

For 1% SNF compressive strength increased by 7.4% from 28-days to 90-days.But at the same time UPV result increased by 12.2%.

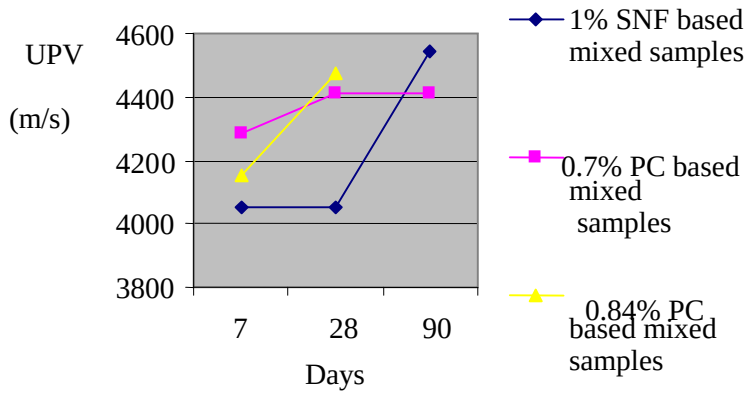

Fig.1 Variation of UPV with age for different dosages of admixtures mixed samples

5.2 Comparison of compressive strength between RH & CTM

The compressive strength of sample cubes were tested by Rebound hammer and correlated with ultrasonic pulse velocity meter test and followed by Compressive strength in CTM. A comparison of compressive strength between RH & CTM of 7,28 & 90 days is given in Figure 2.It shows that 7-days compressive strength by Rebound hammer is higher than CTM in all the samples whereas 28-days compressive strength by CTM is higher than that of Rebound hammer tests. As rebound hammer is based upon surface hardness the 7-days compressive strength becomes higher in all the cases. But the hydration of cement paste continues beyond 7-days for which 28-days strength becomes higher in all the samples by CTM tests. But Rebound hammer test results give a conservative value. Hence rebound hammer strength can be used for general quality assurance purposes. But due to ageing of the structures the carbonation of concrete structures becomes more and at this state the rebound hammer of carbonated concrete may become more. Hence the depth of carbonation has to be ascertained first for old concrete structures to find out the compressive strength by Rebound hammer otherwise a carbonated concrete will always give a higher rebound value. The carbonation can be tested by 1% phenolphthalein spray on the concrete surface. If the structure is carbonated then after spray the color will change to white from pink.

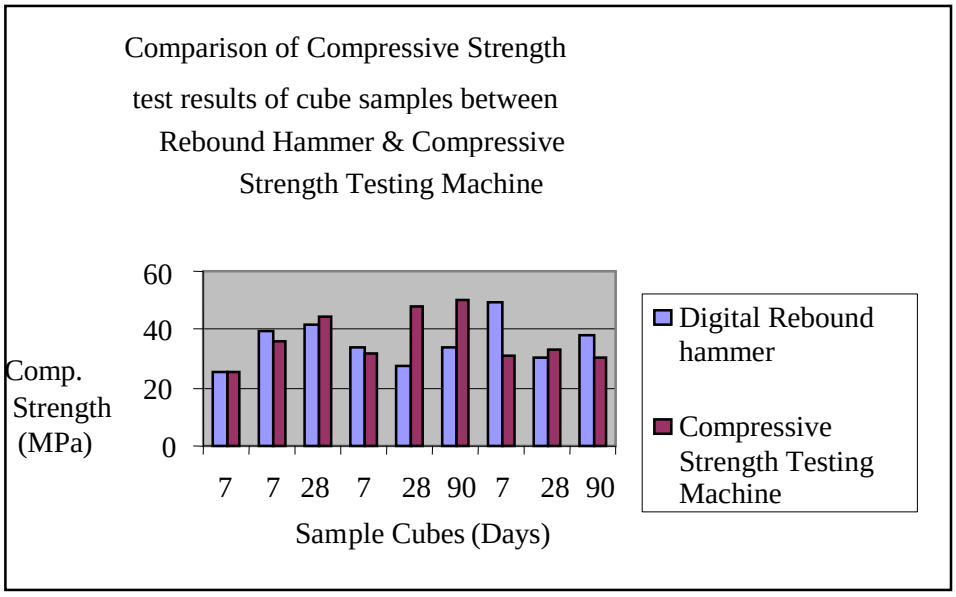

Fig.2 Comparison of Compressive strengths between RH & CTM

5.3 Co-relation between RH & UPV

Structural health monitoring of any structure is being carried out by Rebound hammer and ultrasonic pulse velocity meter. Though Rebound hammer gives the compressive strength but ultrasonic pulse velocity 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 is always has a prime importance for determining the

quality of the structure. Though Rebound hammer gives the surface hardness by measuring the rebound number which in turn being co-related 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 per the local conditions. As rebound hammer is very much handy for determining the compressive strength, a co-relation with ultrasonic pulse velocity will be very much helpful for establishing the standardization of both these NDT equipment for accuracy. A co-relation is shown in Fig.3 between compressive strength by rebound hammer test & 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 ultrasonic pulse velocity there is a wide variation of compressive strengths which may not be true. Hence result of rebound hammer can not be reliable only. It has to be further tested with ultrasonic pulse velocity which gives the actual quality of the concrete.

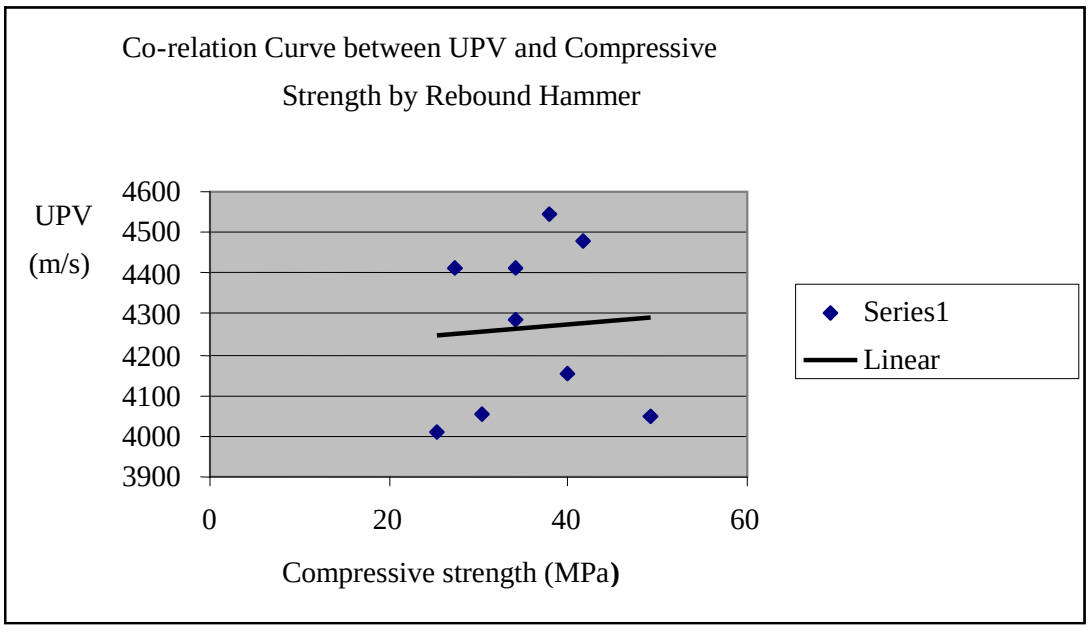

Fig.3 Co-relation between compressive strength by rebound hammer test & UPV

5.4 Co-relation between Compressive strength by CTM & UPV

The same cube samples were tested for compressive strength by CTM to develop a co-relation with UPV for structural health monitoring. The co-relation is shown in Fig.4.The best fitted curve in this case is linear and having wider variations. However this co-relation may not agree with the Compressive strength obtained from Rebound hammer tests. This is because the tests were carried out in laboratory control conditions where as rebound hammer for structural health monitoring at site may not have the same ideal conditions.

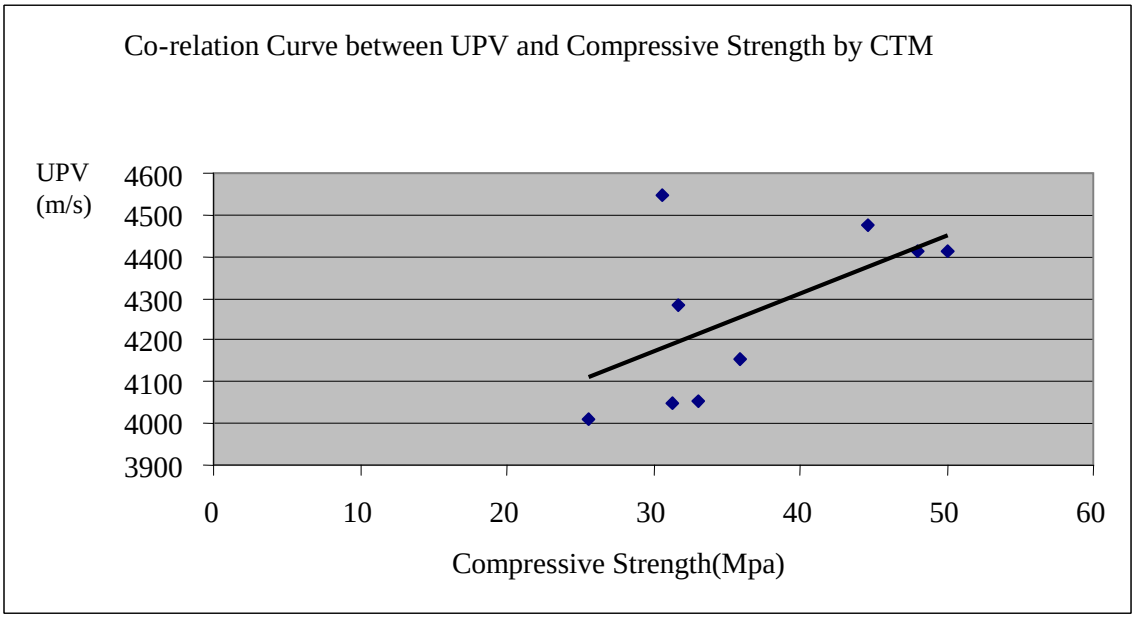

Fig.4 Co-relation between compressive strength by CTM & UPV

6.0CONCLUSION

The structural health monitoring by NDT methods such as UPV and Rebound hammer becomes very useful for predicting the service life of the structures and deterioration of the structures provided the periodical monitoring of the same member of the structures is being carried out. Since the concrete is heterogeneous and tests are affected by various factors such as age of the concrete, carbonation depth, reinforcement, cracks and voids inside the concrete, a combined test helps for assessment the strength and durability. The experimental investigation showed that a good co-relation exists between compressive strength, rebound hammer and ultrasonic pulse velocity. Nevertheless rebound hammer should be used alone to determine the compressive strength of the structures. Ultrasonic pulse velocity is the ideal NDT method to predict the deterioration in the structures and to determine the service life of the structures.

ACKNOWLEDGEMENTS

The author wish to give his sincere thanks to the staffs of Advance Diagnostic Laboratory of Dr. Fixit Institute of Structural Protection & Rehabilitation, Mumbai for conducting these laboratory investigations.

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