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# Combined Use of Non-Destructive Tests for Assessment of Strength of Concrete in Structure

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**Abstract**

Results of an experimental investigation on the effects of concrete materials-, mix- and workmanship-related variables, on the Rebound Number and Ultrasonic Pulse Velocity of concrete, are presented. The investigations aimed at developing a method of combined use of both the non-destructive tests for assessment of strength of concrete with greater accuracy. Workmanship variables included different lengths of moist curing, incomplete compaction and intentionally induced flaws. Rebound Hammer readings increased with the compressive strength of concrete. Ultrasonic pulse velocity values were greatly influenced by the cements and aggregate, extent of moist curing and presence of flaws and voids in concrete, more than their influence on the measured strengths. This demonstrates the limitation of using ultrasonic pulse velocity tests for estimating compressive strength of concrete.IS: 13311 advocates combined use of Ultrasonic pulse velocity (UPV) and Rebound Hammer tests for assessment of concrete strength in structures with greater reliability. However, the approach is qualitative. Adopting such an approach in a quantitative manner, multiple regressions of both Rebound Numbers and Ultrasonic Pulse Velocity on compressive strength of concrete, led to a series of graphs for better assessment of strength.

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*Keywords:* rebound number; ultrasonic pulse velocity(upv); flaws; moist curing; compressive strength.

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## 1. Introduction

The NDT of concrete in today's scenario has received a great importance in terms of practical and engineering value. The subject has received a growing attention during recent years, especially the quality characterisation of damaged structure made of concrete using NDT testing.

The advantages of Non Destructive tests as reduction in the labour consumption of testing (Malhotra 1976), a decrease in labour 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. Rebound hammer is useful to detect changes in concrete characteristics over time, such as hydration of cement, for the purpose of removing forms or shoring. This test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges.

The test procedure is described in IS:13311 Part 2 : 1992 and BS1881 202 (1986). It is portable, easy-to-use, low-cost, and can quickly cover large areas but it is valuable only as a qualitative tool since it measures the relative surface hardness of the concrete. Other tests, such as a compression test, must be used to determine the actual strength of the concrete. The rebound measurement is governed by several factors including the size, age, and finish of the concrete, as well as the aggregate type and the moisture content. A rebound hammer will give a false reading if used over exposed aggregate.

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 non-destructive and has been successful for testing materials other than concrete. The ultrasonic pulse velocity tester is the most commonly used ones in practice. Test is described in (IS: 13311 Part 1; 1992 and BS 1881-203; 1986). 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, coarse aggregate, fine aggregate and water. This complexity makes the behaviour of ultrasonic waves in concrete highly irregular, which in turn hinders non-destructive 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 (Popovics 1998). The use of UPV and rebound hammer has been experimentally investigated by inducing voids in the sample by Lorenzi (2009) and result showed the NDT data can be used to make trustworthy guess about concrete condition with damaging structural elements, if the defects are sizeable enough. The effect of admixture, different water cement ratio, its composition and ages of concrete can create uncertainties in the strength of concrete by Non destructive Testing (A. Benouis).

The use of Non –Destructive test has been discussed individually, but it is possible to use it more than one method at a time. This is advantageous when a variation in properties of concrete affects the test results in opposite direction. The increase in the moisture content increases the ultrasonic pulse velocity but decrease the rebound number recorded by rebound hammer (Bellander 1991).

Recommendations on the use of the combined use of non- destructive testing have been prepared by RILEM (1993). When variation in properties of concrete affect the test results, the use of one method alone would not be sufficient to evaluate the required property. Therefore, the use of more than one method yields more reliable results. Of a number of purely non-destructive tests, the rebound hammer and the ultrasonic pulse velocity combinations are the most commonly used. Attempts have been done to relate rebound number and ultrasonic pulse velocity to concrete strength as demonstrated (Qasrawi 2000, De Almeida 1991, and Khaeder 1998).

The influence of concrete materials, mix, workmanship related variables such as intentionally induced flaws, improper compaction and different lengths of moist curing on Rebound No. and UPV is studied. The aim is to develop correlation curves between compressive strength and NDT testing and to develop multiple regression curves from the results of UPV and Rebound Hammer in determining the compressive strength of concrete for better assessment.

## 2. Experimental Programme

### *2.1. Materials*

The material used are the two types of cement OPC and PPC , aggregate brought from two sources, Type 1-Aggregate locally from Guna (INDIA), and Type-2 Aggregate from Omkareshwar (INDIA). The testing of properties of both type of aggregate was done are shown in Table 1.

Table 1. Properties of Aggregate

| *Property* | *Type-1* | *Type-2* |
|---|---|---|
| Specific gravity | 2.72 | 2.75 |
| Water absorption | 1.60 | 1.45 |
| Crushing value | 27% | 17% |

### *2.2. Mix proportion of concrete*

The concrete mix design was done using IS 456:2000 and IS 10262:1982 and shown in Table 2.

Table 2. Mix Proportion

| *Parameters* | *M20* | *M30* | *M40* | *M50* |
|---|---|---|---|---|
| Cement(kg) | 350 | 375 | 425 | 450 |
| Fine Aggregate(kg) | 665 | 628 | 606 | 581.6 |
| Coarse Aggregate(kg) | 1332 | 1256 | 1211 | 1163 |
| Water(kg) | 175 | 169 | 157 | 158 |
| W/C Ratio | 0.5 | 0.45 | 0.37 | 0.35 |
| Silica fume(%) | - | - | - | 6 |
| Superplasticiser (%) | - | - | - | 5 |

### *2.3. Manufacture and curing of sample*

The concrete specimen of 150 mm cube of different design mix using different types of cement, aggregate, different curing conditions (7days wet + air curing , 28days wet + air curing) and then testing the cube specimens at different ages (7 days, 28 days and 56 days) was done.

The test procedures are as follows:

1. Four samples for each condition were casted; three out of them were for Non - Destructive testing and one for finding out the crushing compressive strength of concrete. Total of around 288 cubes were casted
2. The cubes were casted using the mix proportions as shown in Table 2.
3. At the time of casting , mixing was done using concrete mixer in which all ingredients were added
4. After ensuring proper mixing, the mix was put into the moulds and were kept on vibration table for proper compaction
5. Moulds were kept in air for 24 hrs so that the concrete is properly set and then cubes were taken out of the mould which is then cured in water tanks for different curing condition i.e. 7 days ,28 days and 56 days
6. After curing the cube is taken out and kept in air for sometime so that the surface gets dried
7. The samples are then tested for UPV and Rebound number by following Indian standards (IS 13311 Part 2 1992 and IS 13311 Part 1 1992).

## 3. Result and Discussion

All the readings of UPV, Rebound number, Crushing compressive strength were plotted together to get different relations. Following are the different results and plots:

1. Readings for different curing condition, ages and grades of concrete are shown in Table3.
2. The graph between Rebound number (R) with age (days) for different cement type with respect to 7 days wet + air curing was plotted. Fig.1 and Fig.2 shows that with age of the sample the rebound number(R) value increases for different grade of concrete, but for different cement type with respect to OPC the value of Rebound number is less at initial days for the same grade of concrete.
3. Similarly, graph between UPV (Km/sec) value and age (days) for different cement type i.e. OPC and PPC and 7 days wet + air curing was plotted. Fig.3 and Fig.4 shows that with age of the sample the UPV value increases for different grade of concrete, but for different cement type with respect to OPC the value of UPV is less at the initial stages for the same grade of concrete.
4. The next graph Fig.5 was plotted to see the difference between the readings for different samples of the aggregate. This was done for a single grade i.e. M30 and the readings were compared for 28 day curing.
5. A graph Fig.6 was plotted for M30 concrete mix, in this one plot was with flaw and the other without flaw; here flaws were induced manually by adding small rubber pieces. In this graph it can be seen that there is decrease in the UPV value when the flaws are added in the same mix, this is because when flaws are present in mix then the ultrasonic pulse takes more time to travel in the cube length hence decreasing the pulse velocity.
6. Two graphs were plotted as shown in Fig.7 and Fig.8 between UPV, Rebound number and crushing compressive strength of concrete. By these graph we can find out the compressive strength of concrete by knowing the readings of UPV and Rebound number. In the graphs we can see that with the increase in Rebound number there is an increase in compressive strength, so is the case with UPV.
7. We Compared our readings with the previously published research paper by Dr. Isam H.Nash't, Saeed Hameed in November 2005, In this paper they established relationships between:

   (i) Compressive strength and rebound number:

$$S_c = 1.19 \text{ EXP } 0.715U \qquad (1)$$

(ii) Compressive strength and UPV:

$S_c$=0.788 $R^{1.03}$ (2) (2)

Where, $S_c$ = compressive strength (MPa)

U= Ultrasonic Pulse Velocity (km/sec)

R= Rebound Number

We did the comparison for our M30 readings of PPC with the Eq.1 and Eq.2. shown in Table 4.

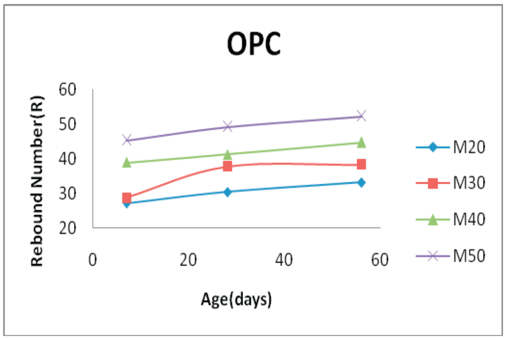


Figure 1. Relation between Rebound Number(R) and Age (days) for OPC cement

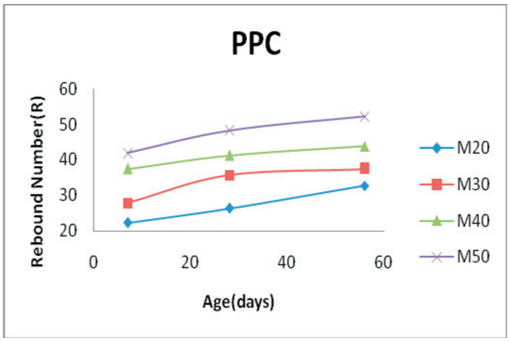


Figure 2. Relation between Rebound Number(R) and Age (days) for PPC cement

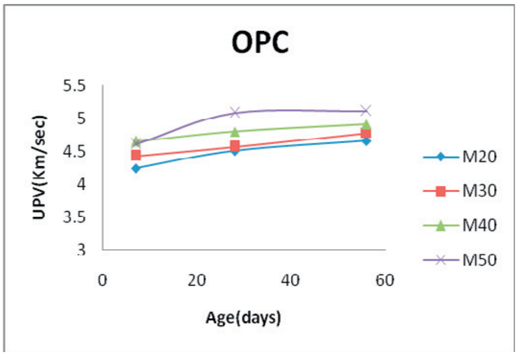


Figure 3. Relation between UPV(Km/sec) and Age(days) for OPC cement

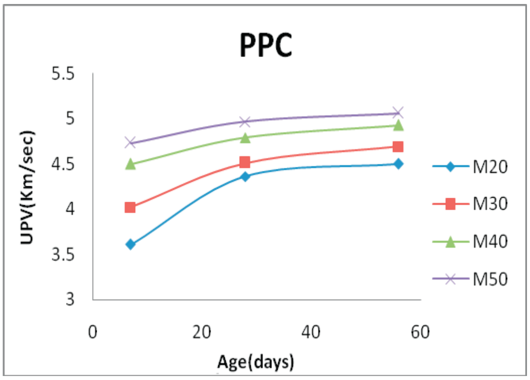


Figure 4. Relation between UPV (Km/sec) and Age (days) for PPC cement

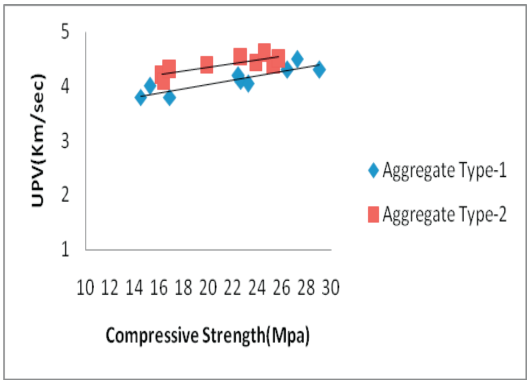


Figure 5. Relation between UPV (Km/sec) and Compressive strength (MPa)

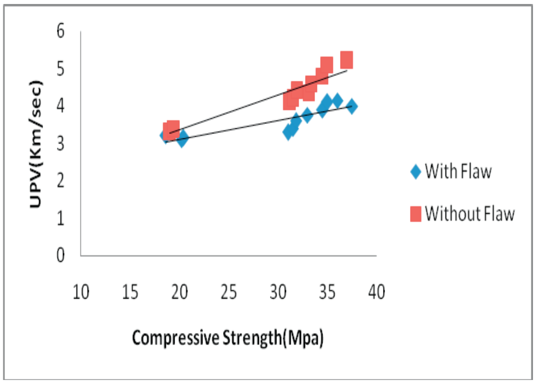


Figure 6. Relation between UPV (Km/sec) and Compressive strength (MPa)

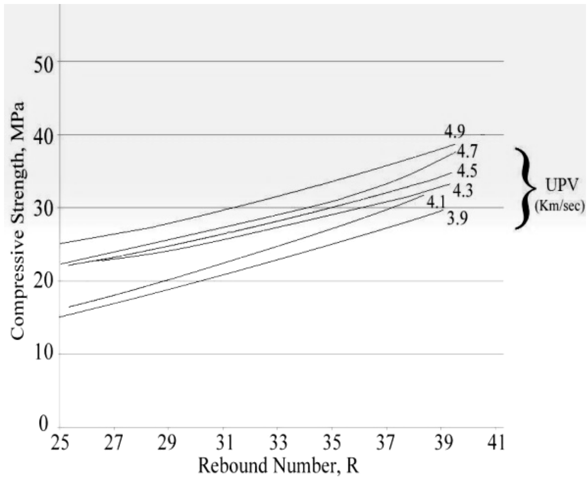


Figure 7. Correlation Curve between UPV, Rebound Number(R) & Compressive Strength

Table 3. Readings for different curing condition, ages and grades of concrete

| *Mix* | *Curing* | *Age* | *Ultrasonic Pulse Velocity (Km/sec)* | | *Rebound Number, R* | | *Compressive Strength (MPa)* | |
|---|---|---|---|---|---|---|---|---|
| | | | PPC | OPC | PPC | OPC | PPC | OPC |
| M20 | 7 Day wet +Air | 7 day | 3.61 | 4.24 | 22.26 | 27.26 | 16.22 | 17.81 |
| | | 28 day | 4.36 | 4.51 | 26.33 | 30.40 | 22.87 | 23.25 |
| | | 56 day | 4.50 | 4.66 | 32.66 | 33.25 | 27.92 | 29.32 |
| | 28 Day wet +Air | 28 day | 4.51 | 4.59 | 27.23 | 30.81 | 23.30 | 25.69 |
| | | 56 day | 4.91 | 4.96 | 29.90 | 33.14 | 28.50 | 30.38 |
| M30 | 7 Day wet +Air | 7 day | 4.02 | 4.43 | 27.83 | 28.71 | 20.13 | 21.10 |
| | | 28 day | 4.51 | 4.57 | 35.70 | 37.85 | 31.23 | 32.26 |
| | | 56 day | 4.69 | 4.78 | 37.46 | 38.40 | 33.89 | 36.15 |
| | 28 Day wet +Air | 28 day | 4.53 | 4.62 | 36.42 | 38.65 | 32.12 | 33.48 |
| | | 56 day | 4.78 | 4.85 | 40.63 | 41.50 | 37.28 | 37.65 |
| M40 | 7 Day wet +Air | 7 day | 4.50 | 4.65 | 37.38 | 38.96 | 31.83 | 33.70 |
| | | 28 day | 4.79 | 4.80 | 41.25 | 41.25 | 42.53 | 42.77 |
| | | 56 day | 4.93 | 4.91 | 43.81 | 44.74 | 44.75 | 45.81 |
| | 28 Day wet +Air | 28 day | 4.82 | 4.89 | 41.10 | 43.54 | 43.23 | 43.67 |
| | | 56 day | 4.96 | 4.91 | 43.97 | 46.65 | 45.74 | 46.97 |
| M50 | 7 Day wet +Air | 7 day | 4.73 | 4.61 | 41.95 | 45.22 | 41.06 | 43.72 |
| | | 28 day | 4.97 | 5.08 | 48.36 | 49.11 | 52.12 | 52.65 |
| | | 56 day | 5.06 | 5.11 | 52.21 | 52.25 | 54.96 | 55.82 |
| | 28 Day wet +Air | 28 day | 5.01 | 5.15 | 50.25 | 51.28 | 53.80 | 54.22 |
| | | 56 day | 5.10 | 5.22 | 53.36 | 53.48 | 59.33 | 58.93 |

Table 4. Comparision Table

| *Mix* | *Curing* | *Age (days)* | *Compressive Strength (MPa)* | *Calculated Compressive strength by Eq.1* | *Calculated Compressive strength by Eq.2* | *% Difference by Eqn.1* | *% Difference by Eqn.2* |
|---|---|---|---|---|---|---|---|
| M30 | 7 Day wet +Air | 7 | 20.13 | 21.08 | 24.23 | +4.5 | +16 |
| | | 28 | 31.23 | 29.92 | 29.51 | -4.3 | -5 |
| | | 56 | 33.89 | 34.03 | 32.9 | +0.4 | -2 |
| | 28 Day wet +Air | 28 | 32.12 | 30.35 | 31.97 | -5.83 | -0.4 |
| | | 56 | 37.28 | 36.29 | 35.78 | -2.7 | -4 |

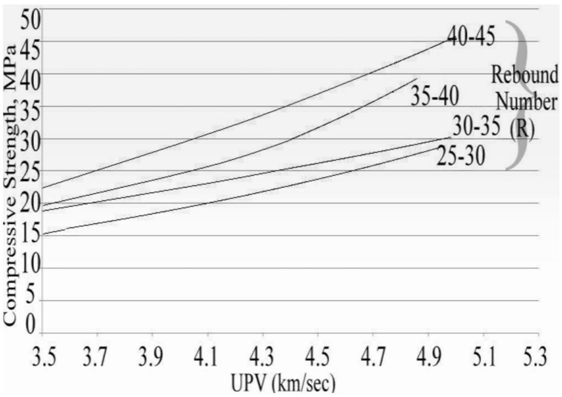


Figure 8. Correlation Curve between UPV, Rebound Number(R) & Compressive Strength

## 4. Conclusion

From the experimental study, we can derive the following conclusions:

1. The readings of UPV increases with age but the change is very small, reason behind it is that the density of the concrete remains same with the increase in age, so UPV alone cannot be used to find out the compressive strength.
2. The readings of rebound number increases with age, this is because hardness of concrete increases with age. We can directly determine the approximate value of compressive strength from the rebound number using the rebound hammer conversion chart.
3. Dependency on just one test method (Rebound Hammer Test or Ultrasonic Pulse Velocity Test) will not give accurate results, so we have developed a correlation curve between ultrasonic pulse velocity (UPV), rebound number (R) and compressive strength.

4. If we have the test results of rebound number and ultrasonic pulse velocity, then we can determine the value of compressive strength using correlation curve.
5. We compared our readings with the previously published research paper by Dr. Isam H.Nash't, Saeed Hameed in November 2005, and we found out that the difference was in the range of ±6%.
6. There is a decrease in the UPV readings when the flaws are added in the same mix, this is because when flaws are present in the mix then the ultrasonic pulse takes more time to travel the cube length hence decreasing the pulse velocity.

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