Non-Destructive Techniques for Evaluation and Health Monitoring of Concrete Structures- A Review

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Abstract: **Authorstried to present the methodologies, merits and demerits besides current work carried in the field of non-destructive techniques (NDT) i.e. ultrasonic pulse velocity (UPV) and rebound hammer (RH). These techniques permits the inspection of larger areas of concrete members at low cost and also provides more information than visual inspection. Influence of w/c ratio, method of casting, direction of casting, dosage of cement on NDT readings has been reported. The intent of this paper is to present the applications of UPV, RH and factors that influence the results. Care that need to take while conducting the NDT tests is also presented.**

Keywords- **NDT, Rebound hammer, Ultrasonic pulse velocity, Health monitoring of concrete structures**

I. INTRODUCTION

As per the latest reports of incident of a five storey building collapsed at JJ junction, Mumbai. Design life of this building were reported 70 years but it collapsed at the age of mere 40 years. Many such other incidents taken place in various corners of India and caused many causalities. It is therefore essential to test concrete structures using NDT before being occupied and at regular interval while in service, to determine whether the structure is suitable for its design use. Non-destructive testing is a method of testing in which the elements or members of structure tested remains totally undamaged. The various NDT techniques are discussed along with advantages, disadvantages and various factors that affects the accuracy of readings.

A. Rebound Hammer (RH)

Schmidt's rebound hammer developed in 1948by an Ernst Schmidt a Swiss engineer for testing concrete. When a sledge strikes surface, the degree of bounce back indicates hardness of material. It comprises of a spring control hammer that slides on a shaft. Hammer strikes up to the shoulder of plunger and it bounce back. The rebound distance travelled by a spring control mass is called the rebound index or number andis measured on a scale which is attached to a rider. Fig. 1 shows the working principle of rebound hammer. It is seen that, concrete with low strength absorbs more energy to yield in a lower rebound number and vice-versa. The standard guideline for RH are presented in IS 13311-2005 (part 2) [1]. This method is used for the purposes like compressive strength, uniformity of concrete, quality of concrete in relation to standard requirements. Though this is an easy and inexpensive method of estimating concrete properties but the results of the test on concrete are affected by various factors such as flatness of the surface, shape of the test specimen, age, external and internal moisture, aggregate type, cement, mould used [2]. It is therefore recommended that the standard rebound hammer test be used as a method of testing variability of strength properties between concrete samples rather than as a substitute for standard compression testing [3]. Since the RH is indicative of surface hardness and near-surface properties of concrete, it may not be indicative of bulk concrete in a structural member [4]. Now digital test hammers are also available which gives automatic calculation of mean rebound number and quick in giving accurate strength of concrete.

The surface condition i.e. dry or moist; a dry surface results in a higher number, presense of layer of corbonation increases the rebound number, roughness, even surface gives higher values and vice-versa, orientation of the instrument also affects the rebound number[5]. Fig. 2 shows the relation of rebound number and cube compressive strength for different orientation of hammer and different age of concrete.

Fig. 1Workingprinciple of rebound hammer [4]

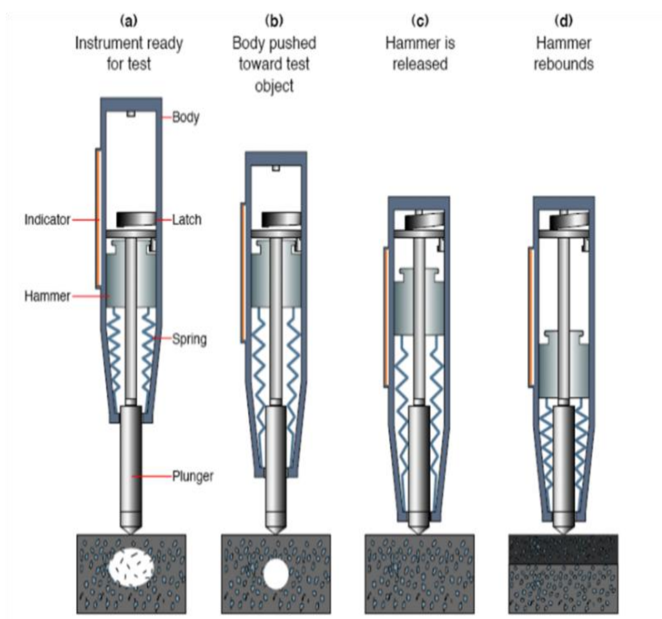
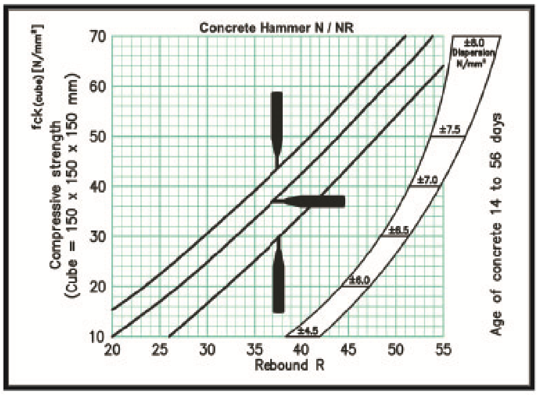


Fig. 2 Rebound number vs. compressive strength [5]



B. Ultrasonic Pulse Velocity Meter (UPV)

In the US, a Soniscope was developed in 1947 by Portland Cement Association incoopration with Ontario Hydro, and its field applications were reported [6]. This technique has increased significant nobility everywhere throughout the world.It includes an estimation of travel time over a known path length pulse of ultrasonic compressional waves.The pulse is produced by utilization of pulsegenerator circuit.The pulse generator circuit comprises of electronic circuit for creating pulses and a transducer. Piezoelectric transducer generate the pulses into concrete and other transducer acts a reciever to display the surface vibration. A timing circuit is used to measure the time for the pulse to travel from the transmitting to receiving transducers and the path length between the transducer divided by time of travel gives the average velocity of wave. Pulse displayed is analyzed to point out voids and internal discontinuities in the concrete. Fig. 3 shows the working principle of ulrasonic pulse velosity meter. Higher and lower velocity shows higher and lower quality respectively. The factors affecting mainly to concreteare types of aggregate, cement , w/c ratio, admixtures and age of concrete,[7]. Additionally, insertedrebars in the pulse path have hostile effect on the measurements of pulse velocity,[8]. UPV methods are excellent means for investigating the consistency and sturdiness of concrete.[6]presented the taxonomy for using pulse velocity to assess quality of concrete as given in Table 1. These values are only suitable for the concrete having density about 2400 kg/m^3. The velocity of sound in a solid material like concrete, Vis calculated from equation (1).

$$V = \sqrt{\frac{gE}{d}} \qquad (1)$$

Where; g= acceleration due to gravity m/s^2, V = L/T= pulse velocity (m/s), L = length of travel (m), T = effective time (s). Once the velocity is determined, the properties of hardened concrete can be attained, as per IS 13311(Part 1): 1992 [9]. Fig. 4 shows the relation of pulse veolity and compressive stregth of concrete.

From the comparisons of the direct, indirect (in the casting and horizontal directions) and semi-direct UPV measurements, Turgut and Kucuk [10] show that the average value of direct UPV higher than that of indirect UPV in the casting direction, indirect UPV in the horizontal direction, and semidirect UPV, respectively. They also oberved that average of indirect UPV in the horizontal direction is slghtly higher than that of indirect UPV in the direction of casting. The bleeding in the concrete caused the weak cement–aggregate bond and the planes of weakness. The void ratio in the horizontal plane of a concrete block were more than that of the vertical plane. Higher value of the indirect UPV in the casting direction were noted when compared to that of in the horizontal direction.

Table. 1 Classification of Concrete Quality Using Pulse Velocity [6]

Pulse Velocity (km/s)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

Fig. 3 Working principle of UPV

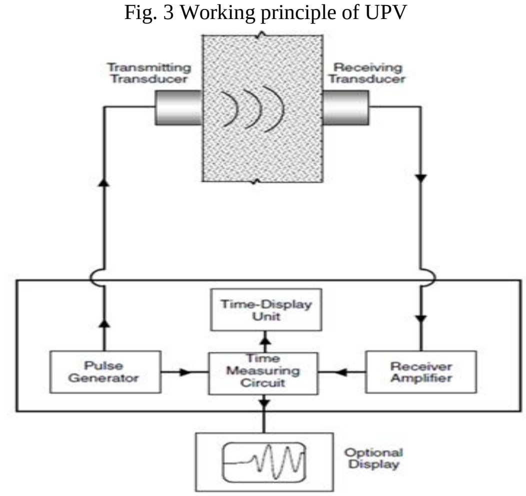
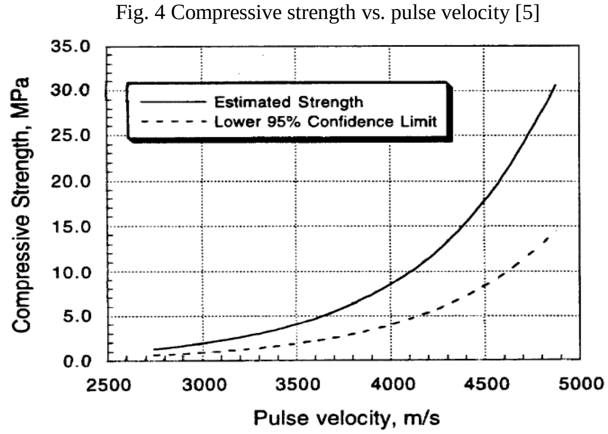


Fig. 4 Compressive strength vs. pulse velocity [5]



To the extent the advantage of the ultrasonic pulse velcity is concerned; it has high penetration power which guarantee simple estimation even for the very deep concrete members; it is exceedingly delicate in this manner giving exact outcomes; simple to use for evaluating the size, shape and nature of flaws in concrete member. This technique have a few disadvantages like; manual operation of the instrument requires watchful consideration by experienced technicians; if the surface is not regular, it is hard to calculate the pulse velocity precisely, need of calibration before every set of test.

II. LITERATURE REVIEW

Critical literature has been carried out to find out the utility and applications of various non-destructive techniques,[4] reviewedthe commonly used NDT of concrete structures. The various factors that subjective the accuracy of NDT are also discussed with alternatives to reduce these. Majority of NDT methods based on the tested parameters with established correlation curves. Relationship provide by manufacturers were found to provide unsatisfactory results. [11] proposed complete taxonomy of test methods for the diagnosis of concrete structures. They focused on suitability of the particular methods and techniques for assessing the durability of structures. They suggested the use of artificial intelligence for evaluation of strength of concrete structures. [12] discussed challenges in preserving ‘historic concrete’ with the help of case studies of productive corrosion condition assessments. Four case studies had been presented with various parameters affecting performance of structure. They used decision making process for evaluation of performance parameter of the structure. [13] presented comparison of properties of shotcrete assessed using destructive and non-destructive methods. They aimed to assess compressive strength of young shotcrete, core strength and compared these results obtained by non-destructive tests. They concluded that rebound hammer is more practically usable for strength evaluation of shotcrete while the use ultrasonic pulse is limited as it can be used indirect way only. [14] reviewed foreign publications in the experimental field on acoustic methods for the NDT methods of concrete. They presented methods of transmission like pulse-echo, and impact-echo methods and the effect of loading in the internal structure of concrete. Factors that affects the relation between the compressive strength and pulse velocity are also revealed. [15] presented use of non-destructive ultrasonic technique to measure the reflection loss of transverse waves at a concrete steel interface. They perceived that the loss of reflection is having linear variation to the strength gain of mortar and concrete at early ages. They also concluded that shape and the final value of the reflection loss curve are responsible to repeat wave reflection measurements on mortar. [16] performed correlations between various segregation indexes based on the percentage of the fine aggregates between top and the bottom of the samples to check whether ultrasonic pulse velocity is efficient or not. Based on the results from experiments conducted, they concluded that UPV method is a quick and easy method of testing segregation of both fresh and hardened concrete. [17] presented comparison between the results obtained experimentally and by NDT methods. They concluded that the results obtained by destructive test and non-destructive test are very close, only due care has to be taken in NDT methods to reduce the variation in the results [18] reviewed NDT methods appropriate to concrete bridge structures. They presented procedure, merits and demerits of a NDT method used. They proposed charts based on damage level along with the NDT method and potential remedial measures for periodic health monitoring of structures. They concluded that, for structures these are inaccessible, dynamic testing like infrared and radar technology are better than other NDT methods. For stone and masonry structures, whose detailsare not maintained or available, proof load test is a better option. [19] established a relation between the compressive strengths and values obtained by UPV and RH. Regression analysis is used to assess the strength and other parameters of concrete. They concluded that RH method were more effectual in calculating the strength parameters of concrete. They also suggested to use combined methods i.e. UPV and RH to have reliable results.[20] proposed an artificial neural network (ANN) approach for establishing relationship between concrete compressive strength, UPV and density values of experimental data obtained from cores taken from RCC structures. They concluded that ANN is an effective tool to predict the strength of concrete and having close results obtained by using UPV and density data. [21] reviewed non-destructive testing techniques in New Zealand building industry. It is used at two levels i) as quality control ii) as inspection tools for diagnostic proposes. He focused on study of NDT for mechanical testing of particle board floors; thermography and electrochemical techniques for quantifying the durability of paint coatings on materials and a vacuum decay techniques of moisture and that standard techniques for moisture and leak detection, concrete timber and steel testing are available and widely used in the New Zealand.[22] implemented statistical analysis and established the relationship between hammer rebound values/ultrasonic pulse velocities and compressive strength of concrete. They proposed use of artificial intelligence model using support vector machines (SVMs) for estimation of strength. They concluded that combined NDT method yields better estimation of strength than single NDT method. Also results obtained from SVMs found to be more precise than the statistical regression model.[23] evaluated the strength parameters of light weight aggregate concrete mixes by UPV. They tested various compositions of 30 to 80 MPa between 3 and 180 days. They reported various factors that influences the relation between UPV and strength. They found that lightweight and normal weight concretes are affected differently by mix design parameters. They also proposed simplified equations to estimate the compressive strength.

III. CONCLUSIONS

Based on the review conducted it is concluded that, following parameters must be taken into account while conducting the NDT of any concrete structures:

1. The surface of the element to be tested should be smooth, dust free and moisture free.
2. Loose plaster or cover should be removed before conducting the test.
3. Calibration of the instrument should be done before every set of test particularly in ultrasonic pulse velocity meter.
4. Orientation of rebound hammer affects the reading and hence approximate correction factors (provided by manufacturer) should be applied.
5. Transducers of UPV must be firm to the surface to ensure the accuracy of reading and should be placed away from embedded reinforcement as the pulse path get affected significantly.

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