

Non-destructive Testing of Concrete Cubes Under Various Curing Conditions: The Inaccuracies and Flaws



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1 Introduction

The non-destructive testing is used to ensure product integrity, manufacturing, in-service inspections and provides a quality level. However, the in situ concrete strength measurement is the main challenge in case of NDT [1]. Because, in the structural defects, material components strength deteriorating is due to improper mix ratios, poor quality material specifications, and inadequate supervision [2]. The strength of the concrete needs to be checked, and there are several methods of non-destructive testing that could determine the concrete strength. The ultrasonic pulse velocity and rebound hammer test offer a promising way among them to assess the concrete strength as it focuses on the elastic wave propagation and hardness of the concrete.

The concrete properties can be influenced by the atmosphere such as relative humidity, ambient temperature, and hot weather [3]. Several studies have been performed to determine the curing temperature effect on the concrete, and from these studies, the results indicated that curing period, type of the solidified sample, and environment and curing condition are the important parameter on concrete strength evaluation [4–6]. According to ACI 308R-01, minimum seven days curing is required to attain the compressive strength of concrete [7]. In these experiments, the idea is to find out the concrete strength under different curing periods along with different curing procedure by the RH testing and UPV and compared the result with the destructive compressive strength of concrete. The study also performs a specific test of ultrasonic pulse velocity on a larger concrete block with a comparatively larger void to find out the specific knowledge gap since the velocity determination by ultrasonic pulse velocity has a flaw in case the void is smaller in size.

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2 Methods and Materials

Depending of the design and material properties, RH testing comprises of direct mechanical solution. The hardness of concrete on the close surface connects to the mechanical solution for the RH estimation. The hardness of the concrete materials again depends on the porosity of materials as the porosity decreases the hardness increases and provides a consistency in the strength assessment. Due to the minimal expense of the procedure, the RH test is considered as one of the straightforward and non-ruinous tests for concrete structures. Ernst Schmidt developed the relationship in between rebound number of RH and the compressive strength. However, the relationship was not unique and needs to be adjusted with the gradation of the concrete and the shape of the structure. Utilizing information from 1 to 40 years of age structures [8], it has found that, equivalent solid strength, RH values are almost 4 points higher than the destructive compressive strength of concrete block.

Numerous variables may influence to an alternate degree concrete strength and hammer number. Their impact has been brought up and measured by numerous authors [9–11] and concrete hardness/thickness, age/carbonation of surface and close surface condition. Voids have high impact where presents extreme size of aggregate, surface routineness, and rugosity.

In the UPV testing, the speed of pulse wave is higher in the first few days after solidifying starts of the concrete blocks. The reason for the higher pulse wave may be related with the Young's modulus, as the wave speed is higher in the elastic media, and in the initial stage the concrete shows more elastic properties which expand the value of wave velocity [12]. So, the UPV results can be related with the strength of the concrete. Though the variation of the wave velocity with time is the major concern in the UPV testing method, the velocity depends on the curing procedure and it generally decreases with time [13]. Other factors may also influence the wave velocity, as in general, it shows higher velocity in the first few days and shows lower value after 5, 6 days [14–16]. These factors may vary from the water–cement ratio, aggregate shapes which are the most influential and rebar condition, and ingredients of cement mixture has lower impact on the wave velocity.

2.1 Materials Characteristics

In this experiment, M25 concrete cube had been used. The M25 stands for the targeted concrete cube strength will be 25 MPa after 28 days [17]. To maintain the quality, the targeted strength was determined 31.6 Mpa and the cube was prepared by maintaining water–cement ratio 0.45. The mixing ratio of cement, sand, and aggregate was maintained properly to achieve the desired strength. 20 and 10 mm two types of coarse aggregate were used.

Table 1 Number of cubes and the curing period

Sample no.	Type	Age of concrete cubes
1,2,3	1	3 days MWC + 3 days NC = Total age 6 days (varied curing)
4,5,6	2	7 days MWC + 21 days NC = Total age 28 days (varied curing)
7,8,9	3	11 days MWC + 17 days NC = Total age 28 days (varied curing)
10,11,12	4	14 days MWC + 14 days NC = Total age 28 days (varied curing)
13,14,15	5	3 days MBC Only = Total age 6 days
16,17,18	6	7 days MBC Only = Total age 7 days
19,20,21	7	14 days MBC Only = Total age 14 days
22, 23, 24	8	28 days MBC Only = Total age 28 days

2.2 Preparation and Curing Period of the Specimen

In the laboratory, the concrete mixtures were prepared at a room temperature of 24°. A total of 24 no. of cubes was prepared, and the total amount of approximately 40 kg of cement, 22 L of water, 67 kg of 20 mm aggregate, 45 kg of 10 mm aggregate and 65 kg of sand were mixed altogether. The casting molds were kept for 24 h to settle down and after that the molds were removed. The samples were then divided into eight different groups (types) where four types of samples kept into water for various days which is referred here as moisture water curing (MWC) and another four types of samples kept under buried moist soil condition for various days which is referred here as moisture buried curing (MBC). Samples, which were kept without curing, is referred as non-curing (NC). Their curing period has been enlisted in the following table (Table 1).

In this works, a pit size of 2 × 1.5 × 1 m was excavated and buried curing performed by placing cubes in the trail pit. Finally, another 24 blocks were kept under water and soil in different days to check the compressive strength of concrete blocks.

2.3 Calibrating the NDT Instruments

One of the fundamental steps for assessing the better grade of concrete properties is NDT equipment calibration. NDT examination includes the estimation, assessment, and analyzing the strength and property of the concrete structures. This estimation has several deficiencies because of different components associated with the investigation interaction. The nature of measurement recorded relies upon the adjustment of the instrument before it is taken on the site. For instance, rebound hammer before utilized on the genuine design or structure, correlation diagram is given on the instrument that is aligned utilizing the laboratory data of concrete blocks [18]. The crushing strength (f_c) is acquired from the chart given in the instrument manual or figuring

from model accessible from the literature. The quality as well as exactness of fc assessment depend on the accuracy of the calibration method and calibration information. Codes and norms additionally recommend calibration of rebound hammer instrument utilizing appropriate strategy and furthermore give calibration curves. The rebound hammer was calibrated in this investigation and correlated the Brinell hardness number of 5000 N/mm².

Accordingly, it is important to adjust the instrument accurately to include the uncertainties associated with the computation. Curve fitting along with regression analysis, artificial neural networks (ANN), and Bayesian methods has been used for the calibration purpose. The calibration charts and conversion models provide more accurateness in the measurement activity. The relationship in between UPV and water immersion and porosity provide a surface plot which help to find out the properties of the concrete materials [19] while the relationship of RN, UPV, and compressive strength of concrete cubes can be determined by 3D plots [20]. The European National code has been proposed for the calibration prior to the usage of the NDT equipment in each project [21]. Linear polarization resistance (LPR) based on Faraday's law and Flick's law has been developed for corrosion occurrence in the materials [22]. These different models suit to find out the real phenomena in the concrete materials, and with the help of this calibration, data known as model calibration determine the suitability of each model in various projects [23, 24].

2.4 Testing Procedure

The hardness and the strength in the cover of the concrete cube can be estimated by the RH test. A specific guideline has provided for the rebound hammer test [25]. The repetition of the RH test on the same cover and same side of the concrete block will decrease its acceptability rather than taking the correlation with the standard strength tests. For instance, if the N value changes in between 10 and 12 points, the results are obviously different.

When the rebound hammer was calibrated, for taking the readings purpose, the hammer was held at right angles to the surface of the concrete structure. The test then needs to be conducted horizontally on vertical surface along with vertically upward or downward on horizontal surfaces. The impact point was kept at least 20 mm away from edge on concrete surface to reduce the shape discontinuity effect on rebound hammer.

Later, UPV test is conducted on the concrete cube. The basic idea of this technique involves the wave propagation through the concrete material and measures the sound speed through transducers to predict the strength of the materials and evaluate the modulus of elasticity and find out the presence of internal damages such as voids, cracking which will affect the inner strength of the concrete and other damage due to the aging of the concrete materials. The main purpose of this method is in finding an areas of weak concrete and the changes in concrete condition of a sound structure.



Fig. 1 Ultrasonic pulse velocity testing

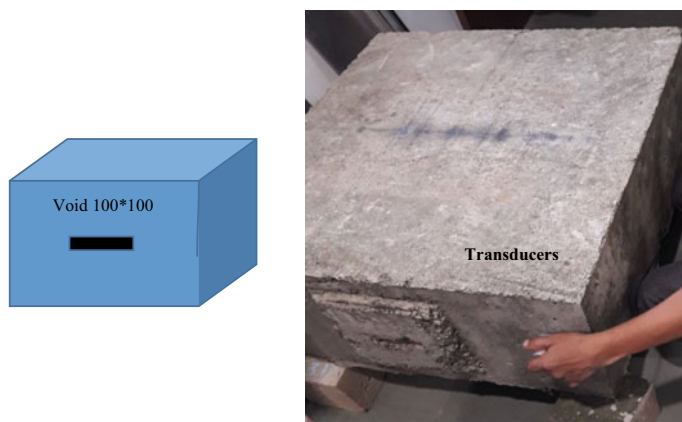


Fig. 2 UPV on a concrete slab

The test had been conducted in direct, indirect, and semi-direct method. In the direct method, it the sound measured by accessing direct contact of propagation and receiving on the transducers by placing it in the opposite direction of the concrete slab. In the semi-direct process, the sound path length was approximately equal to the distance of a third side of a triangle formed by the adjacent sides of a concrete floor (Fig. 1). In the indirect method, the testing requires access on the same surfaces, unless indirect (surface transmission) testing was done.

To compare the UPV which is the natural frequency of transducers (electroacoustical) being 55 kHz is being used in the test a larger concrete slab of 750(L) \times 750(B) \times 350(D) mm was used for the study [26]. Oscilloscope was used to study the change in wave effect. A center void on 100 mm width and 10 mm thick was present (Fig. 2).

3 Results and Discussion

In the rebound hammer test, the test result needs to be compared with the destructive compressive strength testing to get an idea of the testing accuracy.

The NDT testing is counted as a flawless testing; however, the prediction of concrete strength could be allowed $\pm 25\%$ of the actual compressive strength of the concrete. The accuracy is greatly increased if the core samples obtained from the structure and the rebound hammer test conducted on the specimen are made of same mix proportion and the same concrete materials.

In Fig. 3, the compressive strength for cube and hammer test had been gradually increased with curing period. In the x-axis, the sample type represents four types of varied curing for first figure and four types of moisture buried curing for second figure. Each type comprised of three cubes each in totalling of 24 cubes were tested both in cube and hammer test. The sample cubes of equivalent 14 days moisture curing and 14 days non-curing had showed the maximum compressive strength of approximately 32 MPa for both rebound hammer test and crushing cube test. At the same time, sample cubes of 14 days moisture buried curing (MBC) showed almost the maximum compressive strength compared to 28 days buried curing cubes. The compressive strength of cube decreased after 14 days in MBC. Due to non-uniformity in the materials and less voids detection at rebound hammer, the crushing cube test showed 16.6% more compressive strength than the hammer test in varied curing and 20% in MBC. As the hammer test is a non-destructive testing, the compressive strength is at reserve side compared to crushing strength. However, based on rebound number except the first set of samples (3 days curing and 3 days non-curing prior to the test), all the samples performed fair to good quality (Fig. 4).

In Fig. 5, the compressive strength also raised with curing period. The x-axis represents equivalent age of concrete for both figures. However, it is clearly visible that varied curing of concrete cube gives more strength than concrete cube under moisture buried curing.

In Fig. 6, the 24 samples were taken for ultrasonic pulse velocity test after 3, 7, 11, 14, and 28 days later. The sample type 1, type 2, type 3, and type 4 were kept completely under water for such days before testing. At the same time, the sample

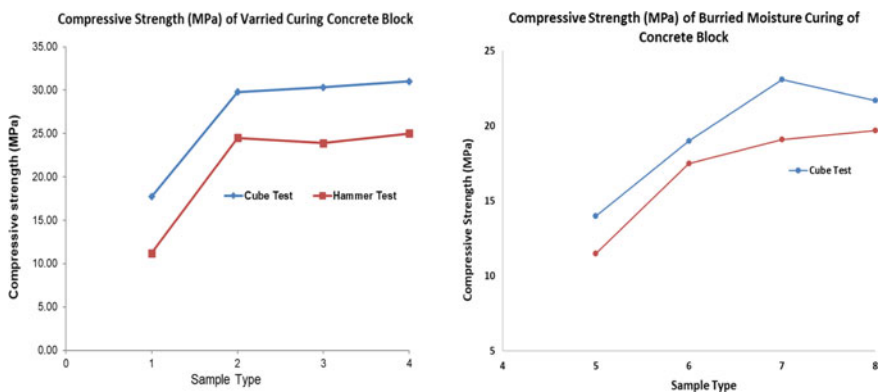


Fig. 3 Comparison of strength between compressive test and hammer test for varied curing (left) and moisture buried curing (right)

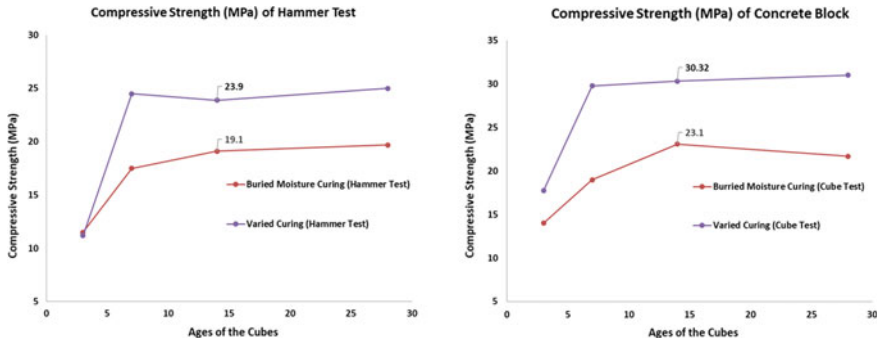


Fig. 4 Comparison between varied curing and moisture buried curing for hammer test (left) and compressive test (right)

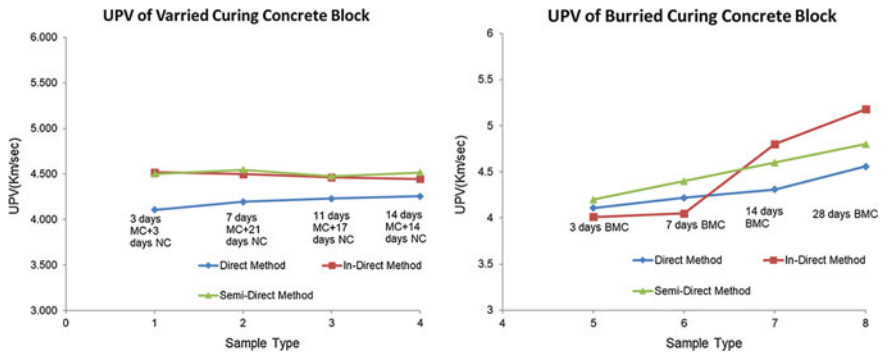


Fig. 5 UPV test value under various methods for varied curing (left) and moisture buried curing (right)

type 5, type 6, type 7, and type 8 were kept completely under moist soil for such days before testing. The compressive strength of such 12 samples was found similar compressive strength result as varied curing condition. However, the compressive strength of 12 samples under moisture buried curing condition slightly increased with the curing period. It has been clearly visible that, the direct method shows the lowest velocity of 8.8%, 6.9%, 5.7% compared to indirect and semi-direct method in case of varied curing condition. Though in the MBC spikes after 14 days of curing clearly indicate that, the cube gained its strength during this time period.

The probable reason for the variation in different direction is that, in direct method, the wave has to travel a shorter way compared to other methods and the defect in the other portion of the concrete could not be detected.

In Fig. 7, direct method is showing better result than indirect and semi-direct method. However, it showed discontinuities in MBC in semi-direct and indirect direction. The probable reason of the discontinuities was due to improper handling

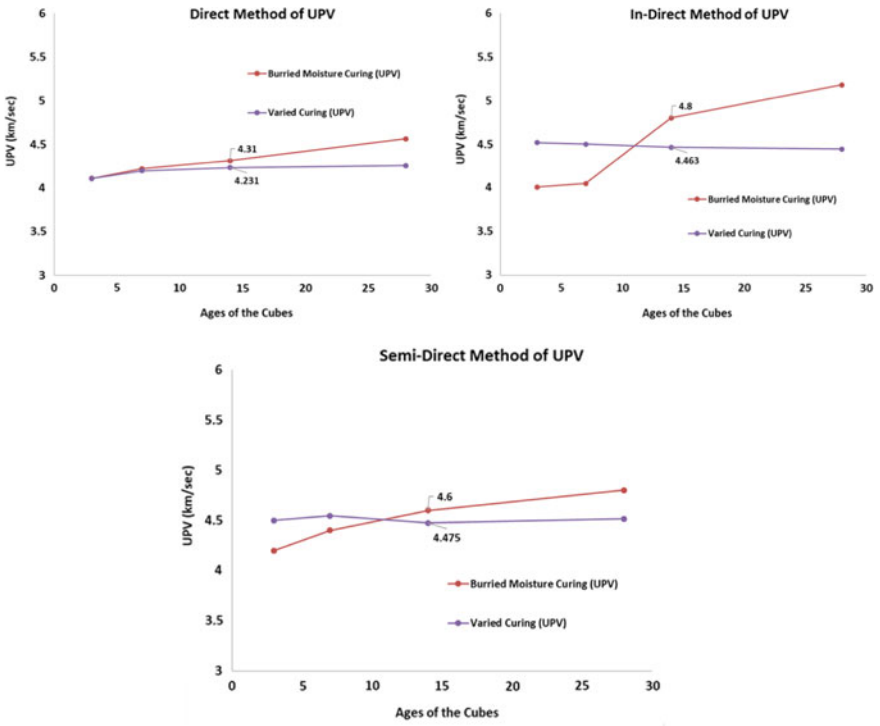
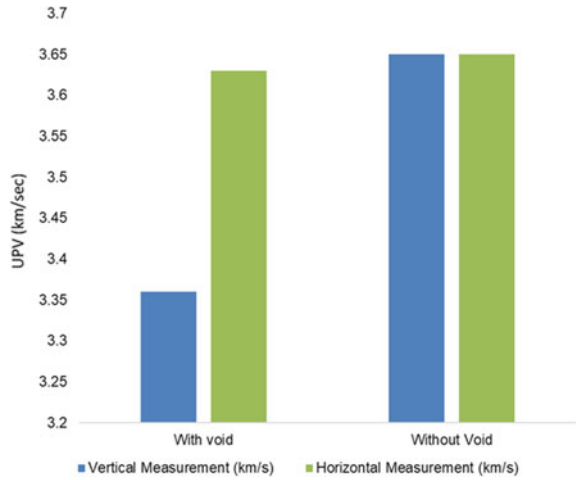


Fig. 6 Comparison of UPV results in between varied curing and moisture buried curing (direct, indirect, and semi-direct method, respectively, from left)

Fig. 7 UPV measurement in different direction



of the transducers in these direction, though further experiments need to continue to find out the animalities of the buried curing condition.

However, the elastic properties and the density of the medium do not fully depend on the curing as the wave velocity varies 3.6% in direct method from varied curing condition to 9% in MBC. The method also indicates that, due to the smaller cube size, the void in the sample could not be determined by UPV. The test later proceeded on the larger void to determine the effectivity of pulse velocity.

UPV is generally used for checking the quality of concreting done but, in this project, show that it can also be used to detect huge voids. While investigating the specimen in vertical direction, there is a significant change in UPV in the specimen whereas while investigating in horizontal direction there is negligible change in UPV.

This is because of the size and directionality of the void (100 mm x 10 mm). This shows that UPV method cannot detect very thin voids in the horizontal direction.

4 Conclusion

The results obtained from the RH tests came up with slight variations between the numbers of rebounds from the hammer and the compressive strength. The strength from the rebounds tested lower than the compressive strength test which is indicative of improper handling of hammer and instrumental error. However, the aged samples that were wet cured for 14 days and dry cured 14 days and samples cured under the earth for 14 days came back with the most promising results with almost highest compressive strength under RH testing for varied and standard curing methods.

The age of the concrete plays more of a significant role then the way it was cured as a defining parameter when it comes to UPV testing which shows that there was little to no changes in the wave velocity due to various curing times. When compared, the highest velocity was obtained from semi-direct and indirect UPV testing, whereas the direct method of measuring velocity came back with a lower value when compared to the other two methods. However, the results obtained from the direct method can be considered as satisfactory or “good” in terms of sensitivity and quality; based on the fact that the results obtained ranged from 3.5 to 4.5 km/s.

The void detection however could not be measured accurately as the compression wave travels for a short duration of time before becoming inaccurate. Therefore, the tests were carried out on samples with large voids on the vertical axis, where transducers were kept in a vertical direction; the result obtained showed 3.35 km/s. When measured in the horizontal axis, where transducers were placed in the horizontal direction, the result obtained showed 3.64 km/s which indicated that the voids were smaller when compared to testing being done in the vertical axis.

The results indicate that concrete can gain its estimated strength after 14 days of adequate curing. However, it also indicates that NDT is still not 100% accurate. Therefore, to obtain the most accurate results, it is recommended that non-destructive testing and destructive testing are carried out side by side when trying to attain a precise gauge on the strength of concrete.

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