Tests and Acceptance Criteria for Concrete Based on Compressive Strength

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Abstract: **This article summarizes current practices for testing of concrete and comparing with the acceptability criteria as per IS based on compressive strength. The compressive strength is determined in sequential manner viz cube testing, core testing, rebound hammer and Ultrasonic pulse velocity. Factors that affect the in-place concrete strength and cubes casted at project sites, are reviewed so locations for sampling can be selected that are consistent with the objectives of the investigation. Methodology of correlations for Rebound Hammer and Ultrasonic Pulse Velocity are presented and acceptance criteria and there limits are presented here.**

This article also provides guidance for checking strength compliance of concrete in a structure under construction and methods for determining an equivalent specified strength to assess the capacity of an existing structure.

1. INTRODUCTION

Testing plays an important role in controlling the quality of cement concrete work. Systematic testing of the raw materials, the fresh concrete and the hardened concrete is an inseparable part of any quality control programme for concrete, which helps to achieve higher efficiency of the materials used and greater assurance of the performance of the concrete in regard to both strength and durability.

One of the purposes of the testing of concrete is to confirm that the concrete used in the structure has developed the required strength. As the hardening of concrete takes time, one will not come to know, the actual strength of concrete for some time. This is an inherent disadvantage in conventional test. But, if strength of concrete is to be known at early stage, accelerated strength test can be carried out to predict 28 days strength. But mostly when correct materials are used and careful steps are taken at every stage of the work, concretes normally give the required strength. The results of the hardened concrete even if they are known late help to reveal the quality of concrete and enable adjustments to be made in the production of further concrete. Tests are conducted by casting cubes or cylinder from the representative concrete or cores cut from the actual concrete. The standard compression test specimens give a measure of the potential strength of the concrete, and not of the strength of the concrete in structure. An actual strength of concrete in structure cannot be directly obtained from tests on separately made specimen.

The tests available for testing concrete ranges from completely non-destructive tests, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pull-out and pull-off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness, surface absorption, reinforcement location, size and distance from the surface.

This article presents measurements of compressive strength and modulus of elasticity of concrete using destructive and non-destructive tests and acceptance criterion given in relevant IS codes.

2. DESTRUCTIVE TESTS

2.1 Compression Testing (Cube Testing)

After the Bhuj, Gujarat earthquake on 26 January 2001, seismic zones of India has been revised, and lesson learnt from the failures of concrete structure, lot of changes have been done in the seismic code and Concrete code. Military Engineering Services has also made changes in construction policies such as the minimum grade of concrete for RCC is M-25 for all buildings and M-30 for costal structure and water retaining structures. Since MES is mostly dealing with the two grades of concrete only, it is imperative to have in depth knowledge about these two grades of concrete to obtain good quality and durable concrete in a structure. Mostly all the Zone they are specifying the conditions of design mix "*The mix design shall be carried out from SEMT Pune/Gov Engineering College/Gov laboratory/MES Laboratory as approved by GE. The representative of GE and the contractor shall be associated with the concrete mix design. In case of dispute, the matter will be referred to the Accepting officer whose decision shall be final and binding*."

In most of the cases on ground it is observed that once mix design is submitted by contractor straightway it is incorporated in the work. There is no association of representative of GE with the laboratory. Also GE/ AGEs are accepting design mix without verifying the workability and making cubes of trial mix(design mix), and testing it for 28 days compressive strength after receipt of design mix which should be made it mandatory in the contract agreement.

It has also been noticed during inspection of works of many GEs formations that provisions of IS 456:2000 are neither being followed for acceptance nor cubes are tested as per IS:516. Most of the site executives are not aware about the amendment No.3 of 2007 modifying clause 15.1.1 of IS 456:2000. Instances of acceptance of concrete on basis of false entries on testing register and without testing the cubes for 28 days strength have also been observed. The main discrepancies are-

- The value of standard deviation is not being established on the basis of results of 30 samples as provided in Table 11 of IS 456 even where 30 samples have been tested.
- Concrete has been accepted on the basis of individual test results without calculating the mean of a group of 4 non overlapping consecutive test results.
- The samples where individual variations are more than ± 15% of average of three specimens are not declared invalid

2.1.1 Frequency of sampling

The minimum number of sample shall be obtained as per IS:456, but it says 3 specimen in one sample for 28 days compressive strength and additional samples may be taken for 7 days strength or to determine duration of curing and to check testing error. In our tenders two samples (six cubes) specified which are tested for 7 days and 28 days compressive strength which is not adequate. In case of testing error at 28 days compressive strength there is no cubes left for testing error. In authors opinion total three numbers of samples (nine cubes) shall be taken one for 7 days strength, one for 28 days compressive strength and one sample for calibration of rebound hammer or for any testing errors.

2.1.2 Cube Testing In Field

Tests for compressive strength of concrete should be conducted on the cube specimens obtained from fresh concrete either from the mixers or at the time of deposition at site. A random sampling procedure shall be adapted to ensure that each concrete batch shall have a reasonable chance of being tested that is, the sampling should be spread over the entire period of concreting and cover all mixing units. Specimen shall be prepared, cured and tested in accordance with IS: 516-1959'. The samples are required to be de-moulded after storage for 24± 1/2 hour at temperature within the range of 22^0 to 32^0C, and thereafter stored in clean water at a temperature of 24^0 to 30°C. Since temperature of moist curing influences the compressive strength of concrete, storage at temperatures beyond this range is likely to affect the test results. Specimens, when received in the laboratory are to be stored in water at a temperature of 27± 2°C until the time of test. Specimens are tested as described in IS 516. The analysis and interpretation of cube strength data and acceptance criteria are complied with as per the IS 456.

The test results of the sample shall be the average of the strength of three specimens. The individual variation should not be more than **± 15 percent** of the average. If more, the tests of the sample are invalid.

The concrete shall be acceptable with the strength requirements when both the following condition are met for all grades of concrete as per IS 456-2000

(i) $\mathbf{fc}_{\mathbf{\textit{individual}}} \geq \mathbf{f_{ck} - 3}$ for all grades of concrete.
$fc_{individual}$ for M-25 and M-30 shall not be less than 22 N/mm^2 and 27 N/mm^2 respectively

(ii) $\mathbf{fc}_{\mathbf{\textit{mean}}} \geq$ greater of $\mathbf{f_{ck} + 0.825 \times SD}$ or $\mathbf{f_{ck} + 3}$
fc_{mean} for M-25 and M-30 shall not be less 28.3 N/mm^2 and 34.12 N/mm^2 respectively if standard deviation not calculated at site.

If the concrete is deemed not to comply pursuant to above the structural adequacy of the parts affected shall be investigated by core test.

2.2 Core Test from Hardened Concrete

Core testing is the most direct method to determine the in-place compressive strength of concrete in a structure. Generally, cores are obtained to:

a) Assess whether suspect concrete in a new structure complies with strength-based acceptance criteria; or

b) Determine in-place concrete strengths in an existing structure for the evaluation of structural capacity.

In new construction, cube strength tests that fail to meet strength-based acceptance criteria may be investigated using the provisions given in IS-456. Here we present the brief procedures for obtaining and testing the cores and interpreting the results in accordance with IS-456 criteria.

A core drill shall be used for obtaining cylindrical core and it is taken perpendicular to a horizontal surface shall be located, when possible, with its axis perpendicular to the bed of the concrete as originally placed. When a core is taken perpendicular to a vertical surface, or perpendicular to a surface with a batter, shall be taken from near the middle of a unit of deposit. Specimens taken perpendicular to the horizontal surface, a short drill is satisfactory. For inclined holes, a diamond drill is satisfactory. The core specimen for compressive strength shall have a diameter at least three times the maximum nominal size of the coarse aggregate used in the concrete, and in no case shall the diameter of the specimen be less than twice the maximum nominal size of the coarse aggregate. The length of the specimen, when capped, shall be as nearly as practicable twice its diameter.

A saw shall be used for securing beam specimens from the structure or pavement for flexural strength tests. The saw shall have a diamond or silicon carbide cutting edge and shall have adjustments that permit of cutting a beam specimen shall normally have a cross-section of 150 x 150 mm and shall be at least 700 mm in length.

A core specimen taken perpendicular to a horizontal surface shall be located, when possible, with its axis perpendicular to the bed of the concrete as originally placed. A specimen taken perpendicular to a vertical surface, or perpendicular to a surface with a batter, shall be taken from near the middle of a unit of deposit. The measurement of specimen are taken as per IS 1199, and IS 516 presents the standard methods for conditioning the specimen, preparing the ends before testing, and measuring the length of the specimen, correction for height/diameter ration and performing the compression test.

The measured strength of a core depends partly on factors that include the ratio of length to diameter of the specimen, the diameter, the moisture condition at the time of testing, the presence of reinforcement or other inclusions, and the direction of coring. If all these conditions are ideally satisfied, than the concrete in the member represented by a core is acceptable if the equivalent cube strength of the concrete (which is 5/4 times the corrected cylinder strength).-

*If the average equivalent cube strength of the cores is equal to at least **85 percent** of the cube strength of the grade of concrete Specified for the corresponding age and no individual core has strength less than **75 percent**.*

In case the core test results do not satisfy the above condition or where such tests have not been done, load test should be carried out on flexural member and for other than flexure member investigated by analysis.

3. NON-DESTRUCTIVE TEST

The crushing of the specimens is the usual destructive test to assess the strength of concrete. Non destructive methods like rebound hammer test and ultrasonic test do not damage buildings and allow to have an inventory of structures and conditions. Non-destructive tests are widely applied to study mechanical properties and integrity of concrete structures. They are simple to use and often economically advantageous. They are suitable for taking measurements on site and taking continuous measurements.

3.1 Rebound Hammer

The rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The impact energy required for rebound hammers is 2.25 Nm for testing normal weight concrete and 30 Nm for roads, air field pavements and mass concreting. There is little apparent theoretical relationship between the strength of concrete and the rebound number RN of the hammer. However, within limits, empirical correlations have been established between strength properties and the rebound number.

Fig. 1. Silver Schmidt rebounds hammer Impact energy 2.207 Nm Type N (10 - 100 Mpa)

3.1.1 Procedure of Obtaining Correlation between Compressive Strength and Rebound Number

The most satisfactory way of establishing a correlation between compressive strength of concrete and its rebound number is to measure both the properties simultaneously on concrete cubes. In the beginning of the project standard test cubes of the specified design mix shall be prepared by site executive before undertaking any concrete work in each project. At least 18 standard cubes necessary for formation of one specimen of specified grade of concrete shall be casted by site executive well in advance. From these 18 cubes any 3 cubes may be selected at random to be tested for crushing strength of 7 days. The crushing strength obtained should satisfy the specified strength for the grade of concrete (approximately 75 % of 28 days strength). If the strength is satisfactory then the remaining cubes will form the standard' samples for calibration of rebound hammer. In case of failure, the site executive should totally reject the samples and remove them also and then make another set of samples by fresh mixing or alternatively, out of the remaining 15 cubes, 3 cubes will be tested on 28 days. If the 28 days tests are found, satisfactory then remaining 12 cubes will form the standard sample for calibration at 28 days' strength otherwise all samples shall be rejected and whole procedure repeated to form a fresh specimen. All the results shall be recorded in a register.

Frequency of taking standard cubes will be once in each quarter or as per the direction and discretion of site executive. Whenever the design mix changed fresh standard specimen shall be prepared.

Same three cubes which are tested for 28 Days strength out of 18 Cubes shall be used to correlate the compressive strength of their concrete with rebound number as per Para 5.2 of the IS 13311(Pt. II). The average of values of the rebound number (minimum readings) obtained in respect of same three cubes passing on 28 days work test shall form the datum reference for remaining cubes for the strength of cubes.

The concrete cube specimens are held in a compression testing machine under a fixed load, measurements of rebound number taken and then the compressive strength determined. The fixed load required is of the order of 7 N/mm^2 (157.5 kN) when the impact energy of the hammer is about 2.2 Nm. The load should be increased for calibrating rebound hammers of greater impact energy and decreased for calibrating rebound hammers of lesser impact energy.

Fig. 2. Strength of concrete by (a) Silver Schmidt rebounds hammer (b) Mechanical Sclerometer rebounds test hammer

The test specimens should be as large a mass as possible in order to minimize the size effect on the test result of a full scale structure. 150 mm cube specimens are preferred for calibrating rebound hammers of lower impact energy (2.2 Nm), whereas for rebound hammers of higher impact energy, for example 30 Nm, the test cubes should not be smaller than 300 mm. At least nine readings should be taken on each of the two vertical faces accessible in the compression testing machine when using the rebound hammers. The points of impact on the specimen must not be nearer an edge than 20 mm and should be not less than 20 mm from each other.

The rebound number of each hammer will be determined on each of the remaining 12 cubes (18-3-3=12). Whenever the rebound number of hammer of any individual cube varies by more than ± 25 % from the datum reading found from first three cubes, that cube will be excluded and will not be considered for standard specimen cubes for calibration. It must be ensured that at least 8 cubes out of 12 that are 66.67 % are within the permissible range of variation of rebound number i.e. ±25% or otherwise whole procedure shall have to be repeated and fresh specimen prepared.

These 8 cubes will form one standard sample in the beginning before commencement of work and shall be kept carefully for the visiting officers who will calibrate their hammers on these cubes.

Standard sample cubes cast shall be carefully, preserved at site under the safe custody of Engineer-in-charge or his representative for making them available together with the charts, to the officers of STE/TE or any other senior departmental officer, during their inspection of the work. They will calibrate their hammer on these cubes if required.

3.1.2 Experimental Studies

Samples were made from OPC 43 Grade, and aggregate of local natural sources for M-25 design mix. Cube specimens were taken from the site all are more than one year old and tested in surface dry condition. Two opposite faces of the cubes were prepared for the Schmidt Hammer test when drying was completed. The specimens were placed in the testing machine and slight load (7 N/mm^2) was applied (Figure 2). Afterwards, a fixed amount of energy is applied by pushing the hammer against the test surface according to the IS 13311(Part 2)-1992. Result of cube strength, strength given by digital Silver Schmit Hammer and Schmidt Hammer are represented in Figure 3

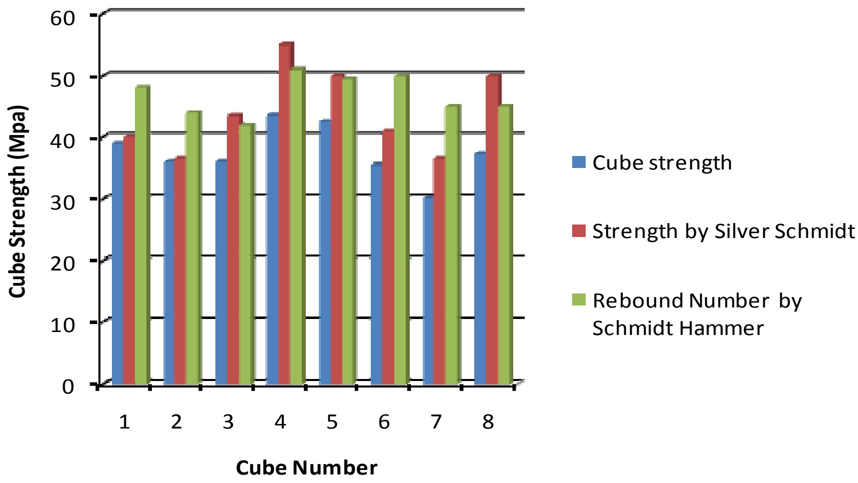
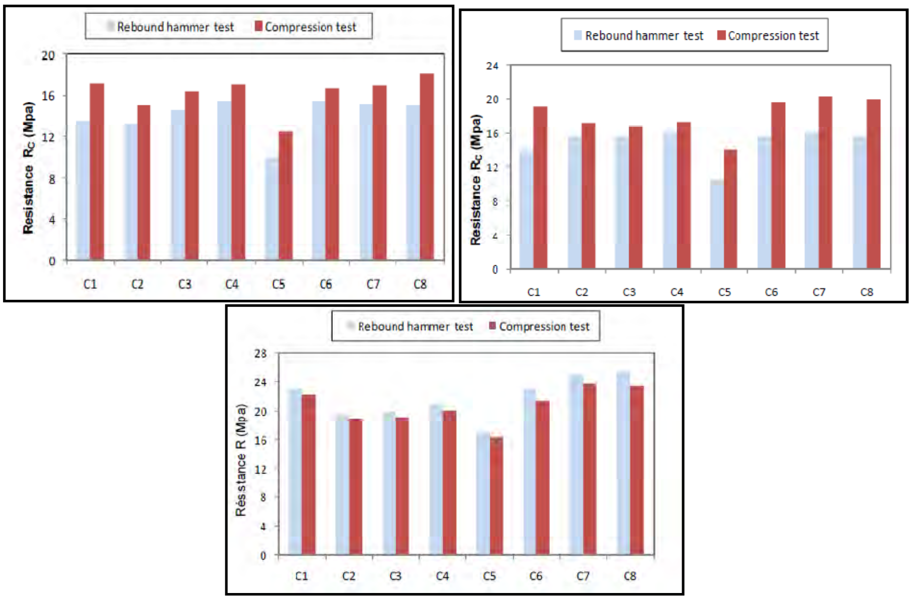


Fig. 3. Strength of concrete

3.1.3 Interpretation of results



(a) **(b)** **(c)**

Fig. 4: Effect of destructive and non-destructive tests on the resistance of concrete at the ages of: 7 days, (b) 14 days, (c) 28 days

The rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by means of establishing a suitable correlation between the rebound index and the compressive strength of concrete. It is also mentioned that rebound indices are indicative of compressive strength of concrete to a limited depth from the surface. If the concrete in a particular member has internal micro-cracking, flaws or heterogeneity across the cross-section, rebound hammer indices will not indicate the same. As such, the estimation of strength of concrete by rebound hammer method cannot be held to be very accurate and probable accuracy of prediction of concrete strength in a structure is ±25 percent.

Figure 3 and 4 shows the compressive strength determined by destructive test (compression test) and non-destructive test (rebound hammer test) at different ages of the concrete. Figure 4 shows at the ages of 7 days, 14 days and 28 days, the resistances obtained by the compression test were higher than those obtained by the rebound hammer test. The respective average differences between the two methods at the ages of 7 days and 14 days were 14% and 17%, respectively. At the age of 28 days, there has been a reversal of the situation; resistances obtained by the compression test were lower than those obtained by the rebound hammer test with an average difference of 5%. This result could be explained by the maturing of the concrete.

The rebound hammer test may be used for evaluating the compressive strength and homogeneity of the concrete in situ without a core. This conclusion is valid for older concretes than for younger concretes.

3.2 PULSE VELOCITY TEST

The ultrasonic pulse is generated by an electro acoustical transducer. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (compression), shear (transverse) and surface (Rayleigh) waves. The receiving transducer detects the onset of the longitudinal waves, which is the fastest.

Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic properties. Pulse velocity method is a convenient technique for investigating structural concrete. The basic principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete.

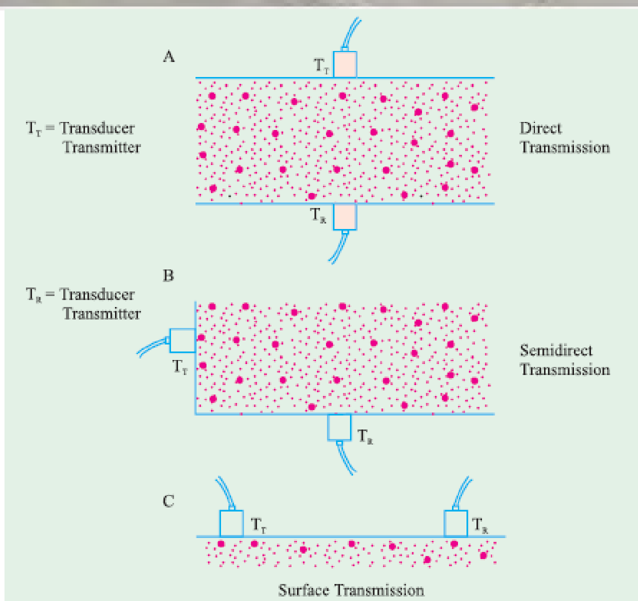


Fig. 5: Ultrasonic pulse velocity tester **Fig. 6. Type of measurement (A) Direct, (B) Semi-Direct, (C) Indirect**

The equipment consists essentially of an electrical pulse generator, a pair of transducers, an amplifier and an electronic timing device for measuring the time interval between the initiation of a pulse generated at the transmitting transducer and its arrival at the receiving transducer.

A pulse of longitudinal vibrations is produced by an electro-acoustical transducer, which is held in contact with one surface of the concrete under test. When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves develops, which includes both longitudinal and shear waves and propagates through the concrete. The first waves to reach the receiving transducer are the longitudinal waves, which are converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time T of the pulse to be measured. Longitudinal ultrasonic pulse velocity is given by:

$$\mathrm{UPV} = \frac{L}{t} \ (\mathrm{m/s}) \tag{1}$$

3.2.1 Dynamic Modulus of Elasticity

The relationship between the dynamic modulus of elasticity(Ed) and the velocity of an ultrasonic pulse travelling in an isotropic elastic medium of infinite dimensions is given below:

$$\mathrm{Ed} = \mathrm{UPV}^2 . \rho . \frac{(1+\mu)(1-2\mu)}{1-\mu} \tag{2}$$

Where

Ed: the dynamic elastic modulus (MPa)
μ : the dynamic Poisson's ratio (0.20 to 0.35 with average 0.24)
ρ : the density (kg/m3)
UPV: the ultrasonic pulse velocity (m/s).

The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc, indicative of the level of workmanship employed; can thus be assessed using the guidelines given in Table 2 of IS 13311(Part-1)-1992, which have been evolved for characterizing the quality of concrete in structures in terms of the ultrasonic pulse velocity.

TABLE 2: Velocity Criterion for Concrete Quality Grading

Sl No.	Pulse Velocity by Cross Probing (km/sec)	Concrete Quality Grading
1.	Above 4.5	Excellent
2.	3.5 to 4.5	Good
3.	3.0 to 3.5	Medium
4.	Below 3.0	Doubtful

The assessment of compressive strength of concrete from ultrasonic pulse velocity values is not adequate because the statistical confidence of the correlation between ultrasonic pulse velocity and the compressive strength of concrete is not very high. The reason is that a large number of parameters are involved, which influence the pulse velocity and compressive strength of concrete to different extents. However, if actual concrete materials ' and mix proportions adopted in a particular structure are available, then estimate of concrete strength can be made by establishing suitable correlation between the pulse velocity and the compressive strength of concrete specimens made with such materials and mix proportions, under environmental conditions similar to that in the structure. The estimated strength may vary from the actual strength by ±20 percent. The correlation so obtained may not be applicable for concrete of another grade or made with different types of materials.

4. ACCEPTANCE CRITERIA OF CONCRETE

4.1 Compressive strength by Cube test

The acceptability criteria of concrete based on the cube results is as per IS:456-2000

(a) "The test results of the sample shall be the average of the strength of three specimens. The individual variation should not be more than ±15 percent of the average. If more, the test results of the sample are invalid."

(b) Once the test results are meeting above conditions than the concrete is acceptable when it complies both the following conditions-

(i) $\mathbf{fc}_{individual} \geq \mathbf{f}_{ck} - \mathbf{3}$ for all grades of concrete.

$fc_{individual}$ for M-25 and M-30 shall not be less than 22 N/mm2 and 27 N/mm2 respectively

(ii) $fc_{mean} \geq$ greater of $f_{ck} + 0.825 \times SD$ or $f_{ck} + 3$
fc_{mean} for M-25 and M-30 shall not be less 28.3 N/mm^2 and 34.12 N/mm^2 respectively if standard deviation not calculated at site.

4.2 Core test

Concrete in the member represented by a core test (equivalent cube strength) shall be considered acceptable if the average equivalent cube strength of the cores is equal to at least ***85 %*** of the cube strength of the grade of concrete Specified for the corresponding age and no individual core has strength less than ***75 %***. Cores generally cut in cylindrical shape its strength should be converted to equivalent cube strength.

4.3 Rebound Hammer

The relative strength of actual field work will be tested with reference to strength of these standard cubes and calibration charts of a hammer for determining the rebound number on the field work. The hammer will be used as per manufacturer's guidelines at various locations chosen at random. The number of location/reading on each all, beam or column etc. shall not be less than 12. All the readings should be within the ±25% range of values prescribed in calibration chart normally. However, reading indicating good strength will be when it is at par with calibrated value or between 100% & 125% and very good if more than 125%. Any value between 100% & 75% of calibrated value shall be considered satisfactory. The concrete indicating rebound number less than 75% of calibrated value shall be rejected.

4.4 Ultrasonic Pulse Velocity Tester

The pulse velocity method is an ideal tool for establishing whether concrete is uniform. It can be used on both existing structures and those under construction. Usually, if large differences in pulse velocity are found within a structure for no apparent reason, there is strong reason to presume that defective concrete is present. Fairly good correlation can be obtained between cube compressive strength and pulse velocity. These relations enable the strength of structural concrete to be predicted within **±20 %**, provided the types of aggregate and mix proportions are constant.

The ultrasonic pulse velocity of concrete can be related to its density and modulus of elasticity. It depends upon the materials and mix proportions used in making concrete as well as the method of placing, compacting and curing of concrete. If the concrete is not compacted thoroughly and having segregation, cracks or flaws, the pulse velocity will be lower as compare to good concrete, although the same materials and mix proportions are used. The quality of concrete in terms of uniformity can be assessed using the guidelines given in table 2 above.

5. CONCLUSION

Among the available non-destructive methods, the Rebound Hammer test is the most commonly used one in practice. It has been used world-wide as an index test for a testing strength of concrete due to its rapidity and easiness in execution, simplicity, portability, low cost and non-destructiveness.

The use of rebound hammer test method on the existing building/old concrete is not suitable to estimate the strength of concrete. Direct use of rebound hammer demonstrates high variations, which makes engineering judgment quite difficult. The Schmidt Hammer method could only be used as a reliable instrument to calculate the compressive strength, if the required calibrations are performed.

The rebound hammer method can be used with greater confidence for differentiating between the questionable and acceptable parts of a structure or for relative comparison between two different structures. It is very useful where core cannot be drilled.

Ultrasonic Pulse Velocity test gives the quality of concrete it does not give the direct compressive strength of concrete and the UPV decreases with the increase of W/C ratio, which promotes a very important capillary porosity. Instead, UPV increases with the age of the concrete.

The dynamic modulus of elasticity determined by ultrasonic measurements, it increases with age of the concrete up to the age of three months. Moreover, the dynamic modulus of elasticity decreases as the W/C ratio increases.

To reduce the errors predicting compressive strength of concrete in the structure, it is preferable to use both ultrasonic pulse velocity and rebound hammer method in combination. In this, if the quality of concrete is assessed to be ‘excellent or good’ by pulse velocity method, only then the compressive strength is assessed from the rebound hammer indices, and this is taken as indicative of strength of concrete in the entire cross-section of the concrete member. When the quality assessed is ‘medium’, the estimation of compressive strength by rebound indices is extended to the entire mass only on the basis of other co lateral measurements. When the quality of concrete is doubtful, no assessment of concrete strength is made from rebound indices.

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