STRUCTURAL HEALTH MONITORING USING NON DESTRUCTIVE TESTING OF CONCRETE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

in

Civil Engineering

By

AYAZ MAHMOOD

Department of Civil Engineering

National Institute of Technology

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Dr. S.K.SAHU

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CERTIFICATE

This is to certify that the thesis entitled, **"STRUCTURAL HEALTH MONITORING USING NON DESTRUCTIVE TESTING OF CONCRETE"** submitted by **Mr. AYAZ MAHMOOD** in fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the any Degree or Diploma.

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CIVIL ENGINEERING

N.I.T ROURKELA

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ABSTRACT

Structures are assemblies of load carrying members capable of safely transferring the superimposed loads to the foundations. Their main and most looked after property is the strength of the material that they are made of. Concrete, as we all know, is an integral material used for construction purposes. Thus, strength of concrete used, is required to be 'known' before starting with any kind of analysis. In the recent past, various methods and techniques, called as Non-Destructive Evaluation (NDE) techniques, are being used for Structural Health Monitoring (SHM).

The concept of nondestructive testing (NDT) is to obtain material properties of in place specimens without the destruction of the specimen nor the structure from which it is taken. However, one problem that has been prevalent within the concrete industry for years is that the true properties of an in-place specimen have never been tested without leaving a certain degree of damage on the structure. For most cast-in-place concrete structures, construction specifications require that test cylinders be cast for 28-day strength determination. Usually, representative test specimens are cast from the same concrete mix as the larger structural elements. Unfortunately, test specimens are not an exact representation of *in-situ* concrete, and may be affected by variations in specimen type, size, and curing procedures.

The rebound hammer test is classified as a hardness test and 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 energy absorbed by the concrete is related to its strength. There is no unique relation between hardness and strength of concrete but experimental data relationships can be obtained from a given concrete. However, this relationship is dependent upon factors affecting the concrete surface such as degree of saturation, carbonation, temperature, surface preparation and location, and type of surface finish. A correlation between rebound number and strength of concrete structure is established, which can be used as well for strength estimation of concrete structures.

The direct determination of the strength of concrete implies that concrete specimens must be loaded to failure. Therefore, the determination of concrete strength requires special specimens to be taken, shipped, and tested at laboratories. This procedure may result in the actual strength of concrete, but may cause trouble and delay in evaluating existing structures. Because of that, special techniques have been developed in which attempts were made to measure some concrete properties other than strength, and then relate them to strength, durability, or any other property. Some of these properties are hardness, resistance to penetration or projectiles, rebound number, resonance frequency, and ability to allow ultrasonic pulses to propagate through concrete. Concrete electrical properties, its ability to absorb, scatter, and transmit X-rays and gamma rays, its response to nuclear activation, and its acoustic emission allow us to estimate its moisture content, density, thickness, and its cement content. However, the term "nondestructive" is given to any test that does not damage or affect the structural behavior of the elements and also leaves the structure in an acceptable condition for the client.

The use of the ultrasonic pulse velocity tester is introduced as a tool to monitor basic initial cracking of concrete structures and hence to introduce a threshold limit for possible failure of the structures. Experiments using ultrasonic pulse velocity tester have been carried out, under laboratory conditions, on various concrete specimens loaded in compression up to failure.

. The aim of the project was to obtain the Calibration Graphs for Non Destructive Testing Equipments viz., the Rebound Hammer and Ultrasonic pulse Velocity Tester and to study the effect of reinforcement on the obtained results. These Non Destructive Instruments were then used to test the columns, beams and slabs of two double storied buildings viz., Hall No.2 and Hall no.7 (a newly constructed hostel) in N I T Rourkela.

The use of the combined methods produces results that lie close to the true values when compared with other methods. The method can be extended to test existing structures by taking direct measurements on concrete elements.

LIST OF FIGURES

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LIST OF ABBREVIATIONS USED

S D	Standard Deviation
USPV	Ultrasonic Pulse Velocity
I R LOAD	Initial Restraining Load
f (ck)	Compressive Strength of Concrete

Chapter 1

INTRODUCTION

INTRODUCTION

To keep a high level of structural safety, durability and performance of the infrastructure in each country, an efficient system for early and regular structural assessment is urgently required. The quality assurance during and after the construction of new structures and after reconstruction processes and the characterisation of material properties and damage as a function of time and environmental influences is more and more becoming a serious concern. Non-destructive testing (NDT) methods have a large potential to be part of such a system. NDT methods in general are widely used in several industry branches. Aircrafts, nuclear facilities, chemical plants, electronic devices and other safety critical installations are tested regularly with fast and reliable testing technologies. A variety of advanced NDT methods are available for metallic or composite materials.

In recent years, innovative NDT methods, which can be used for the assessment of existing structures, have become available for concrete structures, but are still not established for regular inspections. Therefore, the objective of this project is to study the applicability, performance, availability, complexity and restrictions of NDT.

The purpose of establishing standard procedures for nondestructive testing (NDT) of concrete structures is to qualify and quantify the material properties of in-situ concrete without intrusively examining the material properties. There are many techniques that are currently being research for the NDT of materials today. This chapter focuses on the NDT methods relevant for the inspection and monitoring of concrete materials.

Chapter 2

LITERATURE SURVEY

2.1 Structural Health Monitoring

Structural health monitoring is at the forefront of structural and materials research. Structural health monitoring systems enable inspectors and engineers to gather material data of structures and structural elements used for analysis. Ultrasonics can be applied to structural monitoring programs to obtain such data, which would be especially valuable since the wave properties could be used to obtain material properties.

This testing approach may be used to assess the uniformity and relative quality of the concrete, to indicate the presence of voids and cracks, and to evaluate the effectiveness of crack repairs. It may also be used to indicate changes in the properties of concrete, and in the survey of structures, to estimate the severity of deterioration or cracking. Decreases in ultrasonic waves speeds over time can reveal the onset of damage before visible deficiencies become evident. This allows inspectors and engineers to implement repair recommendations before minor deficiencies become safety hazards.

Structural Health Monitoring using Non-Destructive Testing

The quality of new concrete structures is dependent on many factors such as type of cement, type of aggregates, water cement ratio, curing, environmental conditions etc. Besides this, the control exercised during construction also contributes a lot to achieve the desired quality. The present system of checking slump and testing cubes, to assess the strength of concrete, in structure under construction, are not sufficient as the actual strength of the structure depend on many other factors such as proper compaction, effective curing also. Considering the above requirements, need of testing of hardened concrete in new structures as well as old structures, is there to asses the actual condition of structures. Non-Destructive Testing (NDT) techniques can be used effectively for investigation and evaluating the actual condition of the structures. These techniques are relatively quick, easy to use, and cheap and give a general indication of the required property of the concrete. This approach will enable us to find suspected zones, thereby reducing the time and cost of examining a large mass of concrete. The choice of a particular NDT method depends upon the property of concrete to be observed such as strength, corrosion, crack monitoring etc.

The subsequent testing of structure will largely depend upon the result of preliminary testing done with the appropriate NDT technique.

The NDT being fast, easy to use at site and relatively less expensive can be used for

(i) Testing any number of points and locations

(ii) Assessing the structure for various distressed conditions

(iii) Assessing damage due to fire, chemical attack, impact, age etc.

(iv) Detecting cracks, voids, fractures, honeycombs and weak locations

(v) Assessing the actual condition of reinforcement

Many of NDT methods used for concrete testing have their origin to the testing of more homogeneous, metallic system. These methods have a sound scientific basis, but heterogeneity of concrete makes interpretation of results somewhat difficult. There could be many parameters such as materials, mix, workmanship and environment, which influence the result of measurements.

Moreover the test measures some other property of concrete (e.g. hardness) yet the results are interpreted to assess the different property of the concrete e.g. (strength). Thus, interpretation of the result is very important and a difficult job where generalization is not possible. Even though operators can carry out the test but interpretation of results must be left to experts having experience and knowledge of application of such non-destructive tests.

Variety of NDT methods have been developed and are available for investigation and evaluation of different parameters related to strength, durability and overall quality of concrete. Each method has some strength and some weakness. Therefore prudent approach would be to use more than one method in combination so that the strength of one compensates the weakness of the other. The various NDT methods for testing concrete bridges are listed below –

A. For strength estimation of concrete

(i) Rebound hammer test

(ii) Ultrasonic Pulse Velocity Tester

(iii) Combined use of Ultrasonic Pulse Velocity tester and rebound hammer test

(iv) Pull off test

(v) Pull out test

(vi) Break off test

B. For assessment of corrosion condition of reinforcement and to determine reinforcement diameter and cover

(i) Half cell potentiometer

(ii) Resistively meter test

(iii) Test for carbonation of concrete

(iv) Test for chloride content of concrete

(v) Profometer

(vi) Micro covermeter

C. For detection of cracks/voids/ delamination etc.

(i) Infrared thermographic technique

(ii) Acoustic Emission techniques

(iii) Short Pulse Radar methods

(iv) Stress wave propagation methods

- pulse echo method

- impact echo method

- response method

2.2 NON DESTRUCTIVE EVALUATION (NDE) METHODS

Introduction to NDE Methods

Concrete technologists practice NDE methods for

(a) Concrete strength determination (b) Concrete damage detection

2.3(a) Strength determination by NDE methods:

Strength determination of concrete is important because its elastic behaviour & service behaviour can be predicted from its strength characteristics. The conventional NDE methods typically measure certain properties of concrete from which an estimate of its strength and other characteristics can be made. Hence, they do not directly give the absolute values of strength.

Damage detection by NDE methods:

Global techniques: These techniques rely on global structural response for damage identification. Their main drawback is that since they rely on global response, they are not sensitive to localized damages. Thus, it is possible that some damages which may be present at various locations remain un-noticed.

Local techniques: These techniques employ localized structural analysis, for damage detection. Their main drawback is that accessories like probes and fixtures are required to be physically carried around the test structure for data recording. Thus, it no longer remains autonomous application of the technique. These techniques are often applied at few selected locations, by the instincts/experience of the engineer coupled with visual inspection. Hence, randomness creeps into the resulting data.

NDE Methods in Practice

Visual inspection: The first stage in the evaluation of a concrete structure is to study the condition of concrete, to note any defects in the concrete, to note the presence of cracking and the cracking type (crack width, depth, spacing, density), the presence of rust marks on the surface, the presence of voids and the presence of apparently poorly compacted areas etc. Visual assessment determines whether or not to proceed with detailed investigation.

The Surface hardness method: This is based on the principle that the strength of concrete is proportional to its surface hardness. The calibration chart is valid for a particular type of cement, aggregates used, moisture content, and the age of the specimen.

The penetration technique: This is basically a hardness test, which provides a quick means of determining the relative strength of the concrete. The results of the test are influenced by surface smoothness of concrete and the type and hardness of the aggregate used. Again, the calibration chart is valid for a particular type of cement, aggregates used, moisture content, and age of the specimen. The test may cause damage to the specimen which needs to be repaired.

The pull-out test: A pullout test involves casting the enlarged end of a steel rod after setting of concrete, to be tested and then measuring the force required to pull it out. The test measures the direct shear strength of concrete. This in turn is correlated with the compressive strength; thus a measurement of the in-place compressive strength is made. The test may cause damage to the specimen which needs to be repaired.

The rebound hammer test: The Schmidt rebound hammer is basically a surface hardness test with little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. Rebound hammers test the surface hardness of concrete, which cannot be converted directly to compressive strength. The method basically measures the modulus of elasticity of the near surface concrete. The principle is based on the absorption of part of the stored elastic energy of the spring through plastic deformation of the rock surface and the mechanical waves propagating through the stone while the remaining elastic energy causes the actual rebound of the hammer. The distance travelled by the mass, expressed as a percentage of the initial extension of the spring, is called the *Rebound number.* There is a considerable amount of scatter in rebound numbers because of the heterogeneous nature of near surface properties (principally due to near-surface aggregate particles).

There are several factors other than concrete strength that influence rebound hammer test results, including surface smoothness and finish, moisture content, coarse aggregate type, and the presence of carbonation. Although rebound hammers can be used to estimate concrete strength, the rebound numbers must be correlated with the compressive strength of molded specimens or cores taken from the structure.

Ultra-sonic pulse velocity test: This test involves measuring the velocity of sound through concrete for strength determination. Since, concrete is a multi-phase material, speed of sound in concrete depends on the relative concentration of its constituent materials, degree of compacting, moisture content, and the amount of discontinuities present. This technique is applied for measurements of composition (e.g. monitor the mixing materials during construction, to estimate the depth of damage caused by fire), strength estimation, homogeneity, elastic modulus and age, & to check presence of defects, crack depth and thickness measurement. Generally, high pulse velocity readings in concrete are indicative of concrete of good quality. The drawback is that this test requires large and expensive transducers. In addition, ultrasonic waves cannot be induced at right angles to the surface; hence, they cannot detect transverse cracks.

Acoustic emission technique: This technique utilizes the elastic waves generated by plastic deformations, moving dislocations, etc. for the analysis and detection of structural defects. However, there can be multiple travel paths available from the source to the sensors. Also, electrical interference or other mechanical noises hampers the quality of the emission signals.

Impact echo test: In this technique, a stress pulse is introduced at the surface of the structure, and as the pulse propagates through the structure, it is reflected by cracks and dislocations. Through the analysis of the reflected waves, the locations of the defects can be estimated. The main drawback of this technique is that it is insensitive to small sized cracks.

2.3 DESCRIPTION OF THE INSTRUMENTS

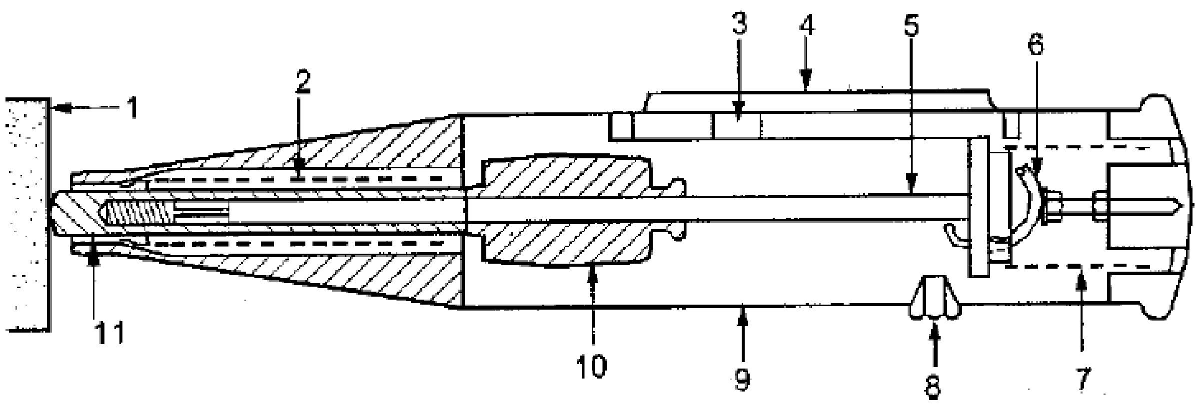
The following instruments were used in the project:

1. Rebound Hammer (Schmidt Hammer) (Impact energy of the hammer is about 2.2 Nm)

2. Ultrasonic Pulse Velocity Tester.

2.3 (a) Rebound Hammer (Schmidt Hammer)

This is a simple, handy tool, which can be used to provide a convenient and rapid indication of the compressive strength of concrete. It consists of a spring controlled mass that slides on a plunger within a tubular housing. The schematic diagram showing various parts of a rebound hammer is given as Fig



1. Concrete surface	5. Hammer guide	9. Housing
2. Impact spring	6. Release catch	10. Hammer mass
3. Rider on guide rod	7. Compressive spring	11. Plunger
4. Window and scale	8. Locking button	

Fig.2.1 Components of a Rebound Hammer

The rebound hammer method could be used for –

(a) Assessing the likely compressive strength of concrete with the help of suitable co-relations between rebound index and compressive strength.

(b) Assessing the uniformity of concrete

(c) Assessing the quality of concrete in relation to standard requirements.

(d) Assessing the quality of one element of concrete in relation to another.

This 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.

The test is classified as a hardness test and 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 energy absorbed by the concrete is related to its strength . Despite its apparent simplicity, the rebound hammer test involves complex problems of impact and the associated stress-wave propagation.

There is no unique relation between hardness and strength of concrete but experimental data relationships can be obtained from a given concrete. However, this relationship is dependent upon factors affecting the concrete surface such as degree of saturation, carbonation, temperature, surface preparation and location, and type of surface finish. The result is also affected by type of aggregate, mix proportions, hammer type, and hammer inclination. Areas exhibiting honeycombing, scaling, rough texture, or high porosity must be avoided. Concrete must be approximately of the same age, moisture conditions and same degree of carbonation (note that carbonated surfaces yield higher rebound values). It is clear then that the rebound number reflects only the surface of concrete. The results obtained are only representative of the outer concrete layer with a thickness of 30–50 mm.

Principle:

The method is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which mass strikes. When the plunger of rebound hammer is pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete. The rebound value is read off along a graduated scale and is designated as the rebound number or rebound index. The compressive strength can be read directly from the graph provided on the body of the hammer.

The impact energy required for rebound hammer for different applications is given below –

Sr. No.	Application	Approximate impact energy required for the rebound hammers (N-m)
1.	For testing normal weight concrete	2.25
2.	For light weight concrete or small and impact sensitive part of concrete	0.75
3.	For testing mass concrete i.e. in roads, airfield pavements and hydraulic structures	30.00

Table 2.1 Impact Energy of Rebound Hammers

Depending upon the impact energy, the hammers are classified into four types i.e. N, L, M & P. Type N hammer having an impact energy of 2.2 N-m and is suitable for grades of concrete from M-15 to M-45. Type L hammer is suitable for lightweight concrete or small and impact sensitive part of the structure. Type M hammer is generally recommended for heavy structures and mass concrete. Type P is suitable for concrete below M15 grade.

2.3 (b) Ultrasonic Pulse Velocity Tester

Ultrasonic instrument is a handy, battery operated and portable instrument used for assessing elastic properties or concrete quality. The apparatus for ultrasonic pulse velocity measurement consists of the following (Fig.) –

(a) Electrical pulse generator

(b) Transducer – one pair

(c) Amplifier

(d) Electronic timing device

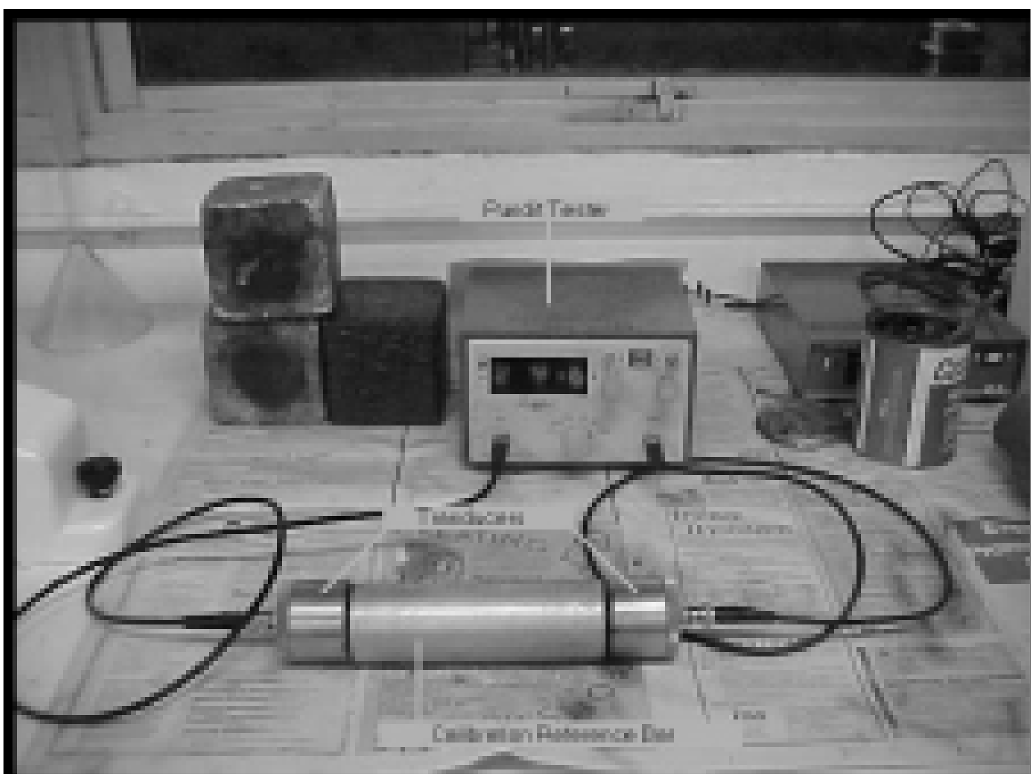


Fig.2.2 Components of a USPV TESTER

Objective:

The ultrasonic pulse velocity method could be used to establish:

(a) the homogeneity of the concrete

(b) the presence of cracks, voids and other imperfections

(c) change in the structure of the concrete which may occur with time

(d) the quality of concrete in relation to standard requirement

(e) the quality of one element of concrete in relation to another

(f) the values of dynamic elastic modulus of the concrete

Principle

The method is based on the principle that the velocity of an ultrasonic pulse through any material depends upon the density, modulus of elasticity and Poisson's ratio of the material. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc. 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 (Reyleigh) waves. The receiving transducer detects the onset of longitudinal waves which is the fastest. 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. For good quality concrete pulse velocity will be higher and for poor quality it will be less. 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 passed 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. Density and modulus of elasticity of aggregate also significantly affects the pulse velocity. Any suitable type of transducer operating within the frequency range of 20 KHz to 150 KHz may be used. Piezoelectric and magneto-strictive types of transducers may be used and the latter being more suitable for the lower part of the frequency range.

The electronic timing device should be capable of measuring the time interval elapsing between the onset of a pulse generated at the transmitting transducer and onset of its arrival at receiving transducer. Two forms of the electronic timing apparatus are possible, one of which use a cathode ray tube on which the leading edge of the pulse is displayed in relation to the suitable time scale, the other uses an interval timer with a direct reading digital display. If both the forms of timing apparatus are available, the interpretation of results becomes more reliable.

The ultrasonic pulse velocity has been used on concrete for more than 60 years. Powers in 1938 and Obert in 1939 were the first to develop and extensively use the resonance frequency method. Since then, ultrasonic techniques have been used for the measurements of the various properties of concrete. Also, many international committees, specifications and standards adopted the ultrasonic pulse velocity methods for evaluation of concrete. The principle of the test is that the velocity of sound in a solid material, *V*, is a function of the square root of the ratio of its modulus of elasticity, *E*, to its density, *d*, as given by the following equation:

$$V = f\left(\frac{gE}{d}\right)^{\frac{1}{2}} \tag{1}$$

Where, *g* is the gravity acceleration. As noted in the previous equation, the velocity is dependent on the modulus of elasticity of concrete. Monitoring modulus of elasticity for concrete through results of pulse velocity is not normally recommended because concrete does not fulfill the physical requirements for the validity of the equation normally used for calculations for homogenous, isotropic and elastic materials

$$V^2 = \frac{E_d(1-\mu)}{\rho(1+\mu)(1-\mu)} \quad (2)$$

where V is the wave velocity, ρ is the density, μ is Poisson's ratio and E_d is the dynamic modulus of elasticity. On the other hand, it has been shown that the strength of concrete and its modulus of elasticity are related.

The method starts with the determination of the time required for a pulse of vibrations at an ultrasonic frequency to travel through concrete. Once the velocity is determined, an idea about quality, uniformity, condition and strength of the concrete tested can be attained. In the test, the time the pulses take to travel through concrete is recorded. Then, the velocity is calculated as:

$$V = L/T$$

where V=pulse velocity, L=travel length in meters and T=effective time in seconds, which is the measured time minus the zero time correction.

From the literature review, it can be concluded that the ultrasonic pulse velocity results can be used to:

(a) check the uniformity of concrete,

(b) detect cracking and voids inside concrete,

(c) control the quality of concrete and concrete products by comparing results to a similarly made concrete,

(d) detect condition and deterioration of concrete,

(e) detect the depth of a surface crack and

(f) determine the strength if previous data is available.

Factors influencing pulse velocity measurement

The pulse velocity depends on the properties of the concrete under test. Various factors which can influence pulse velocity and its correlation with various physical properties of concrete are as under:

Moisture Content:

The moisture content has chemical and physical effects on the pulse velocity. These effects are important to establish the correlation for the estimation of concrete strength. There may be significant difference in pulse velocity between a properly cured standard cube and a structural element made from the same concrete. This difference is due to the effect of different curing conditions and presence of free water in the voids. It is important that these effects are carefully considered when estimating strength.

Temperature of Concrete:

No significant changes in pulse velocity, in strength or elastic properties occur due to variations of the concrete temperature between 5° C and 30° C. Corrections to pulse velocity measurements should be made for temperatures outside this range, as given in table below:

Temperature °C	Correction to the measured pulse velocity in %	
	Air dried concrete	Water saturated concrete
60	+5	+4
40	+2	+1.7
20	0	0
0	-0.5	-1
- 4	-1.5	-7.5

Table 2.2 Effect of temperature on pulse transmission. BS 1881 (Pt 203 Year 1986)

Path Length:

The path length (the distance between two transducers) should be long enough not to be significantly influenced by the heterogeneous nature of the concrete. It is recommended that the minimum path length should be 100mm for concrete with 20mm or less nominal maximum size of aggregate and 150mm for concrete with 20mm and 40mm nominal maximum size of aggregate. The pulse velocity is not generally influenced by changes in path length, although the electronic timing apparatus may indicate a tendency for slight reduction in velocity with increased path length. This is because the higher frequency components of the pulse are attenuated more than the lower frequency components and the shapes of the onset of the pulses becomes more rounded with increased distance travelled. This apparent reduction in velocity is usually small and well within the tolerance of time measurement accuracy.

Effect of Reinforcing Bars:

The pulse velocity in reinforced concrete in vicinity of rebars is usually higher than in plain concrete of the same composition because the pulse velocity in steel is almost twice to that in plain concrete. The apparent increase depends upon the proximity of measurement to rebars, their numbers, diameter and their orientation. Whenever possible, measurement should be made in such a way that steel does not lie in or closed to the direct path between the transducers. If the same is not possible, necessary corrections needs to be applied. The correction factors for this purpose are enumerated in different codes.

Shape and Size of Specimen:

The velocity of pulses of vibrations is independent of the size and shape of specimen, unless its least lateral dimension is less than a certain minimum value. Below this value, the pulse velocity may be reduced appreciably. The extent of this reduction depends mainly on the ratio of the wavelength of the pulse vibrations to the least lateral dimension of the specimen but it is insignificant if the ratio is less than unity. Table given below shows the relationship between the pulse velocity in the concrete, the transducer frequency and the minimum permissible lateral dimension of the specimen.

Transducer Frequency in KHz	Minimum lateral dimension in mm for Pulse specimen velocity in concrete in Km/s		
	$V_c = 3.5$	$V_c = 4.0$	$V_c = 4.5$
24	146	167	188
54	65	74	83
82	43	49	55
150	23	27	30

Table: 2.3 Effect of specimen dimension on pulse transmission. BS 1881 (Part 203 Year 1986)

The use of the ultrasonic pulse velocity tester is introduced as a tool to monitor basic initial cracking of concrete structures and hence to introduce a threshold limit for possible failure of the structures. Experiments using ultrasonic pulse velocity tester have been carried out, under laboratory conditions, on various concrete specimens loaded in compression up to failure. Special plots, showing the relation between the velocity through concrete and the stress during loading, have been introduced. Also, stress–strain measurements have been carried out in order to obtain the corresponding strains. Results showed that severe cracking occurred at a stress level of about 85% of the rupture load. The average velocity at this critical limit was about 94% of the initial velocity and the corresponding strain was in the range of 0.0015 to 0.0021. The sum of the crack widths has been estimated using special relations and measurements. This value that corresponds to the 94% relative velocity was between 5.2 and 6.8 mm.

Chapter 3

TEST METHODOLOGY

TEST METHODOLOGY

3.1 REBOUND HAMMAR

Before commencement of a test, the rebound hammer should be tested against the test anvil, to get reliable results. The testing anvil should be of steel having Brinell hardness number of about 5000 N/mm2. The supplier/manufacturer of the rebound hammer should indicate the range of readings on the anvil suitable for different types of rebound hammer.

For taking a measurement, the hammer should be held at right angles to the surface of the structure. The test thus can be conducted horizontally on vertical surface and vertically upwards or downwards on horizontal surfaces (Fig

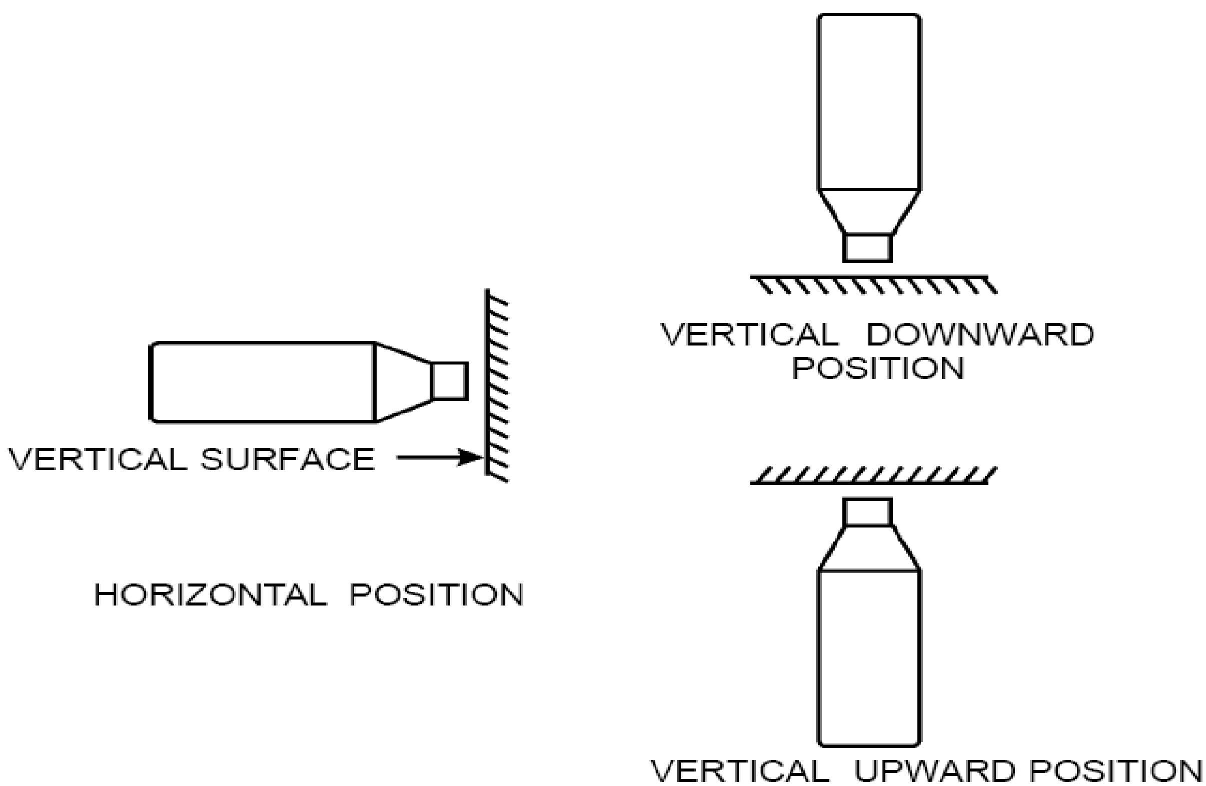


Fig. 3.1 Various positions of Rebound Hammer

If the situation so demands, the hammer can be held at intermediate angles also, but in each case, the rebound number will be different for the same concrete.

The following should be observed during testing –

(a) The surface should be smooth, clean and dry

(b) The loosely adhering scale should be rubbed off with a grinding wheel or stone, before testing

(c) The test should not be conducted on rough surfaces resulting from incomplete compaction, loss of grout, spalled or tooled surfaces.

(d) The point of impact should be at least 20mm away from edge or shape discontinuity.

The ultrasonic pulse velocity results can be used:

(a) To check the uniformity of concrete,

(b) To detect cracking and voids inside concrete,

(c) To control the quality of concrete and concrete products by comparing results to a similarly made concrete,

(d) To detect the condition and deterioration of concrete,

(e) To detect the depth of a surface crack, and,

(f) To determine the strength if previous data are available.

Procedure for obtaining correlation between Compressive Strength of Concrete 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. The concrete cubes specimens are held in a compression testing machine under a fixed load, measurements of rebound number taken and then the compressive strength determined as per IS 516: 1959. The fixed load required is of the order of 7 N/mm2 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. 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. 150mm cube specimens are preferred for calibrating rebound hammers of lower impact energy (2.2Nm), whereas for rebound hammers of higher impact energy, for example 30 Nm, the test cubes should not be smaller than 300mm.

If the specimens are wet cured, they should be removed from wet storage and kept in the laboratory atmosphere for about 24 hours before testing. To obtain a correlation between rebound numbers and strength of wet cured and wet tested cubes, it is necessary to establish a correlation between he strength of wet tested cubes and the strength of dry tested cubes on which rebound readings are taken. A direct correlation between rebound numbers on wet cubes and the strength of wet cubes is not recommended. Only the vertical faces of the cubes as cast should be tested. 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 20mm and should be not less than 20mm from each other. The same points must not be impacted more than once.

3.2 Ultrasonic Pulse Velocity Tester

The equipment should be calibrated before starting the observation and at the end of test to ensure accuracy of the measurement and performance of the equipment. It is done by measuring transit time on a standard calibration rod supplied along with the equipment. A platform/staging of suitable height should be erected to have an access to the measuring locations. The location of measurement should be marked and numbered with chalk or similar thing prior to actual measurement (pre decided locations).

Mounting of Transducers

The direction in which the maximum energy is propagated is normally at right angles to the face of the transmitting transducer, it is also possible to detect pulses which have traveled through the concrete in some other direction. The receiving transducer detects the arrival of component of the pulse which arrives earliest. This is generally the leading edge of the longitudinal vibration. It is possible, therefore, to make measurements of pulse velocity by placing the two transducers in the following manners (Fig

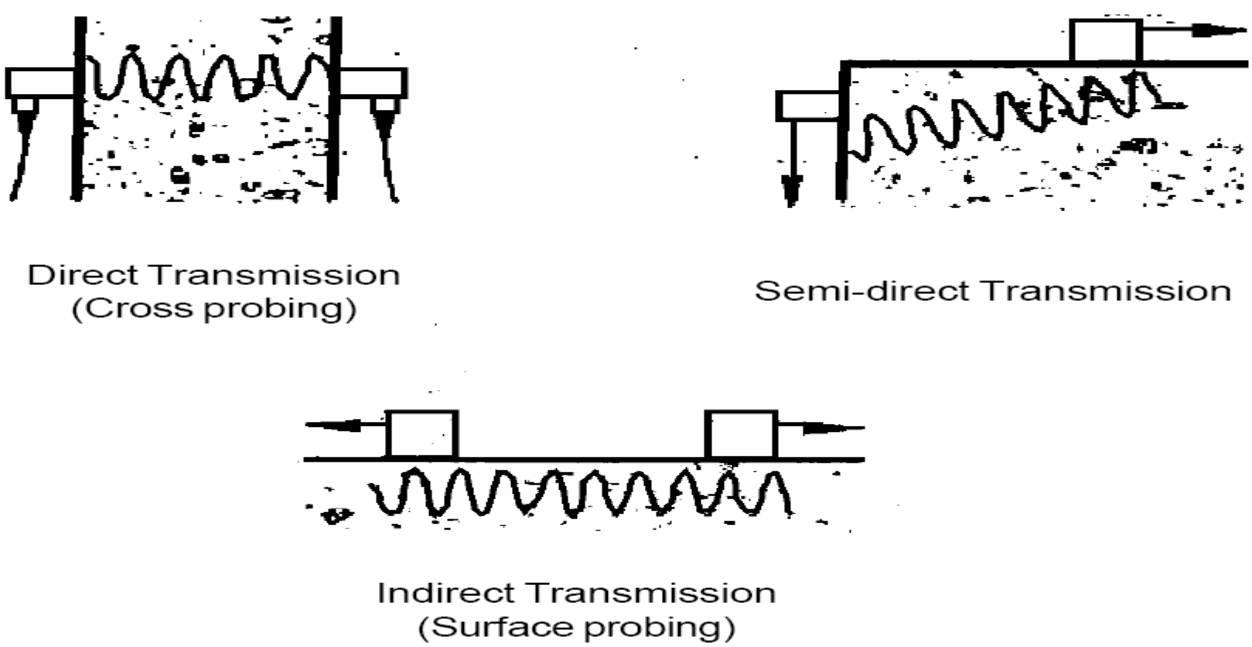


Fig. 3.2 Various Methods of UPV Testing

(a) Direct Transmission (on opposite faces) –

This arrangement is the most preferred arrangement in which transducers are kept directly opposite to each other on opposite faces of the concrete. The transfer of energy between transducers is maximum in this arrangement. The accuracy of velocity determination is governed by the accuracy of the path length measurement. Utmost care should be taken for accurate measurement of the same. The couplant used should be spread as thinly as possible to avoid any end effects resulting from the different velocities of pulse in couplant and concrete.

(b) Semi-direct Transmission:

This arrangement is used when it is not possible to have direct transmission (may be due to limited access). It is less sensitive as compared to direct transmission arrangement. There may be some reduction in the accuracy of path length measurement, still it is found to be sufficiently accurate. This arrangement is otherwise similar

to direct transmission.

(c) Indirect or Surface Transmission:

Indirect transmission should be used when only one face of the concrete is accessible (when other two arrangements are not possible). It is the least sensitive out of the three arrangements. For a given path length, the receiving transducer get signal of only about 2% or 3% of amplitude that produced by direct transmission. Furthermore, this arrangement gives pulse velocity measurements which are usually influenced by the surface concrete which is often having different composition from that below surface concrete. Therefore, the test results may not be correct representative of whole mass of concrete. The indirect velocity is invariably lower than the direct velocity on the same concrete element. This difference may vary from 5% to 20% depending on the quality of the concrete. Wherever practicable, site measurements should be made to determine this difference. There should be adequate acoustical coupling between concrete and the face of each transducer to ensure that the ultrasonic pulses generated at the transmitting transducer should be able to pass into the concrete and detected by the receiving transducer with minimum losses. It is important to ensure that the layer of smoothing medium should be as thin as possible. Couplant like petroleum jelly, grease, soft soap and kaolin/glycerol paste are used as a coupling medium between transducer and concrete. Special transducers have been developed which impart or pick up the pulse through integral probes having 6mm diameter tips. A receiving transducer with a hemispherical tip has been found to be very successful. Other transducer configurations have also been developed to deal with special circumstances. It should be noted that a zero adjustment will almost certainly be required when special transducers are used. Most of the concrete surfaces are sufficiently smooth. Uneven or rough surfaces, should be smoothened using carborundum stone before placing of transducers. Alternatively, a smoothing medium such as quick setting epoxy resin or plaster can also be used, but good adhesion between concrete surface and smoothing medium has to be ensured so that the pulse is propagated with minimum losses into the concrete. Transducers are then pressed against the concrete surface and held manually. It is important that only a very thin layer of coupling medium separates the surface of the concrete from its contacting transducer. The distance between the measuring points should be accurately measured. Repeated readings of the transit time should be observed until a minimum value is obtained.

Once the ultrasonic pulse impinges on the surface of the material, the maximum energy is propagated at right angle to the face of the transmitting transducers and best results are, therefore, obtained when the receiving transducer is placed on the opposite face of the concrete member known as Direct Transmission. The pulse velocity can be measured by Direct Transmission, Semi-direct Transmission and Indirect or Surface Transmission. Normally, Direct Transmission is preferred being more reliable and standardized. (various codes gives correlation between concrete quality and pulse velocity for Direct Transmission only). The size of aggregates influences the pulse velocity measurement. The minimum path length should be 100mm for concrete in which the nominal maximum size of aggregate is 20mm or less and 150mm for aggregate size between 20mm and 40mm. Reinforcement, if present, should be avoided during pulse velocity measurements, because the pulse velocity in the reinforcing bars is usually higher than in plain concrete. This is because the pulse velocity in steel is 1.9 times of that in concrete. In certain conditions, the first pulse to arrive at the receiving transducer travels partly in concrete and partly in steel. The apparent increase in pulse velocity depends upon the proximity of the measurements to the reinforcing bars, the diameter and number of bars and their orientation with respect to the path of propagation. It is reported that the influence of reinforcement is generally small if the bar runs in the direction right angle to the pulse path for bar diameter less than12 mm. But if percentage of steel is quite high or the axis of the bars are parallel to direction of propagation, then the correction factor has to be applied to the measured values.

The zero time correction is equal to the travel time between the transmitting and receiving transducers when they are pressed firmly together.

Determination of pulse velocity

A pulse of longitudinal vibration is produced by an electro acoustical transducer, which is held in contact with one surface of the concrete member under test. After traversing a known path length(L) in the concrete, the pulse of vibration is converted into an electrical signal by a second electro-acoustical transducer, and electronic timing circuit enable the transit time (T) of the pulse to be measured. The pulse velocity (V) is given by V = L / T

where,

V = Pulse velocity, L = Path length , T = Time taken by the pulse to traverse the path length

Fig.3.3 Testing of a beam by USPV Tester

Combined use of Rebound hammer and Ultrasonic Pulse Velocity Method

In view of the relative limitations of either of the two methods for predicting the strength of concrete, both ultrasonic pulse velocity (UPV) and rebound hammer methods are sometimes used in combination to alleviate the errors arising out of influence of materials, mix and environmental parameters on the respective measurements. Relationship between UPV, rebound hammer and compressive strength of concrete are available based on laboratory test specimen. Better accuracy on the estimation of concrete strength is achieved by use of such combined methods. However, this approach also has the limitation that the established correlations are valid only for materials and mix having same proportion as used in the trials. The intrinsic difference between the laboratory test specimen and in-situ concrete (e.g. surface texture, moisture content, presence of reinforcement, etc.) also affect the accuracy of test results.

Combination of UPV and rebound hammer methods can be used for the assessment of the quality and likely compressive strength of in-situ concrete. Assessment of likely compressive strength of concrete is made from the rebound indices and this is taken to be indicative of the entire mass only when the overall quality of concrete judged by the UPV is ‘good’. 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 collateral measurement e.g. strength of controlled cube specimen, cement content of hardened concrete by chemical analysis or concrete core testing. When the quality of concrete is ‘poor’, no assessment of the strength of concrete is made from rebound indices.

Chapter 4

AIM OF THE PROJECT

AIM OF THE PROJECT

The aim of the project was to obtain the Calibration Graphs for Non Destructive Testing Equipments viz., the Rebound Hammer and Ultrasonic pulse Velocity Tester and to study the effect of reinforcement on the obtained results. These Non Destructive Instruments were then used to test the columns, beams and slabs of two double storied buildings viz., Hall No.2 and Hall no.7 (a newly constructed hostel) in N I T Rourkela.

Chapter 5

TEST RESULTS AND DISCUSSION

5.1 CALIBRATION TESTS

PROCEDURE:

The procedure that was followed during experiments consisted of the following steps:

1. Various concrete mixes were used to prepare standard cubes of 150-mm side length.

2. Concrete cubes of unknown history made under site conditions were also brought from various sites for testing.

3. All cubes were immersed under water for a minimum period of 24 h before testing.

4. Just before testing, the cubes were rubbed with a clean dry cloth in order to obtain a saturated surface dry sample.

5. Once drying was complete, each of the two opposite faces of the cube were prepared for the rebound hammer test as described in the specifications.

6. The cubes were positioned in the testing machine and a slight load was applied. The rebound number was obtained by taking three measurements on each of the four faces of the cube. The rebound hammer was horizontal in all measurements.

7. Once the rebound hammer test was complete, each of the two surfaces was prepared for the ultrasonic pulse velocity test as described in the specifications. Care was taken so that there was no effect of the notches produced by the hammer. The time was measured on each of the two opposing surfaces and the average was recorded.

8. Once nondestructive testing on each cube was completed, the cube was loaded to failure and the maximum load was recorded.

9. Results were plotted as shown in Figures.

5.2 REBOUND HAMMER TEST

PREPARATION OF SPECIMEN:

- 6 cubes were cast, targeting at different mean strengths. Further, the cubes were cured for different number of days to ensure availability of a wide range of compressive strength attained by these cubes. Size of each cube was 150×150×150 mm.

TESTING OF SPECIMEN:

- 10 readings (rebound numbers) were obtained for each cube, at different locations on the surface of the specimen.
- The cube was divided into grid blocks of equal spacing and 10 points were marked at equal intervals for taking the Rebound Hammer test.
- The cubes were then given a load of 7 N/mm^2 (as specified by the IS CODE 13311) in the Compression Testing Machine and the Rebound Values were obtained.
- The cubes were then loaded up to their ultimate stress and the Breaking Load was obtained.
- The following tables lists the Rebound numbers (rebound index), Mean Rebound Value, Standard Deviation, the Dead Load on the specimen at the time of testing, the Breaking Load, the Predicted Compressive Strength as predicted by the Rebound Hammer and the actual Compressive Strength as obtained by the Compression Testing Machine.

Fig.5.1 Components of a Rebound Hammer used in the Project

Fig.5.2 Rebound Hammer Testing of a Specimen

SAMPLE NO. 1

SL NO.	R. NO.
1	19
2	25
3	23
4	22
5	23
6	22
7	22
8	22
9	23
10	22
MEAN	22.3
S.D.	1.49

Dead Load =	150 KN
Breaking load =	247 KN
f (ck) N/mm^2 (Predicted) =	14.2 N/mm^2
f (ck) N/mm^2 (Actual) =	11.0 N/mm^2

Table No. 5.1 a

SAMPLE NO. 2

SL NO.	R. NO.
1	19
2	20
3	19
4	20
5	19
6	20
7	19
8	20
9	19
10	22
MEAN	19.7
S.D.	0.94

Dead Load =	150 KN
Breaking load =	311.5 KN
f (ck) N/mm^2 (Predicted) =	13.2 N/mm^2
f (ck) N/mm^2 (Actual) =	13.8 N/mm^2

Table No. 5.1 b

SAMPLE NO. 3

SL NO.	R. NO.
1	24
2	25
3	26
4	26
5	26
6	25
7	25
8	24
9	25
10	25
MEAN	25.1
S.D.	0.737865

Dead Load =	150 KN
Breaking load =	346.5 KN
f (ck) N/mm^2 (Predicted) =	18.8 N/mm^2
f (ck) N/mm^2 (Actual) =	15.3 N/mm^2

Table No. 5.1 c

SAMPLE NO. 4

SL NO.	R. NO.
1	42
2	42
3	41
4	42
5	42
6	42
7	43
8	43
9	43
10	42
MEAN	42.2
S.D.	0.63

Dead Load =	150 KN
Breaking load =	830 KN
f (ck) N/mm^2 (Predicted) =	42.6 N/mm^2
f (ck) N/mm^2 (Actual) =	36.88 N/mm^2

Table No. 5.1 d

SAMPLE NO. 5

SL NO.	R. NO.
1	36
2	37
3	37
4	39
5	40
6	40
7	41
8	40
9	40
10	41
MEAN	39.1
S.D.	1.79

Dead Load =	150 KN
Breaking load =	710 KN
f (ck) N/mm^2 (Predicted) =	36.2 N/mm^2
f (ck) N/mm^2 (Actual) =	31.5 N/mm^2

Table No. 5.1 e

SAMPLE NO. 6

SL NO.	R. NO.
1	38
2	38
3	37
4	37
5	38
6	38
7	37
8	37
9	38
10	38
MEAN	37.6
S.D.	0.516398

Dead Load =	150 KN
Breaking load =	760 KN
f (ck) N/mm^2 (Predicted) =	39.7 N/mm^2
f (ck) N/mm^2 (Actual) =	33.8 N/mm^2

Table No. 5.1 f

The following graph is obtained between the Predicted Compressive Strength by the Rebound Hammer and the Actual Compressive Strength:

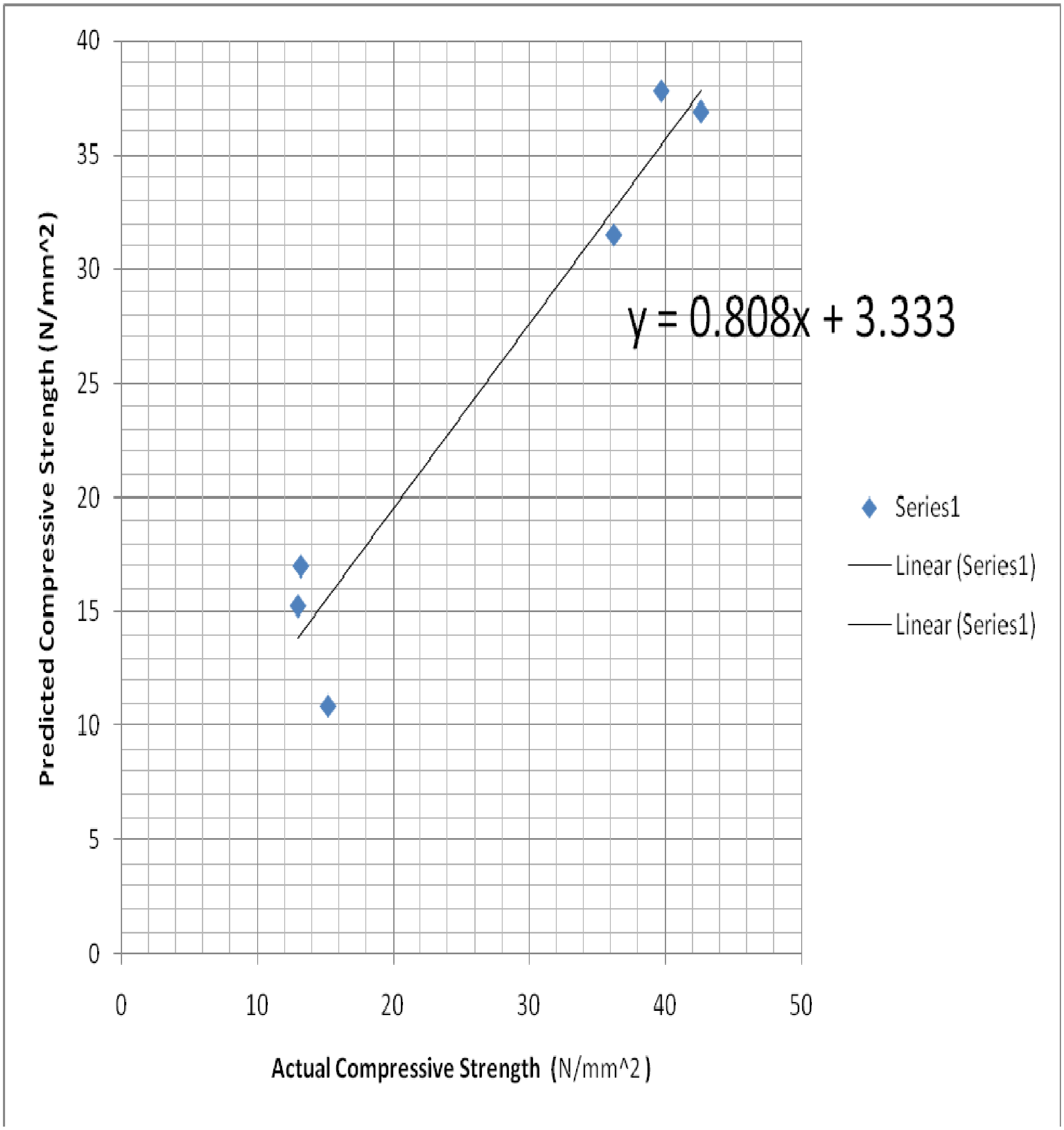


Fig. 5.3 Calibration Graph for Rebound Hammer with its Equation

Ultrasonic Velocity Testing Machine

PREPARATION OF SPECIMEN

9 cubes were cast, targeting at different mean strengths. Further, the cubes were cured for different number of days to ensure availability of a wide range of compressive strength attained by these cubes. Size of each cube was 150×150×150 mm.

TESTING OF SPECIMEN:

3 readings of Ultrasonic Pulse Velocity (USPV) were obtained for each cube.

The cubes were then given a load of 7 N/mm^2 (as specified by the IS CODE 13311) in the Compression Testing Machine and the USPV were obtained.

The cubes were then loaded up to their ultimate stress and the Breaking Load was obtained.

The following table lists the USPV in each specimen with their mean velocity, the Dead Load, the Breaking Load and the actual Compressive Strength as obtained by the Compression Testing Machine.

Fig.5.4 Zeroing of the Transducers

Fig.5.5 USPV Tester used in the Project

Fig. 5.6 USPV Testing of a Specimen

<u>OBSERVATIONS</u>

SAMPLE NO.	V1	V2	V3	V		BREAKING	f (ck) N/mm^2
	(m/sec)	(m/sec)	(m/sec)	(m/sec)	I R LOAD	LOAD	(Actual)
				(Avg)	KN	KN	
1	2825	2916	2913	2884.667	150	562.5	25
2	3350	3585	3218	3384.333	150	669.8	29.77
3	3625	3632	3218	3491.667	150	720	32
4	4219	4213	4007	4146.333	150	841.5	37.4
5	4411	4444	4117	4324	150	875.2	38.9
6	4625	4525	4417	4522.333	150	893.2	39.7

Table 5.2 USPV Testing Results

The following graph is obtained between the Compressive Strength and the Ultrasonic Pulse Velocity:

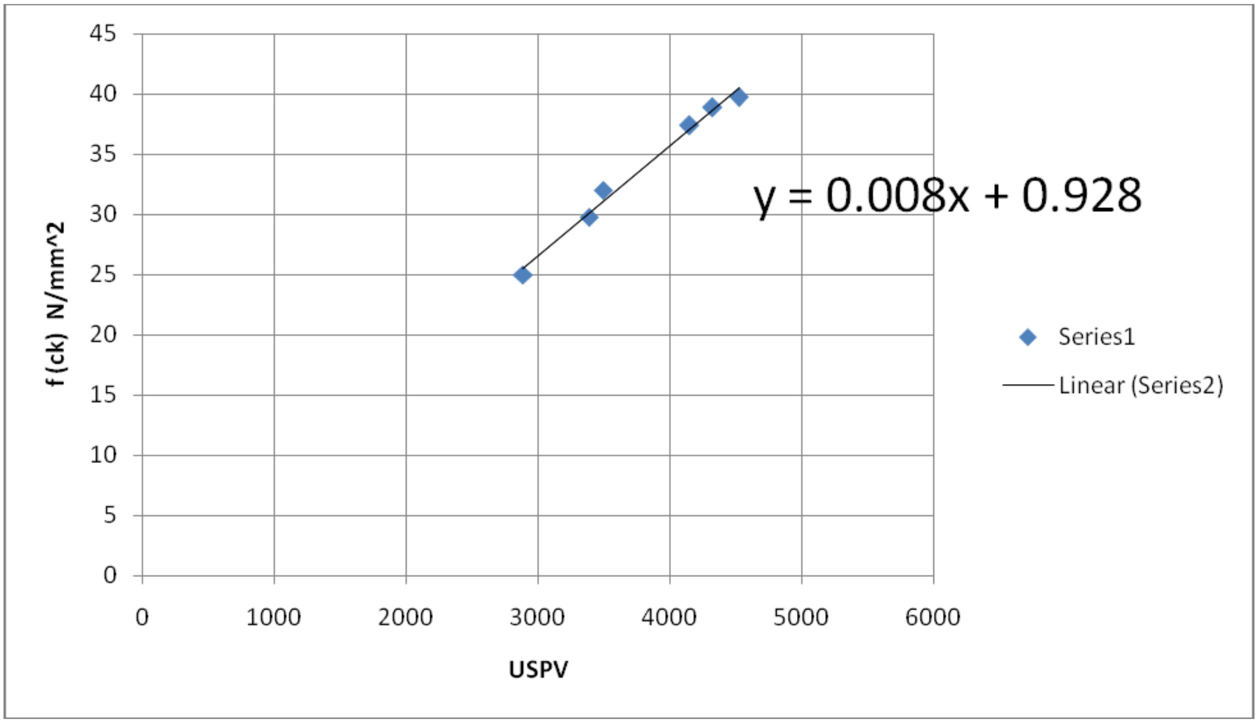


Fig. 5.7 Graph obtained for USPV Testing

This graph can now also be used to approximately predict the Compressive Strength of Concrete.

Although it gives fairly approximate results but it should be verified with some other tests like the Rebound Hammer test.

5.2 Study of Effect of Reinforcement on the Rebound Values and Pulse Velocities

To Study the effect of reinforcement on the Rebound Values and the Ultrasonic Pulse Velocities:

- Two Beams were cast of the following dimensions:

  Length = 1.8 m   Breadth = .2 m   Depth = .25 m
- Grade of Concrete Used: M20 and M25
- The points where the reinforcements existed were known so the testing was done in two stages :

  (i) By avoiding the impact of reinforcements or by trying to minimize its impact.

  (ii) By undertaking the effect of reinforcements or by maximizing its impact.

A comparative analysis is then made to know the effect of reinforcement on the tests

OBSERVATION

Grade of concrete used : M 20

	REBOUND NO.		ULTRASONIC PULSE VELOCITY (m/sec)	
SL NO.	WITHOUT REINF'MENT	WITH REINF'MENT	WITHOUT REINF'MENT	WITH REINF'MENT
1st End	29	30	2861	3155
Quarter Length	28	29	2941	3053
Mid Span	30	31	2991	3075
Three Quarter Length	28	29	2800	2908
2nd End	29	29	2925	3224

Table No.5.3a Testing of a Beam (M 20) for Effect of Reinforcement

Grade of concrete used: M 25

	REBOUND NO.		ULTRASONIC PULSE VELOCITY (m/sec)	
SL NO.	WITHOUT REINF'MENT	WITH REINF'MENT	WITHOUT REINF'MENT	WITH REINF'MENT
1st End	36	36	3161	3688
Quarter Length	36	37	3141	3374
Mid Span	35	37	3191	3488
Three Quarter Length	39	41	3322	3778
2nd End	39	39	3257	3722

Table No.5.3b Testing of a Beam (M 25) for Effect of Reinforcement

The maximum variation obtained for Rebound Value is **3.6 %** whereas in case of Ultrasonic Pulse Velocity the maximum variation is **16.1 % .** Therefore, the variations are well within the tolerable limits.

5.3 TESTING OF HALL NO. 2 AND HALL NO. 7

Tests were conducted on some of the Columns, Beams and Slabs of Hall No. 2 and Hall No. 7 for the assessment of their quality. The observations, results and discussions have been tabulated below:

HALL O7

COLUMN NO 1

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
BOTTOM	28 29 29	28.67	3313	22.5	Testing was done over the plaster. Medium Quality concrete.
MIDDLE	13 14 14	13.67	Over Range	13.4	Void between plaster and column face indicated by a peculiar sound when struck softly by an iron rod
TOP	15 16 15	15.33	Over Range	14.1	Void between plaster and column face indicated by a peculiar sound when struck softly by an iron rod

Table No. 5.4

HALL O7

COLUMN NO 2

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
BOTTOM	32 33 33	32.67	3754	31.3	Good quality concrete
MIDDLE	30 32 30	30.67	3531	30.1	Good quality concrete
TOP	31 31 30	30.67	3255	30.1	Medium quality concrete.

Table No. 5.5

HALL O7

COLUMN NO 3

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
BOTTOM	36 36 36	36	3744	33.9	Good quality concrete
MIDDLE	34 35 35	34.67	3825	33	Good quality concrete
TOP	33 34 35	34	3614	32.8	Good quality concrete

Table No. 5.6

In Hall No. 2 the columns are made of brick masonry so this test is not applicable there.

HALL O7

BEAM NO.1

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
1 ST SUPPORT	40 40 37	39	4468	39.9	Good quality concrete
MID SPAN	32 32 34	32.67	3455	29.9	Medium quality
2ND SUPPORT	34 34 35	34.33	3480	30.8	Medium quality

Table No. 5.7

HALL O7

BEAM NO.2

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
1 ST SUPPORT	33 35 32	33.33	3655	30.5	Good quality concrete
MID SPAN	34 35 36	35	3845	31.6	Good quality concrete
2ND SUPPORT	34 37 34	35	3440	31.6	Good quality concrete

Table No. 5.8

HALL O7

BEAM NO.3

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
1 ST SUPPORT	43 39 36	39.33	4505	35.8	Good quality concrete
MID SPAN	38 45 37	40	4533	36.1	Excellent quality concrete. Proper compaction may be the reason.
2ND SUPPORT	45 49 45	46.33	4861	41.2	Excellent quality. It is the junction of three beams and a column, so heavy reinforcement and proper compaction is indicated

Table No. 5.9

HALL O2

BEAM NO.1

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
1 ST SUPPORT	26 28 27	27	2620	20.3	Doubtful Quality. Requires attention
MID SPAN	25 27 27	26.33	2729	20	Doubtful Quality. Requires attention
2ND SUPPORT	29 28 24	27	2645	20.3	Doubtful Quality. Requires attention

Table No. 5.10

HALL O2

BEAM NO.2

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
1 ST SUPPORT	31 31 34	32	3422	29.8	Medium quality concrete
MID SPAN	33 32 32	32.33	3871	29.8	Medium quality concrete
2ND SUPPORT	35 34 37	35.33	3750	31.1	Good quality concrete

Table No. 5.11

HALL O2

BEAM NO.3

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
1 ST SUPPORT	28 28 29	28.33	1955	23.8	USPV is low, there might be separation of plaster from the beam or internal voids and cracks. Requires attention
MID SPAN	30 32 30	30.67	3233	25.1	Medium quality concrete
2ND SUPPORT	29 33 31	31	3354	25.3	Medium quality concrete

Table No. 5.12

HALL O7

Observations were taken on the top roof slab i.e., the 2nd floor roof slab because the ground floor and the 1st floor slab do not have exosed surface due to application of Tiles. The 2nd floor roof slab has been plastered to protect it from rain, sunlight and other extreme conditions and to give a smooth finish.

SLAB NO.1

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
EDGES	38 39 39	38.67	34.3	4257	Good quality concrete
MID SPAN ALONG EDGES	36 35 35	35.67	32.7	3966	Good quality concrete
CENTRE OF SLAB	34 34 34	34	31.8	3850	Good quality concrete

Table No. 5.13

HALL O7

SLAB NO.2

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
EDGES	33 30 28	30.33	4122	26.5	High USPV may be due to heavy Torsion Reinforcements. Overall good quality concrete.
MID SPAN ALONG EDGES	32 31 31	31.33	3890	27.2	Good quality concrete.
CENTRE OF SLAB	29 30 30	29.67	2855	25.0	Little low. May be due to improper shuttering of slabs and improper compaction.

Table No. 5.14

HALL O7

SLAB NO.3

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
EDGES	30 33 28	29.67	4005	26.4	Good quality concrete.
MID SPAN ALONG EDGES	28 28 27	27.33	3825	25.6	Good quality concrete.
CENTRE OF SLAB	30 29 27	28.67	3988	26	Good quality concrete.

Table No. 5.15

HALL O2

Observations were taken on the 1st floor slabs.

SLAB NO.1

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
EDGES	47 45 44	45.33	5710	47.9	Excellent quality concrete
MID SPAN ALONG EDGES	49 48 44	47	5764	49.3	Excellent quality concrete
CENTRE OF SLAB	53 51 48	50.67	6229	52.6	Excellent quality concrete

Table No. 5.16

HALL O2

SLAB NO.2

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
EDGES	47 42 44	44.33		47.8	Excellent quality concrete
MID SPAN ALONG EDGES	58 47 58	51		52.4	Excellent quality concrete
CENTRE OF SLAB	38 36 40	38		40.5	Excellent quality concrete

Table No. 5.17

HALL O2

SLAB NO.3

	REBOUND VALUE	MEAN	USPV (m/s)	QUALITY f (ck) (N/mm^2)	REMARKS
EDGES	45 46 50	47	5846	51.9	Excellent quality concrete
MID SPAN ALONG EDGES	45 45 47	45.67	5760	49.1	Excellent quality concrete
CENTRE OF SLAB	42 39 33	38	4832	39.5	Excellent quality concrete

Table No. 5.18

Fig No. 5.8 Rebound Hammer Testing of a Column in Hall No.7

Fig No. 5.9 Rebound Hammer Testing of a Slab in Hall No.7

Fig No. 5.10 USPV Testing of a Slab in Hall No. 7

Fig No.5.10 USPV Testing of a Column Hall No. 7

5.4 Interpretation of Results

REBOUND HAMMER:

After obtaining the correlation between compressive strength and rebound number, the strength of structure can be assessed. In general, the rebound number increases as the strength increases and is also affected by a number of parameters i.e. type of cement, type of aggregate, surface condition and moisture content of the concrete, curing and age of concrete, carbonation of concrete surface etc. Moreover the rebound index is indicative of compressive strength of concrete up to a limited depth from the surface. The internal cracks, flaws etc. or heterogeneity across the cross section will not be indicated by rebound numbers.

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. If the relationship between rebound index and compressive strength can be found by tests on core samples obtained from the structure or standard specimens made with the same concrete materials and mix proportion, then the accuracy of results and confidence thereon gets greatly increased.

The Rebound hammer showed erratic result when the compressive strength was below 15 N/mm^2. Above 15 N/mm^2 the predicted compressive strength varied almost linearly with the actual compressive strength.

Ultrasonic Pulse Velocity Tester:

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 below:

Table: Criterion for Concrete Quality Grading
(As per IS 13311(Part 1) : 1992)

Sr. 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

Table. 5.19 USPV Criterion for Concrete Quality Grading

Since actual value of the pulse velocity in concrete depends on a number of parameters, so the criterion for assessing the quality of concrete on the basis of pulse velocity is valid to the general extent. However, when tests are conducted on different parts of the structure, which have been built at the same time with similar materials, construction practices and supervision and subsequently compared, the assessment of quality becomes more meaningful and reliable. The quality of concrete is usually specified in terms of strength and it is therefore, sometimes helpful to use ultrasonic pulse velocity measurements to give an estimate of strength.

The relationship between ultrasonic pulse velocity and strength is affected by a number of factors including age, curing conditions, moisture condition, mix proportions, type of aggregate and type of cement. The assessment of compressive strength of concrete from ultrasonic pulse velocity values is not accurate because the correlation between ultrasonic pulse velocity and compressive strength of concrete is not very clear. Because there are large number of parameters involved, which influence the pulse velocity and compressive strength of concrete to different extents. However, if details of material and mix proportions adopted in the 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 material 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 material.

At some places over plaster in rounded columns USPV gave no results or indicated that the velocity was out of range. In such a place the rebound value was also very low. This place gave a unique sound on striking softly with a hard material like iron which clearly indicated a void between the concrete of pillar and its plastering.

A general trend was obtained in the columns. The trend was such that towards the base of the column the tests always showed a higher quality of concrete i.e., higher compressive strength. The compressive strength went on decreasing as we go up towards the roof .

A graph has been plotted with increasing height against the predicted compressive strength. It is evident from the graph that the compressive strength goes on decreasing with increase in height of column.

The reason for this variation is better compaction at the base. Since all the weight of the column acts at the base higher compaction is achieved and also better compaction facilities are available near the base and process compaction becomes difficult as we go up.

No such regular trend was observed for beams or slabs.

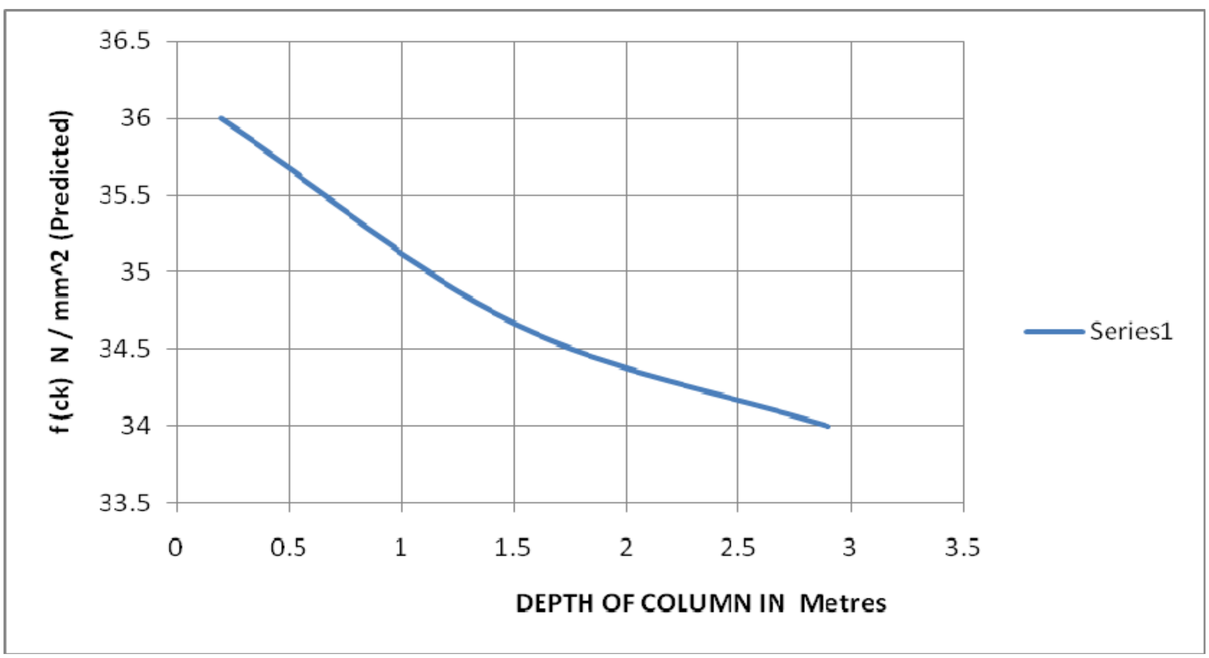


Fig No. 5.11 Variation of Strength with increase in Height of Column

Chapter 6

CONCLUSION

CONCLUSION

Considerable engineering judgment is needed to properly evaluate a measurement. Misinterpretation is possible when poor contact is made. For example, in some cases it may not be possible to identify severely corroded reinforcing bar in poor quality concrete. However, it is possible to identify poor quality concrete which could be the cause of reinforcing bar problems. The poor quality concrete allows the ingress of moisture and oxygen to the reinforcing bars, and hence corrosion occurs. Presently the system is limited to penetration depths of 1 ft. Research is ongoing to develop a system that can penetrate to a depth of 10 ft or more.

When variation in properties of concrete affect the test results, (especially in opposite directions), the use of one method alone would not be sufficient to study and evaluate the required property. Therefore, the use of more than one method yields more reliable results. For example, the increase in moisture content of concrete increases the ultrasonic pulse velocity but decreases the rebound number . Hence, using both methods together will reduce the errors produced by using one method alone to evaluate concrete. Attempts have been done to relate rebound number and ultrasonic pulse velocity to concrete strength. Unfortunately, the equation requires previous knowledge of concrete constituents in order to obtain reliable and predictable results.

The Schmidt hammer provides an inexpensive, simple and quick method of obtaining an indication of concrete strength, but accuracy of ±15 to ±20 per cent is possible only for specimens cast cured and tested under conditions for which calibration curves have been established. The results are affected by factors such as smoothness of surface, size and shape of specimen, moisture condition of the concrete, type of cement and coarse aggregate, and extent of carbonation of surface.

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 or deteriorated 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 per cent, provided the types of aggregate and mix proportions are constant.

In summary, ultrasonic pulse velocity tests have a great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects. Its use for predicting strength is much more limited, owing to the large number of variables affecting the relation between strength and pulse velocity.

The deviation between actual results and predicted results may be attributed to the fact that samples from existing structures are cores and the crushing compressive cube strength was obtained by using various corrections introduced in the specifications. Also, measurements were not accurate and representative when compared to the cubes used to construct the plots. The use of the combined methods produces results that lie close to the true values when compared with other methods. The method can be extended to test existing structures by taking direct measurements on concrete elements.

Unlike other work, the research ended with two simple chart that requires no previous knowledge of the constituents of the tested concrete. The method presented is simple, quick, reliable, and covers wide ranges of concrete strengths. The method can be easily applied to concrete specimens as well as existing concrete structures. The final results were compared with previous ones from literature and also with actual results obtained from samples extracted from existing structures.

Chapter 7

LIST OF FIRMS DEALING WITH NDT EQUIPMENTS

7.1 LIST OF FIRMS DEALING WITH NDT EQUIPMENTS

1. M/s AIMIL LTD., A-8, MOHAN COOPERATIVIE INDUSTRIAL ESTATE, MATHURA ROAD, NEW DELHI.

2. M/s HILTI INDIA PVT. LTD.,8 LSC PUSHPA VIHAR COMMUNITY CENTRE, NEW DELHI

3. M/s ULTRA TECHNOLOGIES PVT. LTD, B-85, KALKAJI, NEW DELHI.

4. M/s. ENCARDIO RITES, LUCKNOW

5. M/s. JAMES INSTRUMENTS LUC. 3727, NORTH AEDZIE AVENUE, CHICAGO ILLINOIS 60618, U.S.A.

6. PROSEQ U.S.A., RIESHASH STRASSE 57 CH - 8034 ZURICH, SWITZERLAND.

7. ELE INTERNATIONAL LTD., EAST MAN WAY, HEMEL HAMPSTEAD HERTFORDSHIRE, HP2 7HB, ENGLAND.

Chapter 8

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Christiane Maierhofer Federal Institute for Materials Research and Testing (BAM), D-12205 Berlin, Germany .

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