Structural Health Monitoring and Audit, Repair and Rehabilitation of Building in Construction Industry

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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, 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. Apart from requiring regular maintenance, many structures require extensive Repair, Rehabilitation &Retrofitting. Over a period of time, as these structures become older, we find in them certain degradation or deterioration with resultant distress manifested in the form of cracking, splitting, delaminating, corrosion etc. Such deteriorated structures can be rehabilitated and retrofitted by using various types of admixtures & modern repair materials. The paper brings out the present state of concrete structures & the major areas where improvement is needed during its service life stage for sustainable development & also the method of carrying out Repair, Rehabilitation &Retrofitting. This has been brought in details in the paper along with Case studies, where the Author of the paper was directly involved in planning and execution of the jobs.

KEYWORDS: Wireless Sensor Networks, Ambient Health Monitoring, Structural Health Monitoring in Construction Management, Technical Challenges, Acoustic emission, Monitoring, MEMS, Structures, Audit, Repair, Rehabilitation.

I. INTRODUCTION

In the most general terms, damage can be defined as changes introduced into a system that adversely affects its current or future performance. Implicit in this definition is the concept that damage is not meaningful without a comparison between two different states of the system, one of which is assumed to represent the initial, and often undamaged, state. This theme issue is focused on the study of damage identification in structural and mechanical systems. Therefore, the definition of damage will be limited to changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity, which adversely affect the current or future performance

of these systems. In terms of length-scales, all damage begins at the material level. Although not necessarily a universally accepted terminology, such damage is referred to as a defect or flaw and is present to some degree in all materials. Under appropriate loading scenarios, the defects or flaws grow and coalesce at various rates to cause component and then system-level damage. The term damage does not necessarily imply a total loss of system functionality, but rather that the system is no longer operating in its optimal manner. As the damage grows, it will reach a point where it affects the system operation to a point that is no longer acceptable to the user. This point is referred to as failure. In terms of time-scales, damage can accumulate incrementally over long periods of time such as that associated with fatigue or corrosion damage accumulation. On relatively shorter time-scales, damage can also result from scheduled discrete events such as aircraft landings and from unscheduled discrete events such as enemy fire on a military vehicle or natural phenomena hazards such as earthquakes. The process of implementing a damage identification strategy for aerospace, civil and mechanical engineering infrastructure is referred to as structural health monitoring (SHM). This process involves the observation of a structure or mechanical system over time using periodically spaced measurements, the extraction of damage-sensitive features the current state of system health. For long-term SHM, the output of this process is periodically updated information regarding the ability of the structure to continue to perform its intended function in light of the inevitable aging and damage accumulation resulting from the operational environments. Under an extreme event, such as an earthquake or unanticipated blast loading, SHM is used for rapid condition screening. This screening is intended to provide, in near real-time, reliable information about system performance during such extreme events and the subsequent integrity of the system.

Damage identification is carried out in conjunction with five closely related disciplines that include SHM, condition monitoring, non-destructive evaluation statistical process control and damage prognosis. Typically, SHM is associated with online–global damage identification in structural systems such as aircraft and buildings. CM is analogous to SHM, but addresses damage identification in rotating and reciprocating machinery, such as those used in manufacturing and power generation. NDE is usually carried out off-line in a local manner after the damage has been located. There are exceptions to this rule, as NDE is also used as a monitoring tool for in situ structures such as pressure vessels and rails. NDE is therefore primarily used for damage characterization and as a severity check when there is a priori knowledge of the damage location. SPC is process-based rather than structure-based and uses a variety of sensors to monitor changes in a process, one cause of which can result from structural damage. Once damage has been detected, DP is used to predict the remaining useful life of a system.

If, further use of such deteriorated structure is continued it may endanger the lives of occupants and surrounding habitation. There is demand of appropriate actions and measures for all such building structures to improve its performance and restore the desired functions of structures which may leads to increase its functional life. The periodical structural auditing and diagnosis for health of existing buildings is thus utmost important for finding the present serviceability and structural viability of structures. The structural audit must be carried out following auditing norms, methods of non-destructive testing and code provisions. The structural auditing will help to implement maintenance and repair work timely which leads to prolonged life of the building and safety of the occupants. In India there are many old buildings which have reduced strength in due course of time. If further use of such deteriorated structure is continued it may endanger the lives of the occupants and surrounding habitation. Appropriate actions should then be implemented to improve the performance of structures and restore the desired function of structures. Thus, it is utmost important to perform structural audit of existing buildings and to implement maintenance/ repair work timely which will lead to prolonged life of the building and safety of the occupant. To act more responsible and pre-emptive towards the dilapidated buildings, the municipal corporation must issue notices to the buildings and co-operative societies which are more than 30 years old to carry out mandatory structural audit and submit the audit report. Structural audit should highlight and investigate all critical areas and recommend immediate remedial and preventive measures. It should cover the structural analysis of existing frame and find critical elements for all types of loadings. It also helps in delivering a strong building structure with cost effective solutions and appropriate maintenance program. This paper deals with study of different parameter of structural audit including visual inspection, non-destructive testing, core sampling and testing. It also emphasizes on different repairs and retrofitting measures to be used for buildings after structural audit.

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.

II. 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.

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.

III. METHODOLOGY

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.

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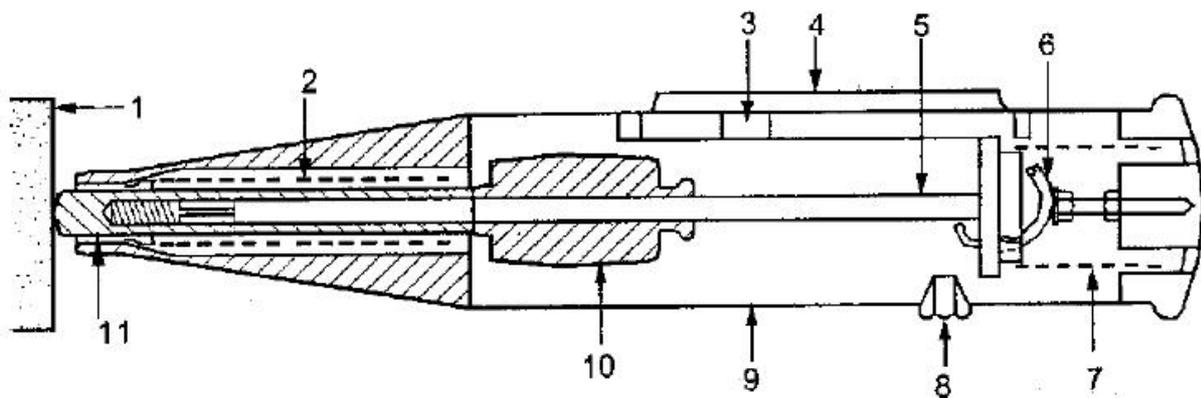
1. Concrete surface	5. Hammer guide	9. Housing
2. Impact spring	6. Release catch	10. Hammer mass
3. Rider on guide rod	7. Compressive spring	11. Plunger
4. Window and scale	8. Locking button	

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 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.

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.

IV. TEST METHODOLOGY

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
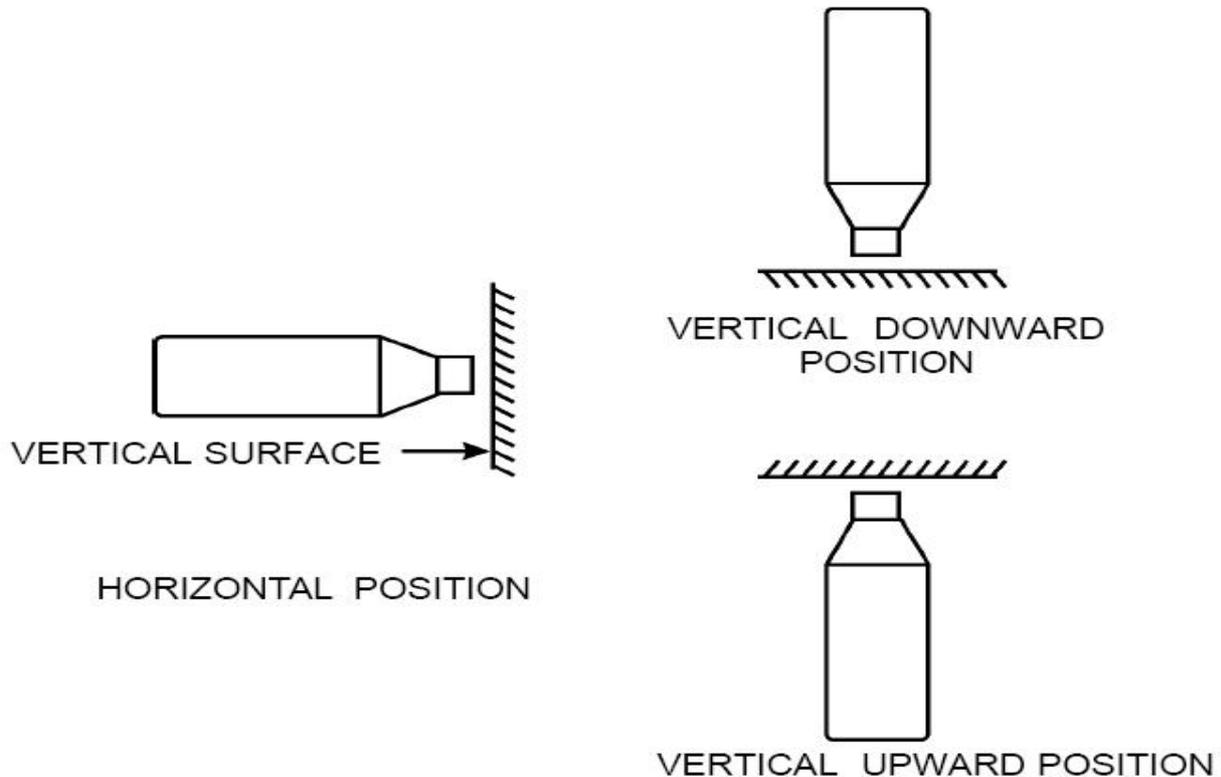
Fig. 4.1 Various positions of Rebound Hammer

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
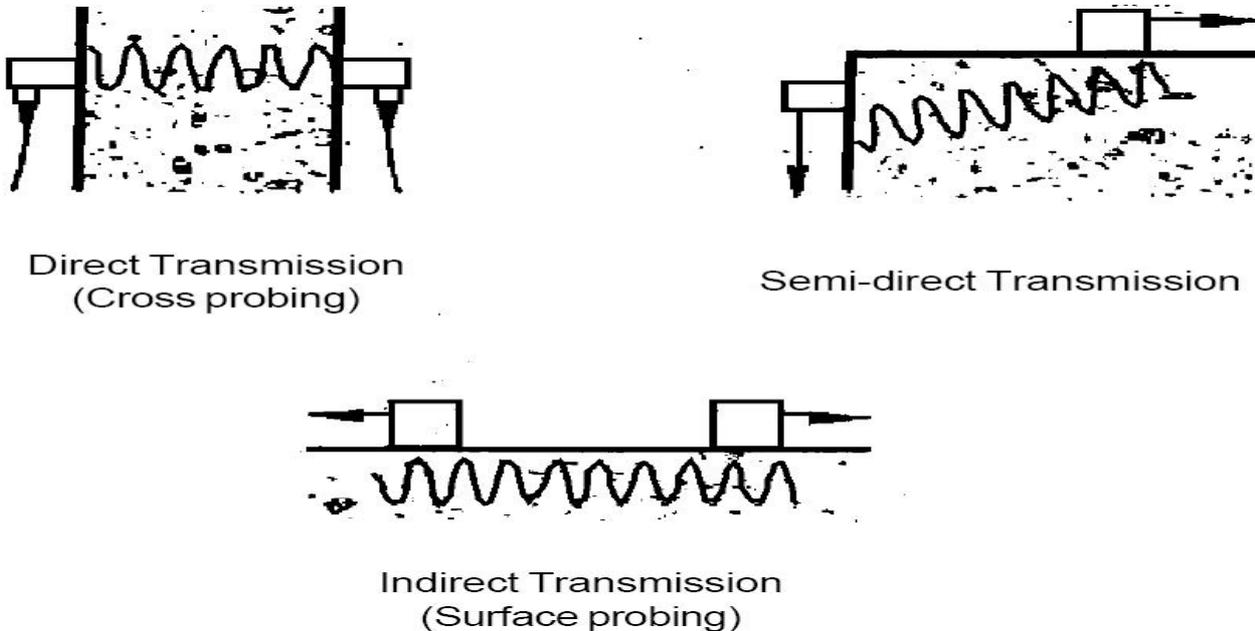
Fig. 4.2 Various Methods of UPV Testing

(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.

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.4.3 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.

V. AUDIT AND REPAIR DEVELOPMENT MODEL

A Norm According to the model bye-law no. 77 for co-operative housing societies, it is mandatory that if the age of a building is 15 to 30 years, a structural audit must be carried out once in five years and for buildings older than 30 years it should be carried out once in three years. One may, however, go for it even earlier if one suspects the condition of the

building to be bad. Perhaps monsoon/ post monsoon is the best time to commission a structural audit since the seepage is more evident at that time. The certificate, issued by a structural engineer registered with BMC, will have to be submitted within a year after a building completes 30 years. For any corrective repairs suggested by the commissioner, the owner or occupants will be asked to submit the structural stability certificates again after a specific period suggested by him. If found unsafe, he has been given the authority to issue a notice to the owner to submit a structural stability certificate within 30 days from the date of notice. It will be binding on owners to carry out corrective repairs to the satisfaction of the commissioner. The certificate, issued by a structural engineer registered with BMC, will have to be submitted within a year after a building completes 30 years. For any corrective repairs suggested by the commissioner, the owner or occupants will be asked to submit the structural stability certificates again after a specific period suggested by him. If found unsafe, he has been given the authority to issue a notice to the owner to submit a structural stability certificate within 30 days from the date of notice. It will be binding on owners to carry out corrective repairs to the satisfaction of the commissioner.

Phases of Model development-

a. Methodology and Investigation

1. Condition survey-

Conditional survey is an examination of concrete for the purpose of identifying and defining area of distress. The objective of condition surveys of a building structure is:

A) To identify**:-**

1. Causes of distress

2. Their sources.

B) To assess:-

1. The extent of distress occurred due to corrosion, fire, earthquake or any other reason.
2. The residual strength of the structure.

C) To priorities the distressed elements according to seriousness of repairs

D) To select and plan the effective remedy.

2. Stages for Condition Survey:-The condition survey has following stages.

1. Preliminary inspection.

2. Planning

3. Visual inspection

4. Field and laboratory testing.

a. Structural Audit Report

A] Case Study of R.C.C. Building

Basic Information	
Type of Structure -	**RCC Building of G+4 floors**
Address -	**Pune**
Type of Structure –	**RCC**

No of wings & stories - 4 storied (4 flats from 1st to 4th floor each and having two flats at ground floors) No & type of apartments - 18 flats
Description of Building

Year of construction-Aug 1987

Age- 27 years
Effects of monsoon - Yes

1. Visual observations

The building was investigated flat by flat for observation and external area of the building. Some of the column, beams & slab within the section were observed for a range of defects such as cracks, spells, crazing, seepage etc. All the defects were marked on the observation sheets with approximate repair area which formed the total data of the structure.

2. Tapping observations

Some of the column & beams inside the flat were subjected to tapping by hammer. The hollow sound was recorded in the observation sheets as follow, which was evaluated for remedial measures.

3. Non-Destructive Observations

Some of the column & beams inside the rooms and the passage areas were subjected to Tests by Ultrasonic Pulse Velocity. The readings were recorded which were evaluated further for remedial measures.

b. Report on Non Destructive Testing Of R.C.C. Members

1] Inspection & testing: - The aim of testing was to arrive at the general quality of concrete, rather than evaluating each RCC Members in detail. Hence, a few RCC members at random were tested. Ultra Sonic Pulse Velocity (UPV) measurements were taken for Columns, Beams.

2] Corrosion: - Rusting of Iron and steel is the most commonly process of corrosion.

Any corrosion of reinforcement results in the formation of rust, which occupies a volume of about 2.2 times that of iron from which it is formed. This corrosion product has literally no place to go so that it produces large internal pressure as high as 1 ton /square inch around the concrete resulting in longitudinal cracks parallel to reinforcement and cracks in the concrete.
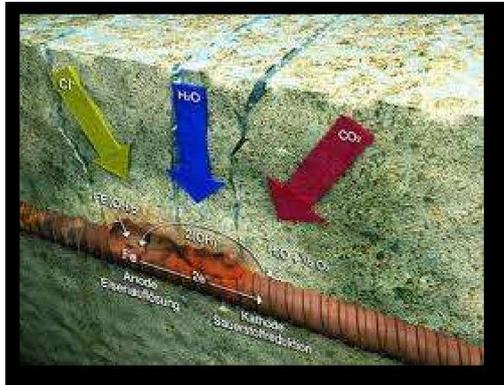
Fig No. 4.4 (a) Corrosion of Reinforcement

Fig.No-4.5 (b) Spalled cover concrete & exposed cover Reinforcement

A. Observations

1. External

Structurally the building appears to be unsound and few structural members show major distress signs at external face & internal area of the building,

☐ The Building is of RCC frame and brickwork / block masonry. RCC Columns and Beams show corrosion based cracks at many places.

☐ The exterior face of the building shows cracks, crazing, and delamination in plaster.

I. Beam & column adjoining to wall delamination is noticed at various places on the facade of the building.

II. All these defects propagate to seepage and leakages. Seepage near any R.C.C. members leads to further propagation of defects like rebars corrosion, etc.

III. Other important problem in the building appears to be the seepages from the dead walls & entire exteriors, more prominent on the south & west sides of the building. The level of damage is more on the account of the south west sides due to atmospheric direction of monsoon.

IV. Due to these problems, the condition of the building appears to be quite leaky and structural distress is observed in most of the corner columns & beams.

2. Plaster

1. External plaster acts as a skin on the RCC frame and the brick / block work, the most vulnerable part is the joints between the RCC and brick work

2. Major cracks observed accelerating the passage of water through the wall resulting in seepages inside flats.

3. The building is crack filled but not painted; which has to be attended periodically to avoid further distress in the building.

4.   At many places joints between RCC members and brick / block work have separated and water is found to be seeping inside.

5.   Most of the plaster in the building sides which are not exposed to monsoons directly, the extent of seepage is lesser than the side's facing monsoon.

6.   Due to forces of weather and carbonation in some places, plaster has deteriorated.

d. Recommendations

1.   Looking into all aspects of the building maintenance and as per our detailed survey, we suggest that the building needs to be thoroughly repaired and painted in a planned manner.

2.   For any RCC framed structure the RCC components are like the bones in a body and hold the entire load of the body and any damage to the same has to be rectified immediately and cannot be left unattended for long period of time.

3.   To bring the RCC components to their near original strength the same have to be repaired by polymer modified mortar method.

4.   The RCC members originally deteriorated due to ingress of water and to prevent it happening **again** all sources of leakages must be stopped completely.

5.   Plaster acts like a skin to the bones in a RCC structure, but the skin also needs to have a raincoat and the same is provided by a good quality resin based coating.

6.   To stop the ingress of water the following steps have to be taken.

7.   Structural Repairs (Wherever Necessary).

8.   External Plaster(Patch)
9.   Crack Filling/Joint Filling.

10.   External Drain down take Plumbing (Wherever Necessary).

11.   Terrace waterproofing by using nondestructive method.

12.   Dead wall / Internal Terrace parapet wall plaster repairs.

VI. 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.

1.   Name of the project :Sheetal Distributors
2.   Location : Sr No 1095 opp sakal press Behind laxman wajan kata wadki, Pune.
3.   Owner : Parshwanath Buildcon
4.   Purpose of project: Industrial purpose.
5.   Consultant: Parshwanath Buildcon
6.   Total Area of construction : 1,50,000 sq.ft.

7. Project highlights : 100% Green energy, STP Plant, Efficient natural light and ventilation.
8. Cost of the project : 15.4 crore.

VII. TEST RESULTS AND DISCUSSION

7.1 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.

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

7.2 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.5.2 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:
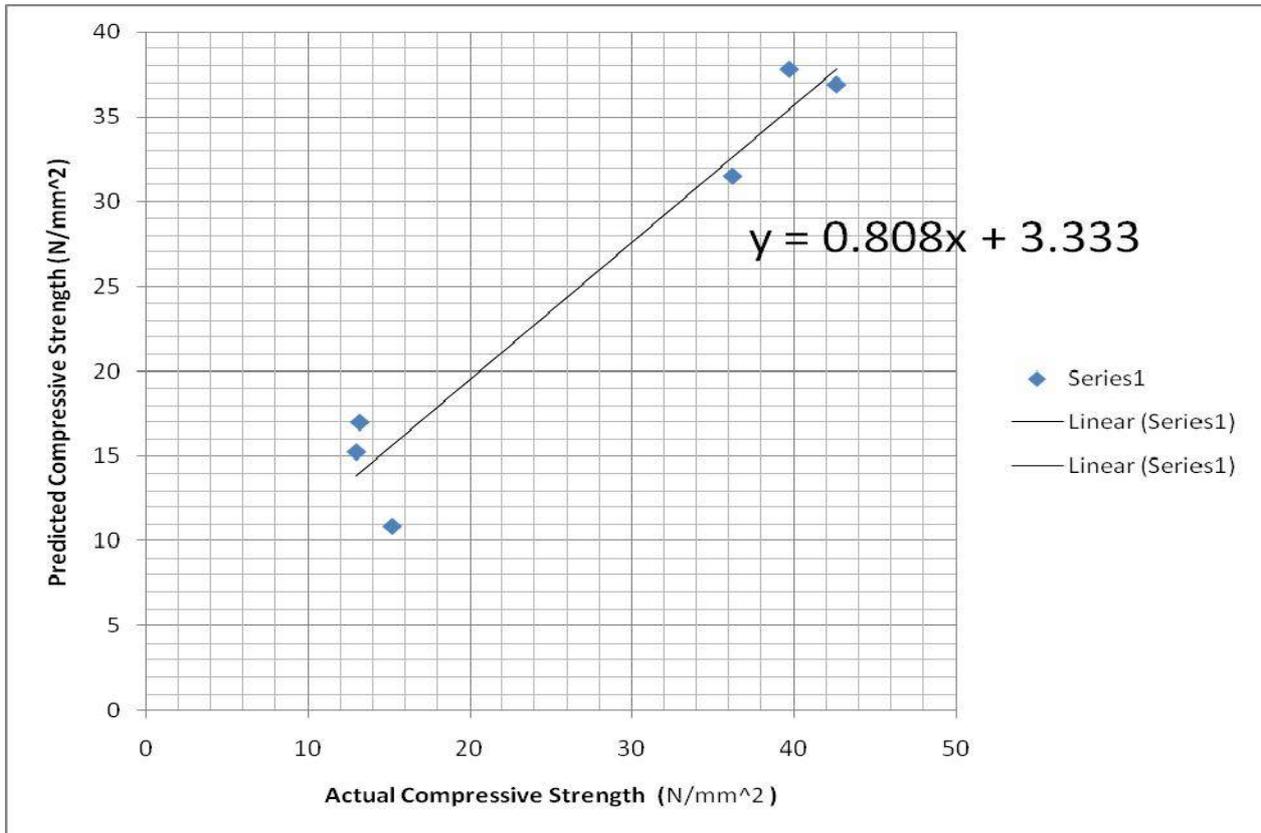

$$y = 0.808x + 3.333$$

Fig. 5.3 Calibration Graph for Rebound Hammer with its Equation

VIII.   CONCLUSION

From the consideration of all the above points we conclude that the defects of structural members are due to combined effects of carbonation, corrosion & effect of continuous drying and wetting. The result of visual survey prompt us to conclude the distress is wide spread and is an ongoing process and so needs to be stopped at this stage so as to avoid complete collapse of the structure. The results obtained in the form of graphical representation confirms that the capacitance based sensor effectively detect the micro cracks in the structure. This sensing device is new era technology, which is relatively cheaper but accurate. By employing this technique we can effectively forecast the development of the cracks in the structure and will be in the state to provide remedies well before collapse of the structure. Such technology plays vital role in the rehabilitation of the structures and makes structural health monitoring easier. Another important feature of this sensor is, as this technology help us to know the development of crack in anticipation, this will certainly minimize the role of F.O.S, which will ultimately make the structure much cheaper by using the ultimate strengths of the materials. Significant future developments of this technology will, in all likelihood, come by way of multi-disciplinary research efforts encompassing fields such as structural dynamics, signal processing, motion and environmental sensing hardware, computational hardware, data telemetry, smart materials and statistical pattern recognition, as well as other fields yet to be defined. These topics are the focus of significant discipline-specific research efforts, and to date not all technologies from these fields that are relevant to the SHM problem have been explored by the SHM research community. Furthermore, there are few efforts that try to advance and integrate these technologies with the specific focus of developing SHM solutions. Without such a focus in mind, these technologies may not evolve in a manner that is not necessarily optimal for solving the SHM problem. Finally, the problem of global SHM is significantly complex and diverse that it will not be solved in the immediate future. Like so many other technology fields, advancements in SHM will most likely come in small increments requiring diligent, focused and coordinated research efforts over long periods of time.

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