STRUCTURAL AUDITING OF
RCC BUILDINGS

Submitted in partial fulfilment of the requirements of the degree of

Bachelor of Engineering

Project by:

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CERTIFICATE

This is to certify that the project titled **“STRUCTURAL AUDITING OF RCC BUILDINGS”** is a bonafide work of

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DECLARATION

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ABSTRACT

Structural Auditing is overall health and performance check up of the building like a doctor examines a patient. This process to create awareness amongst the residents and owners of building towards the health examination of existing concrete buildings called as Structural Audit. The need of structural audit is for maintenance and repairs of existing structures whose life has exceeded the age of 30 years to avoid any mishaps and save valuable human life. The concrete is widely used as construction material being inexpensive, easy for construction, applications and because of it high strength-cost ratio. More than ever, the construction industry is concerned with improving the social, economic and environmental parameters of sustainability. In India, from 1980 onwards the infrastructure industry witnessed stepping up of public investment and growth in infrastructure industry which resulted in construction of new multi-storey concrete apartments which are now in the age of thirty plus years. There are many buildings during this period and earlier that have reduced in strength in due course of time because of structural deficiency, material deterioration, unexpected over loadings or physical damage. lf 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 this project work, an attempt has been made to carry out the structural audit of a (G + 6) residential building at Airoli. Various significant tests are carried out on the building to assess the health of the building & remedial measures are suggested for the repairs.

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INTRODUCTION

1.1 GENERAL:

Reinforced cement concrete (RCC) as a construction material has come into use for the last one century. In India, RCC has been used extensively in the last 50-60 years. During this period, we have created large number of infrastructural assets in terms of buildings, bridges, sports stadium etc., which are lifeline for the civilized society. . These have been created with huge investment of resources. We cannot even dream of recreating such assets out of limited national resources. It is, therefore, essential to maintain them in functional condition. Since, deterioration of RCC is a natural phenomena and has started exhibiting in large number of structures, a systematic approach is needed in dealing with such problems. Identification of the causes of deterioration and consequent repair/rehabilitation strategy at optimum cost needs a scientific evaluation and solution. The first step in repairs and rehabilitation is the proper diagnosis for successful rehabilitation works. It deals with non-destructive evaluation techniques, laboratory tests and condition.

Details of commonly used tests for Non Destructive Evaluation (NDT) like Rebound hammer test, Ultrasonic Pulse Velocity (UPV) test, Pull out test, Core test, Chloride test, Carbonation test, pH measurement, Resistively test, Differential Thermal Analysis (DTA), etc have been dealt with. Symbols for recording distresses on building plans and worksheets have been given. Scheme for scientific analysis, planning and documentation has been developed which will go a long way in grouping / classification of damages. These in turn are useful tools in selection of the appropriate repair technique.

1.2 INTRODUCTION:

After the Independence a rapid development in multi storied infrastructure is seen. Since 1950s, the construction activity in India has been increasing geometrically without matching increase in the availability of quality inputs, in terms of materials and skilled workmen. The gap between the quality planned and the quality achieved continues to become wider. The factors contributing to damages/distresses in buildings have, thus, become intrinsic right from the construction stage. Often these are concealed under external renderings and the defect takes time to manifest itself. The buildings constructed usually loses its strength when the building becomes old i.e;usually after 20 or 30 years old. In Due course of time this buildings have reduced Strength due to Material Deterioration, Unexpected over Loading, Structural Deficiency or Physical Damages. If, further use of such deteriorated structure is continued it may cause severe loss of life and Property. Before attempting any repair procedure it is necessary to have a planned approach to investigate the condition of concrete and reinforcement. While the diagnosis of damage or deterioration in some cases is reasonably straightforward, it may not be so in many cases. Particularly difficult are cases in which the cause and effect phenomenon cannot be readily explained or when prognosis in terms of long-term performance of restored structure is to be made. This will require a thorough technical inspection and an understanding of the behaviourof the structural component, which is being repaired. Inspection calls for detailed mapping of affected areas, documentation of type and location of symptoms and their history and photographic evidences. It may also include the environmental factors, which are likely to accelerate the damage process. Existence of concealed ducts, water lines, wet areas require special attention. Some areas impose severe limitations on access to damaged areas. A comprehensive inspection data helps in making an effective strategy for repair and rehabilitation.

Non-destructive evaluation (NDE) of concrete and components are well known and extensively used. While they are very good tools for establishing quality levels in new constructions, applying these techniques to damaged structures requires certain level of experience and understanding of limitations of these methods. Solving the problem successfully is entirely dependent on the ability of a team of experts engaged to do this job. Both field and laboratory tests are available. It is important to select the appropriate Non Destructive Evaluation (NDE) techniques and location of investigation. This is a specialisedjob and requires sophisticated instruments and trained personnel. A single technique may not be adequate and a combination of techniques has to be adopted to get a truly representative data on the condition of the building.

Structural audit is overall health checkup of the building you ensure that the building is safe and has no risk. It is an important tool to determine the present status of old building. It also suggests some repair and retrofitting techniques required to increase the serviceability and over health of the old buildings. It is also an essential tool for maintenance and repair of buildings having age of more than 25 or 30 years. Structural audit also highlights and investigates the risk areas, critical areas of buildings and also suggests if any urgent attention is required or not. Structural audit is carried out by appointing a structural engineer. It involves visual inspection and Non-destructive tests which are carried out based on the requirement of the building. The periodical diagnosis of building is necessary to know the present serviceability and viability of the structure. The major issues that occur in structural audit is that the people are not aware about the structural audit and its importance and they do not come forward for the execution of structural audit. Also there is no standard procedure for structural audit. Henceforth the purpose of study is to investigate the health of the old building to protect life and property.

1.2.1 The various stages involved in Structural Auditing:

Condition Survey:Condition Survey is an examination of concrete for the purpose of identifying and defining area of distress. While it is referred in connection with survey of concrete and embedded reinforcement that is showing some degree of distress, its application is recommended for all buildings and structures. The system is designed to be used for recording the history of the project from its inception to completion and subsequent life.

Objectives:

Objectives of condition survey of a building structure are

To identify

- causes of distress andtheir sources;

To assess

- the extent of distress occurred due to corrosion, fire, earthquake or any other reason,
- the residual strength of the structure and
- its rehabilitability ;

To prioritise the distressed elements according to seriousness for repairs and

To select and plan the effective remedy.

"Find the cause, the remedy will suggest itself". Sometimes, the source of the cause of distress is different than what is apparently seen. It is, therefore, essential that the engineers conducting condition survey, determine the source(s) of cause so as to effectively deal with it and minimize their effects by proper treatment.

Stages:

Stages for carrying out Condition Survey, largely depend on field conditions, user habits, maintenance etc and have a direct relation with the pattern of distress, whether localised or spread over.

Condition Survey of a building/structure is generally undertaken in four different stages to identify the actual problem so as to ensure that a fruitful outcome is achieved with minimum efforts & at the least cost. The four stages of condition survey are

- Preliminary Inspection,
- Planning,
- Visual Inspection,
- Field and Laboratory testing

1.2.1.1 Preliminary Inspection:

Basic Information Gathering: -A programme has to be evolved to obtain as much information as possible about the distressed structure at reasonable cost and in a reasonable time. Accordingly, the information required from the owner/client has to be listed out even though, many construction details and other related information may not be available with the owners/clients, yet as much as information and details as possible be gathered during the preliminary site visit. Before undertaking a condition survey of a building/structure, the following essential information is required and be obtained from the clients/owners:

- Period of construction;
- Exposure conditions of structure;
- Designed use vis-a-vis present use of structure;
- Previous changes in use, if any;
- Record of structural changes made, if any;
- Record of first occurrence of deterioration, if any;

- Details of repairs, if carried out in the past;
- Reports of previous investigations/condition surveys, if any;
- Apparent cause of distress, as could be ascertained from the owner/client;
- Photographs of distressed portions of structure.

1.2.1.2 Planning Stage

Planning stage involves preparation of field documents, grouping of structural members and classification of damage as under:

- Preparation of Field Documents:
- For condition survey, the following are required to be prepared:
  - Survey objective;
  - Scope of work;
  - Method of survey;
- The field and laboratory testing requirements and field equipments& tools required for the same;
- List of tasks and their sequence for condition survey together with a work schedule;
- Required number of photo copy of available drawings;
- Floor plans based on field measurements;
- Work sheets and tables for recording in a logical manner all information, test results including field data gathered;
- Previous Condition Survey results and Investigation Reports, if any;
- Maintenance and repair records

1.2.1.3 Visual Inspection:

- Visual examination of a structure is the most effective qualitative method of evaluation of structural soundness and identifying the typical distress symptoms together with the associated problems.
- This provides valuable information to an experienced engineer in regard to its workmanship, structural serviceability and material deterioration mechanism.
- It is meant to give a quick scan of the structure to assess its state of general health.

- The record of visual inspection is an essential requirement for preparation of realistic bill of quantities of various repair items.

- Experienced engineers should carry out this work as this forms the basis for detailing out the plan of action to complete the diagnosis of problems and to quantify the extent of distress.

- Simple tools and Instruments like camera with flash, magnifying glass, binoculars, gaugefor crack width measurement, chisel and hammer are usually needed. Occasionally, a light platform/scaffold tower can be used for access to advantage.

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Obstructions to Visual Inspection :

False ceiling, carpets, recently done paints, patch work repairs of plaster, re-plaster etcare create obstructions to visual inspection. Such areas should beanalysed and recorded with due care.

The access height from within and from outside during this inspection could also be a major problem.

Notes of these obstructions/limitations of visual inspection need to be recorded for taking into considerations while preparing the work details on repairs/rehabilitation.

1.2.1.4 NON DESTRUCTIVE EVALUATION TESTS :

The standard method of evaluating the quality of concrete in buildings or structures is to test specimens cast simultaneously for compressive, flexural and tensile strengths. The main disadvantages are that results are not obtained immediately; that concrete in specimens may differ from that in the actual structure as a result of different curing and compaction conditions; and that strength properties of a concrete specimen depend on its size and shape.

A number of non-destructive evaluation (NDE) tests for concrete members are available to determine in-situ strength and quality of concrete. Some of these tests are very useful in assessment of damage to RCC structures subjected to corrosion, chemical attack, and fire and due to other reasons. The term 'non destructive' is used to indicate that it does not impair the intended performance of the structural member being tested/investigated. The non-destructive evaluation have been broadly classified under two broad categories viz 'in-situ field test' and 'laboratory test'. These tests have been put under five categories depending on the purpose of test as under :

- In-situ Concrete Strength
- Chemical Attack
- Corrosion Activity
- Fire Damage
- Structural Integrity/Soundnes

There are various NDT tests available for concrete structures, but based on its suitability and applications they are selected. These tests can be completely non-destructive, or partially destructive tests which may not have much effect on the strength and durability of concrete structure.The following methods are commonly used for NDT of concrete structures. The typical applications of those methods are briefed.

REBOUND HAMMER TEST:

The operation of Rebound Hammer (also called Schmidt's Hammer) is illustrated in fig below when the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass with a constant energy is made to hit concrete surface to rebound back. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale. This measured value is designated as Rebound Number (a rebound index). A concrete with low strength and low stiffness will absorb more energy to yield in a lower rebound value.

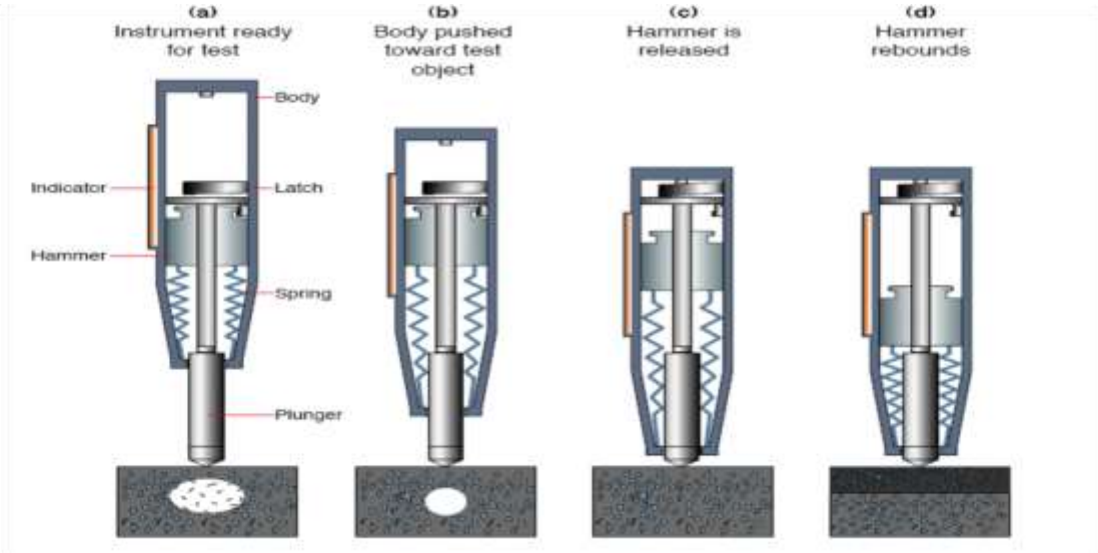


FIG 1.1 REBOUND HAMMER

Procedure to determine strength of hardened concrete by rebound hammer:

i) Before commencement of a test, the rebound hammer should be tested against the test anvil, to get reliable results, for which the manufacturer of the rebound hammer indicates the range of readings on the anvil suitable for different types of rebound hammer.

ii) Apply light pressure on the plunger – it will release it from the locked position and allow it to extend to the ready position for the test.

iii) Press the plunger against the surface of the concrete, keeping the instrument perpendicular to the test surface. Apply a gradual increase in pressure until the hammer impacts. (Do not touch the button while depressing the plunger. Press the button after impact, in case it is not convenient to note the rebound reading in that position.)

iv)Take the average of about 15 readings.

The results are significantly affected by the following factors:

1. Mix characteristics :
I. Cement type,
II. Cement Content,
III. Coarse aggregate type
2. Angle of Inclination of direction of hammer with reference to horizontal
3. Member Characteristics,
I. Mass,
II. Compaction,
III. Surface type,
IV. Age, rate of hardening and curing type,
V. Surface carbonation,
VI. Moisture Condition,
VII. Stress state and temperature.

Since each of these may affect the readings obtained, any attempts to compare or estimate concrete strength will be valid only if they are all standardized for the concrete under test and for the calibration specimens.

Survey of Weak & delaminating Concrete:

As the test requires a flat surface and large number of readings to reduce variability, this test is not generally suitable for use on spalled concrete surfaces of distressed structures. However, comparison of Rebound numbers, which indicate the near surface hardness of the concrete, will help to identify relative surface weaknesses in cover concrete and also can be used to determine the relative compressive strength of concrete. Locations possessing very low rebound numbers will be identified as weak surface concrete and such locations will be identified for further investigations like corrosion distress, fire damage and/or any other reason including original construction defects of concrete. This survey is to be carried out on each identified member in a systematic way by dividing the member into well-defined grid points. The grid matrix should have a spacing of approximately 300mmx 300mm.

ULTRSONIC PULSE VELOCITY TEST:

Ultrasonic test on concrete is a recognized non-destructive test to asses the homogeneity and integrity of concrete. With this ultrasonic test on concrete, following can be assessed:

Qualitative assessment of strength of concrete, its gradation in different locations of structural members and plotting the same.

Any discontinuity in cross section like cracks, cover concrete delamination etc.

Depth of surface cracks.

This test essentially consists of measuring travel time, T of ultrasonic pulse of 50 to 54 kHz, produced by an electro-acoustical transducer, held in contact with one surface of the concrete member under test and receiving the same by a similar transducer in contact with the surface at the other end. With the path length L, (i.e. the distance between the two probes) and time of travel T, the pulse velocity (V=L/T) is calculated (fig.2). Higher the elastic modulus, density and integrity of the concrete, higher is the pulse velocity. The ultrasonic pulse velocity depends on the density and elastic properties of the material being tested. Though pulse velocity is related with crushing strength of concrete, yet no statistical correlation can be applied.

The pulse velocity in concrete may be influenced by:

a) Path length

b) Lateral dimension of the specimen tested

c) Presence of reinforcement steel

d) Moisture content of the concrete

The influence of path length will be negligible provided it is not less than 100mm when 20mm size aggregate is used or less than 150mm for 40mm size aggregate. Pulse velocity will not be influenced by the shape of the specimen, provided its least lateral dimension (i.e. its dimension measured at right angles to the pulse path) is not less than the wavelength of the pulse vibrations. For pulse of 50Hz frequency, this corresponds to a least lateral dimension of about 80mm. the velocity of pulses in steel bar is generally higher than they are in concrete. For this reason pulse velocity measurements made in the vicinity of reinforcing steel may be high and not representative of the concrete. The influence of the reinforcement is generally small if the bars runs in a direction at right angles to the pulse path and the quantity of steel is small in relation to the path length. The moisture content of the concrete can have a small but significant influence on the pulse velocity. In general, the velocity is increased with increased moisture content, the influence being more marked for lower quality concrete.

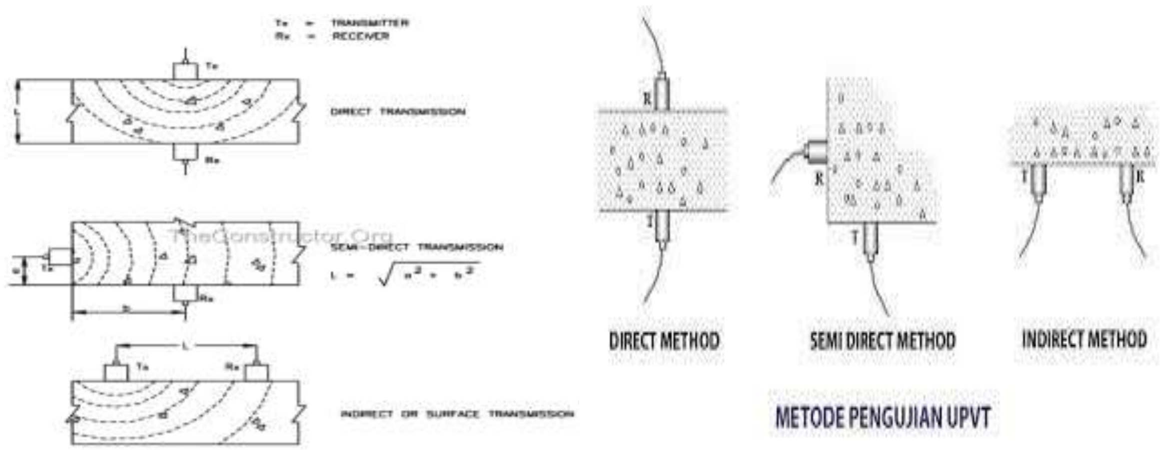


FIG 1.2 METHOD OF UPS

FIG 1.3 ULTRA SONIC PULSE VELOCITY

Measurement of pulse velocities at points on a regular grid on the surface of a concrete structure provides a reliable method of assessing the homogeneity of the concrete. The size of the grid chosen will depend on the size of the structure and the amount of variability encountered.

TABLE 1.1 STANDARD VALUES OF UPV

PULSE VELOCITY	CONCRETE QUALITY
>4.0 km/s	Very good to excellent
3.5 – 4.0 km/s	Good to very good, slight porosity may exist
3.0 – 3.5 km/s	Satisfactory but loss of integrity is suspected
<3.0 km/s	Poor and loss of integrity exist.

Above table shows the guidelines for qualitative assessment of concrete based on UPV test results. To make a more realistic assessment of the condition of surface of a structural member, the pulse velocity can be combined with rebound number. Table 2 shows the guidelines for identification of corrosion prone locations by combining the results of pulse velocity and rebound number.

TABLE 1.2 IDENTIFICATION OF CORROSION PRONE LOCATION BASED ON PULSE VELOCITY AND HAMMER READING

Sl. No.	**Test Results**	**Interpretations**
1	High UPV values, high rebound number	Not corrosion prone
2	Medium range UPV values, low rebound numbers	Surface delamination, low quality of surface concrete, corrosion prone
3	Low UPV, high rebound numbers	Not corrosion prone, however to be confirmed by chemical tests, carbonation, pH
4	Low UPV, low rebound numbers	Corrosion prone, requires chemical and electrochemical tests.

Detection of Defects

When ultrasonic pulse travelling through concrete meets a concrete-air interface, there is a negligible transmission of energy across this interface so that any air filled crack or void lying directly between the transducers will obstruct the direct beam of ultrasonic when the void has a projected area larger than the area of transducer faces. The first pulse to arrive at the receiving transducer will have been directed around the periphery of the defect and the time will be longer than in similar concrete with no defect.

Estimating the depth of cracks

An estimate of the depth of a crack visible at the surface can be obtained by the transit times across the crack for two different arrangements of the transducers placed on the surface. One suitable arrangement is one in which the transmitting and receiving transducers are placed on opposite sides of the crack and distant from it. Two values of X are chosen, one being twice that of the other, and the transmit times corresponding to these are measured. An equation may be derived by assuming that the plane of the crack is perpendicular to the concrete surface and that the concrete in the vicinity of the crack is of reasonably uniform quality. It is important that the distance X be measured accurately and that very good coupling is developed between the transducers and the concrete surface. The method is valid provided the crack is not filled with water.

This test is done as per IS: 13311 (Part 1) – 1992.

Procedure for Ultrasonic Pulse Velocity

i) **Preparing for use**: Before switching on the ‘V’ meter, the transducers should be connected to the sockets marked “TRAN” and ” REC”.
The ‘V’ meter may be operated with either:
a) the internal battery,
b) an external battery or
c) the A.C line.

ii) **Set reference**: A reference bar is provided to check the instrument zero. The pulse time for the bar is engraved on it. Apply a smear of grease to the transducer faces before placing it on the opposite ends of the bar. Adjust the ‘SET REF’ control until the reference bar transit time is obtained on the instrument read-out.

iii) **Range selection**: For maximum accuracy, it is recommended that the 0.1 microsecond range be selected for path length upto 400mm.

iv) **Pulse velocity**: Having determined the most suitable test points on the material to be tested, make careful measurement of the path length ‘L’. Apply couplant to the surfaces of the transducers and press it hard onto the surface of the material. Do not move the transducers while a reading is being taken, as this can generate noise signals and errors in measurements. Continue holding the transducers onto the surface of the material until a consistent reading appears on the display, which is the time in microsecond for the ultrasonic pulse to travel the distance ‘L’. The mean value of the display readings should be taken when the units digit hunts between two values.**Pulse velocity=(Path length/Travel time)**

v) Separation of transducer leads: It is advisable to prevent the two transducer leads from coming into close contact with each other when the transit time measurements are being taken. If this is not done, the receiver lead might pick-up unwanted signals from the transmitter lead and this would result in an incorrect display of the transit time.

CARBONATION TEST:

The phenomenon of carbonation of concrete structures is a chemical phenomenon

CARBONATION OF CONCRETE:

The microstructure of concrete is such that it has capillary pores to the extent of 28%. The extent of pores depends upon quality of concrete and the presence of water at the time of mixing of concrete. Making more dense concrete with less water/cement ratio reduces the amount of pores. These pores are created due to evaporation of excess free water during strengthening of concrete mass. These pores are inter connected and goes inside the concrete mass from surface of concrete structures.

Carbonation of concrete is a process by which carbon dioxide from the air penetrates into concrete through pores and reacts with calcium hydroxide to form calcium carbonates. It has seen that the conversion of $Ca(OH)_2$ into $CaCO_3$ by the action of CO_2 results in a small shrinkage.

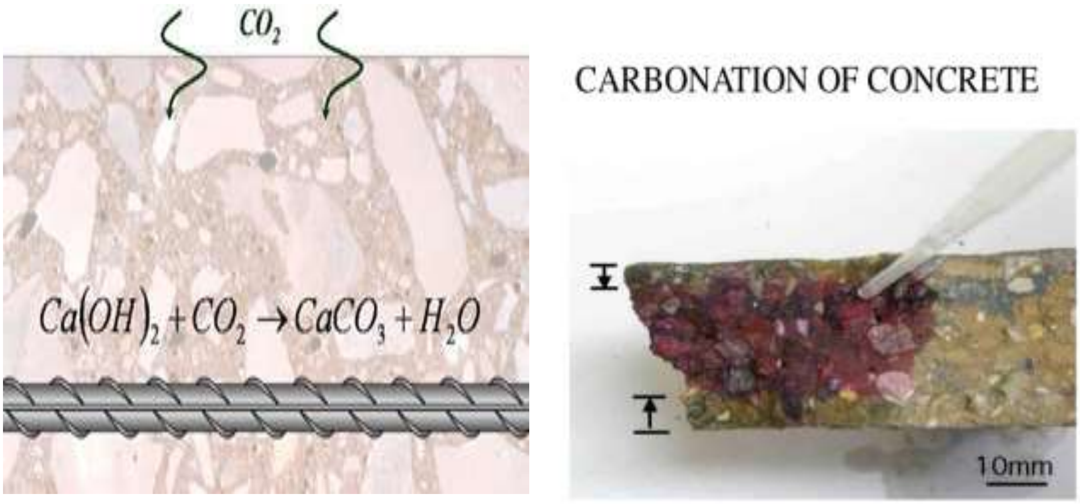


FIG 1.4 CARBONATION TEST

We shall see another aspect of carbonation, as CO2 by itself is not reactive. In the presence of moisture, CO_2 changes into dilute carbonic acid, which attacks the concrete and also reduces alkalinity of concrete (i.e. pH value reduces).

Air contains CO_2. The concentration of CO_2 in rural air may be about 0.03 percent by volume. In large cities the content may go up to 0.3 percent or exceptionally it may go up to even 1.0 per cent. In the tunnel, if not well ventilated the intensity may be much higher.

The pH value of pore water in the hardened concrete is generally between 12.5 to 13.5 depending upon the alkali content of cement. The high alkalinity forms a thin passivating layer around steel reinforcement and protect it from action of oxygen and water. As long as steel is placed in a highly alkaline condition, it is not going to corrode. Such condition is known as passivation.

In actual practice, CO_2 present in atmosphere in smaller or greater concentration, permeates into concrete and carbonates the concrete and reduces the alkalinity of concrete. The pH value of pore water in the hardened cement paste, which was around 13, will be reduced to around 9.0. When all the $Ca\ (OH)_2$ has become carbonated, the pH value will reduce up to about 8.3. In such a low pH value, the protective layer gets destroyed and the steel is exposed to corrosion.

The carbonation of concrete is one of the main reasons for corrosion of reinforcement. Of course oxygen and moisture are the other components required for corrosion of embedded steel.

Testing for carbonation:

The affected depth from the concrete surface can be readily shown by the use of phenolphthalein indicator solution. This is available from chemical suppliers. Phenolphthalein is a white or pale yellow crystalline material. For use as an indicator it is dissolved in a suitable solvent such as isopropyl alcohol (isopropanol) in a 1% solution.

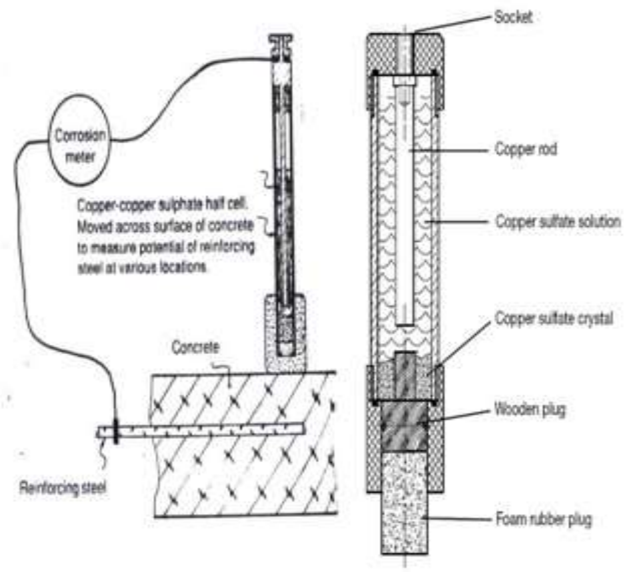
Warning: like all chemicals, phenolphthalein solution should be treated with respect. Both phenolphthalein itself and isopropyl alcohol are harmful and, since it contains alcohol, the indicator solution is flammable. Ingestion, or contact with skin or eyes should be avoided, as should breathing the vapour. Possible effects on the human body include kidney damage and cancer.

The phenolphthalein indicator solution is applied to a fresh fracture surface of concrete. If the indicator turns purple, the pH is above 8.6. Where the solution remains colorless, the pH of the concrete is below 8.6, suggesting carbonation. A fully-carbonated paste has a pH of about 8.4.
In practice, a pH of 8.6 may only give a faintly discernible slightly pink color. A strong, immediate, color change to purple suggests a pH that is rather higher, perhaps pH 9 or 10.
Normal concrete pore solution is saturated with calcium hydroxide and also contains sodium and potassium hydroxide; the pH is typically 13-14. Concrete with a pore solution of pH 10-12 is less alkaline than sound concrete but would still produce a strong color change with phenolphthalein indicator. It therefore follows that the indicator test is likely to underestimate the depth to which carbonation has occurred.
In confirmation of this, microscopy - either optical microscopy using thin-sections, or scanning electron microscopy using polished sections - shows carbonation effects at greater depths than indicated by phenolphthalein indicator. Nevertheless, this test is very useful as a means of making an initial assessment - it is quick, easy and widely used.

The indicator has not changed colour near the top and bottom surfaces,suggesting that these near-surface regions are carbonated to a depth of at least 4 mm from the top surface and 6 mm from the lower surface. Where the indicator has turned purple - the center of the slab - the pH of the concrete pore fluid remains high (above 8.6, probably nearer 10). Whether the cement paste here is completely uncarbonated is unclear, despite the strong purple indicator color; a more complete assessment would require microscopic examination. Indicator was not applied to the concrete at the right of this image and so the concrete here retains its original color.The carbonation depth is approximately proportional to the square root of time. For example, if the carbonation depth is 1mm in a one-year-old concrete, it will be about 3mm after 9 years, 5mm after 25 years and 10mm after 100 years.

HALF CELL POTENTIOMETER TEST:

The instrument measures the potential and the electrical resistance between the reinforcement and the surface to evaluate the corrosion activity as well as the actual condition of the cover layer during testing. The electrical activity of the steel reinforcement and the concrete leads them to be considered as one half of weak battery cell with the steel acting as one electrode and the concrete as the electrolyte. The name half-cell surveying derives from the fact that the one half of the battery cell is considered to be the steel reinforcing bar and the surrounding concrete. The electrical potential of a point on the surface of steel reinforcing bar can be measured comparing its potential with that of copper – copper sulphate reference electrode on the surface. Practically this achieved by connecting a wire from one terminal of a voltmeter to the reinforcement and another wire to the copper sulphate reference electrode. Then generally readings taken are at grid of 1 x 1 m for slabs, walls and at 0.5 m c/c for column, beams.



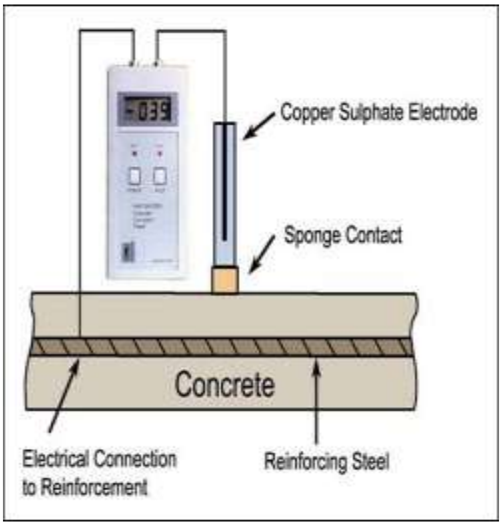


FIG 1.5 HALF CELL POTENTIAL

The risk of corrosion is evaluated by means of the potential gradient obtained, the higher the gradient , the higher risk of corrosion.

The test results can be interpreted based on the following table:

TABLE 1.3 STANDARD VALUES OF HALF CELL POTENTIOMETER

Half-cell potential (MV) relative to cu-cu sulphate Ref. Electrode	% chance of corrosion activity
Less than 200	10%
Between 200-350	50% (uncertain0
Above	90%

This method may by used to indicate the corrosion activity associated with steel embeded in concrete.

This method can be applied to members regardless of their size or the depth of concrete cover.

This method can be used at the any time during the life of concrete member.

Reliability & Limitations :

The test does not actual corrosion rate or whether corrosion activity has already started, but it indicates the probability of the corrosion activity depending upon the actual surrounding conditions. If this method used in combination with resistivity measurement , the accuracy is higher.

If the concrete surface has dried to the extent that it is dielectric , then pre wetting of concrete is essential especially for Cement Silos, Exposed roof slab. The Quality of the cover concrete, particularly its moisture condition and Contamination by carbonation and / or chlorides may affect the results.

Equipments:

Half-cell: The cell consists of a rigid tube or container composed of dielectric material that is non-reactive with copper or copper sulphate, a porous wooden or plastic plug that remains wet by capillary action, and a copper rod that is immersed within the tube in a saturated solution of copper sulphate. The solution is prepared using reagent grade copper sulphate dissolved to saturation in a distilled or deionized water.

Electrical junction device: An electrical junction device is used to provide a low electrical resistance liquid bridge between the surface of the concrete and the half-cell. It consists of a sponge or several sponges pre-wetted with a low electrical resistance contact solution. The sponge can be folded around and attached to the tip of the half-cell so that it provides electrical continuity between the porous plug and the concrete member.

Electrical contact solution: In order to standardize the potential drop through the concrete portion of the circuit, an electrical contact solution is used to wet the electrical junction device. One solution, which is used, is a mixture of 95 ml of wetting agent or a liquid household detergent thoroughly mixed with 19 L of potable water. At temperatures less than $10^{o}C$ approximately 15% by volume of either isotropic or denatured alcohol must be added to prevent clouding of the electrical contact solution, since clouding may inhibit penetration of water into the concrete to be tested.

Voltmeter: The voltmeter should be battery operated and have ± 3% end of scale accuracy at the voltage ranges in use. The input impedance should be not less than 10 MW when operated at a full scale of 100 mV. The divisions on the scale used should be such that a potential of 0.02 V or less can be read without interpolation.

Electrical lead wires: The electrical lead wire should be such that its electrical resistance for the length used does not disturb the electrical circuit by more than 0.0001 V. This has been accomplished by using no more than a total of 150 m of at least AWG No. 24 wire. The wire should be suitably coated with direct burial type of insulation.

PROCEDURE:

Measurements are made in either a grid or random pattern. The spacing between measurements is generally chosen such that adjacent readings are less than 150 mV with the minimum spacing so that there is at least 100 mV between readings. An area with greater than150 mV indicates an area of high corrosion activity. A direct electrical connection is made to the reinforcing steel with a compression clamp or by brazing or welding a protruding rod. To get a low electrical resistance connection, the rod should be scraped or brushed before connecting it to the reinforcing bar. It may be necessary to drill into the concrete to expose a reinforcing bar. The bar is connected to the positive terminal of the voltmeter. One end of the lead wire is connected to the half-cell and the other end to the negative terminal of the voltmeter. Under some circumstances the concrete surface has to be pre-wetted with a wetting agent. This is necessary if the half-cell reading fluctuates with time when it is placed in contact with the concrete. If fluctuation occurs either the whole concrete surface is made wet with the wetting agent or only the spots where the half-cell is to be placed. The electrical half-cell potentials are recorded to the nearest 0.01 V correcting for temperature if the temperature is outside the range 22.2 ± 5.5^{o}C.

Measurements can be presented either with a equipotential contour map which provides a graphical delineation of areas in the member where corrosion activity may be occurring or with a cumulative frequency diagram which provides an indication of the magnitude of affected area of the concrete member.

Equipotential Contour Map: On a suitably scaled plan view of the member the locations of the half-cell potential values are plotted and contours of equal potential drawn through the points of equal or interpolated equal values. The maximum contour interval should be 0.10 V.

Cumulative frequency distribution: The distribution of the measured half-cell potentials for the concrete member are plotted on normal probability paper by arranging and consecutively numbering all the half-cell potentials in a ranking from least negative potential to greatest negative potential.

APPLICATIONS

This technique is most likely to be used for assessment of the durability of reinforced concrete members where reinforcement corrosion is suspected. Reported uses include the location of areas of high reinforcement corrosion risk in marine structures, bridge decks and abutments. Used in conjunction with other tests, it has been found helpful when investigating concrete contaminated by salts.

1.3 OBJECTIVES

1. To save human life and property.
2. To understand the condition of building.
3. To find critical areas to repair immediately.
4. To comply with statutory requirements.

5. To enhance life cycle of building by suggesting preventive and corrective measures, like repairs and retrofitting.
6. To recognize the types of structural defects.
7. To identify any signs of material deterioration.
8. To identify any signs of structural distress and deformation.
9. To identify any alteration and addition in the structure.
10. Structural Audit is an important tool for knowing the real status of the old buildings.
11. The Audit highlights & investigates all the risk areas, critical areas and whether the building needs
12. Immediate attention. It should also cover the structural analysis of the existing frame and
13. Pinpoints the weak structural areas for static, wind & earthquake loads.

1.4 SCOPE

1. Surveying the premises from the insides & outsides i.e. each & every premises to be surveyed to get a proper idea of its present structural condition. This physical survey will be carried out with hammer tapping on the RCC members to ascertain the degree of distress.
2. Identifying and noting allied problems pertaining to leakages & Seepage & any Additions/ Alterations carried out in the premises(which may be detrimental to the present health of the structure)
3. Identifying the nature of damages, extent of damages and its severity.
4. Carrying out NDT test at required locations
5. Analysing various defects observed, identifying the likely causes of all such damages.
6. Finally suggesting remedial measures to be adopted to restore the Structural health of the presently diseased Structure with a view to enhance its Structural Stability and Durability as per the priorities required.
7. Submitting detailed Survey Report containing our observations, suggestions, recommendations and photographic log.

CHAPTER 2

RETROFITTING AND REHABILITATION TECHNIQUES

When the structure is distressed or damaged the normal visual signs are: cracks different patterns and sizes; rust stains or rust spots; peeling of plasters etc.; spalling of concrete; and, rusted reinforcement if exposed. It is the primary task to determine whether the damage is structural or non-structural. Structural repairs are undertaken to restore the structural stability of the structure to carry the present stresses under the service conditions. Non-structural repairs are undertaken to restore the long term durability but do not increase the load bearing capacity of the structure in question. A nonstructural repair or cosmetic repair if not conducted at appropriate time can lead to structural distress.

Steps to be Taken

When the structure shows signs of damage or distress, the following steps should be taken in principle:

(i) Preliminary investigation, detailed investigation
(ii) Diagnosis
(iii) Laying out specifications for repairs
(iv) Selection of materials
(v) Surface preparations
(vi) Actual repairs
(vii) Periodical maintenance

Possible Causes of Structural Concrete Deterioration

Before getting to the investigations about a distress to the structure it is necessary to understand the factors controlling the deterioration of concrete. a knowledge of why, and in-depth investigation can only lead to proper diagnosis. There are two stages at which the deterioration of concrete can start.

To a great extent, through proper measures it is possible for us to arrest or minimize the deterioration of concrete in the first stage, that is before or during construction. However in the second case, most of the factors affecting the durability of concrete are beyond our control. At this stage, we can only take steps to maintain and take immediate action to mitigate the effects.

Cracks in Concrete

Concrete is subjected to tensile stresses in structures. However the concrete cracks when these tensile stresses exceed its tensile strength. This happens often and cracks tend to become one of the inherent defects. The reasons for cracking in concrete are many.

The Causes of Cracks in Concrete

It is essential to know about the cracks. It can be stated that the existence of cracks does not mean that there are defects needing repairs. First it should be established whether the cracks are: (a) structural, or (b) non-structural.
Structural cracks are mostly due to:
(i) Errors in design of stresses
(ii) Errors during construction
(iii) Excess loadings in service conditions vis-a-vis design loads
(iv) Settlements
(v) Unforeseen physical damage like fire and explosions
(vi) Lowering of section of reinforcement in the second stage of corrosion.
Non-structural cracks are mostly due to:
(i) Plastic shrinkage cracking — rapid evaporation of water
(ii) Drying shrinkage cracking
(iii) Plastic settlement cracking — settlement of concrete in formwork
(iv) Thermal contraction cracking — evolution of heat of hydration
(v) Cracking due to bad workmanship
(vi) Alkali aggregate reaction
A careful observation of cracks provides very valuable information not only leading to the reason why the crack appeared but also as a major guideline for the selection of material.Important things to be noted in the cracks:
(i) Pattern of cracks — Vertical, horizontal or diagonal
(ii) Width of the crack
(iii) Movements in the crack — Thermal variations. Dynamic or moving loads
(iv) Moisture in crack
(v) Dirt in crack.
Cracking due to reinforcement corrosion tends to follow the line or reinforcement.

Preliminary Investigation and Detailed Investigation of RCC Structures

The aim of investigation is primarily to determine the extent of damage or distress, whether the damage is structural or non-structural and to know the reasons for such a determination.

As unless the cause of distress is established, the remedial measures shall have no meaning as it is the cause that is to be rectified rather than the surface appearance of the damaged structure .The investigation of concrete structures is carried to ascertain:

(a) Whether the concrete is carbonated
(b) Whether the chloride levels are high
(c) Depth of carbonation and cover depth
(d) Degree of corrosion
(e) Present load carrying capacity of structure
(f) Whether the defects are localized or total area
(g) Appearance of cracks and types of cracks
(h) Whether designed loads and service loads are same.

Important information should be obtained about the age of structure, type of construction, structural design assumptions, present loading conditions, whether already the repairs were carried out and their durability.Investigations for structural repairs should essentially include the semi-destructive and non-destructive tests. Test results should be cross-checked before condemning the concrete.

Diagnosis of Reinforced Concrete Structures

Diagnosis is interpretation of the results obtained from the investigations. The interpretation requires sound knowledge and experience in this field and should essentially be done by qualified engineers.

Specifications for Concrete Repair Methods

Since the field of repairs and maintenance is a specialized one, it is very important that proper specifications are laid out for carrying out the remedial measures. The specifications should include:

(a) Materials for repairs

(b) Calculations for extra reinforcement for structural repairs

(c) Materials for injecting the cracks

(d) Guidelines for surface preparations

(e) Steps for repairs

(f) Precautions to be taken while using the materials as well as the curing procedures etc.

(g) Supervision and quality control at sites

Selection of Materials for Concrete Repairs

The selection of material will be guided by the type of repairs in question.

While selecting a material, the following points should be taken as the basis for selection:

(a) Existing surface and bonding possibilities

(b) Strength of the repair materials required

(c) Non-shrinking characteristics of the material

(d) Temperature at application and service temperatures

Two separate types of materials may be required for total repairs — one type for filling of cracks and the second for the cosmetic repairs. Economic considerations shall also have to be considered while selecting the materials.

Surface Preparations of Damaged Concrete

This step is very important step but generally does not receive the attention it deserves. Many systems involving proper specifications and proper selection of materials fail because improper pretreatment and negligence of proper surface preparation.

Without going into specific details, in general, the concrete surface should be checked for cavities with hammer testing. All loose portions should be chiseled with a chisel and hammer. The reinforcement should be exposed about 50 mm extra from the rusted reinforcement either ways.

The steel should be cleaned with suitable mechanical or other methods. The surfaces should be firm and free from oils and fats, to ensure proper bonding of the subsequent coats.

Actual Repairs Methods for Concrete Structures

The actual repairs will be depending upon the type of damage to the structure that is, structural or non-structural. Steps in both the cases overlap and principally are the same. The basics of civil and structural engineering should be thoroughly adhered to, otherwise the same problems will manifest themselves in larger magnitudes.

In case of structural repairs the following steps must be followed:

(a) Injecting the structural cracks with suitable materials

(b) Strengthening the structure with guiniting

(c) Cosmetic repairs if required or in smaller areas

(d) Surface coatings

In case of non-structural repairs, the steps are:

(a) Sealing of cracks for stopping water leakages etc.

(b) Cosmetic repairs

In case of chloride contaminated concrete, the repairs can be conducted only in two ways:

(a) Providing a complete inert barrier around all reinforcement

(b) Resort to cathodic protection

Periodical Maintenance of Reinforced Concrete Structures

Periodical inspections are very important as they can detect the damages in very early stages and they can be repaired immediately. The periodical inspections should be done to not the following occurrences.

(i) Appearance of cracks

(ii) Rust staining

(iii) Spalling of concrete

(iv) Exposure of reinforcements

(v) Water leakages through body of concrete

(vi) Water leakages through sanitary fittings

(vii) Growth of moss, fungus and plants on wet surfaces

(viii) Peeling off the plasters and mortars

(ix) Degree of deterioration of paints and surface coatings.

A rectification of these defects in time can lead to savings and increasing the life of structures. Inspections can be carried out by qualified engineers once in about three years and documented. The owners should be made aware to report a damage or deterioration at its first occurrence.

Exterior paints are not only for decorative purposes but they also provide additional protection to concrete, seal fine cracks and prevent the ingress of water and oxygen into the body of concrete, thereby lowering the rate of corrosion.

Precautions for Repair, Maintenance and Rehabilitation of Concrete Structures

Though it is an acceptable fact that defects do creep in while construction, which adversely affects the durability of concrete, it is still possible to cast good concrete which can have a long-term durability with minimum maintenance if some basic and not so difficult precautions are observed.

(a) Proper detailing should be done at the design office to show the details of reinforcements etc. at the junctions, where there is congestion of reinforcements. Form work should be designed not only for alignment but also for settlements of props etc.

(b) At the site, proper shuttering must be made, the reinforcement should be aligned with properly designed constant covers by using bar spacers.

(c) Concrete should be of proper slump to enable the flowability in the form work. Water / cement ratio must be strictly adhered to. The mix should be a designed mix with optimum quantity of cement bearing in mind that cement quantity is required not only for strength but also for durability. Chloride free aggregates and potable water should be used for mixing the concrete.

(d) Optimum vibration for proper compaction is required. In case of doubt over vibration is better than under vibration.

(e) Form work should be removed after proper strengths are gained. Honeycombs and cracks should be filled immediately thereafter as delay can lead to filling up of joints etc. with dirt, oil etc.

(f) Proper curing is a must. Curing with membrane forming curing compounds protects the concrete even in the initial stages.

It is evident from the foregoing discussion that precautions are better than cure. Proper supervision at construction sites by qualified engineers is essential. Codes of practice should be strictly adhered to.

The diagnosis and the interpretation of the investigation data should be analyzed by experienced engineers. Selection of materials require not only sound structural knowledge but also of material science.

A knowledge of limitations or disadvantages of materials will be a better guide to the decision maker rather than the advantages and tall claims.

Repairs should be viewed as systems and the work should be allotted to experienced companies. Periodical inspections and timely repair of small defects are required. Short term economy should be forgone for long term implications.

Proper and timely maintenance is key for durability of concrete and longevity of structures.

Techniques for Repairs and Rehabilitation of Concrete Structure

The technique to be adopted for repair or restoration of the structure depends on the cause, extent and nature of damage, the function and importance of the structure, availability of suitable materials and facilities for carrying out repair, and a thorough knowledge of the long-term behavior of the materials used for the repair work.

Depending upon the requirement, the repairing technique may be of a superficial (cosmetic) nature or, in some cases, may involve the replacement of part or whole of the structure.

The repairing techniques can be classified into three major groups:

1. Injection into cracks, voids or honey-combed areas.
2. Surface treatment
3. Removal and replacing of defective or damaged material / area.

A variety of new materials have been developed for the repair and restoration of damaged structures by following any one of the above methods. These are briefly described below.

Materials for Repairs and Rehabilitation of Concrete Structure

Cement, Cement Grouts, etc.In most cases, the repair material may be cement-based, since cement is the only active ingredient in concrete. Dry pack consisting of rich cement concrete or cement grouting may be suitable for sealing damaged areas and cracked portions.

Spraying of concrete or cement sand grout by means of high pressure nozzles, usually termed as ‘shotcrete’ or ‘guiniting’, respectively, may prove effective in many cases where a large surface area is to be repaired. The guiniting or shot crete may be carried out with or without the use of steel reinforcing mesh or steel fibers.

Resin based Repairs of Concrete

The resins normally used are from epoxide, polyester, acrylic or polythene families. The application of resins for repair work requires a thorough understanding of their chemical and physical properties and their performance in the structure, particularly with the passage of time and under unfriendly environs.

Epoxy resin systems find application in civil engineering works such as grouting of cracks, repairs of eroded concrete structures, emergency repairs of bridges, aqueducts, chemically corroded columns and beams.

Generally, resin materials are used in repair and restoration work where properties such as, high strength (hence thin sections), excellent adhesion (hence small patches), quicker curing (hence saving in time), and high chemical resistance are required. One of the most commonly adopted resins is from epoxide. A brief description of the properties and applications of epoxy based resins is given below.

Epoxy Resins for Concrete Repair

The resin mortar may be obtained by adding fillers such as coarse sand or calcined bauxite grit. The chemical reaction begins as soon as the resin and hardener are combined. Most combinations have a pot-life between 30 and 60 minutes. They develop excellent strength and adhesive properties and are resistant to many chemicals besides possessing good water proofing. Epoxy resin when cured with different hardeners offer wide range of properties. Once cured, they form irreversible system (thermosetting).

The characteristic properties of cured epoxy resin systems repair and rehabilitation of concrete structure are

- High adhesive strength to almost all materials
- Low shrinkage during curing
- Exceptional dimensional stability
- Natural gap filling properties
- Thermosetting (does not melt)
- Resistance to most chemicals and environments
- Ability to cure in wet conditions and underwater (for selected grades)
- Ease of application

Procedure of epoxy resin grouting

- Locating the cracks
- Cleaning of the cracked surface

- Drilling and fixing of nozzles for grouting at suitable intervals with epoxy putty
- Grouting of epoxy mixture with the help of the grout pump
- Sealing of nozzles through which grouting is done

A grout vessel essentially consists of a pressure vessel (to withstand 10 – 15 kg/cm2 pressure) with inlet and outlet for resin **mixture**, pressure gauge, connection for compressed air with regulator for pressure grouting.

A pre-mixed resin + hardener is filled in the grouting vessel and through the nozzle the activated resin is pumped in the cracks. When cracks get filled in, the grouting is carried in the next nozzle and so on till all the cracks are filled in.

When cured, the epoxy resin improves the load carrying capacity of the cracked structure.

Bonding Old to New Concrete

Epoxy resin with a special polyamide hardener combination is successfully used for bonding old to new concrete.

The process consists of :

Removal of all loose and damaged concrete using mechanical means or water jet

Surface to be dried

A suitable epoxy resin [unmodified solvent less epoxy resin + polyamide hardener (special grade) is applied with stiff nylon brush

The fresh concrete should be poured when epoxy coating has become just tack free

Care should be taken not to completely dry the coating.

Epoxy resins are a not primary construction material. A judicious use of these resins is required in view of the high cost of these resins. The resins should be used in emergencies.

Properties of epoxy resin systems can be advantageously exploited, when other materials cannot be used due to strength or other considerations. Epoxy resins are finding many new applications in pressing conditions such as underwater repairs of dams, ships, etc. Many new applications will be found using epoxy and other synthetic resins in future.

Polymer Concrete Composites

Most of the deficiencies found in ordinary structural concrete are removed using polymer concrete composites either in the form of a surface coating over the structure or by impregnating it into the structure.

Polymer concrete composites are relatively new developments and have been used in structural applications since 1950. They possess very high strengths and are more durable and resistant to most chemicals and acids.

There are three types of polymer concrete composites, namely polymer impregnated concretes (PIC), polymer concretes (PC), and polymer cement concretes or polymer modified concretes (PCC or PMC). In PICs the monomers (usually styrene, methyl-methacrylate (MMA), polymethyl methacrylate (PMMA), etc.) are impregnated into the pore system of the hardened concrete, thereby filling up the pores and making them impermeable and resistant to chemical attack; In PCs the polymer is the sole binder in lieu of cement and water. In PCCs and PMC s, a polymeric additive (latex or pre-polymer) is added to the normal cement composite during the mixing stage itself.

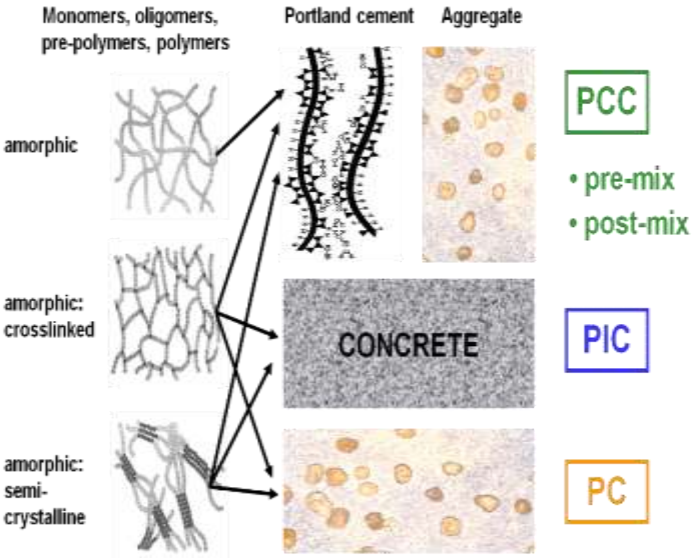


FIG 2.1 POLYMER CONCRETE COMPOSITE

Epoxy injection

Cracks as narrow as 0.002 in.(0.05 mm) can be bonded by the injection of epoxy. The technique generally consists of establishing entry and venting ports at close intervals along the cracks, sealing the crack on exposed surfaces, and injecting the epoxy under pressure. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures (ACI 503R). However, unless the cause of the cracking has been corrected, it will probably recur near the original crack. If the cause of the cracks cannot be removed, then two options are available.

One is to rout and seal the crack, thus treating it as a joint, or, establish a joint that will accommodate the movement and then inject the crack with epoxy or other suitable material. With the exception of certain moisture tolerant epoxies, this technique is not applicable if the cracks are actively leaking and cannot be dried out. Wet cracks can be injected using moisture tolerant materials, but contaminants in the cracks (including silt and water) can reduce the effectiveness of the epoxy to structurally repair the cracks.

FIG 2.2 EPOXY INJECTION

The use of a low-modulus, flexible adhesive in a crack will not allow significant movement of the concrete structure. The effective modulus of elasticity of a flexible adhesive in a crack is substantially the same as that of a rigid adhesive because of the thin layer of material and high lateral restraint imposed by the surrounding concrete. Epoxy injection requires a high degree of skill for satisfactory execution, and application of the technique may be limited by the ambient temperature.

Clean the cracks: The first step is to clean the cracks that have been contaminated; to the extent this is possible and practical. Contaminants such as oil, grease, dirt, or fine particles of concrete prevent epoxy penetration and bonding, and reduce the effectiveness of repairs. Preferably, contamination should be removed by vacuuming or flushing with water or other specially effective cleaning solutions.

Seal the surfaces: Surface cracks should be sealed to keep the epoxy from leaking out before it has gelled. Where the crack face cannot be reached, but where there is backfill, or where a slab-on-grade is being repaired, the backfill material or sub base material is sometimes an adequate seal. A surface can be sealed by applying an epoxy, polyester, or other appropriate sealing material to the surface of the crack and allowing it to harden. If a permanent glossy appearance along the crack is objectionable and if high injection pressure is not required, a strippable plastic surface sealer may be applied along the face of the crack. When the job is completed, the surface sealer can be stripped away to expose the gloss-free surface. Cementitious seals can also be used where appearance of the completed work is important. If extremely high injection pressures are needed, the crack can be cut out to a depth of 1/2 in. (13 mm) and width of about 3/4 in. (20 mm) in a V-shape, filled with an epoxy, and struck off flush with the surface.Install the entry and venting ports. Three methods are in general use:

Fittings inserted into drilled holes: This method was the first to be used, and is often used in conjunction with V-grooving of the cracks. The method entails drilling a hole into the crack, approximately 3/4 in. (20 mm) in diameter and 1/2 to 1 in. (13 to 25 mm) below the apex of the V grooved section.

Bonded flush fitting: When the cracks are not V grooved , a method frequently used to provide an entry port is to bond a fitting flush with the concrete face over the crack. The flush fitting has an opening at the top for the adhesive to enter and a flange at the bottom that is bonded to the concrete.

Interruption in seal: Another system of providing entry is to omit the seal from a portion of the crack. This method can be used when special gasket devices are available that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack without leaking.

Mix the epoxy: This is done either by batch or continuous methods. In batch mixing, the adhesive components are premixed according to the manufacturers instructions, usually with the use of a mechanical stirrer, like a paint mixing paddle. Care must be taken to mix only the amount of adhesive that can be used prior to commencement of gelling of the material.

Inject the epoxy: Hydraulic pumps, paint pressure pots, or air-actuated caulking guns may be used. The pressure used for injection must be selected carefully. Increased pressure often does little to accelerate the rate of injection. If the crack is vertical or inclined, the injection process should begin by pumping epoxy into the entry port at the lowest elevation until the epoxy level reaches the entry port above. For horizontal cracks, the injection should proceed from one end of the crack to the other in the same manner. The crack is full if the pressure can be maintained. If the pressure can not be maintained, the epoxy is still flowing into unfilled portions or leaking out of the crack.

Remove the surface seal: After the injected epoxy has cured, the surface seal should be removed by grinding or other means as appropriate.

Alternative procedure: For massive structures, an alternate procedure consists of drilling a series of holes [usually 7/8 to 4-in. (20 to 100-mm) diameter] that intercepts the crack at a number of locations. Typically, holes are spaced at 5-ft (1.5-m) intervals. Another method recently being used is a vacuum or vacuum assist method.

There are two techniques: one is to entirely enclose the cracked member with a bag and introduce the liquid adhesive at the bottom and to apply a vacuum at the top. The other technique is to inject the cracks from one side and pull a vacuum from the other. Typically, epoxies are used; however, acrylics and polyesters have proven successful.

Routing and sealing

Routing and sealing of cracks can be used in conditions requiring remedial repair and where structural repair is not necessary. This method involves enlarging the crack along its exposed face and filling and sealing it with a suitable joint sealant. This is a common technique for crack treatment and is relatively simple in comparison to the procedures and the training required for epoxy injection. The procedure is most applicable to approximately flat horizontal surfaces such as floors and pavements. However, routing and sealing can be accomplished on vertical surfaces (with a non-sag sealant) as well as on curved surfaces (pipes, piles and pole).

Routing and sealing is used to treat both fine pattern cracks and larger, isolated cracks. A common and effective use is for waterproofing by sealing cracks on the concrete surface where water stands, or where hydrostatic pressure is applied. This treatment reduces the ability of moisture to reach the reinforcing steel or pass through the concrete, causing surface stains or other problems.

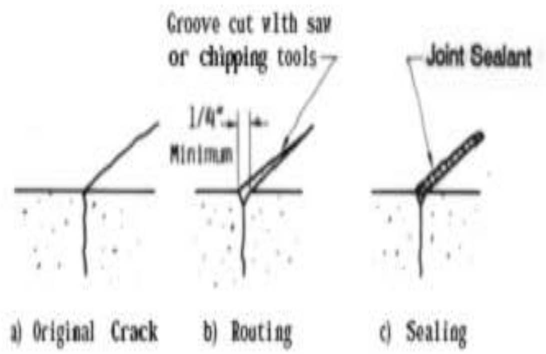


FIG 2.3 ROUTING AND SEALING

The sealants may be any of several materials, including epoxies, urethanes, silicones, polysulfides, asphaltic materials, or polymer mortars. Cement grouts should be avoided due to the likelihood of cracking. For floors, the sealant should be sufficiently rigid to support the anticipated traffic. Satisfactory sealants should be able to withstand cyclic deformations and should not be brittle.

The procedure consists of preparing a groove at the surface ranging in depth, typically, from 1/4 to 1 in. (6 to 25 mm). A concrete saw, hand tools or pneumatic tools may be used. The groove is then cleaned by air blasting, sandblasting, or water blasting, and dried. A sealant is placed into the dry groove and allowed to cure. A bond breaker may be provided at the bottom of the groove to allow the sealant to change shape, without a concentration of stress on the bottom

The bond breaker may be a polyethylene strip or tape which will not bond to the sealant. Careful attention should be applied when detailing the joint so that its width to depth aspect ratio will accommodate anticipated movement (ACI 504R).

Stitching

Stitching involves drilling holes on both sides of the crack and grouting in U-shaped metal units with short legs (staples or stitching dogs) that span the crack as shown in Fig 3.3. Stitching may be used when tensile strength must be reestablished across major cracks. The stitching procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the staples in the holes, with either a non shrink grout or an epoxy resin-based bonding system.

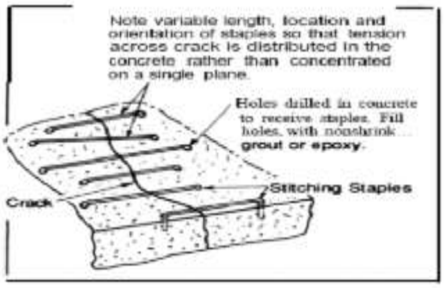


FIG 2.4 STITCHING

Pre-stressing steel

Post-tensioning is often the desirable solution when a major portion of a member must be strengthened or when the cracks that have formed must be closed. This technique uses pre stressing strands or bars to apply a compressive force. Adequate anchorage must be provided for the pre stressing steel, and care is needed so that the problem will not merely migrate to another part of the structure.

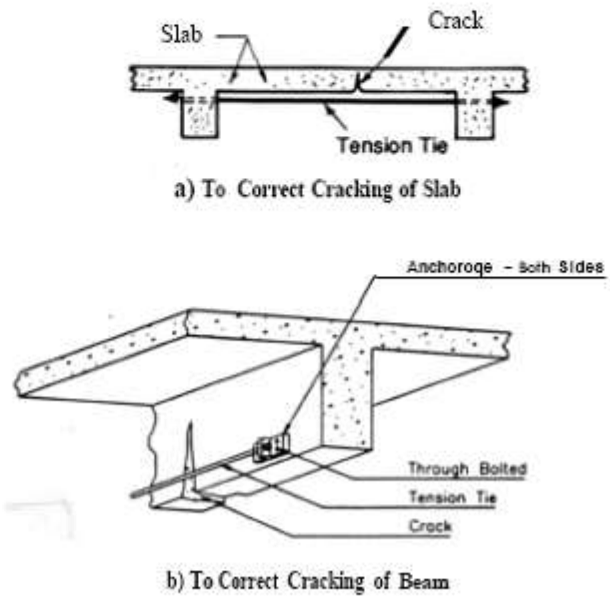


FIG 2.5 METHOD TO CORRECT CRACKING SLAB AND BEAM

Drilling and plugging

This technique is only applicable when cracks run in reasonable straight lines and are accessible at one end. This method is most often used to repair vertical cracks in retaining walls. A hole [typically 2 to 3 in. (50 to 75 mm) in diameter] should be drilled, centered on and following the crack.

The grout key prevents transverse movements of the sections of concrete adjacent to the crack. The key will also reduce heavy leakage through the crack and loss of soil from behind a leaking wall. If water-tightness is essential and structural load transfer is not, the drilled hole should be filled with a resilient material of low modulus in lieu of grout. If the keying effect is essential, the resilient material can be placed in a second hole, the fiat being grouted.

Gravity Filling

Low viscosity monomers and resins can be used to seal cracks with surface widths of 0.001 to 0.08 in. (0.03 to 2 mm) by gravity filling. High-molecular- weight methacrylates, urethanes, and some low viscosity epoxies have been used successfully. The lower the viscosity, the finer the cracks that can be filled. The typical procedure is to clean the surface by air blasting and/or water blasting. Wet surfaces should be permitted to dry several days to obtain the best crack filling. Water blasting followed by a drying time may be effective in cleaning and preparing these cracks. Cores taken at cracks can be used to evaluate the effectiveness of the crack filling. The depth of penetration of the sealant can be measured. Shear (or tension) tests can be performed with the load applied in a direction parallel to the repaired cracks (as long as reinforcing steel is not present in the core in or near the failure area). For some polymers the failure crack will occur outside the repaired crack.

Grouting

Portland cement grouting

wide cracks, particularly in gravity dams and thick concrete walls, may be repaired by filling with Portland cement grout. This method is effective in stopping water leaks, but it will not structurally bond cracked sections. The procedure consists of cleaning the concrete along the crack; installing built-up seats (grout nipples) at intervals astride the crack (to provide a pressure tight connection with the injection apparatus); sealing the crack between the seats with a cement paint, sealant, or grout; flushing the crack to clean it and test the seal; and then grouting the whole area. Grout mixtures may contain cement and water or cement plus sand and water, depending on the width of the crack.

However, the water-cement ratio should be kept as low as practical to maximize the strength and minimize shrinkage. Water reducers or other admixtures may be used to improve the properties of the grout. For small volumes, a manual injection gun may be used; for larger volumes, a pump should be used. After the crack is filled, the pressure should be maintained for several minutes to insure good penetration.

Dry packing

Dry packing is the hand placement of a low water content mortar followed by tamping or ramming of the mortar into place, producing intimate contact between the mortar and the existing concrete. Because of the low water-cement ratio of the material, there is little shrinkage, and the patch remains tight and can have good quality with respect to durability, strength, and water tightness.

Dry pack can be used for filling narrow slots cut for the repair of dormant cracks. The use of dry pack is not advisable for filling or repairing active cracksBefore a crack is repaired by dry packing, the portion adjacent to the surface should be widened to a slot about 1 in. (25 mm) wide and 1 in. (25 mm) deep. The slot should be undercut so that the base width is slightly greater than the surface width. To minimize shrinkage in place, the mortar should stand for 1/2 hour after mixing and then should be remixed prior to use. The mortar should be placed in layers about 3/8 in. (10 mm) thick. Each layer should be thoroughly compacted over the surface using a blunt stick or hammer, and each underlying layer should be scratched to facilitate bonding with the next layer. The repair should be cured by using either water or a curing compound. The simplest method of moist curing is to support a strip of folded wet burlap along the length of the crack.

Overlay and surface treatments

Fine surface cracks in structural slabs and pavements may be repaired using either a bonded overlay or surface treatment if there will not be further significant movement across the cracks. Unbounded overlays may be used to cover, but not necessarily repair a slab. Overlays and surface treatments can be appropriate for cracks caused by one-time occurrences and which do not completely penetrate the slab.

Surface treatments

Low solids and low-viscosity resin-based systems have been used to seal the concrete surfaces, including treatment of very fine cracks. They are most suited for surfaces not subject to significant wear. Bridge decks and parking structure slabs, as well as other interior slabs may be coated effectively after cracks are treated by injecting with epoxy or by routing and sealing. Materials such as urethanes, epoxies, polyesters, and acrylics have been applied in thickness of 0.04 to 2.0 in. (1 to 50 mm), depending on the material and purpose of the treatment. Skid-resistant aggregates are often mixed into the material or broadcast onto the surface to improve traction.

Overlays

Slabs containing find dormant cracks can be repaired by applying an overlay, such as polymer modified Portland cement mortar or concrete, or by silica fume concrete. Slabs with working cracks can be overlaid if joints are placed in the overlay directly over the working cracks. In highway bridge applications, an overlay thickness as low as 1-1/4 in. (30 mm) has been used successfully. Suitable polymers include styrene butadiene or acrylic latexes. The resin solids should be at least 15 percent by weight of the Portland cement, with 20 percent usually being optimum.

Repair of Concrete Columns for Cracks and Damages

Repairs to concrete columns can be divided into two categories. **Surface or cosmetic** repair only covers local deterioration and **structural repair** restores or strengthens the affected columns. If the deterioration does not significantly reduce the cross section, the conventional concrete repair can successfully be employed.

FIG 2.6 DETORIATED COLUMN

Methods of Concrete Column Repair for Damages and Cracks

Columns may be repaired by using one or more of the following methods:

- Encasement or enlargement of the column cross section (jacketing).
- Cathodic protection to stop reinforcing steel corrosion.
- Re-alkalization of the reinforcing steel to stop corrosion.
- Chloride extraction to retard the reinforcing steel corrosion.
- Confinement using steel plate, carbon, or glass fiber materials.
- Addition of shear collars to increase the shear capacity of intermediate floors.
- Addition of a steel plate assembly to increase moment capacity.
- Supplemental columns.
- The application of a protection system to prevent future corrosion.

Following parameters are important for the design and the execution of the column repair:

Unloading Columns

In those cases where the column deterioration is significant, unloading the column is usually required so that the entire cross section of the repaired column is capable of carrying the reintroduced design load. Without this unloading, the new repair will hardly carry any load.

Drying shrinkage of new material may further reduce this share of load. Unfortunately, it can be difficult and expensive to unload columns, especially in high-rise buildings. If the existing load on a column is not removed before the repair, the jacket will only provide confinement to the existing column. The percentage of direct load taken by jacket will be very small (less than 25 percent of the jacket strength).

If it is not possible to remove the load from the column, then a supplemental column system can provide an alternative method of support in combination with the repair of the existing column.

Redistribution of the Load

In case of corrosion of reinforcement and significant concrete deterioration, the load is redistributed in the structure before repair to a new pattern which must be considered while designing the repair. Even the adjoining members may have been affected by this redistribution.

Supplemental Reinforcing Steel

The column ties cannot usually be disturbed during the repair as it may cause buckling of the longitudinal bars. Hence, the supplemental vertical bars may be placed outside the original cage with extra ties. When the supplemental bars are placed outside the tie bars, the column dimensions should be increased to provide adequate cover. Hairpin ties, usually of stainless steel, are used to laterally support the supplemental bars.

Concrete Removal

The removal of concrete within a column cage must only be done if the column is unloaded. Otherwise, the longitudinal bars may buckle and compression failure of column may take place.

Corroded Reinforcing Steel

It is not necessary to remove the corroded reinforcing bar with reduced cross-sectional area if the loss is supplemented with additional reinforcing bars. The lap length of such a splice must be provided corresponding to the area lost by corrosion to either side of the corroded portion of the reinforcing bar that is supplemented.

The partially corroded reinforcing bars that are left in place must be thoroughly cleaned by sandblasting to obtain bare metal. The bars with excessive corrosion must be replaced with fresh reinforcement having full laps on both sides.

Corroded Ties

The corroded ties can be replaced by adding stainless steel hairpin ties that are anchored into the concrete. It is often necessary to deposit extra material around columns to provide adequate cover over the supplemental ties.

Low-strength Concrete

Where the concrete strength is low, resulting in insufficient load-carrying capacity, several alternatives are available:

- Shore the column and remove and replace the in-place concrete.

- Shore the column and increase the size of the column to reduce the bending stresses, and to increase the confinement on already placed weak concrete.
- Wrap the column with carbon- or glass-reinforced plastic.
- Install a supplemental column.

Repair of Reinforcement in Concrete

The damaged bars may either be replaced or supplemented by additional reinforcement based on engineering judgment, the purpose of the reinforcement and the required structural strength of the member.

a) Replacement: In case it is decided to replace the bars, splicing of reinforcement with the remaining steel must be done. The lap length must be according to the provision of ACI 318 and the welding (if used) must satisfy ACI 318 and American Welding Society (AWS) D1.4 (or the codal provisions of the respective country). Butt welding is usually avoided due to the high degree of skill required to perform a full penetration weld because the back side of a bar is not usually accessible. Welding of bars larger than 25 mm may cause problems because the embedded bars may get hot enough to expand and crack the surrounding concrete. Mechanical connectors may also be used according to the code requirements.

b) Supplemental reinforcement: This alternative is selected when the reinforcement has lost cross section, the original reinforcement was inadequate, or the existing member needs to be strengthened. The allowable loss of cross-sectional area of the existing reinforcing steel and the decision to add supplemental reinforcement must be evaluated on a case-by-case basis and is the responsibility of the engineer. The damaged reinforcing bar must be cleaned and extra space is to be created by removing concrete to allow placement of the supplemental bar beside the old bar. The length of the supplemental bar must be equal to the length of the deteriorated segment of the existing bar plus a lap-splice length for smaller diameter bar on each end.

Reinforcing bars, having corrosion of their original deformations, give less bond and this factor must be considered while designing the repair of the reinforcement.

c) Coating of reinforcement: New and existing bars that have been cleaned may be coated with epoxy, polymer cement slurry, or a zinc-rich coating for protection against corrosion. The coating must have a thickness less than 0.3 mm to minimize loss of bond development at the deformations.

CHAPTER 3
LITERATURE REVIEW

RESEARCH WORK AND LITERATURE:

General

This chapter includes a detailed study of various research work and literature related to various NDT techniques, some structural auditing case studies and articles related to maintenance repair and rehabilitation of RCC structures.

Pranjali V Kulkarni, etal;

They studied various cases related to old RCC structures and reviewed the auditing process referring various problems related to auditing process. Currently, Safety of old buildings is one of the critical issues in India. Though, there are many practices to conduct structural audit of such buildings, the issues of structural safety audit remains uncertain due to inconsistency of such practices. The study attempts to evaluate gaps in current such local practices of structural audit of residential buildings. Thereby, intends to offer insights to generate more precise framework of structural audit. The flaws in the process of structural audit and the difficulties in execution of structural audit were studied. Also the recommendations for the safe and universally acceptable framework to carry out structural audit were also studied.

JedidiMalek, etal;

The estimation of mechanical properties of concrete can be carried out by several methods; destructive and non-destructive. An experimental study was conducted to determine the compressive strength of concrete by destructive (compression) and non-destructive (rebound hammer) tests at different ages (7, 14 and 28 days). In addition, the influence of several factors on the modulus of elasticity determined by pulse velocity test was investigated. These factors mainly included the age of concrete and the water/ cement ratio. The results showed that the difference between the resistance values obtained by destructive and non-destructive methods decreases with increasing age of concrete. A simplified expression has been proposed to estimate the rebound number from the value of the dynamic modulus of elasticity determined by pulse velocity test.

BH Chafekar, etal,

To carryout structural audit we must know various details about the structure.Thishelps in proper evaluating various causes of distress its causes and weak areas in the structure.by referring the RCC building as an interconnected structure made of elements to carry load safely to the underground earth by considering the example of table as structure.The legs of tables are column, battens are the beam and ply sheet are slab. When they are joined vertically and horizontally a structure is formed in the same way the building structure is composed of steel and concrete. However after its long use the tableloses its load carrying capacity similarly RCC structures also loses its strength due to material deterioration and when it becomes old. Hence it becomes mandatory to take some actions to overcome this problem.

The health examination of concrete building is called structural audit. Which consist of detailed inspection of the building like a doctor. For old building proven to risk areas, critical areas and weak structural areas etc structural audit becomes a necessary tool to regain overall health of the structure by suggesting various repair techniques wherever necessary.

AB Mahadik, etal;

Structural Audit can be defined as the examination of building to find out the strength of a building so as to enhance its life duration. Structural audit generally is to be done after 15 to 20 years of construction of building. However structural audit after every 3 or 5 years is recommended.

J.C Agunwala, etal;

Done a comparative study of NDT Techniques involving rebound hammer test & Ultrasonic Pulse velocity test. Suggested that NDT of concrete is of great scientific and practical importance especially for determining quality of old concrete .Test was perform to compare the accuracy b/w Rebound hammer and UPV method with two different properties in estimating the strength concrete. The sample were prepared and tested and the comparison strength was calculated.

Patil S R, etal;

It is a case study of structural audit .The general health and performance of a building depends on its quality of maintenance as a building grows old, use and misuse and exposure to the environment can affect the health of the building significantly. The structural audit can be defined as the inspection or examination of the building to evaluate the strength so as to improve its safety, efficiency. In this project the fundamental principal of Non Destructive Test (NDT) method are considered in some detail with a view to establishing a definite role for them in the Structural Evaluation Program.

Structural Audit Report (Case Study of R.C.C. Building)

Basic Information

Type of Structure - RCC Building of G+4 floors

Address - Pune

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

Year of construction-Aug 1987

Age- 27 years .

J. Bhattacharjee

Studied present status of maintenance ,repair and rehabilitation techniques in India and found that India lacks various advanced methods of rehabilitation and retrofitting techniques. At present there is neither any established procedure mandatory to carry out the auditing process. Also studied various causes of distress and cracks in the structure, various measures to be adopted to restore the strength ot the structure. The study also includes various major causes of deterioration of the structures. He also studied various case studies related to structural auditing which includes repair and rehabilitation of jetty at Mumbai, rehabilitation of an overhead reservoir at Silliguri,West Bengal, double storied load bearing structure in Mumbai. Also studied various precautions to be taken while using chemicals for repairs.

Akihiro Kunisue, etal

The authors have been researching and developing methods of retrofitting existing reinforced concrete buildings with elasto-plastic steel dampers. The authors have been researching and developing a retrofitting method using elasto-plastic dampers made of low yield steel. This seismic retrofitting method increases building strength through the dampers' strength and reduces structural response through the dampers' energy-absorbing capacity. This retrofitting method, which requires fewer reinforcing elements than conventional retrofitting methods, minimizes inconvenience to occupants while maintaining a high level of seismic safety.In the proposed seismic retrofitting method, dampers are installed in an existing building to increase its structural strength and at the same time to reduce its seismic response by absorbing energy. This paper reports on a structural test conducted to investigate the structural characteristics of damper-embedded frames. The test results indicate that the proposed method of retrofitting an existing building increases both its strength and its energy absorption capacity. The paper also introduces an example of an application of the proposed seismic response control retrofitting method and demonstrates the effectiveness of the retrofit through earthquake response analysis.

Pravin B Waghmare;

The author studied the technique of jacketing of column and beam using concrete. The study shows that jacketing by concrete can increase both flexural and shear capacities of a column.The compatibility of deformation between old and new concrete, and the durability are better as compared to a new material on a different substrate.Availability of personnel skilled in concrete construction.Analysis of retrofitted sections follows the principles of analysis of RC sections.

Of course, there are certain disadvantages of concrete jacketing depending upon the structure and its use:

- increase in the size of the column and reduction in floor space,
- anchoring of bars for flexural strength involves drilling of holes in the slabs and footings,
- manufacturing of sufficiently workable concrete for the jacket, and
- possibility of disruption to the users of the building.

- Despite the disadvantages, concrete jacketing is a practical option for the buildings where columns are highly deficient in flexure or shear as compared to the required performance.

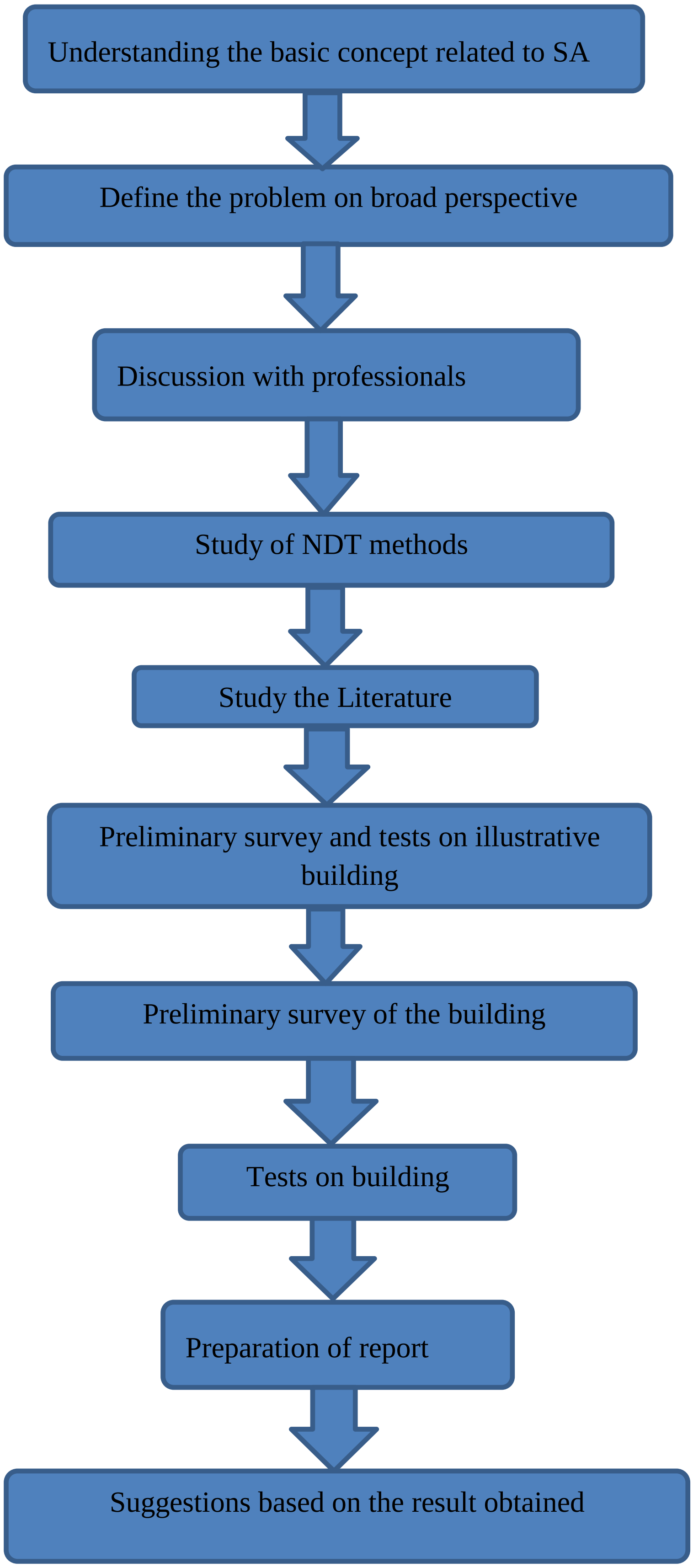
A.K.Singh,etal;

Reinforced Cement Concrete (RCC) is a popular material for building construction in India because it is cheaper than structural steel. Also, construction in RCC is considered to be labourintensive and supposedly requires fewer high-tech tools, infrastructure, and skills than does structural steel. Over the past 10 years, we have seen a boom in the number of low- and medium-rise RC frame buildings with masonry infills. However, the real estate boom over the past decade has resulted in a large, privately constructed building that has not been adequately designed. Nominal mixes (with predetermined proportions of cement, fine aggregates, and coarse aggregates) are used to make concrete without a formal mix design. Volume batching is primarily employed instead of weigh batching; resulting into difficulty of not accounting for moisture in the aggregates, which could at times be large. Also, the placement of concrete is manual. Water available at site is used for concreting without always verifying its suitability; some salts detrimental to the durability and strength of concrete do enter into the concrete. Moreover, the quantity of water is adjusted to ensure good workability, often resulting in higher water content than necessary and in porous hardened concrete.

This paper describes the intensive retrofitting of an existing RCC framed structure. The building of is a multi-storeyed Ground + 12 upper floor RCC framed building owned by a nationalised bank.

CHAPTER 4

METHODOLOGY



CHAPTER 5

STRUCTURAL AUDIT OF (G+6) BUILDING AT AIROLI

5.1 INTRODUCTION:

New Bombay Safalya, CHS Plot no.14 Sector-7, opp Palm Spring Building, Airoli.
The building is RCC structure which contains Ground+6 upper stories.
The building was constructed 22 years back.

FIG 5.1 ILLUSTRATIVE BUILDING

5.2 CONDITIONAL SURVEY

The building was investigated & information was collected from chairman of the building Mr P.S.Lokhande. The building was investigated for its external and internal structural members. Each column, beam & slab was observed for the defects such as minor/major cracks, seepage, dampness, spalling, leakages,etc . Information about the previous repairs was also collected. All these defects, observations and approximate repair areas formed the total data of the structure.

5.3 OBSERVATIONS:

I. EXTERNAL:

The external face of building shows minor cracks in plaster at some locations. Large cracks were observed in two columns with excessive deterioration of concrete as well as reinforcement. Overhead slab at the entrance has become hollow. However the external appearance of the building is fair.

II. INTERNAL:

Seepage marks through dry patches have been observed through the external wall in some units. No major structure layout change has occurred inside the units. Seepage marks and dampness have been observed inside the flats on top floor. Dripping of water in some flats is also observed. Spalling of concrete was seen in kitchens of some flats. Peelings of paints are seen at many locations of common staircase walls and ceiling area.

III. RCC FRAME:

The observations are based on visual inspection and rebound hammer test conducted by our team.

IV. OVER HEAD WATER TANK:

The tank (rectangular) was observed at terrace top. The over head water tank does not have any visual cracks.

Recommendations

After visual inspection & studying the results of Non Destructive Tests (Ultrasonic Pulse velocity Test & Rebound Hammer Test) done on columns, we are of the opinion that the building is suffering from Class 3 Damage. Principal repairs are required to columns & beams at various levels. It is felt that the repair work should start at earliest to avoid further deterioration of the structure. The repair work should include strengthening of columns, plastering, plumbing, waterproofing, etc. Leakages observed in pipes at various locations in canteen. This should be rectified properly as early as possible to avoid further problems.

5.4 OBSERVATION TABLE:

REBOUND HAMMER READINGS:

Column (α=0)

TABLE 5.1 READING OF COLUMN α=0

Name of the column	Rebound No			Compressive Strength (N/mm^2)			Average (N/mm2)
	R1	R2	R3	C1	C2	C3	
CO 1	24	23	22	13	12	11	**12.00**
CO 2	24	23	26	13	12	16.5	**13.83**
CO 3	22	22	22	11	11	11	**11.00**
CO 4	23	25	30	12	14	21	**15.67**
CO 5	22	22	22	11	11	11	**11.00**
CO 6	24	24	22	13	13	11	**12.33**
CO 7	28	22	24	18	11	13	**14.00**
CO 8	26	24	24	16.5	13	13	**14.17**
CO 9	27	25	26	16.5	14	15.8	**15.43**
CO 10	38	31	27	32	22	16.5	**23.5**

Column (α=0)

TABLE 5.2 READING OF EAST SIDE COLUMN α=0

Name of the column	Rebound No			Compressive Strength (N/mm^2)			Average (N/mm2)
	R1	R2	R3	C1	C2	C3	
COE1	32	32	22	23.8	23.8	11	**19.53**
COE2	22	22	22	11	11	11	**11.00**
COE3	22	22	22	11	11	11	**11.00**
COE4	22	22	22	11	11	11	**11.00**
COE5	22	22	22	11	11	11	**11.00**
COE6	22	24	22	11	13	11	**11.67**
COE7	22	32	33	11	23.8	25	**19.93**
CO INSIDE 1	22	28	22	11	18	11	**13.33**

Slab (α-90)

TABLE 5.3 READING OF SLAB α-90

FLAT NUMBER	Rebound No			Compressive Strength (N/mm^2)			Average (N/mm2)
	R1	R2	R3	C1	C2	C3	
GF CENTRE	20	20	20	12.5	12.5	12.5	**12.50**
BD 104	26	32	26	19.8	28	19.8	**22.53**
GF RIGHT	30	30	24	25	25	17	**22.33**
HL 404	20	20	20	12.5	12.5	12.5	**12.50**
KTC 404	20	20	20	12.5	12.5	12.5	**12.50**
BD 401	30	30	30	25	25	25	**25.00**
KTC401	27	24	27	21	17	21	**19.67**
HL 401	27	27	27	21	21	21	**21.00**
BD 602	20	20	20	12.5	12.5	12.5	**12.50**
ST 6-7 FL	25	20	25	18	12.5	18	**16.17**
HL 603	32	32	32	28	28	28	**28**
CH-BED 702	24	30	32	17	25	28	**23.34**
HL 701	20	20	20	12.5	12.5	12.5	**12.5**

Tank (α=0)size5x5x2

TABLE 5.4 READING OF TANK α=0

DESCRIPTION	Rebound No			Compressive Strength (N/mm^2)			Average (N/mm2)
	R1	R2	R3	C1	C2	C3	
CO1	24	24	24	13	13	13	**13.00**
CO2	22	22	22	11	11	11	**11.00**
CO3	28	30	27	18	21	16.5	**18.50**
CO4	30	28	27	21	18	16.5	**18.50**

Beam

TABLE 5.5 READING OF BEAM

DESCRIPTION	Rebound No			Compressive Strength (N/mm^2)			Average (N/mm2)
	R1	R2	R3	C1	C2	C3	
B/W CO2-CO3	24	30	23	13	25	16	**18.00**
BD 401	28	28	28	18	18	18	**18.00**

ST=STAIR, GF=GROUND FLOOR HL=HALL,

BD=BEDROOM, CH-BD=CHILDREN BEDROOM KTC=KITCHEN.

The compressive strengths of the concrete at different locations were obtained. The average compressive strength obtained was less than 15 N/mm² at various locations. Hence weak and deteriorated structural members must be rectified using various retrofitting techniques.

ULTRA SONIC PULSE VELOCITY TEST READINGS:

TABLE 5.6 READING OF COLUMNS, BEAMS AND SLABS

SR NO.	LOCATION	MEMBER	DISTANCE (mm)	TIME (μsec)	VELOCITY (km/sec)	METHOD
1	Ground Floor,C=1	Column	300	62.7	4.78	Indirect
2	Ground Floor,C=2	Column	200	46.4	4.34	Indirect
3	Ground Floor,C=3	Column	300	85.2	3.521	Indirect
4	Ground Floor,C=4	Column	300	131.4	2.283	Indirect
5	Ground Floor,C=5	Column	300	91.8	3.267	Indirect
6	Ground Floor,C=6	Column	300	73.9	4.059	Indirect
7	Ground Floor,C=7	Column	300	236.4	1.269	Indirect
8	Ground Floor,B=1	Beam	300	117.9	2.544	Direct
9	Ground Floor,B=2	Beam	230	110.6	2.0795	Direct
10	Ground Floor,S	Slab	300	327	0.9174	Indirect

UPV test is one of the Non destructive test conducted to determine the velocity of the ultrasonic pulse generated by the instrument. High velocity indicates high density of concrete associated with high modulus of elasticity and vice versa. The ultrasonic pulse velocity obtained was greater than 4.5km/s at some concrete sections which indicates good quality of concrete. However, at some sections the velocity was less than 3.0 km/s which indicates low concrete quality. At the entrance, the velocity value obtained in the slab was 0.917km/s which is a very less value indicating very low density of the concrete. Hence, immediate steps must be taken to increase the strength of the slab at the entrance to avoid any accidental losses and damages.

HALF CELL POTENTIAL TEST READINGS:

TABLE 5.7 READINGS OF COLUMNS AND BEAMS

SR NO.	LOCATION	MEMBER	READIND VOLTS(-V)	READIND VOLTS(-V)	READIND VOLTS(-V)	READIND VOLTS(-V)	READIND VOLTS(-V)
1	Ground floor	C=1	0.341	0.357	0.386	0.403	0.411
2	Ground floor	C=2	0.36	0.397	0.397	0.379	0.361
3	Ground floor	C=3	0.444	0.367	0.369	0.365	0.401
4	Ground floor	C=4	0.326	0.31	0.368	0.394	0.351
5	Ground floor	C=5	0.118	0.128	0.123	0.19	0.137
6	Ground floor	C=6	0.396	0.38	0.328	0.408	0.38
7	Ground floor	C=7	0.354	0.36	0.354	0.344	0.356
8	Ground floor	B	0.324	0.365	0.347	0.368	0.45

Half cell potentiometer is used to determine the corrosion activity in steel reinforcement. The potential as measured by the copper half cell indicates the phase of the corrosion activity occurring in steel reinforcement. The potential values in all the structural members were greater than -350mV which indicates that corrosion activity is occurring positively in the concrete members.

CARBONATION TEST:

TABLE 5.8 READINGS OF CARBONATION TEST

SR NO	MEMBER	DEPTH(mm)	CARBONATION PRESENT
1	COLUMN 1	35	NO
2	COLUMN 2	25	NO
3	COLUMN 3	10	NO
4	COLUMN 4	30	NO
5	COLUMN 5	30	NO
6	COLUMN 6	45	NO
7	COLUMN 7	10	NO

The depth of carbonation is estimated based on change in colour profile of the concrete sections tested using phenolphthalein as indicator. The test was performed by drilling holes in concrete sections followed by spraying of phenolphthalein indicator. The change of colour of concrete to pink was seen which indicates the concrete sections are not carbonated.

5.5 RECOMMENDATIONS:

After visual inspection & studying the results of Non Destructive Tests (Ultrasonic Pulse velocity Test & Rebound Hammer Test , Half Cell Potentio meter Test ,Carbonation Test) done on structural members, It can be said that some structural members of the buildings are suffering from Class 3 Damage. Principal repairs are required to columns & beams at various levels.

It is felt that therepair work should start at earliest to avoid further deterioration of the structure. The repair work should include strengthening of columns, plastering, waterproofing, etc. Leakages were observed in pipes at various locations on top floor. This should be rectified properly as early as possible to avoid further problems due to leakages.

Vegetation growth was observed at the first floor which may further lead to widening of cracks & leakages. To avoid this problem all vegetation should be removed at the earliest.

Quality of RCC was found poor as per the results of Ultrasonic Pulse Velocity Test & Rebound Hammer Test performed at various locations.

Inadequate levels of maintenance, improper workmanship of external finish were found. Since structure is found in distressed condition, it is recommended to carry out the repair work as soon as possible.

Delay in starting the repair work will result in increase of the quantity of work due to the continuous deterioration process.

Note: According to CPWD (Central Public Works Department) Class 3 damage stands for the observations like spalling of concrete cover, structural cracks, etc. In which principal repairs are required.

SLAB AT THE ENTRANCE (HOLLOW WITH VERY LOW UPV VALUE)

SPALLING OF SLAB CONCRETE

Remedial measures:

Removal of deteriorated concrete and strengthening it using the technique of overlaying must be adopted.

Slabs containing fine dormant cracks can be repaired by applying an overlay, such as polymer modified Portland cement mortar or concrete, or by silica fume concrete.

The reinforcement is corroded and hence should be replaced wherever necessary. If cannot be removed then it should be cleaned to remove the rusting and additional reinforcement is to be provided.

Bonding between old and new bars can be achieved by welding.

Application of suitable overlaying material and maintaining suitable conditions after concreting to achieve desired strength.

MINOR CRACKS IN COLUMN

Remedial measures:

Minor cracks in the column can be retrofitted by the injection of epoxy or using high pressure grout technique.

Cracks as narrow as 0.002 in.(0.05 mm) can be bonded by the injection of epoxy.

DETERIORATION OF PLASTER

Remedial Measures:

Removing the deteriorated surface plaster followed by replastering using cement, sand mortar of ratio 1:3 is suggested. Proper curing to be done till the surface attains adequate toughness.

LARGE CRACKS IN COLUMN (GROUND FLOOR)

Remedial Measures:

Jacketing is the process by which a section of an existing structural member can be restored to original dimensions or increased in size by encasement using suitable materials. Using steel reinforcement cage around the damaged section onto which shotcrete or cast-in- place should concrete be placed

The form must be provided with spacers to ensure equal clearance between it and the existing member. Materials, like conventional concrete and mortar, epoxy mortar, grout, and latex-modified mortar and concrete, should be used as encasement materials. For jacketing, the void between the form and the existing member should be filled using pumping, tremie, or preplaced aggregate concrete method.

Before applying jackets, all deteriorated concrete must be removed, cracks must be repaired, existing reinforcement must be cleaned, and surfaces must be prepared. The surface preparation improves the bond of the newly placed materials with the existing structure.

Timber, cardboard and corrugated steel forms may be used as temporary or permanent forms. However use of permanent fiberglass, rubber, and fabric forms will be beneficial because they provide resistance to chemical attack after the repair is complete.

If the material used for jacketing is cement mortar or concrete, the cement content must be exactly according to the requirements; both excessive and less cement contents may be dangerous. Use clean, stable and the largest possible size aggregates. In order to reduce shrinkage, control the temperature of the materials and the immediate surroundings during placing and curing. Use of admixtures such as plasticizers, air-entraining agents, retarders, accelerators and water-proofing admixtures is more beneficial in repair than even the ordinary construction. Expanding mortars / concretes can be made by adding aluminum powder to the matrix to overcome the setting shrinkage and some part of the drying shrinkage. The use of iron fillings or powder can also perform this function if moisture and air are available.

In case grout is used for filling the forms, it is allowed to settle for about 20 minutes after full filling and then is refilled to overflowing condition. The top of the jacket must be finished with pneumatically projected or hand placed concrete.

5.6 FIELD WORK IMAGES

ULTRA SONIC PULSE VELOCITY TEST

HALF CELL POTENTIOMET

CHAPTER 6
CONCLUSIONS

- Building is suffering from Class 3 Damage.
- Principal repairs are required to columns & beams at various levels.
- The repair work should start at earliest to avoid further deterioration of the structure. The repair work should include strengthening of columns, plastering, plumbing, waterproofing, etc. Leakages observed in pipes at various locations.
- All the vegetation should be removed at the earliest.
- Any delay in the structural repair work will result in more deterioration & quantity of work will become more.
- Slabs containing fine dormant cracks must be repaired by applying an overlay, such as polymer modified Portland cement mortar or concrete, or by silica fume concrete.
- The corroded steel must be replaced, wherever necessary. If steel cannot be removed then it should be cleaned to remove the rusting and additional reinforcement is to be provided.
- Suitable overlaying material must be applied and suitable conditions must be maintained after concreting to achieve the required strength.
- Minor cracks in the column must be retrofitted by the injection of epoxy or using high pressure grout technique. Cracks as narrow as 0.002 in.(0.05 mm) can be bonded by the injection of epoxy.
- The deteriorated surface plaster must be scrapped-off & the re-plastering must be done with the mortar of proportion 1:3.
- Column jacketing must be done for the deteriorated columns, as the columns form very important part of the structure & any instability of the column may cause global collapse, affecting the whole building.

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