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Evaluation and Repair Case Study for Existing Structural Systems

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Abstract: ***Civil Engineering Industry is one of the oldest industries which provide a basic infrastructure which give an essential framework to all the people. Structures can be any sort it tends to be Historical, Heritage Structure, Residential building, Commercial building or an Industrial building. Each structure has its own service life, and inside this service life, it should stand solidly on its position. A collapsed mechanism has increased and today's Structures are getting collapsed before their service life. Therefore, it is advisable to monitor it periodically by taking a professional opinion. Structural Audit is a preliminary technical survey of a building to assess its general health as a civil engineering structure. It is normally started as the initial step for repair. The construction material mainly reinforced concrete is being used extensively for various types of construction projects. The structures become older, we find in them certain degradation or deterioration with resultant distress manifested in the form of cracking, spalling, dampness, corrosion etc. In the present time, there is the presence of defects in building as a result of low-quality control during the construction, lack of maintenance and an unfavorable change in the weather condition. It is essential to mai0ntain quality in terms of material quality, mixture with their desire specification, workmanship etc. The main purpose of repair and rehabilitation is the investigation of the present structures and suitable solution for the building defects, distresses and damages. In this project, some Non-destructive test and chemical tests will be done to check the quality and strength parameter of the present structure.***

Keywords: Distress, Condition Assessment, Rehabilitation, Cracks, Repairing work

1. Introduction

In today's world most commonly used construction material is concrete. After 1970 and 1980, all major countries made a consensus of new preventions and suitable durability practices of concrete (IS Code – 456:2000). In the current scenario of Building Research, Repair and Rehabilitation plays a vital role as it serves important in building applications [1]. The major defects reported are discussed and a suitable and economical solution for a particular defect is identified.

Generally, the life of a structure depends on the geography of location, Building material, Technology, and Workmanship [2]. Geography of location includes various aspects such as the type of strata, water table, earthquake or wind or cyclone or flood or snow, pollutant, landslide and tree location with respect to the building. Building materials include cement, lime, fine sand, coarse sand, quality of water, bamboo or wood, brick. Technology includes various aspects such as architectural design, construction methods, and quality practices. Finally one of the major factor workmanship includes various aspects such as structural work, finishing work, waterproofing work, maintenance of the building.

Cracks are the universal problem of concrete structures, this is affecting the art of structure and they are also destroying the walls of integrity, affecting the building safety/security reducing the durable of the structure. Cracks are developing due to concrete work deterioration or reinforcement bars are corroding due to poor construction work or bad construction material and by the temperature and shrinkage effects.
Cracks are divided into two types:

1) **Structural Cracks**: These are the cracks which affects the structural strength and safety of the structure.
2) **Non-Structural Cracks**: This type of cracks does not directly affect the strength and safety of the structure.
   Non-Structural Cracks is:
   - Shrinkage for Long Term Drying
   - Crazing and Corrode of Steel
   - Concrete structure/building corrode
   - Early Thermal Expansion and Contraction
   - The reaction of Alkalis - Aggregates
   - Sulfate Attack

1.1 Aim and Objectives

- To strengthen the existing building
- To increase the service life of the building
- To save the cost and time of maintenance of the existing building
- A suitable solution of the defects
- To transform non-serviceable building to serviceable, due to lack of space for new construction

1.2 Problem Statement

Nowadays concrete is the main building material used for the construction of structures. Some old buildings are still in good working condition but some modern structures start showing signs of distress in a short time due to poor workmanship, poor maintenance, poor material quality, and improper design. Thus most of the old building are required more maintenance and repair of building also due to increase in population and due to increase in their requirements of shelter, they require more space for new construction of building but required amount of space has not available for the new construction or people may have to pay more amount for purchasing new land and construction of new building thus instead of this it is more economical to use existing building by doing rehabilitation of that building.

It is advisable to rehabilitate distressed structure instead of demolishing it and construct a new one. So in civil engineering, repair and rehabilitation of the existing structure are very famous as it is economical and time-saving process rather than build a new structure. Rehabilitation of existing structures needs lots of knowledge and planning to get the work done. Today there were many types of different methods and material are used for rehabilitation of structure. Some materials used are Cement, Epoxy resins, Polymer concrete composites, Steel fiber reinforced concrete, Asphalt coatings etc.

The present paper focuses on condition assessment of an existing 10-year-old Institutional building and their possible solutions for measuring repairing and rehabilitation work with the safety of the structure. The basic process of Repair and Rehabilitation includes visual inspection, photographs of the distresses and defects, a preliminary survey which includes preliminary tests that are performed, identification of problems, and suitable solution for the problem. After the analysis of all the data and results of various NDT methods for assessing the quality of structures has been done and the possible repair and restoration works are suggested.

2. Literature Review

Kajol Merwala, Darshan Mehta and Liza Hirpara [3] discuss the large numbers of monuments and old structures have stood well for a long period, but kind of them starts showing signs of distresses for the faulty design, age, atmospheric effects, pollution etc., which results in shortening of life and strength of the structure. The purpose of this paper is to suggest various techniques and materials for repairing work to solve the deterioration which is necessary and economical than the reconstruction of the structure. Distressed structures are very old and they require proper repair work. Strength evaluation of an existing structure is essential to cover all criteria of maintenance, so that some non-destructive, partially destructive and destructive tests are performed for assessment of structure and to predict the cause of deterioration. Repair and rehabilitation are necessary to increase strength & life and avoid hazardous failure of the building. It is advisable for old a structure which shows the signs of cracks, spalling, corrosion, dampness etc. therefore periodically maintenance of structure is required. The repairing techniques depend on factors such as the location of the site, cost etc. For proper maintenance of the building the test like rebound hammer, ultrasonic pulse velocity etc. are performed and after a detailed study of the problem, we can apply appropriate repair method like concreting, routing, epoxy injection etc.

Shital Pardeshi and U. L. Deshpande [4] have discussed important to choose appropriate techniques, materials, and procedures to repair the building. There are many modern techniques available for structural repair. The selection of material for repair depends upon various factors such as cost, the requirement of repair and suitability of material in damaged part. To maintain the RCC structure, it requires periodic inspection. There are many causes for deterioration of structure like an error in construction, poor material quality, error in design, poor workmanship etc. In this paper, they had defined the term Repair as the process of bringing back the aesthetics of the building, restoration as the process of structural repair and make the structural elements enough to bear the loads coming on them and transfer all loads safely. The repair material used is aluminum powder in OPC, steel in form of bolts, channels, angles, for temporary supports and scaffolding timber and bamboo are used. They had used the material for repair are as follow, Shot Crete, Epoxy resins, Epoxy mortar, Gypsum cement mortar, and mechanical anchors. In this paper, they had concluded that periodic maintenance of structure is required and for assessment of building some non-destructive and destructive tests should be carried and then remedial measures and repair techniques could be employed.

S.S. Chandar [5] discusses Repairer and Rehabilitation engineering requires much more skill and abilities then construction engineering. Due to faulty construction and construction without seismic standards require rehabilitation. The purpose of this paper is to present the process of rehabilitation, selected test and the latest advanced techniques for rehabilitation. In this they had also presented the scope of repair and rehabilitation, health assessment of existing structure and post retrofitting evaluation for the behavior of the structure. As per this paper, the process of rehabilitation is to perform a structural audit then evaluating various methods, materials then perform structural calculation then suggesting suitable rehabilitation method and get it done and at the end post retrofitting tests on the building. He had also showed test such as Schmidt's hammer test, probe penetration, pull out, and break off, core cutter test, ultrasonic pulse velocity, and infrared thermography as well as some methods such as grouting, replacement of structurally fragile concrete, waterproofing, cleaning and passivation concrete near steel reinforcement and re-alkalization of carbonated concrete. He had prepared a table of capacity calculation for existing structural members of the building and remarked that structural member is safe or require repair. As per this paper, it is very important to save the structure from hazardous failure due to deterioration.

Nurul Nadia Omar Bakri and MdAzreeOthumanMydin [6], Today building deterioration is one of the major problems which need proper attention. When the structure fails in operation as it should, we must find the problem in it. First of all, found which causes are responsible for the problem in the building. The defect in the building is divided into two types of structural defect, non-structural defect. There are many common defects in building such as cracks, paint, dampness, the decay of timber, attacks of insects (termites), defects in roof etc. In cracks according to the construction cracks are occurrence due to overloaded or because the structure has settled. Dampness is caused by rain, condensation services leaks. Timber defect is classified into two types non- biological and biological. Typically decay of timber may be occurring at the timber roof, the floor of the timber and timber of joineries like frames of doors and windows. Roof defect is generally exposed to some kind of parts like the degree of temperature and wind action changes. Defects of the roof are a different type of part into faults in structural and defect in the waterproofing materials. The

unstable foundation is one of the most effective damages on structure because the foundation of the building is to support the building if some reason foundation is moving is responsible for cracks in the building. Movement of the foundation is caused by water flow, hilly slope, an earthquake wave. The literature has explored most of the building defects and it's all factor which can be linked to the major these types of paper theme.

Varinder K. Singh [7] explains generally reinforced concrete structures are designed as per codes/ standards but enough care is not always taken during the construction process. As a result, the start showing structures of distress, less than Ten years of working life, requiring repair and rehabilitation of structure. In this search of paper, a case study multi-storied building badly damaged due to corrosion and Bhuj earthquake of 2001, rehabilitation in 2003 has been presented. Repair strategy involved removal of delaminated carbonated concrete cover , application of rust remover , anti-corrosion coating, polymer bond coat, polymer modification mortar , injection of low viscosity epoxy grout to beam-column junction and crack , repair of masonry cracks with polymer modified mortar & grouting with SBR modified cement grout and jacketing of columns at the ground floor. Visual inspection of the buildings indicated heavy rebar corrosion as a result of carbonation due to atmospheric attacks. Beam-column junctions were badly cracked. A many of columns had vertical cracks line to line of concrete (column) cover thickness. The visual inspection required for the detailed calculations for the design of the rehabilitation design.

3. Case Study

Domain: Smt. S. R. Patel Engineering College, Dabhi, Patan-Unjha Road, Gujarat, India. This is G+1 structure which is 10 years old. In this building Ground floor is having JV001 to JV014 and First floor is having JV101 to JV114.

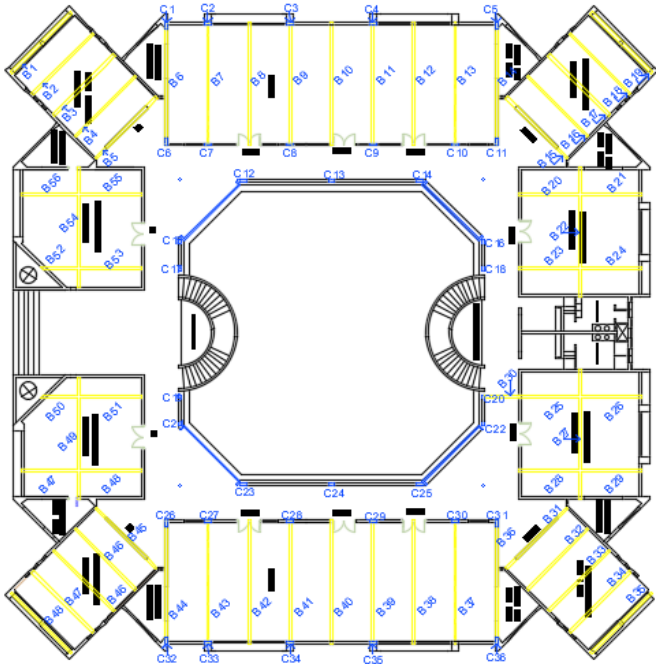


Figure 1: Plan of Building (JV)

4. Methodology

Following are the steps of the project work [6]:

1) Visual inspection and Field inspection
2) Collection of data of the building
3) Click Photographs of distresses and defects
4) Classification of defects and distresses
5) Analysis of defects and their possible solutions
6) Non-destructive testing and Chemical testing
7) Repairing and Testing after repairing

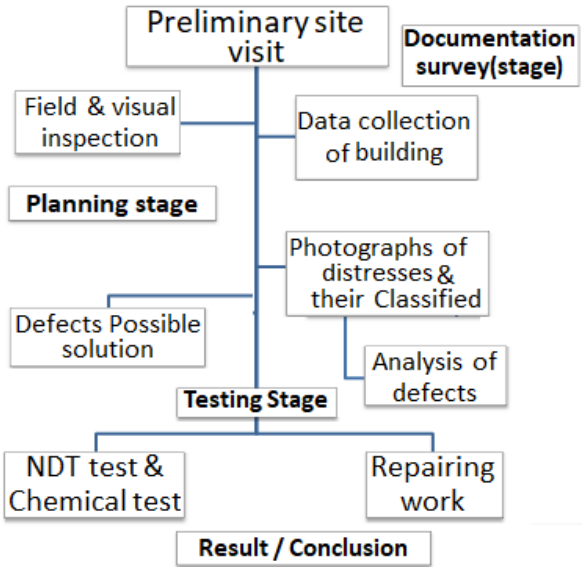


Figure 2: Methodology

In our domain first, we had done a visual inspection and investigate the condition of building with respect to Preliminary inspection, Planning, Survey.

1) After that, we had collected data related to building such as it's architectural drawings, structural plans, date of construction, time required for construction etc.
   a) Structure exposure condition
   b) Data of structural modification
   c) Record when first time deterioration occurred
   d) Past performed all repairing details
   e) Inspection of past reports
2) To click the photo of distressed of all different parts of structure then we had collected photographs of the building and classified that photographs by different distress such as dampness, cracks, corrosion, flooring settlement and Poor/improper maintenance etc.

Photograph 1: Termite

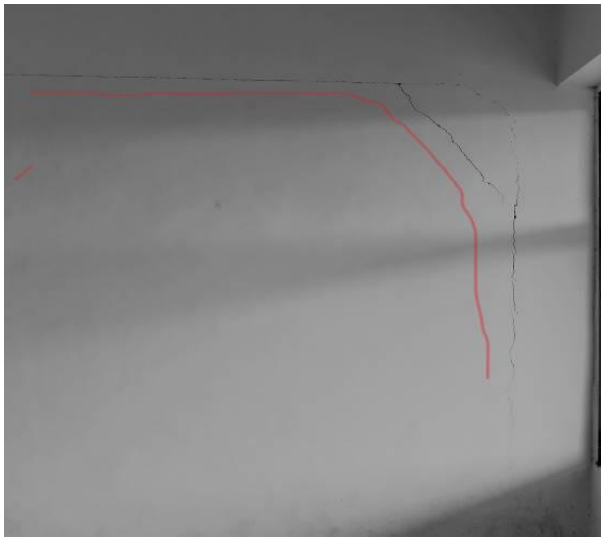
Photograph 2: Vertical crack (Wide crack) Due to Thermal stress

Photograph 3: Open reinforcement and Environmental Effect

Photograph 4: Leakage and Dampness

Photograph 5: - Improper/poor drainage pipe

Photograph 6: Horizontal crack due to shrinkage



Photograph 7: Joint of column-wall and Beam-wall (Diagonal cracks)

Photograph 8: Near vegetation (Diagonal cracks)

Photograph 9: Flooring/ Improper leveling

Photograph 10: Beam-wall / Vertical crack (Expansion joint)

Photograph 11: Beam-wall (Horizontal crack)

Photograph 12: Lack of maintenance

1) After classification of Distresses and Defects, some NDT tests and chemical tests are performed to analyze the distresses and look for their possible solutions.
2) Then find out repairing work and testing after repairing.

NDT Test and Chemical Test

In present conditions Nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system. In other words, when the inspection or test is completed the part can still be used. These conditions are usually inspected and restored only when the embedded steel is highly corroded, followed by cracking and spalling of concrete [1]. Quality of structure can be maintained by Continues monitoring and conducting periodic surveys. In order to protect rusting and erosion of steel in reinforced concrete structures, few of the major non-destructive techniques are proposed in this study [1]. Chemical tests provide main information on the causes of failure of concrete after the analysis of the concrete structure.

4.1 Rebound Hammer Test

Rebound Hammer Test is used to determine the compressive strength or hardness of hardened concrete [8]. The reading is very sensitive due to local variation in the concrete, especially to aggregate particles near to the surface. For testing, smooth, clean and dry surface is to be selected. If the loosely adhering scale is present, this should be rubbed off with a grinding wheel or stone [8]. The point of impact should be at least 20 mm away from any edge discontinuity [8]. The plunger is released before use and then it pressed strongly and vertically or perpendicular to the concrete surface and locked in its position. Take the scale reading on the side window of the hammer, this reading is known as the rebound number. Repeat the all test value to the different point. Compressive strength can then be found using a calibration graph of Compressive strength v/s Rebound (Rebound Hammer conversion chart) as shown in fig.2

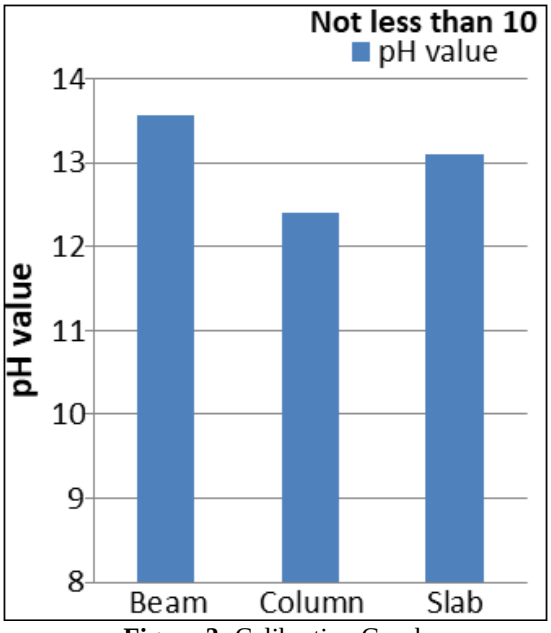


Figure 3: Calibration Graph

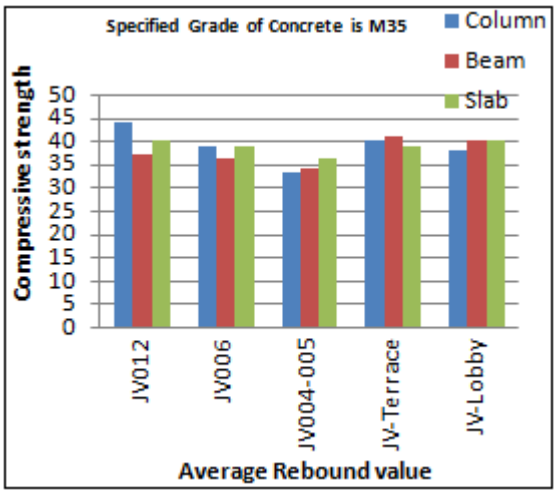


Figure 4: Graph of Rebound number v/s Compressive strength

Rebound hammer (Anvil for concrete test hammer type-N&NR), HT225.

4.2 Crack Depth Measurement

The crack is measured in width, length, and depth and approximate crack size during visual surveys. Depending on the width of crack, these are classified as follows:

Table I: Classification of crack

Classification	Crack width
Thin	<1mm
Medium	1mm to 2mm
Wide	>2mm wide

4.3 The depth of Carbonation

The carbonation test is performed by drilling a hole on the concrete surface up to the concrete cover. Remove the dust by brush and Blow the air to clean the hole. Spray 0.2% solution of the phenolphthalein with injection syringe through broken/hole concrete and observe the change in color. Measure the depth of the uncolored layer (carbonated layer) in millimeters from the external surface at 6 to 8 positions. Take the average of measurement.

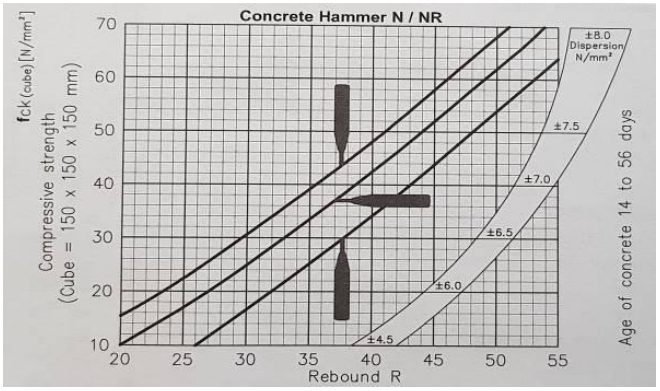


Figure 5: pH Value (Taken average value of beam, column and slab)

The depth of carbonation is proportional to the square root of time. I.e., if the depth of carbonation is 1 millimeter in

one-year-old concrete, it will be 3mm after 9 years, 5mm after 25 years and 10mm after 100 years.

We can also determine the pH value by analyzing the sample of core powder collected by drilling from the site. It is determined by dissolving the powder sample in distilled water and thereafter titration in the laboratory.

4.4 Determination of Chloride

Steel is protected by the concrete cover and self-generated protective layer after cement hydration. When the chloride attacks on concrete, it destroys the protective layer and corrosion starts and reduces the strength & serviceability. Corrosion is like cancer, if not attended in time, it can cause a serious problem. Chloride determination test is conducted to know the number of chlorides present in concrete. The presence of a higher amount of chlorides results in corrosion of rebar. The permissible limit of the test is 0.6 kg/cum [9]. IS: 14959 (part- III) – 2001, prescribe the procedure of determining chloride content in concrete.

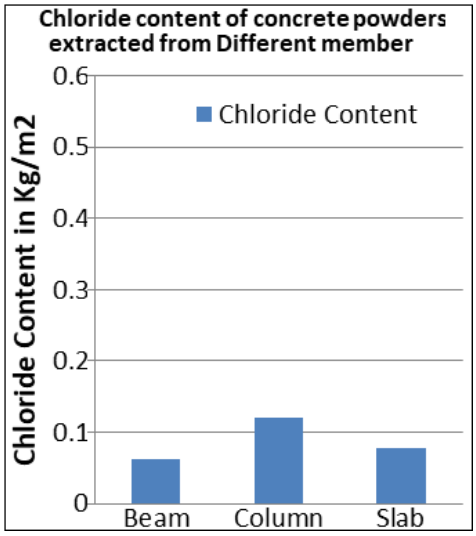


Figure 6: Chloride content of concrete (Taken average value of beam, column and slab)

4.5 Determination of Sulphate

Sulfate determination test is conducted to estimate the amount of Sulphate present in concrete. The presence of a higher amount of Sulphate will result in causing deterioration of concrete due to the reaction of calcium with the excess Sulphate present. The quantity of Sulphate in concrete is expressed as the percentage of Sulphate by weight of concrete. The permissible limit of the test is 4.0% [BS1881: Part 124:1988]

4.6 Cover Meter Measurement

Cover Meter measurement used for the reinforcement is to protect it from corrosion. As per IS: 456-2000 (Table 16), the minimum nominal cover required to meet durability requirement are given below:

Table 2: IS: 456-2000(Table 16)

Exposure	Minimum nominal cover(mm)
Mild	20
Moderate	30
Severe	45
Very severe	50
Extreme	75

A cover meter is used to measure existing cover thickness in specific locations, reinforcement diameter, and spacing of reinforcement. The test result is interpreted as under:

1) The required cover thickness and good quality concrete: Not corrosion
2) The required cover very thickness and bad quality concrete: Corrosion
3) The required cover very less thickness yet very good quality concrete: Corrosion

5. Result and Analysis

The Bar chart (Figure: - 4) was prepared based on the results obtained from the Rebound Hammer Test conducted on selected structural members of the building and a few locations of Beam, Column and Slab. The results were concluded in reference to Calibration graph (Figure: - 3).
From the test results of carbonation test, the initial corrosion of reinforcement in beam, column and slab is being observed. Generally the pH value of fresh concrete was around 12-14 and if pH value falls below 10 then it shows the initial stage of corrosion in reinforcement. The pH test values are shown in Figure: - 5.

The results of crack depth measurement shows the wide cracks at beam/column to wall joints, medium cracks above doors and windows due to lintel is not provided and thin cracks due to drying shrinkage and thermal expansion which are shown in above photographs.

The test results obtained after chloride content test are within considerable limits so that chloride was not the reason for corrosion. The values of test result are shown in Figure: - 6.

The test of cover meter measurement in slab cover thickness and quality of concrete is good, which show no corrosion; beam cover has less thickness and quality of concrete is good, which show Initial corrosion and column cover has very less thickness and quality of concrete is medium, which show corrosion.

As per the CPWD handbook buildings are classified into various classes according to their distresses and structural damage. After test results it is concluded that this domain falls into class-2 which shows the minor structural cracks and initial carbonation in structure, for which minor structural repairing and crack sealing should be done.

6. Repairing and Assessment Work

6.1 Replacing the Floor Tiles

The damaged tiles are removed and the flooring was compacted properly to remove air voids then new tiles were laid in level with cement paste. The popping up of terrace flooring cannot be repaired .It has to be removed and replace

by another flooring and by sealing the joints to make it water proof. So, that moisture or damp air cannot be infiltrate inside the flooring.

In Cement paste add waterproofing admixtures like waterproofing adhesive, its brand name Zentrival PL and Zentrival HS. It is polymer based water proof tile adhesives used for better bond, adhesion, strength, faster work and good waterproofing quality [IS : 2645-1975].

6.2 Concreting work for open at top reinforcement

Prepare fresh concrete and fill all column open reinforcement and also bar should be properly adjusted and placed for future expansion of building.

6.3 Treatment of Dampness on wall

For internal wall bituminous emulsions painting, water proofing solution painting and applying cement wash. For external wall remove vegetation near building, coating with boiled linseed oil as well as use bituminous painting, cement wash and also such type of solutions used for water proofing for external side of building.

6.4 Treatment of Termite

For Termite treatment first of all, holes are drilled at 30cm c/c at a downward angle of 45º from both the sides of the external wall at plinth level and the chemical emulsion is pumped in these holes under pressure. Chemicals used for termite treatment are Aldrin, Heptachlor and Chlordane.

6.5 Treatment of expansion joint

In view of leakages from the expansion joint, it is recommended to clean the joint and fill it with Polyurethane sealant and redo the portion as per IS 5256-1992 provisions.

6.6 Repairing of Cracks between RCC and Masonry Joints

First remove the plaster of cracking portion. The edges are cut square or rectangular shape. Clean the surface with wire brushes, blow with air and wash it with water. It is very important to evaluate the cracks between RCC and masonry joint and then adopt crack filling methods.

Epoxy Injection: Filling cracks with epoxy grout like Dr. Fixit Epoxy Injection Grout.

Grouting and Sealing: Sealing cracks with the flexible sealant like Dow Corning(R) Contractors Concrete Sealant. (Silicon sealant)

Stitching: Stitching the cracks with epoxy adhesives like 3M Synthetic Resin Adhesive and Araldite Standard Epoxy Adhesive.

Polymer Impregnation: Impregnations of the polymer into cracks with polymer mortar like Dr. Fixit Polymer Mortar PX and Dr. Fixit Polymer Mortar HB

6.7 Repairing of Joint cracks of Column-Wall

Cracks usually occur at the junction of concrete column, beams and wall surface finish. People use to attach chicken mesh strips of about 6″ width along the probable line of crack just after wall construction. After applying plaster, it would stay longer (15 to 20 year) without cracking.

6.8 Provide Chajja

To prevent the rain water from entering building the chajja is provided. The chajja made of steel are provided with drilling holes into wall and fixing them into that holes.

6.9 Structural damage

Where external structural damage/cracks are happen in external elevation of building, cracks are filled with mortar then stitches are applied. Sometime cracks are small then it was filled with epoxy grouting and also the cracks enlarged in V shape are filled with weak mortar of 1:2:9 proportions. Portland cement mortar is used for repairing work of structure damages and small defected areas. Portland cement mortar consists of OPC grade cement, clean water and clean graded sand. For repairing Old hardened concrete defects the polymer modified cement mortar is used. The large area repairs with thickness in excess of 50mm, mortars consisting of cement, sand, water and polymer like polymer latexes, liquid resin and water soluble polymer are used.

6.10 Congenital defect

Improper load transmit system, lintel are not provided etc. which are include in congenital defect for improper load transmit system increases width of column or provide extra column. Provide shade on window where lintel is not provided.

6.11 Repair the gap between door frame & wall and window frame & wall:

Door frame/window frame and wall gap filling with the help of joint sealants water proofing chemical. Water proofing chemical is Nitoseal 215(1), Sikalastic and Sani seal. These mortars are consisting of cement, sand, water and Water proofing chemical [IS: 2645-1975].

7. Conclusion

In this domain Smt. S. R. Patel engineering college, the major problems are found termite, RCC-Wall joint cracks, a many of Beam-columns joint had vertical cracks line to line of concrete (column), above door and window horizontal crack due to lintel is not provided and flooring settlement. In this paper different types of cracks like vertical cracks, horizontal cracks, brick masonry cracks and diagonal cracks which are caused due to thermal expansion or contraction

and vegetation in the foundation and also due to the expansion of brickwork and flooring settlement is everywhere at all floor in college building, it is caused during thermal expansion. It is also caused due to less compaction of materials below the floor.

Mainly the problem of termite is observed everywhere in the building. The main reason for this is that it is agricultural land and termite is found in mostly agricultural land. Chemical test analysis classified the test results of carbonation test, sulfate test and chlorination test, the initial corrosion of reinforcement in beam, column and slab is being observed. It can be seen that detailed visual inspection and Non Destructive Testing (NDT) play an important role in condition assessment of existing buildings. Level of distress can be determined using suitable NDT test along with detailed observation and with proper restoration methods the life period of structure can be enhanced.
The admixtures used in repairing work are polymer modified mortar, water proofing chemicals, Dr. Fixit Epoxy Injection Grout, waterproofing adhesives, Dr. Fixit Crack-X Shrink, Epoxy mortar and Epoxy resins, OPC43 grade cement, specified grade sand and clean water. The present paper focused on the condition assessment, safety evaluation and possible repair and restoration methods for existing concrete structure.

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