REPAIR TECHNIQUES AND REMEDIES FOR STRUCTURAL FLAWS FAILURE IN JUIT

Project Report submitted in partial fulfillment of the requirement for the degree of

Bachelor of Technology

In

Civil Engineering

Under the Supervision of

Assistant professor. Poonam Dhiman

By

Kuenzang Dorji (101650)

To

Jaypee University of Information and Technology

Waknaghat, Solan – 173234, Himachal Pradesh

Certificate

This is to certify that project report entitled "**REPAIR TECHNIQUES AND REMEDIES FOR STRUCTURAL FAILURE AND FLAWS IN JUIT**, submitted by *Kuenzang Dorji (101650)* in partial fulfillment for the award of degree of Bachelor of Technology in Civil Engineering to Jaypee University of Information Technology, Waknaghat, Solan, India has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Date: **Assistant Prof. Poonam Dhiman**

ACKNOWLEDGMENT

I would like to take this opportunity to express our sincere gratitude and thanks to my M.Tech seniors Aditya Tiwari and Nikita Gupta in the progress of the project entitled "REPAIR TECHNIQUES AND REMEDIES FOR STRUCTURAL FLAWS FAILURE IN JUIT". Of all the persons who helped me, I would first of all like to thank Assistant Prof. Poonam Dhiman, under whose able guidance I have worked on this project.

Date: **Name of the student:**

Kuenzang Dorji(101650)

B.Tech (CE)

Jaypee University of Information Technology

CONTENT

List of Figures

List of Tables

Abstract

Even though Jaypee University has excellent structures that are made of highest level and maintenance of all the structures in and around are maintained it was evident that no concrete structure is free from environmental factors and human error. So in this project I intend to recommend solutions and remedies for such concrete and masonry structural failure and help the university.

The first chapter is based on the formation of calcium carbonate efflorescence on roof slab of the first floor of the academic block It is situated in hilly area and due to orographic precipitation the weather here is rainy. Therefore buildings may face problem of dampness and water leakage. Due to large diurnal temperature variation and alternate wetting and drying conditions, cracks appear on the surface of concrete.

A crack was observed at the time of placement of conduits pipe after casting of the slab. Pipe was concealed using a rich mix of mortar. Here the defect has been appeared due to the internal cracks in concrete slab. Water percolating from this crack is creating appearance of white scales on the repair work and this is ruining the appearance of slab too. This defect on the slab was due to calcium carbonate efflorescence. In this paper, remedies for the presented calcium carbonate efflorescence are suggested. The internal cracks in concrete slab are believed to be the prime cause of this type of defects. In hilly area, due to orographic precipitation, moisture content in this region is high and the buildings here may face the problem of dampness and water leakage. A white scaling with percolating water is observed under roof slab in the academic block (1^{th} floor) of JUIT, Waknaghat. The prime cause of white scaling (as shown in Fig.1 and 2) defect was a chocking of conduits pipe after casting of slab due to any weight and at the time of wiring these chocked pipes are replaced by new ones. It is observed that during the chiseling of concrete slab for replacement of conduits pipe, the internal cracks has been appeared in the slab. On that repair position a whitish material (lime) appeared. It may be due to any type of efflorescence. Due to water percolating under roof slab, reinforcement may be corroded. Carbonation test was performed to rule out corrosion. So from tests results and inspections the

remedies for such problems and the actual remedy for this case are discussed in detail in the chapter.

The second chapter is based on the de-lamination of shear wall cover and also the cracking along the entire length of the column of a building in C4 block of the faculty residence. Even though the causes of these failures were unknown, survey of the entire structure, inspection and its history and compression with seismic failure of concrete structure rules out failure due to earthquake. However failure due to carbonation was kept in mind and inspection and tests are carried out, there was no sign of chemical attack therefore it was a much easier for finding out the remedies and solutions compared to chapter one in which efflorescence caused a leakage of water in the structure. The remedies are mentioned in detail in the chapter.

INTRODUCTION

Jaypee University of Information Technology is recognized by the state government of Himachal Pradesh, India. It was set up by Act No. 14 of 2002 vide Extraordinary Gazette notification of Government of Himachal Pradesh dated 23 May 2002. JUIT was approved by the University Grants Commission under section 2(f) of the UGC Act, the University commenced academic activities from July 2002.

The university is located 3 kilometers off National Highway 22 (20 km from Shimla) (from Waknaghat) which runs from Kalka to Shimla (India). The campus is spread over 25 acres (100,000 m^2) of the green slopes of Waknaghat. The town of Kasauli can be seen from the university on one side, far on the hill. Though the university campus can be reached by taxi cabs and autorickshaws available at University Gate and Waknaghat. The nearest railway station is Kaithleeghat, 4 kilometers from Waknaghat and the nearest airport is Shimla. Regular bus service is available to Chandigarh, Delhi and most major stations of Himachal Pradesh and Punjab at Shimla and Solan bus stations.

This project is based on all the failure of structures that are within the university and also nearby areas. It is necessary to find the problems that need attention and perform the surveys that include visual inspection, photographic survey, necessary in-situ and laboratory test that will help me determine the cause of failures and then perform researches that will help me determine solutions and remedies for these problems. Finally I will suggest these solutions to the maintenance department and the university through my project to help this university maintain its beautiful campus for years to come.

Failures are mainly in concrete. Concrete construction is generally expected to give trouble free service throughout its intended design life. However, these expectations are not realized in many constructions because of structural deficiency, material deterioration, unanticipated over loadings or physical damage. Premature material deterioration can arise from a number of causes, the most common being when the construction specifications are violated or when the facility is exposed to harsher service environment than those expected during the planning and design stages. Physical damage can also arise from fire, explosion – as well as from restraints, both internal and external, against structural movement. Except in extreme cases, most of the structures require restoration to meet its functional requirements by appropriate repair techniques.

Construction documents contain adequate specifications and instructions required to execute quality works. However, they remain as written document without achieving the desired level of results, because of lack of understanding of their significance by the field engineers. Standard cube test results are taken as a measure of quality in the construction. Whereas the factors such as method of placing, compaction and curing of concrete, which have significant influence on the quality achieved in the hardened concrete, are given scant attention. Many a times, the quality of concrete as placed and hardened in position has no correlation to the cube test results, which are used for quality control measures. Procedures, mandatory or otherwise, for periodic inspection of buildings and structures and documenting defects, like cracks, excessive deflections, corrosion of reinforcement etc., in logical manner, and recording of structural repairs already carried out, are generally not followed or maintained. In some buildings, only visual inspection is carried out for preparing maintenance budget estimates and this exercise is often left to the engineers who have no experience in such problems

The main structural failures that I found were formation of efflorescence and water leakage through the roof slab of the first floor of the academic block in the electronics department. Due to this problem few cabins for the faculty is made unusable. Some of the other structural failure are delamination of shear wall in the faulty residence of C4 block and along with it a column along the edge of the had cracks expanding to the entire length of the structure. However it was unsure from the visual inspection weather the cracks were extending into the reinforcement. It is so because the structures here in JUIT were constructed to the highest level and all the columns and shear walls had thick masonry covers. So carful photographic survey, tests are performed to determine the depth of carbonation, chemical attack, failure due seismic activity, environmental factors and water seepage and leakages that could have caused these problems. Also there was concrete slab which are showing signs of shear failure, further I will look for failures that need attention.

Concrete constructions require proper care in the form of regular maintenance. Buildings remain for several years without getting due attention. Water stagnation, paint pealing, plaster break- off, fungus growth, cracking of external rendering and cover concrete are common and widespread. Penetration of moisture into reinforced concrete components promotes corrosion process and further damages the concrete cover. The engineers responsible for maintaining buildings often begin repair activity without adequate understanding of the factors responsible for the defects. The repairs strategy adopted is replacement of damaged materials without dealing with the real problems. Many engineers unintentionally attempt treating the symptoms, instead of dealing with the cause and effect phenomenon. Such an approach may offer a quick action with minimum inconvenience to the occupants. But in this process, there is a strong possibility that the source and cause for the distress remain unattended and continue to cause problem even after the superficial repairs have been executed. If structural defects are dealt with in this fashion, it remains only as defects camouflaged beneath finishes, which gives a false sense of safety to the occupants allowing the problem to continue without getting treated. A rational approach to any repair and rehabilitation work is to consider the source of the problem and the symptoms together.

Distress identification

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 behavior of 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.

For this project I followed strict guidelines from the repair text books for providing the remedies and tests that were specific for different problems.

Repair Management

Three distinct stages are to be recognized while taking up a repair job. The first stage involves documentation of damage, its type and extent, prognosis of repaired structure and recommendations on repair methodology. For major jobs it will be worth while to engage an independent consultant to do this job.

The second stage requires preparation of detailed drawings, sketches, execution guidelines and notes, material and works specifications and tender document. The tender document should adequately cover various elements to the extent possible. Specific provisions in terms of material specifications should be included. It should clearly define modalities of payment, works measurements and records. This will facilitate in receiving a fair and competitive proposal for the repair works. Guidelines prepared for executing the job should be practical and flexible so as to encourage the ingenuity of the contractor executing the job.

The third stage is actual execution of repairs. This is a specialized job and those who have the necessary expertise and resources in terms of tools and plants should be engaged. The supervising engineer should have a good understanding of the procedures and give an attentive supervision. In some cases it may become necessary to monitor the effectiveness of repairs by various tests before and after the repairs have been executed. Various options in terms of techniques and repair materials are available for executing repair jobs. Selecting a most appropriate material and repair methodology is very important to achieve durable, effective and economic repairs. Matching the response of repaired sections with the main structure is an important task. Compatibility of materials and matching specifications are essential in any repair job. Just as building durable construction requires understanding of structural engineering, material science, and environment/ exposure conditions, repair jobs also require the same level of attention in these areas. The buildings taken up for repair may have structural deficiency and in such cases it is necessary to consider provisions for strengthening through bracing and creating alternative load transfer framing to give additional reserve strength to the structure for adequate safety and serviceability

Three distinct stages are to be recognized while taking up a repair job. The first stage involves documentation of damage, its type and extent, prognosis of repaired structure and recommendations on repair methodology. For major jobs it will be worth while to engage an independent consultant to do this job. The second stage requires preparation of detailed drawings, sketches, execution guidelines and notes, material and works specifications and tender document. The tender document should adequately cover various elements to the extent possible. Specific provisions in terms of material specifications should be included. It should clearly define modalities of payment, works measurements and records.

This will facilitate in receiving a fair and competitive proposal for the repair works. Guidelines prepared for executing the job should be practical and flexible so as to encourage the ingenuity of the contractor executing the job. The third stage is actual execution of repairs. This is a specialized job and those who have the necessary expertise and resources in terms of tools and plants should be engaged. The supervising engineer should have a good understanding of the procedures and give an attentive supervision. In some cases it may become necessary to monitor the effectiveness of repairs by various tests before and after the repairs have been executed.

Various options in terms of techniques and repair materials are available for executing repair jobs. Selecting a most appropriate material and repair methodology is very important to achieve durable, effective and economic repairs. Matching the response of repaired sections with the main structure is an important task. Compatibility of materials and matching specifications are essential in any repair job. Just as building durable construction requires understanding of structural engineering, material science, and environment/ exposure conditions, repair jobs also require the same level of attention in these areas.

The buildings taken up for repair may have structural deficiency and in such cases it is necessary to consider provisions for strengthening through bracing and creating alternative load transfer framing to give additional reserve strength to the structure for adequate safety and serviceability response. If this aspect is overlooked, the symptoms are likely to reappear even after repairs have been carried out.

Familiarity with repair methodology and repair materials is very essential. General civilen1gineering practice does not offer much scope in this area. The engineer undertaking such specialized jobs should have good knowledge of new materials, repair methodologies, its limitation and the fundamentals of structural engineering to ensure safety and serviceability of the buildings during repair and thereafter.

Keeping all these process of repair management all the survey and testing were carried out carefully under the guidance of my project guide. In the future to I will continue to find structural related problems within the campus or outside of campus and find solutions on such problems.

The majority of the areas of Himachal Pradesh lie in Zone V and the few lies in zone IV. This state is very close to the fault line separating the Indo-Australian and the Eurasian plate. Record of past 50 years has verified the above statement. Large earthquakes have occurred in all parts of Himachal Pradesh, the biggest was the Kangra Earthquake of 1905. It had a moment magnitude of 7.8 and at least 28,000 people were killed in the Kangra Dharamsala region of Himachal Pradesh. Another earthquake which took place near Kullu (H.P) on 28 February 1906, with a moment magnitude of 6.4. Damage and casualties were caused in the Bashahr-Shimla hill states. Besides these there are scores of smaller faults, like the Kaurik Fault which triggered the 1975 earthquake with a moment magnitude of 6.8. This earthquake struck in the early afternoon of January 19, 1975. It caused havoc in parts of the Kinnaur, Lahaul and Spiti regions of India. 60 people were killed in this sparsely populated region

Solan district presents an intricate mosaic of high mountain ranges, hills and valleys with altitude ranging from 300 to 3000 m above MSL. The altitude of the hill ranges is higher in northern parts whereas south-western part of the district is represented by low denuded hill range.

CHAPTER 1

DEFECT IN REPAIR WORK ON THE ROOF OF ECE DEPARTMENT

Electronics and communication department which is located in the 1st floor of the academic block in JUIT, Waknaghat, solan, HP, previously repair work was carried out in order to replace the conduit pipes which were chocked and water was leaking. The internal cracks in the concrete slab is the main cause of the leakage. JUIT being located in a hilly area faces orographic precipitation. Moisture content is the air is very high and buildings here face the problem of water leakage and dampness. Along with the water percolating from the slab white scales were formed on the on the slab making few of the cabins unusable for the Professors. The white scales were formed after casting of the slab due to chocking of the conduit pipes due to any weight. On those repaired positions white scales (lime) appeared. This could be due to any kind of efflorescence. Due to internal cracks and water leaking from it the concrete might lose its alkalinity and also could be corroded. So necessary tests were carried out in order to make sure that the concrete and the reinforcement was in good health.

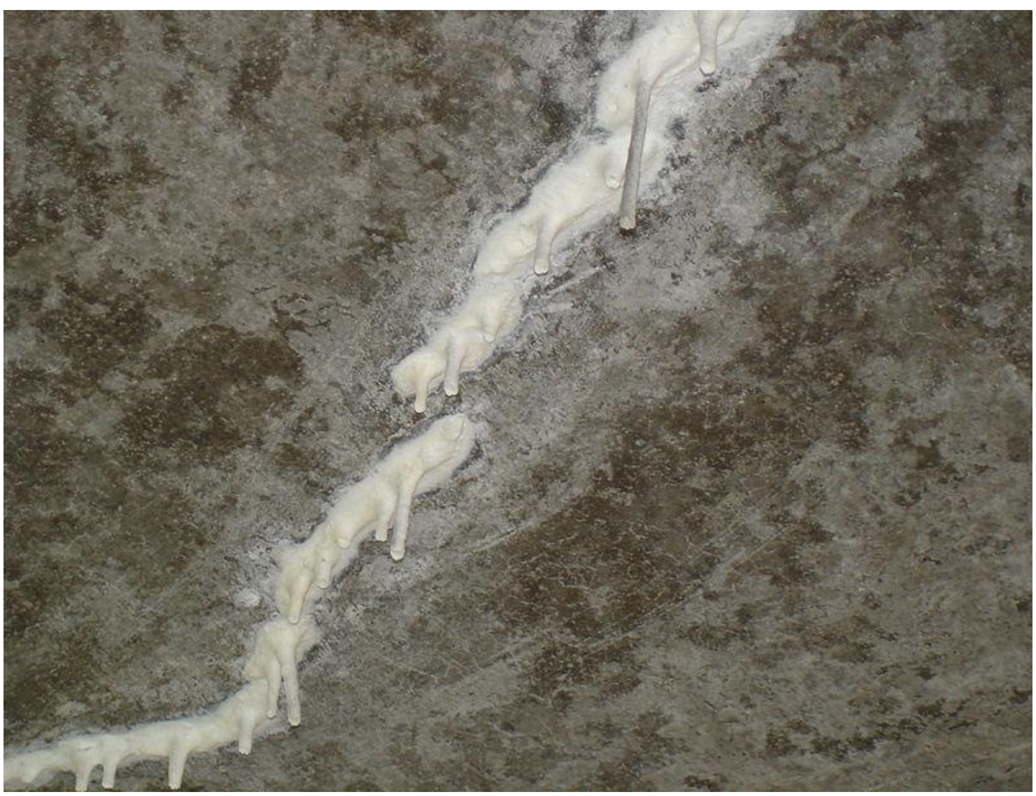

Fig 1 white scales with water percolating from it on the roof of ECE department

1.1 Condition survey and Testing

Condition survey is a examination for the purpose of identifying and defining areas 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.

The objective of the condition survey is:

a) To identify
   - Causes of distress and
   - Their sources;

b) 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;

c) To priorities the distressed elements according to seriousness for repairs and,

d) 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 of cause so as to effectively deal with it and minimize their effects by proper treatment.

There are Four stages of condition survey and they are:

1. Preliminary Inspection.
2. Planning.
3. Visual Inspection.
4. Field and laboratory testing.

The necessary steps and planning of the four stages of condition survey is stated in the flow chart is given below.

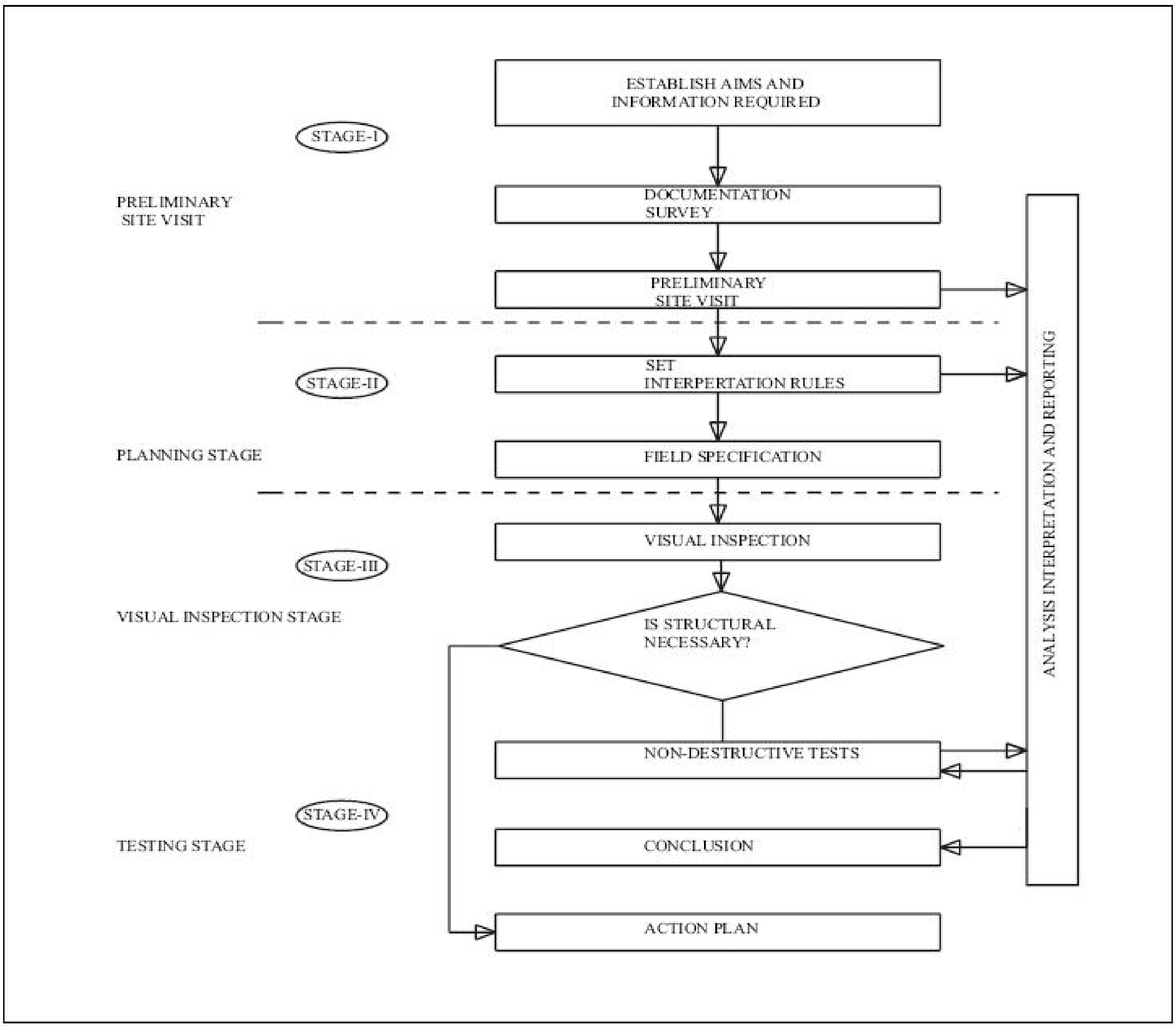

Fig1.1: flowchart showing the process of condition survey.

The entire survey and the inspection was carried out according to the table. Whereby in stage I, when I got my project for this topic , my guide introduced me to this topic and he gave me required information of what was going on and the problems about this topic and visited the site to collect samples and photographs for future tests. In stage II, we had to plan on what caused these problems and what tests might be required for future. From the visual inspection which comes in stage III, we figured out that the cause of this problem was due to chemical attack and due to water leakage. The carbonation and alkalinity test were performed in stage IV to give evidence that the problem occurred to efflorescence.

1.1.1 Preliminary Inspection

Before the full survey is carried out preliminary inspection is carried out to here we find out the history and background of the structure. In JUIT the concrete used was M25 and the repair material used was also of m25. Here I also took the picture of the distressed structure. The structural distress was observed right after the repair work was done for replacement of the conduit pipes for which the concrete along the pipe line was demolished to check for any leakage. The primary objective of this inspection was to assess and collect following necessary information for a thoughtful planning before a condition survey is physically undertaken :

- Background history of the distressed structure from the owners, occupants of the building that is from the teachers from the electronics department and the engineer and the labors involved in the repairing of structure previously.
- Note the records of the earlier repair. That was carried out for the replacement of the conduit pipes.
- I also collected the relevant data such as use of water repelling chemicals in the concrete mortar to prevent the seepage and leakage of water. The concrete used for the repair was M25, same as that of the parent material.

Fig 1.2 Picture survey of the ECE department.

1.1.2 Planning

Planning requires collection of field documents and classification of damage. Field documents couldn't be gathered as there was no record in the hands of the maintenance crew and the engineer. However Mr. Dinesh Kumar gave me an insight into the timeline of the repair and occurrence of the structural distress. From the information gathered I freezed the repair as patch repair under the repair classification of Repair and Rehabilitation text book.

Class of Damage	Repair Classification	General observation on the condition of the concrete	Repair requirements
Class 0	Cosmetic repair	Only final finishes are disturbed.	Redecoration if required.
Class 1	Superficial repair	Final finishes/skin only damaged. No structural	Superficial repair of slight damage to non

		cracks observed. Carbonation depth has not reached the reinforcement level yet.	structural finishes.
Class 2	Patch repair	Minor structural cracks observed. Carbonation depth has reached reinforcement level.	Non structural or minor structural repair limited to crack sealing and restoring the lost concrete cover. If due to corrosion any reinforcement has been effected. Carbonation resistant protective coating should be used.
Class 3	Principle repair	Spalling of cover concrete, major structural cracking along reinforcement due to corrosion leading to substantial reduction of load carrying capacity.	Strengthening repair to reinforced concrete in according to the load carrying requirement of the member. Concrete strength may be extremely low and reinforcement diameter may have been reduced requiring check by design procedure. Make up reinforcement may be provided.
Class 4	Major repair	Major structural loss necessitating replacement of	Major strengthening repair ignoring the original concrete

		structural member.	reinforcement or demolition and recasting.

Table 1: Classes of Damage and Repair Classification

Cracks were observed in the slab and water was leaching from it so it falls into class 2 “patch repair” of the classification. The necessary tests have to be carried out to determine whether the reinforcement bars are corroded or not. The tests are carbonation test and alkalinity test.

The necessary solutions or repair technique as suggested for patch repair is crack sealing and restoring the lost concrete cover. If due to corrosion any reinforcement has been effected. Carbonation resistant protective coating should be used. However further tests and researches should be carried out in order to determine the actual remedies and repair technique.

Patch repair work involves crack sealing and restoring the lost concrete cover. If due to corrosion any reinforcement has been effected. Carbonation resistant protective coating should be used but however this repair technique may not be applicable in our case because the leakage of water was from the conduit pipes and actual repairmen of the conduit pipes were necessary before carrying out crack sealing. It is necessary that the conduit pipes were replaced and reinforcement was checked for corrosion and the concrete for carbonation. So major repair of the structure maybe needed whereby we might have to replace the entire slab, it can be only determined from the tests results of carbonation and alkalinity tests which are stated below.

So I planned on visiting the site and determine the level of damage and take samples if needed. This could help us determine the actual solutions for the damage and tests that were required.

1.1.3 Visual observation

The following were observed on the slab of Electronics department.

1. The color of the cement motor used after replacement of the chocked conduit pipes was different than the original color of the slab.
2. Formation of white unappealing scales was observed on the surface of the slab.
3. Water was leaking from the surface of the white scales which were hollow from inside, appearing like a pipe.

Further explanation of the visual observation:

1. The color of the cement mortar used after the replacement of the chocked conduit pipes was different from the original slab. On talking with Mr. Dinesh Kumar, junior engineer of the maintenance department of the JUIT he said that the water resistant material was used in the cement water to stop the leakage of water.

2. The formation of this whitish material was due to calcium carbonate efflorescence. A few of the lecturers cabin were made unusable because of the continuous leakage of water from the roof. He even concluded that the chocked conduit pipes could not be replaced as the conduit pipes were placed inside reinforcement bars and for replacing it they would have to cut the reinforcement bars which would lead to dismantling the entire slab.

3. Water was leaking from the slab because the above the department is a terrace which had no outlet for rain water that might collect and even the conduit pipes were placed inside the slab, so it could even be due to leakage of water from the conduit pipes. Even after using water resistant material in the cement mortar, water was leaking from the conduit pipes and white scales were formed on the surface of the concrete. This was due to Efflorescence. The white scaling rose on the surface due to presence of some water soluble salts in water, cement, sand, lime or clay, if used. Even rain water carry dissolved sulphates from the air which may percolate into concrete or plaster. These salts get dissolved in moisture present in mass of concrete, plaster or masonry. The water serves as carrying agent for the salt to bring them to the surface of concrete. At the surface of concrete, the water evaporates into air but salt cannot vaporize under normal

conditions hence it gets deposits onto the surface which causes these white spots on the surface. From Fig.1.1 and the slab defects are clearly visible; the whitish bloom material has appeared on the repaired position of slab. Dropout of whitish bloom material on floor due to continue water leakage in slab. To find out the type of material which has appeared on the surface of defective slab, alkalinity test of material was performed.

1.1.4 Field and Laboratory Testing.

Objective:

1. It may neither be feasible nor is the practice to conduct field/laboratory testing on every structural member in an existing distressed building.

2. The field/laboratory testing of structural concrete and reinforcement is to be undertaken, basically for validating the findings of visual inspection.

3. These may be undertaken on selective basis on representative structural members from each of the various groups based on exposure conditions as explained in the preceding sections.

4. The program of such testing has to be chalked out based on the record of visual observation.

In our case the damage is due to chemical attack. So the necessary tests for chemical attack are:

1. Carbonation Test :	It is a field/ lab test for determining the Ph of concrete and depth of carbonation.
2. Alkalinity Test :	To find out the total alkalinity caused by CO_3^- , HCO_3^-, and by OH^-. And a very little alkalinity caused by H^+.
3. Chloride Test :	A field / lab test for assessment of water and acid soluble chlorides in the concrete.

4. Sulphate Test :	A lab /field test for determining the assessment of water and acid soluble sulphate contents of concrete.

Table 2: Tests for Chemical Attack on Concrete.

From all the four tests mentioned above the necessary test that we need to perform in our case are carbonation test and alkalinity test because the white scaling material formed on the roof slab of the electronics department was due to formation of efflorescence and efflorescence is mainly formed due to carbonation in the concrete.

Non Destructive Testing

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 nondestructive 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/Soundness.

1. In-situ concrete strength

Rebound hammer test

The operation of Rebound Hammer (also called Schmidt’s Hammer) is illustrated 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 below.

2 Chemical attack

Carbonation test

This test is carried out to determine the depth of concrete affected due to combined attack of atmospheric carbon dioxide and moisture causing a reduction in level of alkalinity of concrete. A spray of 0.2% solution of phenolphthalein is used as pH indicator of concrete. The change of color of concrete to pink indicates that the concrete is in the good health, where no change in color takes place, it is suggestive of carbonation-affected concrete. The test is conducted by drilling a hole on the concrete surface to different depths up to cover concrete thickness, removing dust by air blowing, spraying phenolphthalein with physician's injection syringe and needle on such freshly drilled/ broken concrete and observing the color change. The depth of carbonation is estimated based on the change in color profile. The PH value can also be determined by analyzing samples of mortar collected by drilling from the site, dissolving the same in distilled water and thereby titration in laboratory.

Chloride test

Chloride content can be determined from broken samples or core samples of concrete. Primarily, the level of chloride near the steel-concrete interface is of prime importance. Chlorides present in concrete are fixed (water insoluble) as well as free (water soluble). Though it is the water soluble chloride ions, which are of importance from corrosion risk point of view, yet total acid soluble (fixed as well as free) chloride contents are determined and compared with the limiting values specified for the concrete to assess the risk of corrosion in concrete. The total acid soluble chlorides are determined in accordance with IS: 14959 Part III 2001, whereas for assessment of water soluble chlorides the test consists of obtaining the water extracts, and conducting standard titration experiment for determining the water soluble chloride content and is expressed by water soluble chloride expressed by weight of concrete or cement. The method gives the average chloride content in the cover region. Further, a chloride profile across the cover thickness will be a more useful measurement as this can help to make a rough estimate on chloride diffusion rate. One recent development for *field testing* of chloride content includes the use of chloride ion sensitive electrode. This is commercially known as “Rapid chloride test kit-4”. The test consists of obtaining powdered samples by drilling and collecting them from different depths (every 5 mm), mixing the sample (of about 1.5 gm weight) with a special chloride extraction liquid, and measuring the electrical potential of the liquid by chloride-ion selective electrode with the help of a calibration graph relating electrical potential and chloride content, the chloride content of the samples can be directly determined.

1.2 Efflorescence

Efflorescence by definition is a fine, white powdery deposits of soluble salts left on the surface of masonry or concrete as water evaporates. It is also defined as leaching of lime compounds leading to formation of calcium carbonate or calcium sulphate on the surface of concrete as water evaporates. These efflorescence salt deposits tend to appear at the worst times, usually about a month after a building is constructed, and sometimes as long as a year after completion. In this case, the cause of white is scaling on repair patch is calcium carbonate efflorescence.

Research has shown that the main source of soluble salts most likely comes from the cement used in mortars and grouts. It recommended that low alkali cement be used to help reduce the chances of efflorescence occurring in masonry construction and concrete.

1.2.1 Types of Efflorescence

There are two types of efflorescence that can occur on any concrete or masonry structure and they are:

- Lime Boom: It appears as white patches on an overall lining of the surface of concrete. This is a construction problem.

Fig 1.3 Lime boom efflorescence

Fig 14 Lime weep efflorescence

- Lime Weeping: it is caused by water leaking through the concrete and dissolving calcium hydroxide from the matrix. On contact with the atmosphere the calcium hydroxide reacts with carbon dioxide to form calcium carbonate, which is precipitated on the surface when water evaporates. Generally at the cracks or joints, serious leakage may be symptomatic of a more severe problem and can lead to durability problems.

  This is the case here in JUIT. Since in hilly area due to orographic precipitation, moisture content in this region is high and the buildings here may face the problem of dampness and water leakage.

1.2.2 Source of Efflorescence

For the process of efflorescence to occur, four things must be present,

1. Salts
2. Physical forces
3. Moisture
4. Opening

Salts: Quantities of water-soluble salts as small as a few tenths of one percent are sufficient to cause efflorescence. The primary source of salts is the calcium hydroxide $Ca(OH)_2$ from hydrated cement. The calcium hydroxide is a by-product of the cement curing process. It can dissolve in water and migrate to the surface of the wall where it remains when the water evaporates. The calcium hydroxide crystals then react with carbon dioxide (CO_2) in the air to form calcium carbonates ($CaCO_3$).

Physical Forces: Efflorescence is particularly affected by temperature, humidity, and wind. These physical forces, as well as others, can increase the absorption of water that leads to efflorescence. For example, wind can force water into a building substrate and its movement over the surface of a building can create pressure differentials that cause the water to move upward. Also, capillary action can cause water to move upward and laterally within a substrate. Hydrostatic pressure present under below-grade slabs and behind below- grade retaining walls can also cause water movement. Additionally, temperature gradients across the wall can drive moisture into or out of the wall.

Moisture: -Water is the vehicle that dissolves and transports the salts to the surface. Possible sources of moisture may include precipitation, water vapor from the interior, poorly aligned sprinklers, or ground water migration.

Opening: - Cement based products such as stucco are naturally porous and thus have numerous capillaries or pathway for water to move through them, these includes hairlines cracks, voids caused by shrinkage, bug holes and improper building designs. Together these four factors result in efflorescence appearing on the surface of a wall, concrete, masonry.

1.2.3 Primary Efflorescence and Secondary Efflorescence

Primary Efflorescence: Primary efflorescence typically occurs during the initial cure of masonry construction, particularly brick, as well as some mortars, when water moving through a wall or other structure, brings salts to the surface. As the water evaporates, it leaves the salt behind, which forms a white, fluffy deposit, that can normally be brushed off. Since primary efflorescence brings out salts that are not ordinarily part of the cement stone, it is not a structural, but, rather, an aesthetic occurrence.

Secondary Efflorescence: Secondary efflorescence does not occur as a result of the forming of the cement stone or its accompanying products. Rather, it is usually due to the external elements, such as chlorides. A very common example would be steel-reinforced concrete bridges as well as parking garages. Saline solutions are formed due to the presence of road salt in the winter. This saline solution is absorbed into the concrete, where it can begin to dissolve cement stone, which is of primary structural importance. Efflorescent stalactites can be formed as a result, causing structural integrity.

The type of efflorescence occurring in the 1st floor of academic block in JUIT is due to lime weeping and secondary efflorescence. Effloresce is not a not a very hazardous and dangerous problem unless it occurs in a large scale. Which if it occurs due to neutralization of the alkalinity of the concrete carbonation can take place and the reinforcement may get corroded and can lead to major failure of the structure. So it is always advised to take control of the minor efflorescence from the time of its occurrence by brushing off with steel brushes and making the building can be protected against efflorescence by treating the material with an impregnating, hydro-phobic sealer. This is a sealer which repels water and will penetrate deeply enough into the material to keep water and dissolved salts well away from the surface.

1.2.4 Carbonation and Alkalinity Test

Carbonation test

Carbonation is when calcium hydroxide chemically reacts with carbon dioxide and is converted into calcium carbonate this chemical process is known as carbonation. It occurs not only at the surface, but also deep within the concrete. It generally occurs during cold weather. Its reaction with these hydroxides causes chemical reaction as under (Equation 1 and 2)

$$CO_2 + H_2O = H_2CO_3 \text{ (Acid)} \qquad (1)$$

$$Ca(OH)_2 + H_2CO_3 = CaCO_3 + 2H_2O \qquad (2)$$

(Alkali) (Acid) (Salt) (Water)

Because of these reactions, the alkalinity of concrete gets reduced. This process is called Carbonation of concrete and leads to corrosion of reinforcement. It can be a problem in areas where the concentration of CO_2 is high and relative humidity is moderate (50-60%). Permeable concrete made with low cement content, high water-cement ratio, and inadequately moist-cured tend to suffer from serious carbonation even due to diurnal or seasonal temperature variations.

Figure 1.5 Carbonation Test

From Fig. 1.6 it can be seen that after spraying of phenolphthalein indicator in cracks and in drilled hole, appearance of pink color is observed. It shows the concrete is not affected by carbonation.

Carbonation test is carried out to determine the depth of concrete affected due to combined attack of atmospheric carbon dioxide and moisture causing a reduction in level of alkalinity of concrete. A spray of 0.2% solution of phenolphthalein is used as PH indicator of concrete. The change of color of concrete to pink indicates that the concrete is in the good health, where no change in color takes place; it is suggestive of carbonation-affected concrete. The test is conducted by drilling a hole on the concrete surface to different depths up to cover concrete thickness, removing dust by air blowing, spraying phenolphthalein with physician's injection syringe and needle on such freshly drilled concrete and observing the color change. This test was performed on the defected part of the slab and on white deposits as well. The color turned pink in both the cases. Therefore, it means the concrete is in good health and not affected by carbonation.

The test is conducted by drilling a hole on the concrete surface to different depths up to cover concrete thickness, removing dust by air blowing, spraying phenolphthalein with physician's injection syringe and needle on such freshly drilled/ broken concrete and observing the color change. The depth of carbonation is estimated based on the change in color profile. The pH value can also be determined by analyzing samples of mortar collected by drilling from the site, dissolving the same in distilled water and thereby titration in laboratory.

2. Alkalinity Test

The alkalinity reserve of concrete is a function of proportions of hydroxides of Calcium, Potassium and Sodium present in the hardened concrete matrix, which in turn is directly related to quantity of cement. Higher the cement content, higher the reserve pH of concrete due to increased quantity of such hydroxides of Calcium, Potassium and Sodium. It is observed that excessive quantities of cement content also lead to other related problems due to heat of hydration, shrinkage etc. For this reason, in the codes, the requirements on durability are expressed in terms of minimum cement content, maximum water/cement ratio, and minimum grade of concrete and minimum cover to reinforcement.
The total alkalinity consists of alkalinity caused by CO_3^-, alkalinity caused by HCO_3^-, and by OH^-.
A very little negative alkalinity is also caused by H^+.

$$\text{Total alkalinity} = CO_3^- + HCO_3^- + OH^- - H^+$$

100 ml distilled water was taken and it mixed with 0.2309 gm sample. After that 1 drop of sodium thiosulfate and 2 drops of phenolphthalein indicator was mixed with contents, then it gave pink color. Now the burette was filled with sulphuric acid and titrate the contents with it till the color changed to colorless. Measure the amount of sulphuric acid was consumed. Further 2 drops of methyl orange indicator added with the contents, it gave yellow color then again titrate it with sulphuric acid till the color changed to red and again measure the amount of sulphuric acid that was consumed and calculate the alkalinity of the sample.
Sample was taken from the slab to use in the alkalinity test.

1.2.5 Calculations

Phenolpthalein alkalinity calculation:

Sl. No.	Volume of sample (ml)	Burette Reading		Volume of sulphuric acid (ml)
		Initial	final	
1	100	0	0.6	0.6
2	100	0.6	1.1	0.5
3	100	1.1	1.7	0.6

Table 3: Phenolphthalein alkalinity

Specimen calculation:

Volume of sulphuric acid (V_1) = 0.6 ml

Normality of sulphuric acid = 0.02 N

Volume of sample = 50 ml

Equivalent weight of $CaCo_3$ = 1000

Phenolphthalein Alkalinity = P

$$P = \frac{\text{Volume of } H_2SO_4 (V_1) \times \text{Normality} \times 50 \times 1000}{\text{Volume of sample taken}}$$

P = 0.6×0.02×50×1000/100 = **6 mg/L as $CaCo_3$ equivalent**

Methyl orange alkalinity calculation

Sl. No.	Volume of sample(ml)	Burette Reading		Volume of sulphuric acid (ml)
		Initial	final	
1	100	1	6	5
2	100	6	13	7
3	100	13	19	6

Table 4: Methyl Orange Test

Specimen calculation:

Volume of sulphuric acid (V_2) = 6 ml

Normality of sulphuric acid = 0.02 N

Volume of sample = 50 ml

Equivalent weight of $CaCo_3$ = 1000

Total Alkalinity = T

$$T = \frac{\text{Volume of } H_2SO_4\ (V_2) \times \text{Normality} \times 50 \times 1000}{\text{Volume of sample taken}}$$

T = 6×0.02×50×1000/100 = **60 mg/L as $CaCo_3$ equivalent.**

Result interpretation

Value of P and T	Alkalinity due to		
	OH^-	CO_3^{2-}	HCO_3^-
P = 0	0	0	T=60
P < 0.5T	0	2P=12	T-2P=48
P = 0.5T	0	2P=12	T-2P=48
P > 0.5T	2P-T= -48	2P-T= -48	0
P = T	T=60	0	0

Table 5: Result interpretation.

- If P=0, The Alkalinity due to Hydroxyl and carbonate ions was 0 and alkalinity due to bicarbonate ion was equal to the Total Alkalinity i.e. T = 60 mg/L
- If P < 0.5T, then the Alkalinity due to Hydroxyl ion was 0 and the Alkalinity due to carbonate ion is 2P. i.e. 2P = 12 mg/ L. Alkalinity due to Bicarbonate ion is equal to the Total Alkalinity minus 2 times Phenolphthalein Alkalinity i.e. T -2P = 48 mg/L.
- If P = 0.5T then the Alkalinity due to Hydroxyl ion was 0 and the Alkalinity due to carbonate ion was 2P. i.e. 2P = 12 mg/L. Alkalinity due to Bicarbonate ion was equal to 0.
- If P > 0.5T then the Alkalinity due to Hydroxyl and carbonate ions were 2P-T. I.e. 2P-T = -48 mg/L. and alkalinity due to Bicarbonate ion was 0.
- If P=T, The Alkalinity due to Hydroxyl was equal to the Total Alkalinity i.e. T = 60 mg/L. Alkalinity due to carbonate and Bicarbonate ions were 0.

Based on the test results, it was found that the alkalinity of the sample is 60 mg/L. It was found that the alkalinity of sample is within the range.

1.3 Remedies for Efflorescence

The water evaporates, leaving insoluble salt on the surface. This residue can usually be rinsed off with plain water and soft scrubbing with a medium bristled bush (not wire) The application of a weak acid cleaner and/or abrasion may be needed in more effected areas. Efflorescence arising similarly from sodium or potassium salts is water soluble and thus more easily removed. Care should be taken to use as little water as possible when cleaning. If all of the salts have not been released from the masonry, the addition of more water during cleaning can result in even more efflorescence as the wall dries out again. Storing the masonry prior to construction can help prevent, or reduce the chances of efflorescence occurring in the first place. Be sure to store pallets or units off of the ground, avoiding any contact with potential contaminants. Construction materials should also be covered to help keep the units or panels dry. And, during construction.

It is very difficult to remove efflorescence once it appears on concrete, masonry and wall surfaces. It can be controlled to some degree if factors such as moisture and salts ingress are kept in check. Following are some remedial suggestion for efflorescence:

- Once efflorescence appears on the surface in powder form the first step in removing it is to identify the salt causing it. If the salts are water soluble, the best removal method is with a dry brush.

- If brushing is not successful, then the stain is probably calcium carbonate efflorescence (which is in this case study). It is more difficult to remove. It usually appears as a white “bloom” and in worst cases forms a hard white crust. To remove calcium carbonate, saturating the wall, slab as thoroughly as possible with water then washing with a diluted acid solution following immediately with an alkaline wash, is a good remedy. The acid recommended is 2-5 parts hydrochloric to 100 parts water or 20 parts vinegar to 100 parts water. A diluted solution of household Ammonia is the recommend alkaline wash.

- The building can be protected against efflorescence by treating the material with an impregnating, hydro-phobic sealer. This is a sealer which repels water and will penetrate deeply enough into the material to keep water and dissolved salts well away from the surface.

- A conventional chemical cleaner (muriatic acid) can be used in a mild solution, usually 1 part muriatic acid to 12 part water. After acid cleaning from the masonry the wall should be sealed.
- If cleaning is not effective in removing, then the wall needs to be fog coated. Fog is the blend of cement, water and dry pigments. It should spray onto the wall but unlike paint, it will not chip, peal or fade.

- All soluble alkali sulfates should be reduced

- The structure should be enough damp proof.

- The construction technique should be good to eliminate migratory paths for moisture from top surface**.**

- For the elimination of source of moisture Brush off the surface and apply oil based sealer and paint.

- High pressure steam curing of concrete should be used.

- Efflorescence that is not soluble in water, such as calcium carbonate, may be removed by high pressure water jetting, with possibly adding fine sand to the stream.

- If the composition of the efflorescence is unknown, washing with acid as for insoluble efflorescence is usually effective and it should be preferable to first try dry-or wet-brushing.

- The concrete permeability and concrete's exposure to wetting and drying cycles should be minimized by using specific admixtures.

- Moisture control is the key to reducing efflorescence. Moisture transfer inside and out of the concrete is essential for efflorescence formation. Therefore, concrete should be protected from wetting and drying during construction.

- Care should be taken to assure that the cleaning solution and technique do not physically damage the surface. Improper cleaning procedures can significantly change the appearance and contribute to additional Efflorescence in the future.

1.3.1 Protection against Reoccurrence

It is possible to protect porous building materials such as brick, tiles, concrete and paving against efflorescence by treating the material with an impregnating, hydro-phobic sealer. This is a sealer which repels water and will penetrate deeply enough into the material to keep water and dissolved salts well away from the surface. However, in climates where freezing is a concern, such a sealer may lead to damage from freeze/thaw cycles.

Efflorescence can often be removed using phosphoric acid. After application the acid dilution is neutralized with mild diluted detergent, and then well rinsed with water. However, if the source of the water penetration is not addressed efflorescence may reappear.

1.3.2 Practical Remedies in This Case

The remedies stated maybe applicable in any case but however how in our case because the leakage of water in our case is from the roof slab and there is chance that the conduit pipes are place

- The first step is to removing the tiles from effected area**.**
- Removing mud plastering from effected area and clean out the surface by steel brushing.
- Treatment of appear hair crack line by making "V" grove and by using Adhesive bonding.
- Apply water proofing over the area by using "*cico or tapcrete*".

  Cico – It is modified bitumen roofing and water proofing members having polypropylene and polyester.

Tapcrete – it is a acrylic based polymer which is also used in pools to prevent the seepage of water.

- Plastering of the surface of 25 mm thickness over the water proofing area by taking cement-sand ratio of 1:4.
- At bottom level clean out surface and after mud plastering use 2 coat of paint as primer and putty.
- Curing is very important of repaired surface.

Formwork

However since the repair work on the roof slab frame work should be provided before all the repair work mentioned above is carried out.

If repairs are required on vertical or overhead surfaces and if the repair material is likely to sag, formwork will be required. Prior to installing forms, the concrete surface must be inspected for any surface contours that could result in air being trapped during concrete placement or pumping. If air is likely to get trapped, concrete must be removed to change the contour, or vent tubes must be installed. Formwork should be secured to the concrete with expansion anchors of standard makes etc. Installed form anchors should be pre-tested for slippage. Preformed foam gaskets or cast-in-place foam maybe required to provide a watertight seal between the concrete and form surfaces.

According to Mr. Dinesh kumar, junior engineer of maintenance department of the college the conduit pipes were placed inside the reinforcement bars so for the replacement of the conduit pipes they might have to dismantle the whole slab and the problems regarding this was there is too much load on the slab and dismantling the slab would mean dismantling of the entire building.

CHAPTER 2

DELAMINATION OF SHEAR WALL AND CRACKING OF BUILDING COLUMN IN C4 BLOCK IN JUIT

2.1 Preliminary Inspection

The structures in JUIT was constructed during the year 2000 and 2002 and since then the college has expand over the years and the investigation was done on 16th November 2014.The C4 block is used as faculty residence in JUIT and location of the buildings in this region are unfamiliar to students and the maintenance department hence this failure has been unnoticed over the years. However on the recommendation of my guide I carried out few research work and surveys to determine the cause and hopefully recommend solutions that may be helpful in practical applications. Two structures were affected in this region were, one being de lamination of shear wall and cracking of shear wall along the edge.

The condition survey of the structure will give an idea regarding extent of damage to concrete due to spalling, original construction defects, loss of strength due to exposure to high temperature and also damage to reinforcement due to corrosion/fire. This can be done based on the field measurements. The observation of the structure can be mapped on a suitable format and the results incorporated in the analysis of structure.

The crack distance was an average of 5.1 cm along the shear wall and 3.4 along the column. Further it was noticed that the building was structures are facing the wind ward side. So all the environmental factors such as high temperature variations, the high moisture content of the area could be the cause of possible failure of the structure. However there was no sign of any chemical attack , fire damage or earthquake failure on the structure.

From the cracks along the edge of the column on the building I could not see if the reinforcement bars were exposed or not, however the crack distance from the edge was 25cm from the edge so it could mean that the reinforced bars may be exposed but from the cracks on the shear wall it was evident that the reinforcement bars were not exposed and the failure was only due to spalling of the masonry cover of the shear wall. This not a big threat to the structure but careful measures should be taken. The damaged cover should be dismantled or removed before it falls off. It is necessary because there is pathway for the residence right below the wall and it could affect and cause damage to human life if it falls off.

So the remedies that I would suggest in this chapter for these two failures will be different. Entire survey of both visual and in-situ inspection was carried out for further proof of the failure of the reinforcement and the structure. It is very important that the failures are not caused due to any seismic activity. Comparisons with the other research work and repair and rehabilitation books are carried out to help me give more ideas for analysis of the damages and also determine the necessary tests for determining the strength of concrete, level of carbonation of the concrete and also if the reinforcement bars were corroded or not. Such tests would be only preformed under the recommendation of my guide.

2.2 Visual Inspection

The following were observed:

1. Cracks were observed on the masonry cover of both the shear wall and the edge of the column.

2. No chemical attack of any sort was visible on the concrete.

3. No sign of water leakage and no history of such any moisture affect on the structure.

4. No sign of carbonation of any sort on the concrete.

5. No reinforcement bars were exposed on the shear wall but unsure in the case of the column.

Detail explanation of the visual inspection.

1. In the shear wall longitudinal cracks of diameter 5 –to 8cm along the longitudinal direction of masonry cover is seen and on the columns the cracks were of diameter 3 to 5cm was observed.

On the masonry cover no reinforcement bars were affected, on the spalling of the masonry cover was seen. However in the case of the building column, the cracks expanded along the entire length of the columns and there is high chance that the reinforcement bars might be corroded.

2. There was no sign of any chemical attack. In over previous case there or earlier chapter is was evident that there was some chemical reaction going on in the concrete and the water leaking through the cracks helped the reaction to expand. But in this case the concrete structure was dry, there was no leakage of water and also there was no formation of any sort of efflorescence. This could only mean that the concrete used in between the cover and the structure lost it strength or were not provided to optimum level in the case of the shear wall.

3. There was no moisture content or water leaking through the cracks of any sort so the structure was not affected due to any moisture from the environment.

4. No sign of carbonation or formation of efflorescence of calcium or sulphate was visible. This may help me in the future pursuit of the solutions for the distress on the structure.

5. Even though the cracks were big there was no sign of exposed reinforcement in the case of cover of the shear wall because the cover was just the masonry and it reinforcement was held within the shear wall. But in the case of the column it is unknown whether the cracks extend throughout the column or it was just the masonry cover, it is so because it was invisible from the cracks .

2.3 Photographic Survey

Fig 2.1 and 2.2 Top view of the cracks in shear wall

Photographic survey of the crack along the longitudinal direction of the column.

Fig 2.3 and 2.4 Cracks in the column of C4 block.

2.4 Consideration For Repair Strategy

In the Condition Survey Report, before arriving at the Repair Strategy, it shall include the following considerations:

1. Identification of the cause of problem and its source is the fundamental for the success or failure. Lack of attention at this point can put a risk at the entire project.

2. For arriving at an effective and economical solution, systematic documentation of all observations is essential, which will greatly facilitate in diagnosing and making assessment of the extent of damage. Also take photographs and samples which will help you to check if any future reference is needed, sampling should be done if there is any necessity of it, for test requirements.

3. Available space and accessibility will determine the selection of repair method and repair strategy.

4. Accessibility to the areas identified for repairs needs consideration.

5. Depending upon the scope and scale of repairs, the repair strategy has to suit and dovetail the ongoing activities in the building.

6. The prioritization of repairs and their sequencing are important components for deciding the repair strategy.

7. Major repair procedure may demand propping the structural members to relieve a part or full component of the load acting on the member. If the building requires extensive propping, vacating the building may become the pre-requisite.

8. Safety measures to prevent any immediate major mishap shall be prescribed without losing further time.

9. The report should also include requirements on safety measures to be adopted during execution of the repair job.

More experienced engineers should look in to special and peculiar distress problems for example; micro cracking or some other subtle defect could be the cause of carbonation and corrosion. Carrying out repairs to corrosion distress, missing the main cause, may simply mean that the problem recurs in a relatively short duration.

2.5 Repair Options And Techniques

in this chapter where our repair of the structure is mainly due to cracking of the cover masonary and no damage on the shear wall or the coloum was visible there was no need for any sore of tests. The concrete underneath the masonry are in good health and strength so therefore I will suggest some simple and some advanced technique for the repair or otherwise replacement of the masonry cover and protection of the concrete underneath it.

2.5.1 General View

The decision to repair or replace a structure or its component can be taken only after consideration of likely service life of the structure is established based on the technical & economic evaluations. Once a decision, based on preliminary investigations, is taken to carry out the repairs, proper diagnosis, identification & extent of distress in structural members has to be correctly assessed. A detailed methodology should be developed, which should include available.

- Methods of repair and
- Repair materials.

Thus, a repair strategy can be adopted, keeping the objective in view. This shall be based on evaluation and available alternative methods of repair & material. Priority should be assigned to, repair of structural defects to ensure safety of the structure and Protection of the structure from further deterioration.

The selected method of repair should achieve one or more of the following objectives:

- Reinstate the structural integrity of the member by restoring or increasing its strength & stiffness.
- Prevent the ingress of distress promoting agents such as moisture, chlorides and carbon dioxide to improve durability.
- Maintaining the aesthetics/appearance of concrete surface.

2.5.2 Repair Options

There are many repair options and I will state them all for any future use, however later the repair technique that is most suitable in our case will be studied in detail. Depending upon the specific condition of deteriorated structure, the option of the repair methods could be one or more of the following:

- Grouting & crack repair
- Patch Repair
- Replacement of structurally weak concrete
- Replacement of spalled, and/or delaminated concrete
- Replacement of carbonated concrete surrounding steel reinforcement
- Cleaning and passivating the corroded steel reinforcement
- Concrete overlays with normal, low or highly fluid concrete, latex modified concrete and corrosion protection such as jacketing etc.
- Re- alkalisation of carbonated concrete.
- Electro-chemical removal of chloride from concrete.
- Water proofing and/or protective coating.

2.5.3 Performance Requirements of Repair System

- Strength, Serviceability and Durability
- Protection of steel
- Bond with parent surface
- Dimensional stability
- Resistance to environmentally induced damage.
- Ease of application
- Appearance

2.5.4 Important factors to be considered for Selection of Repair Methods

There are factors that need to be carefully considered before selecting the repair technique, it is so because like in your pervious chapter the use of water resistant chemicals in the concrete mortar caused the efflorescence so the environmental factors had to be considered before selecting any repair technique.

- Type and extent of distress
- Location of distress
- Environmental exposure
- Availability of skill
- Availability of time and access for repairs
- Appearance
- Cost

2.5.5 Repair Options

- Concrete Removal and Surface Preparation
- Fixing suitable formwork
- Bonding / passivating coat and repair application

2.5.5.1 Concrete Removal and Surface Preparation

Prior to preparation of concrete surfaces, exposed reinforcement should be inspected for access clearance, cross-sectional area and location. Reinforcing bars must be further exposed if the remaining concrete is de-bonded from the reinforcing steel. Removal must be continued to completely expose the bar if more than half of a reinforcing bar perimeter has been exposed. For completely exposed reinforcing bars, a minimum average clearance of 25 mm or nominal maximum size of aggregate plus 5mm, whichever is greater, must be provided between the reinforcing bar and surrounding concrete. A structural engineer should be consulted if the cross-sectional area of an individual bar has been reduced by 15 percent or more or if two adjacent bars have been reduced by 10 percent or more. Out-of-plane and loose reinforcement should be secured in its design location. The general procedure in preparing concrete and reinforcement surfaces for optimum bonding is to sandblast the surfaces and then remove dust and debris by air blasting, low-pressure water blasting, or brooming. If the damage is due to corrosion, a suitable coating may be considered after removal of total rust from its surface to protect the exposed reinforcing steel. Final inspection of the prepared area including remedying any deficiencies should be completed just prior to batching the repair material.

2.6 Repair Options

The various repair methods are available for carrying out the structural repairs to a distressed structure and they are described in detail below.

1. **Repair using mortars.**

Mortar repairs are the most common form of repairs being resorted to in the field without knowing the limitations of such repairs in structural rehabilitation/strengthening. A variety of mortars are available for carrying out repairs of a structure, these are explained with their limitations and areas of application in the following subsections:

- **Portland cement mortar:** Structural repairs with Portland cement mortar shall be made only if specifically approved by the Engineer-in-charge. Approval for hand applied cement mortar repairs will be given only for very small repair areas, not associated with critical performance of the structure. When approved, Portland cement mortar may be used for repairing defects on exposed, new concrete surfaces only. Such repairs are applied only if the defects are small and are too wide for dry pack and too shallow for concrete replacement and only if the repairs can be completed within 24 hours of removing the forms. Portland cement mortar shall not be used for repairs to old or existing concrete or for repairs that extend to or below the first layer of reinforcing steel. Portland cement Mortar shall consist of Ordinary Portland Cement Grade 43, clean water and clean graded sand. The proportion of Portland cement and sand shall preferably be in the same proportion as used in preparation of parent concrete. All materials of mortar mixtures and their application techniques shall be in accordance with relevant specifications.

- **Polymer modified cement mortars:** are used for repairs on old hardened concrete for repairing defects on exposed concrete surface only. For larger repair areas with thickness in excess of 50 mm, concrete, as repair material, is a better option. For thicker applications, over larger areas, it is desirable to use appropriate reinforcing mesh fixed with U-nails. These shall use Polymers admixed in specified proportions, based on selection criterion given in Chapter 5. Other materials shall be same as in Portland Cement Mortars stated above. However, these shall follow the given relevant specifications, if specified.

- **Epoxy mortars:** These mortars consist of resin, hardener and silica sand and are applied over an epoxy bonding coat over old hardened concrete surface.. These mortars attain strength in few hours. These mortars have very high strength and are abrasion resistant, water resistant and can be used in few millimeter thickness overlays. These are used for repair at locations where It is difficult to use epoxy bonded concrete, depth of repair is less than 40 mm or repair areas are small (less than 0.1 sqm) and few in number.

2. Preplaced aggregate concrete (PAC)

Pre-placed aggregate concrete (PAC) is concrete that is made by forcing grout into the voids of a mass of clean, graded coarse aggregate densely pre-packed in formwork . PAC is used where placing conventional concrete is extremely difficult, such as where massive reinforcing steel and embedded items are present, in underwater repairs, concrete and masonry repair, or where shrinkage of concrete must be kept to a minimum. For the purpose of this repair method, grout typically consists of sand, cement, pozzolana, plasticiser/ super-plasticiser and an air entraining agent (for anticipated freeze & thaw problem, if required). The pozzolana and the plasticiser/super plasticizer are used to impart flowability to the grout. The coarse aggregate is washed to remove all fines and screened just prior to placement. Grout is then injected through forms to provide the cementing matrix. Grouting is begun at the bottom of the pre-placed aggregate. Characteristics of the grout are affected by the water content, sand grading, cement, pozzolana and the types & amount of admixtures. For each design of grout mixture, there are optimum amounts of fillers and admixtures to produce the best pumpability or consistency. Proper proportioning for the structural grout mix components is necessary to get the required strength and durability of the finished pre-placed aggregate concrete. Trial mix design is necessary for each job. In underwater repair, injection of grout at the bottom of the PAC displaces water, leaving a homogenous mass of concrete with minimum of paste wash out. In such applications, addition of anti wash admixtures minimizes the paste wash out. For underwater PAC, the quality of underwater should also be tested to determine its influence on PAC over a period of time for taking corrective action.

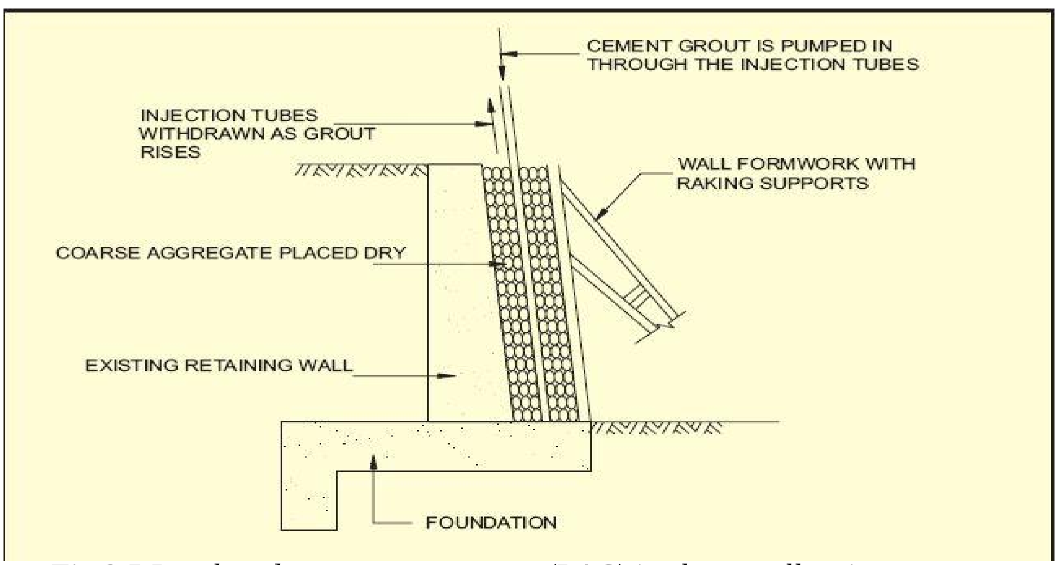

Fig 2.5 Preplaced aggregate concrete (PAC) in shear wall as in our case.

3. Shotcrete

Shotcrete is defined as pneumatically applied concrete or mortar placed directly on to a surface. The shotcrete shall be placed by either the dry mix or wet mix process and they are explained further.

The dry mix process:

- Thoroughly mixing the dry materials,
- Feeding of these materials into mechanical feeder or gun
- Carrying the materials by compressed air through a hose to a special nozzle,
- Introducing water at nozzle point and intimately mixing it with other ingredients at the nozzle.
- Jetting the mixture from the nozzle at high velocity on to the surface to receive the shotcrete.

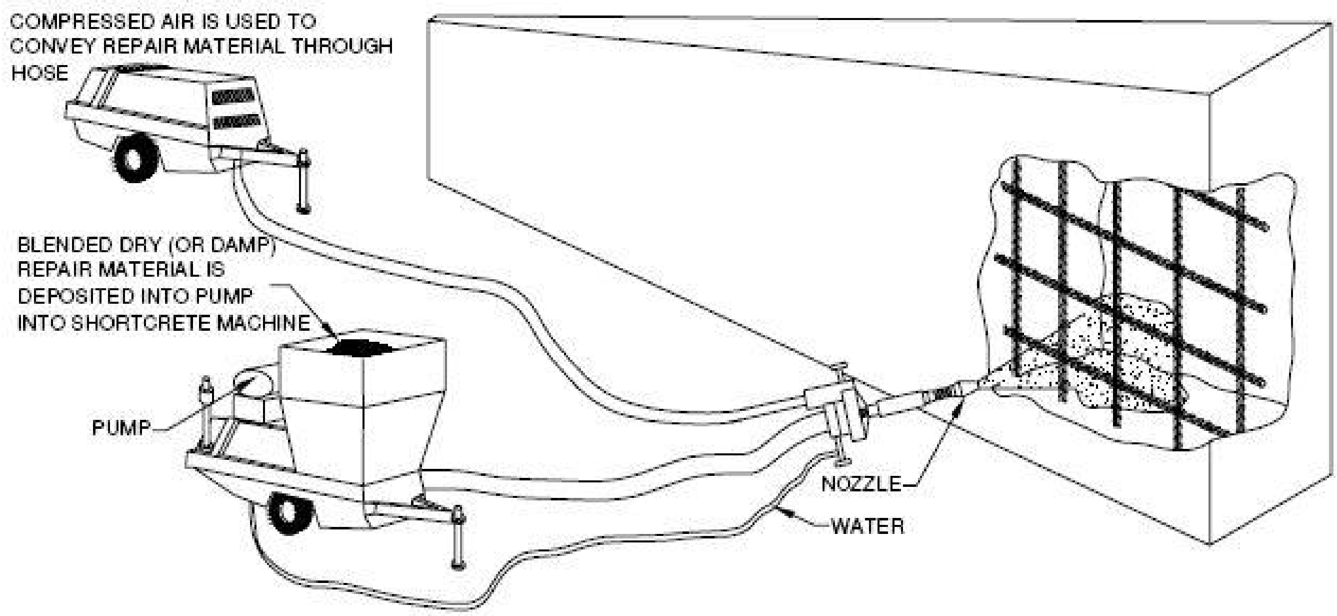

Fig 2.6 Dry mix process of shotcrete

The wet mix process:

- Thoroughly mixing all the ingredients with the exception of the accelerating admixture, if used;
- Feeding the mixture into the delivery equipment;
- Delivering the mixture by positive displacement or compressed air to the nozzle;
- Jetting the mixture from the nozzle at high velocity on to the surface to receive the shotcrete.

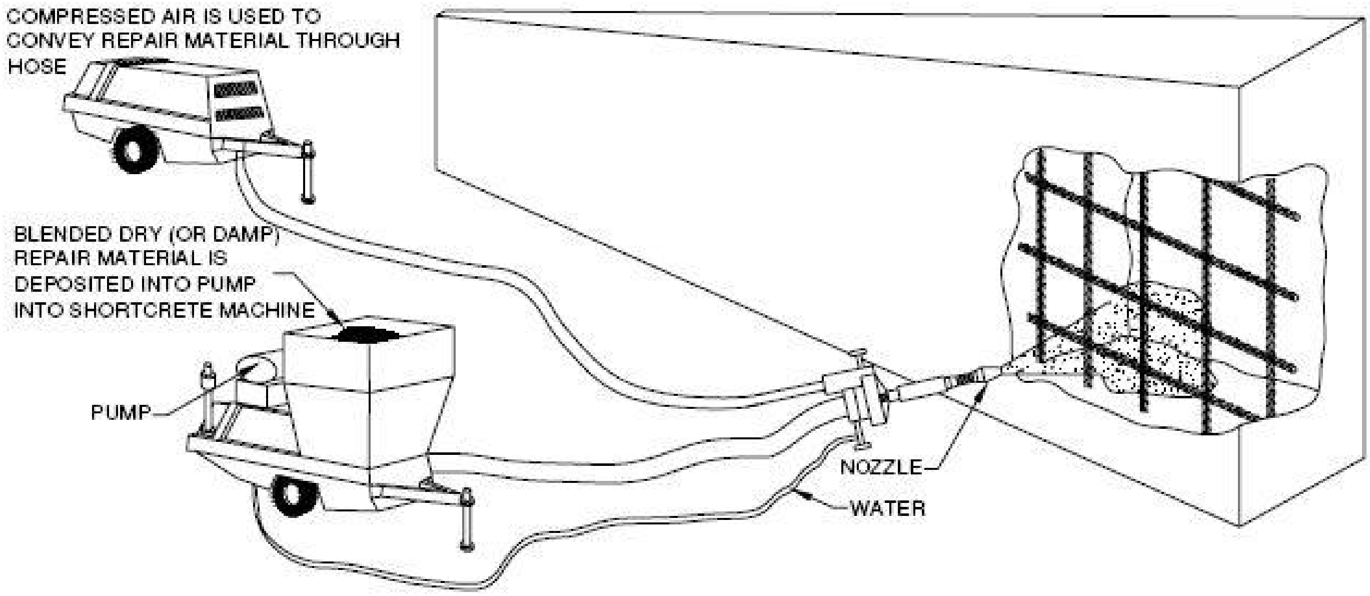

Fig 2.7 Wet mix method of shotcrete

4. Concrete replacement technique

It should be used on areas of damaged or unacceptable concrete greater than 0.1 sqm. having a depth greater than 150 mm or a depth extending 25 mm below or behind the back-side of reinforcement. Concrete replacement shall also be used for holes extending entirely through concrete sections and for longer areas of repair greater than 100 mm in depth when the concrete to be repaired is less than 7 days old. Epoxy bonding agents, latex bonding agents, dry neat cement, cement paste or cement and sand mortar shall not be used to bond, fresh concrete to concrete being repaired by this method.

5. Epoxy bonded concrete method

It is defined as freshly mixed Portland cement concrete that is placed over epoxy resin bond coat on existing hardened concrete. This method should be used when the depth of repair is 40 mm or greater. It will be necessary to provide suitable reinforcement as per design requirement. In addition, epoxy bonded shear keys may also be used for shear transfer through the interface.

6. Strengthening concrete by surface impregnation using vacuum method

The surface impregnation is based upon first creating a partial vacuum within the concrete and then introducing a repair material i.e. the resin of very low viscosity into the cracks, voids, micro cracks and capillary system. The resin so impregnated fills the cracks, including micro cracks down to a width of 5 microns. Upon curing, the repair resin bonds the fractured and fissured matrix into a monolithic structural member of exceedingly high strength. Partial vacuum creation and introduction of repair resin are achieved by maintaining vacuum with the porting devices in the fracture or surface being repaired, connected to the vacuum source. The partial vacuum pressures are, thus, applied to the enclosed system. The repair resins are introduced, while maintaining the negative pressures, to fill the major cracks, interconnected cracks & voids and micro cracks. The concrete matrix, including the voids within fracture, is impregnated with the repair resin materials. This method can also be made applicable to stone or masonry structures. The advantage lies in moisture evacuation along with any deleterious gases and/or materials from the concrete matrix of the fracture wall surfaces. The concrete drying process can be monitored by using in-line hydrometers installed in the special vacuum tubing.

The vacuum process offers the following advantages over pressure injection methods:

- Repairs can be completed in a relatively shorter period of time with no sacrifice to the quality of the repair.
- Repairs could be cost effective.
- Efficient and complete filling of existing fractures, interconnected fractures and voids and the complete filling of micro fractures.

- Total absence of pressure pockets ensures and facilitates deeper fill of repair resin.
- Evacuation of moisture from the interior concrete matrix of the fracture.
- No possible extenuation of the damage due to absence of applied pressures.
- Ability to introduce ultra – low viscosity materials into the fracture areas.
- Improved bonding due to lack of air bubbles normally associated with low viscosity, low specific low specific repair resin.
- Continued corrosion of reinforcement would be significantly diminished because of the evacuation of, and sealing out of moisture from the treated concrete matrix.

a) Using methyl methacrylate (MMA)

In the vacuum system, the requirement is of impregnating concrete with a Methyl Methacrylate (MMA) based monomer catalyst system followed by in-situ polymerization of the monomer by heat. MMA is low viscosity high strength material suitable for vacuum injection processes. Its viscosity is 5-15 cps with superior physical properties, flexibility and superior bonding and wetting properties.

b) Using expanded vinyl ester gel.

These are low viscosity gels, which are water-soluble acrylic monomers. The gel is used for injection and sealing of joints and cracks against water leaks. Due to its ultra low viscosity, it has a very low flow resistance and is able to permeate into the smallest hairline cracks and capillaries. Thus, it seals them reliably and permanently. When it contact with water, it swells to double its volume while retaining its shape. This process is purely physical and reversible. As a result of this unique property, the material will retain its self healing property even when in a dry condition. These processes involve unique materials and hence need specialist advice and close supervision in their field application.

c) Thin Polymer overlays:

Thin polymer overlays are used to improve the abrasion resistance and for creating waterproofing barriers on the surface and act as protective coatings. These are applied in less than 10 mm thickness. It is quite suitable for improving surface characteristics and also it acts as protective coating. It generally comprises of

1. One coat of primer and
2. One or more coats of sealant.

The primer coat shall consist of vinyl ester resin, initiator and promoter. Each coat of sealant shall consist of the same material as in the primer but with the addition of silica filler, titanium dioxide pigment and carbon black pigment.

Type of Cracks	Width,	Movement mm	Water	Type of material	Mode of application and/or principle
Shrinkage cracks in concrete	≤0.2	No	No	Two-component epoxy injection	Surface treatment which works through capillary action
Shrinkage cracks in plaster	≤0.2	No	Generally not	One-component flexible paint or acrylic base	Coat with roller or brush
Structural cracks in concrete, brickwork	0.2-1	No	No	Two component epoxy low viscosity	Low pressure injection, shorter cracks with high pressure injection
Structural cracks in concrete, brickwork	1-2	No	No	Two component epoxy injection and solvent free epoxy	Low pressure injection
Structural cracks in concrete brickwork	2-5	No		Solvent free epoxy thicotropic	Low pressure injection, with hand pump
Structural cracks in concrete brickwork	≥ 5	No	Dry/wet	Polymer modified cement based grout	Grout with injection grout or hand pump
Structural cracks in concrete brickwork	≥15	No	Dry/wet	Non-shrink grot	Cut and fill non-shrink mortar
Moving cracks in concrete, brickwork	0.2-1	Due to temperature changes	Dry/wet	Two component polyurethane injection injection and flexible paints when wet joints, primary injection with polymer gel forming	High pressure injection with (low pressure injection also possible)then coat with roller/brush
Butt joint in pres-tressed concrete (coupling joints)	0.2-2	Vibration	Dry/wet	Two component polyurethane injection and joint sealant, when wet joint, primary injection with polyurethane gel forming	For joints pressure injection, for floors, seal joints with sealant guns or spatulas
Moving cracks in concrete, brickwork and floors	≥2	Vibration	Dry/wet	Sealant on different basis including flowable grades	Sealant gun or spatuals; for horizontal surface flowable grade of joint sealant can be used.

Table 5 Crack distance and possible solutions according to crack length.

2.7 Practical Solutions for Repair of Structure in C4 Block.

In this case only masonry cover of the concrete was spalled and no damage was seen on the actual shear wall and the column. So only minor repair work was needed
The stepwise method is:

Step 1: Measures shall be taken to ensure that no seepage/leakage etc. affects the rcc column/ shear wall.

Step 2: The plaster/finishes over the RCC columns and wall shall be removed and relevant specifications. The concrete surface exposed, spalled and loose cover concrete removed, cracks marked after close examination on the surface of concrete. Whereas the good surface of concrete shall be hacked and roughened for receiving the repair.

Step 3: Wherever loose and spalled cover concrete is removed, it shall be repaired.with polymer modified cement mortar as mentioned technique above.

Step 4: All cracks in RCC columns/beams wherever noticed shall be sealed by injection grouting through nipples fixed along the crack line as per nomenclature and technique mentioned above.

Step 5: Over the prepared surface of RCC columns/beams, 6 mm thick 1:3 cement sand plaster shall be applied with polymer modified cement slurry bond coat within 24 hours of injection grouting as per parameter.

Step 6: Cement plaster shall be cured strictly as per the nomenclature.

Step 7: After RCC columns/beams are cured and completely dried, a protective coating shall be applied over it for protecting the reinforcement and concrete against environmental aggressive chemicals.

However the best technique is preplaced aggregate cement(PAC) because in the shear wall we can fill the cover with the aggregates and fill the cracks with cement mortar. In this technique Pre-placed aggregate concrete (PAC) is concrete that is made by forcing grout into the voids of a mass of clean, graded coarse aggregate densely pre-packed in formwork . PAC is used where placing conventional concrete is extremely difficult, such as where massive reinforcing steel and embedded items are present, in underwater repairs, concrete and masonry repair, or where shrinkage of concrete must be kept to a minimum. For the purpose of this repair method, grout typically consists of sand, cement, pozzolana, plasticiser/ super-plasticiser and an air entraining agent (for anticipated freeze & thaw problem, if required). The pozzolana and the plasticiser/super plasticizer are used to impart flowability to the grout. The coarse aggregate is washed to remove all fines and screened just prior to placement. Grout is then injected through forms to provide the cementing matrix. Grouting is begun at the bottom of the pre-placed aggregate. Characteristics of the grout are affected by the water content, sand grading, cement, pozzolana and the types & amount of admixtures. For each design of grout mixture, there are optimum amounts of fillers and admixtures to produce the best pumpability or consistency. Proper proportioning for the structural grout mix components is necessary to get the required strength and durability of the finished pre-placed aggregate concrete. Trial mix design is necessary for each job. In underwater repair, injection of grout at the bottom of the PAC displaces water, leaving a homogenous mass of concrete with minimum of paste wash out. In such applications, addition of anti wash admixtures minimizes the paste wash out. For underwater PAC, the quality of underwater should also be tested to determine its influence on PAC over a period of time for taking corrective action. It is the best solution in the case of shear wall.

Also in the case of the column since there is only cracks in the cover masonry we can remove the cover and apply water resistant materials and repair the patch by apply epoxy bonded concrete. Or even shotcrete is a excellent solution.

CHAPTER 3

DELAMINATION OF RETAINING WALL NEAR THE JUIT PLAY GROUND AND STRUCTURAL IRREGULARITIES IN WAKNAGHAT

3.1 Delaminated Wall Preliminary Inspection and photographic survey.

Jaypee university of information of technology (JUIT) is located at Waknaghat; in district Solan of Himachal Pradesh state, India. It is situated in hilly area and due to orographic precipitation the weather here is rainy. Therefore buildings may face problem of dampness and water leakage. Due to large diurnal temperature variation and alternate wetting and drying conditions, cracks appear on the surface of concrete. Previous cases in this project are the best example.

Due to heavy rainfall in the month of February and March this problem occurred. Such kinds of problem are common here in JUIT because all the concrete structures here have masonry covers which due to alternate wetting and drying conditions loses its bond strength with the cement paste in between them. During the examination it was found that the all the weep lines are clogged and no maintenance was carried out to clear the weep lines. Weep lines were clogged during the previous rainfalls.

Fig 3.1 front view of the delaminated wall

Fig 3.2 Delaminated wall near the play ground

3.2 Consideration for repair strategy

In the Condition Survey Report, before arriving at the Repair Strategy, it shall include the following considerations:

1. Identification of the cause of problem and its source is the fundamental for the success or failure. Lack of attention at this point can put a risk at the entire project.

2. For arriving at an effective and economical solution, systematic documentation of all observations is essential, which will greatly facilitate in diagnosing and making assessment of the extent of damage. Also take photographs and samples which will help you to check if any future reference is needed, sampling should be done if there is any necessity of it, for test requirements.

3. Available space and accessibility will determine the selection of repair method and repair strategy.

4. Accessibility to the areas identified for repairs needs consideration.

5. Depending upon the scope and scale of repairs, the repair strategy has to suit and dovetail the ongoing activities in the building.

6. The prioritization of repairs and their sequencing are important components for deciding the repair strategy.

7. Major repair procedure may demand propping the structural members to relieve a part or full component of the load acting on the member. If the building requires extensive propping, vacating the building may become the pre-requisite.

8. Safety measures to prevent any immediate major mishap shall be prescribed without losing further time.

9. The report should also include requirements on safety measures to be adopted during execution of the repair job.

More experienced engineers should look in to special and peculiar distress problems for example; micro cracking or some other subtle defect could be the cause of carbonation and corrosion. Carrying out repairs to corrosion distress, missing the main cause, may simply mean that the problem recurs in a relatively short duration.

3.3 Repair Options

In this case the problem falls under the class 3 of repair classification which is principal repair. In which major spalling of the masonry cover is seen, major structural cracks, including cracking along reinforcement due to corrosion or otherwise leading to substantial reduction of load carrying capacity.

Strengthening repair to reinforced concrete in accordance with the load carrying requirement of the member. Concrete strength maybe extremely low and reinforcement diameter might have been significantly reduced requiring check by design procedure. Make up reinforcement may have to be provided in case of deficiencies due to deterioration.

In this case the failure of the wall occurred only due to loss of bond strength which is caused due to alternate wetting and drying conditions and heavy monsoon and clogging of weep line which caused the earth pressure to develop behind the wall since there was no way for the water to get out. No signs of chemical attack, corrosion of reinforcement bars were found.

The best method of repair for this problem is pre-places aggregate method (PAC) or the wall need to be reconstructed as it is usually done here.

3.3.1 Pre – placed aggregate method (PAC)

Pre-placed aggregate concrete (PAC) is concrete that is made by forcing grout into the voids of a mass of clean, graded coarse aggregate densely pre-packed in formwork. PAC is used where placing conventional concrete is extremely difficult, such as where massive reinforcing steel and embedded items are present, in underwater repairs, concrete and masonry repair, or where shrinkage of concrete must be kept to a minimum. For the purpose of this repair method, grout typically consists of sand, cement, pozzolana, plasticiser/ super-plasticiser and an air entraining agent (for anticipated freeze & thaw problem, if required). The pozzolana and the plasticiser/super plasticizer are used to impart flowability to the grout. The coarse aggregate is washed to remove all fines and screened just prior to placement. Grout is then injected through forms to provide the cementing matrix. Grouting is begun at the bottom of the pre-placed aggregate. Characteristics of the grout are affected by the water content, sand grading, cement, pozzolana and the types & amount of admixtures. For each design of grout mixture, there are optimum amounts of fillers and admixtures to produce the best pumpability or consistency. Proper proportioning for the structural grout mix components is necessary to get the required strength and durability of the finished pre-placed aggregate concrete. Trial mix design is necessary for each job. In underwater repair, injection of grout at the bottom of the PAC displaces water, leaving a homogenous mass of concrete with minimum of paste wash out. In such applications, addition of anti wash admixtures minimizes the paste wash out. For underwater PAC, the quality of underwater should also be tested to determine its influence on PAC over a period of time for taking appropriate corrective action.

Step wise method for pre- placed aggregate method.

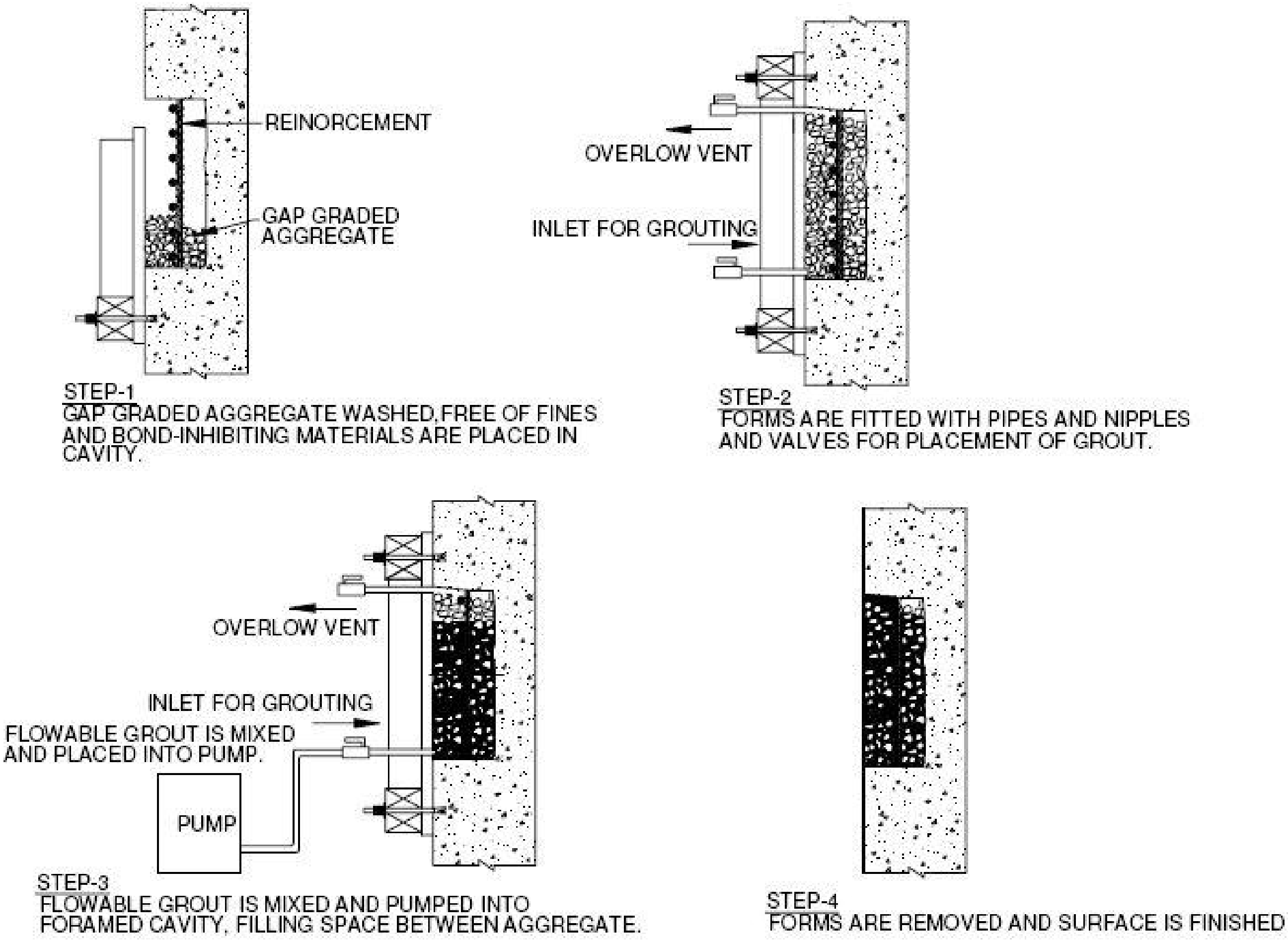

Fig 3.3 preplaced aggregate concreting

3.3.2 Shotcrete

Shotcrete is defined as pneumatically applied concrete or mortar placed directly on to a surface. The shotcrete shall be placed by either the *dry mix* or *wet mix process*.

The *dry mix* process shall consist of:

1. Thoroughly mixing the dry materials,
2. Feeding of these materials into mechanical feeder or gun,

3. Carrying the materials by compressed air through a hose to a special nozzle,
4. Introducing water at nozzle point and intimately mixing it with other ingredients nozzle;
5. Jetting the mixture from the nozzle at high velocity on to the surface to receive the shotcrete.

The *wet-mix* process shall consist of:

1. Thoroughly mixing all the ingredients with the exception of the accelerating admixture, if used;
2. Feeding the mixture into the delivery equipment;
3. Delivering the mixture by positive displacement or compressed air to the nozzle;
4. Jetting the mixture from the nozzle at high velocity on to the surface to receive the shotcrete.

If specified, fibres of steel, poly propylene or other material, as may be specified, could also be used together with the admixtures to modify the structural properties of the concrete/mortar being placed in position.

3.3.3 Concrete Replacement

It should be used on areas of damaged or unacceptable concrete greater than 0.1 sqm. having a depth greater than 150 mm or a depth extending 25 mm below or behind the back-side of reinforcement. Concrete replacement shall also be used for holes extending entirely through concrete sections and for longer areas of repair greater than 100 mm in depth when the concrete to be repaired is less than 7 days old. Epoxy bonding agents, latex bonding agents, dry neat cement, cement paste or cement and sand mortar shall not be used to bond, fresh concrete to concrete being repaired by this method.

3.3.4 Epoxy Bonded Concrete

It is defined as freshly mixed portland cement concrete that is placed over epoxy resin bond coat on existing hardened concrete. This method should be used when the depth of repair is 40 mm or greater.

It will be necessary to provide suitable reinforcement as per design requirement. In addition, epoxy bonded shear keys may also be used for shear transfer through the interface.

3.4 Structural Irregularities in Waknaghat

A building that lacks *symmetry* and *discontinuity* in geometry, mass, or load resisting elements is called as *irregular building*. IS 1893 (part 1):2002 has categorized irregularities in to two main types: (i) Horizontal Irregularity (ii) Vertical Irregularity. Horizontal irregularities refer to asymmetrical plan shapes like L,T,U or even discontinuities in the horizontal resisting elements such re-entrant corners whereas Vertical irregularities referring to sudden change of strength, stiffness, geometry, and mass. In this paper, an effort is made to study structural irregularities and construction defects of buildings situated in Waknaghat and Kandaghat (district Solan, HP). The objective of the presented study is to know about the current construction practices being used by local masons for non-engineered buildings. It is found that most of the buildings have such defects which lead to discontinuity in seismic load paths. There are chances of failure of such buildings during strong ground shaking. For any building more than three stories, structural engineer must be consulted and for any building with irregularity, a 3-D dynamic analysis must be carried out.

Fig 3.4 Column Offset.

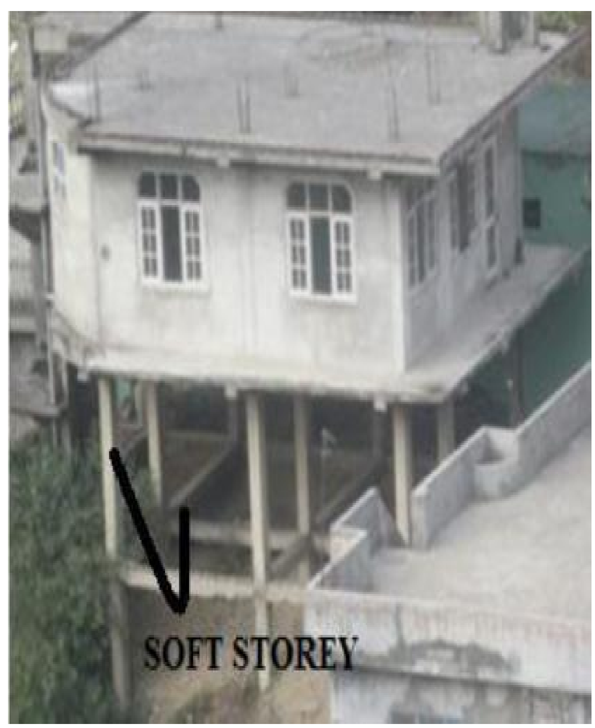

Fig 3.5 Soft Storey.

3.4.1 Column Offset

The building shown in Fig. 1 is a hotel under construction located in Waknaghat. Column of upper storey has a horizontal offset with the lower column. It may be due to the poor workmanship. Due to the misalignment of the reinforcing bars and improper or no bonding of two columns, there is a possibility of sudden failure of this joint during an earthquake. At the construction stage, care must be taken to avoid this irregularity correct alignment in the columns of the building and by employing good workmanship.

3.4.2 Soft Storey

A soft storey is one in which the lateral stiffness is less than 70% of that in the storey immediately above, or less than 80% of the combined stiffness of the three stories above. The essential characteristic of a weak storey consists of a discontinuity of stiffness, which occurs at the second storey connections. This is caused by lesser strength or increased flexibility and also the structure results in excessive deformations in the first storey of the structure, which in turn results in concentration of forces at the second storey level. These stories are more likely to get collapsed or were severely damaged during earthquake. Many buildings with an open ground storey (soft storey) were observed in Kandaghat. Fig. 3.4.2 shows a residential house being constructed and the ground and first floor are left empty whereas a house is dwelled in second storey. Fig. 3 and Fig. 4 are also good examples of soft storey. This defect can be minimized by constructing shear walls at the ground level so as to eliminate the discontinuity in the lateral load resistance path and to increase stiffness of soft storey .making it comparable with other.

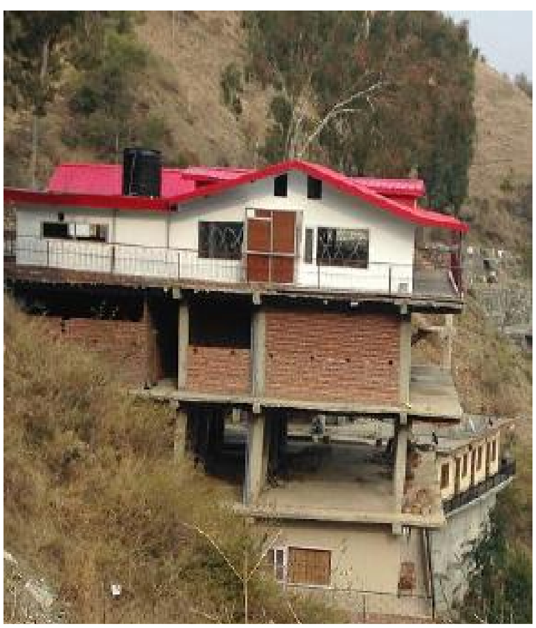

Fig 3.6 Soft storey of a hotel in Waknaghat

3.4.3 Hanging Column

Buildings with columns that hang or float on beams at an intermediate storey and do not go all the way to the foundation, have discontinuities in the load transfer Path. It may lead to catastrophic failure of buildings. The buildings shown in Fig.3.4.4 and Fig. 3.4.5 are located in the main market of Kandaghat. Fig. 3.4.4 is a residential building where people dwell in first and second storey and ground storey is used as shopping area. This building has hanging column whose load is going nowhere but borne by beams only. Fig. 3.4.4 clearly show that the column do not continue up to the foundation but rather end at an upper level. Due to this, Shear is induced to overturning forces to another resisting element of a lower level. Thus, site Engineer must be aware of the fact that load transfer path should be continuous. All the columns and walls must extend to the foundation in order to mitigate horizontal ground motions. Fig. 3.4.5 also shows a residential building with a numbers of hanging, long and short columns (discussed in coming text). There must not be any floating columns in buildings.

Fig 3.7 Hanging columns or floating columns

Fig 3.8 floating columns or short columns

CHAPTER 4

REPAIR OR STRENGTHENING OF COLUMNS

These form the basic structural elements in most of the building structural systems, which are deteriorated and require attention to improve the load carrying capacity. Their structural modification or strengthening would give the required relief to the structure and enhance its performance.

Retrofitting is a technique to enhance the structural capacities including the strength, stiffness, ductility, stability, and integrity of a building that is found to be deficient or vulnerable. It can effectively raise the performance of a building against earthquake to a desired level, and to even satisfy the requirements of an upgraded design seismic code. The building need not be deteriorated or damaged. The retrofit is intended to mitigate the effect of a future earthquake. In this paper, an effort is made to elaborate the procedure of providing concrete jacketing to the column as per guidelines of IS 15988: 2013. It is seen that the overall performance of the column significantly improves after jacketing. Retrofitting can generally be classified in two categories: Global and the local. The global retrofitting technique targets the seismic resistance of the building. It includes adding of infill wall, adding of shear wall, adding of steel bracings and base isolation. Adding of infill wall in the ground story is a viable option to retrofit buildings with soft story. Shear walls can be introduced in a building with flat slabs or flat plates. A new shear wall should be provided with an adequate foundation. Steel braces can be inserted in frames to provide lateral strength, stiffness, ductility, and to improve energy dissipation. These can be provided in the exterior frames with least disruption of the building use. Local retrofitting technique targets the seismic resistance of a member. The local retrofit technique includes the concrete, steel or Fiber reinforced polymer jacketing to the structural members like beams, columns, beam column joint, foundation. Concrete jacketing involves adding a new layer of concrete with longitudinal reinforcement and closely spaced ties. The jacket increases both the flexural strength and the shear strength of the beam or the column. The following are the advantages of retrofitting. It increases the seismic resistance of the building without any demolition. It increases the ductile behavior and lateral load capability of the building Strength and stiffness of the building is also improved.

These form the basic structural elements in most of the building structural systems, which are deteriorated and require attention to improve the load carrying capacity.

Their structural modification or strengthening would give the required relief to the structure and enhance its performance as under:

- **Columns**: The strengthening of columns may be required for the following

1. **Capacity:** The load carrying capacity of the column can be enhanced by section enlargement.
2. **Ductility/confinement:** The ductility of the column can be enhanced by providing additional tiles, steel plate bonding, and fibre wrap.
3. **Joints:** The joints play crucial for resisting earthquake forces. The joints can be strengthening by enlargement, jacketing by steel collar and fibre wrap.

4.1 Ferro – Cement

Ferro-cement is a thin wall type composite, having a total thickness ranging between 12 to 30 mm. It is composed of hydraulic cement mortar reinforced with a minimum two layers of continuous and relatively small diameter orthogonally woven wire mesh separated by 4 to 6 mm diameter galvanized spacer wires**.** The cement mortar is admixed with plasticizers and polymers for sealing pores. The wire mesh is mechanically connected to the parent surface by U-shaped nails fixed with suitable epoxy bonding system. The mesh may be made of hot dip galvanized MS wire or some other metallic or suitable material. Special technique for compacting Ferro-cement layer is used with the help of orbital vibrators to ensure proper encapsulation of wire mesh in mortar.

It is a durable composite material, in which shrinkage cracks are distributed uniformly due to the presence of closely spaced, thin woven galvanized wire mesh. It is coupled with excellent corrosion resistance and impermeability to the ingress of water.

This repair technique is used for providing protective reinforced membrane for rehabilitation of distressed RCC structures. This acts as a protective layer against the vagaries of the environment. It is also used as a water proofing technique over reinforced concrete shell structures and RCC slabs as it provides impermeable thin membrane, which prevents seepage and leakage of water.

4.2 Plate Bonding

Plate bonding is an inexpensive, versatile and advanced technique for rehabilitation, up gradation of concrete structures by mechanically connecting MS plates by bolting and gluing to their surfaces with epoxy as shown in Fig 3.5.1. Plate bonding can substantially increase strength, stiffness, ductility and stability of the reinforced concrete elements and can be used effectively for seismic retrofitting.

In this method the bolts, which are first used to hold the plates in position during construction, act as permanent shear connectors and integral restraints. The bolts are also designed to resist interface forces assuming the epoxy glue used as non-existent assuming it as destroyed by fire, chemical break down, rusting or simply bad workmanship. Since epoxy is prone to premature de-bonding, use of mechanical anchorage along with epoxy bonding is considered more reliable. Since the steel plates are unobtrusive, with this technique original sizes of the structural members are not increased significantly. This method is preferred where enlargement of the members is going to affect the headroom, existing windows, doors and other fixtures.

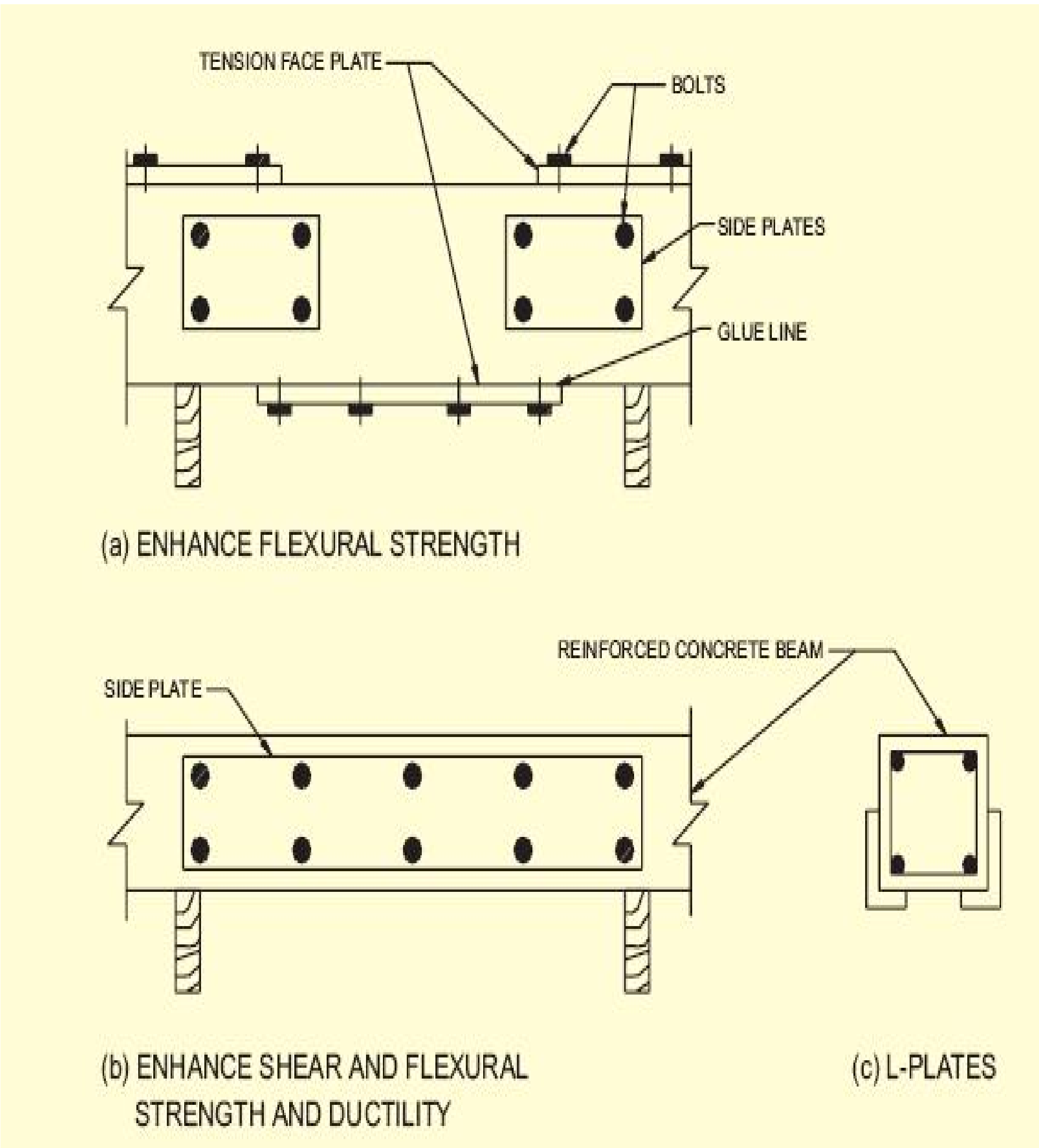

Fig 4.1 Tension face plates

4.3 RCC Jacketing

Reinforced concrete jacketing increases the member size significantly. This has the advantage of increasing the member stiffness and is useful where deformations are to be controlled. If columns in a building are found to be slender, RC jacketing provides a better solution for avoiding buckling problems. Design for strengthening/repair work is based on composite action between the old and the new work. Strain compatibility calculations may have to be carried out carefully giving due account to factors such as creep. As the new jacket is to behave compositely with the parent member, the new jacket can take additional loads only with the increase in the stresses & strains in the old one. The problem arises if the;

1. Old concrete has reached limiting strain and is not likely to sustain any more significant strain.
2. Old concrete is weak and porous and started deteriorating due to weathering action and corrosion of reinforcement.

The question then arises as to whether the composite action should be abandoned and the new jacket (plate or RC) designed to carry the entire load. It is perhaps best to design the strengthening in this manner, but detailing must be right to ensure transfer of load to the new jacket, if the old concrete fails. It is however, necessary to ensure perfect bond also between the old and new concrete by providing shear keys and effective bond coat with the use of epoxy or polymer modified cement slurry giving strength not less than that of new concrete. Plate bonding and RC jacketing are the common methods of strengthening RCC structures. The cost difference between the two methods is not significant. A choice has to be made between the two methods based on actual needs and the suitability of each method with respect to the structural /architectural and other details of buildings.

There are two main purpose of jacketing of columns:

(i) To increase in shear capacity of columns (strong column-weak beam design).

(ii) To improve the column's flexural strength. After carrying out the detailed analysis of the existing building, deficient members are identified. A list of provided and required reinforcements is tabulated and highlighted. All these members require strengthening in order to increase their ductile strength. Hence, retrofitting of these members is carried out using Jacketing.

Shear walls shall be provided with reinforcement in the longitudinal and transverse directions in the plane of the wall to resist bending moment and to prevent premature shear failure. The minimum reinforcement ratio for ordinary shear walls shall be 0.001 5 of the gross area in each direction. For ductile shear walls this value is increased to 0.002 5 in the horizontal direction. This reinforcement shall be distributed uniformly across the cross-section of the wall.

Seismic strengthening for improved performance in the future earthquakes shall be achieved by one of several options given in this clause. The chosen seismic strengthening scheme shall increase the redundancy of lateral load resisting elements to avoid collapse and overall instability.

The deficient frame members and joints are identified during detailed evaluation of building. Members requiring strengthening or enhanced ductility shall be jacketed by reinforced concrete jacketing, steel profile jacketing, and steel encasement or wrapping with FRPs where possible, the deficient members shall first be stress relieved by propping.

Reinforced concrete jacketing improves column flexural strength and ductility. Closely spaced transverse reinforcement provided in the jacket improves the shear strength and ductility of the column.

4.4 RCC Jacketing Of Columns

Column jacketing is carried out as per recommendations of Indian standard code IS 15988 (2013): Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings – Guidelines published By Bureau of Indian Standards [4]. Reinforced concrete jacketing improves column flexural strength and ductility. Closely spaced transverse reinforcement provided in the jacket improves the shear strength and ductility of the column. The procedure as per article 8.5.1.1 of the code for reinforced concrete jacketing is as follows:

1. The seismic demand on the columns, in terms of axial load P and moment M is obtained.

2. The column size and section details are estimated for P and M as determined above.

3. The existing column size and amount of Reinforcement is deducted to obtain the Amount of concrete and steel to be provided in the jacket.

4. The extra size of column cross-section and Reinforcement is provided in the jacket.

5. Increase the amount of concrete and steel actually to be provided as follows to account for losses,

$$Ac = (3/2)\, A'c \quad \text{and} \quad As = (4/3)\, A's$$

Where *Ac* and *As* = actual concrete and steel to be provided in the jacket; *and A'c and A's* = concrete and steel values obtained for the jacket after deducting the existing concrete and steel from their respective required amount.

The minimum specifications as per article 8.5.1.2 of the code for jacketing Columns are:

a) Strength of the new materials shall be equal or greater than those of the existing column. Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete.

b) For columns where extra longitudinal reinforcement is not required, a minimum of 12φ bars in the four corners and ties of 8φ @100 c/c should be provided with 135° bends and 10φ leg lengths.

c) Minimum jacket thickness shall be 100 mm.
d) Lateral support to all the longitudinal bars shall be provided by ties with an included angle of not more than 135°.

e) Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter.

f) Vertical spacing of ties shall not exceed 200 mm, whereas the spacing close to the Joints within a length of ¼ of the clear height shall not exceed 100 mm. preferably, the spacing of ties shall not exceed the thickness of the jacket or 200 mm whichever is less.

4.5 DESIGN OF RC COLUMN JACKETING

The firs Details of existing column are as follows: Height of the Column=1500 mm, Cross-Section = (250X400) mm, Effective Cover = 40 mm Grade of Concrete = 20 N/mm^2 and Grade of steel = 415 N/mm^2, Load, Pu =1528.68 KN, Moment M = 72.33 KN-m, Reinforcement provided=8-16 mmØ bars.

Procedure:

$$P \quad = 0.4f \quad \times A \; + 0.67f \quad \times A$$

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete.

Thus, taking value of f =25 N/mm^2 and assuming A = 0.8%A .

1528.68 x 10^3 = 0.4 x 25 x A + 0.67 x 415 x (0.8 %A) or 1528 x 10^3 = 12.22Ac or

Ac =125096.56 mm^2

According to 8.5.1.1 (e) of IS 15988:2013, Ac = 1.5$A'c$

Thus, A = 187644 mm^2

Assuming the cross sectional details as:

B = 400 mm,

D = 187644/400 = 500 mm

Jacketing details of cross section:

B = (400 - 250)/2 = 75mm, D = (500 - 400)/2 = 50 mm.

However, According to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013

Thus,

New size of the column:

B = 250+100 +100=450 mm,

D =400 +100 +100=600 mm.

New concrete area=450x600=270000mm^2 $>$ Ac = 125096.56 mm^2

Area of steel, As =0.8% x 450 x 600 = 2160 mm^2

But according to 8.5.1.1 (e) IS 15988:2013, *As* = (4/3)*A's*

As = (4/3) x 2160=2880 mm^2

Assuming 16mm Ø bars,

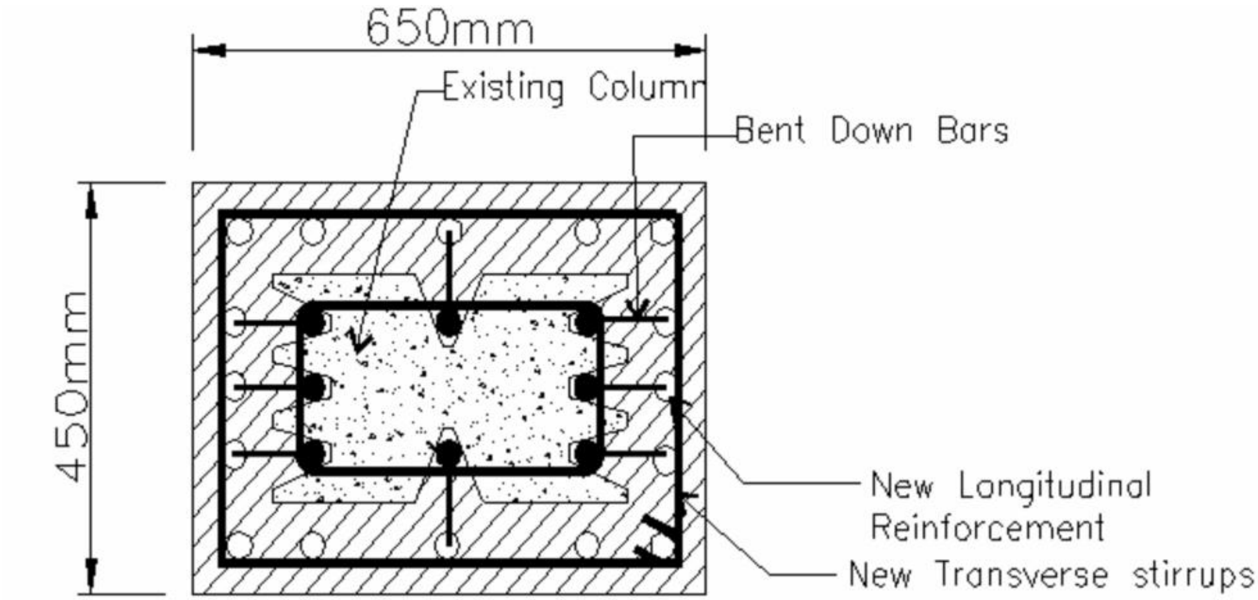

Fig 4.2 Typical column section showing Jacketing.

4.5.1 Design of lateral Ties

As per 8.5.1.2 (e) of IS15988: 2013,

Minimum diameter of ties shall be 8 mm and not less than one-third of the longitudinal bar diameter. Diameter of bar =1/3 of Ø of largest longitudinal bar = 1/3 x 16 = 6 mm ….take 8 mm.

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013

The code suggests that the spacing, s of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket is given as:

$$\boldsymbol{s} = \frac{f \quad dh^2}{\sqrt{f} \quad t}$$

Where f = yield strength of steel, f = cube strength of concrete, *dh* = diameter of stirrup, and t = thickness of jacket.

$$s = \frac{415 \times 16^2}{\sqrt{25} \times 200}$$

$$s = 110 \text{ mm}$$

Provide 8mm Ø @110 mm c/c. However, For columns (Figure 3.5.3) where extra longitudinal reinforcement is not required, a minimum of 12φ bars in the four corners and ties of 8φ @100 c/c should be provided with 135° bends and 10φ leg lengths.

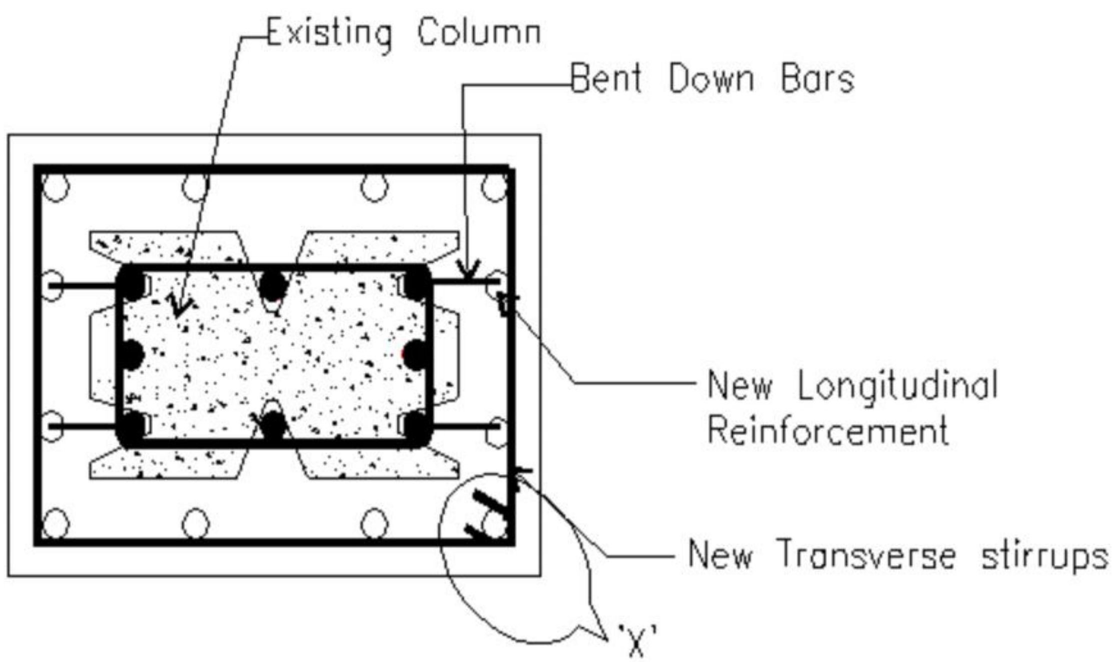

Fig 4.3 Actual diagram of the jacketed column

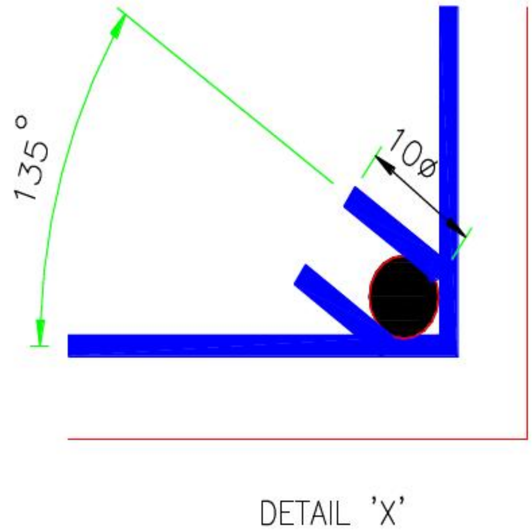

Fig 4.4 Reinforcement jacketing detailing for minimum level of retrofit

The above solved problem is an example of designing RC jacket for columns. However, the practical technique of surrounding the old and existing columns with a new RC jacket involves a sequence of actions. There are few steps which are to be followed before applying Jacketting. First step is to repair the surface of old and existing column. This can be done by removing the deteriorated concrete by hand chipping, jack hammering or any other method that causes micro cracking of substrate (concrete of existing Column). This is then followed by sand blasting or water demolition technique , which makes the surface of column rough. The third and an important step is to use a bonding agent like epoxy resin. After the resin application, steel connectors are used. This is then followed by temporary shoring of existing RC columns. Finally, adding of longitudinal and transverse reinforcement with steel connectors. This is how RC Column Jacketing is given a practically shape.

The method of RC Jacketing is suitable for the following situations:

(1) The old and existing building that are constructed without considering IS 1893:2002, are very liable for damage during an earthquake.
(2) The columns that are damaged in the past earthquake during an accident like fire, explosions.
(3) Situations involving change in the functionality of the structure.
(4) The weak columns of monumental buildings.
(5) The weak columns of soft storey and extremely soft storey.

Thus, Jacketing for these types of building becomes a necessity in order to minimize the effects of future seismic shaking. The Jacketing of the existing building is carried out by using IS 15988:2013. This code also provides the data for retrofitting of the buildings by means of adding shear wall and bracings.

4.6 PROPPING AND SUPPORTING

Problem arises in deciding on propping and supporting the structure to give relief in stresses and strains in some of the existing weak members being strengthened. Mere vertical props sitting on some beams & slabs may not be enough. Diagonal bracing to transmit the loads to the adjacent columns should also be considered.

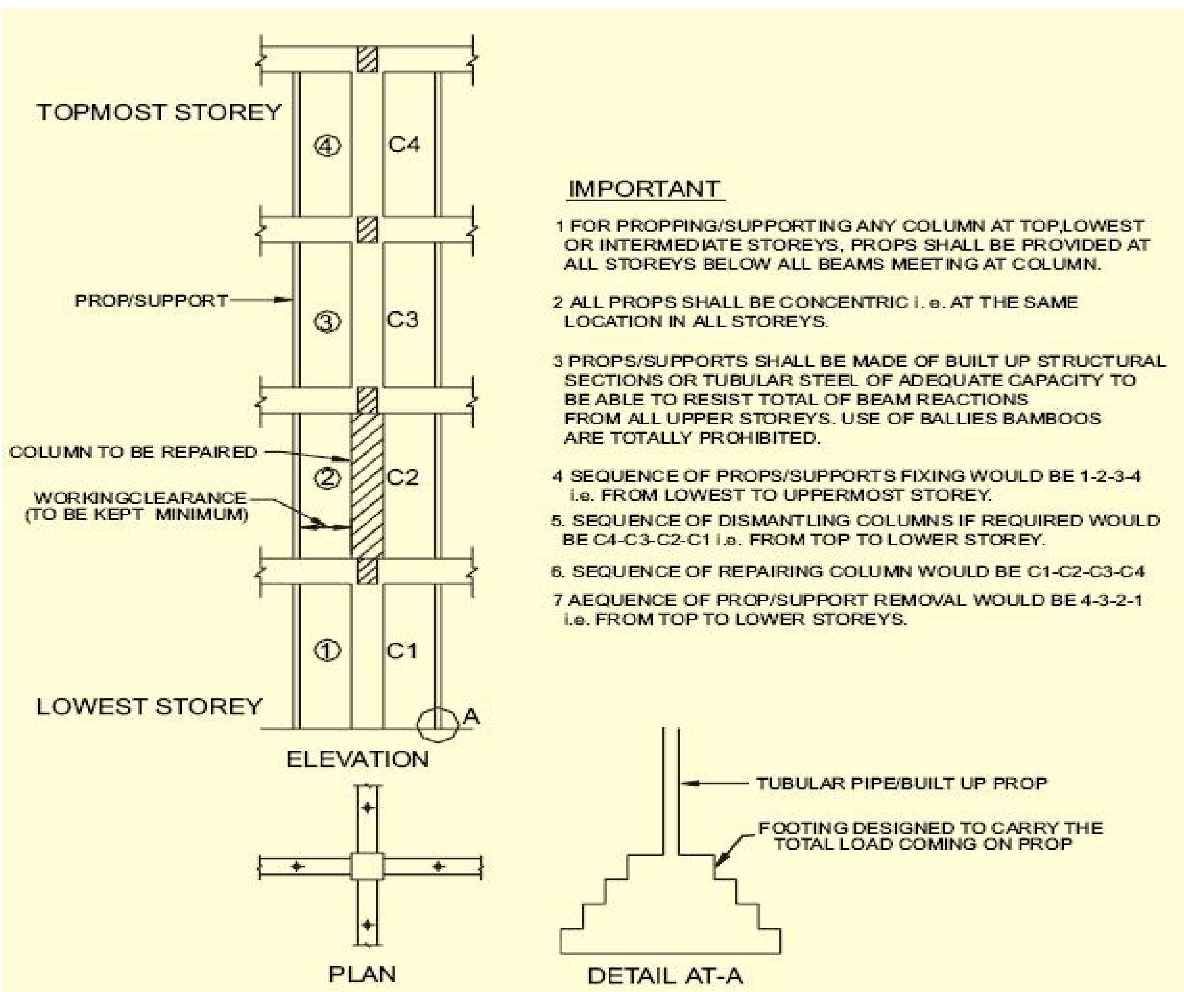

Fig 4.5 Typical Arrangement For Propping & Supporting a Column to Relieve at Form Load

4.7 FIBRE WRAP TECHIQUE

The fibre wrap technique, also known as Composite Fiber System is a non-intrusive structural strengthening technique that increases the load carrying capacity (shear, flexural, compressive) and ductility of reinforced concrete members without causing any destruction or distress to the existing concrete. There are two systems followed in adopting this technique:

I. Bi-directional Woven Fabric:

This system comprises of woven fabric presoaked in specially formulated epoxy and applied over prepared surface after application of epoxy primer. Woven fibre fabric is composed of bi-directional high strength fibers that are combining with specially formulated epoxy in a pre-determined proportion to form a composite-Material. This composite material is wrap applied onto the reinforced concrete or steel member requiring strengthening or protection and left to cure at ambient temperature. The subsequent layer/s of unidirectional fibre fabric could be applied after giving the required overlap along the direction of fibres as per design requirements.

II. Uni-directional E-glass Fibres:

This system comprises of precut unidirectional E-glass fibre wrapped over epoxy primer applied prepared surface of member requiring structural strengthening and/or surface protection. Subsequent to its wrapping, it is saturated with epoxy using rollers and stamping brushes manually to remove air bubbles, if any and left to cure at ambient temperature. The subsequent layer/s of unidirectional fibre fabric could be applied after giving the required overlap along the direction of fibres as per design requirements.

Though the underlying principle of the above two methods is more or less identical, but the application techniques and basic materials adopted are at slight variance. Each of the above systems has their own merits. Enhancement in lateral drift ductility and horizontal shear carrying capacities of a concrete member can also be obtained by confinement of the member by this method. The flexural, shear and axial load carrying capacities of the structural members can be enhanced by appropriate orientation of primary fibres of the composites. The resulting cured membrane not only strengthens the reinforced concrete member but also acts as an excellent barrier to corrosive agents, which are detrimental to concrete and the reinforcement. Ingress of water, oxygen and carbon dioxide through the external surface of concrete member is prevented by the application of composite jacket.

Dimensions of FRP jacket is determined assuming composite action between fiber and existing concrete. The rupture strength of FRP is used as its limiting strength. Dimensions of FRP jacket is determined assuming composite action between fiber and existing concrete.
The rupture strength of FRP is used as its limiting strength. Limit state moment capacity of FRP retrofitted member is given by:
Ultimate flexure strength is determined based on the assumption that compressive concrete reaches a strain of 0.003 5 and FRP reaches its maximum strain.

Shear strength of a beam after strengthening:

$$V = V\text{con} + V\text{s} + V\text{FRP}$$

Where:

$$V\text{con} = T\text{c} \times b \times D$$

$$V\text{s} = 0.87 \times f\text{y} \times A\text{sv} \times (d/s\text{v})$$

$$V \quad = A \quad \times F \quad \left(\frac{d}{s}\right)$$

*V*con = shear contribution of concrete;
*V*s = shear contribution of steel; and
*V*FRP = shear contribution of FRP sheet.

CHAPTER 5

CONCLUSION AND REFERENCE

The few of the structural problems that are discussed in detail and out of which was formation of calcium carbonate efflorescence on the roof slab in the first floor of academic block in the electronics department, it was mainly caused after the repair work was carried out on the slab to replace the conduit pipes which were choking. The problem aroused when the construction crew found out that the conduit pipes were placed inside the reinforcement bars and they could not replace the pipes because replacing the pipes would mean dismantling the entire slab since reinforcement bars will need to be cut in order to take out the pipes. So what they did was they repaired the patches by using cement mortars of M25 grade with water proofing chemicals which lead to formation of calcium carbonate efflorescence and even the color of the concrete were on repair patches became darker than the parent material.

Efflorescence is ugly in appearance and can readily spoil the looks of mortar, concrete or brickwork, particularly where the decorative properties are very important. However, it is not normally deleterious to long term concrete durability. There are a number of remedial treatments discussed above, which must be applied with great care. Special polyurethane membranes can stop efflorescence from forming in the first instance in both concrete materials and in brickwork, by effectively cutting off the water flow to the surfaces. Waterproofing agents can be applied to bricks, mortars and concretes. But in our case it is inevitable that in the long run we will have to destroy the entire slab and recast it because the leakage cannot be stopped.

Further in chapter two I discussed on the topics cracks in the cover of shear wall extending throughout the wall and also there was a crack along the entire length of the column in longitudinal direction on a resident building of the faculties in C4 block. The causes of these problems were mainly due to temperature variations and could have been due to less bonding between the structure and its masonry cover. The structure was compared with failures caused due to seismic activity, fire damage, chemical attack and carbonations and the sings of failure didn’t match any of the damages caused due to these.

However it was a relief that in both the cases the reinforcement of the structure was unaffected and the failure was just on the masonry cover.

Repair options and techniques are detailed in the above regarding such failures and also failures that are more severe than these.

A building that lacks symmetry and discontinuity in geometry, mass, or load resisting elements is called as irregular building.
IS 1893 (part 1) : 2002 has categorized irregularities in to two main types:

I. Horizontal Irregularity
II. Vertical Irregularity.

Horizontal irregularities refer to asymmetrical plan shapes like L,T,U or even discontinuities in the horizontal resisting elements such re-entrant corners whereas Vertical irregularities referring to sudden change of strength, stiffness, geometry, and mass. In this paper, an effort is made to study structural irregularities and construction defects of buildings situated in Waknaghat and Kandaghat (district Solan, HP). The objective of the presented study is to know about the current construction practices being used by local masons for non-engineered buildings. It is found that most of the buildings have such defects which lead to discontinuity in seismic load paths. There are chances of failure of such buildings during strong ground shaking. For any building more than three stories, structural engineer must be consulted and for any building with irregularity, a 3-D dynamic analysis must be carried out.
If the irregularities in test results are due to the testing procedure, these can be corrected and tests repeated. If the irregularities are due to other reasons, the assessor has to use a lot of judgment. He may decide to carry out a lot more tests on the critical members of the structure before coming to a conclusion on the condition of the structure.
There are numerous buildings that are constructed in these locations with a number of structural irregularities in them. Since H.P lies in zone IV and zone V, these areas are more prone to earthquake damage. Thus, various remedies are suggested to come up with these defects.

1. For RCC framed buildings more than three stories, IS 1893 and IS 13920 must be used.
2. Good workmanship is very important to inculcate all design aspects suggested by design engineer.
3. For the masonry buildings, Use of lintel band, as suggested by the Bureau of Indian Standards (IS 13828:1993) proves to be a good option. This seems to suggest that additional horizontal bands, possibly at the skill level and at plinth level, are needed This can be explained more clearly with

4. Shear wall can be properly employed for increasing the stiffness where ever necessary and must be uniformly distributed. Fig. 12 shows a remedy for a soft storey. The ground storey which was earlier a soft storey is now being provided with shear walls.

Reinforced concrete jacketing increases the member size significantly. This has the advantage of increasing the member stiffness and is useful where deformations are to be controlled. If columns in a building are found to be slender, RC jacketing provides a better solution for avoiding buckling problems. Design for strengthening/repair work is based on composite action between the old and the new work. Strain compatibility calculations may have to be carried out carefully giving due account to factors such as creep. As the new jacket is to behave compositely with the parent member, the new jacket can take additional loads only with the increase in the stresses & strains in the old one.

A building that lacks *symmetry* and *discontinuity* in geometry, mass, or load resisting elements is called as *irregular building*. IS 1893 (part 1):2002 has categorized irregularities in to two main types: (i) Horizontal Irregularity (ii) Vertical Irregularity. Horizontal irregularities refer to asymmetrical plan shapes like L,T,U or even discontinuities in the horizontal resisting elements such re-entrant corners whereas Vertical irregularities referring to sudden change of strength, stiffness, geometry, and mass. In this paper, an effort is made to study structural irregularities and construction defects of buildings situated in Waknaghat and Kandaghat (district Solan, HP). The objective of the presented study is to know about the current construction practices being used by local masons for non-engineered buildings. It is found that most of the buildings have such defects which lead to discontinuity in seismic load paths. There are chances of failure of such buildings during strong ground shaking. For any building more than three stories, structural engineer must be consulted and for any building with irregularity, a 3-D dynamic analysis must be carried out.

The majority of the areas of Himachal Pradesh lie in Zone V and the few lies in zone IV. This state is very close to the fault line separating the Indo-Australian and the Eurasian plate. Record of past 50 years has verified the above statement. Large earthquakes have occurred in all parts of Himachal Pradesh, the biggest was the Kangra Earthquake of 1905. It had a moment magnitude of 7.8 and at least 28,000 people were killed in the Kangra Dharamsala region of Himachal Pradesh. Another earthquake which took place near Kullu (H.P) on 28 February 1906, with a moment magnitude of 6.4. Damage and casualties were caused in the Bashahr-Shimla hill states. Besides these there are scores of smaller faults, like the Kaurik Fault which triggered the 1975 earthquake with a moment magnitude of 6.8. This earthquake struck in the early afternoon of January 19, 1975. It caused havoc in parts of the Kinnaur, Lahaul and Spiti regions of India. 60 people were killed in this sparsely populated region

Soil Type

Solan district presents an intricate mosaic of high mountain ranges, hills and valleys with altitude ranging from 300 to 3000 m above MSL. The altitude of the hill ranges is higher in northern parts whereas south-western part of the district is represented by low denuded hill ranges of Siwalik. The soils of the State can broadly be divided into nine groups. These are:

(i) Alluvial Soils
(ii) Brown Hill Soil,
(iii) Brown Earth
(iv) Brown Forests Soils
(v) Grey Wooded Orpodzolic Soils
(vi) Grey Brown Podzolic Soils
(vii) Planosolic Soils
(viii) Humusand Iron Podzols
(ix) Alpine Humus Mountain Speletal Soils.

The Soil Found In The Districts Of Mandi, Kangra, Bilaspur, Una, Solan, Hamirpur And Sirmaur Is Generally Brown, Alluvial And Grey Brown Podzolic, Kullu And Shimla Have Grey Wooded Podzolic Soils, While Kinnaur, Lahaul And Spiti And Some Parts Of Chamba District Have Humus Mountain Speletal Soils.

There are numerous buildings that are constructed in these locations with a number of structural irregularities in them. Since H.P lies in zone IV and zone V, these areas are more prone to earthquake damage. Thus, various remedies are suggested to come up with these defects.

1. For RCC framed buildings more than three stories, IS 1893 and IS 13920 must be used.
2. Good workmanship is very important to inculcate all design aspects suggested by design engineer.

3. For the masonry buildings, Use of lintel band, as suggested by the Bureau of Indian Standards (IS 13828:1993) proves to be a good option. This seems to suggest that additional horizontal bands, possibly at the sill level and at plinth level, are needed. This can be explained more clearly.
4. Shear wall can be properly employed for increasing the stiffness where ever necessary and must be uniformly distributed. Fig. 12 shows a remedy for a soft storey. The ground storey which was earlier a soft storey is now being provided with shear walls.

REFERENCES

I. Er. Krishan Kumar Director General (Works), Central Public Health Department(CPWD), Government Of India, New Delhi "*Handbook on repair and rehabilitation of rcc buildings.*

II. "*Environmental lab mannual*" of JUIT, waknaghat district solan (HP), India. page no. 21.

III. *Concrete mesonary structure Cleaning And Maintenance Concrete Masonry Walling MA41*" Concrete Masonry Association Of Australia(CMAA), 2000.

IV. Investigation of defect in repair work. "*Aditya Kumar Tiwary, Poonam Dhiman* "

V. NAKAW Crop. "*Efflorescence prevention in brick work*".

VI. Technical notes on brick construction, Reston, Virginia. "*Efflorescence causes and revention"*

VII. Merrigan, M.W., "Efflorescence: Cause and Control," *The Masonry Society Journal*, Vol. 5, No. 1, The Masonry Society, Boulder, CO, 1986.

VIII. Duggal S.K-*Earthquake Resistant Design of Structures* **(2007)**