INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)

www.ijprems.com
editor@ijprems.com

Vol. 04, Issue 03, March 2024, pp: 450-457

e-ISSN : 2583-1062

Impact Factor: 5.725

A REVIEW OF STRUCTURAL FAILURES AND REMEDIAL MEASURES

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DOI: https://www.doi.org/10.58257/IJPREMS32937

ABSTRACT

Structural failures are one of the important phenomena which should be very important to deal with. Structural failures occur then and causing heavy damage to both property and human lives. Structural elements include beam, column, slab etc. The failure of the horizontal load bearing member beam is considered. Building failure can be defined as the collapse of structure, while building disaster gives evidence of a structural member being unsafe before the actual collapse. Building failure in a construction sector is an indispensable factor that must be considered with great care and skills. In this Research, various reasons for structural failures like Faulty Design, Inferior quality of materials, Poor Workmanship, Weathering conditions, Natural calamities etc. It will discuss about the various methods of doing the repair woks that is remedial measures. To know better about the nature of concrete elements, the most effective and also most economical

Keywords: Structural failures; reasons; retrofitting materials;causes

1. INTRODUCTION

In early days man used to live in huts which were constructed with the materials available in abundance in nature. But due to increase in population and the invention of new building materials, it becomes important to know about failures in structures and their remedial measures. Failures in construction are caused by deterioration of various building materials with age. Awareness about various agencies causing deterioration is essential to understand the problem and to find out the solution for it.The history of failure of structures started from very olden time from 300A.D. and continues till date. Figure 1 shows the splitting of a tall structure into two portions in a vertical manner at Oogue at Siberia. One more example is the failure of World Trade Centre at New York by air crash. Structural integrity and failure is an aspect of engineering that deals with the ability of a structure to support a designed structural load (weight, force, etc.) without breaking and includes the study of past structural failures in order to prevent failures in future designs.Structural integrity is the ability of an item—either a structural component or a structure consisting of many components—to hold together under a load, including its own weight, without breaking or deforming excessively. It assures that the construction will perform its designed function during reasonable use, for as long as its intended life span.

Items are constructed with structural integrity to prevent catastrophic failure, which can result in injuries, severe damage, death, and/or monetary losses.Structural failure refers to the loss of structural integrity, or the loss of load-carrying capacity in either a structural component or the structure itself. Structural failure is initiated when a material is stressed beyond its strength limit, causing fracture or excessive deformations; one limit state that must be accounted for in structural design is ultimate failure strength. In a well designed system, a localized failure should not cause immediate or even progressive collapse of the entire structure. Structural integrity is the ability of a structure to withstand its intended loading without failing due to fracture, deformation, or fatigue. It is a concept often used in engineering to produce items that will serve their designed purposes and remain functional for a desired service life.To construct an item with structural integrity, an engineer must first consider a material's mechanical properties, such as toughness, strength, weight, hardness, and elasticity, and then determine the size and shape necessary for the material to withstand the desired load for a long life. Since members can neither break nor bend excessively, they must be both stiff and tough. A very stiff material may resist bending, but unless it is sufficiently tough, it may have to be very large to support a load without breaking. On the other hand, a highly elastic material will bend under a load even if its high toughness prevents fracture.

Generally the structural failures are classified as Cracks, Damping, Leakage and Spalling. The reasons forfailures may be due,

- Inferior quality of materials
- Poor workmanship
- Improper study
- Weathering actions
- Effect of chemicals
- Fire Hazards

- Faulty construction
- Faulty system of maintenance
- Inappropriate cleaning
- Misuse of buildings
- Environmental aspects
- Chemical factors and
- Biological growth

The failures in building like Cracks, Dampness, Leakage and Spalling shows the weakness of building. That is the way of talking of a building to a Civil Engineer as a patient talks to a Doctor about his/her illness. Sowe have to take care of the buildings. Some of the examples of failures are shown the Figures 1 , Figure 2 and Figure 3

Fig- 1 Corrosion of steel and Spalling of concrete in a RCC canopy.

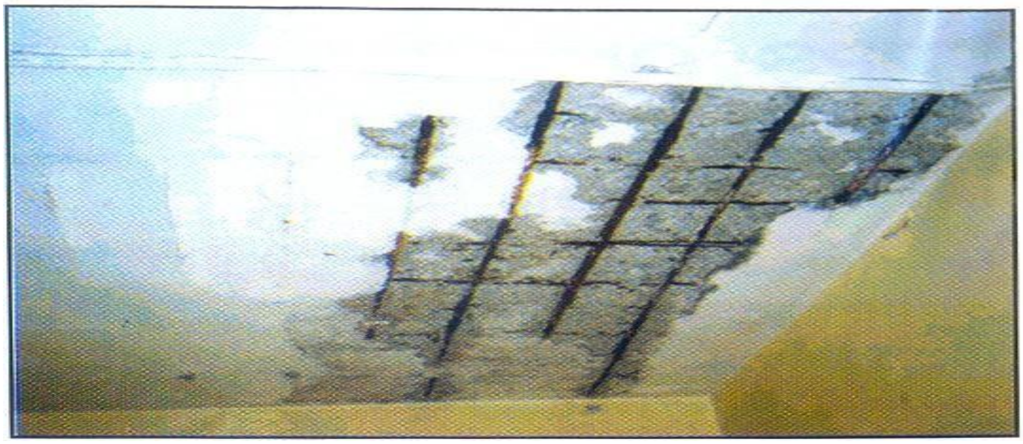

Fig 2 Corrosion of steel and Spalling of roof concrete on a slab

Fig -3 Crack in concrete due to corrosion of steel

1.2 Structural collapse

In a perfect world, all buildings would be designed, constructed, and maintained with the utmost care. Unfortunately, any number of issues can lead to structural failures and collapses. These include:

- Poor planning and design of the structure
- Engineering errors
- Improper design and construction of the foundation
- Failure to perform load tests and placing excess weight on the structure
- Use of improper or defective building materials
- Errors during construction
- Negligent inspection and maintenance of the structure

Anyone in the vicinity of a building collapse can suffer serious injuries and even be killed. However, those most at risk tend to be workers involved in the building, renovation, or demolition of a structure.Maggiano, DiGirolamo & Lizzi understands the devastating impact of construction collapses on workers and their families. If you or a loved one suffered harm in the structural failure and collapse of a building in New Jersey or New York, our attorneys can investigate the accident and pursue full compensation on your behalf.Many building collapses originate due to errors before, during, and after construction. However, while these factors may account for the root cause of the collapse, they do not necessarily describe the mechanics that cause the structure to fail.

1.3 Structural failure that leads to a building collapse can be caused by the following:

Bending: Load-bearing components of a structure can bend if they are subject to excess stress. This bending can cause deformation of the structure's supports or, in extreme cases, bend the support to its breaking point.

Shearing: Shear occurs when a structural element is subject to two forces moving in the opposite direction. If the shear forces are too great, the structure can collapse.

Buckling: All structures have a critical load, which is the maximum amount of weight the structure can hold before it fails. Buckling occurs when the critical load is exceeded, resulting in bending, bowing, and other deformation of structural components. In turn, this leads to instability that can cause structural failure and collapse.

Tensile failure: Tensile strength is a material's resistance to tension (i.e., a pulling force). Rigid materials used in construction have limited elasticity. As such, structural failure and collapse can occur if the materials are subjected to too much tension.

Compressive failure: Compression is the opposite of tension; it involves forces pushing inward on a structure rather than pulling outward. Materials and elements of a structure also need to be able to withstand compressive stress. If the stress becomes too great, the structure may fail.Inspection of the debris after a building collapse can reveal telltale signs of damage from these mechanisms of structural failure. A construction collapse lawyer will hire engineering experts to review the evidence and determine (a) how the collapse occurred and (b) what issues of negligence may have been involved.

1.4 Different Types Of Structural Collapse

Structural collapses take one of two different forms: complete and partial. In a complete collapse, the entirety of the structure falls down. With a partial collapse, meanwhile, only part of the structure fails and falls.One of the most serious concerns with any structural failure is the potential for a progressive collapse. A progressive collapse occurs when the failure of one or more primary structural components causes other elements of the structure to fail. In this scenario, what might have consisted of localized damage puts the entire structure in jeopardy.Whether partial or complete, most structural failures and collapses can be categorized as follows:

V-shaped collapse: If floor joists become overloaded, the center of the floor may collapse while the walls remain standing. This creates a V-shaped collapse site.

Lean-to collapse: Wall collapses are a serious concern on construction sites. A lean-to collapse occurs when one load-bearing wall fails while the others remain standing.

A-frame collapse: Also known as a tent collapse, this structural failure occurs when the floor comes loose from the exterior walls but the center interior wall remains intact.

Pancake collapse: A pancake collapse occurs when the stories of a multi-level structure crash down on top of one another. This is also known as a horizontal collapse, as the entirety of the floors and walls fail.

Cantilever collapse: In structural engineering, a cantilever is a central support that holds one end of a structural element that extends outward. (For purposes of illustration, the Queensboro Bridge in New York is a cantilever bridge.) In a cantilever collapse, one or more of the structure's walls fail, leaving support for the structure dependent on the remaining wall(s). This is an extremely dangerous situation, as a progressive collapse could occur if the remaining wall or walls are not promptly reinforced.

Understanding the mechanics of the building collapse is essential for determining the cause of structural failure. It is also crucial for identifying potential negligence on the part of contractors and subcontractors, the owner of the property, material manufacturers, and other parties.

1.5 Causes Of Failure

The following points describe the leading causes of the progressive collapse:

•Inadequate shear stiffness was developed due to the insufficient design of shear reinforcement.

•Dowel bars were deeply embedded inside the concrete shell and created cracks in the concrete roof.

•Several cracks were formed as a result of higher-than-expected construction loads and differential moisture and thermal movements.

- Investigation reports suggested that the margin of safety was lesser than anticipated during the design.
- Cracks in concrete developed due to the misplacement of tensile reinforcement. Thus, the tensile stresses were not resisted effectively.
- The horizontal column ties and longitudinal support beams were inadequate to provide enough support to the structural members.

Damage Inflicted At Beam-Column Joints

The Ranau earthquake had majorly inflicted damages on the beam-column joints. Enormous cracks and spalling of the concrete cover were noted in those studied. It was found that the confinement of reinforcement between the beam-column joints was inexistent in these structures. The reinforcement detailing was found only eligible for gravity load when considering the design buildings based on BS8110-1997. In seismic contemplation, these beam-column joints failed to withstand the lateral load caused by the seismic excitation. In Eurocode 8 Clause 5.4.3.3 states that the horizontal confinement reinforcement in joints of primary seismic beams with columns should be predefined and specified for the critical regions in the columns. Hence, this confinement reinforcement must be placed within the beam-column joints, as proposed for the critical regions in the columns. A significant increase in ultimate load and ultimate displacement was observed by increasing the amount of confinement reinforcement in the beam-column joints . In some cases, severe cracks were observed at the beamcolumn joint and elongated to the critical regions in the columns, which caused permanent displacement. The columns seemed to display inadequate strength to resist any lateral load induced by the earthquake. This study has identified that less damage was inflicted at the beam because of the effective presence of good tie beams, but not in the column area, as demonstrated in the 2011 Maden (Elazig) earthquake in Turke. This condition indicates that most of the case study buildings experienced weak-column strong-beam behaviour, which did not comply with the seismic design provision. This behaviour can be interpreted based on severely-damaged and collapsed RC buildings during the 2011 Van earthquake in Turkey. These joints are considered as the weakest link in a structural system due to the distribution of seismic loadings.

2. LITERATURE REVIEW

Geis et al. (2012) studied 1,029 snow-induced building failure incidents in the United States between 1989 and 2009 and 91 international incidents between 1979 and 2009 in 16 countries spanning four continents, as shown in Table 1. The study involved collection of data via newspaper archives, including 1,345 articles from 883 unique sources. They have reported that the most commonly causes of snow-related building failures were excessive snow (89% of total incidents), rain-on-snow (13% of total incidents), and building problems (9.0% of incidents). Structural members experience deterioration as building age elapse and may become damaged. A higher percentage of incidents in older buildings were attributed to building problems, including 28% of historic building incidents and 26% of midage building incidents, compared to 5.4% of new building incidents in the U.S. dataset (Geis et al., 2012). Failures due to melting snow, drifting snow, drainage issues, and people on the roof were also reported

Ghacem Portland cement (Ghana Grey) procured from Ghana and Portland cement (UK Grey) and Snowcrete white Portland cement (UK white) purchased from UK. Clay-free was used as sand and obtained from Portsmouth, UK. The water used was from the Civil Engineering laboratory tap of University of Portsmouth, UK. The assessment was done by comparing the strength properties namely compressive strength, water absorption and dry density of Type I cements from UK and Ghana, in order to find out whether Ghana's cement is of sub-standard or not. They concluded that the quality of Ghana cement is comparable to that of UK, and therefore may not be a contributing factor of building collapses in Ghana. They asserted that further studies on the quality of sand, standard of cement to sand mix ratio in Ghana and the quality of other building materials namely reinforcement bars, timber, aggregate and water are still needed in order to identify which material is of sub-standard and contribute to the collapse of buildings in Ghana.

In the same vein, Boateng and Danso (2013) reported that the UK Portland cements (white and Grey) particles are the fineness, with the white being finer than the Grey. The UK Grey cement is deeper in colour than Ghana Grey cement. The Alkali ($Na_2O + K_2O$) content in Ghana cement is more than UK cements while the calcium oxide (CaO) content in UK cements exceeded that of Ghana cement. Alinaitwe and Ekolu (2014) opined that the causes of collapse of structures in the construction phase among others are: (a) poor materials and workmanship, (b) design and construction errors, (c) absence of professional supervision of site-works, (d) wrong implementation of construction methods, (e) neglect of design approval procedures. They asserted that if the right procedures are followed in the design, construction and operation of the structures, construction failures can be prevented. A study by Kioko (2014) on the causes of building failure, identified the use of poor concrete mix ratio, poor reinforcement, cost cutting by contractors by changing recommended concrete mix or reducing the amount of reinforcement recommended, among others as the causes of structures collapse in Kenya.

Tchamba and Bikoko (2016) conducted an investigation on ‘‘Failure and Collapse of Building Structures in the Cities of Yaoundé and Douala, Cameroon from 2010 to 2014’’. The methods employed in the collection of data included the administration of questionnaire to professionals in the building industry (professional engineers, architects and construction professionals), site inspections and case studies for the sites. The data collected were analysed using descriptive and analytical statistics. They reported that the causes of building collapse were: absence of soil investigation and foundation, structural design, detailing, degradation due to environmental factors, use of poor quality materials, concrete processing, excessive loading .

3. VARIOUS RETROFITTING METHODS FOR REPAIR AND REHABILITATION FOR CONCRETE FAILURE

Concrete can fail under compression, tension, torsion or flexure. Any failure is possible depending on the kind of loads under which the concrete is exposed. As concrete is weak in tension, tension failures are quite prominent and one needs to study fracture mechanics to understand the actual manner in which concrete fails. Material limitations, design and construction practices, and severe exposure conditions can cause concrete to deteriorate, which may result in aesthetic, functional, or structural problems. Concrete can deteriorate for a variety of reasons, and concrete damage is often the result of a combination of factors.Despite its durability, concrete can be damaged and degraded by a long list of factors, such as-

- Insufficient reinforcement
- Chloride attack
- Chemical damage
- Carbonation
- Weather exposure
- Impact damage
- Excessive loads
- Structural damage
- Fire damage
- Seismic damage
- Blast damage

All structures, and all engineering products, will eventually fail overtime. Buildings, in particular, are not expected to last for a very long time without periodic maintenance. These periodic maintenance (which may occur for every 6months, a year or more) are carried out to put a check on all structural failures that could have surfaced on the structures during the time of its utilization (for whatever purpose it was built for). Engineers usually recognize the need to attend to failures on time before it results in catastrophes. In this regard, discussed below are few of the techniques of repair and rehabilitation of concrete structures.

Various types of retrofitting methods for repair and rehabilitation of concrete structure failure

Guniting

Guniting is mechanically applied material consisting of cement, aggregates and water. The cement and sand are batched and mixed in the usual way and conveyed through a hose pipe with the help of compressed air. A separate pipe line brings water under pressure and the water and cement aggregate mix are passed through and intimately mixed in a special manifold and then projected at high velocity to the surface being repaired.

Shotcreting

Shotcrete is defined as "mortar or concrete pneumatically projected at high speed onto a surface" (American Concrete Institute, 1990). There are two basic types of shotcrete—dry mix and wet mix. In dry mix shotcrete, the dry cement, sand, and coarse aggregate, if used, are premixed with only sufficient water to reduce dusting. The two types of shotcrete produce mixes with different water contents and different application characteristics as a result of the distinctly different mixing processes. Dry mix shotcrete suffers high dust generation and rebound losses varying from about 15 percent to up to 50 percent. Wet mix shotcrete must contain enough water to permit pumping through the delivery line.

Concrete Stitching

Stitching is a rehabilitation method used at cracks to maintain aggregate interlock and provide added reinforcement to minimize the relative movement of concrete slabs at the cracks. It is also used at the longitudinal joints to keep the slabs from separating. There are three types of stitching used; cross-stitching, slot-stitching, and U-bar stitching. The stitching procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the staples in the holes, with either a non shrink grout or an epoxy resin-based bonding system.

Resin Injections

Resin Injections are designed for injecting cracks in concrete and masonry where there is a need to consolidate a structure or exclude water and air from contact with reinforcement. Cracks greater than 0.2mm in width are injected with Low Viscosity resins. If a crack is clean, free of impacted debris or paint, and 0.088 in. (2.2 mm) or greater in width, pack the epoxy into the crack. No surface preparation, other than perhaps blowing loose particles from the crack, is required. Work the resin (a slick gel works best) into the crack using a flexible metal or plastic spatula. The seal should be placed to a minimum depth of twice the crack width. Packing the seal is faster and easier than shaping a cap over the crack. It also consumes a fraction of the material, yet is stronger because the epoxy is bound in shear by the rough sides of the crack. In fact, the concrete will give way before a packed seal will. Another plus is that there is no protruding seal to be removed after injection.

Dry packing

This is the method of ramming into a confined area a mixture of portland cement, aggregate, and enough water to make it moist. It is usually used as a method of repair. Thorough curing is required. This method is used for repairing holes having a depth nearly equal to greater than the least surface dimension, i.e. for any holes and narrow slots cut for the repair of cracks. This method is not used for shallow depressions; for filling patches where reinforcement is exposed or holes which extend through and through walls or beams For better results and when water tightness is a requisite, the holes should be sharp and square at the surface edges, but corners within holes should be rounded. Holes for dry packs should have a minimum depth of 2.5 cm.

Polymer impregnation

Polymer impregnation has been proven to increase environmental and mechanical resistance of tuff (a soft volcanic rock), suggesting its potential application for restoration of monuments or reinforcement of structures. Polymer impregnated concrete is one of the widely used polymers composite. It is nothing but a conventional precast concrete, cured and dried in an oven or by dielectric heating from which the air in open cells is removed by vacuum process. Then a low viscosity liquid monomer or pre polymer partially or fully is impregnated or diffused into the pore system of the hardened cement composites or cement concrete and then polymerised using radiation or by the application of heat or by chemical initiation. The partial or surface impregnation improves the durability and chemical resistance, but the overall improvement in the structural properties is modest. On the other hand in depth or full impregnation improves structural properties considerably.

Vacuum impregnation

The metal casting process is very sophisticated, but it still has inherent imperfections. When liquefied and injected into a mold, metal creates gas bubbles that get trapped inside the molded form as the metal solidifies. Gas bubbles create air pockets, folds and inclusions. Depending on their size and their random placement within the casting, this porosity can cause metal parts to leak when placed under pressure. Herein comes, Vacuum impregnation. This technique seals porosity and leak paths that form during the casting or molding process. Vacuum impregnation stops casting porosity and allows manufacturers to use parts that would otherwise be scrapped. Vacuum impregnation is the preferred method to seal porosity in order to prevent fluids or gases from leaking under pressure.

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Impact Factor: 5.725

Autogenous healing

Autogenous healing is the natural process of crack repair that can occur in concrete in the presence of moisture, and the absence of tensile stress. The repair is by a combination of mechanical blocking by particles carried into the crack with the water and the deposition of calcium carbonate from the cementitious material. Autogenous healing has practical applications for closing dormant cracks in a moist environment, such as may be found in mass structures and in water retaining or watertight structures.

Drilling and plugging

This method consists of drilling down the length of the crack and grouting it to form a key. A hole, typically 50 to 75 mm in diameter should be drilled, centered on and following the crack. The drilled hole is then cleaned, made tight and filled with grout. The grout key prevents transverse movements of the sections of concrete adjacent to the crack. The key will also reduce heavy leakage through the crack and loss of soil from behind a leaking wall. When structural strength is not the criteria but water- tightness is essential, the drilled hole, should be filled with a resilient material of low modulus in lieu of grout. If the keying effect is essential, the resilient material can be placed in a second hole, the first being grouted.GunitingShotcretingResin Injections Dry packing Polymer impregnation Autogenous healing

Epoxy injection

The injection procedure will depend on the application and location of the crack. Horizontal, vertical, and overhead cracks require different approaches. Size and accessibility of the crack shall also be considered. Depending on the specific requirements of the job, crack repair by epoxy injection can restore structural integrity and reduce moisture penetration through concrete cracks. As for all repair procedures, surface preparation is the key to crack injection. Depending on the condition and location of cracks it must be cleaned from foreign matter and any loose or damaged concrete shall be removed. The surface where the injection takes place must be strong to take the pressure of the injected resin. Proper sealing of the crack surface is necessary to avoid losses during injection. Follow the instructions, given in the manufacturer's product literature.

Polymer concrete composite usage

Polymer concretes are a type of concrete that use polymers to replace lime-type cements as a binder. In some cases the polymer is used in addition to portland cement to form Polymer Cement Concrete (PCC) or Polymer Modified Concrete (PMC). Polymer concrete may be used for new construction or repairing of old concrete. The adhesive properties of polymer concrete allow repair of both polymer and conventional cement-based concretes. The corrosion resistance and low permeability of polymer concrete allows it to be used in swimming pools, sewer structure applications, drainage channels, electrolytic cells for base metal recovery, and other structures that contain liquids or corrosive chemicals. It is especially suited to the construction and rehabilitation of manholes due to their ability to withstand toxic and corrosive sewer gases and bacteria commonly found in sewer systems. Unlike traditional concrete structures, polymer concrete requires no coating or welding of PVC-protected seams. It can also be used as a bonded wearing course for asphalt pavement, for higher durability and higher strength upon a concrete substrate, and in skate parks, as it is a very smooth surface. Polymer concrete has historically not been widely adopted due to the high costs and difficulty associated with traditional manufacturing techniques. However, recent progress has led to significant reductions in cost, meaning that the use of polymer concrete is gradually becoming more widespread.

Routing and Sealing

This is a common technique for crack treatment and is relatively simple in comparison to the procedures and the training required for epoxy injection. The procedure is most applicable to flat horizontal surfaces such as floors and pavements. However, this method can be accomplished on vertical surfaces as well as on curved surfaces. This technique is used to repair both fine pattern cracks and larger, isolated cracks. A common and effective use is for waterproofing by sealing cracks on the concrete surface where water stands, or where hydrostatic pressure is applied.The sealant may be of several materials, including epoxies, silicones, urethanes, polysulfides, asphaltic materials and polymer mortars. Cement grouts should be avoided due to the likelihood of cracking. For floors, the sealant should be sufficiently rigid to support the anticipated traffic.

Strengthening of existing structure

The seismic behaviour of old existing buildings is affected by their original structural inadequacies, material degradation due to time, and alterations carried out during use over the years such as making new openings, addition of new parts inducing dissymmetry in plan and elevation, etc. Commonly, strengthening procedures should aim at one or more of the following objectives, which are- increasing the lateral strength in one or both directions, by reinforcement or by increasing wall areas or the number of walls and columns, giving unity to the structure by providing a proper connection between its resisting elements, in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that have the ability to resist them, eliminating features that are sources of weakness or that produce concentrations of stresses in some members. Asymmetrical plan distribution of resisting members, abrupt changes of stiffness from one floor to the other and avoiding the possibility of brittle modes of failure by proper reinforcement and connection of resisting members.

Cracking Repair by Prestressing Steel

When a major portion of a member is to be strengthened, or a crack is to be closed, post- tensioning is often the desirable solution. The technique uses prestressing strands or bars to apply a compressive force. Adequate anchorage must be provided for the prestressing steel. The method of correction is crack in slab and beam.

Beam Jacketing

Before taking up the strengthening of a beam, the load acting on it should be reduced by removing the flooring tiles and bed mortar from the slab. Props are erected to support the slab. After clipping off the existing plaster on the beam, additional longitudinal bars at the bottom of the beam to- geather with new stirrups are provided. Stirrups are inserted by making holes from the slab. The longitudinal bars are passed through the supporting columns through holes of appropriate diameter drilled in the columns. The spaces between bars and surrounding holes are filled with epoxy grout to ensure a good bond.

4. CONCLUSION

Concrete is typically designed for the compressive strength and has significantly lower tensile strength. If the internal tensile stresses are greater than the tensile strength of the concrete, a crack can develop. Excess water in the concrete mix can also increase the probability of cracking. When placing the concrete, avoid adding extra water to the mix. The excess water will evaporate from the concrete which will lead to increased shrinkage. Make sure that you choose the proper concrete mix for your project. If any disruption appears on your concrete structure, choose the retrofitting method best fitted for your work, with expert advice.

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