Structural Audit, Repair and Rehabilitation Techniques

Pankaj Lipte[1], Abhijit Galatage[2]

[1]P.G Student, Department of Civil Engineering, Savitribai Phule Pune University, Maharashtra, India
[2]Professor, Department of Civil Engineering, Savitribai Phule Pune University, Maharashtra, India

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Abstract - Structural Audit is a technical survey of an engineering structure to assess its health. Evaluation of current vague practices of Structural Audit paved way to understand the drawbacks of those processes and modify the same for methodical implementation of Structural Audit. This research aims at understanding the drawbacks if any in the current procedure, recast the structural auditing process and propose some improvement measures to the governing body. Structural audit is the technical survey of the building in order to check its strength and stability. Structural audit is the first step in repairing procedure of the building. Structural audit is generally recommended for older buildings. Structural audit was first introduced by Indian society of structural engineers. Structural audit helps in improving the safety, efficiency and gives idea about the strength of the structure by detailed technical inspection. In present study attempt have been made to carry out structural audit of the old RCC building by carrying out site inspection, performing NDT on the structure. Building is modelled and analyzed using ETABS and Demand to capacity ratio is determined. After checking strength and stability of the structural members suitable recommendations are given in order to retrofit unsafe structural component. Finally structural audit report is prepared for the building. This paper also deals with the repair rehabilitation measures that are to be enacted after the Audit and prepare an advanced operating procedure for Structural Audits.

Key Words*: *Structural Audit, Non-Destructive Test, Repair, Rehabilitation.

1. INTRODUCTION

The need of structural audit is for maintenance and repairs of existing structures whose life has exceeded the age of 30 years to avoid any mishaps and save valuable human life. The concrete is widely used as construction material being inexpensive, easy for construction, applications and because of it high strength-cost ratio. More than ever, the construction industry is concerned with improving the social, economic and environmental parameters of sustainability. In India, from 1980 onwards the infrastructure industry witnessed stepping up of public investment and growth in infrastructure industry which results in construction of new multi-storey concrete apartments which are now in the age of thirty plus years. There are many buildings during this period and earlier have reduced strength in due course of time because of structural deficiency, material deterioration, unexpected over loadings or physical damage. If, further use of such deteriorated structure is continued it may endanger the lives of occupants and surrounding habitation. There is demand of appropriate actions and measures for all such building structures to improve its performance and restore the desired functions of structures which may leads to increase its functional life. The periodical structural auditing and diagnosis for health of existing buildings is thus utmost important for finding the present serviceability and structural viability of structures. The structural audit must be carried out following auditing norms, methods of non-destructive testing and code provisions. The structural auditing will help to implement maintenance and repair work timely which leads to prolonged life of the building and safety of the occupants.

1.1 Research Objectives

a) Performing a Structural Audit of the building.
b) Evaluating various retrofitting options, materials, feasibility and economy.
c) Performing structural calculations and capacity demand ratio for structural members.
d) Suggesting retrofitting/construction system and getting the rehabilitation of the building done.
e) Post retrofitting tests on the building.

1.2 Methodology

A Norm According to the model bye-law no. 77 for co-operative housing societies, it is mandatory that if the age of a building is 15 to 30 years, a structural audit must be carried out once in five years and for buildings older than 30 years it should be carried out once in three years. One may however, go for it even earlier if one suspects the condition of the building to be bad. Perhaps monsoon/ post monsoon is the best time to commission a structural audit since the seepage is more evident at that time. The certificate, issued by a structural engineer registered with BMC, will have to be submitted within a year after a building completes 30 years. For any corrective repairs suggested by the commissioner, the owner or occupants will be asked to submit the structural stability certificates again after a specific period suggested by him. If found unsafe, he has been given the authority to issue a notice to the owner to submit a structural stability certificate within 30 days from the date of notice. It will be binding on owners to carry out corrective repairs to the satisfaction of the commissioner.

2. METHODOLOGY AND INVESTIGATION

Conditional survey is an examination of concrete for the purpose of identifying and defining area of distress. The objective of condition surveys of a building structure is are to identify the causes of distress and their sources. To assess the extent of distress occurred due to corrosion, fire, earthquake or any other reason. To assess the residual strength of the structure. To priorities the distressed elements according to seriousness of repairs. To select and plan the effective remedy. Stages for Condition Survey to be carried out such as Preliminary inspection, Planning, Visual inspection, Field and laboratory testing.

2.1 Structural Audit

Case Study of monsoon affected G+4 floor RCC building of age 27 years at Pune.

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

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

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

D. External observation: Structurally the building appears to be unsound and few structural members show major distress signs at external face & internal area of the building. The Building is of RCC frame and brickwork / block masonry. RCC columns and beams show corrosion based cracks at many places. The exterior face of the building shows cracks, crazing, and delamination in plaster. Beam & column adjoining to wall delamination is noticed at various places on the facade of the building. All these defects propagate to seepage and leakages. Seepage near any R.C.C. members leads to further propagation of defects like rebar, corrosion, etc. Other important problem in the building appears to be the seepages from the dead walls & entire exteriors, more prominent on the south & west sides of the building. The level of damage is more on the account of the south west sides due to atmospheric direction of monsoon. Due to these problems, the condition of the building appears to be quite leaky and structural distress is observed in most of the corner columns & beams.

E. Plaster observation: External plaster acts as a skin on the RCC frame and the brick / block work, the most vulnerable part is the joints between the RCC and brick work. Major cracks observed accelerating the passage of water through the wall resulting in seepages inside flats. The building is crack filled but not painted; which has to be attended periodically to avoid further distress in the building. At many places joints between RCC members and brick / block work have separated and water is found to be seeping inside. Most of the plaster in the building sides which are not exposed to monsoons directly, the extent of seepage is lesser than the side's facing monsoon. Due to forces of weather and carbonation in some places, plaster has deteriorated.

2.2 Recommendations

a. Looking into all aspects of the building maintenance and as per our detailed survey, we suggest that the building needs to be thoroughly repaired and painted in a planned manner.
b. For any RCC framed structure the RCC components are like the bones in a body and hold the entire load of the body and any damage to the same has to be rectified immediately and cannot be left unattended for long period of time.
c. To bring the RCC components to their near original strength the same have to be repaired by polymer modified mortar method.
d. The RCC members originally deteriorated due to ingress of water and to prevent it happening again all sources of leakages must be stopped completely.
e. Plaster acts like a skin to the bones in a RCC structure, but the skin also needs to have a raincoat and the same is provided by a good quality resin based coating.
f. To stop the ingress of water the following steps have to be taken.
g. Structural Repairs (Wherever Necessary).
h. External Plaster (Patch)
i. Crack Filling/Joint Filling.
j. External Drain down take Plumbing.
k. Terrace waterproofing by using non-destructive method.

3. RESULTS AND DISCUSSOIN

Sustainable development has become the challenge for humanity particularly with rapid growth of urbanization. Critical issue is to provide food, shelter and other basic needs to rapidly growing world population and save natural resources on which the very existence of population depends. We have got wide variation in the Perception of responsibility to future generations and ethical issue. There is an urgent need of us the professional to understand and implement cleaner production and sustainable development and maintenance objectives at all level of responsibility. The buildings in which we live, work, and play protect us from Nature's extremes. Yet they also affect our health and environment in countless ways. The design, construction, operation, maintenance, and removal of buildings takes enormous amounts of energy, water and materials, and generates large quantities of waste, air and water pollution. As the environmental impact of buildings becomes more apparent, a concept called green building is gaining momentum. Green or sustainable building is the practice of creating healthier and more resource efficient models of construction, renovation, operation, maintenance, and demolition. Research and experience increasingly demonstrates that when buildings are designed and operated with their lifecycle impacts in mind, they can provide great environmental, economic, and social benefits. It is worth noticing that most of us talk about energy consumption and pollution because of industry and transport, when about 40% of the total energy produced is consumed by buildings only. Hence sustainability in construction and maintenance has become so important, while developing all civil Engineering Infrastructures. There is a growing National/International concern about the premature deterioration of our buildings/structures, particularly concrete structures. Cement concrete is one of the most widely used construction material and has proved to be almost indispensable to the present day civilization. Though concrete is quite strong mechanically, it is highly susceptible to deterioration and thus gets damaged & even fail ultimately, unless some measures are adopted to counter deterioration. Such measures would enhance the durability of structures. The maintenance of building is a lifelong continuous process. It has been observed that the minimum maintenance of concrete structures require an integral approach which need the introduction of as much preventive measures as possible in accordance with the basic established concept –"Prevention is always better than cure". Repair/rehabilitation/retrofitting is the fastest growing segment of the concrete industry. Across the globe, billions of dollars are spent annually in repair and restoration of distressed concrete structures. Thus selection and evaluation of repair materials and protective coatings is receiving more and more attention among Civil Engineers in the recent past. The new technologies and new repair materials, which have been extensively being used by the advanced countries, are also being tried in developed country like India. This paper highlights the present state of maintenance especially in developing country like India and about the utilization of those new techniques/materials for repair/restoration of the buildings/structures, for long term sustainable development.

3.1 Present state of maintenance repair & rehabilitation:

It is a matter of serious concern of us the civil Engineers, that in some countries, the repair activities of structure done today account for nearly half the total annual expenditure on total construction activities. Such a state of affairs is of great concern mainly for two reasons. Firstly, concrete is, in essence a proven, durable & mostly maintenance free material. This is exemplified by a large number of structures constructed properly more than half a century back & is still in good stead today. Secondly, the know-how of making concrete, which does not need major repair/rehabilitation, is already well documented and is known to us. Inspite of all these, the trend of early deterioration of concrete structure continues unabated. At present there is neither any established existing procedure, mandatory or otherwise, for periodical inspection of buildings/structures and recording the structural defects and symptoms, like cracks, spalling ,corrosion, and deflection of structure, in a logical manner nor any record of structural repairs/rehabilitations carried out, is maintained properly even for public buildings. We have barged into a repair activity without adequate preparation. Persons involved in repair/rehabilitation need to be better civil engineers. In fact repair/rehabilitation/retrofitting activity is a much more advanced application of science and technology involved in civil engineering, which is the most difficult challenge to engineers. We need to opt for new techniques and materials to resolve these difficulties. We have enough options to select from various construction chemicals, minerals, methods for repairs/rehabilitations, the economics etc. to set right the damage. These all are to be considered in totality before deciding upon the repair/rehabilitation/retrofitting strategy and hence required enough background preparation. Replacement of damaged materials is the trend for repair/rehabilitation. Mass scale replacements are convenient repair strategies, which were being followed mostly in developing country like India, as these offer fast turn-over & are more profitable. This is normally a cosmetic strategy, restricted to the facade and offers a sense of safety due to the impressive new looks. The really needed repairs i.e. Structural repairs to the actual load-bearing structural members are often missed. Rather structural distress is camouflaged and buried beneath finishes. Thereby damage syndrome recurs and continues unabated. The ordinary classical methods of repair/rehabilitation. It is often found that in traditional repairs, the same problem may recur fast. Investigations have brought out that the repair measures in such cases failed basically due to two reasons for RCC buildings i.e. Corrosion of steel not being totally removed and Bonding between old and new concrete being inadequate. For repair of any concrete structures, use of construction chemical is very common in advanced countries, for obtaining long term results, which in India is still very much lacking. It is difficult to match the response of the non-repaired and the repaired areas in rehabilitated structures. In India we are yet to opt for new technologies and materials on large scale to resolve the difficulty of attaining durable repaired structures on long term basis. In fact normal periodical maintenance is often very much lacking & thereby requirement of rehabilitation is also increasing.

3.2 Major causes of deterioration of structure:

Concrete normally provides excellent corrosion protection to embedded reinforcement. The high alkaline environment in concrete results in the formation of a protective oxide film on steel bars. However unless concrete is well compacted and dense, it is susceptible to carbonation, losses its capacity to protect reinforcement. The deterioration of typical concrete structure starts from the time it is exposed to the elements of nature, primarily under high humidity, high temperature conditions & variation in temperatures; thus certain parts of structures including roofs and structural elements directly exposed to weather condition, are more susceptible to deterioration. The deterioration of materials such as concrete & reinforcement reduce the strength of the structural members. While elements such as temperature variations, pollution, wind, rains, floods etc. contribute towards deterioration; sometimes changes in environment after construction and changes in functional requirement also contribute towards premature deterioration. Corrosion of embedded steel is the prime cause of damages to the reinforced concrete structures. It is like a "CANCER", which progresses with slow deteriorating process and if neglected or not attended in time, may spread over a large area and cause extensive disintegration/deterioration of structural elements. It may even lead to catastrophic structural failure, in the absence of timely remedial measures. Various causes which create conducive conditions to accelerate/propagate rate of corrosion are as under.

a. Inadequate cover to reinforcement.
b. Use of inadequate grade of concrete for the purpose.
c. Use of rusted steel.
d. Workmanship/workability/compaction, thus leaving concrete porous.
e. Poor Unsuitable ingredients (both coarse & fine aggregate).
f. Use of high W/C ratio resulting in fine hairline cracks in concrete during drying.
g. Use of water containing high incidence of salts/sulphates.
h. Wave action (alternate wetting and drying processes).
i. Presence of harmful gases in the air.
j. Contact with acids/fumes. Exposures to relatively high humidity (>70%).

Apart from these, other main reasons for deterioration of any structure are:-

a. Foundation settlements.
b. Lateral movements.
c. Accidental overload.
d. Poor maintenance during service life.

3.3 Method of repair, rehabilitation & retrofitting:

The techniques and materials used for repair/rehabilitation/retrofitting and maintenance depend upon the extent of deterioration. Construction chemicals/polymers entered the world of concrete during the late Sixties. Today one can say that they are an integral part of many concretes. Broadly, polymers are chemical compounds, which essentially consist of repeating structural units. Though polymers are in use in concrete for quite some time; they are known by the respective roles they play such as admixtures, bonding agents, sealants and so on. Some of the most commonly used polymer-modifiers in concrete & mortar are ethylene vinyl acetate co-polymer, styrene-butadiene co-polymer and acrylic resins. Polymer-concrete composites display several improvements in the mechanical properties, including substantial increase in the strength & modulus of elasticity. In India, though the use of polymers in the construction industry particularly in repair/rehabilitation & maintenance field is growing, we are yet to have our own set of standards & Codes, which can ably guide both the specifier & the customer in their proper use. There is large number of products available in the market. As such there is a requirement of coming up with general guidelines and standard evaluation techniques, which should enable users to make the best use of products available. We all will gain from such a standardisation.

3.4 Requirement & method of retrofitting for structure:

Retrofitting/strengthening is a technical option for improving the strength and other attributes of resistance of building to seismic and other forces. The requirement of retrofitting of any structure is arises mainly due to the fact that old buildings which were designed as per old codal provisions may not be having adequate strength as per requirement of latest codal provisions. Moreover, in certain cases deterioration of concrete of foundation and other structural elements etc. takes place due to various reasons including settlement of soil strata etc. Foundations are a very important part of building. The strengthening is also required, whenever we want to increase any additional floor of a building due to increase in FAR etc. Shoring and underpinning are important in repair/retrofitting of any foundations. Shoring is the forms of temporary support given above the foundation to the existing building to avoid any damage due to collapse of the building during repair/retrofitting. Underpinning is the process of strengthening the foundation of an existing building by repair. The process of strengthening the foundation of an existing building is called underpinning. The main objective of underpinning is to transfer the foundation load to a lower stronger depth. The reason for underpinning can be due to any one of the following.

a. Larger than permissible settlement of the building.
b. Increase in loading.
c. Lowering the level of adjacent ground below the foundation of the building for some construction on the adjacent site.

There are various methods available for underpinning; one is Traditional Methods, others are Needle and pile underpinning of walls, Angle piling and Underpinning of Column Foundations by Jack Pile Method. Further, there are methods available for improving Foundations on Expansive clays also. The Strengthening of RC Beams, Columns and Slabs can be carried out by Plate Bonding, RC Jacketing and by FRP systems. The Strengthening of Columns and Beams can be done also by RC Jacketing. RC jacketing is jacketing with additional layer of steel and concrete. It is one of the simple methods of strengthening of columns and beams. The RC slab Strengthening is carried out by Concrete Overlay. This is applied, where RC slab already constructed but found having structural deficiencies. In India, due to changes in codal provisions particularly for earthquake code, most of the existing old important buildings require retrofitting for structural safety against calamity like earthquake, tsunami and cyclone etc.

3.5 Repair, rehabilitation & materials techniques:

A. Polymer

High strength, resilient materials which have high resistance to attack from chlorides & sulphates are normally used for repair materials. The polymer modified concrete (PMC)/polymer modified mortar, which are commonly used as repair material has following properties:-

a. High compressive strength at early age.
b. Increased flexural & tensile strength.
c. Water tightness
d. Adhesion
e. Resilience, durability & impermeability etc.

The polymer to be used is latex. SBR latex or other equivalent polymer should be used. It imparts the following properties to concrete.

a. High strength
b. Resilience
c. Impermeability
d. Resistance to carbonation & chloride ion penetration.

The polymer is mixed in water prior to addition in cement concrete. The PH value of polymer should be more than 7.5. The 28 days flexural strength should be at least 50 kg/cm2. The minimum compressive strength is 150 kg/cm2 at 3 days & 350 kg/cm2 at 28 days. The split tensile strength should be at least 25 kg/cm2 at 28 days.

B. Classification of Admixtures

The admixtures can be classified according to type of material constituting the admixtures or to the characteristic effects of their use. The Table 1 shows how admixtures used for repair/rehabilitation is classified.

C. Epoxy Mortar/Grouting

Epoxy mortars are used for repair of spalled concrete in underside of slab floor/roof slab & chajjas having damage less than 75mm. Epoxy grouting is used normally for filling of cracks. Epoxy grouting systems have high mechanical strength. They obtain strength only in a few hours and are resilient in nature. Epoxy systems are immune to sulphate & chloride attack and are impermeable. They have got high compressive & tensile strength also. Since epoxy grouting system can be injected into even hair line cracks, effective repairs can be carried out with them.

D. Polymer Coating

For enhancing the life of structure, coatings like IPN (Interpenetrating Network) or other equivalent polymer should be applied on all the concrete surface of the structure. The coating prevents any future ingress of air & harmful chlorides, sulphates etc. into the structure. It thus protects the entire structure from corrosion & spalling. However, these coats are to be applied periodically, normally with interval of 5 years or so, depending on type of product being used.

3.6 Methodology for repair, rehabilitation & retrofitting:

Common Guide Lines:

Presently number of companies is manufacturing various construction chemicals for repair/rehabilitation of civil engineering structures, in India. Various products manufactured by these companies cover all the repair materials available in India. However, their product range & utility varies. In case corrosion of steel has not started but carbonation of concrete has taken place unto reinforcement surface, coating of required thickness can be applied to prevent/retard the carbonation process. Depending upon the severity of carbonation, polymer or epoxy resins or polymer modified mortar concrete provide adequate protection. Such coating also stops penetration of chloride and other deleterious elements. Whenever the process of corrosion has set in, the restoration techniques depend on the extent of damage to the concrete and or steel. But following guidelines are common:-

a. Remove all unsound concrete & expose reinforcing steel all round.
b. De-rust the steel by appropriate methods viz sand blasting, brushing & applying rust removers etc.
c. Restore reinforcement with anchorages i.e. shear connectors, wherever required.
d. Apply tack/binding coat of polymers or Epoxy based materials.
e. Use one of the several stitching techniques to restore concrete to the original surface level.
f. Injection of cement slurry or polymer modified slurry or epoxy of suitable grade to fill up the
g. Pores, internal cracks or segregation.
h. Apply suitable protective coating.

4. CONCLUSION

The repair/rehabilitation/Retrofitting of Concrete repair projects are very challenging, as is true with most repair and renovation projects. Repair/Rehabilitation of concrete structure is comparatively a new subject in India. It is a real challenging task to carry out the repair/rehabilitation work, when structure has already undergone major structural damages/deterioration. As such, there is a requirement of periodical/timely assessment and maintenance with latest available techniques and materials as described in this paper. This will go a long way to arrest deterioration and extend the lease of life to the structure. As the time passes, many more concrete structures will come up for major rehabilitation. Time has come to have a structural auditing of all the old concrete buildings/structures, which were constructed during sixties and earlier. Depending on the severity of the environmental effect, the restorative measures can be selected. In poor country like India, we cannot afford to spend money on replacing the building, which is against implementation of green building concept also. As such selection & evaluation of right repair material and protective coatings will save enormous money & time by reducing the frequent repair costs of already repaired concrete buildings/structures. To modify/improve the properties of concrete or mortar, a large number of polymers/admixtures have been tried and extensively used in other countries. World over polymers/admixtures have been in use for over 45-50 years and their long term behaviour patterns are known. The superiority of polymer modified mortars/concretes over normal mortars/concretes in repair/rehabilitation field is established beyond doubt. In India, such effective polymers/admixtures have only become available during last two decade mainly. Now a number of internationally known and time tested polymers/admixtures are available all over India. However, before using various new polymers/construction chemicals available in the market, one must be familiar with the products and its limitations. Further, the repair/rehabilitation works should be undertaken only after ascertaining properly the cause of deterioration. It is imperative that the Engineer understands the reasons which led to damage and or deterioration prior to developing a repair programme. The underlying causes should be corrected, although it is a difficult process.

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