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Structural Rehabilitation, Retrofitting and Strengthening of Reinforced Concrete Structures

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***Abstract*—**Reinforced cement concrete is getting extensively used for construction of different type of structures for the last one century. During this period, we have constructed many structures like buildings, bridges, industrial structures, pavement, water tanks etc. using this construction material. These structures have been created with huge investment of resources. It is essential to maintain those structures in functional condition. Since deterioration in RCC Structures is a common and natural phenomenon it is required to have a detailed plan, methodology for structural repair and rehabilitation shall be in place for dealing such issues. It is important to know exact reason of distress, type of distress and correct method of repair concrete structures. The different methods of repair are described in paper according to distress category which can be refereed for repair. Major finding of the study is that to protect our structure we need to have maintenance frequency and correct material to be chosen for repair. Also workmanship during repair needs to be taken utmost care for quality repair.

***Keywords*—**Deterioration, functional condition, reinforced cement concrete, resources.

I. Introduction

THIS is reality that for reinforced concrete structures, civil engineers and other discipline does not realized that it needs any periodic attention for its maintenance. As a result, the factors necessary for durability of RCC structures many times not given due importance for construction and maintenance. But on international level now, this topic is drawing attention for all civil engineers. Hence, requirement has been initiated for structural rehabilitation, retrofitting and strengthening of RCC structures. Certain advancement has been made in the field of protection and repairs of concrete structures. [1]

II. Procedure for Structural Protection

A. Material Science

Material is very important for protection and repairs of civil structures. Many construction chemicals nowadays are present for giving protection and for retrofitting of civil structures. Polymer science is new advancement in this field.

B. Conditional Survey/Inspection

It is required to do conditional survey of concrete structures at regular interval/frequency to see the degradation pattern. Structures which are functioning in severe environmental conditions shall be monitored frequently.

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C. Selection of Material

Selection of material plays an important role in repair of the structures. Correct specification, correct chemicals to be selected for repair.

Detailed inspection of concrete structures required to be done to find out the root cause of deterioration of structures. There must be expert and experienced person to visualize the defects along with NDT test to come on the conclusion on structural assessment. Generally, concrete structures deteriorate due to below reasons:

- Corrosion of embedded steel,
- Concrete quality and poor workmanship during construction,
- Concrete strength,
- Environmental conditions,
- Design deficiency,
- Poor maintenance,
- Selection of construction materials.

The compatibility of repair material on existing structure which is to be repaired is an essential requisite for any successful repair. Cement, additive, admixtures, polymers, epoxies have their limitations for repairs

III. Methods of Repair, Rehabilitation and Retrofitting

The decision of repair or replace the structures or its components depend upon the service life of the structure and based on technical and economical evaluation. The selected method shall meet below objectives:

- Ensure structural integrity and reliability,
- Prevent the ingress of distress promoting agent,
- Maintaining health and aesthetics of RCC structures.

Repair strategy to be chosen such that it meets the above objective.

IV. Repair Options

Depending upon the condition of structure we may choose any of the below repair methodology:

- Grouting and crack repair,
- Patch repair,
- Replacement of structurally weak concrete,
- Replacement of spalled concrete,
- Replacement of carbonated concrete surrounding steel,
- Reinforcement strengthening,
- Concrete overlay,
- Structural Jacketing,

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- Polymer repairs,
- Repair in form of carbon fiber laminates etc.

V. Performance Requirement for Repair System

- Strength serviceability and durability,
- Protection of steel,
- Bond with parent surface,
- Dimensional stability,
- Resistance to damages from environment,
- Ease of application and appearance.

VI. Important Factors to be Considered for Selection of Repair Methods

- Type and extent of distress,
- Location of distress,
- Environmental conditions,
- Availability of skills,
- Availability of time and access for repairs,
- Appearance,
- Cost.

VII. Repair Stages

- Concrete removal and surface preparation,
- Fixing suitable form work,
- Bonding coat and suitable repair application.

Expose the cracked / spalled elements completely. Use long sharp chisels of about 16-20 mm dia and hammers up to 2 lbs weight. Remove the complete corrosion of reinforcement with wire brushes (preferably mechanical type). Remove all the loose and damaged concrete particles till sound concrete of uniform texture is visible. Apply rust removers like 'Rusticide SS' or equivalent to the reinforcement to remove the traces of rust. Clean the reinforcement once again with the wire brush. Wash the complete concrete surface including the reinforcement to remove the traces of rust remover. Apply a coat of rust passivator and Cement' or equivalent as per the recommendations of the manufacturers. The concrete surface treated for corrosion shall be patch repaired with Polymer Mortar like as per the manufacturer's recommendations.

- Separation cracks at the junction of masonry and RCC members shall be rectified as:

These types of cracks are noticed almost all structures like sub-station building, office building etc. This is resulted due to dissimilar expansion of material i.e. concrete and masonry:-

- **Procedure for repair of these cracks are as follows:**
- Expose the crack with sharp flat nose chisel and light weight hammers including removal of plaster approximately 6" inches on either side of cracks.
- Clean the cracks by vacuum cleaner.
- Fill the crack with cement modified mortar i.e. 1 part of cement and 3 part of quartz sand with addition of non-shrink additive in the proportion as specified by the manufacturer.
- Required quantity of water need to be added in the mortar to have desired consistency.
- Application of bonding agent (Acrylic Polymer based bonding coat are added advantage) in the proportion as specified by the manufacturer should be applied prior to application of cement modified mortar.
- Replaster the area with the application of fiber mesh on the either side of crack.
- **Cracks exist at the junction of subsequent concrete pours:**

These types of cracks are observed particularly on the RCC wall construction horizontal junction between the subsequent pours as showing the cracks at many locations. These cracks are repaired as follows:

- Open the cracks by making "V" grove with the help of mechanical cutters with least possible damage to the surrounding concrete areas. [2]
- Vacuum clean the cracks.
- Seal the crack after application of polymer based bond coat with polymer modified mortar prepared by mixing of acrylic polymer cement and quartz sand in proportion of 1:5:15.
- Applied mortar must be compacted at the laid position with the help of held vibrators. The application of the mortar shall be continued till the level of sealing material matches with the surrounding concrete surface.
- Air cure polymer mortar as specified by manufacturer.
- The cracks with surrounding concrete of suspect quality and width of crack is more than 2" inches i.e. 50mm shall be filled with micro concrete with the application of bond coat as specified as per the manufacturer recommendations.
- Structural cracks i.e. the cracks other than the separation, corrosion, junction, etc. it exists in the failure zone of structural members. These type of cracks has identified in the data sheet of particular structures shall have to be grouted with low viscous epoxy of standard manufacturer. These cracks are also required to be opened up and to be sealed with epoxy putty. Low viscous epoxies are required to grout the cracks having width less than 0.2 mm with the pressure of 2.5 to 3.00 kg per sq. cm. Special nipples like brass nipples fixed properly along the crack with the help of epoxy putty / M-seal must be used to sustain such pressured injection.
- **Honey Combing, weak areas around the construction joints: [6]**

These areas shall be grouted with cement grouting with addition of non-shrinking additives. Aluminum / PVC multiperforated nipples may be used to carry out the injection operation. The pressure of 1.00 to 1.5 kg per sq. cm may be applied for grouting. Care should be taken to escape trapped air inside the crack; honey combing areas to avoid back pressure.

- **Severely damaged RCC** members **i.e. columns, beams, RCC walls:**

Members which are severely damaged in particular columns of pipe rack structure needs to be stabilized till the completion of entire rectification / remedial measures are carried out. These members shall be stabilized with epoxy mortar in proportion of

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1:6 to 1:8 i.e. one part of epoxy and 6 or 8 part of quartz sand with the application of bonding coat of epoxy.

Care must be taken to remove the dust around the application area with the help of vacuum cleaners as the entire efficacy of the epoxy is depending on the surface preparation.

- **Leakage, seepage through expansion joint:** Faulty expansion material in the joints must be replaced with the similar material with the improved material properties. Various options are available in the market. Area around joints must be closely inspected for the defects and should be rectified prior to the replacement of the joints. Injection grouting a week concrete areas also should be carried out where ever required.
- **Concrete surface exposed to chemical attack:** Concrete surface of various tanks exposed to severe chemical or chemical actions resulted due to various process, must be treated with anti-carbonation chemical coating. External surface of some of the tanks, exposed to chemical environment should also be treated with at the anti-carbonation coating and painting.

Different SMP's shall be available with Civil Department for improving reliability of equipment in safe condition. Audits for the can be done for its implementation at site.

VIII. Root Cause Analysis

RCA for failure is being done for different civil equipment's depending upon its criticality.

IX. Monitoring of Civil Structures in Industry

Identification of all civil structure shall be done and equipment tag to be provided for all civil structure. It is to be uploaded in SAP/Inspection portal system. Based upon inspection frequency set up as per approved document automatically inspection time/history of inspection and repair will be pop up for civil structure in SAP.

This will help in monitoring of civil structure as per fixed frequency of inspection and obviously help in improving the reliability of civil structures.

X. Structural Certification

Civil concrete structures are very critical plant assets & used for support to various equipment, pumps /motors/vessels/pipe supports as a foundation. It is therefore imperative to ensure their indicated value/status is correct & plant can be run safely & with optimum efficiency. [3] For achieving this objective, it is required to verify their functioning from time to time & correct the deviation, if any, found during the inspection and testing. Certification of civil structure integrity need to done by authorize persons & records maintained for future reference & traceability.

Visual Inspection is supported by following NDT Test for interference:

a. Rebound Hammer,
b. Ultra-sonic pulse velocity test,
c. Carbonation Test,
d. Chemical test,
e. Half-cell potentiometer,
f. Compressive strength of core (destructive test),
g. Cover meter test.

XI. Durability Certification Process

Durability certification depends upon distress condition, maintenance practices as well as type of repairs we undertake. Structure durability certification is generally undertaken in 4 different stages to identify the actual problem, so as to ensure that a fruitful outcome is achieved with minimum efforts and at the least cost. The four stages are:

a. Preliminary inspection,
b. Planning,
c. Visual inspection,
d. Field and laboratory testing.

XII. Preliminary Inspection

1) Primary objective of the preliminary inspection is 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 client.*
- *Notes and records of earlier repairs if carried out.*
- *All possible relevant data and information.*
- *The practical restriction in conducting field survey and device methods to overcome the same.*
- *The safety requirement for condition survey team.*
- *Necessary site preparation including access scaffolds, working platforms. The extent and content of survey works. The approx. time required for survey.*
- *The requirement of field testing equipments.*

2) To define the scope of work of filed investigation in consultation with the client.

- Construction details including architectural, structural and as built drawing,
- Exposure condition of structure,
- Apparent cause of distress,
- Record of structural changes if made any.

XIII. Photographic Record

It is always necessary to carry a camera with a flash, during such preliminary inspection to take necessary photographs of the distressed structures and it members

XIV. Planning Stage

Planning stage involves preparation of filed documents, grouping of structural members and classification of damages.

1) Preparation of field documents.

a) Survey objective,
b) Scope of work,
c) Method of survey,

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d) Field and laboratory testing requirement,
e) Maintenance and repair records,
f) Floor plans based on filed measurements.

2) Grouping of the structural members: Soon after the preliminary site visit and perusal of building plans, the structural members shall be grouped as per the type and based on similarity of exposure and condition for proper appreciation of the cause of the distress. For example in a building subjected to normal environment attack, the grouping could be done as under: [4]
3) Classification of Damages: Based on preliminary data collected on site visit the engineer should freeze the interpretation rules and divide the repair classification into five classes as class 0 to class 4, cosmetic repair, superficial repair, principle repair and major repair.

XV. Visual Inspection

Visual inspection is very effective method for evaluation of structure condition. It also helps us in evaluating requirement of maintenance required for the structure as well as tell us the health of the building.

1) Obstruction to visual inspection: false ceilings, carpets, recently done paints, replaster etc. are likely to create obstructions to visual inspection such areas should be analyzed and recorded with due care.
2) Structural system: It is necessary that the engineer should be familiar with the structural system, structural behavior and service ability requirements. In case of non-availability of structural drawings, the existing framing bracing have to be recorded during the inspection.
3) Leakage, seepage due to in-effective drainage system: Water stagnating area in a structure attracts dampness, leakage etc. are subjected to alternate wetting/ drying cycle, such areas are more prone to early corrosion of embedded steel reinforcement. Particularly at terrace floor of the building, dampness due to improper terrace treatment, its slope or in-efficiency of rain water disposal system may not be noticeable to the eyes, but damage continues till spalling of cover concrete takes place, hence efficiency of rain water disposal system should be carefully examined during such inspection.[1]
4) Types of cracks and their patterns: It is generally easy to differentiate various types of cracks and relate them with the cause of distress. The location of cracks and their pattern gives the first indication of the problem. Cracking and spalling and rust staining are the visual indication of corrosion of the steel n the concrete structures. Rust staining in freshly laid concrete is indicative of honeycombed concrete, which could result in severe rusting and deterioration of the concrete at the later stage. A mesh pattern of crack suggests, drying shrinkage, surface crazing, frost attack or AAR.
5) Colours and texture of concrete surface: The texture of a concrete surface may indicate the possibility of a chemical attack and associated with disintegration by leaching. In fire damaged structure the color of the concrete gives an indication of maximum temperature level to which the surface has been subjected.

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

The field lab testing of a structural concrete and reinforcement is to be undertaken, basically for validating the findings of the visual inspection. The program of such testing has to be chalked out based on the record of the visual inspection.

Certification can be done by certified factory inspector or competent civil structural consultant for civil concrete structures after every 5 years.

XVI. Preventive Maintenance of Refinery Structures

Preventive maintenance is a proactive technique to prevent untimely breakdown. Preventive Maintenance is planned maintenance actions aimed at the prevention of breakdown or failures. The primary goal of preventive maintenance is to prevent the failure of structures before it actually occurs. It is designed to preserve and enhance structures reliability by repairing/replacing worn structural components before they actually fail.

The objective of PM for civil structures is:

- To protect Civil Structures from deterioration
- To ensure that civil structures adequately support their assigned missions.

There shall not be any fixed frequency for preventive maintenance of civil structure. Preventive maintenance will be done as per requirement of plant operation against no production loss due to civil structures failure.

Preventive maintenance criteria shall be decided on following inputs:

- Previous structure failure and repair records.
- Requirement and recommendation of different department like Mechanical / Electrical / Instrumentation / plant operation etc.
- Civil Inspection Recommendation.
- External agency recommendation and reports based on distress category provided and NDT results.
- Operating criteria
- Design life of structures
- Ageing mechanism
- Consequences of failures
- Structure criticality and availability.

Preventive maintenance of civil structures shall mostly as per requirements of plants and recommendation of Civil Inspection. Civil Inspection along with plant operation shall decide whether it would cost more for regularly scheduled downtime and maintenance than it would normally cost to operate structure until repair is absolutely necessary. This may be true for some structures; however there should not be any comparison only on costs but the long term benefits and saving associated with preventive maintenance shall also be considered. Without preventive maintenance for example, costs for lost production time from unscheduled structure breakdown will be incurred. Also preventive maintenance will results in savings due to an

increase of effective system service life. Preventive maintenance also depends upon the uses of the structures.

Following points shall must be considered while deciding preventive maintenance:

- Function of the structure
- Degradation Mechanism
- Credible effect and consequences (What would happen if the asset fails, described in physical units?)
- Determine Condition Status (at most recent inspection)
- Estimate Remaining Functional Life (as of most recent inspection date) [5]

Based on above preventive maintenance can be taken up keeping reliability as well as type of repair and estimated cost up to the life cycle of structure. As a result, more insight into and control over the maintenance of structures is desired.

Below three points are important for inspection and maintenance related to structure distress:

1) Technology to discover damage in early stage which leads to serious situation
2) Technology to rightly evaluate present available performance (durability and load resistance performance)
3) Technology to estimate the progress of damage (degradation prediction technique).

Based on inspection and diagnosis from the viewpoint of preventive maintenance is done by Civil Inspection on case to case basis during availability of plant and equipment and also during shutdown. Accordingly, preventive maintenance shall be carried out as a preventive maintenance programme for civil structures.

XVII. Maintenance Strategy of Civil Structures

- Use-based maintenance: Maintenance actions are taken after a certain use (painting/waterproofing/flooring etc.).
- Condition-based maintenance: Maintenance actions are taken after a certain (unacceptable) condition limit is exceeded and noticed (by inspection, monitoring, performance, etc.).

XVIII. Conclusion

Generally, concrete structures are getting neglected in industries. We must have inspection and maintenance at required interval for all industrial concrete structure. Reliability and Durability of structures can be ensured if all care as mentioned in clause can be ensured.

Acknowledgment

This paper has been undertaken as part of improving awareness level project for refineries towards repair and retrofitting methods and for preventive inspection and maintenance plan of civil structures.

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