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Non-Destructive Testing in Distress Structures – An Overview

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Abstract: **Buildings and structures are normally designed for a specified target life based on the functional and economical aspects. Now-a-days it is very common to see the structures, getting degraded and distressed much before attaining their design life. It is due to the fact that the assumptions are made regarding durability of material without knowing the behavior of material completely in real environment. Before taking up the repair & rehabilitation of structures, the causes of distress must be identified as clearly as possible by means of initial visual appraisal, detailed investigations and strength assessment of structures. The various tests are to be carried out to assess the causes & extent of distress, the quality/strength of concrete and adequacy of structure. The paper briefly discusses various NDT techniques such as Rebound Hammer, Ultrasonic Pulse Velocity, Carbonation Test, Rebar Locator Test & Impact Echo Test, from a practical standpoint of an experienced Structural Engineer along with some partial-destructive testing methods of in-situ concrete.**

Keywords: ***NDT Test, Repair and Rehabilitation, Distress, Deterioration, Concrete Structure.***

1. INTRODUCTION

Concrete construction is generally expected to give trouble free service through out 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. The deterioration of structures is a time dependent process caused by several factors such as plastic deformations, interaction with the environment, initial design and construction flaws and accidents like fire and earthquake.

The assessment of integrity of structures consists of not only evaluation of the present concrete strength but also prediction of the cause of deterioration and its future projection. It is a crucial problem to have the correct assessment of concrete strength to enhance the life of the structure. If the cause of deterioration is predicted and a proper assessment of the structure is made, it may be economically feasible to repair the distressed structure and prolong its life.

Assessment of the quality of existing structure can be achieved by conducting in-situ tests on the structure besides visual inspection. These tests have been developed with a primary objective of quickly evaluating the condition of in-situ concrete in structural members. While some of the methods are non-destructive, others are partially destructive. Each method has its own merits and demerits. These methods include mapping of the crack pattern, distress location, crushed concrete, reinforcement bending/yielding etc. Evaluation of existing structure is an essential part of its retrofitting. Evaluation is also required for retrofitted structures to assess the adequacy of the retrofitting.

2. DISTRESS DIAGNOSIS & REHABILITATION OF STRUCTURES

The purpose of distress diagnosis and appraisal of structures is as follows:

- Ascertain the present state of deterioration & distresses in structure.
- Assessment of structural adequacy with respect to (i)Durability (ii)Structural strength (iii) Function / Serviceability (iv) Appearance.
- Estimation of probable deterioration & distress in structures in future.
- Advice for appropriate remedial measures.

Although the approach to the appraisal of a simple structure and that for more complicated structure will differ considerably, however, the following procedure shall be adopted:

- Establish brief
- Check for access & safety
- Undertake initial appraisal
- Carryout desk top study
- Detailed investigations

- Analysis of data
- Identification of damages/problems
- Suggestion for remedial measures
- Consider legal matters
- Preparation & submission of final report

A. Methodologies of Evaluation

Evaluation is generally carried out at two levels:

Preliminary Investigation

Preliminary investigation provides initial information regarding the condition of the structure, the type and seriousness of the problems affecting it, the feasibility of performing the intended rehabilitation. This investigation decides whether the detailed investigation is needed or not as in some cases, the preliminary investigation may determine that it is not desirable to proceed with a further detailed investigation in the case where excessive damage has already so much occurred that the structural integrity cannot be economically restored or the owner's objectives cannot be satisfactorily met. Depending on the project size and complexity, the preliminary investigation can involve the follows;

- Review of plans, specifications, construction records, structural details, repair history etc.
- Conditions assessment of structures
- Measurement of geometry, deflections, displacements, cracks, and other damage
- Nondestructive testing
- Exploratory removal
- Sampling, testing, and analysis
- Preliminary report

Detailed Investigation

Detailed investigations have to be conducted when the construction drawings and the structural details of the building including the specifications about the materials used and the foundation details are not available. In the detailed investigation measurements will also have to be made on the existing building for obtaining dimensions of the building elements. Non-Destructive Testing (NDT) and partial destructive testings are also required for obtaining properties of structural materials i.e. concrete, steel reinforcement and masonry in the representative structural members. These tests may be conducted in the field and in the laboratory. The detailed field investigation is carried out after the preliminary investigation is over, the owner's goals identified and tentatively determined to be feasible. The objectives of the detailed investigation should be properly defined before starting this investigation. Owner should be apprised of the project budgets and costs of the detailed investigation before proceeding with the detailed investigation. The detailed investigation may be divided into following:

- Documentation
- Field observations and condition survey
- Sampling and material testing
- Re-evaluation
- Final report

The findings of the detailed investigation will directly influence the final outcome of the evaluation process, the choices of various rehabilitation alternatives, and ultimately the selection of the appropriate rehabilitation method. Therefore extreme care is required in planning and executing the detailed investigation.

Essential data relating to all defects is as follows.

- Location, type (e.g. crack, spalling, dampness, etc.) and dimensions of the structural member in which each defect or group of defects occur, noting any change in geometry of the member near to the defects.
- Dimensions relationship of defects to reinforcement, movement or construction joints, repairs, modifications or any other features which could help to establish causes. A cover meter should be used to locate the position of reinforcement.
- Whether, and to what extent and in what form (and colour if relevant), any other defects are associated with those being described.
- The environmental in which the defects have occurred (e.g. external and open to rain, buried in waterlogged soil, in centrally heated building, above chlorinated water in swimming bath, etc.). Always bear in mind that environmental conditions may have changed since the damage was done. Recording devices are available.

B. Assessment of Distressed Structures

To assess the quality of concrete, a number of non-destructive, partially destructive and destructive techniques are available. Out of these techniques, Non-destructive tests (NDT) are most suitable for the assessment of concrete structures and for the prediction of the cause of deterioration of the concrete in the existing structure and, therefore, interest in this field is increasing worldwide. With the revolution in electronics world and advent of micro-computers, a large number of sophisticated instruments have been developed for NDT testing. With these tests, it is possible to know in-situ

strength/quality of concrete and the extent of damage & various causes of the distressing of the structure could be precisely identified. Based on the results of these tests, remedial measures to enhance the life of the structures can be suggested. Details of some of the methods, generally used in the assessment of the structures, are as follows:

Rebound Hammer Test

This test is carried out to assess the quality of concrete and to identify the presence of any delamination. It is a quick method for assessing the quality of concrete based on the rebound number. The rebound number, which indicates the hardness of the surface of the concrete, helps to identify surface weaknesses in the concrete and is used to determine the strength of concrete.

The operation of rebound hammer test is that when the plunger of rebound hammer is pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The rebound distance is measured on graduated scale and is designated as rebound number. The various factors such as type of cement coarse aggregates form, moisture presence of carbonation, curing, age surface structure and orientation of instrument affects rebound significantly hence proper calibration is required. Rebound hammer has it owns limitations. If all factors are taken into consideration the strength of concrete may be found up to ±15% accuracy. Further, this method represents the hardness of the surface only and gives no idea about the quality of inside concrete. IS: 13311-1992(Part-2) explains the standard procedure for test and correlation between the compressive strength of concrete and the rebound number.

Ultrasonic Pulse Velocity (UPV) Test

Schmidt hammer test can indicate the quality of concrete, only near the surface where as the UPV test can indicate the quality over a length, through which the pulses are transmitted. It is, generally, used for the measurement of concrete uniformity, determination of cracks & honeycombing, strength estimation and relative quality between members or with in a member. UPV test determines the propagation velocity of a pulse of a vibrational energy through a concrete member. In concrete, this test consists of transmitting electro-acoustic pulse through the concrete medium from one side, receiving the signal from other side, and measuring the transit time over a known travel distance. Transit time depends mainly on elastic modulus of concrete. The direct method of testing, in which transmitting and receiving points are on the opposite faces, is the most reliable from the point of view of transit time measurement, as maximum pulse energy is transmitted at right angles to the face of transmitter.

This method is considered to be a valuable and reliable method of examining the interior of a body of concrete in a non-destructive way. However, the operator must be well trained and the results should be properly evaluated and interpreted by the experienced engineers. The detection of flaws within the concrete is not reliable in wet conditions by this method.

Rebar Locator Test

By this test, bar diameter, cover to reinforcement, spacing of the reinforcement, number of bars and any discontinuity in the bars can be detected. This test is performed using Cover meter which is based on electro-magnetic theory.

Carbonation Test

Concrete is having micro-pores and these pores are filled with liquid, having pH-value as high as 12.5. Thus, Concrete is alkaline in nature. Due to alkaline nature of concrete, steel does not corrode. Calcium present in the concrete react with the moisture which lowers the alkalinity of the concrete (pH-value of about 8.3) thus, reducing the ability of the concrete to protect the steel from corrosion. The outer zone of concrete is affected first, but with the passage of time, carbonation penetrates deeper into the mass. If the depth of penetration becomes equal to the cover of concrete, reinforcement is then prone to corrosion.

Impact Echo Test

This test is very important for assessment of integrity and durability performance of concrete structures. This test can be used to assess the non-visible cracks, voids, honeycombing, delamination etc. in the concrete structure. In the impact-echo method, a transient stress pulse is introduced into a test object by mechanical point impact. The pulse consists of compression (P) and shear(S) waves, which propagate into the object along spherical wave fronts and a Rayleigh ® wave, which propagate along the surface. These waves are reflected by internal defects and boundaries of the object; the reflected waves propagate back to the top surface. At the top surface, waves are again reflected and they propagate into the object. Thus, a transit resonance condition is set up by multiple reflections of waves between the top surface and internal flaws or external boundaries. A displacement transducer located close to the impact point is used to monitor the surface displacements caused by the arrival of these reflected waves.

To successfully identify wave arrivals, a short duration impact must be used, and the impact point and receiving transducer must be located sufficiently far from the edge of a test object so that wave reflections from the edge do not interfere with internal reflections. Once the wave speed is known, amplitude spectra obtained from portions of the slab containing flaws can be interpreted.

Pull Out Test

In the Pull out test, either an insert is cast in the concrete or fixed into a hole, which is drilled into the concrete. Force required to pull out the insert is measured which is correlated with the compressive strength. Although the result relates to the surface zone only, the advantage is that a more direct measure of strength and at a greater depth, compared to the surface hardness test, is available.

Pull Off Test

This test is based on the measurement of the in-situ tensile strength of concrete by applying a direct tensile force. The method is specifically useful in measuring the bond between the overlays. In this test, a metallic disk is glued either to the concrete surface or to the surface of partial core. The force required to pull off the disk, causing tensile failure of concrete, is measured and correlated to the strength of concrete. The test requires the care in preparing surface and can cause difficulty with damp surfaces.

Core Test

Core Test is one of the best methods to assess the strength of the concrete in RCC construction. Compression testing and Petrographic examination of cores, cut from hardened concrete, is a well established and most reliable method enabling visual inspection of the interior regions & direct estimation of the strength. In this method, cores of various sizes & lengths are cut from the hardened concrete by using core cutting machine. These cores are, then, tested for the compressive strength by applying a compressive force.

The results obtained from the other non-destructive tests are generally verified using core test. The main limitations of this test are those of high cost, inconvenience, damage to the structure and localised nature of the results.

C. Rehabilitation of Distressed Structures

The success of repair activity depends on the identification of the exact cause of the deterioration as clearly as possible. Surprisingly, the identification of exact cause of damage is being disregarded many times; resulting further repairs have to be carried out within a very short time. Sometimes the cause is apparent as, for example, in many cases of accidental damage but, more often than not, careful investigation is required. If the cause of deterioration/ damage is properly identified, appropriate repair strategies and methodologies be chosen and implemented for the improvement of strength and durability, thus extending the life of the structure. Repairs of the structure should be carried out as soon as the deterioration of concrete is observed.

The main objective of repair is generally to restore on enhance one or more of the following: (i) Durability (ii) Structural strength (iii) Function/serviceability and (iv) Appearance. Of these four requirements, restoration of durability is by far the most common in repair work. It is also very important to consider whether the repair is to be permanent or temporary before finalizing the repair methodologies. When it is found by the various tests that concrete is porous/honeycombed, this should be treated with pressure grouting. In the pressure grouting process, grout material (generally consist of cement slurry or epoxy) is injected into the concrete under constant pressure. Shotcrete is another way to rehabilitate the structure, in which a dense and firmly adhesive coating is applied over the exposed surfaces. Before shotcrete is applied to any surface, that surface should be thoroughly cleaned.

Following steps are generally used in the rehabilitation of distressed concrete structures:

- Support the structural members properly, if required.
- Remove all loose concrete and expose the reinforcement.
- Clean the surface and exposed steel reinforcement through sand blasting / water jetting or through steel wire brush.
- Provide additional reinforcing bars as per the requirement, if the loss in reinforcement is more than 10%. New and old steel reinforcement shall be coated with anti corrosive paint.
- Apply shotcreting/Polymer concrete for patch repair work and grouting for porous/honeycombed concrete.
- Apply protective coatings over the exposed/repaired surface.

D. Deterioration Normally Observed and Remedial Measures

Distresses diagnosis and rehabilitation of structures has been one of the main thrust areas of CBRI, Roorkee. It is based on the experience gained through various past and on-going research projects. The different types of distress in the buildings are summarised as below;

- Dampness / Seepage through roof, walls, toilet floors, service shaft.
- Deterioration plaster of walls.
- Honeycombed concrete.
- Spalling of concrete and concrete of lower strength.
- Carbonation up to depth of 100 mm.
- Brick masonry in damaged / decayed condition with lost section.
- Poor waterproofing system of roofs, toilets and bathrooms.

- Deteriorated Chajja over windows.
- Damaged RCC roof top water tanks.
- Vertical crack in masonry wall the external staircase wall.
- Leaking ducts carrying water/ sanitation line.

Based on the analysis of data, visual inspection and information provided by concerned client's recommendations for repair and strengthening measures have been suggested and main of those are reproduced below.

Repair of deteriorated/ lost plaster

- Remove all loose plaster from the walls.
- Chip out the decayed brick surface so that all loose material is removed.
- Rake out the masonry joints and clean them properly.
- Apply a bond coat of cement slurry mixed with bond improving admixture over the entire exposed area.
- Seal coat is also to be applied to cover the cracks etc. Reapply the bond coat over the entire area and plaster the area with a rich 1:4 (cement: sand) mix.
- Proper curing should be done for at least 10 days.

Repair of cracked masonry with deteriorated/ lost plaster

- Remove all loose plaster from the walls.
- Chip out the decayed brick surface so that all loose material is removed.
- Rake out the masonry joints and widen the cracks.
- Apply a bond coat of cement slurry mixed with bond improving admixture over the joints which are to be packed with seal coat.
- Reapply the bond coat over the entire area and plaster the area with a rich 1:4 (cement sand) mix.
- If there are larger gaps in corners of masonry joints or cracks-fix nozzles and pressure grout with cement based grout. A time gap of 36 hours should be allowed for setting up of nipples.
- Mix of pressure grout slurry must be added with non shrink compound and polymer bond improving admixtures.
- Fix 40 mm long 3~4 mm dia. anchor/ nails at 300 to 500 mm centre to centre in the packed joint position.
- Apply bond coat after washing and wire brushing the chipped masonry surface and then apply a layer of polymer modified mortar over the masonry in distress area and make it rough.
- Fix a layer of hot dip Galvanized woven wire mesh 20/ 22 gauge ½" x ½" opening over both sides of wall and hold these with the anchors/ nails fixed in the joint positions.
- Apply a coat of cement slurry mixed with bond improving and pore sealing chemical over the area to be treated.
- Ferro cement treatment should be carried out as explained in annexure.
- Proper curing should be done for at least 10 days.

Rehabilitation of Damped Plaster

- Remove the damped/ distressed plaster.
- Rake out the joint mortar – clean this exposed surface properly and repack using seal coat after applying bond coat layer.
- Re-plaster using rich mix.
- Apply coating of water proofing.

Rehabilitation of Spalled of Concrete Roof Slab/Lintel Beam

- Support the roof/beam properly and effectively.
- Remove all loose concrete and expose the reinforcement.
- Clean the surface through sand blasting / water jetting or at least use steel wire brush.
- Clean the reinforcement and provide additional reinforcing bars as per requirement. New and old steel reinforcement shall be coated with anti corrosive paint.
- Fix the grouting nozzle and rebuild the area using polymer mortar layer. Proper compaction shall be ensured.
- Pressure grout after 36 hours and finish the surface with polymer modified mortar.

Repair of Honeycombed Concrete

- Remove the honeycombed concrete wherever visible.
- Clean the exposed area properly.
- Drill and fix pressure grouting pipes in slabs/beams/columns.
- Repack area around the grouting nozzle with non shrink polymer mortar – wait for 36 hours – pressure grout using machine mixed grout. Finish the surface properly with polymer modified mortar.

Repair of Leakage through Toilet Seat

- Remove the old seat and check the joints of pipes for leakage.
- Water proof area around the seat pit with the help of Ferro cement lining of 14 mm thick.

- Re-fix using new pipes with strict care for the joints and pack properly.
- Check all the drainage points and rectify, if any.
- Check all water supply lines – replace all leaking valves, pipes and fittings.

Repair/Replacement of Chhajjas

- Partially deteriorated chhajjas should be cleaned properly and plaster the same with rich mix after applying bond coat.
- Remove all damaged chhajjas above doors/windows.
- Replace either with single stone piece or with precast Ferro cement with M S angles. Maintain proper slope of around 5-10%

Water Proofing Treatment of Roof

- Remove existing old water proofing treatment over the roof terrace.
- Provide new water proofing layer as given below:
- Repair the cracks by epoxy/ cement grouting if any
- Repair the patch with modified cement mortar.
- Apply cement slurry as bond coat.
- Lay 20mm thick modified cement mortar (Seal Coat) for slope correction.
- Lay polyester felt water proofing system as per specifications of reputed firm.
- Top of the treatment should be finished with proof cote elastomeric compound or equivalent in desired shade.
- The joints at parapet walls etc. should be properly sealed and treatment needs to be monolithic.
- Proper golas should be prepared all over the roof edges and proper khurras should also be made.

3. CONCLUSIONS

The appraisal and distress diagnosis is very important for assessment of health of the structure for suggesting appropriate remedial measures. Various NDT methods to assess the strength/quality of the concrete structures have been discussed in the paper. It is important to note that almost all the NDT methods indirectly estimate the concrete strength and strength obtained by these methods, in most of the cases, is comparable. Even then, no single method can be said to be fully reliable and therefore, more than one method should be performed and results should be correlated. It is suggested that NDT tests should be carried by the skilled operators but interpretation of the results must be done by the experts, having experience and knowledge of application of such NDT tests. Some useful suggestions for the rehabilitation of the distressed structures are given. Also, chemicals from standard and reputed companies should only be used. The precautions and mix proportions specified by the manufacturer should also be adhered to.

This paper can be useful tool for selecting appropriate NDT test, equipment and common distresses observed in the building with reference to the rehabilitation measures.

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