Condition Assessment and Structural Repair of RCC Structures - Case Studies

TVG Reddy, Ankit Sharma

Abstract

In the present paper, we have discussed the case studies of condition assessment & repair done on two RCC structures of 40 years old 150 mtrs. high, RCC Chimney and 25 year old Turbo Generator (TG) foundation in Thermal Power Stations located in semi-arid region in India. Condition Assessment study using Non Destructive Evaluation techniques was carried out on both structures for finding out the cause & extend of distress. Repair methodology i.e Surface preparation & Sand blasting reinforcement treatment, epoxy grouting, bond coat polymer modified mortar etc. was proposed based on the test results obtained. Non Destructive Evaluation Techniques like Rebound Hammer, Ultrasonic Pulse Velocity, Core extraction and Pull off Test etc. were also done to verify the effectiveness of repair work.

Keywords: Condition Assessment, Nondestructive Tests, Repair, Repair Methodology

Introduction

Concrete is the most versatile man made building material and assessment has to be initiated when the it has started deterioration in terms of spalling, cracks, corrosion of reinforcement etc. Condition assessment of structures is one of the most important and emerging fields in Civil Engineering. Assessment can be initiated, when there has been a change in resistance of concrete, such as structural deterioration due to time-depending processes (e.g. corrosion, fatigue), also when there will be a change in loading or an extension of the design working life. Assessment can also be carried out to analyze the current structural reliability (e.g. for environmental hazards like earthquake or extreme winds and/or waves). The Non Destructive Evaluation (NDE) of concrete in today’s scenario has received a great importance in terms of practical and engineering value. The first step in concrete repair is to evaluate the current condition of the concrete structure. This evaluation may include a visual inspection of the structure, a review of available design and construction documents, a review of records of any previous repair work, review of maintenance records before any repair work is put in hand, and the cause of damage must be identified as clearly as possible. Because many deficiencies are caused by more than one mechanism, a basic understanding of the causes of concrete deterioration is essential to determine what has actually happened to a particular concrete structure and why.

Finally, Quality assurance/Quality control is considered during repair in order to evaluate the performance of repair materials to achieve a satisfactory repair, with adequate strength and durability.

Case Study of RCC Chimney

The investigated structure is 40 years old 150 mtrs. high RCC Chimney in Thermal Power Station located in semi-arid region. The condition assessment study was carried out due to distress condition of the structure with ageing. During the visual inspection, rust strains were observed at many locations, which gave an indication of the corrosion on rebars. The concrete cover to the reinforcement was delaminated, cracked and spalled (refer fig 1&2). Also the concrete cover was found to be inadequate at many locations. Inspection of the concrete showed honeycombing at few locations that may be due to inadequate compaction at the time of construction. The damage to the exposed surface of RCC Chimney was mostly at the higher elevations.
i.e. above 65 mtrs. No apparent visual distress was observed at lower elevations of the chimney.

Sand blasting was done to clean the prepared concrete surface of all loose, lightly sticking materials, including the foreign materials, loose concrete, aggregate etc. so as to provide a good bond with the applied mortar. Coarse sand conforming to Zone II as per IS 383:2016 was sprayed over the substrate using air compressor having pressure 4-7 Kg/cm².

**Reinforcement Treatment**

After carrying out the chipping, chemical rust remover was applied by brush over the corroded reinforcement surface thoroughly. After 24 hrs. of application the surface was cleaned with wire brush and all the loose particles were removed. Since rust remover was slightly acidic in nature, the reinforcement was washed with water and was allowed to dry. Visual inspection was carried out to verify whether the rust was properly removed or not. Two coats of Anti-corrosion was applied over the cleaned reinforcement by brush @ 5 to 6 sqm per liter. Also two coats of corrosion inhibitors was applied over the concrete @ 4 sqm per liter.

**Epoxy Grouting**

V-cuts of size 10 mm x 10 mm and fixing of Polyvinyl Chloride (PVC) nipples after drilling holes @ 300mm c/c was done along the cracks. Subsequently sealing/closing the V-cut using epoxy mortar was done one day prior to carrying out injection grouting (refer fig 3). Epoxy was then grouted into the cracks with pump at a pressure of 3-5 kg/cm² (refer fig 4). In case of vertical cracks injection was started at the lowest nipple and continued until the injected grout begins to flow out at the next higher nipple. Whereas in case of horizontal locations, the injection was started from one nipple and continued until the injected grout begins to flow out at the other nipple. After minimum of one day, when the system was cured, the nipples were cut.
After the completion of epoxy grouting, cores were extracted on cracked portion to physically verify the depth of ingress of grout material (refer fig 8). Wherever the epoxy grout was found to be filled in the crack, the same was regrouted. The UPV test using surface probing was also carried out over the grouted cracked portion to verify the ingress of grout material (refer fig 9). UPV values were found to vary from 3.70 Km/sec to 4.76 km/sec with an average velocity of 4.34Km/sec that indicated Good quality as per IS 13311:1992 (Part I). The photograph showing the core extracted and UPV test over the crack is shown below.

Bond Coat

Epoxy bond coat was applied by brush over the concrete substrate. It was ensured that the PMM was applied while the bond coat was in tacky condition, however if the epoxy bond coat loses its tacky condition, the same was removed or slightly abraded and second coat of epoxy was applied before placing the PMM. It was ensured that during the application of bond coat the atmospheric temperature was below 40°C. The material was consumed @ 0.5-0.6 kg/sqm.

Polymer Modified Mortar

Building up the profile of structural member up to required depth by using SBR latex conforming to ASTM C1059 Type-I in damaged areas (1 Cement-3 part graded cleaned river sand + 15 % latex by weight of cement) with 0.35 w/c ratio, in 15-20 mm or 10-15 mm thick layers by applying bond coat between successive/each layers was done. Polypropylene fibers were also added to reduce shrinkage in PMM. Proper curing was done for the repair work. Gunny bags were used for effective curing if needed. 3 days of wet curing followed by air curing was done. A bonding coat of SBR (Styrene Butadiene Rubber) Polymer (@10% of cement weight) modified cementitious bond coat was applied between each layer of polymer modified mortar. Such bonding coat was not allowed to dry before application of new layer of mortar.

Non-destructive testing i.e. Rebound hammer and UPV test was carried out using random sampling technique over the PMM (refer fig 5 & 6). The test results as obtained over the PMM are shown in Table 1:

<table>
<thead>
<tr>
<th>Location</th>
<th>Compressive Strength based on rebound hammer test (N/mm²)</th>
<th>UPV test results in km/sec (Surface Probing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 @ EL+ 105m</td>
<td>41.5 to 43</td>
<td>2.86 to 3.42</td>
</tr>
<tr>
<td>L2 @ EL+ 105m</td>
<td>38 to 41</td>
<td>2.68 to 3.01</td>
</tr>
<tr>
<td>L3 @ EL+ 100m</td>
<td>39</td>
<td>2.60 to 3.42</td>
</tr>
</tbody>
</table>

Note: As per clause 5.4.1 of IS 13311:1992 (Part I), surface probing in general gives lower pulse velocity than in case of cross probing and depending on number of parameters, the difference could be of the order of about 1 Km/sec.

Pull off Test

Pull off testing was done to check the bonding of new material with substrate. Locations for the Pull off testing were randomly identified and 50mm dia cores were drilled.
and metal disc was adhered at two different locations (refer fig 9). The results of Pull off test indicate that the bond strength was greater than the tensile strength of the overlay mortar. The test setup of the pull off test is shown in figure below.

Also the core was extracted once again over the surface where the PMM was recast and the quality of the mortar was found to be satisfactory by this time (refer fig 10).

Procedure for application of GFRP system included: (a) Surface preparation of all affected area of RCC column using mechanical grinder to smoothen the surface was carried out. (b) Application of Primer over the prepared surface, followed by. (c) Application of thixotropic putty to fill the holes and uneven surface (d) Application of 900 gsm GFRP wrapping to Strengthen the concrete around the cracked portions by wrapping chimney stack in desired orientation using tamping roller to avoid any air voids. (e) After application of GFRP Wrap, a coat of epoxy saturant was applied after a minimum of 12 hours. (g) Finishing the surface was done using 10mm thick PMM.

Fibre Wrapping

Excessive moisture in concrete at the time of coating can destroy the performance of protective coating systems by causing blistering and detachment of the film. Hence it is necessary to measure moisture content in concrete prior to application of any coating.

ASTM D4263-2005 describes a method for Indicating Moisture in Concrete by the Plastic Sheet Method. This is a nondestructive test that requires firmly taping the perimeter of a sheet of plastic to the concrete and allowing it to remain in place for a minimum of 16 hours. At the end of the exposure, the underside of the sheet and surface of the concrete was visually examined for the presence of moisture. After the sheet was removed from the concrete surface, no apparent excessive moisture was noticed. Acceptance criteria are not explicitly stated in the standard, but coatings are typically not applied if the test indicates that moisture is visibly present.

Before applying the protective coating, the moisture content was also measured using Humidity meter. The value of moisture content is obtained with the help of graph between Specific resistance and moisture content. The moisture content as obtained from the graph was 5.26%. As per Cement Concrete & Aggregates Australia (CCAA), the concrete is deemed dry enough when the moisture content is not more than 5.5%. Based on the test results, the concrete was deemed dry enough; hence there was no problem in applying the protective coating over concrete.

The chemical resistance coating has to be applied over the top 50 mtrs. height of chimney in three layers to achieve a total Dry Film Thickness (DFT) of 185-215 microns. At lower elevations, Anti-carbonation coating has to be applied with one primer coat of silane siloxane and two anti-carbonation coats to achieve total DFT of 225-240 microns. The thicknesses of the coatings will be measured using wet film thickness gauge. Dry film thickness will then be calculated by multiplying solid content in coating to wet film thickness.
Case Study 2: Turbo Generator (TG) foundation

The investigated RCC structure is 25 years old 210 MW Turbo Generator (TG) foundation with turbine running @ 3000 r.p.m in Thermal Power Plant in India. The TG Deck consist of TG Deck slab and twelve RCC columns having different sizes of 1mx1m (2 columns) & 1m x 1.4m (10 columns). Excessive damage in the form of cracks had appeared in eight RCC columns of TG Decks as shown in Fig 11.

Findings on Cause & Extent of Damage

Based on the visual assessment of distress and tests conducted, it was found that the quality of concrete in the top portion of the RCC columns i.e. portion between horizontally aligned cracks & soffit of TG Deck, was considerably lower as compared to the portions below the level of the horizontally aligned crack. Results clearly indicated the presence of voids/honeycombing in the top portion up to -500mm below TG Deck soffit in various RCC columns. The presence of honeycombing was verified by extracting core samples from the effected portions of the RCC columns.

The poor quality concrete in upper portions of the columns could not withstand the vibrations of TG deck over the period and lead to cracks which in turn increased vibrations and thus further increase in distress.

Execution of Work

To repair the cracked portion & fill the voids in the internal honeycombed portion, the injection grouting of Epoxy-A resin system comprising of resin & hardener having low viscosity of 190-200 cps was carried out through nozzles @ 300 mm c/c @ 6 kg/cm² till firm resistance was received. The firm resistance could be experienced when the Epoxy-A mix rebounds from the nozzle. In this way sufficient quantity of Epoxy-A was injected in each RCC column.

On carrying out UPV testing after grouting operation on honeycombed portion up to -500mm below soffit of TG deck, the UPV values were found to be lower at few points. Therefore it was decided to carry out grouting at nipple spaced @ 150 mm c/c in such portions of the RCC columns for injection grouting using Epoxy B. The epoxy with viscosity 190-200 cps as generally used for filling cracks and voids, was used to fill larger voids and cracks. The epoxy type B which is near water thin with viscosity 3-5cps was used to strengthen the matrix by filling smaller voids. This thin grout gets absorbed in the concrete matrix and improves the poorly placed concrete.

To strengthen the concrete matrix in the portion between 0.5m to 7m below soffit of the TG deck, on the remaining nozzles the Epoxy-B having high molecular weight & very low viscosity (3-5 cps) was injected using pressure @ 5-6 kg/cm² till firm resistance was received. After completion of injection grouting, the concrete was allowed for setting for 24 hours. Protruding grouted nipples were cutoff in line with surface of each RCC column.

After epoxy grouting the surface of RCC columns were smoothened by using mechanical grinder. There after RCC columns were strengthened using 900 gsm Glass fibre Reinforced Polymer (GFRP) Wrapping system (refer Table-4&5). In the six highly distressed/cracked RCC Columns namely C1, C2, C8, C10, C11 & C12, the GFRP wrapping was applied in double layer up to 7m below soffit of the TG deck. For the remaining six RCC columns with minor cracks namely C3, C4, C5, C6, C7 & C9, the GFRP wrapping was applied in double layer up to 2m below soffit of the TG deck.

Quality Control Measures taken up at the Site

Grout Material: As already explained, for filling the inner voids, flaws & cracks two different grades of epoxy were used. Compressive strength and density of two types of epoxy used in filling the voids to strengthen the concrete as obtained in samples of cubes prepared at site is given in Table – 2.
Assessment of Effectiveness of Grouting by Ultrasonic Pulse Velocity (UPV) Testing as per IS: 13311 – 1992 (Part I)

To verify the effectiveness of grouting, Ultrasonic Pulse Velocity (UPV) Testing as per IS: 13311 – 1992 (Part I) was carried out on the grouted RCC columns. Based on the results of UPV testing, quality of the epoxy grouting done to seal the internal voids of concrete portions in terms of quality grading as prescribed in Table 2 of IS: 13311 – 1992 (Part I) was found to be varying from “Good to Excellent” Quality. The UPV observations obtained on all affected locations of RCC columns indicated that the epoxy grouting done on these columns was effective in filling the voids in concrete as indicated by the increase in UPV values. The typical results obtained on columns C11 and C12 at ground floor and first floors are presented in the form of histogram below (Fig. 13).

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Dimension (mm)</th>
<th>Age (days)</th>
<th>Density (Kg/m³)</th>
<th>Load of failure (kN)</th>
<th>Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy-A</td>
<td>50x50x50</td>
<td>14</td>
<td>1136</td>
<td>215.04</td>
<td>86.02</td>
</tr>
<tr>
<td>Epoxy-B</td>
<td>50x50x50</td>
<td>14</td>
<td>1096</td>
<td>229.45</td>
<td>91.78</td>
</tr>
</tbody>
</table>

Table 2. Test result of Epoxy Cube

Verification of Effectiveness of Repair and Strengthening

To verify the performance of the repair and strengthening work carried out to control vibrations, visit was conducted at the site in November 2014. During the visit, no distress was observed in the RCC Members repaired and strengthened using grouting and GFRP technique. (Fig 14-15). The vibrations in the bearing of TG were reported to be within limits. The vibrations in the TG foundations are generally monitored by measuring displacement at bearing levels regularly. The limits for permissible displacements during operation depend upon the excitation frequency, lower rotor speeds permitting higher foundation amplitudes. As per IS/ ISO 10816 part 2, going by criterion II, if vibration exceeds an established baseline substantially, it can be considered as excessive. As per the data provided by plant authorities, the measured values of shaft vibrations displacements which on a day, one month prior to noticing high vibration and cracks, were in the range of 4.4 - 44.2 micron, further increased to 28.0-56.3 micron when cracks were also noticed in columns. The max displacement noticed in bearing was 31.4 micron. After more than six months of repair in November 2014, the vibration displacement values measured for shaft and bearing were reported to be well within earlier established range.
Conclusion

• The repair & rehabilitation of Concrete structures are very challenging, and is comparatively a new subject in India.
• There is a requirement of periodical/timely assessment and maintenance with latest available techniques and materials as described in this paper.
• Condition assessment study using Non Destructive Evaluation (NDE) of concrete in today’s scenario has received a great importance in terms of practical and engineering value, which also help to decide the repair methodology to RCC Structures.
• Testing for the performance of repair materials play an important role to achieve a satisfactory repair, with adequate strength and durability.
• During the execution of repair work, quality inspection should be carried out by qualified/experienced engineers to follow the approved repair methodology and QAP etc.
• In order to increase the efficiency of power plants, Strong and Durable concrete structures are the only option for the trouble free operations

References

1. ACI Committee 548.1. Guide for the Use of Polymers in Concrete, American Concrete Institute. 2008.
2. ACI Committee 548.3. Polymer Modified Concrete, American Concrete Institute. 2003.
3. ACI Committee 548.4R-93, Standard Specification for Latex modified Concrete (LMC) Overlays, American Concrete Institute, 1998.
5. EN 1504: Products and systems for the repair and protection of concrete structures.
14. IS 9103: 1999, Specification for Concrete Admixtures
18. ASTM C882/ C882M - 13a, Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear.