REPAIR, RESTORATION & RETROFITTING OF IN SERVICE CONCRETE STRUCTURES IN POWER PLANTS

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ABSTRACT

Due to inadequate specifications to different deteriorating influences to resist durability, numerous RCC structures constructed during early 80's & late 90's & even upto 1999 in India, till the revision of codal provision on strength and durability as laid down in IS 456:2000, are found to be either in partly or fully distressed conditions. With the objective of enhancing the Residual life of RCC members, condition assessment study needs to be carried out through visual, field and laboratory evaluation of samples collected. The paper pertains to the sustainable solution through repair, restoration & retrofitting of in service concrete structures carried out by NCB. Repair and remedial measures & specifications adopted for restoration of different RCC structures including Turbo Generator foundation & Residential building are given in paper. Based on the analysis of the test data obtained by Non Destructive & Partial Destructive Evaluation techniques, the indigenously available repair and strengthening measures to restore the service life of the structure are described. This covers application of anti-corrosive treatment, epoxy grouting, bond coat, polymer modified mortar as per ACI Committee Report, an anti-carbonation protective coating, unidirectional glass fibre reinforcement polymer (GFRP) wrapping technique using epoxy saturant as applicable to RCC structures.

1.0 Background

Concrete is most widely used man made materials, next only to water with 0.50 cum per person on the planet. Durability represents one of the key characteristics of the concrete that has pushed engineers and designers around the world to innovate. Initially, concrete was regarded as having an inherently high durability, but more recent experiences have shown that this is not necessarily the case unless durability design forms an integral part of the design and construction process. A structural engineer can decide on the size and shape of components and carry out the necessary calculations (or get a computer to do them) and determine load bearing capabilities with great accuracy. No such process is possible with considerations of durability. Clients are now expecting their structures to last longer with service lives for long term repairs they are looking for a 'warranty' from the construction company and, in many cases, giving them contractual responsibilities for long term maintenance.

With aging of infrastructure, many concrete structures in India and abroad are in condition of distress caused by carbonation and chloride penetrated/penetrating into the concrete cover apart from problems of durability caused by freeze thaw, sulphate attack and alkali silica/carbonation reaction. Over a hundred years ago in 1907 Knudson showed in his paper entitled 'Electrolytic Corrosion of Iron and Steel in Concrete' that a passage of a small current through the reinforcement in concrete would cause corrosion. Later on Rosa, McCullom & Peters shared the opinion of Knudson that stray currents were the cause of the problem and concluded that 'the presence of chlorides always facilitated trouble' (Electrolysis of Concrete, 1912). It was not until half a century later (after lab finding by Knudson in 1907), the problem of chloride attack was detected while use of deicing salting became widespread when deterioration of bridge and highway structure were detected.

2.0 Literature Survey of assessment, repair & restoration of concrete structures

Extensive research on the complex phenomenon of deterioration of concrete in service and premature durability issues has been reported around the globe. P.E. Gratten-Bellew[1]studied the microstructure investigation of deteriorated Portland Cement Concretes. D.C.K. Tay et. al. [2] reported the In situ investigation of the strength of deteriorated concrete. Predictive models for deterioration of concrete structures has been studied by P.A.M. Basheer et. al. [3]. Kenneth C. Hover [4] covered special problems in evaluating the safety of concrete bridges and concrete bridge components. A wide range of repair options to repair and rehabilitate damaged reinforced concrete structures is reported by John Broomfield [5]. John Bickley et. al. [6] investigated the Issues related to performance based specifications for concrete. Odd E. Gjorv et. al. [7] carried out the study on the advances in durability design and performance based specifications. The Study on the present and future perspective on maintenance and repair system for concrete structures is reported by Toyoaki Mit Agawa[8]. H. Mihashi et. al. [9] worked for the Establishment of JCI Special Technical Committee on the Great East Japan Earthquake Disaster and its Activity Plan. Satish Sharma et al. [10] reported the Distress Assessment, Repair and Strengthening of RCC members of Turbo Generator Foundation of Anpara Thermal Power Station at Uttar Pradesh (India).A case study on Non Destructive Evaluation and repair and strengthening of corrosion distressed RCC structure was done by Satish Sharma et.al [11]. .A study on Quantities and Durability of concrete for revetment in Gunkanjima Island after long term service has been done by Yoshikazu Akira et. al. [12]. Ryoichi Tanaka et al. [13] studied the Soundness of Histrical Concrete revetment Gunkanjima Island in Japan. Rahmita

Sari Bintirafdinal et al. [14] reported deterioration evaluation and life-extension strategy of 77 year old concrete structure exposed to Indonesian marine Environment. Roberto Torrent et al. [15] studied site testing of Air Permeability as indicator for Carbonation rate in old structures. The study on Influence of construction work condition on the relationship between concrete carbonation rate and the air permeability of surface concrete was done by Kazuaki Nishimura et al. [16].Haixue Liao [17] studied corrosion control of reinforced concrete in corrosive environment. Hirozo Mihashi[18]worked on JCI Guidelines for assessment of Existing concrete structures 2014.

3.0 Retrofitting of In service Structures

What is retrofitting? Retrofitting is method or process for the strengthening of a structure. It is a technique used to enhance the stability & durability of the existing aged structures to prolong their service life. The retrofitting when properly carried out not only increases the economic life of structure but also increases the sustainability of concrete structures.

Reasons for retrofitting:

-Change in the intended use of structure
-Change in prevailing Codes
-Premature distress to structures
-Damage to structure due to aging.
-Protect from disasters.
-Add additional strength to structure.

Strengthening Options & Strategies (as per IS 15988-2013):

Strengthening for improved performance in the future shall be achieved by one of several options given below. The chosen strengthening scheme shall increase the redundancy of lateral load resisting elements to avoid collapse and overall instability.

a) Strengthening at Member Level
Member level modification shall be undertaken to improve strength, stiffness and/or ductility of deficient members that include jacketing by reinforced concrete jacketing, steel profile jacketing, and steel encasement or wrapping with FRPs where possible, the deficient members shall first be stress relieved by propping.

b) Eliminating or Reducing Structural Irregularities
An effective measure to correct vertical irregularities such as weak and/or soft storey is the addition of shear walls and braced frames within the weak/soft storey. Braced frames and shear walls may also be effectively used to balance stiffness and mass distribution within a storey to reduce torsional irregularities. Shear wall shall be placed such that it forms an integral part of load flow path for lateral loads. Minimum two shear wall shall be constructed in each orthogonal direction in opposite side of shear centre away from centre as far as possible to add better torsional resistance to the entire structure. The stiffness centre of the complete structure at a floor level after adding shear wall shall be such that eccentricity with respect to centre of gravity of mass is reduced to a minimum.

4.0 Case I: Investigation on 15 Year Old RC Columns of Steam Turbine Generator (STG) Located In A Power House Near The Sea Shore In India

The typical layout plan of RC Columns located in the power house is shown in fig 1. The subject RC structure was situated at a distance less than 1 kilometre from the seashore and was constructed in the year 1999.As per the drawings, the grade of concrete used at the time of construction was M30. The main objective was to investigate the cause and extent of damage that had occurred due to ageing, using the methodology discussed in the paper.

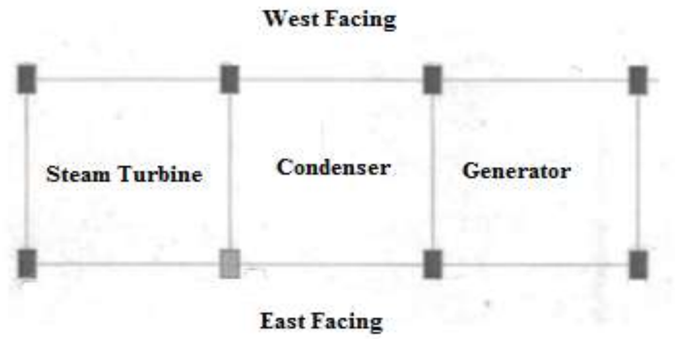


Fig. 1: Typical plan of RC Columns located in power house near sea shore in India

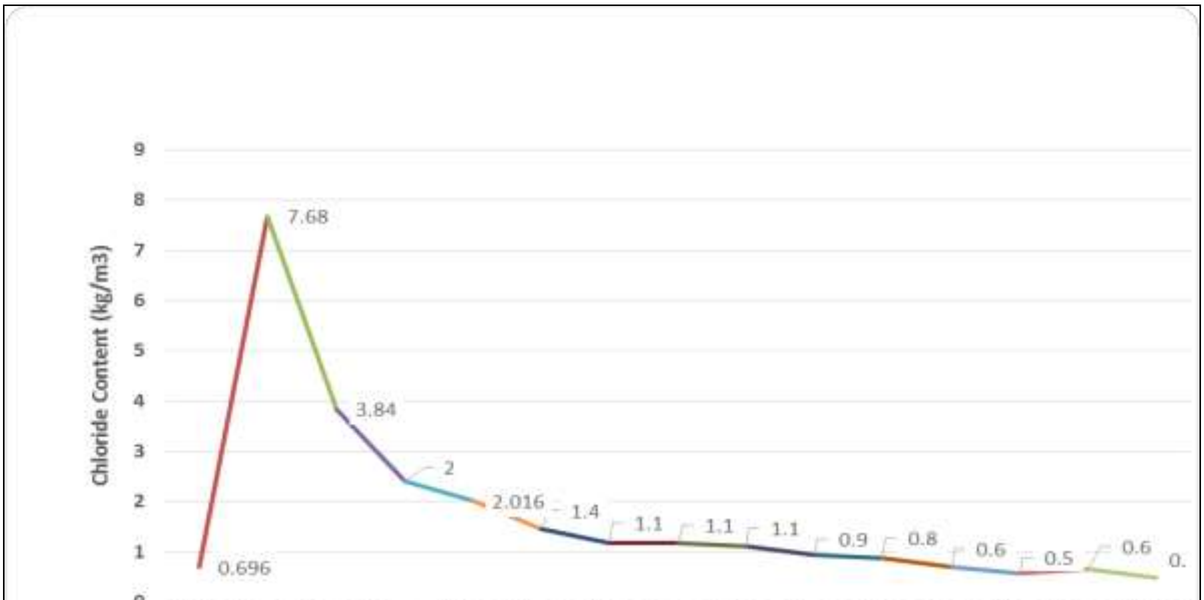
Visual Survey: During the visual survey, distress in the form of vertical cracks, spalling of concrete and exposure of corroded reinforcement was observed at different locations in the RC Columns as shown in fig. 2 & 3. Only two faces of two RC Columns were found distressed due to abrasion/erosion of concrete surface due to constant splashes of sea water leakage from pipes adjoining the RC Columns.

Fig. 2: Shows vertical crack and abrasion of concrete surface in RC Column located in power house near sea shore

Fig. 3: Shows horizontal crack and abrasion of concrete surface in RC Column located in power house near sea shore

Investigations on RC Columns of Steam Turbine Generator (STG): Quality of concrete as obtained by UPV testing as per IS 13311-1992 (part 1) carried out on RC Columns has indicated Good grading. Compressive strength of concrete in RC Columns as assessed as per IS 516 & IS 456, is found to be meeting the specifications of M30 grade of concrete. The results of chloride content on concrete powder samples extracted by drilling cores of 60mm diameter from three different depths of cover concrete (0-20mm, 20-40mm & 40-60mm). The chloride content of the concrete core powder of one of the RC Columns obtained after grinding in layers by profiling was determined at the NCB laboratory and is shown in Fig 4.

During the field and laboratory investigation it was found that the amount of chloride in the cover portion of the concrete was very high and it reduced as the depth increased. The pH values were also found to increase with depth. The sulfate contents were found to be within prescribed limits. The water used was sea water. Test results of water sample drawn from the pipes adjoining the RC Columns indicated excessive chloride, sulphate, organic & inorganic matter was beyond the prescribed limit of IS 456 – 2000.



Core Profile	0mm-1mm	01mm-3mm	3mm-6mm	6mm-10mm	10mm-15mm	15mm-20mm	20mm-25mm	25mm-30mm	30mm-35mm	35mm-40m	40mm-45mm	45mm-50mm	50mm-55mm	55mm-60mm	60mm-70mm
Series1	0.696	7.68	3.84	2.4	2.016	1.464	1.176	1.176	1.104	0.936	0.864	0.696	0.576	0.648	0.48

Fig 4: Test results of chloride content of RC Column located in power house near sea shore obtained after profiling

Repair and Rehabilitation Measures

The repair scheme was developed taking both technical and economic considerations that deteriorated reinforced concrete should be repaired with impermeable highly alkaline cement based materials closely matching the properties of the parent material. Extensive research was carried out to evaluate different methodologies of repair to evolve at the best possible solution to the problem at hand.

After careful observation based on similar work done in India and abroad, following structured procedure for the repair and restoration were adopted.

1. Removal of all soft and loose concrete from the visible distressed portion and chipping using light hammer (2lb hammer)
2. Cleaning of rust wherever required followed by anticorrosive treatment.
3. Applying two component epoxy bond coat conforming to specifications of ASTM C 881 - 13 TYPE II to ensure the effective bond of old substrate obtained after chisel cutting of cover concrete and new concrete.
4. Applying the Polymer Modified Mortar (PMM) to build the profile of structural members in damaged cover portion as per ACI Committee report (ACI 548.3 R-03).
5. Strengthening of distressed RC Columns using indigenously available nonmetallic composite fiber wrapping system.
6. Applying protective coating on surface of RC Columns to protect from the further corrosion to reinforcing bars.

5.0 Case II: Turbo Generator (TG) foundation of Power Plant

The investigated RCC structure is 25 years old 210 MW Turbo Generator (TG) foundation with turbine running @ 3000 r.p.m. While in operation, the TG stopped due to excessive vibrations caused by sudden appearance of cracks (refer fig. 5) on the surface at different locations of RCC columns supporting the TG Deck. The width of crack at the surface of different RCC columns was assessed by using optical Crackscope (refer fig. 6). Width of cracks when measured by using Crackscope was found to vary from 0.5mm to 1mm.

Fig.5: Horizontal Crack in RCC Column C11

Fig.6: Crack width being assessed by using Crackscope at site

Testing of structure

UPV testing was carried out to determine Quality of concrete in RCC columns and for detecting internal discontinuities/flaws in the concrete. This variation in UPV values clearly indicated the presence of discontinuities in concrete of the top portion of eight distress effected RCC columns The quality of concrete was found to vary from medium to excellent. To verify the discontinuity/honeycombing in concrete as indicated by UPV values, few cores were extracted from the effected portion of the RCC columns that verified honeycombing/ voids in concrete. The depth of cracks were determined by using UPV testing technique as per BS 1881 Part-203 that was found to be vary from 8mm to 24mm.

Findings on cause & extent of damage:

Based on the 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.

Repair and Rehabilitation Measures

The main objective of the repair and strengthening of RCC Columns supporting TG Deck was to develop a repair scheme to resist/eliminate the chances of appearance of cracking during operation/functioning of TG for power generation using indigenously available technology.
After careful evaluation it was decided to use multiple epoxy grouting system (refer fig. 7) to fill the large and small voids and to repair the cracks found in the upper portions of columns. But even with extensive grouting, strengthening only could have been achieved and weakness would have remained, strengthening of upper part using GFRP wrapping system was also recommended.

Fig. 7: Grouting being done in Column C11 of TG Deck Unit#1

6.0 Case III: Residential Quarters (Stlit+6 floors)

Distress in the form of cracking, spalling of concrete & corrosion of reinforcing rebar was observed at work site in different RCC members of different blocks of the society. Cracks were observed along the longitudinal direction of reinforcing rebar. Based on the geometric line of cracks, it seems corrosion has caused these cracks. Grit wash applied on the RCC members of different blocks was found to be de-bonded at many locations. Water Proofing was observed to be damaged in terrace. The quarters were 16 years old.

Fig.8: Front view of Housing society quarters

Fig.9: Spalling of concrete & exposure of reinforcement In RCC Beam

Testing of Building

The main objective was to investigate the cause and extent of damage that has occurred due to ageing, using the methodology comprised of (a) visual survey, (b) Determination of Surface compressive strength using Rebound hammer technique as per IS: 13311 (Part – II) -1992, (c) Determination of locations of internal voids/faults in concrete using UPV testing technique as per IS: 13311 (Part – I) -1992 (d) Determination of equivalent cube compressive strength of concrete core as per IS:516 & IS 456 (e) Carbonation study and Concrete cover study using ferro scanning technique (f) Determination of 'Corrosion status' using Half-cell potential survey as per ASTM C876[and (g) Chemical analysis to determine pH value, chloride content & Sulphate content.

Findings on cause & extent of damage:

The test results were analyzed to work out the cause and extent of damage and find out the suitable specifications for repair. Based on Ultrasonic Pulse Velocity & Rebound Hammer testing done on representative samples by random sampling technique on RCC Columns, RCC Beams and RCC Slabs, overall quality of concrete is graded as ' Good' and 'Medium' at some locations. The test results of concrete cores indicate that the equivalent cube compressive strength values for RCC Columns/beams/slabs is found to meet the specified characteristic compressive strength of M20 grade concrete. Based on the half cell potential measurement, corrosion is found to be alarming state in RCC Columns whereas in transit state of corrosion at few other locations. Carbonation is found to be within the cover of concrete. Chloride was found to be beyond the specified value of 0.6 Kg/m^3 as per IS 456:2000. Hence the cause of damage for distress in structure is found to be chloride content. Based on the cause & extent of damage, repair & strengthening measures are recommended.

Repair and Strengthening Measures

In the present investigation most of the distresses in the RCC structural members of service structure are caused by chloride content in concrete, leading to corrosion of reinforcing steel. To carry out repair & restoration of corrosion effected RCC Columns/Beams/Slabs and based on similar work done by NCB, systematic procedure for repairing is suggested. This includes,

(i) Removal of all soft and loose concrete from the visible distressed RCC members and chipping using light hammer (2lb hammer) from RCC Columns/beams and slabs.

(ii) Cleaning of rust from corroded reinforcing steel and providing additional steel bars wherever required to compensate for corrosion losses followed by anticorrosive treatment.

(iii) Applying concrete penetrating corrosion inhibitor (CPCI) as per manufacturer/supplier specifications over the entire finished surface.

(iv) Applying two component epoxy bond coat conforming to specifications of ASTM C 881 - 13 TYPE II to ensure the effective bond old substrate obtained after chisel cutting of cover concrete and new concrete.

(v) Building up the profile using Polymer Modified Mortar in 15-20 mm thick layers with application of bond coat between each layers.

(vii) Strengthening of distressed RCC Columns using nonmetallic composite fiber wrapping system.

(viii) Applying protective coating on surface of RCC Columns/beams/slabs to protect from the further corrosion to reinforcing bars.

7.0 Selection of Repair Materials

Selection of repair material is imperative for the success of repair & rehabilitation process of concrete structures. System approach for the repair as described and testing the materials before and after application is found to be very effective.

Grout Material: The injection of epoxy into structural was done by using pressure grouting technique for restoration of the structural integrity of cracked concrete. Epoxy grout materials having low viscosity less than 350 cps and conforming to ASTM C 881 (Type IV) were used for structural repairs.

Corrosion Treatment: Corrosion of reinforcement being the main cause for the deterioration of the concrete it had to be dealt with caution so that it may not reappear again after the repair is carried out. For this purpose, many literatures suggest use of corrosion inhibitors as well as other anti-corrosive measures. In this case, it was suggested to use non toxic water based organic corrosion inhibitors on the surface of concrete to reduce the corrosion rate of the embedded reinforcing bars. After cleaning the rust on the corroded reinforcement using suitable mechanical or manual means, two coats of sacrificial zinc rich coatings were applied over both the old and the new reinforcements.

Bond Coat: The success of the repair depends on achieving intimate and continuous contact between the repair material and the substrate. Styrene Butadiene Rubber (SBR) Latex bond coat that can be useful for areas subject to high humidity and water immersion was selected. The SBR resins having solid content not less than 48% and qualify the requirements of Type II as specified in ASTM C1059 (Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete) was used. The latex used qualified the requirements of ASTM C 1042 (Standard Test Method for Bond Strength of Latex Systems Used with Concrete by Slant Shear).

Polymer Modified Mortar (PMM): As per ACI Committee Report 548.1 Styrene-butadiene latex-modified mortars and concrete are useful for a variety of applications. For most of these applications, bond to substrate and low permeability are most important. Keeping this in mind, a mix proportion was selected with latex addition in latex solids to cement ratio of 0.15. Using this ratio a typical mix proportion with 1 43 Grade OPC meeting specification of IS 8112 Cement: 3 Coarse Sand meeting the requirements of Zone I sand of IS 383 and having a water/binder ratio of 0.30 was selected. SBR Latex @ 10% by weight of OPC was used in PMM used in RCC repair. The minimum compressive strength to be achieved was 30 – 35 N/mm^2.

E - Glass Fibre Wrapping: Following the repair and re-profiling of damaged concrete in the Fanstack and affected columns, it was suggested to strengthen these members using FRP Wrapping using wet layup system. The surface was cleaned thoroughly with wire brush. A epoxy primer compatible with the substrate was then applied after filling the holes and uneven surface with thixotropic putty. E-glass fibre having a density of 900 gsm was then wrapped to the structural element in desired orientation using tamping roller to avoid any air voids. Over the FRP Wrap, a second coat of epoxy saturant was applied after a minimum of 12 hours and river sand was pasted over it to make the surface rough.

Protective Coating: After the repair and re-profiling of damaged concrete areas, a protective impregnation or protective coating was applied to prevent water and chloride ingress and to provide a barrier against future carbonation. Suitable protective impregnations were selected according to the porosity and exposure of the concrete surfaces. In this case, the surface was cleaned to completely expose the concrete without chipping and without damaging the repaired surface. After cleaning, a coat of penetrating silane siloxane primer was applied over the surface. Over it, two or more coats of ready mixed UV resistant single component aliphatic acrylic polymer based waterproofing and protective coating was applied to minimize further chloride penetration/accumulation.

CONCLUSION & RECOMMENDATION

1. In addition to weakness in load carrying capacity caused by durability problems associated with existing RCC structures in service, our structures in India are likely to be more vulnerable to natural disasters such as Floods, Cyclones, Tsunamis, Earthquakes etc.
2. The Design Standards of BIS pertaining to the earth quake has been revised in 2002 (IS 1893:2002) taking into consideration the dynamics of earthquake, there is need to protect the buildings constructed on stilt columns and lacking the provisions of shear walls
3. For safety point of all such old RCC Structures needs to be rechecked for their stability with present standards of design and durability.
4. Distress caused by the diffusion of chloride and carbonation to cover concrete is a global phenomenon and lot of research has already been carried out in different countries abroad to carry out the repair & retrofitting of structures.
5. Apart from RCC buildings of different categories, heavy engineering concrete structures of power house and dam in India are also in the state of distress. Loss of stability caused by durability issues associated with the quality of cover zone of concrete structures, there is a huge challenge to carry out strengthening & retrofitting of these structures after their assessment.
6. To find out durable and sustainable solution for repair, restoration & retrofitting of in service concrete structures in India various technologies have been developed. Today there is a need to coordinate the implementation of technologies. To implement the technologies on repair, restoration & to mitigate the phenomenon of electro-chemical corrosion, current euro code EN 1504, can be vital. Apart from these recently developed technologies on chloride extraction, re-alkalization, use of sacrificial anode, infra-red curing technique and Cathodic Protection technique, if properly utilized can protect the durability losses and enhance the life of concrete structures that will be of considerable advantage in India.
7. There is a need to disseminate/implement the above technologies on materials and construction front to enhance the service life of existing structures in India.

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