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Structural Repair and Rehabilitation of Multi-Storeyed (G+11) Residential Buildings: A Case of Surat, Gujarat

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Abstract - Although RCC structures are designed as per codes / standards but sufficient care is not taken during construction process. As a consequence, the structures start showing indications of distress, sometimes less than 10 years of service life, requiring early repair and rehabilitation work. In this paper, a case study of a (G+11) multistoried building badly damaged due to corrosion and aging effect of concrete is rehabilitated in 2018 has been presented. Repair strategy was finalized after Non-Destructive Testing and Structural analysis of building and it involved removal of delaminated carbonated concrete cover, application of rust remover, anti-corrosion coating, polymer bond coat, polymer modified mortar, injection of low viscosity epoxy grout to beam-column junctions and cracks, repair of masonry cracks with polymer modified mortar and grouting with SBR modified cement grout and jacketing of columns at the ground floor. SBR polymer modified mortar were selected for durable repairs. Strict quality control and assurance both in material and workmanship was adopted.

Index Terms - spalls, delamination, carbonation, corrosion, non- destructive testing, SBR polymer

1. INTRODUCTION

Concrete is the most versatile man made building material of the recent past because of its ability to take any shape but it has certain limitations like lower flexural, tensile strength , poor bond between old and hardened concrete to new and fresh concrete, poor resistance to chemicals, porosity and permeability, shrinkage etc. Due to these limitations the concrete structures starts showing distresses in the form of cracks, spalls, delamination and ultimate complete collapse as a result of carbonation of concrete, corrosion of reinforcement due to moisture penetration, chloride attack, and alkali-aggregate reactions etc. Ingress of dissolved substance from the external environment may cause various forms of chemically induced deterioration by reaction with cement paste aggregate constitutions. The resistance of concrete to chemical attack is in general directly influenced by its porosity, the cement composition used in the concrete and condition under which cement paste hardened. In such circumstances, proper evaluation of damage by non-destructive tests and structural analysis followed by repair and rehabilitation using construction chemicals which are superior to ordinary study of a (G+11) multistoried residential building has been presented.

In Ahmedabad Asset of ONGC, three no. multi-storeyed (G+8) buildings viz. Heera (C3), Panna (B5) and Ratna (B6) each having 68 quarters with half G.F as parking were constructed in year 1989-1990. These buildings were already sick due to severe reinforcement corrosion as evident from so many spalls, delaminations on column corners located at different heights, beam/ fin soffits, slab soffits, leached plaster on parapets corroded and leaking drainage pipes, water supply lines and stagnated water on terraces due to improper gradient etc. These were further damaged by the Bhuj earthquake on 26th Jan, 2001 in the form of separation cracks at beam-column junctions, RCC-masonry wall interfaces (Fig 6), cracks in masonry in-fills(Fig 5); even complete crumbling at some places, heavy de-bonding and dismantling of plaster at both exterior and interior surfaces etc. Due to fast deterioration, it was decided to rehabilitate these buildings at the earliest.

2. PRELIMINARY INVESTIGATION

Visual inspection of the buildings indicated heavy rebar corrosion as a result of carbonation due to environmental attacks. At certain locations of beams, columns, fins and slabs concrete cover had got spalled (Fig 3) and some shear stirrups were totally eaten up by corrosion (Fig1). Beam - column junctions were badly cracked (Fig 2). Some masonry walls at GF level were totally cracked due to earthquake. A number of columns had continuous vertical cracks along the line of concrete cover thickness (Fig 4). The visual inspection necessitated the need for detailed evaluation for design of the rehabilitation design.

Fig.1

De-lamination of beam concrete cover due to rebar corrosion.

Fig.2-

Severe corrosion and spalling of beam – column junction due to poor workmanship and in-adequate cover at GF level.

3. DETAILED INVESTIGATION

3.1 REBOUND HAMMER TEST: Rebound hammer test was carried out at different points to access the strength of the structural elements. Rebound numbers were determined after exposing the concrete surface by removing plaster and removing slurry and by taking at least nine readings at a point and averaging them the results showed that compressive strength in columns and beams varied from 16.3 N/mm^2 to 31.6 N/mm^2.

3.2 CORE TEST: Eight core Tests were also carried out in the building (Table 1). The results showed that compressive strength in columns, beams and slabs varied from 20.3 N/mm^2 to 40.5 N/mm^2

3.3 ULTRASONIC PULSE VELOCITY TEST

The UPV Test was carried out on 39 nos of columns and 7 nos beams and the results obtained are -

3.3.1 COLUMNS

In general, the tests on columns showed good quality of concrete. Out of 39 columns, 30 columns (about 77%) mean observation showed doubtful quality of concrete, 8 (about 20%) showed satisfactory quality and 1 no. column showed good quality of concrete. In all columns including those of good quality category, the quality of concrete near the floor had spots of relatively lower value of UPV.

The test results showed that consistency of inferred quality was high. Observations in 7 columns of 28 good quality columns were having high (more than 10%) value of coefficient of variation (CV). In fair and doubtful quality columns, the inconsistency was poorer. This means that the quality of concrete was erratic in general. Only 23% of columns showed consistent quality (CV <5%). This means that barring those columns with CV < 5%, rest columns have patches of variable quality of concrete in general.

3.3.2 BEAMS

Seven beams were tested out of which six beam in satisfactory quality consistently. On the whole UPV values in beams were on lower end of good quality range.

From the USPV tests of beams and columns, it was concluded that-

i. Quality of concrete varied significantly.

ii. Weak patches are observed at bottom near the floor.

iii. The quality variation is reflected in probable estimated strength. The probable variation is from 10 N/mm^2 to 24 N/mm^2. Generally the values found were between 14-16 N/mm^2 in sample columns. The values of estimated possible strengths of concrete in beam varied from 13 N/mm^2 to 23 N/mm^2 in sample beams. In B5 block, these were from 19 N/mm^2, 22 N/mm^2 and 23 N/mm^2. Those in sample beams in B6 were 13, 14, 22 N/mm^2.

The buildings were constructed with cement concrete (1cement:1.5fine aggregate:3coarse aggregate) with minimum cube strength of 20 N/mm^2, but the NDT showed that compressive strength was found less than minimum strength required at many locations. Some members showed compressive strength even less than 10 N/mm^2 indicating poor quality of concrete in all the three buildings.

4. REPAIR STRATEGY - The following strategy was adopted for rehabilitation of buildings

i. Removal of damaged plaster / concrete.

ii. Removal of corrosion on steel reinforcement by mechanical and chemical action and further application of corrosion inhibitor.

iii. Application of bond coat of polymer - cement mix to join old concrete with new mortar.

iv. Repair of RCC columns, beams, slabs by polymer modified mortar.

v. Jacketing of some columns with concrete.

vi. Epoxy grouting in RCC columns, beams to repair cracks.

vii. Crack sealing in masonry walls with polymer modified mortar.

viii. Polymer modified non-shrinkage grouting in cracks of masonry walls.

ix. Concrete grading on terraces

x. Replacement of damaged cast iron drainage pipes and water supply GI lines.

xi. Sealing of drainage pipe joints with PMM.

xii. Re-plaster and Acrylic paint to exterior walls.

5. REPAIR METHODOLOGY- The repair of structural members were carried out as follows-

5.1 REMOVAL OF DAMAGED CONCRETE

At the location, where concrete cover had already spalled eg. Columns corners, soffit of beams, slabs and fins, loose concrete was removed 25cm more than the length of spall. For other areas which were not spalled, hammer sounding method was used to locate delaminated concrete and marked with paint. Surface repair boundary with 5mm groove using concrete saw cutter with minimum edge length was prepared. The beams, slabs were supported with props before removal of damaged concrete. After it was ensured that the surface to which cement based polymer modified mortar was to be bonded was sound, it was cleaned off all loose and foreign materials by means of stiff wire brushing. All dust and loose particles resulting from such pre-treatments was removed by washing with water under pressure [1].

5.2 REINFORCEMENT CLEANING AND ANTI CORROSIVE COATING

Fig.7

Column rebars with anti -corrosive coating

All concrete sticking to the rebars was removed by light hammering and manual chipping. Wire brush was used to remove unwanted oxide from steel surface completely. One coat of rust remover was applied all-round the steel rebars. The coverage rate of rust clear coating on the steel bars came out to be about 3.86 sq. m per litre only much lesser than the claim in the technical brochures. Care was taken that the backside of the bars also gets coated with the rust remover. The rust remover was allowed to act for 24 hrs and then steel bars were rubbed with wire brush to remove the rust followed with washing with water jet to completely remove the rust. If the rust was not removed effectively than another coat of rust remover was applied, waited for 10 minutes and then again rubbed with wire brush[1].

Anti corrosive zinc primer was coated on freshly cleaned and dry reinforcing steel on complete periphery as per manufacturer's specifications and allowed the primer to dry for 4 hrs (Fig 7). The second coat of zinc primer after 4hrs of the application of first coat was also applied. Care was taken to cover all the steel without leaving even the smallest part of steel uncovered. The coverage rate of zinc based anti –corrosion coating on the steel bars came out to be about 2.4 sq. m per litre of the chemical which was much lesser than the claims in the technical brochures. The bars having more than 20% of the reinforcement steel bar cross sectional area corroded were replaced with the additional reinforcement by welding with existing bars or by drilling holes in to concrete and inserting the steel bars with epoxy mortar. There was severe corrosion of shear stirrups in beams resulting in decrease in diameter by more than 25%, so these were also replaced with new U- shape stirrups.

5.3 APPLICATION OF BONDING COAT TO SUBSTRATE

All concrete surfaces prior to application of bond coat was thoroughly inspected and made free from any deleterious materials such as oil, dust, dirt etc. The surface was kept wet for 24hrs ensuring that they are well saturated but free of surfaces water after natural drying. A bonding slurry of cement and Acrylic polymer in the ration 1:1 (I cement: 1 acrylic polymer) by volume with required quantity of water was prepared to a lump free creamy consistency. The coverage rate was found to be 0.8-1.1 sq.m of the concrete substrate. The bonding slurry was worked well into surface of the parent body using a stiff brush ensuring that no pin holes are visible. If a second coat was felt necessary, the same was applied at right angle to first coat to ensure complete coverage after the first coat was touch dry. The bonding slurry was applied to prepared concrete substrate after tying in new reinforcement wherever specified. Care was taken that cement based polymer modified mortar was applied as soon as possible after application of bonding coat, but always during the open time of adhesive [1].

5.4 APPLICATION OF POLYMER MODIFIED MORTAR

There are no codes/standards available for preparation of polymer modified mortar for rehabilitation of concrete structures, so extensive testing was carried out for different polymer samples from different manufacturers yielding different strengths [2]. The buildings were originally constructed with concrete mix (1 cement: 1.5 sand: 3 coarse aggregates) with minimum strength requirement of 20 N/mm^2 min., so it was decided that the polymer modified repair mortar must have compressive strength of 25 N/mm^2. Based on the polymer test reports, concrete mix used in the construction of these buildings, extent of damage and technical guidance from CBRI, Roorkee, the following specifications for polymer modified mortar preparation were designed.

Solid Content- 46% mini., Compressive strength -25 N/mm^2 min.,Tensile strength-3.5 N/mm^2 mini.

Flexural strength- 8.5 N/mm^2 mini. ,Direct shear bond strength- 2 N/mm ^{2} mini.

Polymer modified mortar mix was prepared in the proportion Cement (OPC) 50 kg : sand (graded Zone II)150 kg :Acrylic polymer @ 20-25% of cement content by weight and water cement ratio was kept below 0.4 (by weight). With this mix, the laboratory test reports of one batch of acrylic polymer yielded following strengths- Solid Content- 51.2 %, Compressive strength- 42.13 N/ sqmm, Tensile strength- 4.01 N/sqmm, Flexural strength -14.25 N/sqmm, Direct shear bond strength- 2.77 N/sqmm.

These strengths satisfied our specifications and hence rehabilitation of structural members was carried out with this mortar mix. The test cubes of size 7.06 cm x7.06 cm of the PMM prepared at site for concrete repair were also got tested from the laboratory as quality assurance measure which showed compressive strengths between 26 to 32.40 N/mm^2 meeting the specifications.

5.5 COLUMN JACKETING

Some of the columns were badly cracked throughout their height in the parking area and some had deep spalls at corners due to rebar corrosion. Some columns were badly damaged at floor level. These columns were jacketed with new rebars and jacketing concrete by 75mm thickness all-round to increase its strength and stiffness and to protect its reinforcement from further corrosion (Fig 9). The ready to use jacketing concrete in which coarse aggregate of 6-10 mm down size was to be added as per recommendation of the manufacturer was used. The Jacketing concrete was of following properties with water powder ratio of 0.21 at 30^{0}C and with 100% aggregates: Compressive strength- 30N/sqmm mini at 30days, Flexural strength -3.0N/sqmm mini at 30days , Young's Modulus- 22 KN/sqmm.

Fig.9

Jacketing of columns from the footing level.

5.6 CRACK REPAIR

5.6.1 MASONARY CRACKS

The plasticized expanding grout admixtures along with Styrene Butadiene Rubber (SBR) polymer was used for sealing of masonry wall cracks. The SBR polymer with the same specifications as that for acrylic polymer was added to grout admixture for enhancing its bonding with cracked masonry inside. The laboratory test of one of the batch of SBR polymer used in the work had following properties: Total solid content- 51.1%, Compressive Strength- 42.80N/sq mm, Tensile strength- 4.91 N/sq mm, Flexural strength- 11.86 N/sq mm, Bond strength - 3.06 N/ sq mm.

5.6.2 RCC CRACKS

Cracks in RCC members especially beam-column joints were grouted with epoxy grout of the following composition specially formulated to meet the required specifications (100 gms GY257+21 gm Aradur 21 + 4 gms Aradur 2958) from Araldite and the grout was of the following properties: Viscosity at 25^{0}C max: 2 N/ sq m, Minimum Gel time: 30 minutes,14 days bond strength at

25^0C - 3.5 N/ sq mm, Compressive yield strength at 7 days: 60 N/ sq mm, Tensile strength at 7 days: 45 N/sq mm, Elongation at break min: 1 %.

Fig.10

Epoxy injection in beam-column junctions

7. QUALITY CONTROL AND ASSURANCE

All the construction materials were prior tested from reputed laboratories like Ahmedabad Textiles Industrial Research Association (ATIRA), Nirma University, Ahmedabad & IIT-Mumbai to check conformity to standards. Construction chemicals from reputed companies like STP, Roffe, Fosroc, Sunanda, Ventico performance polymers were used for this work. The non-destructive testing was carried out by M/s. KCT Consultancy Services and M/s. KBM Engineering Research Laboratory, Ahmedabad. .

CONCLUSIONS

The detailed investigation of the buildings with rebound hammer test, ultrasound pulse velocity test and core tests, carbonation test and chloride tests have indicated that there is lot of variation in the compressive strengths of concrete in beams as well as columns. At certain locations, the strengths were found around 10 N/mm^2 only indicated poor quality of concrete practices adopted in the original construction. Lower value of compressive strengths also indicates higher permeability of the concrete leading to ingress of harmful agents like carbon dioxide gas , chlorides etc from the environment resulting in corrosion of steel bars and disintegration of concrete covers. From this case study, following recommendations / conclusions are drawn for durable concrete constructions requiring minimum structural rehabilitation at later stages of life.

- There is no substitute for good quality concrete construction practices for durability of reinforced concrete structures. The quality control of materials and workmanship viz. water-cement ratio, concrete cover, compaction and curing etc. which are prerequisites for good quality construction are very important parameters and must be strictly observed at site. Poor quality concrete construction done cannot be rectified at a later date except repeated costly repairs to keep the structure functional.
- To achieve the quality at site, the role of manpower is very significant. The engineers and workers responsible for construction should be well experienced, quality conscious and must be fully aware of the repercussions of poor quality work. Also sufficient technical staff should be deputed for achievement of quality construction with full support and encouragement from top management.
- The early deterioration of concrete structure is also due to poor maintenance practices. The water supply and drainage system should be kept intact so that there is no leakage/ seepage on the walls and no stagnated water on roofs due to overflow of water tanks or rains which acts as an enemy to the structural integrity of the buildings.
- The repair/ rehabilitation of damaged structure should be carried out urgently to avoid further deterioration with time so that the life of the structure and the occupants is not jeopardized.
- The design for structural rehabilitation should be carried out after laboratory testing of the repair materials because the claimed strengths in the brochures from the manufacturers may not always be achievable.
- Structural rehabilitation is more challenging then new concrete construction. It requires special considerations for evaluation of damage, selection of suitable material, technical specifications, and techniques for repair and quality control of material and workmanship. Therefore sufficient time and cost allocations should be made for durable rehabilitation work.

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