STRUCTURAL RETROFITTING: CASE STUDY

A.K. Singh[1] and R.S. Jangid[2]

Reinforced Cement Concrete (RCC) is a popular material for building construction in India because it is cheaper than structural steel. Also, construction in RCC is considered to be labour intensive and supposedly requires fewer high-tech tools, infrastructure, and skills than does structural steel. Over the past 10 years, we have seen a boom in the number of low- and medium-rise RC frame buildings with masonry infills. However, the real estate boom over the past decade has resulted in a large, privately constructed building that has not been adequately designed. Nominal mixes (with predetermined proportions of cement, fine aggregates, and coarse aggregates) are used to make concrete without a formal mix design. Volume batching is primarily employed instead of weigh batching; resulting into difficulty of not accounting for moisture in the aggregates, which could at times be large. Also, the placement of concrete is manual. Water available at site is used for concreting without always verifying its suitability; some salts detrimental to the durability and strength of concrete do enter into the concrete. Moreover, the quantity of water is adjusted to ensure good workability, often resulting in higher water content than necessary and in porous hardened concrete.

This paper describes the intensive retrofitting of an existing RCC framed structure. The building of is a multi-storeyed Ground + 12 upper floor RCC framed building owned by a nationalised bank.

Detail of the Structure:

The subject building is Ground + 12 upper floors RCC framed residential building structure with masonry infills and is more than 30years old. The building belongs to Syndicate Bank namely Panchratna CHS Ltd., 4-E, Damodar Park, Ghatkopar (W), Mumbai 400086. The building was identified as dilapidated structure by Municipal Corporation (MCGM) for immediate demolition within 30 days through their notice no. B&F/B119/304/354 dated 01-09-2007 of M.M.C/ACT 2007-08 under section 354 0f MMC Act.

[1] Shri Bhagubhai Mafatlal Polytechnic, Irla, Vile Parle (W), Mumbai 400 056, e.mail : akksingh@yahoo.com.

[2] Professor, Department of Civil Engineering, IIT Bombay, Powai, Mumbai – 400 076.

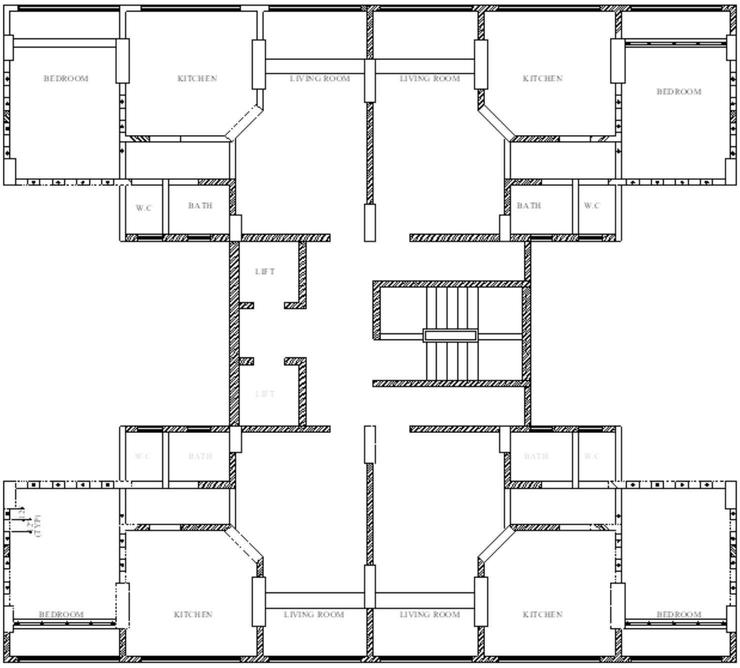


Fig 1: Typical Floor Plan

The building has symmetrical layout. Two lift shafts are eccentrically placed opposite to staircase. The building was examined for its current structural condition and to suggest the remedial measures. Following was the specific scope of the study:

i) Needful investigation of building to precede proposed Repair-Rehabilitation-Strengthening.
ii) Assessment of building structure for decay, deterioration.
iii) Setting the priority of work.

The strategy adopted was aiming to recover the original performance, for which the damaged or deteriorated portion of structure was to be repaired or replace with new elements or new material. Detailed investigation for upgrading original structural performance was not included in the scope of examination.

APPROACH TO PROBLEM:

Basic approach to the problem of retrofitting of the structure of was considered in the following manner.

1. It was important to understand the damage occurred in the structure due workmanship, lack of codal provisions followed at the time of construction and poor maintenance.
2. To save the building from the immediate threat of collapse due to dilapidated columns at the ground floor.

3. To identify the repair measures to the damage, which are not very significant and to make the same good.
4. To identify the repair measures to the damage, which are structurally very significant and to evaluate the possibility of replacing the same.
5. To evaluate the different strengthening measures against the possibility of re-development from the techno-commercial viewpoint.

IMPORTANT OBSERVATIONS

1. GENERAL CONDITION:

Photograph 1

Stability check was not carried out as the scope was to recover the original performance and detailed investigation for upgrading original structural performance was not included in the scope of examination. The major type of distress observed in RCC elements were of moderate damage level. Age related distress and fatigue were identified in all RCC members. Distress were in the form of cover failure to reinforcing bars, spalling of concrete due to corrosion born internal stresses, Open cracks etc. Overhead water tank was showing major sign of distress and stored water was continuously leaking from the cracks. The columns supporting the over head tank were showing the cracks running above the line of reinforcement and were uniform in width (see Photograph 1). Foundation was inspected up to pile cap then further digging was stopped as concrete found was sound.

2. LOCALISED EXTREMELY DAMAGE TO RCC:

Photograph 2

There were 8 columns at ground floor, which severely damaged (see Photograph 2, 3 & 4). The loss of main reinforcement was more than 70% and concrete has eroded in the core portion. The sizes of these columns were reduced 10% of original. In column no C1 and C2 the cross section was nil as concrete was fully disintegrated. This resulted the tilt of about 25mm of the building. These columns had become a potential threat to stability of the building.

Photograph 3

Photograph 4

3. SCATTERED DAMAGES:

Minor cracks coupled with swelling on plaster were an indication of continuing corrosion activities in the embedded metal. Swellings of concrete were observed at majority of locations. Corrosion of negative reinforcing bars due to moisture and inadequate cover were noticed in the form of upheaval of slabs / floor at the beam supports.

DIAGNOSIS:

FRAME OF DIGNOSIS

Diagnosis for the distressed structure was done by eliminating possibilities until some conclusion appeared. A frame of such step–by–step procedure was prepared for the structure under investigation.

Step 1: Categorisation into one of the three manifestation of concrete damage – cracking, spalling or disintegration.

Step 2 : Error in design (not available)

Step 3: Relate basic symptoms to potential causes.

Step 4: Eliminate the possibilities which are readily identified like corrosion of Reinforcement, Reinforcing bars rust and cover spall, Parallel cracks along reinforcing bars and Rust stain

Step 5: Analysis of available clues like Disintegration of surface, Unsound material, Weathering conditions, Abrasion action, Swelling of Concrete, Chemical reactions, Moisture absorption, Crack penetration / depth of crack and Cold or construction joints

Based on above frame the causes of damage were identified as under:

1: Workmanship -

No design / drawing pertaining to structural details were available, nothing much could be diagnosed on this part. Building was old and at the time of design the Indian Standard Code followed for was IS 456:1964. The code did not have any say on durability aspect of the RCC. Thus the durability parameters like water/cement ratio, minimum cement context, maximum size and particle size distribution, crack width calculations, minimum grade of concrete, expected environmental exposure condition, minimum concrete cover to reinforcing bars, etc. were not given much importance. These resulted into a fast propagation of damage to the structure. Also growing pollution has severely affecting the RCC building.

2: Corrosion of Embedded Metal

Corrosion is an electrochemical process requiring an anode, a cathode and an electrolyte. A moist concrete matrix forms an acceptable electrolyte, and steel reinforcement provides the anode and cathode. Electrical current flows between cathode and anode and the reaction results in an increase in metal volume as the *Fe* (Iron) is oxidized into $Fe(OH)_2$ and $Fe(OH)_3$ and precipitates as *FeOOH* (rust colour). Water and oxygen must be present for the reaction to take place. In good concrete the corrosion rate will be very low.

3: Carbonation

In good quality concrete, the carbonation process is very slow. An estimate rate of carbonation penetration is 1 mm. per year. As stated earlier, the Indian Standard Code followed at the time of design of building, ignored the thickness and quality of concrete cover to reinforcing steel bars. Also, the carbonation process requires constant change in moisture level dry to damp to dry.

4: Moisture Vapour

Water vapour travels through concrete when a structural / non–structural member's surface are subjected to different level of relative humidity (RH). Moisture vapour travels from high RH to low RH. The amount of moisture vapour transmission is a function of RH gradient between faces and permeability of the cementitious product. One of main causes to severe damage to ground floor columns could be attributed to the same.

5: Height and Unprotected Surface

The high energy released upon hitting the building façade surface, especially near the sharp edges of corners and parapet causes abrasion of surface by rubbing and friction. Generally surface is uniformly worn away, including cement matrix and aggregates. If plaster has high level of porosity, the abrasion rate would be high.

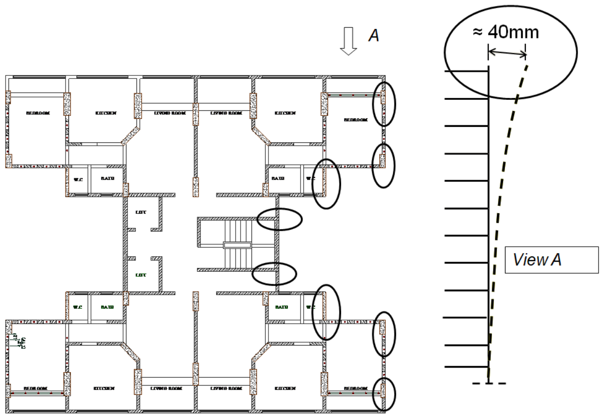


Fig. 2 : Columns at Ground Floor in Dilapidated condition and tilt of building towards East.

REMEDIAL MEASURES

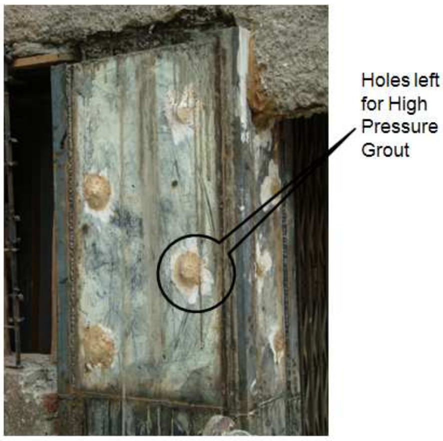
1: IMMEDIATE:

a. Propping: Immediate threat to the building stability was due to dilapidated columns at the ground floor and same could not be left unattended. It was recommended to provide the load release system. Such system was proposed based on the load on the columns. These columns are shown in the figure 2. The props were planned in such a manner that each prop should temporally relieve the loads of slabs contributing to the dilapidated columns. The estimated load on each props were 120KN. To achieve the proper contact of slab to slabs / beams the adjustable bolts were used (Photograph 5).


Photograph (5): Props as part of load release system

Photograph 6: Steel Plate Jacket

b. Restoration of severely damaged RCC columns: It was mandatory to see that these columns do not jeopardise the stability of structure during restoration. It was recommended to build up the original profile of columns and pardis using non-shrink super fluid micro-concrete. New rebars were to be put in position. Three columns were taken in one sequence and balance five was taken in next two sequences. The Column C1 and C2 were taken up to 2nd floor. Two more columns were treated in the similar manner. These columns were near staircase but these were taken only up to mid landing level. The form work should be in steel plates duly coated with anti-corrosive chemical from in side. These plates were to be left permanently to act as casing and hoop confining materials. (Photograph: 6). To fill the cavities of disintegrated column concrete, high pressure grouting of very low viscosity epoxy was done. For this purpose the holes were left in the steel plates, which were plugged after grouting. (Photograph: 7 & 8).



Photograph 7: Provision for high pressure grout

Photograph 8: Completed Steel Jacket Frame

c. Restoration of mildly damaged RCC elements:

While recommending following parameters were considered besides compatible properties of general RCC repair materials.

1. Low shrinkage properties
2. Requisite setting / hardening properties
3. Workability
4. Good bond strength with existing sub–strata
5. Compatible coefficient of thermal expansion
6. Compatible mechanical properties
7. Minimum curing
8. Alkaline character

9. Low water permeability
10. Cost
11. Durable, non–degradable or non–biodegradable due to various forms of energy like ultra violet rays, heat, etc.
12. Non–hazardous / non–polluting

1. Latex Modified Cementitious Mortar: The most suitable material for RCC repair is Latex Modified Cementitious Mortar. The advantages of such mortar are underlying in its properties of control strength gain, set time and reduce shrinkage. These contain Polymers to improve low permeability and to enhance the adhesion.
2. Micro-concrete: Properties of micro-concrete are similar to above. It has the added advantage of its flowability which enables it to encapsulate the steel bars where access is not possible. Due to Rheoplastic nature it can be utilized as grout to fill the large cavities. The added advantage of this material is its ability to eliminate honey combing in areas of high steel congestion. In addition the material is free flowing, self compacting, shrinkage compensated and early strength gain. Early stripping time of formwork and very low permeability are another good feature.
3. Replacing Concrete : Areas of concrete which have been cut away were made good depending on situation, scope of work and type / importance of member under repair. Recasting of broken chajjas (sun sheds), coping, etc. were done using ordinary concrete.
4. Grouting: There were certain locations where honeycomb or rock pockets existed. Such locations required the packing by non–shrink low viscosity material. The existing cracks in RCC were sealed by low viscosity and very low viscosity.
5. Polymer Fibre Reinforced Mortar: To reduce the risk of cracks resurfacing due to shrinkage and to ensure full contact with host concrete, the proprietary ready to use structural repair mortar is recommended. This material possessed a good bond characteristics to steel reinforcement and concrete, reinforced with Polymer Fibre, shrinkage compensate, high strength and extremely low permeability ensured the success and longevity of repair.

6. FRP Jackets: Ground floor of the building had soft storey as there are minimal infill walls. It was proposed to wrap the concrete with a continuous FRP jacket at Ground floor and 1st floor to resist the transverse expansion of the concrete. This resistance provided a confining pressure to the concrete. The improvement to the behaviour of concrete was quantified based on the fact that concrete wrapped with FRP jacket exhibits a bilinear stress-strain response. Initially the stress strain behaviour is unchanged from that of unconfined concrete. However, beyond the peak stress for unconfined concrete, the stress level in confined concrete continues to increase with increasing strain. The rate of increase is roughly proportional to the stiffness of the confining jacket. Moreover the acceleration is not increased due to no increased stiffness, thus attracting much less lateral forces. FRP, in turn, will extremely light weight and thus will not increase the mass of the structure and also it will not add significantly towards the stiffness of the structure and basic behaviour of the structure will be unaffected.

CONCLUSION:

The final completion certificate was issued to Municipal Corporation vide Ref. AK/ST/SYNDIACATE/RETRO03-2009 Dated: 26-03-2009 to certify that the building was restored to the original required strength and the building was stable against the intended forces / loads for which it had been originally designed. The post retrofitting maintenance guidelines were issued to the Bank, the owner of the structure. The next structural audit of the building is due in 2012 and maintenance related work will be due in 2014, which will involve painting the building as during the painting work RCC damage / distress treatment, crack filling, etc. the workers will have close access to the surface of the building on scaffolding.

CREDIT:

The project could be safely and successfully completed with a delay of 50 days. The cost escalation was 28%. Follwing were the persons / firms involved in completing the project.

1. Dr. R. S. Jangid, IIT-Bombay, 2. Er. Chahal, Manager (Maintenance, Syndicate Bank), 3. Mr. Himanshu Shah, Managing Director, MRIPL (Contractor), 4. Dr. Gopal L. Rai, S&P India (P) Ltd., 5. Er. Kulvinder Singh, Manager (Tech), R&M International