Investigation of Structural Defects and Renovation of a RC Residential Building

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Abstract— The aim of the present work is to describe an investigation about detecting the causes of some structural defects in a multistoried reinforced concrete residential building and its remedies for renovation. For this purpose, non-destructive testing for distressed columns, physical tests for reinforcing bars, chemical tests for concrete and water were carried out. In addition, the structural drawings were checked with the detailed design calculation. Based on the analysis of the test results, visual inspection and design calculation, some remedies are recommended for repairing, and strengthening the distressed and damaged components of the building.

Keywords— Corrosion, damage, retrofitting, structural defects

I. INTRODUCTION

IN an evening of 2009, some portion of the parapet wall on the roof could not take wind load and fell down on the cantilever projection of the roof slab in a multistoried reinforced concrete residential building in Delhi, India. Consequently, damaged portion broke the window and fell down on the floor slab that had been cracked and distressed. Apart from, the columns in the soft story and below the water tank in the roof, and some other cantilever projection of the roof slab were distressed. Some minor cracks were observed in some partitioned wall and the drainage was not proper in the roof slab. This is a very common type of multistoried building with a frame structure of reinforced concrete. This type of building is designed and constructed as per Indian Standard Codes. It can be stated that Indian Standard Codes have always been of high quality and this is due to an important research activity developed by the concerned authority.

In this paper, the cause of the failure of the structural components of the building is investigated. Other defects are also investigated. For investigation, Non-destructive tests like Schmidt rebound hammer and pulse velocity tests are performed to assess the quality of existing materials without damaging the existing structures as per Indian Standard [1, 2]. The deterioration of steel reinforcement in building structures subjected to aggressive environment poses a great threat to the

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concrete construction. The corrosion process has been recognized as major source of deterioration of concrete. The physio-chemical study of reinforced concrete is performed to determine the percentage loss of steel due to corrosion and to determine whether chloride, sulphate and carbonation are major factors contributing to corrosion. The structural drawings were checked with design calculation.

Finally, based on the analysis of the laboratory tests, visual inspection and checking of design calculation, the distressed and damaged parts are re-designed, and the rectification methods are recommended with the order of activity for construction. The concept of the present work may be useful for repairing, retrofitting, and renovation of this type f building.

II. TEST RESULTS AND DISCUSSIONS

A. Non-destructive Test Resultss

Non-destructive tests (Schmidt rebound hammer and pulse velocity tests) are performed to assess the quality of existing materials without damaging the existing structures. The Schmidt rebound hammer is principally a surface hardness tester which works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges.

In pulse velocity test, a pulse of longitudinal vibrations is produced by an electro-acoustical transducer and it is held in contact with one surface of the concrete for the test. When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material like grease or cellulose paste etc. which undergoes multiple reflections at the boundaries of the different material phases in the concrete. A complex system of stress waves such as longitudinal and shear waves develop and then propagate through the concrete. The first waves which reach the receiving transducer are the longitudinal waves and later these are converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time T of the pulse to be measured and longitudinal pulse velocity is calculated in km/s or m/s.

Schmidt rebound hammer and pulse velocity tests were carried out on the distressed columns of the soft/stilt storey and beneath the overhead water tank on the roof. In order to conduct non-destructive testing (NDT) on concrete of distressed columns, an area of 6''X6'' of grit wash including plaster under it in the middle of all the four faces, at mid-height level and 14'' above the stilt floor level was removed and smoothened using sand paper (to remove sand mortar

only) to get the concrete surface of the distressed column exposed. For this purpose, 4 nos. of distressed columns of soft storey and 1 number of column supporting overhead water tanks were worked on by an experienced mason and then the tests were performed. The rebound hammer test has been performed in the four corners of each 6''X6'' square on each column. As the concrete is damaged in some locations, it had not been possible to perform the tests.

The obtained test results are compared for the columns of soft/stilt storey and columns supporting the water tank as well as per clause 7.1.1, Table 2, IS 13311, part 1 [1]. It is seen that the pulse velocities and rebound numbers vary with a large variation in the results in different locations of a column. Same variation has been noticed in the results between the columns indicating the inhomogeneity of concrete and spurious quality of its ingredients having deleterious materials like excessive silt, high pH water etc. Some of the results of pulse velocity are below 3.0 km/s which indicate the 'doubtful' quality.

B. Physical Analysis of Reinforcement Bars

The deterioration of steel reinforcement in building structures subjected to aggressive environment poses a great threat to the concrete construction. The corrosion process has been recognized as major source of deterioration of concrete. The structures, which are directly exposed to aggressive environments, are very vulnerable to corrosion. The corrosion of steel in concrete may be initiated and maintained by two general mechanisms. The first mechanism is the reduction of alkalinity by leaching of alkaline substances with water or partial neutralization by reaction with carbon dioxide or other chemical agents. The second mechanism is the electrochemical action involving chloride ions in the presence of oxygen. Chemical agents may originate from the environment or within the concrete itself. This is caused by the reactions of the ions with each other which reduce the original characteristics of the reinforced concrete and hence induced corrosion. The objective of the study is to determine the percentage loss of steel due to corrosion and to determine whether chloride, sulphate and carbonation are major factors contributing to corrosion.

The samples of corroded steel bars detached from lintels, exposed concrete along with mortars and ground water samples have been collected. The methodology includes visual inspections, careful separation of rusts from deteriorated steel bars and evaluation of percentage reduction in steel. The results indicate the deterioration of reinforcement bars of diameter 8 mm and 10 mm. The percentage corrosion for 8 mm bars and 10 mm bars is near about 50%. The results concluded that the reinforcement bars highly corroded. It may be due to several factors such as high pH, high chloride, sulphate, carbonate and low workmanship.

C. Chemical Analysis of Concrete and Water

The chemical analysis of concrete has been carried out for pH, chloride and sulphates. The chloride and sulphate ions have been extracted from the samples as per standard procedure. Thereafter, extracts have been analyzed as per the procedure described in BS 1881 – 124 – 1998 [3]. The water

samples have also been analyzed for pH, chloride and sulphates as per Indian Standard methods of water and wastewater examination [4].

The parameter pH touches the maximum permissible limit (pH = 8.5) and chloride content is higher than the maximum amount allowed (3%) in some samples. The affected part considered in this study is Chajja, in which chloride ions are probably supplied by the water used construction of the structures. The sulphate content observed much more than that of maximum permissible limit i.e. 4% of cement content. The high contents of sulphate in the concrete may also be supplied from ground water. The sulphate attack can therefore be considered as a factor that contributes to the deterioration of the concrete surface.

The water sample analysis results show that color of water lies within the permissible limit, but it is highly contaminated with respect to chloride and sulphate content in some cases.

III. Rectification Methods And Structural Design

A. Parapet Wall

Checking of the height of existing parapet wall:
Load calculation:
Self weight = 0.12 * 25 = 3.0 kN/m^2
Mud phuska = 0.1 * 16 = 1.6 kN/m^2
Tiles = 0.05 * 20 = 1.0 kN/m^2
Total dead load = 5.6 kN/m^2
Live load of approachable terrace = 1.5 kN/m^2
Total load = 7.1 kN/m^2
Ultimate load = 1.5*7.1 = 10.65 kN/ m^2
Cantilever projection of chajja = 1m
w_u = ultimate load of parapet wall
From the design taken from drawings supplied, moment of resistance of the cantilever slab = 8.07 kNm per meter width (assuming steel is not corroded at all)
(10.65)*(1)^2/2 + w_u *(1) = 8.07
w_u = 2.745 kN/m
w = 2.745/1.5 = 1.83 kN/m
Allowable height of wall = 1.83/(0.115*24 + 0.23*20) = 0.248 m and 1.83 kN/m load due to wall can be carried by cantilever projection.
Existing load acting on the free cantilever projection as parapet walls = (0.115*24 + 0.23*20)*1.25 = 9.2 kN/m
Excess load being applied on free edge of the cantilever = (9.2 – 1.83) = 7.37 kN/m.

As per IS: 456 -2000 [4], the cantilever slab of 1m projection, having reinforcement (uncorroded / virgin) shown in the drawings of the slab, can carry 0.34m wide and 0.248 m high parallel parapet walls of 115 mm concrete along with 230 mm brick masonry at its free end. However, the height of the existing 0.34 m wide parapet wall is 1.25 m which makes the cantilever slab *highly unsafe.*

Present calculations reveal that cantilever projection must get rid of the existing parapet wall without delay to avoid what had happened on the fateful windy evening.

Dismantling all the existing parapet walls: It is being recommended that on the free end of cantilever projection, existing parapet walls will be replaced by steel grill (height of

1 m) on 6'' wide and 12'' high new R.C.C.(1:1:2) short parapet wall to be monolithic with cantilever R.C.C. projection as per the given design.

To maintain the aesthetic of the building and more importantly to lighten the structure from heavy dead load from the existing parapet wall that too on topmost level, parapet walls lying on panel wall/beam line also needs to be replaced by same lighter steel grill secured in 9''X14'' plain concrete pedestals with 9''X14'' brick works. The replacement of the existing parapet walls by proposed steel grill shall also reduce the wind load to zero.

B. Design of Cantilever Wall

Though, as being advised, the cantilever slabs are to be lightened of heavy dead load of parapet wall and to be replaced by lighter steel grill at the existing location of the parapet walls, yet strengthening of distressed components and recasting of the collapsed components is required. The design of cantilever corner and other cantilevering slabs is proposed as per As per IS: 456 -2000 [4].

C. Repairing of Distressed Slab Panel

Design of the slab panel has been checked and found to be alright. However, the appearing cracks along the reinforcing bars on the ceiling are visible by naked eye. The cover to the positive reinforcement from the ceiling was removed to have a look on the reinforcing bars. Reinforcing bars are found to be badly corroded. The terrace of this slab panel is in bad shape and looked like it had accumulation of water overflowing from water-tank for a long period of time as slope of terrace of this panel is almost reversed. The accumulated water seeped through the impaired/weathered terrace and remained in contact of the RCC roofing slab and its porosity due to poor grading of course aggregate used in construction allowed ingression of the water up to re-bars and damaged the reinforcing steel bars by corrosion. Collapse of the corner cantilever projection along with very heavy dead load of parapet wall on it made the entire structure to vibrate vigorously. This vertical vibration made the plaster of the ceiling of this distressed slab panel to spall off.

Although, the load carrying capacity of slab can be ensured by load test, yet on the basis of wide cracks clearly visible by naked eye shows that the slab panel has failed in limit- state of serviceability, cracking. Therefore, it is recommended that this particular slab panel be repaired.

D. Columns

The results from NDT namely rebound hammer test and pulse velocity test revealed that quality of concrete in the columns of stilt storey varies from column to column. The reason of which may be because of use of concrete ingredients from different sources and poor control of water cement ratio.

The quality of concrete in some columns is doubtful. A good numbers of exterior columns are having vertical cracks due to corrosion of longitudinal as well as lateral steel.

Lateral ties:

The spacing and diameter of special transverse reinforcement for bottom and top h/6 of different columns are calculated as per IS 13920: 1993, clause no. 7.4.8 [5] as follows.

Let, one of the column 230X460 mm^2
$h = (230 – 2*32 + 2*20 + 2*12) = 230$ mm
$b = (460 – 2*32 + 2*20 + 2*12) = 460$ mm
$A_k = 230*460 = 105800$ mm^2
$A_g = (230 + 2*40)*(460 + 2*40) = 167400$ mm^2
$A_{sh} = 0.18 * S*h* f_{ck}/ f_y *(A_g /A_k – 1)$
$A_{sh} = 0.18 * 75 * 230 * 25/415*(A_g /A_k – 1) = 108.9$ mm^2
Assuming, 50 % area is intact of existing lateral ties after corrosion, required
$A_{sh} = (108.9 – 0.5*3.14*8^2/4) = 83.78$ mm^2 <113.1 mm^2
Hence, provide 12 mm diameter bar @ 75mm as lateral tie for the column 230X460 mm^2. Similarly, the diameter of lateral hoop and their spacing in bottom and top h/6 length are calculated and given below in table 1. Elsewhere, in the middle 2h/3 length of the column, spacing shall not be more than 200 mm.

Capacity-wise jack requirement for jacketing of column:

For jacketing of the column, the capacity and numbers of the jack for each distressed column were calculated as follows:

Let, one of the column 230X450 mm^2
Load carried by area of chipped off concrete of the column to be jacketed
$= (A_g - A_k)*f_{ck}/3 = (230X450) - (230 - 2*40)*(450 - 2*40) = 48000$ mm^2
Load carried by the jacks $= (48000*20)/ (3*10000) = 32.0$ t
Numbers of jacks required of 10 t capacity ≈ 4
Assuming the bearing capacity of soil of 10 t/ m^2, bearing area required on soil
$= (50/100) = 0.5$ m^2
Use 750X750 mm^2 bearing plate on soil.
From bearing strength of floor concrete, bearing area required on floor
$= (50*1000)/(0.25*15) = 13333.3$ mm^2
Provide 150X150 mm^2 bearing plate on the stilt floor.
From bearing strength of beam concrete, bearing area required
$= (100*1000)/(0.25*15) = 26666.6$ mm^2
Provide 230X230 mm^2 bearing plate under the soffit of the beams.

Recommendation: It is recommended that all the exterior columns should be jacketed following the procedure as under:

1. Only one column to be taken up for repair in each block at one time. When a particular column is under repair, adjacent columns should not be taken up for repair.
2. The column under repair should be relieved of the load by propping adequately with screw jacks as recommended. Prior to the commencement of concrete chipping off, the screw jacks are to be put under the beams framing with the column.
3. Each identified column shall be exposed below the floor level upto the plinth/tie beam level by careful excavation around the column after effectively supporting it. If cracks in column/pedestal or corrosion of reinforcement are observed, further excavation upto foundation level may be required.
4. *Repair of columns:*
a) Chip off all cover concrete to expose the reinforcements (longitudinal and transverse both).

b) Remove the rust/scales form the longitudinal reinforcement bars and lateral ties. Chisel the concrete around the bars to completely remove the rust. Use wire brushing and compressed air to clean the bars.

c) Remove all loose concrete and clean the surface by compressed air.

d) Apply 'SIKA RUSTOFF 100' on the existing bars.

e) Add extra 20 mm diameter bar for each existing longitudinal bars. New bars should start from top of plinth beam or below and extended up to soffit of stilt roof beams.

f) Provide lateral ties with diameter and spacing given in table.

g) Apply 'SIKA RUSTOP' coat on the old and new bars.

h) If there are visible cracks in exposed concrete, inject low viscosity epoxy under pressure (>4 kg/cm^2) by drilling holes, installing PVC nozzles, sealing the cracks and pressure grouting.

i) Weld master hoop of 75X6 mm flat at the top and bottom of column enclosing the new/virgin longitudinal reinforcing bars of the column.

j) Apply a bonding coat of epoxy such as SIKADUR 32 on the old concrete surface.

k) Pour machine mixed M25 concrete (1:1:2) with maximum 10 mm size of coarse aggregate using super-plasticizer, within stipulated time after applying bonding coat. This activity should be done in 3 lifts. Use proper (plywood) formwork for smooth finish. Cover to new lateral hoop reinforcement/tie should not be less than 40 mm.

l) Concrete shall be properly vibrated using form-mounted vibrators.

m) Top portion of the column shall be grouted with non-shrink cement grout.

n) Cure the concrete by MCD (Municipal Corporation of Delhi) sweet water for 14 days for at least twice a day.

o) Plaster the column with 1:4 (cement : coarse sand) cement mortar with chicken wire mesh.

p) Remove the temporary props & jacking after 21 days

q) Final finish (grit finish or smooth finish) to be done.

6. All materials and work shall conform to relevant Indian Standard Codes of Practice.

7. Compacting back filling and making good of floor/paving to the original form shall be completed as soon as possible.

IV. ORDER OF ACTIVITY

A. *Dismantling of Parapet Walls*

1. For dismantling the weighty masonry and, porous and cracked R.C.C. parapet walls, put minimum 5 genuine metallic props with appropriate bracing under adjacent slab panels.

2. Remove additional masonry wall brick by brick. Not more than 50 bricks should be piled up at one place, particularly at mid span of roofing slab panels. Bricks to be used for erecting the proposed steel grill on the panel walls or exterior beams may be kept on the interior beams but not more than in 4 layers.

3. After dismantling the additional brick masonry parapet wall and storing the required numbers of bricks on interior beam only, distressed RCC parapet wall shall be dismantled using light weight hammer and chisel by applying light blows from outside. Debris (Melba) shall be simultaneously removed from the terrace.

B. *Corner Cantilever Projection*

4. As all the existing corner cantilevers had been improperly designed/detailed with reinforcement and therefore to be dismantled and recasted as per given design.

5. The concrete of the cantilever projection up to 600 mm (adjacent to corner cantilever projection) from inner face of the corner column to be dismantled using light hammer without damaging steel reinforcement.

6. Make appropriate and reliable scaffolding for drilling holes in the web of beams to secure bottom bars of the cantilever projection. Drill the holes and secure the 10 mm diameter tor-steel bottom bars as per drawing.

7. Chip off the top concrete of the corner slab panel including supporting beam of area 850 X 850 mm^2 to get the top steel of slab and top flexural steel of beam clearly exposed.

8. Insert top two 16 mm diameter tor-steel bars each inside the stirrups of beams removing concrete.

9. Make the corroded steel bars free of rust by applying SIKA RUSTOFF 100 on all existing corroded bars.

10. Overlap full exposed secondary steel reinforcement as well as weld (not less than 300 mm length) the 10 mm diameter tor-steel bars.

11. Overlap as well as weld the 10 mm diameter tor-steel main bars with top steel slab and top steel of beams and bind the bars they are crossing elsewhere by double binding wires.

12. Give a genuine rich coating of concrete bonding agent NITOBOND EP/SIKADUR 32 to the dust free exposed concrete surface cleaned by wire brush and compressed air nozzle.

13. Pour M25 (1:1:2) machine mixed concrete of workable slump using super plasticizer to keep w/c ratio not more than 0.45 only on the horizontal part of the cantilever projection with on shuttering preferably of water proof ply/board supported on metal props and compact using vibrator and finish it leaving 150 mm wide end strip unfinished.

14. Cure the concrete by sweet MCD water for 14 days.

C. *Other Cantilever Projection*

15. Dismantling of the RCC parapet wall shall expose the flexural steel reinforcement at free edge of cantilever projection. Dismantle the concrete only of 320 mm

from free edge and overlap as well as weld the 10 mm diameter additional tor-steel bars.

16. Remove loose aggregate particles using wire brush and compressed air nozzle; give a rich coating of NITOBOND EP/ SIKADUR 32 (Epoxy resin concrete bonding agent) on the exposed concrete surface.

17. Cast the cantilever projection, and cure it using moist gunny /jute bags with MCD sweet water for 14 days.

18. Cast the 150 X 300 concrete parapet as per section 1-1 and section 2-2 with M25 (1:1:2) concrete along with steel grill keeping the slope of 150 mm wide inward and cure it using moist gunny /jute bags with MCD sweet water for 14 days.

D. Repairing of Distressed Slab Panel

19. For retrofitting the distressed slab panel, put minimum 5 props under each of the slab panels with appropriate bracing.

20. Unload the distressed slab panel from any superimposed load by removing the terracing material from top of the slab.

21. Remove the ceiling plaster and concrete cover to get the corroded steel bars clearly exposed of the distressed slab panel. Remove loose particles using compressed air nozzle. Clean the corroded steel bars with SIKA RUSTOFF 100.

22. Splice the extremely corroded bottom bars having present area less than half the original diameter with 10 mm diameter virgin tor-steel bar and to be anchored in the supporting beams by drilling holes along the edges of the slab.

23. Give a coat of NITOBOND EP/ SIKADUR 32 to entire exposed ceiling concrete.

24. Give a coat of SIKA RUSTOFF 100 to all the steel bars.

25. Anchor the SIKA RUSTOFF 100 coated steel welded wire mesh of 16 gauge wires (1.65 mm dia.) and of mesh size 50 mm, to the concrete slab using fasteners adequately.

26. Gunite / shotcrete the ceiling to get minimum 15 mm clear cover to the mesh.

27. Cure the ceiling by sprinkled MCD sweet water for seven days.

28. Plaster the ceiling with thin 10 mm plastering mortar of 1:1.5:1.5 (cement: fine sand: coarse sand) sprinkling the cement slurry to the ceiling. Cure the ceiling plaster for seven days with sprinkling MCD sweet water.

29. Relay the terrace giving afresh bituminous coat on top surface of the strengthened slab, providing the required slope.

30. Remove the props under the adjacent slab panels after finishing the terracing work.

E. Repair of Minor Cracks in the Wall

Partition walls generally display distress in the form of diagonal cracks attributed to the following reasons:

1. Brick masonry of partition wall is made of spurious components i.e. bricks and/or coarse sand – cement mortar.
2. Poor workmanship
3. Transfer of load from beam/slab due to their excessive deflection
4. Any combination of I, II and III above.

The cracked wall is to be repaired as given below:

4. Remove the plaster from the both faces of wall
5. Secure 10 mm diameter bars across the cracks minimum 3 in nos. on each face of wall keeping 600 mm above the uppermost crack and 600 mm below the lowermost crack
6. Plaster the wall with 1:4 (cement: coarse sand) cement mortar with chicken wire mesh on both the faces

F. Drainage of Roof

Cantilever portion of roof beyond parapet wall is to be provided with brick kova having its slope outward. Its slope may be kept 1:30. Outer edge of cantilever projection is to be of 100 mm wide on hacked slab for proper bonding. Top of the concrete edge is to be sloped outward with brick kova.

Terrace within the parapet walls is to be of mud phuska and brick tiles on it in the slope 1:40 towards the khurras, neatly furnished with rich mortar.

G. Strengthening of Columns under Water Tank

The column under water tank is to be strengthened with the same procedure as given in the main report for stilt/soft storey column.

V. CONCLUSION

The causes of the structural defects of a multistoried reinforced concrete residential building have been investigated with non-destructive tests, physical and chemical tests, checking of structural drawings with design calculation, and visual inspection. Based on the analysis of investigation, it was seen that due to excessive chloride, sulphate content and pH in water; poor quality of construction, the steels were corroded and the concrete was deteriorated. Even improper structural design was the causes of failure of the parapet wall in the roof. The distressed components of the building were re-designed and order of activity for construction of these components is discussed here. The present work may be very useful for repair, renovation and retrofitting of this type of building.

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