International Journal of Chemical, Environmental & Biological Sciences (IJCEBS) Volume 1, Issue 3 (2013) ISSN 2320-4079; EISSN 2320–4087

Investigation of Structural Failure of a RC Hotel under Construction

Dr. Akil Ahmed, Prof. Mehtab Alam, and Dr. Asif Husain

***Abstract*—** The objective of this work is to describe an investigation about detecting the causes of structural failure of a multistoried reinforced concrete hotel building which was under construction. Non-destructive testing for distressed columns and available cubes, physo-chemical tests for concrete for concrete and water, geotechnical investigation for soil were carried out to find out the reasons. In addition, the structural analysis was performed with the help of STAAD PRO software for checking the design of constructed components of the building. Based on the analysis, it can be concluded that the main causes of the crack/damage were varying lateral earth pressure around the retaining wall, ground water pressure beneath the mat, and poor grade of concrete for construction.

***Keywords*—** Corrosion, geotechnical investigation, lateral earth pressure, non-destructive tests, structural failure, STAAD PRO.

I. Introduction

The present work deals with multistoried hotel building in Delhi, India. The building was under construction. Suddenly wide cracks were appeared in the raft in the basement, even some parts of the basement were damaged. Apart from that, the concrete was deteriorated and steels were corroded of the columns and retaining walls. This is a very common type of multistoried building with a frame structure of reinforced concrete designed and constructed as per Indian Standard Codes.

The reasons of the failure of the constructed structural components of the building was investigated. For investigation, non-destructive tests like Schmidt rebound hammer and pulse velocity tests were carried out to assess the quality of existing materials without damaging the existing structures as per Indian Standard [1, 2]. The physio-chemical study of reinforced concrete is performed to determine the quality of construction and material and to determine whether chloride, sulphate and carbonation are major factors contributing to corrosion, geotechnical investigation for investigating the sub-soil condition. The structural design for damaged/failed components were verified with the help of STAAD PRO.

Dr. Akil Ahmed is with the Jamia Millia Islamia (A Central University), New Delhi, India 110025 (E-mail: akilhm@gmail.com).

Prof. Mehtab Alam is with the Jamia Millia Islamia (A Central University), New Delhi, India 110025 (E-mail: mehtablm04@gmail.com).

Dr. Asif Husain is with the Jamia Millia Islamia (A Central University), New Delhi, India 110025 (E-mail: asifjmi@gmail.com).

The existing structure was analysed using STAAD-PRO. The existing structure has been modelled as it is and applied with loads acting mainly lateral earth pressure and water pressure along with vertical water pressure from beneath. The properties of the elements have been given as per the existing structure a few of which are different from those shown in the drawings submitted. Partial safety factor of 1.5 on loads has been considered.

II. Observation, Test Results and Discussions

A. Observation

1. Structure observation:

As per the site condition, the following type of crack can be seen in the failed columns. After seen these cracks, it is clear that these cracks are mainly due to excessive shear produced by lateral earth pressure (Fig. 1).

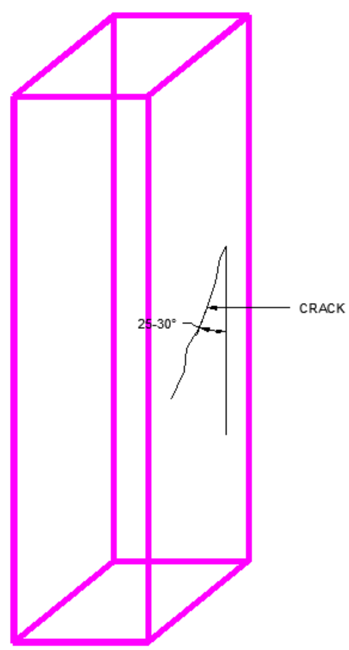

Fig.1 Type of cracks in the structure

2. Material Observation:

Test Certificate given by concerned testing laboratory submitted show that ***moderate*** exposure condition has been considered in the design of the M-20 concrete. As per IS 456:2000 the minimum grade of concrete for moderate exposure must have been M-25.

3. Drawing Observation:

Ties in the columns are not as per IS 13920 -1993: *Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces – Code of Practice* [3].

4. Concrete used in structure:

Concrete used in raft and retaining walls is of grade M-20. Salinity of the ground water indicates severe-moderate type of exposure to the raft and retaining wall. Therefore, not less than M-25 grade of concrete should have been employed in the raft and retaining wall design and construction.

B. Non-destructive Test Results

1. Schmidt Hammer Test:

Schmidt rebound hammer test was carried out on 8 columns at the basement. The test has been performed at the four locations on each face of the column at the mid-height level. It is seen that the values vary from lower to higher range indicating the inconsistency in the quality of concrete in the columns. Similarly, the Schmidt rebound hammer test was performed on five cubes of M25 and also on five cubes of M30 grades at the four locations on each face of the cube. The values showed the consistent quality of concrete in the cubes.

2. Ultrasonic Pulse Velocity Test:

Ultrasonic pulse velocity test was carried out on 8 columns at the basement. The pulse velocity test has been performed on b and D face of the column at the same height like the rebound hammer test. It is seen that the pulse velocities vary form lower to higher range indicating the inconsistency in the quality of concrete in the columns. Most of the results of pulse velocity are below 3000 m/s which show the 'doubtful' quality of the concrete as per clause 7.1.1, Table 2, IS 13311 [1]. Similarly, the Ultrasonic pulse velocity test was performed on the cubes of M25 and M30 grades on each face of the cube. The values are above 4500 m/s which show that the quality of concrete in the cubes is excellent.

C. Compressive Strength of Cubes

The cubes of M25 and M30 grades have been tested by Automatic Compression testing Machine (ACTM) as per recommendations of BIS to get the compressive strength of the cubes. It is observed from the results that the compressive strength of most of the cubes is excellent which corroborates with results of pulse velocity and rebound hammer on the same cubes.

D. Geotechnical Investigations

Geotechnical investigations were performed to obtain information on the physical properties of soil around the site to design foundations for proposed structures. A geotechnical investigation would include surface exploration and subsurface exploration of a site. To establish the parameters for the foundation design of the structure, various properties and parameters regarding the subsoil at site were required. These parameters were achieved through geo-technical investigations viz. soil profile, engineering properties & physical characteristics of the soil strata, variation in strength of soil strata etc.

For achieving the aforesaid objectives, the scope of work included:

1. Making three bore holes up to a depth of 25m below existing ground surface in subsoil or refusal whichever was encountered earlier on the site at random locations.
2. Conducting Standard Penetration Tests (S. P. T.) at 1.5 m depth interval.
3. Extracting disturbed & undisturbed soil sample at different depth interval.
4. Observing ground water table after a stabilization period of 24 hours.
5. Conducting laboratory tests on disturbed and undisturbed soil samples collected during the subsurface exploration.
6. Compiling and submitting report containing field and laboratory tests results and suggestion & recommendations regarding type & depth of foundations and allowable load bearing capacity of soil and other desired parameters at various depths.

Based on field and laboratory investigations and the analysis carried out thereafter, following general recommendations were being made:

1. Based on various findings of the subsoil, in the present case, the type of foundation could be adopted as isolated or raft Foundation.
2. If any loose pockets were observed during excavation for shallow foundation, the same should be filled with brickbats/gravel and compacted. Foundation could subsequently be placed over this prepared surface.
3. As per the analysis done for the liquefaction potential of the subsoil strata, it was found that the subsoil strata up to the explored depth were not prone to liquefaction during earthquake.

E. Physio-chemical Study of Reinforced Concrete

The samples of exposed concrete along with mortars and ground water used in concrete had been collected from the site. The methodology included visual inspections, careful separation of rusts from deteriorated steel bars and as well as chemical analysis of concrete. The chemical analysis of concrete had been carried out for pH, chloride and sulphate. The chloride and sulphate ions had been extracted from the samples as per standard procedure. Thereafter, extracts had been analyzed as per the procedure described in BS 1881 – 124 – 1998 [4]. The ground water samples had also been analyzed for pH, chloride and sulphate as per standard methods of water and wastewater examination [5].

1. Chemical analysis of concrete:

The parameter pH of samples 1 and 2 was higher than the maximum permissible limit (pH = 8.5). The results shown indicated chloride content (6.67%) higher than the maximum amount allowed (4%) in sample 1. However, in sample 2 the chloride content had been found to be 5.3%, which was also more than the permissible limit. The sulphate content in sample 1 had been observed to be 9.48%, which was also much more than that of maximum permissible limit i.e. 3% of cement content. However the suphate content in sample 2 had been observed to be 10.2%, which was also more than that of maximum permissible limit. The high contents of sulphate in the concrete might also be supplied from ground water. The sulphate attack can therefore be considered as a factor that contributes to the deterioration of the concrete. The presence of chloride and carbonation seems to be major factors that accelerate the process.

2. Chemical analysis of water:

The water sample analysis results showed that color of water lies within the permissible limit. The pH of sample 1 had been observed to be 7.9, The sulphate content in sample 1 had been found to be 456 mg/l. The chloride content in sample 1 had been found to be 570 mg/l. The water quality results showed that sample 1 was contaminated with respect to chloride and sulphate content.

F. Structure Analysis

The analysis of the existing structure was analysed using STAAD-PRO. The existing structure had been modelled as it was and applied with loads acting mainly lateral earth pressure and water pressure along with vertical water pressure from beneath. The properties of the elements had been given as per the existing structure a few of which are different from those shown in the drawings submitted. Partial safety factor of 1.5 on loads had been considered.

Codes used:

The analysis had been performed as per the following codes:-

- IS 456-2000: Code of Practice for Plain and Reinforced Concrete [5]
- Design Aid to the IS 456 [6]

Materials Parameters:

1) Concrete Characteristics

Characteristic compressive strength of concrete for raft slab, f_{ck} = 20 MPa

Characteristic compressive strength of concrete for column, f_{ck} = 30 MPa

Characteristic compressive strength of concrete for retaining wall, f_{ck} = 20 MPa

2) Reinforcement

Characteristic strength of reinforcement grade Fe 415, f_y = 415 MPa

G. Methodology of Analysis

Modelling of the structure:

The modelling of the structure had been done in STAAD-Pro. The beam and column of the structure were modelled as member element whereas the slab and walls were modelled as plate element (Fig. 2).

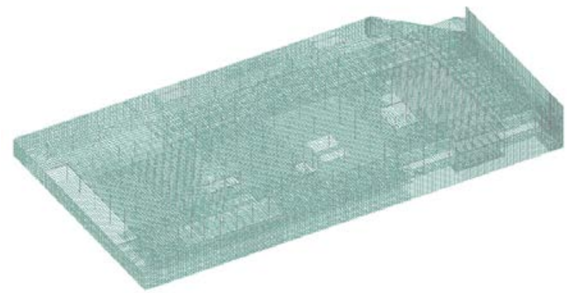

Fig. 2 3D-model of the hotel in STAAD-Pro

Loading in the structure:

1) Self Weight

The self weight of the structure was assigned by STAAD-Pro itself.

2) Earth Pressure on Wall

The earth pressure applied on the retaining wall was as per the site condition (Fig. 3). It is worth noting that the height of the retaining wall was not the same on all the five sides, rather varying on the three consecutive sides while almost equal on the remaining two sides.

- Calculation of Ka
  $K_a = (1-\text{Sin}\alpha)/(1+\text{Sin}\alpha) = 1/3$
- Maximum horizontal pressure for 4.5 m height from top having soil density of 1.80 Mton/m^2
  $= y * H * K_a = 2.70$ Mton/m^2
- Maximum horizontal pressure for remaining 6 m height having saturated density of 1.78 Mton/m^2
  $= y_s * H * K_a = 0.78$ Mton/m^2

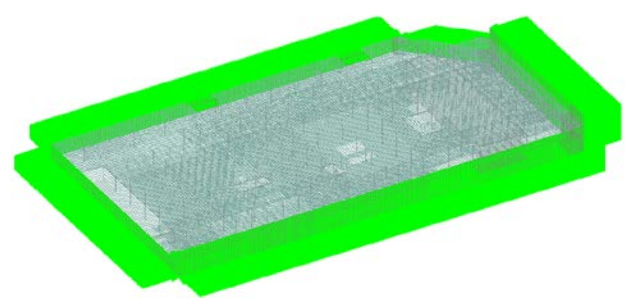

Fig. 3 Earth pressure applied on wall

3) Water Pressure on Wall

The water pressure applied on the retaining wall is as per the site condition (Fig. 4). That means wherever whatever the earth pressure has been observed during the site visit is modelled in the structure.

Density of water = 1 Mton/m^2

Max Horizontal pressure

$= w*h$

$=1*6$

$= 6$ Mton/m^2

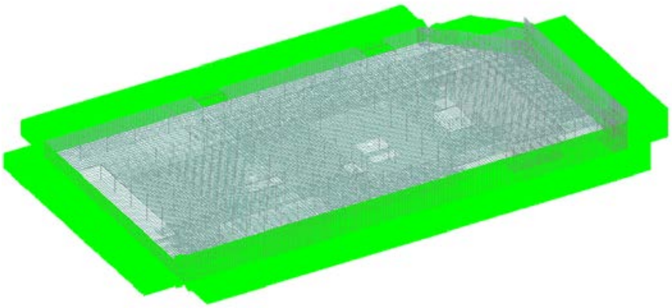

Fig. 4 Water pressure applied on wall

4) Surcharge on Structure

The surcharge applied on the retaining wall was as per the site condition (Fig. 5). That means wherever whatever the earth pressure has been observed during the site visit was modelled in the structure.

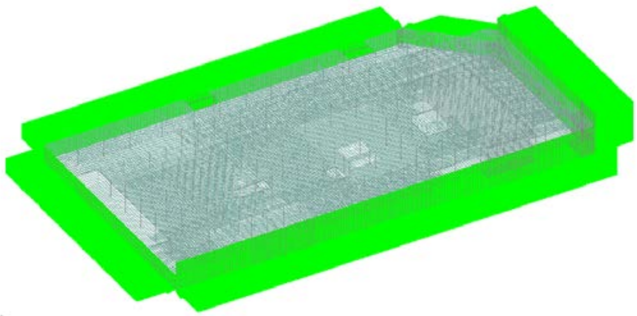

Fig. 5 Surcharge

5) Pressure from Base

Soil pressure according to the self weight of existing structure and water pressure of 6.5 Mton/m^2 had been applied on the raft from below (Fig. 6).

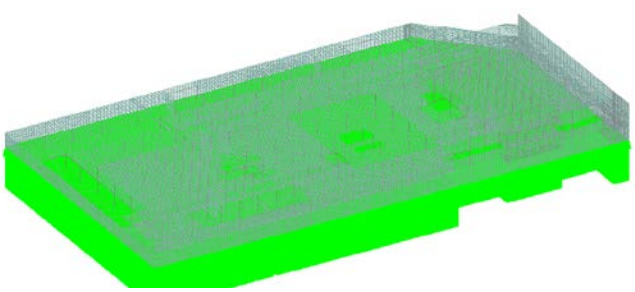

Fig. 6 Water and soil pressure from below

H. Results of Failed/Distressed Elements

Some of the outputs of STAAD PRO for a column has been given below as a sample example (Figs. 7 - 11):

Column N-3 (800*800mm):

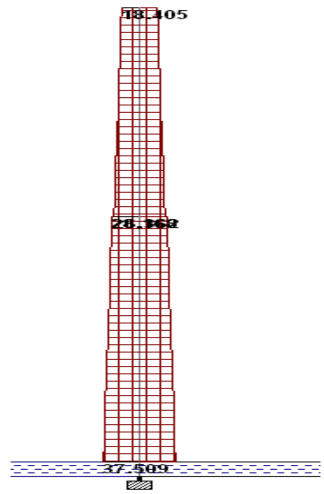

Fig. 7 Axial force diagram for column N3

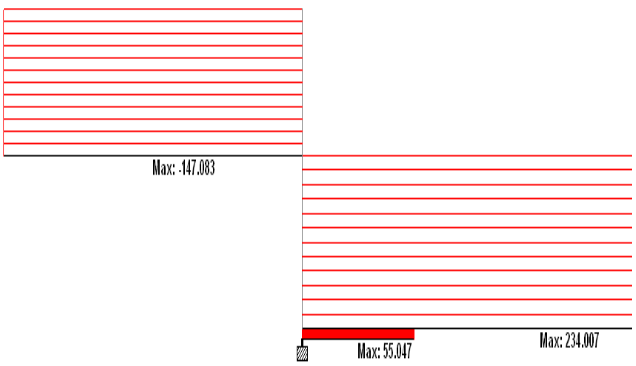

Fig. 8 Critical shear force diagram in local z direction for column N3

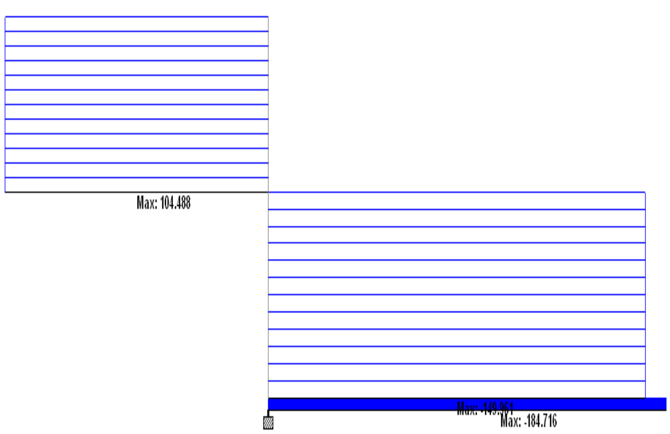

Fig. 9 Shear force diagram in local y direction for column N3

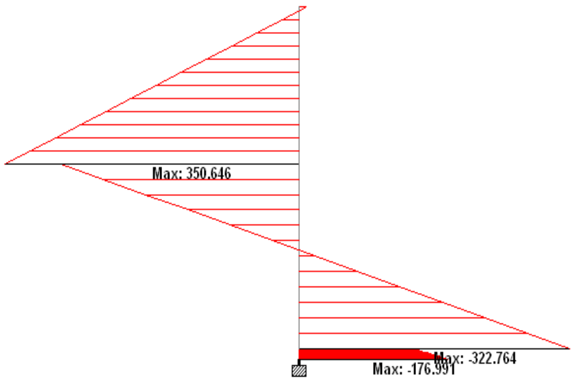

Fig. 10 Bending moment diagram in local z direction for column N3

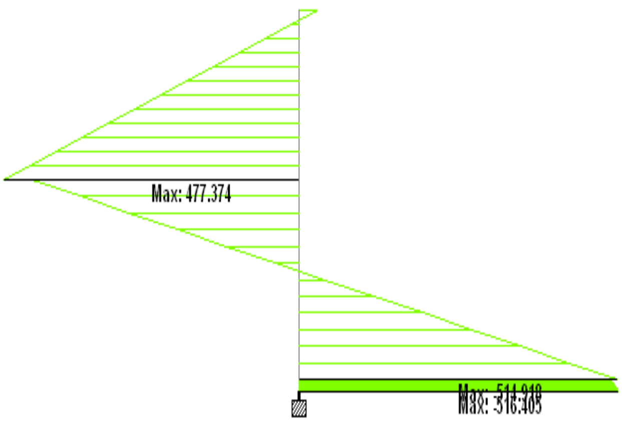

Fig. 11 Bending moment diagram in local z direction for column N3

Shear check in column

Sectional Parameters:

b= 0.8 m, width of the section

D = 0.8 m, overall depth of the section

d= 0.75 m, effective depth of the section

Material Parameters:

f_{ck} = 30 MPa, characteristic strength of concrete

f_y = 415 MPa, yield strength of steel

Forces:

V_u = 234.007 Mton, Ultimate Shear Force .

Calculation of Shear Stress:

τ_v = 3.6 MPa

As per Table 20 of IS-456:2000 [5]

$\tau_{c,\,max}$ = 3.5 MPa < 3.6 MPa

Section is not Safe

Shear wall at H-14 (300 mm Thick):

Maximum shear stress (Fig. 12) in the shear wall is 4.84 MPa > $\tau_{c,\,max}$ = 3.5 MPa. Therefore, the shear wall section is unsafe.

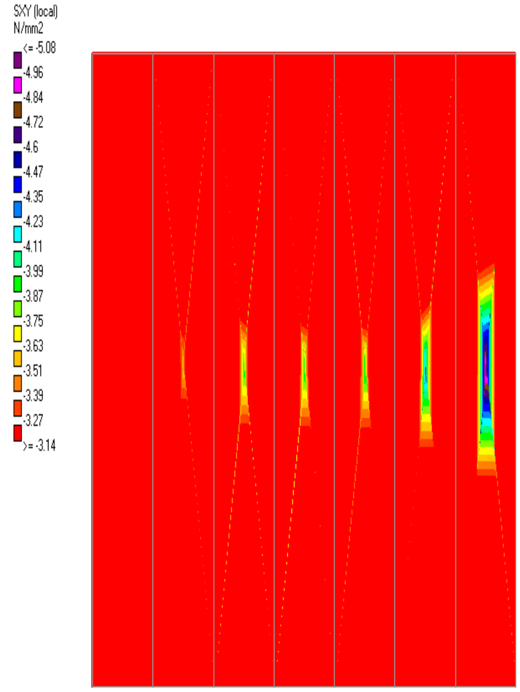

Fig.12 Shear stresses

III. Conclusion

Based on the analysis, test results and visual inspection, the conclusion is enumerated as follows:

1. The causes of the crack/damage were varying lateral earth pressure, ground water pressure, and poor grade of concrete. The lateral reinforcement was not adequate in the columns.
2. The cracks/damage to the structure had left it unsafe.
3. The quality of construction used was not as per standards and process of construction was not supervised by qualified and trained engineers.
4. Mix for M-20 grade of concrete is not as per IS 456:2000 recommendations. Other mixes i.e. M25 and M30 were okay.
5. A bit inferior quality of concrete and poor quality of shuttering used.
6. Coarse and fine aggregate were not available on the site for investigation.
7. The structural design needs to be revised for a high rise structure/building. The damaged components have to be repaired/retrofitted/re-casted depending upon the degree of damage.

References

[1] IS 13311, Part 1, 1992: Non-destructive testing of concrete: Ultrasonic pulse velocity

[2] IS 13311, Part 2, 1992: Non-destructive testing of concrete-methods of test : Rebound hammer

[3] IS 13920, 1993: Ductile detailing of reinforced concrete structures subjected to seismic forces - Code of practice

[4] BS 1881, Part 124, 1998 : Testing concrete: Methods for analysis of hardened concrete

[5] IS 456, 2000: Plain and reinforced concrete – code of practice

[6] SP16: Design Aids for IS 456 - 2000