RETROFITTING AND ADDITION OF FLOORS FOR EXISTING STRUCTURES

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Abstract- *There are various distresses which occur in buildings due to many reasons which may be due to natural calamities, faulty construction or ageing of structures. In case of ageing of the structure, there is lot of distress in the structure which can be observed during visual inspection. A thorough visual survey & non-destructive testing of the structure is required to take appropriate decisions for renewal measures.*

M/s NIOH proposed to carry out additions and alterations in existing structures namely Library Building and Canteen with guest house building situated at Ahmadabad, Gujarat which was constructed in late eighties and early nineties. The said structure was affected during Bhuj Earthquake in 2001. The library building comprises of two floors and two part mezzanine floors. Canteen with guest house building comprises of ground and two upper floors. There was a requirement of addition of 3 floors for library building and 2 floors for canteen with guest house building. The structure was designed for gravity load. Considering the seismic Zone III, it was necessary for seismic design of both the structures and to check the stability of existing structures for additional load.

The scope is to verify the analysis and design of existing structure based on the details and drawings as per site visit and to check the feasibility of addition of three floors for library building and two floors for canteen with guest house building after carrying out renewal and strengthening measures. We had to carry out independent analysis of Library and canteen with guest house building structure using ETABS 9.5. The building is analyzed for beam column Frame System. Before the analysis design work and repair methodology, visual survey and structural audit has been done. Repair methodology involves chipping; grouting with epoxy resin followed by corrosion inhibitors; polymer treatment such as application of bond coat, polymer IPN (Interpenetrating network) on concrete surface; column jacketing and fibre wrapping.

Keywords- Delamination, Non-destructive test, Corrosion, Spalling, Repairs, Tensile strength, Flexural strength, Compressive strength, Cracks, Grouting, Column Jacketing, Visual Survey.

I. INTRODUCTION

A. General

The National Institute of Occupational Health (NIOH) is one of the premier institutes, under the Department of Health Research, Ministry of Health and Family Welfare, Government of India. This medical research institute is located at Meghani-nagar, Ahmadabad in the state of Gujarat. There are two public buildings in this Campus, which were constructed about 25 to 30 years ago. As seen visually the structures seemed under distress. The client M/s. NIOH proposed to carry out structural audit to assess the structural stability of the said structures and explore the possibility of adding additional floors to the existing building. The above said public buildings comprised of a library building and a canteen with guest house building. The library building comprised of ground with two upper floors and two-part mezzanine floors. The canteen with guest house building comprised of ground with two upper floors.

Due to ageing of structures which is 25 to 30 years old, there were lots of distresses in the structures which can be easily seen by visually. So, this distress which occurs in the structure may be attributed to many reasons such as natural calamities, faulty construction and ageing of the structure.

Hence, it was proposed to carryout structural audit, the structural audit was carried out by adopting visual inspection and non-destructive tests (NDT). These NDT include rebound hammer test, ultra-sonic pulse velocity test, corrosion test, carbonation test and rebar locator test.

The above structures were affected during Bhuj earthquake in the year 2001. After this earthquake, the cracks and the damage caused were not assessed and left unattended due to which corrosion was induced in the reinforcement of the structures which after structural audit was found about 30% of distressed and thus was recommended to retrofit. Based on the structural audit report, the client M/s NIOH proposed to carry out additions and alterations in existing structures.

II. OBJECTIVE OF STUDY

As structure was observed to have undergone distress, hence, appropriate remedial steps were needed to be taken. The

steps taken can be summarized as:

- To carry out structural audit which included
  - Visual survey
  - Non-destructive test
  - Repair philosophy
- Structural analysis which include checking the structure for additional three floors for Library building and two floors for Canteen with guest house building by using software such as E-tabs and cross verifying analytically.
- After checking the structure for additional floors, designing the additional floors as per standard methods of practice.

III. METHODOLOGY

1. NDT Methodology:

a. Visual survey:

The structure being a RCC framed structure was investigated grid to grid for ease in observations. Each column, beam and slab within the section was observed for a range of defects such as cracks, seepage. These defects were noted on the observation sheets, which formed the bulk of the data collected. The basis on which the observations were made is given below:

i. The de-lamination that had taken place in the brick/ RCC walls and the RCC columns and beams.
ii. The cracking pattern, was observed & its type- whether there were separation cracks between masonry walls and the columns.
iii. Special attention was given towards the cracking pattern observed on beams, columns and slabs.

b. Tapping:

Every columns, beams and slabs were subjected to tapping. This gave a clear picture about the status of the member subject to tapping. Members in sound condition gave a clear ringing sound while the member, who was in stage of deterioration, gave a hollow sound. The members, which gave hollow sound, were recorded and would be taken up for repairs.

c. Instrumentation:

Four NDT tests were carried out on select columns, beams and slab to get clear pictures about the strength of the RCC framework.

i. Rebound Hammer test:

Rebound hammer test is to give a picture of the surface strength of the Reinforced Concrete Section. The principle is that when a spring-loaded shaft strikes a surface its rebound is a function of the hardness of the surface. The force on the shaft and its rebound are developed and measured by the hammer. The operations are very simple. They consist of releasing the plunger from locked position by pressing gently against the hard surface and check for zero setting of rebound number indicator on the graduated scale. The hammer is then strongly pressed against the surface under investigation this releases the spring load weight, which strikes the plunger and causes the impact.

ii. Integrity testing; ultrasonic pulse velocity method (UPV):

UPV test is to test the integrity and depth of defect in a Reinforced Concrete Section. It is known that speed of a sound wave varies with the density of its propagation. Concrete it is a medium through which ultrasonic pulse is made to propagate. The pulse is sent through a transmitting transducer acoustically coupled with the surface and is received by a similar transducer placed in position. The time elapsed from transmittance to receipt of pulse is measured in microseconds and displayed on LCD display of ultrasonic pulse tester. The pulse velocity is calculated by expression

$$\text{Pulse velocity} = \frac{\textit{Distance travelled}}{\textit{time taken}}$$

The UPV in concrete is a function of density and compactness of concrete, which limits bears a relationship with strengths and elastic properties of concrete. Beyond this limit, the relationship is very weak. This test should be performed as per IS: 13311 Part-1 -1992

iii. Corrosion test:

Corrosion test is to check the probability of corrosion in Reinforced Concrete Section. This test is to determine the extent of corrosion of steel in the reinforced concrete section. This test was carried out only at locations were there was wide cracks and the steel was available for testing.

iv. Carbonation test:

Carbonation test is to check the probability of carbonation depth in Reinforced Concrete Section. This test was conducted by spraying phenolphthalein on the already expose concrete and observing the change in colour. The depth of carbonation is estimated based on the change in colour profile**.**

v. Rebar locator test:

This method is used to assess reinforcement bar diameter and spacing of main bars and stirrups. For new structures it can be used to determine the exact usage of steel. In old buildings this is used to gather information on the reinforcement, not available or otherwise. This information is then used to prepare the structural drawings as constructed.

2. Analysis and Design Methodology using ETABS model

a. Analysis Methodology :

To simulate the structure so as to get an accurate behavior, the structure will be modelled as a three-dimensional structure with RCC column, beams and floor slab using latest software package ETABS 9.5. The floor slab will be modelled as a membrane type. The structure is analysed for basic load

cases and for lateral loads and designed as per load combination mentioned in IS codes. Miscellaneous structural elements like staircases, floor slabs, lintel beams and slabs are analysed locally by conventional manual methods**.**

b. Design Methodology :

The structure is assumed to respond elastically to all the working loads. The deflections of structures will be within the Limits as specified in Specific Codes and as such justify use of normally adopted methods of linear response. Suitable load combinations are performed and performance of the structure in various states of serviceability and collapse has been checked accordingly. Design is based on limit state design for reinforced concrete structures. Whole structure has been designed according to the Limit State Method as specified in IS: 456:2000. Appropriate loads and its combination as per relevant clauses in IS 456:2000 for the most unfavorable effects are chosen for design.

V. SITE INVESTIGATION AND DESCRIPTION

1. Field observation:

This is the preliminary investigation that gives us initial information about the condition of the structure and the seriousness of the problem affecting the structure. Based on these investigations, there are observations noted for library and canteen with guest house buildings are mentioned below

- **Library Building**
  - **Internal Observation**
    i. Improper concrete cover & exposed steel reinforcements was observed on ceiling at various locations at all floor levels.
    ii. Structural crack was observed on beam bottom due to corrosion of steel reinforcements.
    iii. Damaged Concrete cover was observed on beam bottom at few locations due to corrosion of reinforcements.
    iv. De-bonding & hollow sound heard on concrete cover on slab at many locations at all floor levels
    v. Leakages marks were observed on ceiling & walls at various locations.
  - **External Observation**
    i. Major structural cracks were developed on columns at various locations from external face on back side of building.
    ii. Improper concrete cover was observed on column at few locations.
    iii. Steel bar dowels for columns were observed at terrace level. Corrosion activity was started for the exposed steel bars.
    iv. De-bonding terrace top at various locations.

- **Canteen Building**
  - **Internal Observation**
    i. Improper concrete cover & exposed steel reinforcements was observed on slab bottom at various locations at stilt floor.
    ii. Structural crack was observed on beam bottom of stilt floor due to corrosion of steel reinforcements in between columns no. C 20 & C21.
    iii. De-bonding of concrete cover was observed on slab portion of stilt floor at many locations.
    iv. Heavy leakages marks & vegetation growth was seen at stilt level on ceiling & columns no. C-24.
    v. Structural crack at first floor was developed at beam bottom near sunken slab.
    vi. De bonding concrete area was observed at first floor on slab panels at many locations.
    vii. Dampness marks at first floor were observed on internal walls due to external plaster cracks & damages.
    viii. Heavy leakages marks were observed on entire ceiling area due to damages of terrace top.
  - **External Observation**
    i. At Stilt level, de-bonding of concrete cover was observed for columns at bottom portion.
    ii. Heavy vegetation growth seen on external walls at various locations.
    iii. De-bonding of external plaster & cracks was observed at all floor levels.
    iv. Separation cracks were observed on external pardi.
    v. Steel bar dowels for columns were observed at terrace level. Corrosion activity was started for the exposed steel bars.
    vi. De-bonding terrace top at various locations.

2. NDT test results for library building (summary):

Test	**RCC members**	**Ground floor**	**First floor**	**Second floor**
Rebound hammer Test	Column	153 kg/cm^2	150 kg/cm^2	153 kg/cm^2
	Slabs and Beams	150 kg/cm^2	148 kg/cm^2	149 kg/cm^2
	Footing	155 kg/cm^2	-	-

UPV	Column	2.0 km/sec	2.1 km/sec	2.0 km/sec
	Slabs and Beams	2.0 km/sec	2.0 km/sec	1.9 km/sec
	Footing	1.9 km/sec	-	-
Corrosion	Approximate 35 - 45% in isolated location			
Carbonation	Surface carbonation up to a depth of 25 – 30 mm occurred.			

3. NDT test results for canteen with guest house building (summary):

Test	Rcc members	Ground floor	First floor	Second floor
Rebound hammer Test	Column	148 kg/cm^2	150 kg/cm^2	153 kg/cm^2
	Slabs and Beams	149 kg/cm^2	156 kg/cm^2	149 kg/cm^2
	Footing	152 kg/cm^2		
UPV	Column	1.8 km/sec	2.0 km/sec	1.9 km/sec
	Slabs and Beams	1.9 km/sec	1.9 km/sec	1.9 km/sec
	Footing	1.9 km/sec		
Corrosion	Approximate 20% in isolated location			
Carbonation	Surface carbonation up to a depth of 25 mm occurred.			

VI. DESIGN AND RETROFITTING

a. Structural audit:

During the site visit many defects has been observed and noted in the visual survey. The as built architectural and structural drawings were prepared using AutoCAD software. Based on this above observation, the defects were superimposed on structural drawings. These drawings are known as distress drawings. Further Nondestructive testing were carried out and these tests included Rebound hammer test, Ultrasonic pulse velocity test, Carbonation test, Corrosion test and Rebar locater test. The Rebound hammer test was done on the foundation, column and beams and the strength of the concrete was achieved. Corrosion test also gave us the percentage of corrosion present. These tests also provided us grade of concrete and steel.

b. Remedial Measures:

Retrofitting/strengthening is the technique for upgrading of existing structures so that structure is more capable to resist seismic forces. Reinforced concrete structures often have to face modification and improvement of their performance during their service life. The main contributing factor was sizes and depth of footing of the existing structure and it was on the lower side. To strengthen the existing structures, plinth P.C.C and soil filling was excavated and removed. All Footings to be strengthen as per the detailed drawing prepared. Foundation strengthening scheme has been proposed considering additional load, distress level. The structural repair work such as polymer and anticorrosive treatment must be carried out for columns before jacketing work.

c. Structural Data for feasibility of the structure with additional floors:

Two models were prepared for Library and Canteen building both, which are existing building and extended building. The analysis and design of existing structure is based on the details and drawings as per the site visit and to check the feasibility of addition of floors. Based on these model results, the foundation and column size were obtained. The buildings are analyzed for beam column Frame System. The following are the structural description:

Structural Description	Library Building		Canteen Building	
	Existing Building	Extended Building	Existing Building	Extended Building
Material Parameters				
Grade of concrete	M15	M30	M15	, M30
Grade of steel	Fe 332	Fe 415, Fe 500	Fe 332	Fe415, Fe 500
Structural data				
Column Size (mm)	230X700	380X900 , 300X900	230X600	300X750 , 380X750
Beam Size (mm)	230X450 , 230X600	230X450 , 230X600	230X450 , 230X550	230X450 , 230X550 , 230X600
Slabs Size (mm)	125, 175	125, 150.	125	125, 150
Height of structure From Ground (m)	10.34	21.14	9.55	16.75
Seismic Parameters				
Response Reduction Factor (R)	3	3	3	3

Importance Factor (I)	1	1	1	1
Seismic Zone Factor (Z)	0.16	0.16	0.16	0.16
Soil Type	II	II	II	II
Wind Parameters				
Terrain Category	3	3	3	3
Structure Class	A	B	A	B
Wind Speed Vb (M/S)	39	39	39	39
Topography Factor	1	1	1	1

d. Structural loads:

Structural analysis is the important part of designing the building. The building regulations are necessary where the structure must be able to withstand all the type of load. The following are the different type of loads as below:

i.Dead Load

a) The Wall loads for all floors wall load is considered as 150mm thick Siporex wall having density not more than 8 kN/m^3.
b) Sunken load: Any sunken loads to be filled with siporex waste only.
c) Floor finish load are considered as 1.50 KN/m^2 as per IS 875 (part I):1987.

ii. Live load

Live loads are the imposed loads which are usually changeable, temporary and dynamic. Live load is taken as per IS 875 (part II):1987.

iii. Earthquake load

Earthquake loads are the horizontal loads imposed on a structure when the earthquake occurs. Buildings in the areas of seismic activity are to be analyzed and designed carefully so that the structure is safe.

iv. Wind load

Wind loads can be applied by the movement of air relative to the structure. Wind load is the load due to wind speed and its air density on the building.

e. Analysis and design of additional floors based on the modified design parameters after retrofitting existing distress structure:

The structure is assumed to respond elastically to all the working loads. Suitable load combinations are performed and performance of the structure in various states of serviceability and collapse has been checked accordingly. Design is based on limit state design for reinforced concrete structures. Whole structure has been designed according to the Limit State Method as specified in IS: 456:2000. Appropriate loads and its combination as per relevant clauses in IS 456:2000 for the most unfavorable effects are chosen for design.

To simulate the structure so as to get an accurate behaviour, the structure will be modelled as a three-dimensional structure with RCC column, beams and floor slab using software package ETABS 9.5. The floor slab will be modelled as a membrane type. The structure is analysed for basic load cases and for lateral loads and designed as per load combination mentioned in IS codes. Miscellaneous structural elements like staircases, floor slabs, lintel beams and slabs are analysed locally by conventional manual methods. The followings are the design of footing, column and additional floors for both the structures after retrofitting these said distress structures.

VII. RESULT AND CONCLUSION:

Conclusion

Based on the analysis and design results for Library and canteen building, the conclusion is mentioned below:

i. Existing structure is designed for Gravity load only. No Seismic loading has been considered.
ii. From analysis considering the additional floors and seismic loads for Ahmadabad zone it can be stated that steel reinforcement provided in all column groups appears to be on the lower side based on the analysis and design output.
iii. Sizes and depth of foundation provided is on the lower side in all column groups.
iv. Grade of concrete for existing lower floors can be taken as M15 for analysis purpose based on Non-Destructive test results.
v. All the brick walls (internal and external) to be replaced with Siporex wall of not more than 150mm thick from Stilt floor and above.
vi. All the toilet sunk if any and other floor sunk to be filled with Siporex / equivalent light weight material from Second floor and above.
vii. After performing non destructive tests on the structure it was found out about 30% distress in the structure. In order to overcome this distress, repair activity like anticorrosive treatment on corroded reinforcement, application of corrosion inhibitors and polymer treatment etc. were carried out. As per requirement of additional floor from client M/s NIOH, the feasibility

of the existing structure was checked for additional floors. Thus it was recommended to carry out strengthening of foundation and column jacketing to accommodate the additional floor load. Subsequently, fibre wrapping was carried out on columns and beam column joints to provide ductility.

Recommendation

i. All columns to be strengthened from footing top to existing terrace level.
ii. All Footings to be strengthened.
iii. Supporting to the adjacent slabs and beams required to be done prior to exposure of foundations for strengthening work.
iv. All the structural repair work such as polymer, anticorrosive treatment to be carried out for columns prior to jacketing work.
v. Shear connectors to be proposed to hold the new concrete/steel with the existing core.

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