NON-DESTRUCTIVE TESTING AND LINEAR DYNAMIC ANALYSIS OF EXISTING RC FRAMED STRUCTURE

Seismic Evaluation of Existing RC Framed Structure using Response Spectrum Analysis

[1]Sushant. S. Desai, [2]Dr. Chandrakant. B. Pol
[1]P.G. Scholar, [2]Associate Professor
[1]Applied Mechanics Department,
[1]Walchand College of Engineering, Sangli, Maharashtra, India

Abstract: Assessment of the current strength of structure is an important aspect before taking measures of seismic requalification and retrofitting of an existing concrete structure, if required. The assessment of concrete structure is not only about evaluation of its present condition but to predict the cause of deterioration and its residual life as well. Structural audit is the technical survey of the building in order to check its strength and stability. In this case non-destructive testing methods are widely applied to study mechanical properties and structural integrity of the concrete. The concept of non-destructive testing (NDT) is to obtain material properties of specimens without the destruction of the member/element of structure and to do the structural health monitoring together. Also the maintenance, rehabilitation and upgrading of structural members is one of the most critical problems in civil engineering applications. The paper provides an overview of the different tests performed on existing RC framed structure carrying various equipment for health assessment and further provides a brief account of the results along with response spectrum analysis of that existing RC framed structure is performed.

Index Terms **- Multistoried building, Visual inspection, NDT, Response Spectrum Analysis**

1 INTRODUCTION

Buildings/Structures which are not safe and weak in service are taken to be demolished and a new one is usually erected. Nowadays, it is preferable to strengthen old existing structures instead of demolishing and constructing a new one. Engineers who assess old existing buildings either for increased live loads, dead loads, change of use of the building, new design codes, revision in loading standard etc. have tried to obtain a safe, efficient methods to strengthen the structures considering the best in economy.

Specified safety and performance level of the structure or a structural member can be brought by structural rehabilitation. Depending on condition of structure or structural elements, rehabilitation can be classified into two categories: Repair and Strengthening. Repair is rehabilitation of a damaged structure or a structural element, while strengthening is upgrading an undamaged/damaged structure or the element. [1]

But prior to this, we need to carry out one important procedure – NDT. Non-destructive testing consists of various techniques which are utilized to determine the integrity of a material or a structure or to measure some characteristic of an object without destroying the object without destroying the object under consideration. Concrete spalling and steel corrosion, exposure of steel reinforcement, improper drainage causing leakage are affected by the structure or layout change in original design which may increase the dead load on the structure and thus reduces strength of the structures. It leads to structural deficiency and hence it is need of hour to identify the livability/stability/safety of the existing structure. [2]

It is known that many buildings designed based on old codes were susceptible to serious damage during an earthquake. Old buildings have been structurally designed for much lesser seismic actions when compared to buildings that are designed today. Existing buildings need seismic evaluation because our understanding the effect of earthquakes has improved after buildings were constructed. [3]

2 PROPOSED WORK

2.1 Methodology

The study is focused on the non-destructive testing and analysis of three story reinforced concrete frame building with number of equipment resting. In this work, an attempt is made to check the stability and safety requirement of existing reinforced concrete frame 3-floor building with number of equipment resting located in Goa region. The building lies in zone 3 with an overall dimension of building as 8m width 10m Length and 13.45m height. The building was designed as per old codes prior to codes that are related to earthquake which make it susceptible in the event of an earthquake. In this study few non-destructive testing methods which are done on this structure is studied and then the structure is being modelled in ETABS software followed by linear dynamic analysis is carried out. Basic structural and dynamic properties of the building have been found out by model and comparison with different parameters have been presented in this paper.

2.2 Building data

The building is reinforced concrete SMRF structure having 3 story. The building consist of number of equipment (cool condenser) on different floor. Live image of this structure is shown below in Picture 1.

Picture 1 Real View of the building

Table 1 Building data

Story	G+2
Type of structure	R.C Framed Structure
Plane dimension	8 m x 10 m
Terrain type	Plain
Loading	DL, LL, Equipment load
Terrain category	Two
Height of structure	13.45 m
Wind speed	44 m/s
Geometry of the structure	Rectangle base

3 NDT AND ANALYSIS OF BUILDING

3.1 Visual Inspection

Detailed visual inspection of the structure under reference i.e. existing structure of cooled condenser was carried out in sequence wise and the distresses observed were recorded and summarised as below.

- Honey combing and localised cracks due to the corrosion of the reinforcement were observed.
- Moss growth, water logging etc. were noted on the floor slab
- Weathered surfaces were noted on the RCC columns and beams.
- Unfinished cut-outs noted made in the existing RCC slabs so as to accommodate process pipes.

3.2 Inference of NDT results

The details are as below –

- **Ultrasonic Pulse Velocity Test:** For checking the quality of concrete.
- **Cover Meter Test:** For checking cover of concrete over the reinforcement
- **Schmidt Rebound Hammer Test:** For checking approximate compressive strength of concrete
- **Core Extraction:** For tests like carbonation, chemical analysis, compressive strength etc. on the core samples
- **Carbonation Test:** To check the depth of ingress of carbonation in the concrete.

3.2.1 Ultrasonic Pulse Velocity Test

This instrument works on the principle of passing high frequency sound waves through the body of the concrete & measuring the time taken. Distance of path length divided by the time taken provides velocity of the waves through the concrete member being tested. Depending on the velocity, the quality of concrete as regards homogeneity can be judged. Lower velocity (less than 3 Km / sec) indicates some defects like honey combing, cracks, voids, rebounding etc. at the location of test.
As per IS, velocity below 3.00 Km / sec indicates 'Doubtful' quality concrete, velocity between 3.00 to 3.50 Km / sec indicates 'Medium' quality concrete and velocity above 3.50 Km / sec indicates 'Good' quality concrete. And velocity 4.50 Km / sec indicate 'Excellent' quality concrete. From the above parameters we can judge the quality of concrete.

Details of Testing:

The test was conducted at total 46 representative locations of the R.C.C. members. Out of the said 38 locations, RCC columns tested at 36 locations and RCC beam 10 tested at location.

- Maximum reading obtained as 4.88 km/sec on RCC Beam.
- Minimum reading obtained as 2.31 km/sec on RCC Column.

3.2.2 Cover Meter Test

This test indicates the cover of concrete over the reinforcement. In this case the cover is without the plaster.

Details of Testing:

- The test was conducted at total 10 representative locations of R.C.C. members. Out of the said 10 locations, RCC Columns Tested at 06 locations and RCC beam tested at 04 location
- Cover of concrete obtained For RCC column ranging between 35 mm to 98 mm
- Cover of concrete obtained For RCC beam ranging between 42 mm to 84 mm

3.2.3 Schmidt Rebound Hammer Test

Total 16 impact readings were taken at each location and average of middle ten was calculated after discarding the top three and bottom three readings. In this manner, total no. of points was tested on the selected concrete members.
The probable accuracy of prediction of concrete strength by the rebound hammer is + 25% as per IS code 13311(part II).

Details of Testing:

- The test was conducted at total 12 representative locations of R.C.C. members. Out of the said 12 locations; RCC columns were tested at 06 locations and RCC beams were tested at 06 locations.
- Maximum reading obtained as above 635.0 kg/cm^2 on R.C.C. columns and R.C.C. beams
- Minimum reading obtained as 440.00 Kg/ cm^2 on RCC Beam.

3.2.4 Concrete Core Strength

This test is performed to acquire the actual strength of the concrete in the structure. This test is done by extracting 75 mm. diameter cores from the structural member of the structure i.e. R.C.C. Slab and testing the same in the laboratory on a compression testing machine.

Details of Testing

- The test was conducted at 01 representative location.
- The strength of the concrete obtained is 43.31 N/mm^2

3.2.5 Carbonation Test (Ref BS 1881 Part 201: 1986)

This test is carried out to measure the depth of concrete from the external face up to which it has undergone carbonation.
The test requires core samples of 25 mm or 50 mm diameter to be taken out for a depth of about 80 to 100 mm for column and 100 – 130 mm for beam. Higher diameter cores taken can also be used for this test. The core sample is sprayed by 2% phenolphthalein solution starting from the exposed or external surface of concrete. If sprayed concrete turns pink, it is considered as non-carbonated. The depth of carbonation is measured in millimeters as the depth from the external face of concrete to the point beyond which the phenolphthalein sprayed concrete turns pink in color. If the core of concrete is not available, the test can be performed by suitably exposing the concrete by cutting or breaking with a chisel and performing the test on this freshly exposed surface as described above.

Details of Testing

- The test was conducted on the core sample extracted from one representative location.
- Surface Carbonation is obtained for RCC foundation.

Sr. No.	Location	Member	Observation	Conclusion
1	Column No.A1	RCC Columns	Surface Carbonation	Readings obtained means ingress of carbonation has not reached in the core of the concrete.

3.3 Response Spectrum analysis of Existing Structure

Important seismic parameters have been calculated which includes calculation of time period of the structure, maximum story displacement, story drift, and Story shear, etc.

3.3.1 Details of Existing Structure

Following Table gives brief information about existing structure:

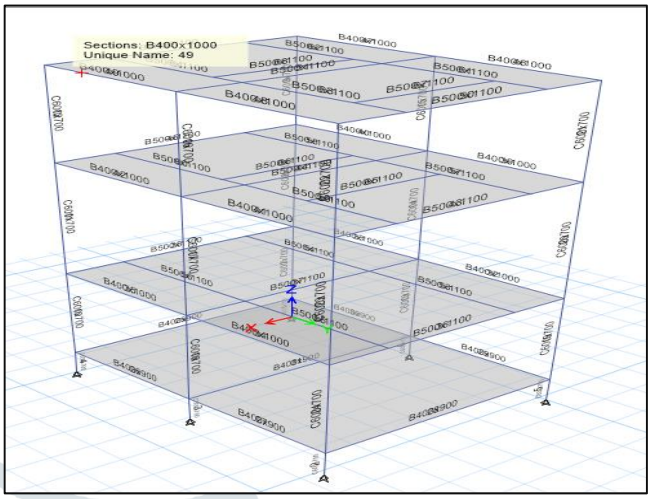
Table 1 Details of Structure

Story	G+2
Type of structure	R.C Framed Structure
Plane dimension	8 m x 10 m
Terrain type	Plain
Loading	DL, LL, Equipment load
Terrain category	Two
Height of structure	13.45 m
Wind speed	44 m/s
Geometry of the structure	Rectangle base

3.3.2 Modelling of structure

Above existing reinforced concrete frame structure having number of equipment on it is being modelled in finite element software. Following table gives details of structural elements along with picture of model is shown below.

Grade of concrete, fck	25 MPa
Grade of steel, fy	250 MPa
Column Size	600 mm x 700 mm
Beam size	400 mm x 1000 mm 400 mm x 900 mm 500 mm x 1100 mm 500 mm x 9550 mm
Operating Wt. of 1 equipment	75 kN



3.3.3 Load Cases & Combinations

Following are the various load cases we have considered while modelling the RC structure:

Table 3 Load Cases

Dead	Linear Static
Live	Linear Static
Eqx	Linear Static
Eqy	Linear Static
Equip- Test	Linear Static
Equip- Operating	Linear Static
RSx	Response Spectrum
Rsy	Response Spectrum
SDL	Linear Static

- Following load combinations are applied to this current model as per IS 456:2000 and IS 1893:2016. Total 13 different load combinations are applied in this case –

- **1.5 (DL+SDL+LL)**
- **1.2 (DL+SDL+LL±EQx)**
- **1.2 (DL+SDL+LL±EQy)**
- **1.5 (DL+SDL±EQx)**
- **1.5 (DL+SDL±EQy)**
- **0.9 (DL+SDL) ± 1.5 (EQx)**
- **0.6 (DL+SDL) ± 1.5 (EQy)**

3.3.4 Response Spectrum function

Following data is taken into account while defining response spectrum function

Table 4 Response Spectrum Function

Ref. Code	IS 1893:2016
Zone	III
Value of z	0.16
Soil type	Medium
Damping ratio	0.05
Importance factor	1.5

3.3.5 Analysis

It is known that many buildings designed based on old codes were susceptible to serious damage during an earthquake. The above existing structure is more than 35 years older. Thus at the time of construction of the structure, earthquake forces were not been considered as codes for earthquake in India came into existence in early 2000 (IS 1893:2002). Thus after NDT is need of time to check whether the structure is adequate enough to bare the earthquake forces likely to come on it.

Hence we have performed response spectrum analysis of the structure as seismic evaluation of the structure is to be known. The data for earthquake forces is taken from available codes, studying the area in which structure falls, etc.

4 RESULTS

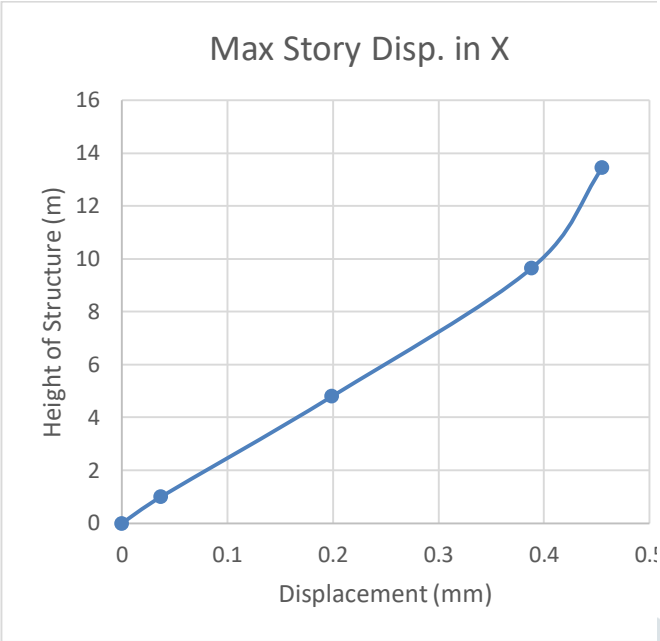
4.1 NDT

Table 4 Recommendation after NDT

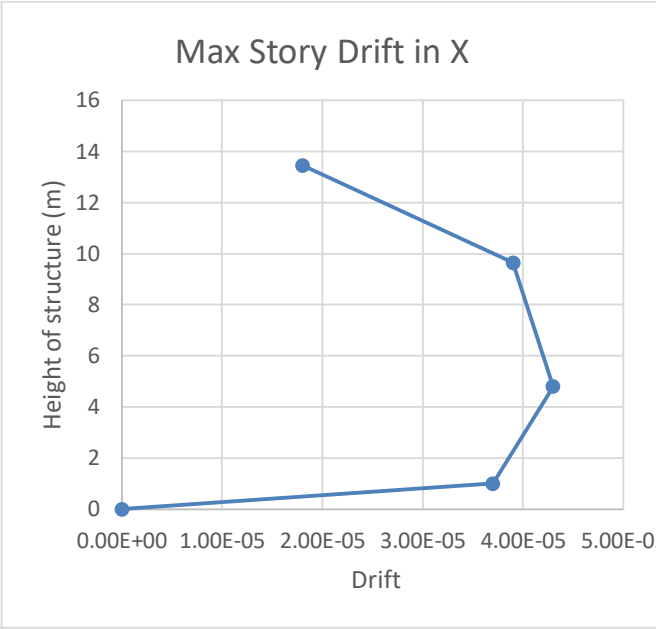
Sr. No	Name of Structures	Distresses	Recommendation
1	Adequacy check of existing Cooled condenser structure	1.Honey combing and localized cracks due to the corrosion of the reinforcement were observed	Cement grout and patch repair with the use of Polymer modified mortar as per standard methodology
		2.Broken top edges of the top surface of the RCC pedestals	Replacement of the same as per the existing materials & specifications.
		3. Corrosion noted on bolts provided to support the equipment's installed on the particular RCC foundation	Removal of existing corrosion (as per the standard methodology currently being adopted at site) and the same should be further protected with good quality protective Paint as per manufacturer's recommendations
		4. Unfinished cut-outs noted made in the existing RCC slabs so as to accommodate process pipes.	Unfinished cut – outs should be filled properly using micro- concrete of an approved brand

4.2 Linear Dynamic Analysis

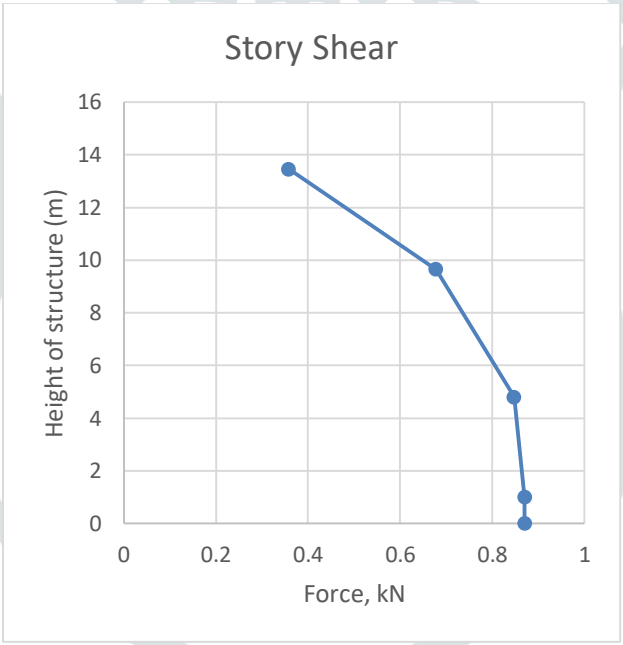
Linear Dynamic Analysis of structure is carried out for current loading along with earthquake force as per IS 1893:2016. Analysis is carried out using ETABS software. Following graph (a) compares the absolute displacements which are calculated by software and maximum permissible displacements (h/100) at different heights. It indicates that maximum permissible displacements are higher than absolute displacements. Also graph (b) representing story drift is obtained, where permissible story drift is 0.4% of story height as per IS code. Later graph (c) shows the story shear at different story of the structure.



(a) Max Story Displacement



(b) Max Story Drift



(c) Story Shear

Based on analysis performed in ETABS following table 5 shows result of time period and table 6 shows modal participating mass ratios.

Mode number	Time period (seconds)
1	0.589
2	0.568
3	0.457

Table 5 Time Period of Structure

Sum UX	0.994
Sum UY	0.9974
SUM UZ	0.9006

Table 6 Modal Participating Mass Ratios

5 CONCLUSIONS

After NDT we get to know that the structures showed several types of damages and distresses. However looking to the nature and extent thereof, it could be concluded that these structure were in repairable condition. However it required repairs; as suggested in the recommendations; so as to restore the same to its sound structural conditions. If the Civil and structural repairs as suggested in the recommendations are carried out by adopting appropriate techniques, using proper materials as also by undertaking periodic maintenance works, the serviceable life span of the structure could be improved considerably. Timely maintenance is important, so as to ensure proper treatment to the areas which may show the distresses during its serviceable life. The later study of linear dynamic analysis of the structure shows that story displacement and story drift are well behind respective permissible limits. Thus they are safe in that case. Then the modal participation mass factor is above 90% and thus meet the criteria. As time period of first three modes is most significant we have considered those three and it is approximately similar with theoretical time period value. Thus we can conclude that this given structure is safe for earthquake loading if occurred as per relevant IS codes. It will be also matter of interest if one can check the structure for wind loading as per IS 875:2015 Part 3.

6 ACKNOWLEDGMENT

The project was supported by TEQUIP-III NPIU India and management of Walchand College of Engineering Sangli, Maharashtra, India. I would like to express my deep appreciation and sincere thanks to those who supported me in preparing this paper.

7 REFERENCES

[1] S. S. Raval and U. V. Dave, "Effectiveness of various methods of jacketing for RC beams," *ELSEVIER*, pp. 1-10, 2012.

[2] R. Karnavat, "Assessment of structural efficiency of an existing building structure by performing non-destructive tests : A case study," *International journal of research in engineering and technology*, 2017.

[3] S. A. El-Betar, "Seismic vulnerability evaluation of existing RC buildings," *HBRC*, 2019.

[4] D. V. Mehta, "Application of non-destructive test forstructural health monitoring - State of the art review," *International journal of research in engineering and technology*, 2015

[5] M-Sal,am, A. R. Shaikh, K. R. Ghadge and S. I. Khan, "Seismic Evaluation and comparative study of various retrofitting techniques of RC building," *International journal of engineering research and applications(IJERA)*, 2015

[6] V. A. Kumar and V. D. L. Babu," A survey of methods and techniques used for seismic retrofitting of RC buildings" *International Journal of Civil and Structural Engineering*, **Volume2**, No. 1, 2011