



# Structural Auditing with a Case Study

J. M. Sadamate<sup>1</sup>, Dr. G. A. Hinge<sup>2</sup>  
ME (CM) Student<sup>1</sup>, Vice-Principal<sup>2</sup>  
Department of Civil Engineering

TSSM's Bhivarabai Sawant College of Engineering & Research Narhe, Pune, Maharashtra, India

## Abstract:

Structural audit is an overall health and general check-up of buildings. In India, from 1980 onwards the infrastructure industry witnessed stepping up of public investment. Growth in infrastructure industry which results in construction of new multistorey concrete apartments, which are now in the age of thirty plus years. It is important to the buildings to check their safety and these building have no risk. It is process of analyses of building. This process suggests an appropriate repairs and retrofitting measures required for the buildings. To perform better in its service life. Structural audit is an important tool for knowing the real health status of the old buildings. Structural auditing create awareness amongst the civil engineers, residents and owners of building towards the health examination of existing concrete buildings. This paper deals with a case study of Structural auditing process by visual inspection and Non destructive test on a residential building. In this paper visual inspection report is given in grades and colour coding instead of description so as to simplify it for Non Technical person. According to NDT test results following repairs are suggested.

**Keywords:** Structural Audit, Non-Destructive Test, repairs and controls, audit standards.

## I. INTRODUCTION

In India there are many old buildings which have reduced strength in due course of time. As per If further use of such deteriorated structure is continued it may endanger the lives of the occupants and surrounding habitation. According to Mahadik A B<sup>1</sup> and Jaiswal M H<sup>2</sup> (2014), A structure is a system of inter connected elements such as frames to carry loads safely to underground earth. The health examination of concrete building called as "Structural audit" or structural audit is an overall health and performance check-up of building like a doctor examines a patient. India is a heritage of old building and Structures. These buildings have age more than 30 years. It also suggests some Repair to increase the Serviceability of the building. It is necessary for maintenance and Repair of Existing Structure having age more than 30 years.

This paper deals with study of different parameters of structural audit including visual inspection, non-destructive testing, core sampling and carbonation testing. It also emphasizes on different repairs and retrofitting measures to be used for buildings after structural audit.. I. H. Shah has published work for "Structural Audit of Existing Buildings" "Nondestructive Test Methods for Evaluation of Concrete in Structures" reported by ACI Committee 228.D K Kulkarni and Teke Sudhakar S Health assessment of Reinforced Concrete Structures-Case Study. N R Patil- Non destructive testing (NDT) advantages and limitations. Select Document, select margins, input .75 for left and right margins, and 1.0 for top and bottom margins This will create correct margins and columns throughout the paper.

## Bye-Laws

As per clause No.77 of revised Bye-Laws of Cooperative Housing Societies: "The Society shall cause the 'Structural Audit' of the building as follows: A Norm According to the model bye-law no. 77 for co-operative housing societies, it is mandatory that if the age of a building is 15 to 30 years, a

structural audit must be carried out once in five years and for buildings older than 30 years it should be carried out once in three years. One may, however, go for it even earlier if one suspects the condition of the building to be bad. Perhaps monsoon/ post monsoon is the best time to commission a structural audit since the seepage is more evident at that time. The certificate, issued by a structural engineer registered with BMC, will have to be submitted within a year after a building completes 30 years.

For any corrective repairs suggested by the commissioner, the owner or occupants will be asked to submit the structural stability certificates again after a specific period suggested by him. If found unsafe, he has been given the authority to issue a notice to the owner to submit a structural stability certificate within 30 days from the date of notice. It will be binding on owners to carry out corrective repairs to the satisfaction of the commissioner.

## II OBJECTIVES

1. To know history of the various components of buildings.
2. To study and use Visual inspection methods
3. To study and use NDT methods
4. To suggest repairs and retrofitting to the building

## III METHODOLOGY

### How Structural Audit is carried out?

- 1) Study of architectural and structural drawings, design criteria, design calculations, structural stability certificate of existing structures
- 2) If the Architectural plans and Structural plans are not available, the same can be prepared by any Engineer.

3) To study and use of Visual Inspection by complete building surveying.

4) To study and use of various Non Destructive Tests i.e. rebound hammer test, upv test, core test and carbonation test.

**Non Destructive and Destructive Testing:**

As per IS: 13311 (Part - I): 1992 & BS 1881: Part 203: 1986 and IS: 13311 (Part 2): 1992 & BS 1881: Part 202: 1986. In addition to visual inspection, the real strength and quality of a concrete structure need to be checked with non-destructive tests.

A number of non-destructive tests (NDT) for concrete members are available to determine present strength and quality of concrete. In case of destructive testing, to verify the integrity of a component, it is always possible to cut or section through the components and examine the exposed surfaces. Components can be pulled or stressed and pressurized until failure to determine their properties of strength and toughness. Materials can be chemically treated to determine their composition.

Some of these tests are very useful in assessment of damage to RCC structures subjected to corrosion, chemical attack, fire and due to other reasons. These tests have been put under four categories depending on the purpose of test as under:

**Concrete Strength**

- Rebound Hammer Test: To measure surface hardness of concrete
- Ultrasonic Pulse Velocity Test: To assess homogeneity of concrete, to assess strength and quality of concrete qualitatively, to determine structural integrity
- Core Sampling and Testing: To measure strength, permeability, density of concrete.

**Chemical Attack**

- Carbonation Test: To assess depth of carbonation and pH of concrete

**Core Testing**

This is direct method of assessing strength of concrete. In this method cylindrical core samples are taken from existing structures. The cores are visually inspected and tested in laboratory to check its compressive strength.

**IV. OBSERVATION AND RESULTS:-**

**A] Case Study of R.C.C. Building**

Name of Building:Renuka Residency

Name of owner: V S Shinde,

Address: Katraj kondwa road, Gokul nagar, katraj,Pune.

Year of Construction: 2004

Name of Auditor:-United consulting engg pune.

**V. VISUAL INSPECTION**

**Table.1. General Observations**

Sr no	DESCRIPTION	REMARK
1	Type of building	Residential
2	Age of building	13 Years
3	No of wings	2 wings
4	Mode of use	Commercial Residential
5	No of stories	G+8 floors
6	No of flats	108 flats
7	Architectural plan available	Not Available
8	Structural plan available	Not Available
9	Building plan approval date	2004
10	Occupation certificate date	Not Available
11	Last repair date	2014
12	Cost of repair	Rs 50,000/-
13	Details of repair	Plumbing work, leakages, minor cracks
14	Structural plan available	Not Available

**Table.2. Structural Observations:**

S.R. N.O.	DESCRIPTION	REMARK	GRADE
A	<b>Settlement</b>		
1	Column	No settlement	8
2	Walls	No settlement	8
3	Cracks in column, walls, joint at plinth	Minor cracks	7
B	<b>Cracks</b>		
1	Column	Diagonal Cracks and minor cracks	4
2	Beams	Hair cracks	7
3	Slab	Hair cracks	7
4	Plaster	Peeling of plaster	6
5	External wall	Minor cracks	8
6	Internal wall	Major cracks	3
C	<b>Corrosion of steel</b>		
1	Column B-2	Steel exposure and no corrosion	6
2	Beams	No corrosion	8
3	Slab	No corrosion	8
D	<b>Leakages and dampness and water proofing</b>		
1	External wall	Peeling of plaster and Dampness	5
2	Toilet	Dampness of tiles and walls	5
3	Terrace	Dampness & leakages at side of tanks	5
4	Top floor slab	Yellow Patches	6
5	Inspection of overhead water tank	Dampness and Leakages, Minor cracks	6
6	Inspection of underground water tank	Not inspected	0
7	Leakages & damages plumbing lines/ waterlines, drainage lines	Leakages in particular floors, algae attack over external pipes	6
E	<b>Deflection</b>		
1	Beams	No deflection observed	8
2	Slab	No deflection	9
3	Overloading on slab	No deflection	9
4	Cantilever deflection	No deflection	9
F	<b>Condition of other component</b>		
1	Staircase	Not much problems( steel exposure at terrace)	8
2	Balcony	Not much problem only side dampness due to pipeline	8
3	Flooring	Undulations and cracks in tiles	6
4	Ducts	Dampness and Leakages	6
5	Terrace	Algae and dampness	6
6	Plumbing System	Leakages problems	6
7	Electric Supply Line	Not much problem	8
8	Water Supply Line	Dampness around and algae attack	7

**RESULT:**

Table no 1 show General Observations of the building and Table no 2 Structural Observations of building and also descriptions of defects observed in buildings. As shown in table no 3 the remarks of Structural Audit Report should be given in grades and colour coding instead of description so as to simplify it for Non Technical person. As per Swapnil Biraris<sup>1</sup> and Pounima vispute<sup>2</sup> (2017). Structural audit of old

buildings Grade system for Visual inspection is implemented. As per this paper the component of buildings which are in between Red and Yellow codes are further suggested NDT testings. As per above visual observations:

1. There is no major problem in Settlement of component, corrosion of steel and deflection of components.
2. Major part observed is leakage problems and dampness and even cracks.

**Table. 3. Grades and colour coding system:**

Sr. No.	Grade	Description	Colour code
1	0 to 3	Major Distress	Red
2	3 to 5	Considerable Distress & Repairable	Yellow
3	5 to 7	Moderate Distress and Repairable	Blue
4	7 to 10	Sound Structure	Green

**Case Study No. 1:**

It was designated as **Bldg. No. 1** for study purpose. It's a Renuka Residency catering needs of Katraj kondwa road,. The Building is 13 years old. Grade of concrete used was M25. It is G+8 storeyed building. The ground floor and first floor used as commercial complex and the 2<sup>nd</sup> floor is used as a parking for the customer of shopping complex. The Owners have observed corrosion related cracks on slab bottom; beams and columns hence they wanted to know the strength & quality of the concrete. Hence they appointed M/s. BHOOMI GEOTECH PVT.LTD. For assessing the strength & integrity of concrete elements of this building by carrying out non-destructive testing. As a fig 1 showing the internal surface of the concrete to conduct rebound hammer test and fig.2 showing technician Mr. Tulsi, Bhoomi Geotech Pvt. Ltd. performing Rebound Hammer test on actual site.

**Figure.1. Photograph showing an internal surface of concrete**



**Figure.2. Rebound Hammer test**

**Reference Code:** - IS: 13311 (Part 2): 1992 & BS 1881: Part 202: 1986

**Table. 4. Quality of concrete according to rebound number**

Average rebound number	Quality of concrete
> 40	Very good hard layer
30 – 40	Good layer
20 – 30	Fair
< 20	Poor
< 10	Delaminated

**Reference code:** - IS: 13311 (Part - I): 1992 & BS 1881: Part 203: 1986

**Table. 5. Concrete grading for USPV**

Sr. No	Ultrasonic Pulse Velocity by Cross probing (Km/Sec)	Concrete quality grading
1	Above 4.5	Excellent
2	3.5 to 4.5	Good
3	3.0 to 3.5	Medium
4	Below 3.0	Doubtful

Based upon above criterion, grading of concrete quality is determined at test locations

### Estimation of Cube Strength

As per IS: 516 – 1959, the equivalent cube strength is calculated by formula

$$\text{Equivalent cube strength} = 1.25 \times f_c \times k$$

$$\text{Where } k = 0.87 + 0.13 \{ (L/d) - 1 \}$$

Table no 4 shows quality of concrete according to rebound number and table no 5 shows concrete grading for USPV according to IS 13311-1992

**Table .6. NDT test results of column**

Location	Rebound hammer test						Average rebound No.	Ultrasonic pulse velocity test			Visual inspection (Remark)
	1/7	2/8	3/9	4/10	5/11	6/12		Distance (mm)	Reading (micro Sec.)	Velocity (km/Sec.)	
GROUND FLOOR COLUMNS											
C-2	31	27	28	30	26	21	26	400	166	2.4	(Minor cracks)
	20	23	27	28	24	26					
D-2	33	23	25	27	26	28	25	400	168	2.4	(Patches)
	20	24	26	25	22	24					
C-1	45	42	40	38	41	44	41	400	148	2.7	
	33	41	43	40	39	42					
Location	Rebound hammer test						Average rebound No.	Ultrasonic pulse velocity test			Visual inspection (Remark)
	1/7	2/8	3/9	4/10	5/11	6/12		Distance (mm)	Reading (micro Sec.)	Velocity (km/Sec.)	
E-1	29	33	32	31	40	30	30	400	125	3.2	
	32	33	23	27	26	27					
D-1	36	37	38	42	47	40	39	400	138	2.9	
	38	39	40	30	36	44					

**Table.6. Ndt test results of beam**

GROUND FLOOR BEAMS											
Location	Rebound Hammer test						Average rebound No	Ultrasonic pulse velocity test			Visual inspection (Remark)
	1/7	2/8	3/9	4/10	5/11	6/12		Distance (mm)	Reading (micro Sec.)	Velocity (km/Sec.)	
B2 & B-1 (beam)	31	32	33	34	36	33	36	200	69	2.9	
	40	41	39	38	36	39					
C-1&C-2	29	34	33	32	35	36	35	200	63	3.2	
	41	40	38	36	33	33					
D-1&D-2	33	31	34	36	35	34	32	200	68	2.9	
	32	27	30	31	29	31					

**Table.7. Core cutting Test Results**

Sr. No	Location ID	Height (mm) L	Dia (mm) D	L/D Ratio	Load (KN)	fc= Load/Area (N/mm <sup>2</sup> )	Estimated equivalent in situ core strength (N/mm <sup>2</sup> )	Corrected equivalent in situ cube strength as per IS:516 (N/mm <sup>2</sup> )
Slab thickness 150mm Ground Floor								
1	Slab Near Col. C2-D2	145.9	74.4	2.0	49	11.3	14.0	15.15*
2	Slab Near Col. E2-F2	95.2	74.3	1.3	119	27.6	31.2	33.7
3	Slab Near Col. C1-B1	115.6	74.4	1.6	68	15.7	18.5	20.0
AVERAGE =							21.3	26.9
Slab thickness 150mm First floor								
4	Slab Near Col. B2-C2	90.4	74.4	1.2	117.6	27.0	30.3	32.7
5	Slab Near Col. A1-B1	104.3	74.4	1.4	78.4	18.0	20.7	22.4
6	Slab Near Col. D2-E2	94.5	74.4	1.3	113.55	26.1	29.6	31.9
AVERAGE =							26.9	29.0

**Table.8. Grading of Results of Rebound hammer tests and UPV test**

Sr. No.	Column ID	Rebound Nos.	In-situ Compressive Strength (N/mm <sup>2</sup> )	Direct USPV (Km/sec)	Concrete Quality Grading
Ground Floor Columns					
1	C-2	26	6.7-22.3	2.4	Doubtful
2	D-2	25	6.2-21.8	2.4	Doubtful
3	C-1	41	24.2-39.8	2.7	Doubtful
4	E-1	37	18.7-34.3	-	-
5	F-1	34	14.7-30.3	-	-
Number =		5	5	2	
Average =		33	21.9	2.5	Doubtful
Standard Deviation =		6.9	7.8	0.2	
Coefficient of variation =		21	35.0	8.3	

"\*" sign indicate that this value are not considered for analysis being abnormally high or low than 25% of avg then it considered that, it is suppose that test might be wrong.

**Table. 9. Carbonation Test Results**

Sr. No	Location ID	Depth Of Carbonation (mm)
1	C-2	20
2	D-2	15
3	C-1	70
4	D-1	40
5	B-1	30
6	B-2	50
7	E-2	20
8	A-1 & A-2 (BEAM) B1	60
9	D-1 & D-2 (BEAMS)	20
10	B-1 & B-2 (BEAM)	80
AVERAGE		40

**VI. RESULTS**

**Core Test Result:**

As shown in table no 7, Total 6 nos. of cores were extracted from the slab, out of which 3 nos. of core were extracted from Basement slab & 3 nos. of cores were extracted from first floor slab. The analysis of core test results indicate that average equivalent cube strength for basement slab is 26.9 N/mm<sup>2</sup> & that on first floor slab tested is 29.0 N/mm<sup>2</sup>. Hence, subject concrete could be classified as of M-25 grade for first level slab & of M-30 grade for first second level slab as per acceptance criteria for concrete.

**Carbonation Test:**

The average depth of carbonation as shown in table no 8, avg carbonation at columns is observed as 40 mm and the maximum depth of carbonation is 80 mm .The carbonation observed on the core surfaces is also in the same range. This is in line with the inferior quality of concrete , indicates high probability of corrosion in near future as the entire cover concrete is expected to be affected by carbonation .

**VII. SUGGESTIONS AND REPAIRS**

**According to the Watt, D. \_1999\_. Building pathology: Principles and practice,** Blackwell Science, Oxford, U.K following suggestions and repairs are suggested.

**Repairs in Masonry work**

- Improper jointing work
- Remove all loose and weak masonry work which visible.
- Create proper voids in adjacent wall for locking purpose
- Take care to minimize damages to already completed masonry
- Execute repairing work carefully. If required re-do the affected portion also observe curing on all repaired work

### Repairs in waterproofing

- Repairs in water proofing should be done by the approved agencies only
  - External and internal ghabadi finishing after fixing the rainwater pipe, should be done by the waterproofing contractor carefully with waterproofing chemical.
  - If the water-proofing agency has done excess waterproofing treatment on walls of WC get rectified by the same agency, before fixing glaze tiles
  - Ensure necessary precautions for the required water tightness
  - All repair works should be properly cured

### Repairs in Tiling/Flooring

- Broken mosaic tiles during polishing of the flooring should be repaired before further polishing as specified below
- Remove the broken tile piece, by breaking it from the center. Ensure that the adjacent tiles are not disturbed.
- Remove any such disturbed tiles.
- Prepare a rich cement slurry and re fix the tile with proper finish at the joints.
- Cure this work properly
- If possible use a polish to bring repaired portion and adjacent polished tile in one level and line.
- Balance coats of polishing should be carried out on the entire area.

### VIII. CONCLUSION:-

According to the Visual inspection and NDT tests it is concluded that repairs are required to the buildings

1. During performing NDT testings it is observed that various columns and beams whose quality and strength is doubtful as shown in table no 6 and 9 for such beams and columns it is concluded that Jacketing should be done .
2. According to core test, subject concrete should be classified as of M-25 grade for first level slab & of M-30 grade for first second level slab as per acceptance criteria for concrete.
3. According to results of carbonation test the line with the inferior quality of concrete, indicates high probability of corrosion in near future as the entire cover concrete is expected to be affected by carbonation.
4. As per specifications proper repairs and retrofitting should be done, to maintain building in good condition.

### XI. REFERENCE

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