“STRUCTURAL AUDIT OF AN OLD BUILDING”(A CASE STUDY)

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Abstract. In India there are infinite old structures that are at the verge of damages. There are many buildings which have reduced their strength due to time passes, due to deterioration of concrete from structural element, due to development of cracks. The structure is a combination of load carrying members, damages in members cause failure of structure and it is harmful for living beings. To prevent old structure from future the technique is adopted known as Non-Destructive Testing (NDT). With the help of non-destructive testing auditing of an old structure is get easier. NDT examine the total health of an infrastructure in order to check strength and stability of building. NDT is a bunch of various testing consist of Ultrasonic pulse velocity test (UPV), Rebound hammer test (RHT), Half-cell test, etc. Conducting NDT on building and analyzing testing result decide to repair building as per IS code, technique like grouting, Retrofitting, etc. to increase strength and stability of building. In this project structural has to be done on old structure which is situated at Nagpur. Audit done by NDT consist of Ultra-sonic pulse velocity test, Rebound hammer test, Half-cell test. After analyzing all test result including visual inspection it is found that structure need to repair and retrofitted to make it safe and stable for all static loadings. Column jacketing also provide to structure.

Keywords: -Non-destructive testing, Structural Auditing, Compressive Strength, Material, Quality of concrete.

1. INTRODUCTION

A civil infrastructure is a model of linked, associated element that form together a system which can carry the external loads on it. As time goes structure get older and lessen its strength due to unpredictable load on it, deterioration of materials or physical damages (1). Use structure with this defect it may cause dangerous loss of property and livings as well. That’s why we have to maintain and scrutinize structure to prevent structure from future damage. (2) To control this problem a structural audit, have to do after 15 or 20 years to know the condition of building and materials used. Structural audit ensure that the building is guarded and haven’t dangerous. Structural audit consists of testing like Ultrasonic pulse velocity test, rebound hammer test, pH test, etc. from this test result come to know the quality of concrete, strength of concrete and condition of reinforcement. According to this we can strengthening and modify structural element to regain its capacity and withstand longer. Use of structural auditing in future can help in limiting damages to structure and life as well (3). This paper covers the study and type of tests conduct for structural Auditing of an old structure.
2. OBJECTIVES

- Carried out various NDT method on the existing structure.
- Identification of the possible causes leading to the damages of the structure.
- To analyze the Condition of building.
- To find critical areas to repair immediately.
- To save Human lives and life of building.
- To suggest corrective and preventive measures like repair of building.

3. METHODOLOGY

1. Study of Architectural and Structural Drawings, Designs Criteria of Existing Structure.
2. Visual Inspection.
3. Non-Destructive Testing
   - Ultrasonic pulse Velocity
   - Rebound Hammer Test
   - Half-cell Test
   - pH Test
4. Preparation of Structural Assessment and Audit Report
5. Post Structural Assessment and Audit
6. Repairs and Strengthening of the Structure etc.
7. Retesting of the Existing Structure after Repairs and Strengthening with Non-Destructive Testing

3.1. Non-Destructive Testing (NDT)

3.1.1 Ultra Sonic Pulse Velocity Test (UPV): - As per IS 13311 (Part I) 1992-The instrument indicates the time taken for the earliest part of the pulse to reach the receiving transducer measured from the time it leaves from a suitable point on the surface of the material (4)

| No | U.P.V (Km/sec.) | Quality of concrete |
|----|----------------|---------------------|
| 1. | Above 4.5      | Excellent           |
| 2. | 3.5 to 4.5     | Good                |
| 3. | 3.0 to 3.5     | Medium              |
| 4. | Below 3 km/sec.| Doubtful            |

Table 1. Ultrasonic Pulse Velocity

![Figure 1. Ultra-Sonic Pulse Velocity Test](image)
3.1.2 Rebound Hammer Test (RHT): As per IS 13311 Part II-The Schmidt Rebound hammer is principally theSurface hardness tester. The surface hardness and rebound is taken to be related to the compressive strength of concrete. The rebound is read of along the graduated scale and is designated as the rebound number.

Table 2. Rebound Hammer

| Sr. No. | Average rebound | Quality of Concrete |
|--------|-----------------|---------------------|
| 1.     | >40             | Very good           |
| 2.     | 30-40           | Good                |
| 3.     | 20-30           | Fair                |
| 4.     | <20             | Poor                |

3.1.3 Half-Cell Test (IS 13311 (part II) 1992): - This test is used to determine the condition of reinforcement from structural element. The instrument measures the potential and the electrical resistance between the reinforcement and the surface to evaluate the corrosion activity as well as the actual condition of the cover layer during testing.[1]

Figure 2. Half Cell Potentiometer Test

4. Testing Results

4.1 UPV Test Results of an Existing Structure

Before Strengthening Test Results

Table 3. UPV Test results before Strengthening

| Sr. No. | Description | Type of Methods | No. of points. | Transit Time (T) in Micro Seconds | Path Length (L) in mm | Velocity V= L/T in Km/Sec | Corrected Factor Reading |
|---------|-------------|-----------------|----------------|-----------------------------------|-----------------------|---------------------------|--------------------------|
| 1.      | Column C1   | Direct          | 4              | 82.6                              | 230                   | 2.72                      | 2.72                     |
| 2.      | Column C2   | Indirect        | 6              | 107.1                             | 200                   | 1.83                      | 2.83                     |
| 3.      | Column C3   | Indirect        | 6              | 83.1                              | 200                   | 2.35                      | 3.35                     |
| 4.      | Column C5   | Direct          | 4              | 127.1                             | 230                   | 1.81                      | 1.81                     |
|   | Column | Type  | Span | Primary | Secondary |
|---|--------|-------|------|---------|-----------|
| 5. | C5     | Indirect | 6    | 113.0   | 2.77      |
| 6. | C6     | Direct  | 4    | 95.2    | 2.1       |
| 7. | C7     | Indirect | 6    | 105.3   | 2.9       |
| 8. | C8     | Direct  | 4    | 74.0    | 3.11      |
| 9. | C9     | Direct  | 4    | 80.1    | 2.87      |
|10. | C10    | Indirect | 6    | 114.9   | 2.74      |
|11. | C11    | Direct  | 4    | 76.9    | 2.99      |
|12. | C13    | Indirect | 6    | 120.5   | 2.66      |
|13. | C14    | Indirect | 6    | 99.1    | 2.66      |
|14. | C15    | Direct  | 4    | 82.7    | 2.78      |
|15. | C16    | Direct  | 4    | 87.5    | 2.63      |
|16. | C17    | Direct  | 4    | 75.7    | 3.04      |
|17. | C19    | Indirect | 6    | 113.0   | 2.77      |
|18. | C20    | Indirect | 6    | 121.2   | 2.65      |

**FIRST FLOOR**

| 19. | C2     | Indirect | 6    | 180.2   | 2.11      |
|20. | C7     | Indirect | 6    | 122.0   | 2.64      |
|21. | C10    | Indirect | 6    | 111.7   | 2.79      |
|22. | C13    | Indirect | 6    | 114.9   | 2.74      |
|23. | C15    | Indirect | 6    | 124.3   | 2.85      |

**SECOND FLOOR**

| 24. | C8     | Indirect | 6    | 112.2   | 3.05      |
|25. | C11    | Indirect | 6    | 127.1   | 2.81      |
|26. | C16    | Indirect | 6    | 134.5   | 2.71      |
|27. | C17    | Indirect | 6    | 105.0   | 3.19      |

**THIRD FLOOR**

| 28. | C7     | Indirect | 6    | 114.3   | 2.75      |
|29. | C10    | Indirect | 6    | 104.7   | 2.91      |
|30. | C13    | Indirect | 6    | 89.7    | 3.23      |
|31. | C15    | Indirect | 6    | 113.3   | 3.03      |
Table no.1 shows readings of the UPV test conduct on an old structure before strengthening. Table contains type of method of UPV test whether it is direct method, indirect method or semi direct method. Number of points of testing taken as 6 points on each member. Transiting time calculated by UPV instrument, and length should be considered as face length of column. Velocity can be calculated from formula as per given IS code. As per the Ultrasonic Pulse Velocity Test reading with direct and indirect method before strengthening maximum readings are coming in between 1.72 to 3.22 Km/Sec. which indicate the quality of concrete doubtful at maximum locations. (4)

4.2 RHT Test Results of an Existing Structure

Before Strengthening Test Results

Table 4. RHT Test result before Strengthening

| Sr. No. | Description | Rebound No. | Average | Probable Compressive Strength (MPa) |
|---------|-------------|-------------|---------|-------------------------------------|
| GROUND FLOOR                                      |
| 1.      | Column C1   | 26 28 30 22 24 30 26 26 28 | 26.67   | M12                                 |
| 2.      | Column C2   | 28 30 30 32 30 28 30 28 30 | 29.55   | M15                                 |
| 3.      | Column C3   | 28 26 28 28 30 26 28 28 28 | 27.77   | M14                                 |
| 4.      | Column C5   | 24 26 28 22 24 28 24 24 28 | 25.33   | M10                                 |
| 5.      | Column C6   | 24 24 26 22 24 26 24 26 24 | 24.44   | M18                                 |
| 6.      | Column C7   | 22 22 24 22 26 24 22 24 24 | 23.33   | M16                                 |
| 7.      | Column C8   | 22 24 28 30 24 22 24 26 24 | 24.89   | M10                                 |
| 8.      | Column C9   | 26 30 24 26 24 26 24 24 22 | 25.11   | M10                                 |
| 9.      | Column C10  | 20 22 20 24 22 22 24 20 24 | 22.00   | M16                                 |
| 10.     | Column C11  | 28 26 30 28 24 30 30 28 24 | 27.56   | M20                                 |
| 11.     | Column C13  | 22 26 22 24 24 22 24 24 26 | 23.77   | M18                                 |
| 12.     | Column C14  | 24 22 24 20 20 22 24 22 22 | 22.22   | M16                                 |
| 13.     | Column C15  | 26 26 24 26 22 24 24 24 28 | 24.88   | M18                                 |
| 14.     | Column C16  | 22 24 26 24 22 20 22 22 22 | 22.66   | M10                                 |
| 15.     | Column C17  | 24 28 28 26 28 24 26 26 22 | 25.77   | M18                                 |
| 16.     | Column C19  | 24 22 24 24 20 22 24 24 24 | 23.11   | M16                                 |
| 17.     | Column C20  | 20 22 20 24 22 24 24 20 22 | 22.00   | M10                                 |
| 18.     | Column C21  | 24 24 22 20 24 26 24 22 22 | 23.11   | M10                                 |
| FIRST FLOOR                                     |
| 19.     | Column C2   | 24 26 30 26 30 28 26 30 27.33 | 27.33   | M12                                 |
Table no. 2 shows the readings of Rebound Hammer Test. From Rebound hammer rebound numbers can be calculated, taking average of all number’s strength can be calculate from the graph given in IS code. As per the Rebound Hammer Test reading maximum readings are confirming to M10 to M20 grade of concrete before strengthening which indicate the quality of concrete is not good at maximum locations. (5)

4.3 Half-Cell test Results of an Existing Structure

Table 5. Half Cell Potentiometer Test Result

| Sr. No. | Description   | Half Cell Potentiometer Test |
|---------|---------------|------------------------------|
| 1.      | Column C1     | Half Cell Readings (mV)      |
|         |               | -355, -346, -321, -272,     |
|         |               | -241, -232, -223, -216, -168|
| 2.      | Column C2     | -319, -317, -315, -250,     |
|         |               | -247, -240, -238, -224, -212|
| 3.      | Column C3     | -436, -412, -407, -398,     |
|         |               | -376, -370, -366, -364, 362 |
| 4.      | Column C5     | -412, 407, -401, -395,     |
|         |               | -390, -388, -384, -379, -370|
| 5.      | Column C8     | -341, -333, -321, -308,     |
|         |               | -302, -291, -279, -269, -263|

SECOND FLOOR

| 20. Column C7 | 28 | 26 | 26 | 24 | 26 | 22 | 24 | 26 | 28 | 25.55 | M22 |
|---------------|----|----|----|----|----|----|----|----|----|------|-----|
| 21. Column C10| 26 | 22 | 22 | 24 | 22 | 24 | 26 | 24 | 24 | 23.77 | M16 |
| 22. Column C13| 22 | 24 | 24 | 24 | 24 | 22 | 24 | 24 | 24 | 23.55 | M16 |
| 23. Column C15| 26 | 26 | 28 | 26 | 28 | 26 | 24 | 26 | 24 | 26.00 | M20 |

THIRD FLOOR

| 24. Column C8 | 28 | 26 | 26 | 28 | 30 | 30 | 32 | 30 | 28 | 28.67 | M15 |
|---------------|----|----|----|----|----|----|----|----|----|-------|-----|
| 25. Column C11| 28 | 26 | 30 | 28 | 26 | 26 | 28 | 28 | 28 | 27.55 | M20 |
| 26. Column C16| 28 | 28 | 30 | 32 | 30 | 30 | 30 | 32 | 32 | 30.22 | M18 |
| 27. Column C17| 24 | 26 | 26 | 26 | 22 | 24 | 24 | 26 | 24 | 24.66 | M18 |

| 28. Column C2 | 28 | 30 | 30 | 28 | 28 | 30 | 30 | 29.11 | M15 |
|---------------|----|----|----|----|----|----|----|-------|-----|
| 29. Column C7 | 32 | 32 | 30 | 34 | 32 | 32 | 32 | 32.22 | M18 |
| 30. Column C10| 26 | 24 | 24 | 24 | 26 | 24 | 24 | 24.44 | M18 |
| 31. Column C13| 24 | 26 | 24 | 22 | 24 | 24 | 24 | 23.77 | M17 |
Table no.3 represent the reading of half-cell potentiometer test, which conduct on an old structure before strengthening. As per Half-cell Potentiometer Test results maximum readings are in between -250 and -410 which indicates that there is severe corrosion found at most of the location.

Analyzing all NDT results and from visual inspection of an existing structure, the strength of column get decreased to deterioration of concrete, due to time passes, due to development of cracks on element, etc.

Hence to increase the strength of existing structure and to make it sustainable, building needs to repairs and retrofitting like Grouting, jacketing of column, etc.

### 4.4 Selection of Column for Jacketing

| Column No. | Existing Column Size | Fck (as per NDT) | L.C.C. of Existing Column (Factored kN) | Actual Load on Column (Factored kN) | Remark |
|------------|----------------------|------------------|----------------------------------------|-----------------------------------|--------|
| C1         | 230 x 450            | 12               | 748                                    | 882                               | Required Jacketing |
| C2         | 230 x 450            | 15               | 872                                    | 1450                              | Required Jacketing |
| C3         | 230 x 450            | 14               | 831                                    | 1380                              | Required Jacketing |
| C4         | 230 x 450            | 10               | 665                                    | 748                               | Required Jacketing |

### 4.5 Design of R.C.C Column

**STEP 1**

The details of existing column:
- Column Size = 230x450mm
- Grade of concrete = M15 (As per Rebound HammerGraph)
- Grade of steel = Fe-415 N/mm²
- Load on column = 1450 KN

**STEP 2**

Calculation of load carrying capacity of existing column

\[ Pu = 0.4 \times fck \times Ac + 0.67 \times fy \times Asc (6) \]
Pu = 0.4 x 15 x 230 x 450 + 0.67 x 415 x (π/4 x 122 x 8) - (Assume)
Pu = 0.4 x 15 x 230 x 450 + 0.67 x 415 x 905
Pu = 872 KN [87.2 T.]

STEP 3
Actual Load coming on column P_a = 145.0 T.
Net load for column jacketing P_j = P_a - P_u
P_j = 145.0 - 87.2
P_j = 57.8 T.

STEP 4
According to the provisions provided in 8.5.1.2 (a) IS15988:2013, Concrete strength shall be at least 5 Mpa greater than the strength of existing concrete
Thus, taking fck = 25 N/mm²
fy = Fe - 500 N/mm²

Assuming Asc = 0.8% Ac
PJ = 0.4 x fck x Acj + 0.67 x fy x 0.8% Acj
PJ = 57.8 x 104 x 1.5 = 0.4 x 25 x Acj + 0.67 x 500 x 0.008 x Acj
Acj = (3/2) x 68375.39
Acj (req) = (3/2) x 68375.39

Asj = 0.8% Ac
Asj = 0.008 x 232500
Asj = 1860mm²

But According to IS 15988:2013 As = (4/3) A’s
As = (4/3) x 1860 As = 2480mm²

Assuming 16mm dia. Bars Thus, No. of bars = Asj / As = π/4 x (16) x 2 = 201 mm²
Thus, No. bars = 2480 / 201
= 12.33 nos. say = 14 Nos.

Thus, provide 14 nos. 16ø vertical bars for jacketing.

STEP 6
Design for stirrups
As per IS 15988:2013- 8.5.1.2 minimum diameter of stirrups shall be 8mm and not less than one third of longitudinal bar diameter.

Diameter of bar = 1/3 x 16 = 6mm
Thus, take 8mm ø stirrups for jacketing Spacing of stirrups is given by
S = fy x d2h √fck x tj where, dh = diameter of stirrups & tj = Thickness of jacketing

S = 500 x 82
√25 x 125S = 51.2mm

But as per IS 15988:2013 (8.5.1.2)
The spacing of ties shall not exceed the thickness of jacket or 200mm whichever is less.
Therefore, provide 125mm spacing.
Thus, provide 8mm ø @ 125mm c/c spacing of stirrups.

STEP 7
Design of shear connectors
Load taken by old column = 145.0 T.
Balance load to be taken by jacketing = 57.8 T. Neglecting shear stress taken by old and new concrete bond

Total shear force taken by shear connectors.

No. of shear connectors = Load taken for jacketing

Shear taken by one connector

Therefore, assume 12\text{mm}\phi bar for shear connector

\[
\text{Ast} = \frac{\pi}{4} \times 12^2 = 113 \text{ mm}^2
\]

\[
0.45 \times f_{y} \times \text{Ast} = 0.45 \times 500 \times 113
\]

\[
= 25425 \text{ N}
\]

Therefore, No. of shear connectors = 57.8 = 22.63 nos, say = 24Nos.

2.54

Existing column height = 3.0m. Therefore, spacing of shear connector by deducting beam depth = 2550 / 6 = 425 mm c/c.

Thus, provide 4 Nos.12\text{mm}\phi shear connectors @425 mm/c at each face of column.

4.6 UPV Test Results of an Existing Structure

After Strengthening Test Results

Table 7. UPV Test Results After Strengthening

| Sr. No. | Description            | Type of Methods | No. of points. | Transit Time (T) in Micro Seconds | Path Length (L) in mm | Velocity V= L/T in Km/Sec | Corrected Factor Reading |
|---------|------------------------|-----------------|----------------|----------------------------------|-----------------------|--------------------------|--------------------------|
| 1       | Column C1 (Jacketed Column) | semi direct     | 6              | 84.1                             | 325                   | 3.8                      | 4.8                      |
| 2       | Column C2 (Jacketed Column) | semi direct     | 6              | 102                              | 283                   | 2.76                     | 3.76                     |
| 3       | Column C3 (Jacketed Column) | semi direct     | 6              | 106                              | 283                   | 2.6                      | 3.6                      |
| 4       | Column C5 (Jacketed Column) | semi direct     | 6              | 122                              | 325                   | 2.66                     | 3.66                     |
| 5       | Column C6 (Indirect)     | Indirect        | 6              | 83.3                             | 200                   | 2.4                      | 3.4                      |
| 6       | Column C7 (Indirect)     | Indirect        | 8              | 90.5                             | 200                   | 2.21                     | 3.21                     |
| 7       | Column C8 (Jacketed Column) | semi direct     | 6              | 120.8                            | 325                   | 2.69                     | 3.69                     |
| 8       | Column C9 (Jacketed Column) | semi direct     | 6              | 122.6                            | 325                   | 2.65                     | 3.65                     |
| 9       | Column C10 (Indirect)    | Indirect        | 8              | 94.3                             | 200                   | 2.12                     | 3.12                     |
As per the Ultrasonic Pulse Velocity Test reading after strengthening with indirect and semi direct method maximum readings are coming in between 3.02 to 4.90 Km/Sec which indicate the good quality of concrete.

4.7 RHT Test Results of an Existing Structure

After Strengthening Test Results

Table 8. RHT Test Results after Strengthening

| Sr. No. | Description                        | Rebound No. | Average | Probable Compressive Strength (MPa) |
|---------|------------------------------------|-------------|---------|--------------------------------------|
| 1       | Column C1 (Jacketed Column)        | 28 28 26 28 26 30 28 28 28 30 28 | 28 28 M24 |
| 2       | Column C2 (Jacketed Column)        | 28 28 30 28 28 30 26 28 28 30 28 | 28.22 M25 |
| 3       | Column C3 (Jacketed Column)        | 26 28 28 30 28 26 28 28 28 30 28 | 27.78 M24 |
| 4       | Column C5 (Jacketed Column)        | 28 30 30 28 32 30 28 30 28 30 28 | 29.33 M26 |
As per the RHT Test reading after strengthening maximum readings are found out between to M20 to M26 grade of concrete which indicate that quality of concrete is in good and fair range due to increased compressive strength. (5)
4.8 Graphical Representation of Results before and after NDT Testing

4.8.1 Rebound Hammer Test Result

![Rebound Hammer Test Result](image1)

**Figure 3.** Comparison of Compressive Strength with Rebound after column Jacketing

![Ultrasonic Pulse Velocity Test Result](image2)

**Figure 4.** Comparison of Compressive Strength with Rebound after repair.

![Ultrasonic Pulse Velocity Test Result](image3)

**Figure 5.** Ultrasonic Pulse Velocity Test after Column Jacketing

![Compressive strength chart after repair](image4)

**Figure 6.** Comparison UPV Test Result

5. CONCLUSION

Based on NDT results, Analysis and Design following conclusions are made:

The original grade of concrete was 20 N/mm². Due to carbonation effect and age of concrete strength is reduced. While conducting visual inspection on existing structure we found major cracks in columns, reinforcement exposed on various locations of columns, honeycombing and seepage, deterioration of concretoe observed on maximum locations. They are repaired by using epoxy grouting and micro fine cement grouting with epoxy bonding agent, polymer repair and micro concrete. Rebound Hammer test & Ultrasonic pulse velocity test have been performed to check the quality and compressive strength of concrete and it is found in doubtful condition at maximum locations before strengthening and found in good and excellent condition after strengthening at maximum locations. Half-cell potentiometer test carried out to check the probable corrosion in reinforcement and sever corrosion observed at most of the locations of columns. As per the pH test and depth of carbonation test it is observed that carbonation observed on various columns and pH of concrete cover is reduced and passive layer over reinforcement is not intact.

Based on above all Non-Destructive test results it is observed that columns at ground floor are damaged and load carrying capacity is reduced. Hence, we had strengthened corresponding weak and damaged columns with R.C.C. jacketing as per methodology and specifications given. After repair and retrofitting of the structure retesting such as Rebound hammer test and Ultrasonic pulse velocity test
have been performed to check the strength of concrete and as per the results the existing structure is safe for all static loadings.

REFERENCES

[1] Subramanyam, K., Menon, J.P, Shaw, C.k and Shah. *Ultrasonic technique for monitoring concrete strength gain at early age.* s.l. : ACL Material Journal, 2003.

[2] *Structural Audit.* B.H. Chafekar, O. F. Kadam. 2013, International journal of Civil and Structural Engineering Research(IJCSEER).

[3] *Health Asessment of Renforced concrete structure- ACase Study.* Prof. Dr. D K Kulkarni, MrTeke Sudhakar. s.l. : IOSR Jornal of Mechanical And Civil Engineering. ISSN: 2278-1684,PP:37-42.

[4] INDIAN STANDERD. *IS 13311:1992 PART-1"NON DESTRUCTIVE TESTING OF CONCRETE-UPV"*. 

[5] INDIAN STANDARD. *IS 13311:1992 PART-2"NON-DESTRUCTIVE TEST OF CONCRETE-REBOUND HAMMER TEST"*. 

[6] N. Krishnaraju. *Design of Renforced concrete structure.*