STRUCTURAL AUDIT, REPAIR AND REHABILITATION OF BUILDING

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ABSTRACT

Structural Audit is a technical survey of an engineering structure to assess its health. Evaluation of current vague practices of Structural Audit paved way to understand the drawbacks of those processes and modify the same for methodical implementation of Structural Audit. This research aims at understanding the drawbacks if any in the current procedure, recast the structural auditing process and propose some improvement measures to the governing body. Structural audit is the technical survey of the building in order to check its strength and stability. Structural audit is the first step in repairing procedure of the building. Structural audit is generally recommended for older buildings. Structural audit was first introduced by Indian society of structural engineers. structural audit helps in improving the safety, efficiency and gives idea about the strength of the structure by detailed technical inspection. In present study attempt have been made to carry out structural audit of the old RCC building by carrying out site inspection, performing NDT on the structure. Building is modeled and analyzed using ETABS and Demand to capacity ratio is determined. After checking strength and stability of the structural members suitable recommendations are given in order to retrofit unsafe structural component. Finally structural audit report is prepared for the building. This paper also deals with the repair rehabilitation measures that are to be enacted after the Audit and prepare an advanced operating procedure for Structural Audits.

Keywords:-*Structural Audit, Non-Destructive Test,Repair, Rehabilitation.*

1.INTRODUCTION

Structural audit is the overall health and performance checkup of the building like doctor check the patient. Structural audit helps to understand the status of the old building. The Audit helps to highlight & investigate all the risk areas, critical areas and whether the building needs immediate attention. It cover the structural analysis of the existing frame and highlight the weak structural areas for static, wind & earthquake loads. If the bldg. has changed the user, from residential to commercial or industrial, this should bring out the impact of such a changerecent years witnessed the boom of construction sector in MH. In cities like Mumbai, Pune and Delhi urbanization has started very long before, such that now the buildings are aged. Thus there are many structures that have reduced strength in due course of time. It may endanger the life of people who are living inside those buildings. In such a case appropriate actions should be proposed and implemented to improve the performance of structures and restore the desired function of these buildings. There came up the importance to perform structural audit of existing buildings and to put forward maintenance/ repair work timely which will lead to prolonged life of the building and safety of the occupant. Structural Audit of a building is the preliminary technical survey [3] to assess its general health as a civil engineering structure. With the study of current process of Structural Audit there is a need to find the lacks of the current processes and advancing the process for efficient implementation of Structural Audit on present day structures.

1.1 Background

The need of structural audit is for maintenance and repairs of existing structures whose life has exceeded the age of 30 years to avoid any mishaps and save valuable human life. The concrete is widely used as construction material being inexpensive, easy for construction, applications and because of it high strength-cost ratio. More than ever, the construction industry is concerned with improving the social, economic and environmental parameters of sustainability. In India, from 1980 onwards the infrastructure industry witnessed stepping up of public investment and growth in infrastructure industry which results in construction of new multi-storey concrete apartments which are now in the age of thirty plus years. There are many buildings during this period and earlier have reduced strength in due course of time because of structural deficiency, material deterioration, unexpected over loadings or physical damage. If, further use of such deteriorated structure is continued it may endanger the lives of occupants and surrounding habitation. There is demand of appropriate actions and measures for all such building structures to improve its performance and restore the

desired functions of structures which may leads to increase its functional life. The periodical structural auditing and diagnosis for health of existing buildings is thus utmost important for finding the present serviceability and structural viability of structures. The structural audit must be carried out following auditing norms, methods of non-destructive testing and code provisions. The structural auditing will help to implement maintenance and repair work timely which leads to prolonged life of the building and safety of the occupants.

1.2 Motivation

In India there are many old buildings which have reduced strength in due course of time. If further use of such deteriorated structure is continued it may endanger the lives of the occupants and surrounding habitation. Appropriate actions should then be implemented to improve the performance of structures and restore the desired function of structures. Thus, it is utmost important to perform structural audit of existing buildings and to implement maintenance/ repair work timely which will lead to prolonged life of the building and safety of the occupant. To act more responsible and pre-emptive towards the dilapidated buildings, the municipal corporation must issue notices to the buildings and co-operative societies which are more than 30 years old to carry out mandatory structural audit and submit the audit report. Structural audit should highlight and investigate all critical areas and recommend immediate remedial and preventive measures. It should cover the structural analysis of existing frame and find critical elements for all types of loadings. It also helps in delivering a strong building structure with cost effective solutions and appropriate maintenance program. This paper deals with study of different parameter of structural audit including visual inspection, non-destructive testing, core sampling and testing. It also emphasizes on different repairs and retrofitting measures to be used for buildings after structural audit.

Structural Audit is an overall health and performance check-up of a building like a doctor examines a patient. It ensures that the building and its premises are safe and have no risk. It analyses and suggests appropriate repairs and retrofitting measures required for the buildings to perform better in its service life. Structural audit is done by an experienced and licensed structural consultant.

1.3 Need for Structural Audit

1. To increase life of property
2. To know the health of building and its expected life.
3. To check actual reliability of the structure.
4. In order to recommend rehabilitation techniques.
5. In order to highlight the critical areas and repair them immediately.
6. For structural audit certificate required by municipality and other authorities.

2. METHODOLOGY

A. General

The Technical Audit is a solely technical achievement where technically sound personal/ Experienced Civil Engineer, conduct the audit with a few handheld equipment.

B. Architectural and Structural Plans

It is crucial that we must have Architectural and Structural plans of the buildings. These drawings will help in the identification of the location of the different tests done, and it helps in the future references also.

C. Visual Inspection of the Building

All foundations settle to some extent as the earth materials around and beneath them adjust to loads of the building. Slight tapping with hammer can reveal deterioration in concrete. Freezing and thawing cycles can be very detrimental to concrete over time. Corrosion [5] of the reinforcing steel in concrete can be a major structural issue. Under normal conditions, the pH level of concrete is high (above 12.5). The high pH of concrete allows an inactive layer of ferric oxide to form around the reinforcement, preventing rust [1]. Dampness can damage much more than a buildings appearance. It may lead to the deterioration of plaster and masonry, promote timber decay and create unhealthy conditions for occupants.

D. Non-Destructive Testing

1) **Ultrasonic Pulse Velocity Test:** In UPV test [6] thequality of concrete is assessed based on the pulse generated by the electro- acoustical transducers which are placed on the concrete surface. The pulse encounters multiple reflections at the boundaries of the various material phases and reaches the receiving transducer. The underlying principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality lower velocities are obtained.

1. The members to be tested are identified and the dimensions are measured for member size and path length.
2. Grid points are marked at 300 x 300mm sizes as per the provisions of IS: 13311 (Part – 1) 1992.
3. The junctions of the grids are cleared of all surface undulations or deformations by using carborundum stone, grinder or any other suitable methods.
4. Suitable acoustic couplants like petroleum jelly, grease, liquid soap or kaolin glycerol paste shall be applied at each of the junctions before initiating testing.
5. The probes are connected to the display unit via cables of suitable lengths and calibrated onsite using the calibration rod supplied along with the device.
6. Once calibration is done the probes are faced on either side of the marked locations; ensuring that the probes are geometrically opposite to each other.
7. The readings are taken and noted into the field data sheet.
8. The equation for calculating pulse velocity is:

Pulse Velocity V= L/T, where

V is the pulse velocity in concrete in km/second.

L is the path length measured between the probes in millimetres.

T is the time taken by the pulse to travel from one probe to another in µS.

TABLE 1- Ultrasonic Pulse Velocity vs. Concrete Quality

Sr.No	Ultrasonic Pulse Velocity	Concrete Quality
1	Above 4.5	Excellent
2	3.5-4.5	Good
3	3.0-3.5	Medium
4	Below 3.0	Doubtful

2) **Core Test:** In most structural investigations [4] ordiagnoses extraction of core samples is unavoidable and often essential. Cores are usually extracted by drilling using a diamond tipped core cutter cooled with water. Broken samples, for example, due to popping, spalling and delamination, are also commonly retrieved for further analysis as these samples may provide additional evidence as to the cause of distress..

3) **Rebound Hammer Test:** The test is performed toestimate the in situ strength of concrete based on the correlation established between in-situ strength [9] at the particular location & rebound numbers. The plaster is removed at test locations. The compressive strength of concrete against each rebound number is obtained from graph prepared on correlation established between rebound numbers at core test locations & equivalent cube strength values.

4) **Half Cell Potentiometer Test:** The method of half-cell potential [8] measurements normally involves measuring the potential of an embedded reinforcing bar relative to a reference half-cell placed on the concrete surface. The half-cell is usually a copper/copper sulphate or silver/silver chloride cell but other combinations are used. The concrete functions as an electrolyte and the risk of corrosion of the reinforcement in the immediate region of the test location may be related empirically to the measured potential difference.

5) **Cover Meter Scanning:** Cover meter [7] test iscarried out on RC Columns, beams and slabs in order to assess the thickness of cover concrete provided for embedded peripheral rebars.

6) **Abrasion Resistance Test:** The surface of concretecubes is subjected to impingement of an abrasive [10] charge. As a result, abrasion of the concrete surface of the cubes occurs and resulting loss in mass of the cubes is taken as the abrasion loss of concrete. This loss of mass of the specimen gives us a clear idea of

the abrasion occurred on the concrete specimen and this can be directly related to the concrete abrasion resistance.

7) **Windsor Probe Test:** The Windsor probe, like therebound hammer, is a hardness tester, and its inventors' claim that the penetration of the probe reflects the precise compressive strength in a localized area is not strictly true. However, the probe penetration does relate to some property of the concrete below the surface, and, within limits, it has been possible to develop empirical correlations between strength properties and the penetration of the probe.
8) **Permeability Test:** Permeability of concrete isimportant when dealing with durability of concrete particularly in concrete used for water retaining structures or watertight sub-structures. Permeability tests measure the ease with which liquids, ions and gases can penetrate into the concrete.
9) **Radar Test:** Ground penetrating radar (GPR) is anon-destructive technique with a wide range of potential applications in the testing of concrete. It is gaining acceptance as a useful and rapid technique for non-destructive detection of delamination's and the types of defects, which can occur in bare or overlaid reinforced concrete decks.
10) **Acoustic Emission:** Acoustic emissions are microseismic activities originating from within the test specimen when subjected to an external load. Acoustic emissions are caused by local disturbances such as micro cracking, dislocation movement, intergranular friction, etc. An acoustic signal travels to a number of piezoelectric transducers, which convert the acoustic signals (mechanical waveforms) to electric signals.
11) **Chemical Test:** The samples of deterioratedconcrete particles are to be tested for pH, Chloride content, Sulphate content, Depth of carbonation etc.

3. STANDARD OPERATING PROCEDURE-CASE STUDY

Description of the Building:

The "SaiApartmnet" is situated at the heart of Pune City. The foundation stone of the Sai Apartment Building was laid on 4th January 1958 under the guidance of Mr. Sanjay Shelar. The planning and designing of the building was given to a Pune based Engineering cum Architectural Firm. The total number of floors is G+2. The structure is constructed partially as load bearing and partially framed. The building has been in use since the beginning of the diocese and has undergone very minor changes. The structure is in a well maintained condition.

NAME: Sai Apartment

1. **LOCATION: Pune**
2. **STOREY: G+2**
3. **TYPE: Residential**
4. **STOREY Height:3.4m**
5. **EARTHQUAKE ZONE:3**
6. **NO OF FLATS: Four 2bhk Flats on Each Floor**

Fig 01.Sai Apartment

TABLE 2- Tasks and Responsibilities

Task	Authorized	Responsible
Formalities for performing NDT	ENGINEER	CONSULATNT
Built drawings	DRAFTSM	ENGINEER
Visual Inspection of Structure	ENGINEER	CONSULATNT
Conducting Tests	ENGINEER	CONSULATNT
Developing Audit Report	ENGINEER	CONSULATNT

4. RESULT AND DISCUSSION

4.1 RAPID VISUAL INSPECTION AND TAPPING OBSERVATION

1. **Visual inspection:** In this building is thoroughly inspected from flat to flat noting cracks, spells, crazing, seepage etc. Highlighting critical area of investigation and repair same is marked on the plan of the building.

Fig 2: Cracks in structural members due to corrosion

2. **Tapping observation:** Column and beams of the building were subjected to tapping by the hammer .For some of the beams and column hollow sound was recorded. This hollow sound was due to loss of integrity between reinforced steel and surrounding concrete.

Selection of critical area for further Non-Destructive testing: Based on above observations flat no:2 of the ground floor was found most unsafe due to bad condition of structural elements such as beam, column and slab. Status of beams of this area is critical beams are sagging due to deflection and corrosion. There is bulging in column due to corrosion of reinforcement and dis- integration of concrete has resulted in exposure of the reinforcement.

4.2 TESTS RECOMMENDED FOR STRUCTURAL AUDIT OF THE BUILDING

1. **Rebound Hammer**: For determination of the compressive strength of the concrete

2. **Profometer test**: Location of rebar and cover

a. Rebound Hammer

I. Application of rebound hammer test:

1. For determination of the compressive strength of the concrete
2. Determine uniformity of the concrete.
3. Determine quality of the concrete.

II. Method of testing:

1. Prepare the instrument for the test, remove the plunger from lock position by pushing the plunger on the surface and push it slowly against the surface.
2. Hold the plunger perpendicular to the testing surface.
3. As the body is pushed, the main spring connecting the hammer mass to the body is stretched. When the body is pushed to the limit, the latch is automatically released and the energy stored in the spring propels the hammer mass towards the plunger tip. The mass impacts the shoulder of the plunger rod and rebounds.
4. This rebound distance is measured on the graduated scale and is termed as rebound number.

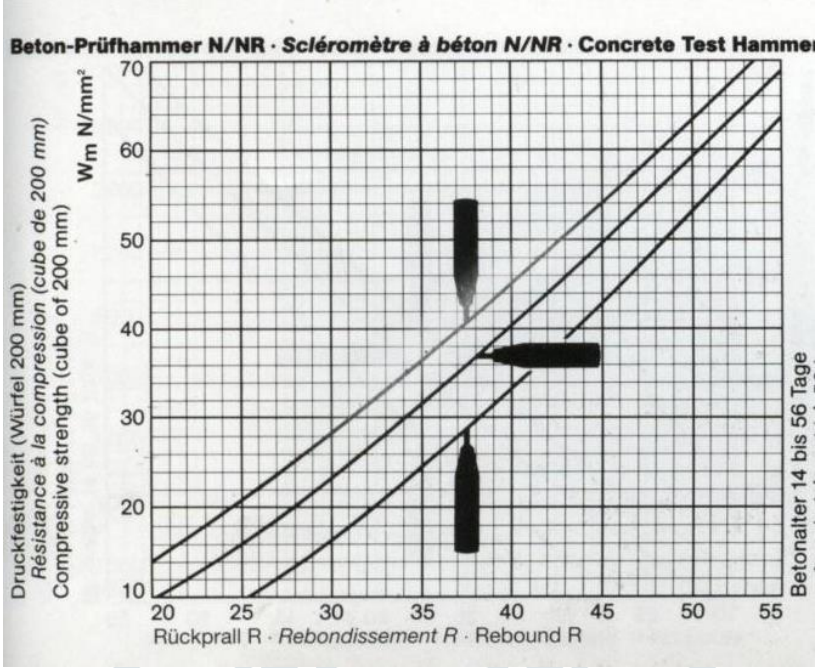

Fig 3: Rebound hammer chart

III. Results of rebound hammer number:

TABLE 4: Rebound hammer number for slab

SL NO	SLAB LABEL	HAMMER POSITION	REBOUND NO	COMP STRENGTH
1	S1	VERTICALLY UP	29	16
2	S2	VERTICALLY DOWN	20	16
3	S3	VERTICALLY DOWN	22	16
4	S4	VERTICALLY DOWN	26	17
5	S5	VERTICALLY DOWN	24	18
6	S6	VERTICALLY DOWN	20	16
7	S7	VERTICALLY DOWN	26	17

TABLE 5: Rebound hammer number for Beam

SL NO	COLUMN NO	COLUMN SIZE	POSITION	REBOUND NO	AVG	HAMMER POSITION	C.S
1	A6	300X400 MM	BOTTOM	10	10.67	HORIZONTAL	<10
			MID	12		HORIZONTAL	
			TOP	10		HORIZONTAL	
2	A8	300X400 MM	BOTTOM	32	29.00	HORIZONTAL	24
			MID	31		HORIZONTAL	
			TOP	24		HORIZONTAL	
3	B9	300X400 MM	BOTTOM	34	31.33	HORIZONTAL	24
			MID	34		HORIZONTAL	
			TOP	26		HORIZONTAL	
4	C6	300X400 MM	BOTTOM	27	29.00	HORIZONTAL	24
			MID	30		HORIZONTAL	
			TOP	30		HORIZONTAL	

TABLE 6: Rebound hammer number for column

SL NO	BEAM NO	BEAM SIZE	POSITION	REBOUND NO	AVG	HAMMER POSI	C.S
1	B1	230X700	START	30	30.67	VERTICALLY UP	
			MID	30		VERTICALLY UP	
			END	32		VERTICALLY UP	15
2	B2	230X700	START	32	21.33	VERTICALLY UP	
			MID	20		VERTICALLY UP	
			END	12		VERTICALLY UP	10
3	B3	230X700	START	26	21.67	VERTICALLY UP	
			MID	20		VERTICALLY UP	
			END	19		VERTICALLY UP	10
4	B4	230X700	START	31	30.67	VERTICALLY UP	
			MID	29		VERTICALLY UP	
			END	32		VERTICALLY UP	15
5	B5	230X700	START	30	31.67	VERTICALLY UP	
			MID	31		VERTICALLY UP	
			END	34		VERTICALLY UP	15

4.4 DEMAND TO CAPACITY RATIO

Determination of capacity of beams

Step 1: Determine size of the structural members, actual reinforcement present in the members.

Step 2: Determine the actual load and moment carrying capacity of the members using IS:456:2000 . To get actual capacity of the members.

Step 3: Capacity of the structural members is determined using ETABS analysis of the members carried out in previous step.

Step 4:Compute demand and capacity ratio for the members.

Step 5: Recommend the remedial measure.

TABLE 7: Demand to capacity Ratio

SL NO	BEAM	STEEL	CAPACITY(KN)	DEMAND(KN)	D/C RATIO
1	B1	2-#12	52	19	0.37
2	B2	2#12,1#10	69	32	0.46
3	B3	2#12,1#10	69	35	0.51
4	B4	2#16,2#12	69	85	1.23
5	B5	2#16,2#12	69	85	1.23
6	B6	2#16,1#12	69	72	1.04
7	B7	2-#12	69	21	0.30
8	B8	2#12,1#10	69	27	0.39
9	B9	2#16	69	42	0.61
10	B10	2#16	69	39	0.57

5. CONCLUSIONS

5.1 From above observation of the building we conclude that:

1. Due to combined effects of carbonation, corrosion & effect of continuous drying and wetting and harsh weather condition building structure is in really bad condition and should be subjected to the repair immediately.
2. Structural building appears to be unsound due to external and internal defects. Structural members shoes cracks due to corrosion of the RCC members.
3. Major cracks observed accelerate the passage of water through the wall resulting in leakage of the water.
4. Looking at the aspect of building maintenance it is recommended to repair the building in planned manner.
5. In RCC framed structure RCC members are the major load taking elements so they cannot be left unattended for long period of time.
6. Original strength of the RCC members can be restored by polymer modified mortar method. Major damage in RCC members are due to seepage of water in the members this need to be prevented by stopping the seepage of water into the members.

5.2 Rehabilitation of the RCC members

Propping the structure wherever necessary
Removing loose/disintegrated concrete
Cleaning the affected steel
Adding steel wherever necessary
Applying Passivator coat to the steel
Applying Bond Coat and doing Polymer /Micro Concrete treatment depending on the requirements
Finishing with new plaster

5.3 Rehabilitation techniques recommended:

1. Polymer Modified Mortar Treatment
2. Jacketing to columns - Micro concrete.
3. Recasting of Slabs
4. Water proofing Treatment

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