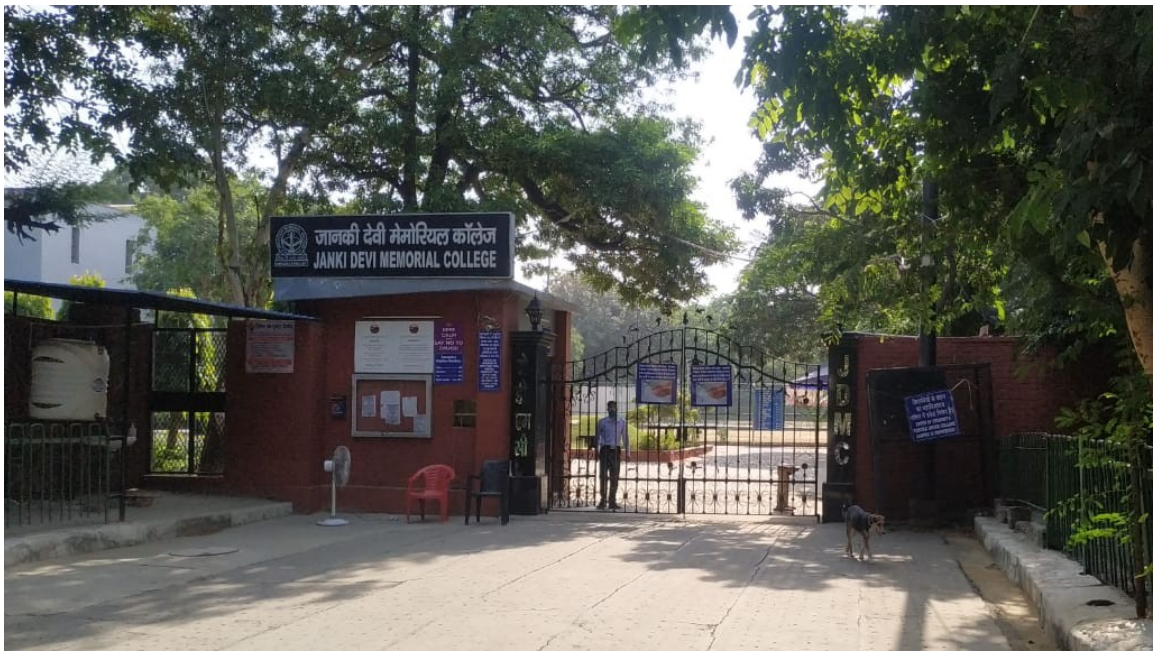
STRUCTURE AUDIT REPORT OF MAIN COLLEGE BUILDING OF JANKI DEVI MEMORIAL COLLEGE, SIR GANGA RAM HOSPITAL ROAD, NEW DELHI.



SANJEEV KUMAR SHARMA
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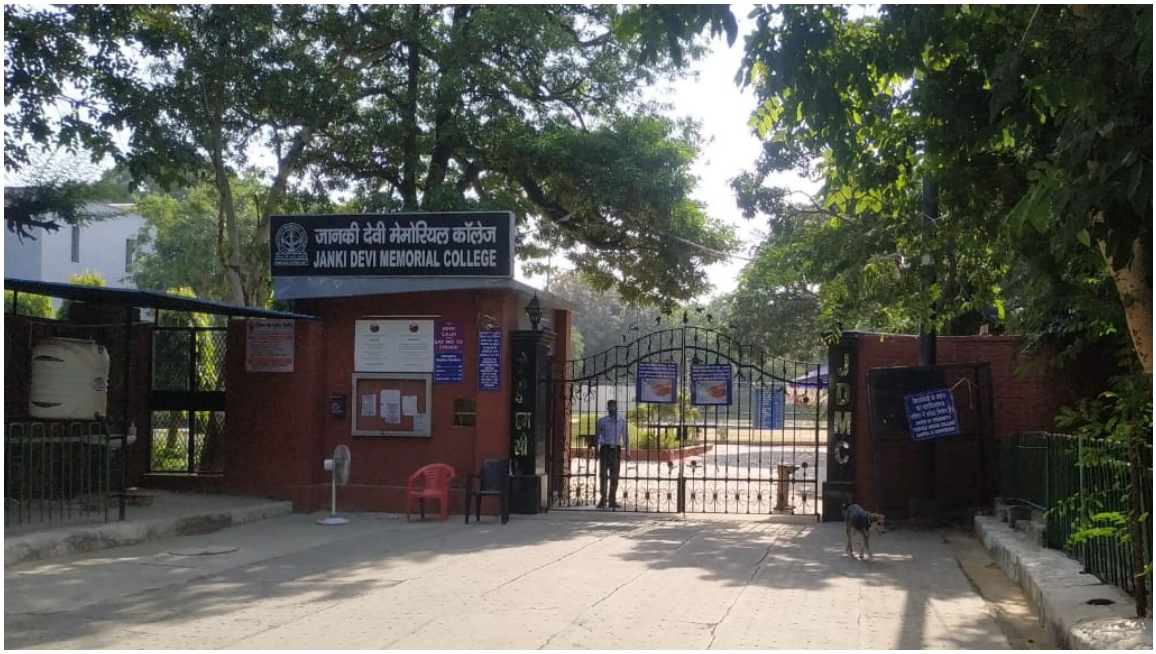
- **Earthquakes do not kill; unsafe buildings do.**
- **Earthquakes are natural phenomena. But when and where exactly the next earthquake will occur cannot be predicted by modern science.**
- **Get your building assessed for its seismic vulnerability.**
- **If the building is found unsafe, get it suitably retrofitted. Prevention is better than cure.**
- **In the case of an old building, the retrofit should be carried out so that the building has at least 70 percent of the seismic resistance capacity required of a new building as per the prevailing design code.**



PROJECT NAME	:	**MAIN COLLEGE BUILDING OF JANKI DEVI MEMORIAL COLLEGE, SIR GANGA RAM HOSPITAL ROAD, NEW DELHI – 110060**
REPORT NO	:	**DRA/STR./2025/JDM-04-03**
CLIENT/OWNER	:	**JANKI DEVI MEMORIAL COLLEGE**
REF. WORK ORDER/ DATE	:	**NIL**
CLIENT ADDRESS	:	**JANKI DEVI MEMORIAL COLLEGE, SIR GANGA RAM HOSPITAL ROAD, NEW DELHI – 110060**
BUILDING CATEGORY	:	**INSTITUTIONAL**
DATE OF INSPECTION	:	**01ST MARCH 2025 TO 09TH APRIL 2025**
PRESENT	:	**SANJEEV KUMAR SHARMA (Structure Engineer)** **TESTING TEAM** **OTHER HELPING STAFF**

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FINAL CONCLUSION

FINAL CONCLUSION

The building had withstood since constructed till date the fury of nature like earthquake, wind forces, rain and other calamities

After considering all data I have come to the conclusion that building requires repair as given at page no: 58 of this report.

ER. SANJEEV KUMAR SHARMA
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SOME BASIC CONDITION OF STRUCTURE AUDIT

As per National Building Code of India, IS 456, IS 15988, IS 4326, IS 13827, IS 13828, As per Guidelines of Rapid Visual Screening of Masonry Buildings issued by CPWD and National Disaster Management Authority and other relevant codes and specification: -

As per IS 456 all the structural evaluation is to be done as per latest standards, specification, IS codes even though the structure is designed and constructed on older versions.

As per IS 15988 Clause 5 EVALUATION CRITERIA

5.1 General
The seismic performance of existing buildings is evaluated in relation to the performance criteria in use for new buildings. This section defines the minimum evaluation criteria for the expected performance of life safety of existing buildings with appropriate
modification to IS 1893 (Part 1) seismic force which is applicable for the seismic design of new buildings.
5.2 Since the provisions of this standard are strongly correlated with the design criteria of new buildings contained in IS 1893 (Part 1), reference shall always be made to the current edition of IS 1893 (Part 1). All existing structural elements must be able to carry full other non-seismic loads in accordance with the current applicable standards related to loading and material strengths.
5.3 Basic inputs for determination of seismic forces such as seismic zone, building type, response reduction factor are to be taken directly from IS 1893 (Part 1). Alternatively, a site-specific seismic design criteria developed along the principles described in IS 1893 (Part 1) may be used. Modification to seismic forces as given in IS 1893 (Part 1) and to material strengths will be applicable to both preliminary and detailed assessments described in this standard.

As per IS 15988 Clause **6.3 Acceptability Criteria**
A building is said to be acceptable, if it meets all the configuration-related checks as well as global level checks on axial and shear stress as outlined in the following clauses.

As per IS 15988 Clause **6.6 Recommendation for Detailed Evaluation**
A building is recommended to undergo a detailed evaluation as described in **6**, if any of the following conditions are met:
a) Building fails to comply with the requirements of the preliminary evaluation;
b) A building is 6 storeys and higher;
c) Buildings located on incompetent or liquefiable soils and/or located near (less than15 km) active faults and/or with inadequate foundation details; and
d) Buildings with inadequate connections between primary structural members, such as poorly designed and/or constructed joints of pre-cast elements.

As per IS 13935 Clause **4.1.2**
Non-structural and architectural components get easily affected/dislocated during the earthquake. These repairs involve one or more of the following:
a) Patching up of defects such as cracks and fall of plaster;
b) Repairing doors, windows, replacement of glass panes;
c) Checking and repairing electric conduits/ wiring;
d) Checking and repairing gas pipes, water pipes and plumbing services;
e) Re-building non-structural walls, smoke chimneys, parapet walls, etc;
f) Replastering of walls as required;
g) Rearranging disturbed roofing tiles;
h) Relaying cracked flooring at ground level; and
j) Redecoration — white washing, painting, etc.

The architectural repairs as stated above do not restore the original structural strength of structural components in the building and any attempt to carry out only repairs to architectural/non-structural elements neglecting the required structural repairs may have serious implications on the safety of the building. The damage would be more severe in the event of the building being shaken by the similar shock because original energy absorption capacity of the building would have been reduced.

As per IS 13935 Clause 4.2.1
Prior to taking up of the structural repairs for restoration of original strength and any strengthening measures, it is necessary to conduct detailed damage assessment to determine:
a) the structural condition of the building to decide whether a structure is amendable for repair; whether continued occupation is permitted; to decide the structure as a whole or a part require demolition, if considered dangerous;

Above are some of the basic conditions copied and produced from relevant codes for details the referred codes can be seen for further details.

BASIC DATA OF BUILDING

3.1 DATA COLLECTION:

In order to facilitate seismic evaluation, it is necessary to collect relevant data of a building as much as possible through drawings, enquiry, design calculations, soil report (if available), inspection reports, reports of previous investigation, previous repair works, any complaints by the occupants etc. A site visit is essential for data collection.

3.2 BASICS:

The building being evaluated is a Institutional building i.e. MAIN COLLEGE BUILDING OF JANKI DEVI MEMORIAL COLLEGE, SIR GANGA RAM HOSPITAL ROAD, New Delhi – 110060 situated in Central Delhi in the ridge region. As per micro zonation map the building is situated in moderate risk zone. The building is a Load bearing structure. The building is of low height less than 15.0 mtr height with Ground + First Floor + Second + Third Floor. Building was constructed in year 1974 by engaging an Architect and structure engineer.

As per the made available it seems that the provision of earthquake as per masonry building at the time of design was taken due care in structure design.

The water table in the area is low due to ridge rocky area.

Best quality material and workmen ship was used to construct the building under proper technical supervision and guidance.

The building was constructed after taking due approvals from the concerned government departments and proper maintenance is being carried out in the building as required from time to time.

3.3 LOCATION OF BUILDING:

MAIN COLLEGE BUILDING OF JANKI DEVI MEMORIAL COLLEGE, SIR GANGA RAM HOSPITAL ROAD, NEW DELHI - 110060

3.4 Building survey data sheet: General data

S. No.	Description	Information	Notes
Building Description			
1	Address of the building • Name of the building • Plot number • Locality / Township • District • State • PIN	Main College Building Janki Devi Memorial College New Delhi New Delhi 110060	
2	Name and type of owner / tenant	Government	Private / government
3	Name of builder	Janki Devi Memorial College	
4	Name of architect		
5	Name of engineer		
6	Use of building	Residential	Residential / office / commercial / industrial
7	Year of construction and subsequent remodeling, if any	1974	
8	Plan size (approximate)	N. A.	
9	Building height	15.0 meters	
10	Number of storeys above ground level	Two	
11	Number of basements below ground level	Not Applicable	
12	Type of structure • Load bearing wall • RC frame • RC frame and shear wall • Steel frame	Mised with Load bearing walls & RCC columns	
13	Open ground storey	No	
14	Roof-top water tank, heavy machinery or any other type of large mass	Yes	Water Tank
15	Architectural features	No	
16	Expansion / Separation joints	No	
17	Photograph / sketch	Yes	Attach with sheet
Survey			
1	Visited building site	Yes	
2	Structural drawings available	No	
3	Architectural drawings available	No	Provided by owner
4	Geotechnical report available	No	
5	Construction specifications available	Yes	Provided by owner

6	Designer contacted	Not available	
Exposure condition			
1	Environment	Dry	
2	Deterioration noticed	Yes	
Geotechnical and geological			
1	Type of soil	Medium	Soft / medium / hard rock IS 1893:2002, Table 1
2	Type of foundation	Isolated	Isolated / combine footing / pile / raft
3	Design safe bearing capacity	Not Available	IS 1904: 1986
4	Footings on sloping ground	No	
5	Seismic zone	IV	IS 1893: 2002, Figure 1
6	History of past earthquakes	Yes	
7	Presence of liquefaction-susceptible, saturated, loose granular soil at foundation level	No	
8	Building situated close to slope susceptible to fail under earthquake	No	
9	Building situated close to known surface fault	No	
Variables for analysis			
1	Dead loads (unit weights) • Masonry • Concrete • Steel • Other materials	As per code	IS 875: 1987 (Part 1)
2	Imposed (live) loads • Floor loads • Roof loads	As per code	IS 875: 1987 (Part 2)
3	Wind loads	Not Applicable	IS 875: 1987 (Part 3)
4	Snow loads	Not Applicable	IS 875: 1987 (Part 4)
5	Safe bearing capacity	Not Applicable	IS 1904: 1986
6	Importance factor, *I*	1.5	IS 1893: 2002, Table 6
7	Seismic zone factor, *Z*	0.24	IS 1893: 2002, Table 2
8	Response reduction factor, *R*	3	IS 1893: 2002, Table 7
9	Fundamental natural period, *T*	0.02	IS1893:2002, Cl.7.6

VISUAL INSPECTION (RAPID VISUAL SCREENING)

VISUAL INSPECTION (RAPID VISUAL SCREENING)

General Comments of Visual Inspection

1. The building is an old building constructed in 1975.
2. Building is a mixed structure with brick walls, brick columns, RCC beams, RCC roof, and RCC stairs and RCC Columns.
3. The building is stand alone.
4. The building is constructed in C Shape.
5. The building was constructed in three phases with each phase on different level of ground due to topography of ground.
6. Parapet walls at roof are of brick work.
7. Stair case & Balcony railing is of brick work.
8. No settlement of floor visible in building.
9. There is no adjoining structure.
10. The water tanks are placed on the terrace.
11. Cracks in building are seen at the junction of buildings.
12. Cracks and deterioration seen in circular columns in corridor.

Some photographs of the building with Individual comments are also given for reference and location of damage.

Building 1 = Front building

Building 2 = Middle building

Building 3 = Back building of Library

Crack at Junction of Building 2 & 3

Corridor Building 1 & 2

Stairs building 2

Terrace building 3

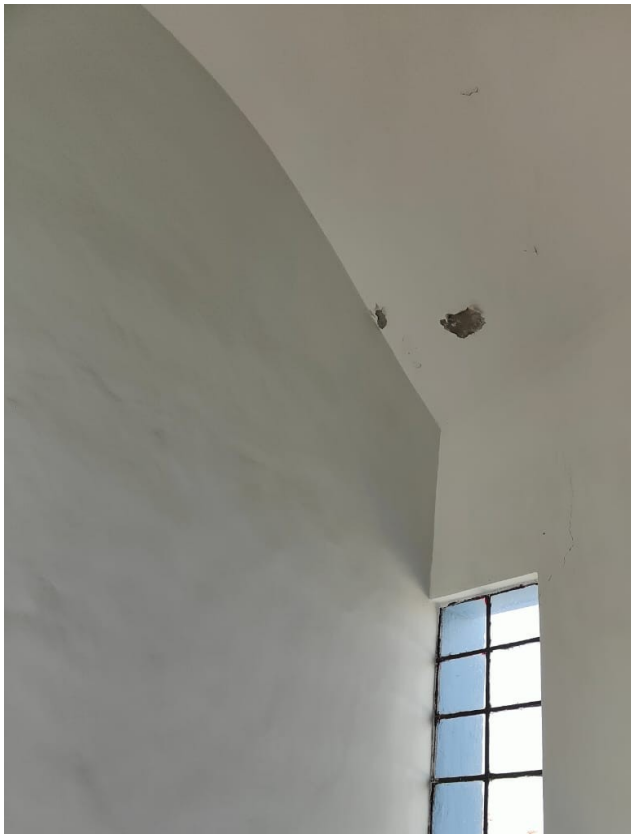
Crack in building 1

Corridor

Corridor

Horizontal Crack at the junction of Building 1 & 2

Horizontal Crack at the junction of Building 1 & 2



Concrete fallen from roof

Crack at junction of building 2 & 3

Corridor

Testing in circular column at ground floor

Testing of circular column

Testing of circular column

Testing in Room 13 Roof

Testing in Roof Beam


13
JDMC-131


PHILOSOPHY DEPT.

Crack in wall

Crack in wall

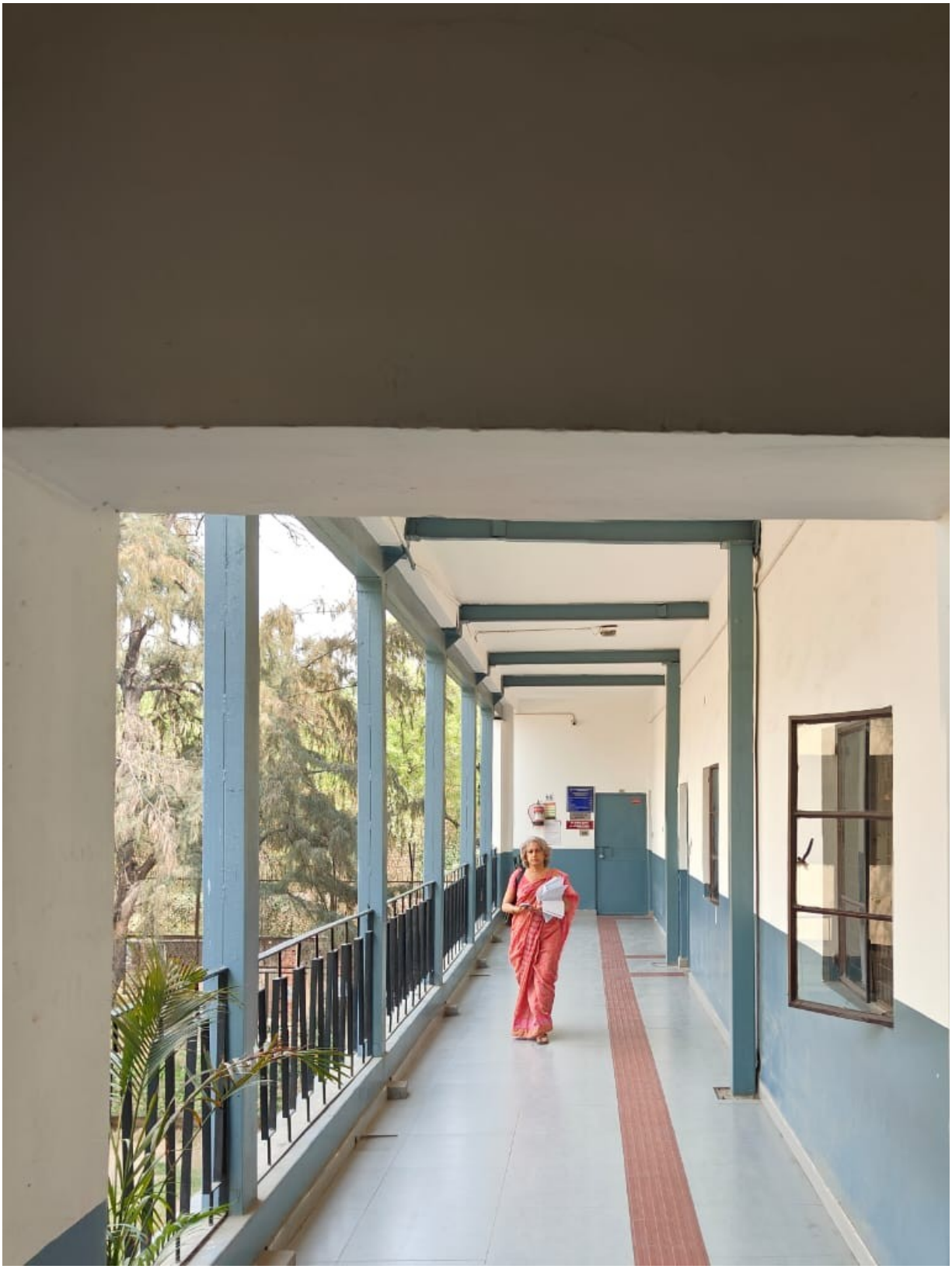
Library Back Side

Library Front Side

Library Back Side

Library Back Side

In building three back side towards Vacation center some times back the building tilted and slab also settled and due to this the building was strengthened using steel I Section, Channel etc. by way of columns beams making a steel frame from ground floor to terrace, for which it is made clear from following photographs.



Non-Destructive Testing & Analysis

Rebound Hammer Test Results

Test Method: IS-516 (Part5-Sec.4): 2020

Location- Janki Devi Memorial College, J.D.M.C. Road, Rajender Nagar, New Delhi.

S No.	Locations	Impact	Rebound No.						Average. Rebound No.	Comp. Strength (N/mm2)	As per IS 456 Test result of Rebound hammer has variation of +/- 25% hence to be on safer we consider the strength as -25%	Minimum required as per IS 456, 2016 for individual core = 75% of M20 = 75% of 20 = 15.00 hence result fail/ Pass as under
			1	2	3	4	5	6				
1st Floor												
1	Slab Room No. 13	Upward	36	40	36	34	36	40	37	28.4	21.30	Pass
2	Column Room No. 13 Corridor	Horizontal	28	30	28	30	28	30	29	22.1	16.58	Pass
3	Column Room No. 12 Corridor	Horizontal	28	26	30	28	26	28	28	20.6	15.45	Pass
4	Column Room No. 14 Corridor	Horizontal	30	28	30	28	26	30	29	22.1	16.58	Pass
5	Stair Beam Lift Area	Horizontal	28	28	26	26	30	28	28	20.6	15.45	Pass
6	Column Room No. 17 A	Horizontal	28	30	22	26	26	28	27	19.1	14.33	Fail
7	Slab Room No. 17 A	Upward	38	38	36	36	34	36	36	26.8	20.10	Pass
8	Stair Slab Lift Area	Horizontal	30	28	26	28	28	30	28	20.6	15.45	Pass
TOTAL										**180.30**	**135.23**	
AVERAGE										**22.54**	**16.90**	Pass
2nd Floor												
1	Column Room No. 40 Corridor	Horizontal	28	26	24	24	26	28	26	17.7	13.28	Pass

2	Column Room No. 39A Corridor	Horizontal	26	28	30	26	24	28	27	19.1	14.33	Fail
3	Slab Room No. 40	Upward	30	30	28	30	28	30	29	16	12.00	Fail
4	Column Room No. 41 Corridor	Horizontal	30	30	28	26	28	30	29	22.1	16.58	Pass
5	Column Room No. 46 Corridor	Horizontal	28	28	26	26	28	30	28	20.6	15.45	Pass
6	Stair Slab Lift Area	Upward	30	28	30	32	30	28	30	17.5	13.13	Fail
7	Beam Stair-3	Horizontal	28	26	26	30	26	28	27	19.1	14.33	Fail
8	Stair-3 Slab	Upward	22	24	26	28	26	26	25	10.8	8.10	Fail
9	Beam Room No. 46	Horizontal	28	30	30	28	30	26	29	22.1	16.58	Pass
10	Slab Room No. 46	Upward	30	32	34	32	32	34	32	20.5	15.38	Pass
11	Stair-2 Slab	Upward	34	36	32	34	34	32	34	23.5	17.63	Pass
12	Stair-2 Beam	Horizontal	28	30	28	28	30	26	28	20.6	15.45	Pass
TOTAL										**229.60**	**172.20**	
AVERAGE										**19.13**	**14.35**	Fail
3rd Floor												
1	Column Room No. 69, Corridor	Horizontal	24	26	26	28	26	28	26	17.7	13.28	Fail
2	Column Room No. 68, Corridor	Horizontal	28	30	30	28	26	28	28	20.6	15.45	Pass
3	Column Room No. 66, Corridor	Horizontal	30	32	34	32	30	28	31	25.2	18.90	Pass
4	Stair-3 Beam	Horizontal	28	30	30	30	28	26	29	22.1	16.58	Pass
5	Stair-3 Slab	Upward	38	36	34	36	38	40	37	28.4	21.30	Pass
TOTAL										**114.00**	**85.50**	
AVERAGE										**22.80**	**17.10**	Pass

Average of all Three floors = (16.90 +14.35+17.10)/3 = 16.12 N/mm2

Surface strength of concrete is as per IS:456-2016. Rebound hammer test depicts the surface strength of RCC and as per IS code it has to be read with uPV test.

Ultra Sonic Pulse Velocity Test Results					
Test Method: IS: 516 (Part 5/Sec.1): 2018					
Location- Janki Devi Memorial College, J.D.M.C. Road, Rajender Nagar, New Delhi.					
Sl. No.	**Locations**	**Method of Probing**	**Observed UPV m/sec**	**Corrected UPV m/sec**	**Quality of concrete as per IS-516 (Part5/Sec.1): 2018**
1st Floor					
1	Slab Room No. 13	Indirect	3128	3628	Doubtful
2	Column Room No. 13 Corridor	Indirect	2639	3139	Doubtful
3	Column Room No. 12 Corridor	Indirect	2290	2790	Poor
4	Column Room No. 14 Corridor	Indirect	2963	3463	Doubtful
5	Stair Beam Lift Area	Indirect	2996	3496	Doubtful
6	Column Room No. 17 A	Indirect	2529	3029	Doubtful
7	Slab Room No. 17 A	Indirect	3259	3759	Good
8	Stair Slab Lift Area	Indirect	3296	3796	Good
2nd Floor					
9	Column Room No. 40 Corridor	Indirect	2165	2665	Poor
10	Column Room No. 39A Corridor	Indirect	2619	3119	Doubtful
11	Slab Room No. 40	Indirect	3169	3669	Doubtful
12	Column Room No. 41 Corridor	Indirect	2842	3342	Doubtful
13	Column Room No. 46 Corridor	Indirect	2328	2828	Poor
14	Stair Slab Lift Area	Indirect	2752	3252	Doubtful
15	Beam Stair-3	Indirect	3135	3635	Doubtful
16	Stair-3 Slab	Indirect	3319	3819	Good
17	Beam Room No. 46	Indirect	3010	3510	Doubtful
18	Slab Room No. 46	Indirect	3063	3563	Doubtful
19	Stair-2 Slab	Indirect	3315	3815	Good
20	Stair-2 Beam	Indirect	2812	3312	Doubtful
3rd Floor					
21	Column Room No. 69, Corridor	Indirect	2519	3019	Doubtful
22	Column Room No. 68, Corridor	Indirect	2310	2810	Poor
23	Column Room No. 66, Corridor	Indirect	2269	2769	Poor
24	Stair-3 Beam	Indirect	3062	3562	Doubtful
25	Stair-3 Slab	Indirect	3169	3669	Doubtful

uPV Test depicts the homogeneity of concrete. As per test results it shows that may be at the time of casting of concrete compaction is not done properly. Also if the water used is saline, quality of material is not good, silt content is more in material used, workmanship is poor then also this may happen. It depicts about that due to chemical reaction and ageing of concrete internal deficiencies appears. This test is to be correlated with rebound hammer test as per IS code as both the test compliments each other.
If a column passes in one test either in rebound hammer or uPV and fails in other rebound hammer or uPV then in it needs repair and strengthening.

Excellent: Column is OK
Good: Column is OK
Doubtful/ Poor: Column needs immediate repair with injection grouting, chemical treatment and other methods.
As per IS code rebound hammer test and uPV test complement each other and if any structure member passes in both tests, then it is ok otherwise it fails and require repair but in present case all the members have passed in both the tests.

Half-Cell Results			
Test Method: IS 516(Part5/Sec2):2021			
Location- Janki Devi Memorial College, J.D.M.C. Road, Rajender Nagar, New Delhi.			
Sr No.	Location	Result (mV)	Percentage Chance of Active Corrosion
1	Stair Beam Lift Area, 1st Floor	(-195)	Up to 10%
2	Stair Room No. 17 A, 1st Floor	(-217)	10 to 50%
3	Slab Room No. 40, 2nd floor	(-205)	10 to 50%
4	Column Room No. 68, 3rd Floor	(-221)	10 to 50%

Testing Photos

Photo 1: RH Test is in Progress

Photo 2: RH Test is in Progress

Photo 3: RH Test is in Progress

Photo 4: RH test is in Progress

Photo 5: RH Test is in Progress

Photo 6: RH test is in Progress

Photo 7: RH Test is in Progress

Photo 8: RH Test is in Progress

Photo 9: RH Test is in Progress

Photo 10: RH Test is in Progress

Photo 11: RH Test is in Progress

Photo 12: RH Test is in Progress

Photo 13: RH Test is in Progress

Photo 14: RH Test is in Progress

Photo 15: RH Test is in Progress

Photo 16: RH Test is in Progress

Photo 17: RH Test is in Progress

Photo 18: RH Test is in Progress

Photo 19: RH Test is in Progress

Photo 20: RH Test is in Progress

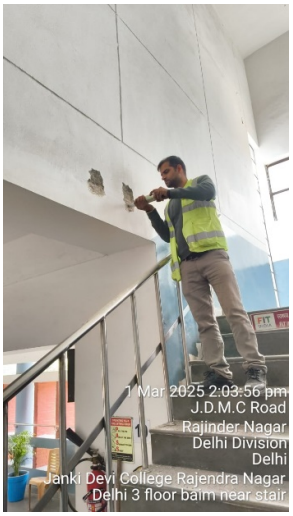


Photo 21: RH Test is in Progress

Photo 22: RH Test is in Progress

Photo 23: RH Test is in Progress

Photo 24: UPV Test is in Progress

Photo 25: UPV Test is in Progress

Photo 26: UPV Test is in Progress

Photo 27: UPV Test is in Progress

Photo 28: UPV Test is in Progress

Photo 29: UPV Test is in Progress

Photo 30: UPV Test is in Progress

Photo 31: UPV Test is in Progress

Photo 32: UPV Test is in Progress

Photo 33: UPV Test is in Progress

Photo 34: UPV Test is in Progress

Photo 35: UPV Test is in Progress

Photo 36: UPV Test is in Progress

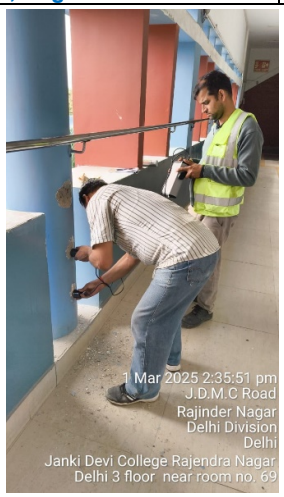


Photo 37: UPV Test is in Progress

Photo 38: UPV Test is in Progress

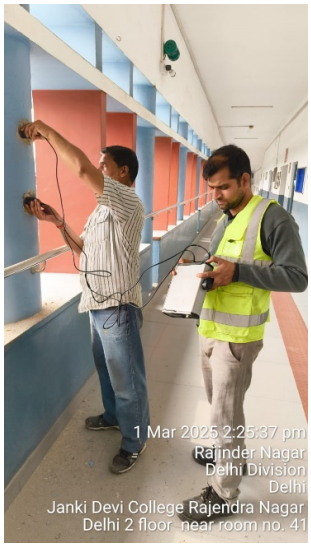


Photo 39: UPV Test is in Progress

Photo 40: UPV Test is in Progress

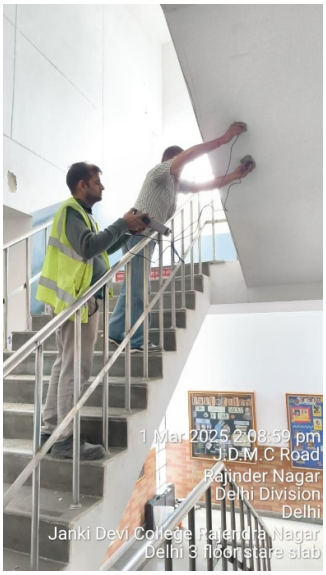


Photo 41: UPV Test is in Progress

Photo 42: UPV Test is in Progress

Photo 43: UPV Test is in Progress

Photo 44: UPV Test is in Progress

Photo 45: UPV Test is in Progress

Photo 46: UPV Test is in Progress

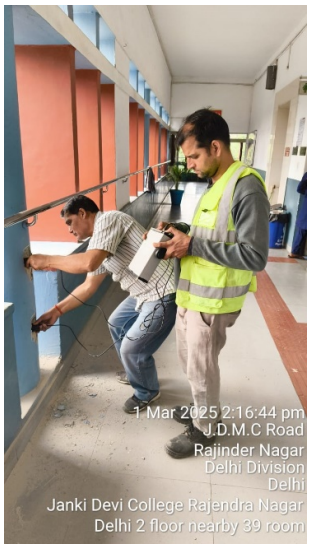


Photo 47: UPV Test is in Progress

Photo 48: Half cell Potential Test is in Progress

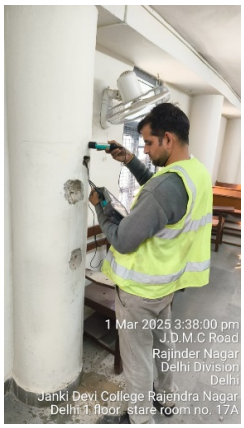


Photo 49: Half cell Potential Test is in Progress

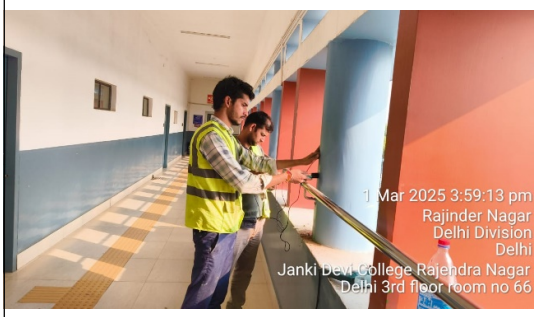


Photo 50: Half cell Potential Test is in Progress

Photo 51: Half cell Potential Test is in Progress

Final Recommendations

FINAL CONCLUSION

The building had withstood since constructed till date the fury of nature like earthquake, wind forces, rain and other calamities

After considering all data I have come to the conclusion that building requires repair work as suggested below: -

1. All RCC columns in corridor at all floors are required to be jacketed as per standard details given in this report under the section of retrofitting from foundation to terrace using Main vertical reinforcement of 12 no's- 20 mm dia (Fe 550) and 8 mm dia rings @ 100 mm c/c with 10 mm dia shear keys. Minimum length for rebar of vertical reinforcement to be 230 mm.
2. All cracks at junction should be repaired as per procedure.
3. All cracks at other places as indicated should be repaired.
4. At one place as per photograph attached above concrete has fallen from slab, it should be repaired.

The building should be repaired in a phased manner.

The portion of building which is strengthened using steel frame should be retrofitted/ strengthened by appropriate method so that it becomes safe during earthquake.

SANJEEV KUMAR SHARMA
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PROCEDURES, STANDARD METHODS & SPECIFICATION OF STRUCTURE AUDIT WORK

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1.0 INTRODUCTION

This paper deals to create awareness amongst the civil engineers, residents and owners of building towards the health examination of existing concrete buildings called as Structural Audit. 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 multistory 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.

1.1 Brief History/ Back Ground:

A PIL was file in the Honorable High Court of Delhi vide no: WP(C) 4534/2015 Arpit Bhargava & Others V/s NDMC & others subsequent to various orders of the Honorable High Court of Delhi and provision of the notification of GNCTD dated 24/04/2019 & 10/02/202 a public notice was published in newspaper on 18/06/2020 by all the three Municipal Corporation of Delhi stating the in compliance to the orders of Honorable High Court of Delhi that general public is hereby informed that they have to get the structure audit of their building got done as per further details given in the under notice.

1.2 NEED FOR SEISMIC EVALUATION OF EXISTING BUILDINGS

On a priority basis, seismic evaluation and retrofit are undertaken for the life-line buildings, such as hospitals, police stations, fire stations, telephone exchanges, broad casting stations, television stations, railway stations, bus stations, airports (including control towers), major administrative buildings, relief co-ordination centers and other buildings for emergency operations. The next set of important buildings includes schools, educational institutions, places of worship, stadia, auditoria, shopping complexes and any other place of mass congregation. High rise multi- storied buildings, major industrial and commercial buildings, historical and heritage buildings are also among the important buildings.

Seismic vulnerability of an existing building is indicated under the following situations.

1. The building may not have been designed and detailed to resist seismic forces.
2. The building may have been designed for seismic forces, but before the publication of the current seismic codes. The lateral strength of the building does not satisfy the seismic

forces as per the revised seismic zones or the increased design base shear. The detailing may not comply with the requirements of the current codes to ensure ductility and integral action of the components.

3. The construction is apparently of poor quality.
4. The condition of the building has visibly deteriorated with time.
5. There have been additions or modifications or change of use of the building, which has increased the vulnerability. For example, additional storeys have been constructed.
6. The soil has a high liquefaction potential.

Especially under such situations, and specifically, in the case of life-line and other important buildings, there is a clear need for a structural assessment of the existing buildings for their adequacy to withstand the design seismic loads.

1.3 Structural Audit – Why and When

The structural stability is affected by number of reasons such as Aging, Construction Quality, Exposure condition, External forces etc.

The Structural Audit is a process of assessing the present health of structure, identifying the loads & forces acting on the structure, identifying the effects of these loads and forces and finally assessing the stability & safety of the structure to withstand for its remaining life.

If the structural audits are carried out on regular intervals of @ 5 years, it helps to identify the problems in the initial stage. After structural audit, if the required repairs / Rehabilitation and preventive maintenance are carried out regularly, it substantially reduces the overall maintenance / repair cost of the structure. Stitch in time saves nine

The Structural Audit is carried out mainly for -

- As a statutory requirement
  - O After every 5 years as per Inspector of factories
  - O After 30 years at every 5 years as per Municipal Act
  - O After 15 years at every 5 years and after 30 years at every 3 years as per Co-operative society Act.
- For Insurance
- For Bank – Mortgage
- For Valuation
- Structure showing Distress
- Proposed Additions, Alterations, Extensions in building / structure
- For Damage assessment due to earthquake, fire, blast, vibration, corrosion etc.

1.4 Description and scope of work:

As per tender documents.

1.5 Objectives of the overall investigation:

As per tender documents.

2.0 SEISMOLOGY OF DELHI

Geological Setting of Delhi

Delhi, the capital of India is bounded by the Indo-Gangetic alluvial plains in the North and East, by Thar Desert in the West and by Aravalli hill ranges in the South. The terrain of Delhi is flat in general except for allowing NNE-SSW trending ridge which is considered and extension of the Aravalli hills of Rajasthan. A computer image of the surface topography of Delhi is presented in the figure below.

Seismicity around Delhi appears to be associated with a major geological structure, which is known as the Delhi-Hardwar Ridge. It coincides with the extension of the Aravalli Mountain belt beneath the alluvial plains of the Ganga basin to the northeast of Delhi towards the Himalayan Mountain (Jain, 1996).

Seismic zoning

The country has been classified into different zones indicating the intensity of damage or frequency of earthquake occurrences. These zoning maps indicate broadly the seismic coefficient that could generally be adopted for design of buildings in different parts of the country. These maps are based on subjective estimates of intensity from available information on earthquake occurrence, geology and tectonics of the country. The zoning of a country is a continuous process which keeps undergoing changes as more and more data on occurrence of earthquakes in that country becomes available.

The region with intensity less than V is designated as Zone 0. Thus, the designation of area as seismic Zone V indicates activity. Delhi is located in zone IV which has fairly high seismicity where the general occurrence of earthquakes is of 5-6 magnitude, a few of magnitude 6-7 and occasionally of 7-8 magnitude. Delhi thus lies among the high-risk areas.
Seismicity in North India, including the Himalayas, is due to collision of the Indian plate with Eurasian plate. This is a continuous process happening for the last 50 million years. These colliding plates flex, storing energy like a spring, and when the plate's margin finally slip to release energy, an earthquake result.

In the past, five earthquakes of Richer Magnitude 5.5 to 6.7 are known to have occurred in the UT of Delhi or close to it since 1720 AD. Two major lineaments namely Delhi-Haridwar ridge and Delhi-Moradabad faults pass through the territory, both having potential of generating earthquakes of magnitude up to MSK VIII will be quite probable in the Delhi territory. Normal depth of 30 km may be assumed for these earthquakes. It will be prudent to consider the effects of such a potential earthquake for developing a prevention-cum-preparedness plan

Issues

The city's settlement pattern has never been viewed in relation to location and geological characteristics.

Pockets with high rise buildings or ill-designed high-risk areas exist without specific consideration of earthquake resistance. Similarly, unplanned settlements with substandard structures are also prone to heavy damage even in moderate shaking.
The Central Business District namely Connaught Place, numerous District Centers and sprouting high rise group housing schemes are high risk areas due to the vertical as well as plan configurations. The walled city area, the trans-Yamuna area, and scattered pockets of unplanned settlements also figures as high-risk zones due to their substandard structures and high densities.
So far as housing is concerned, vulnerability analysis has never been carried out and preliminary estimate of damages is not available for strengthening of structures under normal improvement development schemes.

The most recent Chamoli earthquake (29 March 1999) was felt all over Delhi. There have been reports of cracks in a few tall buildings located on alluvial deposits in the trans-Yamuna area. This event has been recorded by instruments maintained by CBRI.

Past earthquakes around Delhi

Damaging earthquakes have occurred around Delhi since ancient times. Mahabharata mentions about earthquakes during the war at Kurukshetra (Circa 3000 BC?). More recently, damage to Delhi in the 1720 earthquakes (intensity IX in Delhi) is well discussed by Kafi Khan. Tandon (1953) mentions of damage to the Qutab Minar during the 2803 earthquake near Mathura.

Srivastava and Roy (1982) discuss several more earthquakes in Delhi region. These include: (a) earthquake of year 893 or 894 (Intensity XI XII) which took place not far from Delhi in which many persons died; (b) earthquake of 22 March 1825 near Delhi Intensity VII; earthquake of 17 July 1830 near Delhi (Intensity VIII); and (d) earthquake of 24 October 1831 near Delhi (Intensity VI)

Delhi has also sustained earthquake damage in more recent times. For instance, Srivastava and Somayajulu (1966) mention of (a) Khurja earthquake (M6.7) of 10 October 1956 in which 23 persons were killed in Bulandshahr and some injured in Delhi; (b) M6.0 earthquake of 27 August 1960 near Delhi wherein about 50 persons in Delhi were injured; and (c) an earthquake near Moradabad on 15 August 1966 that killed 14 persons in Delhi. Iyengar (2000) also mentions about damage to one of the minarets of Delhi's Jama Masjid during the M4.0 earthquakes on 28 July 1994.

Most recently, the 1999 Chamoli earthquake (M6.5) took place about 280 km from Delhi. Such a moderate earthquake does not normally cause damage at such large distance. And yet, several buildings in Delhi sustained non-structural damage possibility due to peculiar geological and geotechnical features if this area. Fig. 1 shows damage to the ground storey parttion walls of a multistory apartment building in the Patparganj area. Collapse of a few architectural fins at the Shastri Bhawan during this earthquake is shown in Figs.2 (a, b). In 1985, an earthquake about 400 km from Mexico City caused very considerable damage and deaths in Mexico City, primarily due to the peculiar site conditions there. The Chamoli earthquake effects in Delhi indicate that there is real possibility of a large earthquake in the Himalaya causing considerable damage to Delhi.

It is therefore seen that Delhi is prone to severe earthquake damage both by nearby earthquakes and by large earthquakes occurring in the Himalayas. The scientists and engineers need to

urgently take up detailed investigations to develop a more quantitative understanding of the seismic hazard faced by Delhi. Unfortunately, not many such studies have been carried out so far. For instance, paleoseismics studies to locate major earthquake events of the past, e.g., the 1720 and the 1803 events, would add significantly to the hazard evaluation. Due to its complex geological setting, some areas of Delhi are likely to sustain much higher levels of damages than the others and to evaluate this; detailed micro zonation studies are needed. (e.g., Iyengar, 2000).

Current status of building stock

the first code of practice for earthquake resistant design was developed in India as early as 1930's after the 1935 Quetta earthquake (e.g., Jain and Nigam, 200). The Bureau of Indian Standards developed its first code on aseismic design in 1962 (IS: 1893-1962). However, till date there is no legal framework to require that all constructions in Delhi must implement seismic code provisions. The result is that most buildings in Delhi may not meet codal requirements on seismic resistance. Moreover, even if from now on we somehow ensure that all new construction will be earthquake resistant, there still will remain a very large inventory of old buildings that will be deficient for seismic safety. We need to develop a rational seismic retrofitting policy, first for the government-owned buildings and later for the private constructions.

As per Vulnerability Atlas of India (1997), for shaking intensity VIII, 6.5% houses in Delhi have high damage risk; and 85.5% houses have moderate damage risk. These estimates are based on very simplistic assumptions. Systematic studies are needed on vulnerability of different types of constructions in the area. This will require experimental studies to evaluate strength, stiffness and ductility of different types of constructions as well as analytical studies such as the Push over Analysis. Experiences of past earthquakes both in India abroad have clearly outlined the vulnerability of multistory reinforced concrete buildings if not designed and constructed correctly. Huge number of multistory reinforced concrete buildings in Delhi, particularly those with open ground storey to accommodate vehicle parking, could also pose a major challenge in the event of a strong earthquake.

Infrastructure and other implications

Delhi is currently passing through a major infrastructure development phase with a large number of bridges, flyovers and the metro project under construction. After a severe earthquake, the transport infrastructure is earthquake resistant and the old one is seismically retrofitted. Indian seismic code (IS: 1893-1984) is not applicable for major projects which require special studies on seismic design criteria. Moreover, the Indian seismic codal provisions on bridges as these exist today are obsolete and inadequate (e.g. Jain and Murty, 1998).

Earthquake disaster in Delhi has the potential to go well beyond the statistics of deaths and injuries. Such a disaster in the country's capital, which also happens to be a major commercial and industrial center, will have huge economic and political implications which will affect the entire country and not just the population of Delhi. This adds an extra dimension to the earthquakes problem for Delhi.

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Plan of action

A valid question at this stage will be: should one be concerned about an earthquake which has a very low probability of occurrence, when Delhi faces so many day-to-day problems of environment, noise, traffic, water and power shortage, etc.? The consequences of a severe earthquake to not seriously address the problem. Put it differently, considering the potential for a mega disaster, we cannot afford ignore the earthquake problem.

3.0 VISUAL INSPECTION

The Rapid Visual Screening (RVS) procedures are simple enough to be used by an inspector with proper training. The steps of RVS are planning for the survey, execution of the survey and interpretation of the results.

The main uses of RVS are as follows.

1. To identify if a particular building requires further evaluation for its seismic vulnerability.
2. To assess the seismic damageability (probability of damage) of the building and seismic retrofit needs.
3. To identify simplified retrofit schemes for the buildings for which further evaluation is not considered necessary or not found to be feasible.

Since the RVS is based on visual inspection, the results may occasionally vary from that of a detailed analysis. For example, a building found to be vulnerable by RVS may perform better under the detailed analysis.

Walkover survey and visual inspection

Visual inspection is the initial non-destructive test. It forms the basis of the subsequent inspections. A detailed visual inspection makes it possible to narrow down the critical areas in a structure that need further investigation using sophisticated techniques. The trained eye of an inspector can often reveal information that is sometimes difficult to pick up using hi-tech instruments.

First and foremost activity in a condition survey and structural investigation, especially in distressed building, is a walk over survey or systematic visual inspection so as to gather readily available information about the structure in question. The visual observations and documentation was made for the structures to determine if there are any obvious signs of distress, deflection or deterioration in the structure, sign of seepage, leakage, growing vegetation etc. Based on the visual inspection, redistribution of the number of tests to be performed as per the scope of work and their point of conductance will be proposed so as to confirm the recommendations and findings of visual inspection.

4.0 SESMIC ANALYSIS

INTRODUCTION

At present, the structural analysis is performed using a suitable computer analysis program. The steps involve developing a computational model of the building, applying the external forces, calculating the internal forces in the members of the building, calculating the deformations of the members and building, and finally interpreting the results.

Structural analysis is a part of the detailed evaluation of an existing building. A detailed evaluation is decided based on the results of preliminary evaluation. Structural analysis can be linear or non-linear, elastic or inelastic, static or dynamic. In a linear elastic analysis, the deformation in a member is considered to be proportional to the internal force and recoverable when the applied force is removed. In a non-linear inelastic analysis, the deformation in a member need not be proportional to the internal force. There is plastic deformation (deformation that cannot be recovered when the applied forces are removed) and energy absorption in a member for higher levels of internal force. This type of non-linear behavior is referred to as material non-linearity. In addition, geometric non-linearity due to P-□ effect can be incorporated. The P-□ effect refers to the increase in moment in the columns due to its lateral deflection or due to the drift of a storey.

In a static analysis, the vibration mode shapes or the time-wise variation of the quantities are not considered. In a dynamic analysis these are considered to a certain extent. The different methods of analysis can be grouped as shown in Table

Table Methods of structural analysis

	Linear elastic	**Non-linear inelastic**
Static	Equivalent static method	Pushover analysis
Dynamic	Response spectra method, Linear time history analysis	Non-linear time history analysis

Because of the difficulties and uncertainties in a non-linear dynamic analysis, this is not used in regular design practice. This chapter discusses the other types of analysis. The main purpose of these analyses, from the perspective of seismic evaluation, is to check the adequacy of the building components and ascertain code compliance.

Adequate information is required to develop a reliable computational model of an existing building. The necessary documents include the following.

1. Architectural drawings
2. Structural drawings
3. Geotechnical report
4. Reports from data collection, preliminary evaluation and condition assessment.

STRUCTURAL DESIGN DATA

Building Type

I) Residential.

Earth quake Zone: IV (Delhi)
Zone Factor = 0.24
Importance factor = 1.5
2. Structural System

Existing Buildings has RCC frame within built brick walls acting as shear walls with plinth beam and Lintel over openings. It is assumed that a R.C.C Beam – Column framing is chosen as the principal structural system for both gravity and lateral loads.

Bricks with specific weight of 20.0 Kn/m3 have been used as masonry work.

Foundation System
The foundation system is different for different buildings like raft foundation with plinth beams, independent footing, load bearing etc. as per design requirement and space available. The bearing capacity of soil as assumed at this stage is 09 ton/m2 at depth of 1.5 meter below NGL as soil test report is not available.

LOADING PARAMETRES
As per IS 875

SEISMIC LOADS:
Seismic loading has been considered as per IS: 1893(Part-1) -2016.
Value of importance factor has been taken as 1.5 as per table 6 of IS: 1893-2016.

Spectral Acceleration co-efficient Sa/g is taken as per clause 6.4.5 of IS: 1893-2016.

Soil conditions (Medium)
Zone factor Z has been taken from table 2 of IS: 1893-2016 as 0.24 for seismic zone IV.

Response Spectrum reduction factor is taken as 5.0 from table 9 of IS: 1893-2016 for special Reinforced Cement Concrete Frames (Moment resisting frames specially detailed to provide ductile behavior).

The Time period of the structure shall also be worked out using STAAD software. The building has been designed for base shear based on codal time period in accordance with i.e. 7.6.1 of IS: 1893-2016 using modification factor = □VB/VB where□VB is calculated

based on codal time period and VB is calculated based on time period given by ETABS software.

The horizontal earthquake force has been calculated for the full dead load & 25% of live load as per clauses 3.29, 7.3 & 7.4 of IS: 1893-2016.

Lap Length shall be considered as per IS 456. The details of which are given below:

Development Length (Ld.) for Fe 500 bars:

Concrete M 25	= 49 times the dia of bar.
Concrete M 30	= 46 times the dia of bar.
Concrete M 35	= 40 times the dia of bar.
Concrete M 40 / M50	= 36 times the dia of bar.

ANALYSIS, MODEL AND SOFTWARE USED:

Super Structure: - The building has been analyzed as a 3-dimensional skeletal structure of beam column frame structure using STAAD Pro software. Rigid diaphragm property has been assigned to the slab system at the floor level and slab has been assigned membrane property. Core slab has been modeled as finite element mesh to assess the inter-active in plane shear acting between flats at each floor under lateral loading.

Sub Structure: - Winkler Bed Method has been adopted for the analysis of raft foundation.

DESIGN & DETAILING OF RCC STRUCTURE:

The design of RCC Beam & Slab has been done using IS: 456-2016 and SP-16. Limit state method of structure design is being followed. Columns has been Designed using STAAD software.

Various load combinations to be considered are as follows:-

For Column Design & Beam design:

1. 1.5 (D.L+ L.L)
2. 1.2 (D.L + L.L+EQX)
3. 1.2 (D.L +L.L-EQX)
4. 1.2 (D.L + L.L+ EQZ)
5. 1.2 (D.L L.L - EQZ)
6. 1.5 (D.L + EQX)
7. 1.5 (D.L - EQX)
8. 1.5 (D.L + EQZ)
9. 1.5 (D.L - EQZ)
10. 0.9 (D.L) +1.5 E.Q. in X-direction
11. 0.9 (D.L) - 1.5 E.Q. in X-direction
12. 0.9 (D.L) +1.5 E.Q. in Z-direction
13. 0.9 (D.L) - 1.5 E.Q. in Z-direction

For Foundation Design:

1. (D.L + L.L)

2. (D.L + L.L + EQX)
3. (D.L + L.L -EQX)
4. (D.L + L.L + EQZ)
5. (D.L + L.L - EQZ)
6. (D.L + EQX)
7. (D.L - EQX)
8. (D.L + EQZ)
9. (D.L - EQZ)

D.L =Dead loads
L.L = Live loads
E.Q= Earthquake loads
However, un factored loads are used for size & pressure calculations of foundation.
Detailing of R.C.C. beams and columns conforms with IS: 456-2000,
IS: 4326 (Earthquake resistant design and construction of buildings),
IS: 13920 (Ductile detailing of reinforced concrete structures subjected to seismic forces).

MATERIALS OF CONSTRUCTION USED: -
As per Latest IS Codes

Now the structure as per the architectural and structure drawing made available is compared as per National Building Code of India 2016, IS 13920: 2016, IS 1893, IS 456:2016 and other relevant codes.

The structure requirement for being earthquake complaint as per latest IS: 1893, IS 13920 and NBC of 2016:-

1. Column size minimum dimension required as per IS 13920- 2016

= 300 mm
= 15 dB = 15 x 16 mm = 240 mm
Hence minimum dimension of some of the columns required is 300 mm which is not met

2. For moderate exposure of structure minimum grade of concrete required is M25.
3. Minimum and maximum percentage of steel was used as per code and calculations of the structure design.

5.0 REFERENCE MADE

Sr. No.	Code	Description
1.	IS-875 (Part-1)-1987	Code of practice for design loads (other than earthquake) for buildings and structures – Unit weights of buildings materials and stored materials.
2.	IS-875 (Part 2)- 1987	Code of practice for design loads (other than earthquake) for buildings and structures – imposed loads.
3	IS- 875 (part 3) - 1987	Code of practice for design loads (other than earthquake) for buildings and structures – wind loads)
4.	IS-875 (Part 5) – 1987	Code of practice for design loads (other than earthquake) for buildings and structures – special loads and load combinations.
5.	IS:456 – 2000	Code of practice for plain and reinforced concrete.
6.	IS: 1786 – 2008	Specification of high strength deformed bars and wires for concrete reinforcement.
7.	IS: 432 (Part-2) – 1982	Specification for mild steel and medium tensile steel bars and hard drawn steel wire for concrete reinforcement – hard drawn steel wire.
8.	IS:13920 – 1993	Ductile detailing of reinforced concrete structures subjected to seismic forces – code of practice.
9.	IS:2062 – 1999	Steel for general structural purposes, specification.
10	IS: 1161 – 1998	Specification of steel tubes for structural purpose.
11	IS: 800 – 2007	Code of practice for general construction in steel.
12.	IS: 2210-1998	Criteria for design of reinforced concrete structures and folded plates.
13.	IS:1893-2016, 2005, 2002	Criteria for design earthquake resistant design of structures (general provision and buildings).
14.	IS : 269 – 1989	Specification for ordinary, rapid hardening and low heat Portland cement.
15.	OS : 455 – 1989	Specification for Portland blast furnace slag cement
16.	IS: 1489 – 1991	Specification for Portland pozzolana cement
17.	IS: 383 – 1970	Specification for course and find aggregates from natural sources for concrete.
18.	IS : 516 – 1959	Method of test for strength of concrete.
19.	IS: 2645 –	Specification for integral cement water proofing compounds.

	1975	
20.	IS:3370-2009 Part 1 & 2	Liquid retaining structures.
21.	IS 4923	HOLLOW STEEL SECTION FOR STRUTURAL PURPOSE
22.	IS 13935:1993	Repair and seismic strengthening of buildings-guidelines
23.	IS 13827: 1993	Guidelines for improving earthquake resistance of earthen buildings
24.	IS 13827: 1993	Guidelines for improving earthquake resistance of earthen buildings
25.	IS 13828: 1993	Guidelines for improving earthquake resistance of low strength masonry buildings
26.	CPWD	Handbook on repair and rehabilitations of RCC buildings
27.	Government of India	National Building code of India, 2016
28.	IS 4326 : 1993	Earthquake resistant design and construction of Buildings
29.	CPWD	Specification
30.	IS 13311	Non- Destructive Testing of Concrete
31.	IS 516	Test for Strength of Concrete
32.	IS 8900	
33.	IS 1199	Methods of sampling and analysis of concrete
34	SP 70	Safety in construction
35.	IS: 15988 : 2013	Seismic Evaluation and strengthening of Existing Reinforced Concrete Buildings- Guidelines
And other related BIS specification as required for the work.		

6.0 TEST RESULT AND INTERPRETATION

Now before interpreting the test reports we must understand and derive what minimum strength of concrete is required as per IS code and what is its basic qualities etc.

1. As per clause no: 6 CONCRETE sub clause 6.1.2 of IS 456 the minimum grade of concrete for plain and reinforced concrete shall be as per Table 5.

   As per table no 5 the minimum grade of concrete to be used for Reinforced concrete with Moderate Exposure is M25. For exposure condition we can refer to Table 3 of IS 456. We have considered the bare minimum exposure for the structure. The value M25 is taken as per the prevailing at the time when the structure of the school was designed. Also as per structure drawings made available by the society the structure is designed in M25 (1:1.5:3) grade of concrete

   Now the characteristics of M25 can be defined firstly by Table 2 of IS 456. Where in M refers to the MIX and 25 stands for 28 days compressive strength of 150 mm (15 cm) cube.

2. Further as per clause 6.2 properties of Concrete, sub clause 6.2.1 Increase of strength with Age of IS 456 clearly states that "There is normally a gain of strength beyond 28 days. The quantum of increase depends upon the grade and type of cement, curing and environmental conditions etc."

   It means that if everything is done satisfactorily at site then the strength of concrete will increase not decrease.

3. Further as per clause 8 DURABILITY OF CONCRETE sub clause 8.1 General of IS 456 states that "A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service. The materials and mix proportions specified and used should be such as to maintain its integrity and if applicable, to protect embedded metal from corrosion."

   It means that the strength of concrete should at least remain the same which was used / minimum required to be used. At least it should not become lesser.

4. As per clause no: 16 ACCEPTANCE CRITERIA sub clause 16.1 Compressive strength of IS 456 states that the compressive strength of the concrete sample should be as per Table 11 of IS 456 and assumed standard deviation should be as per Table 8 of IS 456 then only it can be said to comply the minimum strength requirement.

   As per this the strength required for M25 grade of concrete should be as under:-

   Formula 1: 25 + (0.825 x 4.0) = 28.3 i.e. **28.50 N/ sq. mm**

   Formula 2: 25 + 4 = 29 i.e. **29.0 N/ sq. mm**

   Value whichever is higher of the two to be considered.

   Hence as per this clause the minimum strength required to pass the test is 29.0 N/ sq. mm----------XX

5. As per clause 17.4 Core Test of IS 456, the testing of core strength and sampling to be done as per this clause and for acceptance of core strength sub clause 17.4.3 Concrete in the member represented by a core test shall be considered acceptable if the average equivalent cube strength of the cores is equal to at least 85 percent of the cube strength of the grade of concrete Specified for the corresponding age and no individual core has a strength less than 75 percent.

   I.e. Average strength of all cores 85% strength for M25 = 0.85 x 25 = 21.25 N/ Sq. mm

   Minimum Individual Core strength 75% strength for M25 = 0.75 x 25 = 18.75 N/ Sq. mm

   Hence as per this clause minimum average result should not be less than 21.25 N/ sq. mm and no core should have strength less than 18.75 N/ sq. mm ------YY

6. Rebound hammer test to be done as per IS 13311(Part 2) and as per clause 8.1 of IS13311 (Part 2) the accuracy of the test result is +/- 25% of the test result.

   Hence, we can consider the minimum value by decreasing the value of result by 25% to be on safer side.

7.0 RETROFITTING METHODS PROCEDURE & SPECIFICATION

A retrofit strategy is a technical option for improving the strength and other attributes of resistance of a building or a member to seismic forces. The retrofit strategies can be classified under global and local strategies. A global retrofit strategy targets the performance of the entire building under lateral loads. A local retrofit strategy targets the seismic resistance of a member, without significantly affecting the overall resistance of the building.

The grouping of the retrofit strategies into local and global are generally not be mutually exclusive. For example, when a local retrofit strategy is used repeatedly it affects the global seismic resistance of the building. It may be necessary to combine both local and global retrofit strategies under a feasible and economical retrofit scheme.

Global Retrofit Strategies

When a building is found to be severely deficient for the design seismic forces, the first step in seismic retrofit is to strengthen and stiffen the structure by providing additional lateral load resisting elements. Additions of infill walls, shear walls or braces are grouped under global retrofit strategies. A reduction of an irregularity or of the mass of a building can also be considered to be global retrofit strategies. The analysis of a building with a trial retrofit strategy should incorporate the modeling of the additional stiffening members.

Local Retrofit Strategies

Local retrofit strategies pertain to retrofitting of columns, beams, joints, slabs, walls and foundations. The local retrofit strategies are categorized according to the retrofitted elements. The retrofitting of foundations is separately. The analysis of a building with a trial local retrofit strategy should incorporate the modeling of the retrofitted elements.

The local retrofit strategies fall under three different types: concrete jacketing, steel jacketing (or use of steel plates) and fiber-reinforced polymer (FRP) sheet wrapping. Out of the first two types, each one has its merits and demerits. It may be noted that deviations are expected in individual retrofit projects.

CONCLUDING REMARKS

1) Importance of condition assessment and seismic evaluation

Before undertaking seismic retrofit, it is essential to determine the condition and diagnose the deficiencies in a building. Condition assessment helps to determine the actual condition of the building as opposed to the information available from the construction documents. Seismic evaluation helps to identify the deficiencies of the building with respect to resistance to seismic forces. Based on the condition and deficiencies, repair and retrofit strategies are selected.

Considering the cost of retrofit, it is imperative to have seismic evaluations of a building both for the existing and retrofitted conditions to justify the selected retrofit strategies. When a new

member is added to an existing building under a global retrofit strategy, the load transfer and the compatibility of deformation between the new and the existing elements are crucial. The load transfer should be judged from the analyses of the building. The compatibility of deformation should be ensured by proper detailing of the connections of the existing and new members.

Selection of a retrofit strategy

When a building is severely deficient for the design seismic forces, it is preferred to select a global retrofit strategy to strengthen and stiffen the structure. Next, if deficiencies still exist in the members, local retrofit strategies are to be selected. Beyond this recommendation it is not prudent to prescribe a retrofit strategy as a generic application. Each retrofit strategy has merits and demerits depending upon the project. A retrofit strategy is to be selected after careful considerations of the cost and constructability. Proper design of a retrofit strategy is essential. The failure mode in a member after retrofitting should not become brittle. A global retrofit strategy that involves a shift in either of the center of mass or center of rigidity should be checked for torsional irregularity. Any alteration of the load path has to be carefully detected and any overstressed member has to be identified. Additional demand on the foundation has to be accounted for.

Quality of construction

Retrofit aims at overcoming the deficiencies of an existing building. The quality of construction for a successful retrofit scheme cannot be overemphasized. Any sort of patch work will be a wasted effort.

The members can be saved by strengthening/ retrofitting as per the provisions of IS codes and handbook published by CPWD. The main purpose strengthening is to upgrade the resistance of a damaged member so that further deterioration of concrete and steel is stopped along with strengthening as per clause 4.3 of 13935: 1993

As stated in clause 4.4 & 4.5, 4.5.1 of 13935: 1993 “Replacement of damaged buildings or existing unsafe buildings by reconstruction is generally avoided due to number of reasons as explained in clauses.

In order to save the building from complete demolition it is recommended that if proper repair & restoration work is carried out as per the provisions of

a) IS 13935:1993 (Repair and seismic strengthening of buildings-guidelines?
b) IS 13827: 1993 (Guidelines for improving earthquake resistance of earthen buildings?
c) IS 13828: 1993 (Guidelines for improving earthquake resistance of low strength masonry buildings)?
d) Handbook on repair and rehabilitations of RCC buildings – issued by CPWD.

6.1 Repairing of Cracks

The cracked elements without any indication of concrete getting de-bonded or the core concrete after removal of cover for repair if found to have cracks; or if the concrete as a whole has gone porous, the same shall be treated by sealing the cracks with epoxy putty and grouting the same with low viscous epoxy grout. The steps involved in repair of cracks are as follows:

- Surface preparation,
- Fixing of packers,
- Filling of cracks, &
- Injection of low viscosity epoxy.

Surface Preparation: Clean the concrete surface, 2 cm on either side of the crack to ensure bonding of sealing materials used to seal the crack. Ideally, wire brushes shall be used to make

the surface rough. Where the cracks are already filled with some material or concrete is found to be weak immediately next to cracks, the cracks needs to be opened up completely. In any case, opening of crack in the form of V with top width of minimum 10mm and depth of at least 10mm would be very ideal to avoid future problems. Normally, a surface sealing of the crack would not help during the injection process. When the crack was cut open, using suitable tools, the muck and mud deposited over a time shall be removed mechanically.

Fixing of Packers: At intervals, install packers of size 12 mm diameters along the crack. For fixing the packer, holes of required diameter are drilled into the concrete up to a depth of at least 100mm. The packers are installed into the drilled hole and mechanically tightened to make them remain fixed. The periphery of the packer shall be sealed with epoxy putty of BASF (Concessive 2200) or equivalent.

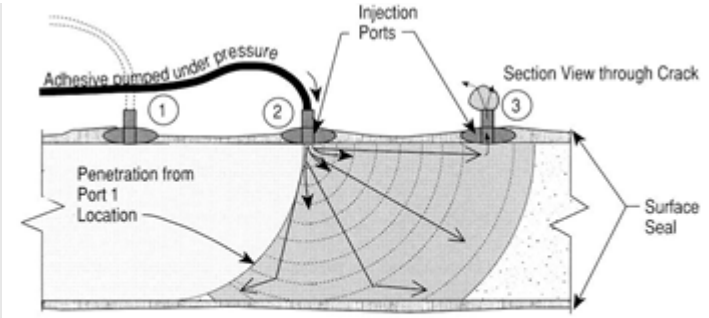
Sealing the Cracks: The opened crack between two packers shall be sealed with epoxy putty. When mixed, epoxy putty achieves a paste type consistency, which can be applied with thin metal piece. The material shall be carefully pressed into the crack to fill the entire depth of the crack and trowelled at the top making it in line with existing concrete surface. The epoxy putty shall be allowed to set completely before initiating the injection process. This would take typically 20 to 30minutes depending on the ambient temperature.

Injection of Low Viscous Epoxy: Once the epoxy putty is completely set, the fixed packers shall be injected with two components, low
Viscous epoxy grout of BASF (Concessive 1315) or equivalent. The injection process shall be started from the widest part if it is a horizontal surface or from the lowest point if it is a vertical surface. The pressure to be maintained shall be a minimum of 2kgs/sq.cm. Inject in each port or nipple (keeping all others closed except the next immediate one). When the resin starts issuing out of the next port/nipple, close it and continue injection until the pressure can be maintained. After maintaining the pressure for 1 to 5 minutes to allow for total penetration, close the port and then disconnect the pump. Continue the process until all the ports or nipples are similarly injected. The typical advantage of using packers for this injection is that they have a non-return valve at the mouth, which will not allow the injected grout to flow back.
Packer Removal: The injected packer shall be removed by simply cutting it at the line of concrete. The gap formed shall be sealed with epoxy putty of BASF (Concessive 2200) or equivalent. The putty shall be allowed to cure before any further treatments.

6.2 Repairing of Damaged Concrete Due To Corroded Reinforcement

Wherever corrosion in the reinforcement is found, the corrosion treatment shall be done as below:

- Chipping of unsound weak concrete / cover of reinforcement over slab/ beams or walls as per site requirement shall be done and reinforcement shall be exposed.
- Reinforcement shall be cleaned of total rust using alkaline chemical rust remover with paint brush and removing loose particles after 12 hours of its application with wire brush and passivator coating shall be applied by brush to treated reinforcement as per manufacturer˘s instructions.
- Polymer Based Bond Coat (Monobond/ Aquabond 150/ NITOBOND or equivalent) shall be applied in layer of approximate 15 mm thickness (hand packed concrete) on chipped portion of RCC as per manufacturer˘s specification and direction of the Engineer at site.



Surface mounted port injection typical flow paths of injected adhesive.
Injection begins at location 1. Injection continues until adhesive flows from location 2. After air and debris is free from the flow at location 2, location 1 injection is discontinued and injection is restarted at location 2. The process is continued until the fracture is filled. (Port to Port method)

FIG.180: TYPICAL FLOW PATHS OF INJECTED ADHESIVE

6.3 Repairing Of Damaged Columns & Beams Where Carbonation Depth Has Reached Reinforcement Level

- Prop and support the structural member in order to relieve stresses due to load coming over it.
- Remove plaster and finishes all around the distressed structural member. Thereafter remove loose, cracked and spalled concrete to expose the rusted reinforcement.
- Remove concrete from all around the reinforcement in order to get average 25mm air gap all around including the reinforcement. Clean the reinforcement of concrete and rust by using alkaline chemical rust remover with paintbrush.
- Put additional reinforcement wherever the reinforcement diameter has been reduced by more than 15% with necessary overlap / anchoring / welding with the existing reinforcement.
- Fix shear keys of appropriate diameter at specified spacing in both directions over the surface to be covered with the repair material.
- Apply appropriate passivating coat over the reinforcement and bond coat over the prepared RCC surface. Shot crete the RCC member within the tacking period of bond coat. If necessary, RCC jacketing can be adopted using self-compacting concrete.
- Apply 6mm thick finishing coat with cement sand plaster 1:3 (1 cement: 3 fine sand) within 48 hours of application of shot crete.
- Wet curing shall be done over the finished surface of the shot Crete for a minimum period of 7 days.
- After RCC column /beams are cured and completely dry, a suitable protective coat shall be applied over them for protecting the reinforcement and concrete against carbonation attack.

Repairing Of Damaged Slabs Where Carbonation Depth Has Reached Reinforcement Level – Repairing With Polymer Modified Cement Mortar (For Small Areas)

- Prop and support the RCC slab under distress.
- Remove all loose and spalled cover concrete including finishing plaster (detected to be loose by tapping).
- Clean the rusted reinforcement of concrete preferably by using sand blasting to obtain a minimum 15mm clear air gap all around including behind the reinforcement.

- Provide additional reinforcement where necessary and tie the same to the existing reinforcement with necessary binding wire and nails / overlapping / anchoring.
- Fix shear keys of appropriate diameter at specified spacing in both directions over the surface to be covered with the repair material.
- Clean the reinforcement of rust using alkaline chemical rust remover with paintbrush. Apply appropriate passivating coat over the prepared surface.
- The prepared concrete surface shall be covered with appropriate mix of polymer modified cement mortar in layers including behind the reinforcement over the bond coat of polymer modified cement slurry. The mortar cover thickness shall be not less than 15mm over the reinforcement. The maximum thickness shall be not more than 30mm with each layer not exceeding 10mm.
- Wet curing shall be carried out for a minimum period of 7 days.

Repairing Of Damaged Slabs Where Carbonation Depth Has Reached Reinforcement Level – Repairing With Shot crete (For Large Areas)

- Prop and support the RCC slab under distress.
- Remove all loose and spalled cover concrete including finishing plaster (detected to be loose by tapping).
- Clean the rusted reinforcement of concrete preferably by using sand blasting to obtain a minimum 15mm clear air gap all around including behind the reinforcement.
- Provide additional reinforcement wherever necessary and tie the same to the existing reinforcement with necessary binding wire and nails / overlapping / anchoring.
- Fix shear keys of appropriate diameter at specified spacing in both directions over the surface to be covered with the repair material.
- Clean the reinforcement of rust by using alkaline chemical rust remover with paintbrush. Apply appropriate passivating coat over the RCC surface.
- Apply shotcrete with average thickness of 50mm over the prepared surface of concrete within the tacking period of epoxy bond coat.
- Finishing plaster, If necessary, may be provided within 48 hours of shotcreting without allowing the RCC slab to become dry during the intervening period.
- Water curing shall be carried out for a minimum period of 7 days.

6.4 RCC Jacketing

Reinforced concrete jacketing increases the member size significantly. This has the advantage of increasing the member stiffness and is useful where deformations are to be controlled. If columns in a building are found to be slender, RC jacketing provides a better solution for avoiding buckling problems. Design for strengthening/repair work is based on composite action between the old and the new work. Strain compatibility calculations may have to be carried out carefully giving due account to factors such as creep. As the new jacket is to behave compositely with the parent member, the new jacket can take additional loads only with the increase in the stresses & strains in the old one. The problem arises if the;

- Old concrete has reached limiting strain and is not likely to sustain any more significant strain
- Old concrete is weak and porous and started deteriorating due to weathering action and corrosion of reinforcement.

The question then arises as to whether the composite action should be abandoned and the new jacket (plate or RC) designed to carry the entire load. It is perhaps best to design the strengthening in this manner, but detailing must be right to ensure transfer of load to the new jacket, if the old concrete fails. It is however, necessary to ensure perfect bond also between the

old and new concrete by providing shear keys and effective bond coat with the use of epoxy or polymer modified cement slurry giving strength not less than that of new concrete.
Plate bonding and RC jacketing are the common methods of strengthening RCC structures (detail procedure and stages given in Fig 6.8). The cost difference between the two methods is not significant. A choice has to be made between the two methods based on actual needs and the suitability of each method with respect to the structural /architectural and other details of buildings.

Propping and Supporting:
Problem arises in deciding on propping and supporting the structure to give relief in stresses and strains in some of the existing weak members being strengthened. Mere vertical props sitting on some beams & slabs may not be enough.

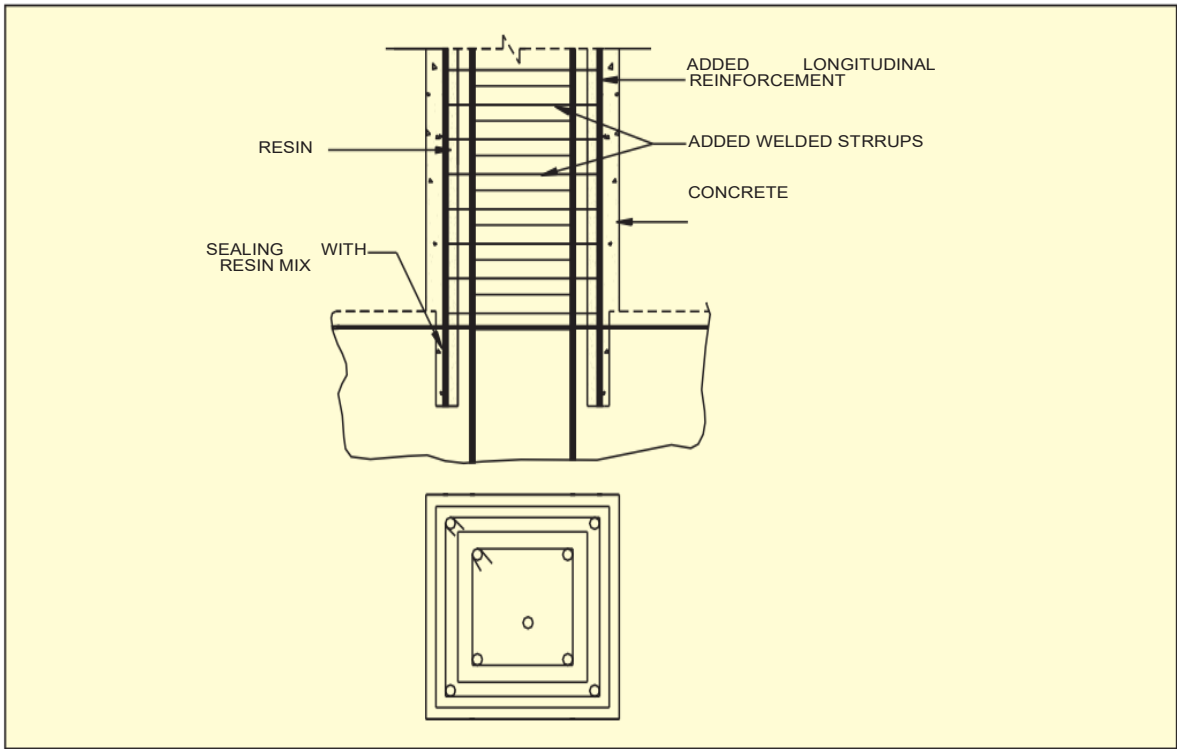


FIG.181: Column Strengthening Concrete Jacket

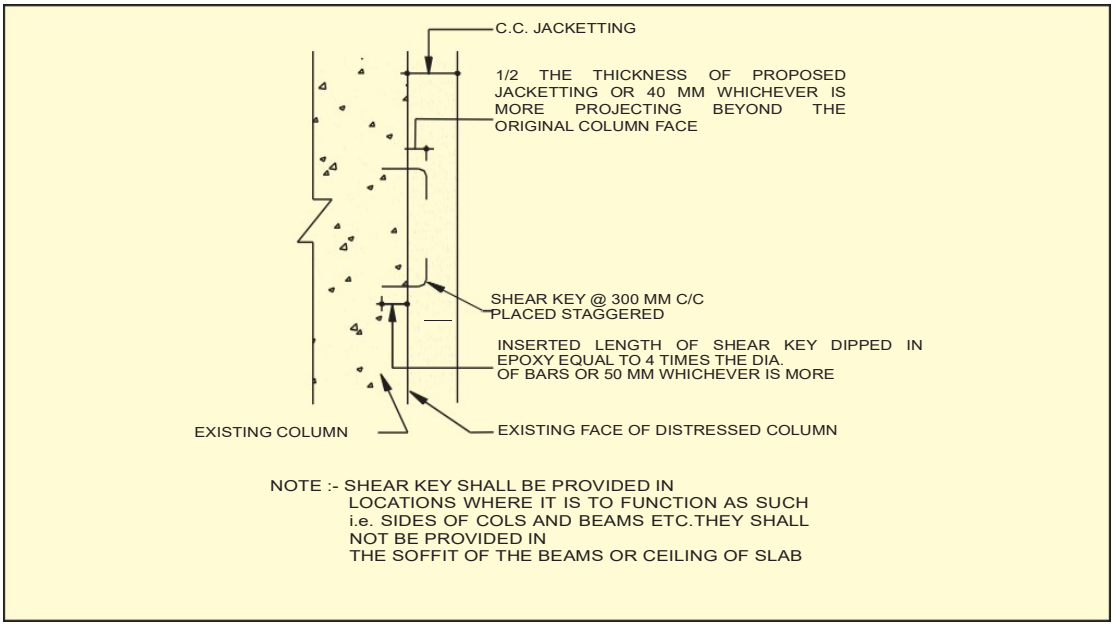


FIG.182: Details of Shear Key Bars

Diagonal bracing to transmit the loads to the adjacent columns should also be considered.

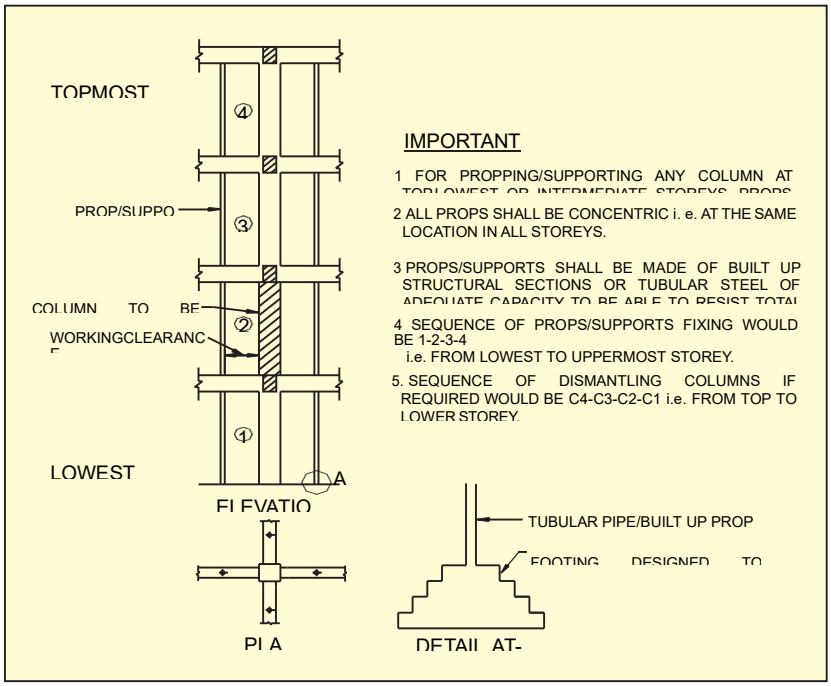


FIG.183: Typical Arrangement for Propping & Supporting a Column to relieve at Form Load

6.5 Shotcrete

Shotcrete is defined as pneumatically applied concrete or mortar placed directly on to a surface. The shotcrete shall be placed by either the dry mix or wet mix process.
The dry mix process (Fig 6.5) shall consist of

- Thoroughly mixing the dry materials,
- Feeding of these materials into mechanical feeder or gun,
- Carrying the materials by compressed air through a hose to a special nozzle,
- Introducing water at nozzle point and intimately mixing it with other ingredients at the nozzle.
- Jetting the mixture from the nozzle at high velocity on to the surface to receive the shotcrete.

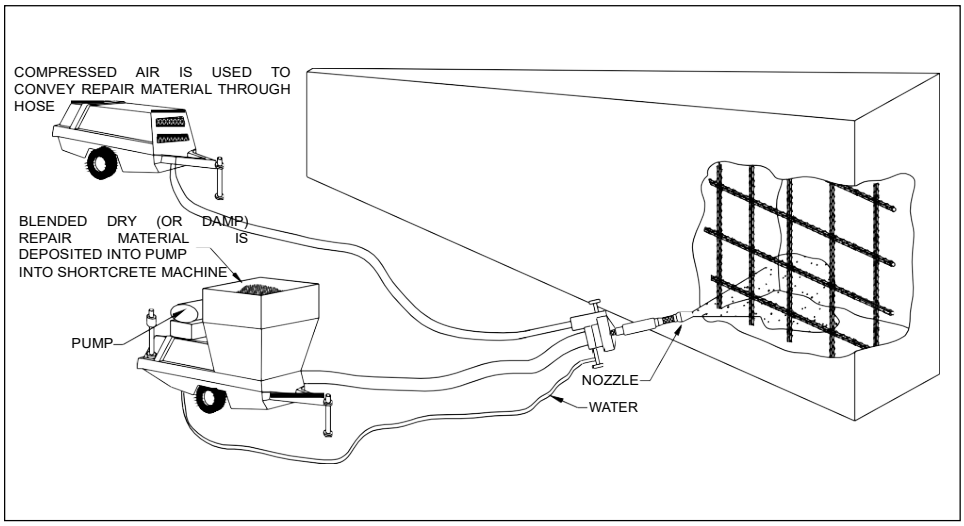


FIG.184: Dry Mix Shortcrete

The wet-mix process (Fig 6.6) shall consist of

- Thoroughly mixing all the ingredients with the exception of the accelerating admixture, if used;
- Feeding the mixture into the delivery equipment;
- Delivering the mixture by positive displacement or compressed air to the nozzle;
- Jetting the mixture from the nozzle at high velocity on to the surface to receive the shotcrete.

If specified, fibres of steel, poly propylene or other material, as may be specified, could also be used together with the admixtures to modify the structural properties of the concrete/mortar being placed in position.

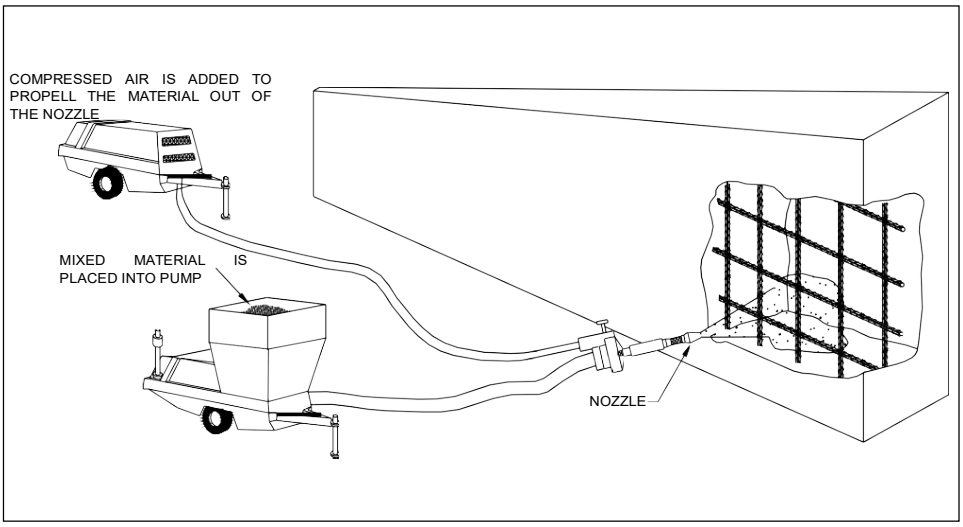


FIG.185 Wet Mix Shortcrete

6.6 Foundation Rehabilitation Methods:

The methods to repair and rehabilitate a structure having foundation distress generally involve shoring & underpinning work for structures that are out of plumb, or are sensitive to effects of small settlement etc.

A. Shoring: Before any shoring work is commenced, the building should be carefully surveyed & record of levels, cracks & tilts kept. The observations should be continued throughout the period of shoring & under pinning and till the time when detectable measurements have ceased. The terminology used is:

1. Raking shores with the angle of shores generally 60o to 75o are usually used where external support is necessary. In case, the feet of raking shores are to be kept free, then flying shores can be provided which strut against another structure or wall.
2. Flying shores merely provide a restraint against building or tilting.
3. Dead shores are verified struts bearing on the ground at the required distance & supporting the vertical load of a wall wherever required in conjunction with flying shores or horizontal ties.

The level of raking shores & flying shores are so arranged as to bear on the wall at floor or ground with a firm bearing. Folding wedges should be inserted at the foot of shores to take up yielding if any, of the ground & elastic shortening of the struts. Columns can be shored up individually by needle beams. The needle system has to be properly designed to suite the particular requirements. Suitable placing of jacks for exerting upward pressure can also be planned & designed.

B. Underpinning: If underpinning is necessary to arrest settlement, it is essential that the underpinned foundation should meet the requirements of correct allowable bearing pressures. Depending on the cause of settlement, shallow underpinning may be satisfactory in some cases, whereas in some cases the underpinning has to be taken down to a deeper & relatively incompressible stratum. Underpinning material are metals in case of comparatively shallow underpinning? Underpinning by piles or piers is suitable, only if the new bearing stratum is deep.

- Underpinning piles are normally provided in pairs, one on each side of the load bearing walls or in groups around the sides of columns.
- Micro-piles are a useful means of underpinning. They can be installed from the ground

surface without deep excavation and the equipment in installing the piles is suitable for working in confined spaces. The rotary drilling results in less damage & loss of ground, as compared to the percussion method.

- Proprietary jacked piles with pre-cast segments are another means of underpinning. In the proprietary 'pretest' methods of underpinning the underlying ground is preloaded before the load of the structure is finally transferred by means of jacking between the tilted existing structure & the new underpinning. There are various patented systems of jacking, involving interconnection of jacks with centralized pumping plant etc.
- Underpinning by injection of the ground with cement or chemicals to fill voids or to permeate and strengthen the ground is sometimes used. Various forms of grout can be introduced into granular soils or cavernous rock formations to increase their strength to reduce their compressibility grouts, however, cannot be induced to permeate clays or clayey silts, though by means of high injection pressure and using closely spaced points the "hydro- fracture" technique can be used to uplift the mass of clay or self & thereby provide a means of raising a structure. However, it may be worthwhile in many cases to take the foundation down to a deeper & more incompressible stratum say by piles rather than try to compensate & stop the settlement by grouting.

At the end, it is worthwhile bearing in mind that a foundation is not an entirely nor an end in itself. The ability to discern differences in type of framing etc. , is also an essential attribute of an expert investigator. In certain, cases, the results of fresh site investigates would indicate that the settlement may continue but at a deceasing rate. In that case, a possible solution could be to keep on monitoring and when the rate of settlement has decreased sufficiently, the building could simply be "patched up".

It is worth noting that damage investigations include both the design & operation (or lifetime usage) assessment, which involve "looking backwards in time" as are time dependent. As stated earlier the concept of time scale is important. In any case, for a good & effective damage investigation, proper causation statement are essential. They need to cover information about the damages, technical details, facts about what & when precise explanation of the causes of damages etc. causation is about opinion & fact meshed together so that they explain what happened. There must be clarity and it must be based on evidence. This will then load to the appropriate repair & rehabilitation strategy, always bearing in mind that foundation is not an isolated entity but a part of the structure as a whole.

6.7 COLUMN REPAIR: -

A. The columns require immediate strengthening, the system of repair to be followed is as under: -
   - Firstly, all the columns are to be injection grouted as per procedure explained.
   - Columns from foundation level to stilt roof level to be jacketed as per procedure/ drawing given hereafter.

After stilt roof level to terrace it is not practically/ economically not feasible to do the jacketing hence it is recommended that the columns to be repaired as per procedure given hereunder.

- All the loose concrete wherever cracks are seen to be removed up to reinforcement only. Please note that don't remove the concrete beyond the cover of reinforcement.
- Then Injection grouting to be done.
- The exposed reinforcement to be treated chemically to remove the rusting.
- All the reinforcement main or transverse/ stirrups to be replaced with new

reinforcement wherever required.
- After this micro concrete of grade M60 to be applied on the surface to maintain the cover.
- Finally, a coat of finishing plaster to be applied.
- When the jacketing will be done the foundation will get exposed at that time repair to foundation should be done as per instructions issued by the structure engineer supervising the work.

6.8 BEAM REPAIR: -

B. The beams require immediate strengthening, the system of repair to be followed is as under: -
- Firstly, all the beams are to be injection grouted as per procedure explained.
- All the loose concrete wherever cracks are seen to be removed up to reinforcement only. Please note that don't remove the concrete beyond the cover of reinforcement.
- Then Injection grouting to be done.
- The exposed reinforcement to be treated chemically to remove the rusting.
- All the reinforcement main or transverse/ stirrups to be replaced with new reinforcement wherever required.
- After this micro concrete of grade M60 to be applied on the surface to maintain the cover.
- Finally, a coat of finishing plaster to be applied.

6.9 SLAB:

All the slabs which are cracked and Spalling has taken place to be shortcreted as explained in charter no: 8, clause 8.11 and as explained hereunder: -

a. Remove the loose plaster and concrete by exposing the reinforcement.
b. Treat the corroded reinforcement by chemical/ replacing the reinforcement as per requirement.
c. Use method of short creting/ Guniting to recover the reinforcement and creating a cover to reinforcement.
d. Apply plaster on the treated surface.
e. Please ensure safety of structure by erecting proper support.

6.10 The method of repair where RCC work is meeting brick work and crack has appeared due to this, method for repair is explained as under:-

a. The plaster to be demolished.
b. The surface to be cleaned with wire brush and all loose concrete/ mortar to be removed.
c. Wires mesh (Chicken Mesh/ Murga Jalli) of appropriate size to be fixed.
d. Then plastering to be done with cement mortar 1:4 mixed with non-shrinking compound.

6.11 The sunken slabs/ slabs of toilet are to be repaired by water proofing. The process is as under :-

a. The sunken portion to be dug up.
b. Cleaned by removing all the mulba
c. Water proofing to be done as per DSR 2018 item no: 14.82.
d. The back filling to be done with light weight cement blocks.
e. All the pipes i.e. SWP, WWP, water supply pipes etc. To be changed/ repaired as required.
f. The bottom of toilet slabs to be repaired using shortcrete method as described in this chapter before.

8.0 GENERAL NOTES

1. The repair work to be taken up immediately.
2. One column at a time to be repaired by erecting proper support to the structure.
3. One beam at a time to be repaired by erecting proper support to the structure.
4. All loose material to be removed.
5. All work to be cured for minimum seven days before covering up.
6. All safety measures as required before, during and after the construction to be taken.
7. It is suggested/ recommended that the work to be executed under the supervision of a qualified site structure engineer.

8. The design of repair/ strengthening/ structure/ checking of design of existing structure to be got done by a qualified design structure engineer and duly checked/ vetted by another agency.

9. Maximum care is taken in preparing this report but there are chances that at the time of execution of work some hidden items/ things will come into light which are not covered in this report as when the structure will be opened then at that time some deviations may appear, It is suggested that the structure engineer who is supervising the work should take due care of those hidden items and if required may contact us for clarification/ remedy.

10. Structure audit must be repeated as per the frequency given above or as in National Building Code of India.

11. **Whenever in doubt do not guess contact us.**

Disclaimer

This report is intended for the sole purpose of presenting the results of investigation required by the client. The conclusions and inferences if any; presented in the report reflect the general opinion of our experts based on findings of the investigations. This report under any circumstances shall not be used for legal or other purposes by anyone, either in person or as an entity. The auditor under any circumstances will not be held liable for any direct or indirect damage or dispute that culminates based on this report. Testing samples quantity is as per client and accordingly sample taken and tested and based on the quantity of sample test results are obtained and interpretation is done and these samples are considered as the mirror of the whole structure.

VALIDITY OF REPORT: As per National building code of India.