1. INTRODUCTION

1.1 General

Reinforced concrete structures after being exposed to fire losses their strength and durability. Thermal load results in micro-structural alterations that modify the concrete behavior (Nechnech et al, 2001). According to Hertz (2004), when the concrete temperature rises, the water inside the concrete thyrotrophic structure evaporates. This evaporation leads to pressure increase inside the concrete. When the temperature becomes close to 1500C the water in the hydrated calcium silicates, is freed. At 3000C the gravel expands and the binding cementations material shrinks. Between 4500C and 6100C, the calcium hydroxide breaks down into calcium oxide and water. This leads to development of more water vapor and further pressure. High pressure may lead to cracking and concrete spalling. Therefore, It is extremely important to map the damage caused by fire exposure to assess the serviceability of a fire exposed building.

Nondestructive testing is the simple and easy way to assess that. Elevated temperatures deteriorate the microstructure of concrete and degrade its integral strength and therefore, such an assessment is relevant with UPV and other NDT methods. Non-destructive testing (NDT) methods were employed to assess the residual durability properties and residual mechanical properties of the damaged structures. Single NDT method alone is not sufficient and reliable enough to predict structural health and integrity of reinforced concrete on fire damaged structures. Health assessment of concrete must be carried out by combination of non-destructive techniques.

Government of Maharashtra has made "Structural Audit" of all old building compulsory as per the amendment to MMC ACT 1888 incorporating a new section 353 B enforcing from 13/2/2009. As per by-laws of Co-operative Housing society and clause no 77. Structural Audit is mandatory for all housing society buildings as per corporation directive and as follows:-

Age of the Building	Structural Audit (Compulsory)
15 to 30 years	Once in 5 years
Above 30 years	Once in 3 years

Table No. 1.1 Structural audit for age of building

Nowadays, there is a demand of NDT method for old structures with repairs and retrofitting to enhance its performance and restore the required strength of the structures which may lead to an increase in its functional life. As time passes, structures become older, we find certain degradation or deterioration in structure with resultant distress showed in the form of cracking, splitting, delaminating, corrosion, voids, honeycombing, etc. Such weakened structures can be restored and retrofitted by utilizing different kinds of admixtures and modern repair techniques. NDT method would not only locate a defect, but it would also be used to measure strength, durability and overall quality of concrete. NDT method is handy in monitoring long-term changes in concrete properties from which an estimate of strength, durability and elastic behavior of material are obtained. The condition and behavior of the structural system depend on its quality of maintenance as a building grows old, aging, use or misuse and exposure to the environment can greatly affect the health of the structure.

Types of tests Performed:

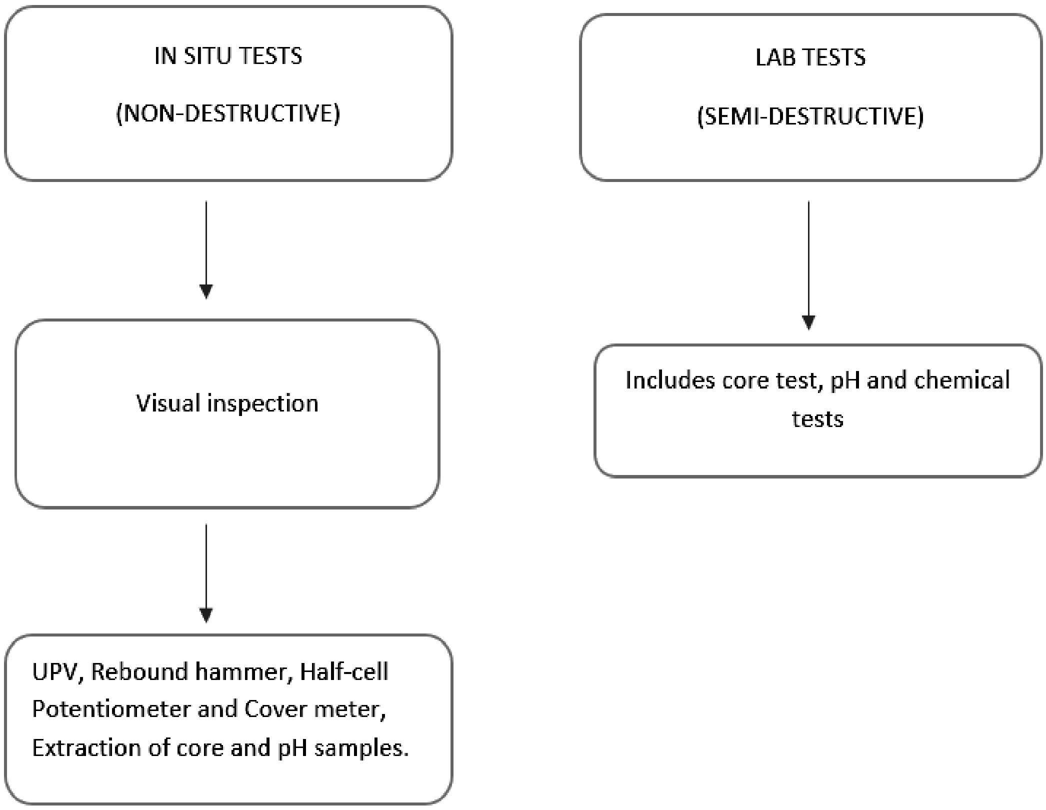


Figure No. 1.1 Type of Test Performed

1.2 OBJECTIVES

- Identifying the various Non-Destructive Testing carried out on structure/building
- To assess the condition of building.
- Highlight the critical areas that need to be attended with immediate effect..
- To comply with Municipal or any statutory requirements.
- To identify any signs of material deterioration and critical areas to repair immediately
- To enhance life cycle of building by suggesting preventive and corrective measure like repairs.
- To check the strength after strengthening.

2. LITERATURE REVIEW

2.1 Overview

The Chapter two presents a critical appraisal of the previous work published in the literature. Some papers are thoroughly analysed for Non-Destructive tests applied on different types of buildings.

2.2 Review of Technical Papers.

1. **Assessing concrete strength in fire-damaged structures**
   Julia Wroblewska, Robert Kowalski
   This paper presents a review of concrete assessment methods: laboratory and in situ (non-destructive and semi-destructive tests) in application to reinforced concrete structures after fire. One of the most important phenomena affecting the load-bearing capacity of these structures is the reduction in concrete strength at high temperature and after cooling. Traditional test methods, commonly used in normal conditions (e.g. destructive test on core specimens), usually do not take into account the non-uniformity of concrete after a fire. Therefore, other methods are proposed to determine the depth of the damaged concrete in the external layers of a given structural member.

2. **A case study on fire damage assessment of a two-story building with precast pretensioned hollow core slabs**
   Mazen Ali Musmar
   The study comprises conducting a structural assessment of a two-story building operated as a textile factory. The floor slabs are composed of pre-tensioned precast hollow core slab units . The slab units are assembled side by side to make up the floor slabs. The remaining structural elements of the building are of reinforced concrete. The work involved assessment of the damage using various tools such as on-site inspection for a preliminary evaluation of the construction and the assessment of the severity of fire attack. Then field and laboratory testing were carried out to estimate the amount of damage. The study encompasses proposing appropriate repair methods or to decide whether the demolition of elements or the whole structure is more appropriate. Based on the carried out study, it was concluded that the demolition of the structure is more convenient.

3. Experimental fast-assessment of post-fire residual strength of reinforced concrete frame buildings based on non-destructive tests.

Luis López, Pablo Alcaíno, Hernán Santa-María, Carolina Magna-Verdugo

Assessment of the residual strength of reinforced concrete buildings subjected to fire is a problem that requires fast and sufficiently reliable resolution, necessary for the action of firefighters, forensic fire investigation, and structural assessment of post-fire condition of the building to take place. In all cases safety and integrity of firefighters and researchers can be at risk, and it is necessary to have rapidly and sufficiently reliable information in order to choose whether to enter freely, to enter with caution, or simply do not enter to the burned structure. This required prompt assessment gives no time or background to develop mathematical models of the structure and damage propagation. This work presents an experimental methodology for a fast assessment of post-fire residual strength of reinforced concrete frame buildings based on the high correlation between the loss of strength and non-destructive test results of frame concrete elements subjected to fire action.

4. Evaluation of high-performance self-compacting concrete using alternative materials and exposed to elevated temperatures by non-destructive testing.

Mohammed Abed, Jorge de Brito

The present study quantitatively evaluates the residual density, compressive strength, flexural strength and ultrasonic pulse velocity (UPV) of high-performance self-compacting concrete (HPSCC) after exposure to elevated temperatures. The produced HPSCC is expectably an eco-efficient concrete since it is produced incorporating coarse recycled concrete aggregate and alternative waste materials as partial replacement of coarse natural aggregate and cement respectively. The waste materials are waste fly ash, perlite and cellular concrete powders. Tests of 21 HPSCC mixes were conducted to check the correlation between the relative residual UPV and other properties of concrete after exposure to elevated temperatures ranging from 20 ◦C to 800 ◦C. HPSCC, a potentially sustainable and fire-resistant concrete, has been evaluated after exposure to elevated temperatures, by observing changes in its density, mechanical properties, and UPV. The incorporation of RA as replacement of NA as well as alternative sustainable materials as CRMs not only increased its sustainability but also improved its performance after exposure to elevated temperatures.

5. **Non-destructive testing of fired tunnel walls: the Mont-Blanc Tunnel case study.**
Odile Abraham, Xavier DE 'Robert

The investigation of fired tunnel walls typically relies on visual inspection and a comprehensive study of core samples. Visual inspection is limited to surface diagnosis, while core samples only provide a detailed image of the damaged zone at a single point. In order to gain an extensive view of the entire depth of the damaged zone as well as specific material properties, both the seismic refraction method and ground penetrating radar investigation may be carried out. This feasibility study has shown that a zone classified moderately deteriorated is in fact more heavily damaged than that classified very deteriorated, a finding that can be explained both by the limit imposed on visual inspection and by the heterogeneity of concrete along the tunnel. Cores may be representative of very small areas, in which case non-destructive testing methods are able to effectively position them and then proceed with a good interpolation between them to produce a reliable diagnosis.

6. **New NDT techniques for the assessment of fire-damaged concrete structures**
Matteo Colombo, Roberto Felicetti

An extensive research programme has been performed at Politecnico di Milano in order to identify quick and easy methods for the assessment of the thermal damage undergone by reinforced concrete structures in consequence of a fire. As a result, three new investigation techniques have been proposed, which allow to assess the whole thermal damage profile in one single test: a simplified interpretation technique for the indirect Ultrasonic Pulse Velocity (UPV) method (based on the refraction of longitudinal waves), an affordable approach to concrete colorimetry and the real-time monitoring of the drilling resistance. In this paper, the pros and cons of the proposed techniques are pointed out, as revealed by laboratory tests. The actual in situ viability of each method is then discussed, after the investigations conducted on two full-scale structures: a precast R/C industrial building surviving a real fire and a concrete tunnel submitted to a series of hydrocarbon-pool fire tests.

7. **Assessment of damage and residual load bearing capacity of a concrete slab after fire: Applied reliability-based methodology**

   Tom Molkens, Ruben Van Coile, Thomas Gernay

   For most fires occurring in buildings with a concrete structural frame, the structural elements do not collapse during fire exposure, and further use of the building after fire may be possible. Fire can nevertheless result in a permanent loss of strength and thus a post-fire evaluation of the residual load bearing capacity has to be made to inform decisions on continued use and the need for structural repairs. In this paper a comprehensive methodology is presented for the assessment of the residual capacity of concrete structures after exposure to fire. The methodology is introduced through application to a real-life case study of an apartment fire with a focus on the end-span of the affected continuous concrete slab. It results in a reliability-based evaluation of the maximum allowable characteristic value for the imposed load on the slab. The presented methodology is useful to make informed decision about continued use of structures after a fire event.

8. **Forensic Investigation of Fire-affected Reinforced Concrete Buildings**

   Awoyera, P.O., Akinwumi, I.I., Ede, A.N., Olofinnade, M.O.

   This study focused on forensic investigation of fire-affected reinforced concrete buildings. Post-fire investigation was conducted on structural elements in fire-affected concrete buildings, in order to ascertain their in situ residual strengths and also to provide data for use in future assessment of fire-affected buildings. Rebound hammer and ultrasonic pulse velocity are two non-destructive tests apparatus used for this investigation. Average values of pulse velocity were fitted into an established model in order to estimate the probable temperature, which the buildings were subjected to. Tests were conducted on beams, columns and slabs in both the affected and the unaffected parts of the buildings. From the results, visual examination of the fire-affected buildings revealed changes in the colour of the concrete, delamination of plaster of slab and exposure of reinforcement for severe cases at various locations on the concrete members. In addition, there was notable reduction in the in situ strengths of the fire-affected structural members when compared with the unaffected members. It was deduced that concrete members subjected to temperatures above 6000C lost about 70 % of its strength.

9. A case study on the structural assessment of fire damaged building

M H Osman, N N Sarbini, I S Ibrahim, C K Ma, M Ismail, M F Mohd

This paper presents a case study on the structural assessment of building damaged by fire and discussed on the site investigations and test results prior to determine the existing condition of the building. The building was on fire for about one hour before it was extinguished. In order to ascertain the integrity of the building, a visual inspection was conducted for all elements (truss, beam, column and wall), followed by non-destructive, load and material tests. The load test was conducted to determine the ability of truss to resist service load, while the material test to determine the residual strength of the material. At the end of the investigation, a structural analysis was carried out to determine the new factor of safety by considering the residual strength. The highlighted was on the truss element due to steel behaviour that is hardly been predicted. Meanwhile, reinforced concrete elements (beam, column and wall) were found externally affected and caused its strength to be considered as sufficient for further used of building. The new factor of safety is equal to 2, considered as the minimum calculated value for the truss member. Therefore, this fire damaged building was found safe and can be used for further application.

10. A Review on Fire Impacts on Concrete Structures

Shoib Bashir Wani

Concrete has been used as a construction material due to its versatile behaviour. It exhibits a high degree of fire-resistance. The characteristic ability of concrete structures to combat one of the most devastating catastrophes can be attributed to its constituent materials which make it passive and have relatively poor thermal conductivity. However, concrete structures must be designed for fire outbreaks. The properties of concrete must be balanced against concerns about its fire resistance and susceptibility to spalling at elevated temperatures. In this paper, several reasons of structural failure and degradation of concrete due to fire have been summarized. Moreover, the effects of fire and different technology to improve fire resistance capacity of reinforced concrete have been described. Improve structural design methodology, testing for fire protection materials, technology and systems, changing building operations and maintenance functions while sustaining the modern technology and materials that constitute elements of the fire protection system must be introduced to reduce fire threat.

2.2.1 Summary

In this chapter brief review of various papers search is presented. The review has lead in framing the objectives of the project.

3. WORKDONE

3.1 Ultrasonic Pulse Velocity Test.

This test is done to assess the quality of concrete by ultrasonic pulse velocity method as per IS: 13311 (Part 1): 1992 and IS 516(Part 5/Sec 1) : 2018 The underlying principle of this test is The method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete being tested. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc.

Fig 3.1 Ultrasonic Pulse Velocities Test.

3.2 Schmidt Rebound Hammer test.

Rebound Hammer test is a Non-destructive testing method of concrete which provide a convenient and rapid indication of the compressive strength of the concrete. The rebound hammer is also called as Schmidt hammer that consist of a spring controlled mass that slides on a plunger within a tubular housing. The operation of rebound hammer is as When the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass with a constant energy is made to hit concrete surface to rebound back. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale. This measured value is designated as Rebound Number (rebound index). A concretewith low strength and low stiffness will absorb more energy to yield in a lower rebound value.

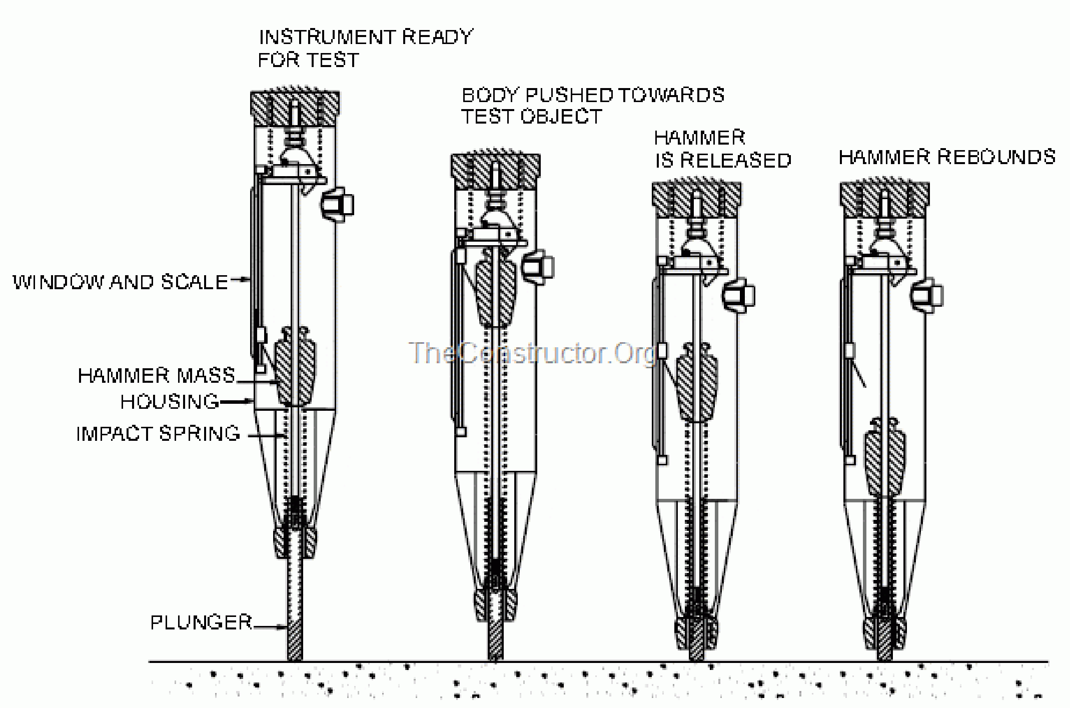


Fig 3.2 Schmidt Rebound Hammer Test.

3.3 Half-Cell Potentiometer test.

Corrosion is a natural process that occurs when a structure is exposed to elements like CO2 or chloride, which can penetrate the concrete all the way to the steel reinforcement. This can have serious durability and safety consequences, which is why it is important to monitor corrosion using an accurate and trusted method. The half-cell potential test is the only corrosion monitoring technique standardized in ASTM C876 – 15: Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete. It is used to determine the probability of corrosion within the rebar in reinforced concrete structures.

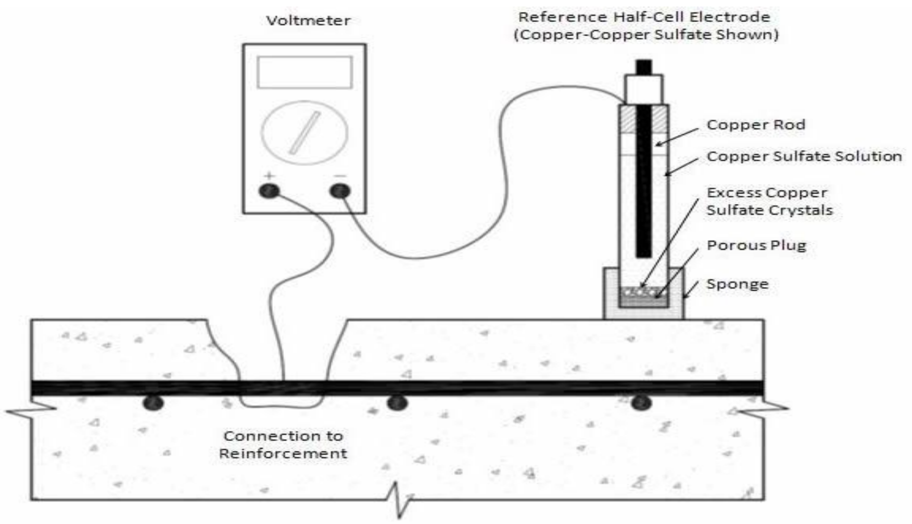


Fig 3.3 Half Cell Potentiometer test.

3.4 Ph Test and Chemical Test.

The reaction of concrete with carbon dioxide reduces the pH in the concrete. ... When phenolphthalein comes into contact with high pH (>10) concrete the solution shows as bright pink. When the solution comes into contact with low pH (<10) the solution shows no color change and the concrete can be considered carbonated.

3.5 Cover Meter test.

A cover meter is an instrument to locate rebars and measure the exact concrete cover. Rebar detectors are less sophisticated devices that can only locate metallic objects below the surface. Due to the cost-effective design, the pulse-induction method is one of the most commonly used solutions.

3.6 Extraction of Core.

This test is used to determine the compressive strength of a concrete core, which has usually been extracted from an existing structure. The value of compressive strength can then be used in conjunction with other measured properties to assess the condition of the concrete.

4. RESULTS

4.1 Overview

Preliminary analysis of three case studies with the help of Non-Destructive tests, STAAD pro analysis and their recommendation with its detailed design.

Case 1: Nitika Pharmaceuticals, a G+2 storied building damaged by extreme fire.

Case 2: Vyankatesh Udyog, a G+2 Storied building damaged by extreme fire,

Case 3: Nityanand Udyog, a G+2 storied building damaged by fire,

4.2 Preliminary analysis of the structures.

4.2.1 CASE 1: 'Nitika Pharmaceuticals'

The plan of the building () shown in the figure was taken to carry out the necessary Non-Destructive tests (NDT) to assess its condition whether to retain it or demolish with the help of the following data extracted with the help of NDT and STAAD pro analysis.

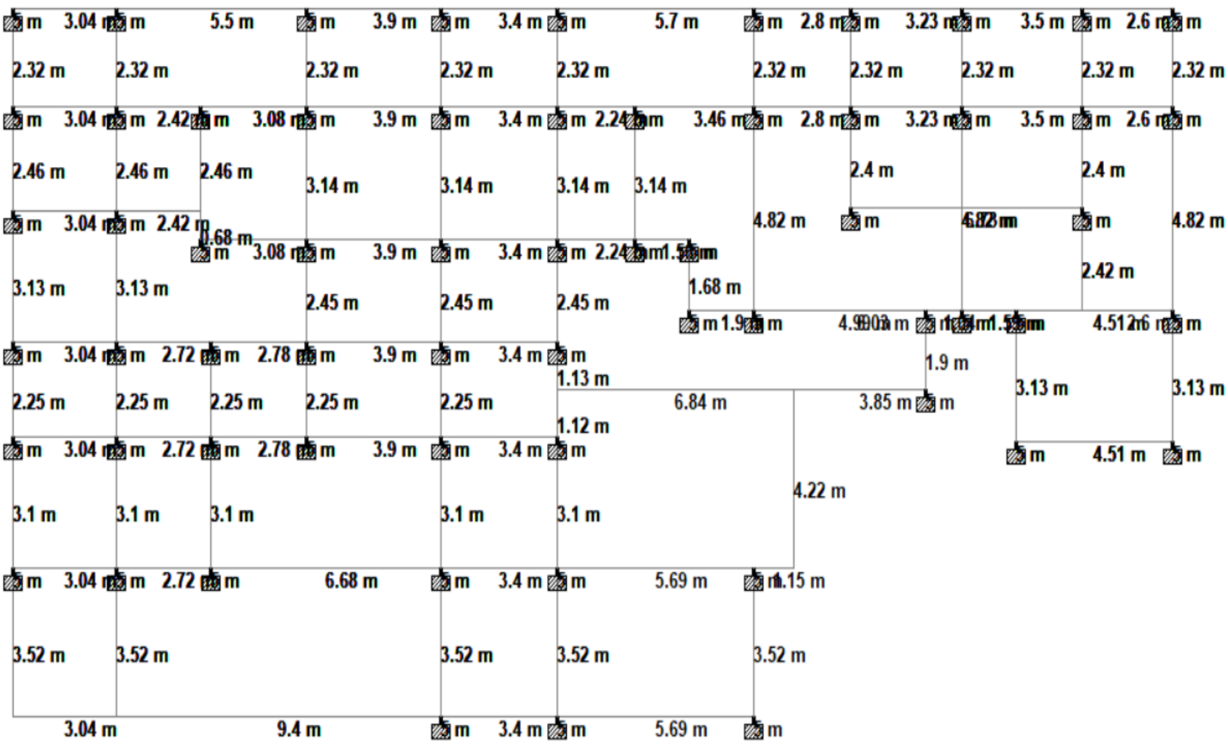


Figure No. 4.1 The plan of the building

NDT Results of Nitika Pharmaceuticals:

- Visual observation: It is observed that there is colour change, cracks, splitting, delamination, spalling, exposed reinforcement, porous concrete.

- Ultrasonic pulse velocity test:

As per IS 516(Part 5/Sec 1): 2018

U.P.V. (km/sec.)	Concrete Quality Grading
Above 4.40	Excellent
3.75 to 4.40	Good
3.00 to 3.75	Doubtful
Below 3 km/sec.	Poor

It is observed that the Ultrasonic Pulse velocity results with direct and indirect method indicate the maximum readings between 1.05 Km/Sec to 3.49 Km/Sec .IS 516(Part 5/Sec 1) : 2018 Hardened concrete - methods of test Part 5 Non -destructive testing of concrete section 1 Ultrasonic Pulse velocity testing (First Revision). The quality of concrete is poor at maximum locations and doubtful at few locations. As per IS 516 (Part 5) Sec 1: 2018 the Ultrasonic Pulse Velocity readings with indirect method gives less reading than direct methods generally by 0.5 km/sec and readings given in the report are factored.

- Schmidt rebound hammer:

As per the Rebound hammer test (refer IS 13311 part II 1992) maximum readings are confirming M10 to M20 grade concrete.

- Half-cell potentiometer test on reinforcement:

It is observed that the maximum reading are between -255 MV to -384 MV which indicates reinforcement is not intact and active corrosion of reinforcement is observed at maximum location.

Below -350MV	Corrosion Started

Between -350 to -650MV	Active Corrosion
Above -650MV	Corrosion above 60%

- Cover meter test:

As per the cover meter test the cover is within the acceptable limit (30mm to 40mm).

- pH and Carbonation test:

As per pH and carbonation test on concrete, it is observed that the pH of cover concrete is reduced and the passive layer over the reinforcement is not intact and the carbonation depth has crossed the reinforcement level at few locations.

- Core Tests:

1. UPV on Core: The readings are between 2.25 km/sec to 3.55km/sec IS 516 (Part 5) Sec 1:2018. The quality of concrete is doubtful at maximum and poor at few core samples.

2. Compressive strength of core samples: Some of the core samples got crushed during the extraction process and the probable compressive strength on remaining core samples are between M10 to M15 grade of concrete.

SAMPLE ULTRASONIC PULSE VELOCITY TEST RESULTS

SR. NO.	DESCRIPTION	PARTICULARS	TRANSIT TIME in Micro Seconds (T)	PATH LENGTH (L) (mm)	VELOCITY V=(L/T) (in KM/SEC)	FACTORED VALUE OF U.P.V. Km/Sec	REMARK
GROUND FLOOR							
1.	Column No :- A1	Indirect	162	200	1.23	1.23	Poor
		Indirect	152	200	1.32	1.32	Poor
		Indirect	133	200	1.50	1.50	Poor
		Indirect	141	200	1.42	1.42	Poor
		Indirect	139	200	1.44	1.44	Poor
2.	Column No:- B1	Direct	151	230	1.52	1.52	Poor
		Direct	126	230	1.83	1.83	Poor
		Direct	182	230	1.26	1.26	Poor
		Direct	186	230	1.24	1.24	Poor
		Direct	177	230	1.30	1.30	Poor

3.	Column No:- C1	Direct	192	230	1.20	1.20	Poor
		Direct	182	230	1.26	1.26	Poor
		Direct	172	230	1.34	1.34	Poor
		Direct	165	230	1.39	1.39	Poor

Table No. 4.1 Sample Ultrasonic Pulse Velocity Test Results

SAMPLE SCHMIDT REBOUND HAMMER TEST RESULTS

Sr. No.	Particulars	Rebound No.	Average	Probable Compressive Strength (N/mm^2)
GROUND FLOOR				
1.	Column No:-A1	20,22,24,18,20,18	20.33	10.0
2.	Column No:-B1	22,26,18,20,22,20	21.33	12.0
3.	Column No:-C1	20,18,20,24,22,22	21	12.0
4.	Column No:-C2	20,24,20,28,24	23.2	15.0
5.	Column No:-D1	22,24,20,20,22	21.6	14.0
6.	Column No:-C	22,24,20,22,20,18	21	12.0

7.	Column No:-B3	30,34,34,28,26	30.4	27.0
8.	Column No:-B4	20,32,20,30,24	25.2	19.0
9.	Column No:-A2	24,22,30,28,26	26	20.0

Table No. 4.2 Sample Schmidt Rebound Hammer Test Results

SAMPLE HALF CELL POTENTIOMETER TEST RESULTS

SR. NO.	PARTICULARS	**HALF CELL**
1.	Column No. C Ground floor	-289
		-277
		-301
		-256
		-255
		-268
		-294
		-355
2.	Column No. E1 Ground floor	-309
		-282
		-286
		-278
		-270
		-268
		-264
3.	Column No. C1 Ground floor	-284
		353
		-352
		-331
		-350
		-349
		-269
		-277
4.	Column No. D1 Ground floor	-334
		-333
		-296
		-331
		-279

		-327
		-325
		-264
		-323
		-268
		-321
5.	Column No.9 First floor	-386
		-297
		-295
		-394
		-381
		-376
		-375
		-374

Below -250 NO Corrosion, -250mv to -350mv Possibility of corrosion, Above -350 mv Active corrosion.

Table No. 4.3 Sample Half Cell Potentiometer Test Results

SAMPLE pH TEST AND CHEMICAL TEST RESULTS

SR. NO.	PARTICULARS	POTENTIAL MV		pH
		40mm	80mm	
NITIKA PHARMACEUTICAL SPECIALITIES PVT. LTD				
1.	Column No. C1 Ground floor	-117	-127	8.67 to 9.31
2.	Column No. C2 Ground floor	-120	-135	8.52 to 9.16
3.	Column No. B1 Ground floor	-137	-156	8.19 to 9.14
4.	Column No.B3 Ground floor	-156	-154	8.12 to 10.22
5.	Column No.A5 Ground floor	-158	-159	9.13 to 10.94
6.	Column No. A6 Ground floor	-159	-160	8.24 to 9.34
7.	Column No.A4 Ground floor	-164	-171	9.26 to 10.26
8.	Column No.F1 First floor	-165	-178	8.72 to 9.27
9.	Column No.G3 First floor	-153	-164	8.23 to 9.66
10.	Column No.F6 First floor	-139	-147	8.67 to 9.17
11.	Column No.F7 First floor	-146	-159	8.91 to 9.60

12.	Column No.F3 First floor	-136	-164	8.80 to 9.65
13.	Column No.G1 First floor	-146	-161	8.91 to 9.20
14.	Column No.F5 First floor	-161	-172	8.29 to 9.36
15.	Column No.N2 First floor	-153	-162	8.39 to 9.83

Table No. 4.4 Sample Ph Test and Chemical Test Results

SAMPLE COVER METER TEST RESULTS

SR. NO.	DESCRIPTION	COVER TO THE REINFORCEMENT IN (MM)
GROUND FLOOR		**DATE:17/09/2020**
1	Column No:-A1	42,39,33,38
2	Column No:-B1	57,39,33,38
3	Column No:-C1	46,49,51,53
4	Column No:-D1	53,59,47,41
5	Column No:-B4	51,56,47,55
6	Column No:-B5	59,61,65,56
7	Column No:-A3	51,49,43,61
8	Column No:-A6	59,63,49,43
9	Column No:-C3	61,63,77,48
10	Column No:-C4	39,43,51,56
11	Column No:-E	41,42,59,61
12	Column No:-B5	53,55,56,59

13	Column No:-B3	44,46,51,55
14	Beam:-01	36,43,49
15	Beam:-02	49,43,46

Table No. 4.5 Sample Cover Meter Test Results

SAMPLE ULTRASONIC PULSE VELOCITY TEST RESULTS ON CORE

SR. NO.	LOCATION OF CORE	METHOD OF TEST	TRANSIT TIME in Micro Seconds (T)	PATH LENGTH (L)(mm)	VELOCITY V=(L/T) (in km/sec)	FACTORED VALUE OF U.P.V. (km/sec)	QUALITY OF CONCRETE
NITIKA PHARMACEUTICAL SPECIALITIES PVT. LTD							
1.	First Floor Column F-7	Direct	36.7	120	3.27	3.27	Doubtful
		Direct	33.8	120	3.55	3.55	Doubtful
		Direct	34.2	120	3.51	3.51	Doubtful
2.	Ground Floor Column A-6	Direct	28.9	100	3.46	3.46	Doubtful
		Direct	34.3	100	2.92	2.92	Poor
		Direct	31.0	100	3.23	3.23	Doubtful
3.	Ground Floor Column B-3	Direct	29.3	100	3.41	3.41	Doubtful
		Direct	30.7	100	3.26	3.26	Doubtful
		Direct	33.3	100	3.00	3.00	Doubtful

4.	First Floor Column AA'	Direct	33.9	100	2.95	2.95	Poor
		Direct	32.9	100	3.04	3.04	Doubtful
		Direct	30.1	100	3.32	3.32	Doubtful

Table No. 4.6 Sample Ultrasonic Pulse Velocity Test Results On Core

CORE TEST RESULTS OF CONCRETE CORE SAMPLES

NAME: NITIKA PHARMACEUTICAL SPECIALITIES PVT. LTD ,AT PILI NADI SITE,NAGPUR

SR. NO.	Location Identification	Dimension of core		Wt. of Sample (Kg)	Cross Section Area (sq. mm)	Crushing Load (k/N)	Compressive Strength (N/mm²)	H/D Ratio	H/D Correction Factor	Compressive Strength (N/mm²) After apply H/D Correction	Corrected Compressive Strength (N/mm²) After apply diameter correction factor 1.08 as per SP 24:1983	Compressive Strength (N/mm²) After apply Equivalent Cube strength correction 5/4
		Dia (mm)	Length (mm)									
NITIKA PHARMACEUTICAL SPECIALITIES PVT. LTD												
1.	Ground Floor Column A-6	39.29	108.94	0.309	1212.91	10.40	8.57	2.773	1.000	8.57	9.26	11.57
2.	Ground Floor Column B-3	39.12	110.48	0.319	1202.23	8.90	7.40	2.824	1.000	7.40	7.99	9.99
3.	Ground Floor Column A-4	Core Crushed During Extraction Of Sample										
4.	First Floor Column AA	39.41	108.41	0.303	1220.13	9.70	7.95	2.751	1.000	7.95	8.59	10.74
5.	First Floor	39.66	113.77	0.327	1236.07	12.00	9.71	2.868	1.000	9.71	10.49	13.11

	Column F-7											
6.	First Floor Column G-1	Core Crushed During Extraction Of Sample										

Table No. 4.7 Core Test Results Of Concrete Core Samples

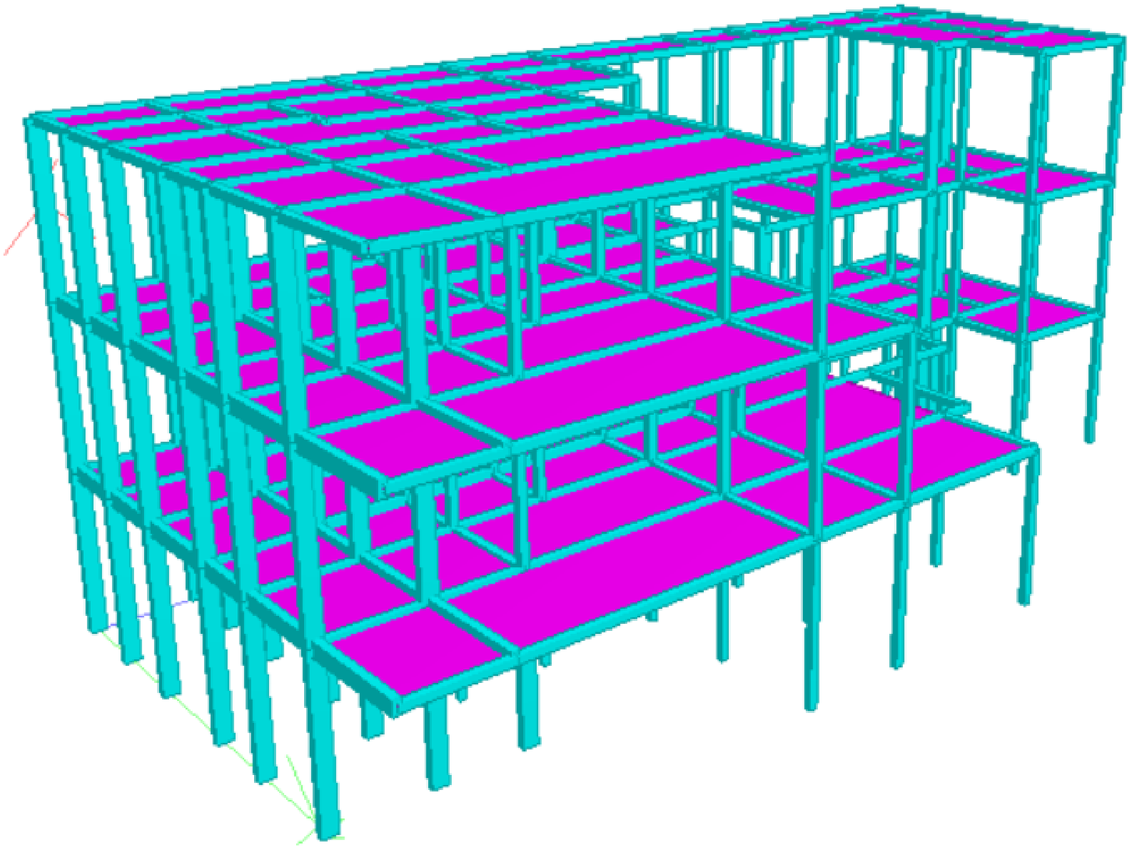


Figure No. 4.1 Design of column jacketing as per IS 15988:2013

- Recommendations:

Based upon all the Test results it is recommended to demolish some area and to repair damaged area as with the help of column jacketing for the strengthening of columns.

4.2.1.1 Design of column jacketing as per IS 15988:2013

- **Height of Column= 5 m, Width (b) = 230 mm, Depth (D) =460 mm, Ultimate Axial Load (P) = 1051 kN, Ultimate Moment (M) = 26.12 kN.m, original grade of concrete= 20N/mm2 Concrete grade by NDT=10 N/mm2, d'= effective cover = 50 mm., Reinforcement Provided: 8-12Ø = 904 mm2**

Solution:-

Due to corrosion area of reinforcement is reduces

For analysis purpose steel area is neglected

Pu = 0.4 x fck x Ac + 0.67 x fy x Asc

Pu = 0.4 x 10 x ((230x460)-(904)) + 0.67 x 415 x 0

Pu = 422.3 kN < 1051 kN …..…not safe

Load deficiency = 1051 – 422.3 = **628.7 kN**

Reinforcement required

d'/D = 50 / 460 = 0.108

P/fck bD = 628.7 x 103 / (10 x 230 x 460) = 0.594

M/ fck bD2 = 26 x 106 / (10 x 230 x 4602) = 0.053

Using the P – M interaction curve for rectangular section

According to the provisions provided in to 8.5.1.2 (a) of IS 15988: 2013, Concrete strength shall be at least 5 MPa greater than the strength of the existing concrete

P / fck = 0.02

% p = 0.02 x 25= 0.5%

Area of steel required = 0.5 % x 230 x 460 = 529 mm2

But as per IS 15988:2013 8.5.1.1 (e), Area of steel for jacketing = (4/3) As

= (4/3) x 517.5 = 705 mm2

But minimum steel for jacketing section= 0.8% of C/S Area of jacketed section

= 1410 mm2

Hence provide 12-12 Ø for jacketing section.

However, according to the code specified above, Minimum jacket thickness shall be 100 mm as per 8.5.1.2 (c) of IS 15988:2013

We are taking 150 mm thick jacketing section

Revised jacketed section of the column will be 530mm wide x 760mm deep

Design of literal Ties

As per 8.5.1.2 (e) of IS15988: 2013, Minimum diameter of ties shall be 8 mm and not less than one third of the longitudinal bar diameter.

Dia of bar = ¼ of Ø of largest longitudinal bar

= ¼ x 16 = 4mm …. take 8mm

Spacing of bar

Spacing of ties as per 8.5.1.1 (f) of IS 15988:2013- The code suggests that the spacing, s of ties to be provided in the jacket in order to avoid flexural shear failure of column and provide adequate confinement to the longitudinal steel along the jacket

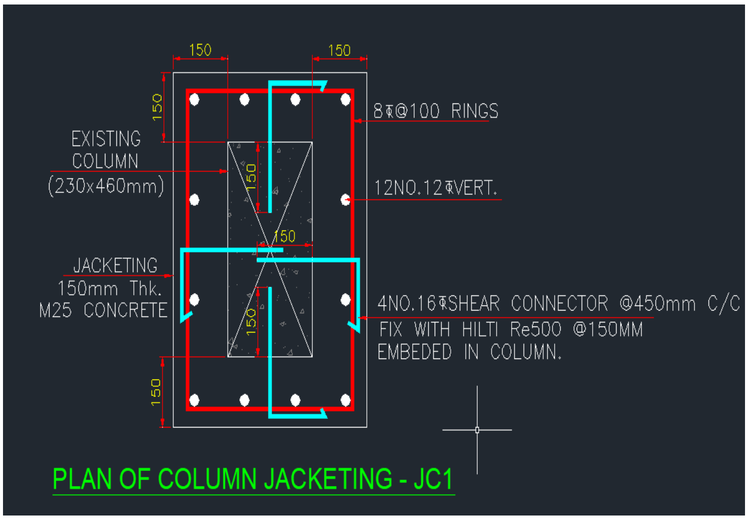
$\boldsymbol{s = \frac{Fy\ dh^2}{\sqrt{Fck}\ tj}}$ = 79.68 ……. Take 100mm C/C

Fy = Yield strength of steel = 415N/mm2

Fck = Cube strength of concrete = 25N/mm2

tj = thickness of jacket = 150mm

Provide 8mm Ø @100mm C/C



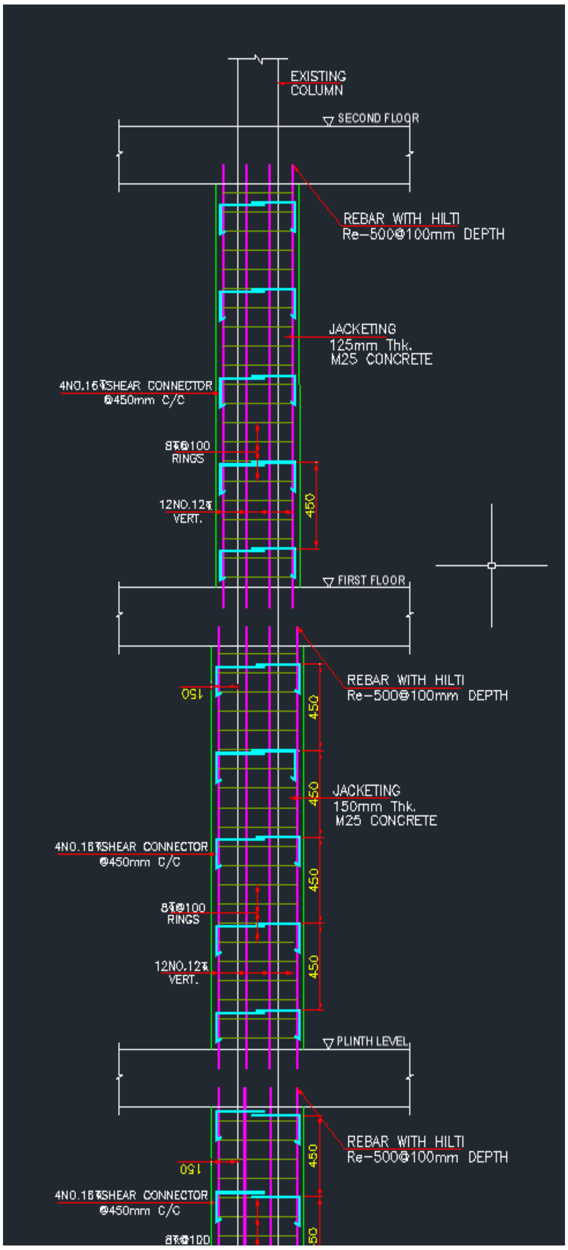


Figure No. 4.2 Plan of column jacketing JC1

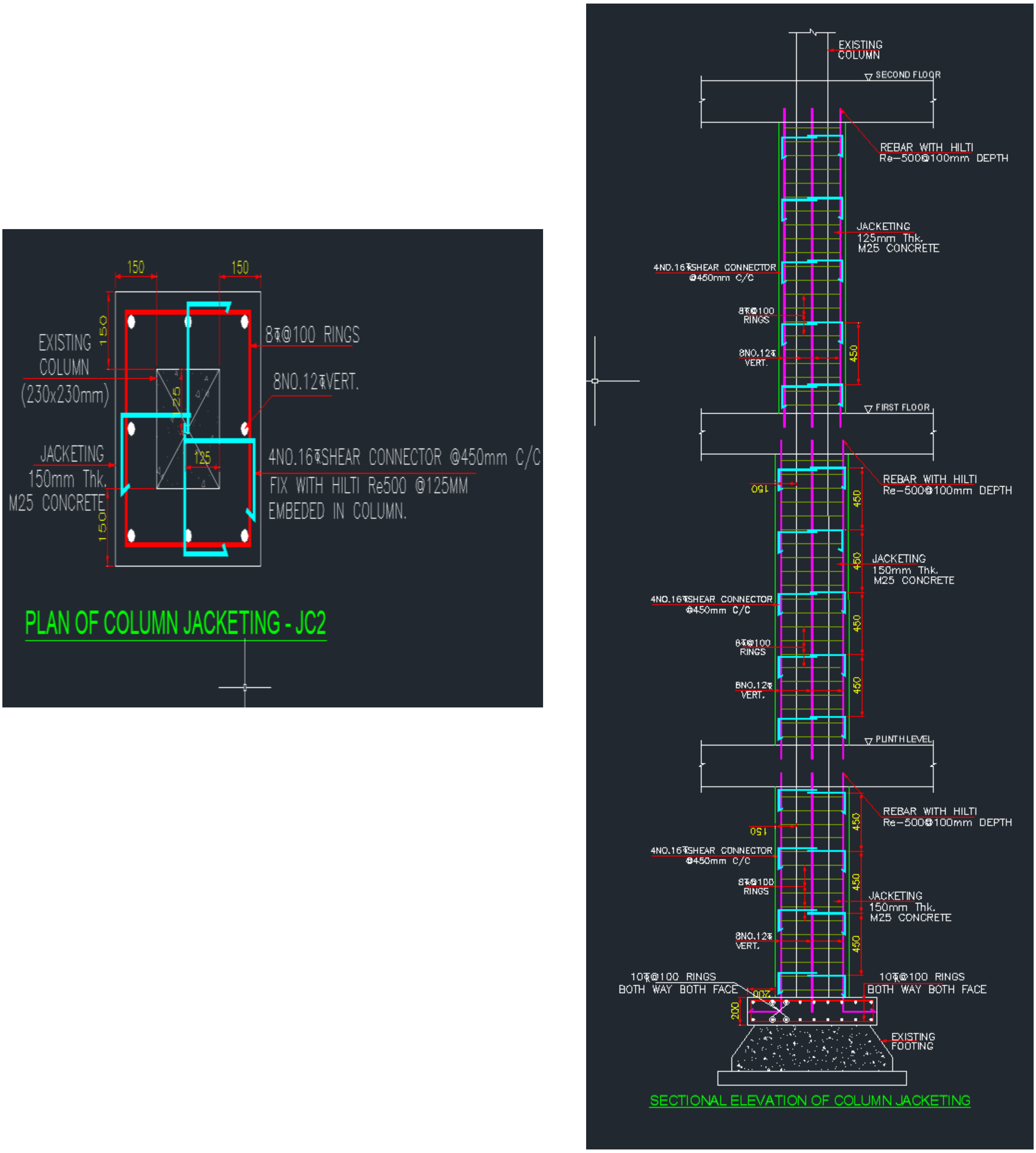


Figure No. 4.2 Plan of column jacketing JC2

COLUMN NO	MAX BM OF PRE-ANALYSIS (KN-m)	MAX BM OF POST-ANALYSIS (KN-m)	REDUCTION OR INCREMENT (%)
E	-76.442	11.8	< 84.56 %
D	-36.228	-6.9	< 80.96 %
C	-23.16	-5.06	< 78.16 %
B	-17.656	-2.2	< 87.54 %
E1	81.481	9.063	< 88.88 %
D1	-42.581	-5.668	< 86.69 %
C1	-21.342	4.748	> 21.748 %
B1	-17.314	-4.601	< 73.43 %
A1	-12.785	-4.12	< 67.78 %
E2	-4.343	11.401	> 262.51 %
C2	-4.656	5.807	< 124.72 %
B3	-15.739	9.642	> 163.23 %
B4	6.037	2.479	< 58.94 %
A2	-12.292	4.3	> 34.98 %
D4	-2.242	2.2	> 98.125 %
B5	11.331	4.198	< 62.96 %
C4	-4.77	1.91	> 40.041 %

Table no. 4.8 Comparison of pre and post strengthening analysis

4.2.2 CASE 2: 'Vyankatesh Udyog'

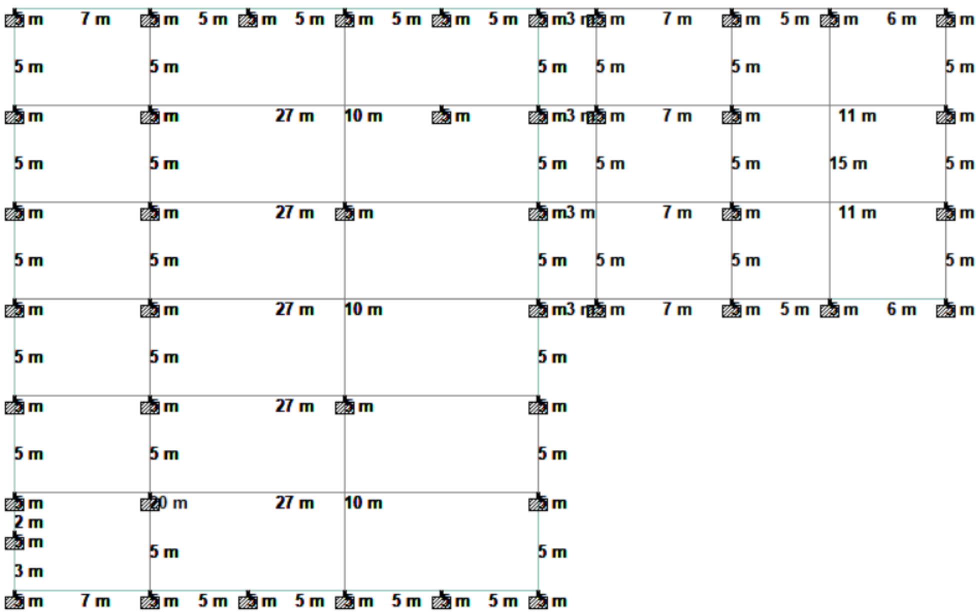


Figure no. 4.3CASE 2: 'Vyankatesh Udyog'

NDT results of vyankatesh udyog:

- Visual observation: It is observed that there is colour change, cracks, splitting, delamination, spalling, exposed reinforcement, porous concrete.
- Ultrasonic pulse velocity test:

As per IS 516(Part 5/Sec 1) : 2018

U.P.V. (km/sec.)	Concrete Quality Grading
Above 4.40	Excellent
3.75 to 4.40	Good
3.00 to 3.75	Doubtful
Below 3 km/sec.	Poor

It is observed that the Ultrasonic Pulse velocity results with direct and indirect method indicate the maximum readings between 3.69 Km/Sec to 0.52 Km/Sec .IS 516(Part 5/Sec 1) : 2018 Hardened concrete - methods of test Part 5 Non -destructive testing of concrete section 1 Ultrasonic Pulse velocity testing (First Revision). The quality of concrete is poor at maximum locations and doubtful at few locations. As per IS 516 (Part 5) Sec 1: 2018 the Ultrasonic Pulse Velocity readings with indirect method gives less reading than direct methods generally by 0.5 km/sec and readings given in the report are factored.

- Schmidt rebound hammer:

As per the Rebound hammer test (refer IS 13311 part II 1992) maximum readings are confirming M6 to M18 grade concrete.

- Core Tests:

1. UPV on Core: The readings are between 1.50 km/sec to 3.54km/sec IS 516 (Part 5) Sec 1:2018. The quality of concrete is poor and doubtful.

2. Compressive strength of core samples: Some of the core samples got crushed during the extraction process and the probable compressive strength on remaining core samples are between M9 to M23 grade of concrete.

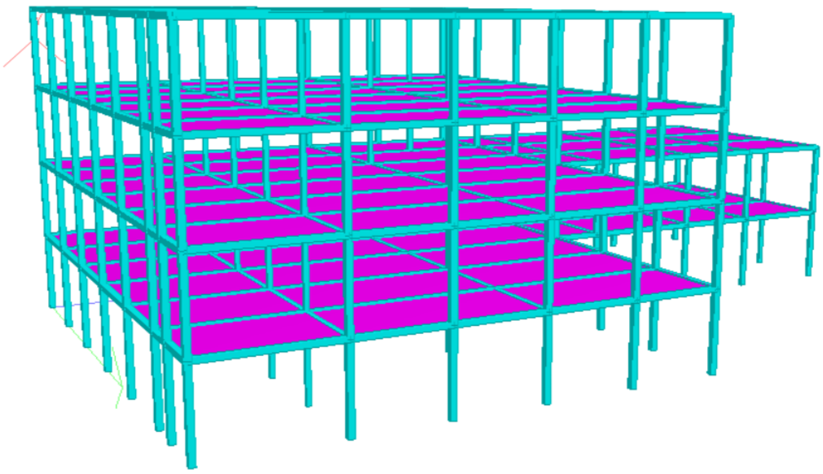


Figure No. 4.4 NDT Results of Vyankatesh Udyog

- Recommendation:

As per the non-destructive test results, visual observation and Analysis on STAAD pro it is observed that the existing structure is in dilapidated condition and beyond repair. Hence it is recommended to demolish the building as early as possible. Looking into condition of structure this building is unfit for occupation

4.2.3 CASE 3: 'Nityanand Udyog'

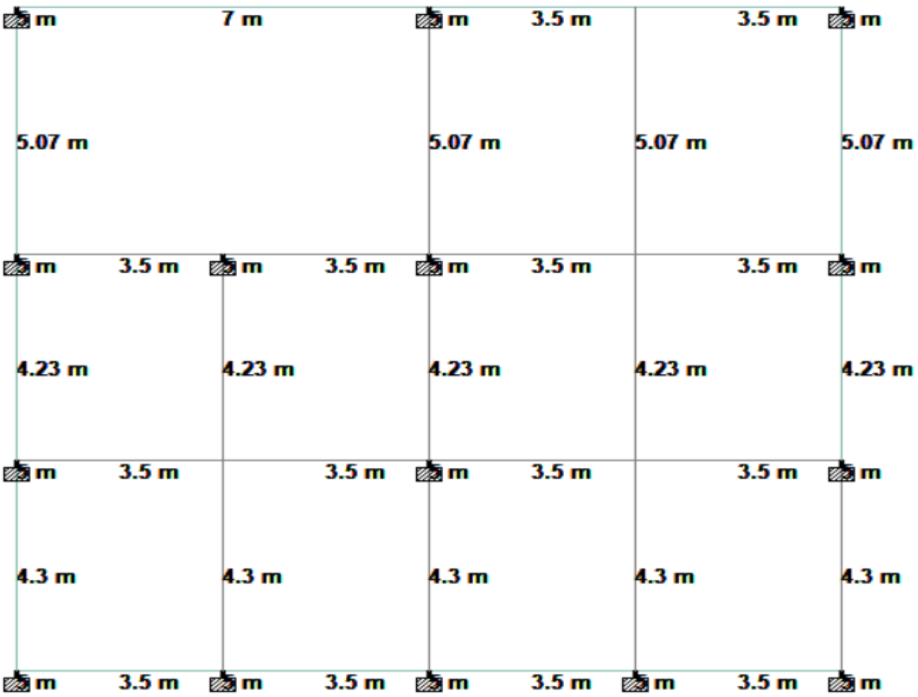


Figure No. 4.5 NDT results of Nityanand Udyog

NDT results of Nityanand Udyog:

- Visual observation: It is observed that there is colour change, cracks, splitting, delamination, spalling, exposed reinforcement, porous concrete.
- Ultrasonic pulse velocity test:

As per IS 13311(Part 1): 1992

U.P.V. (km/sec.)	Concrete Quality Grading
Above 4.40	Excellent
3.75 to 4.40	Good
3.00 to 3.75	Medium
Below 3 km/sec.	Doubtful

As per the non destructive testing carried out on above mentioned structure, it is observed that the ultrasonic pulse velocity results with direct and indirect methods indicates that out of total numbers of UPV 60 points, 11.66% readings are Excellent, 8.33% readings are Good, 3.33% readings are Medium and 76.66% readings are Doubtful. (Refer to IS 13311 (Part 1) 1992 "Non Destructive Testing of concrete methods of test, Ultrasonic Pulse Velocity" The readings are taken with indirect method and as per (Refer to IS 13311 (Part 1) 1992 indirect readings give less pulse velocity than direct method generally by 1.0 Km/sec. All the readings given in this report are factored.

- Schmidt rebound hammer:

As per the Rebound hammer test (refer IS 13311-part II 1992) maximum readings are confirming M14 to M18 grade concrete.

- Half-cell potentiometer test on reinforcement:

It is observed that the maximum reading are between -217 MV to -360 MV which indicates corrosion has started in the reinforcement and well within the acceptable limits.

Below -350MV	Corrosion Started
Between -350 to -650MV	Active Corrosion
Above -650MV	Corrosion above 60%

- pH and Carbonation test:

As per pH and carbonation test on concrete, it is observed that the pH of cover concrete is reduced and the passive layer over the reinforcement is not intact, pH of core concrete is well within the acceptable limits. The carbonation depth has crossed the reinforcement level at maximum locations.

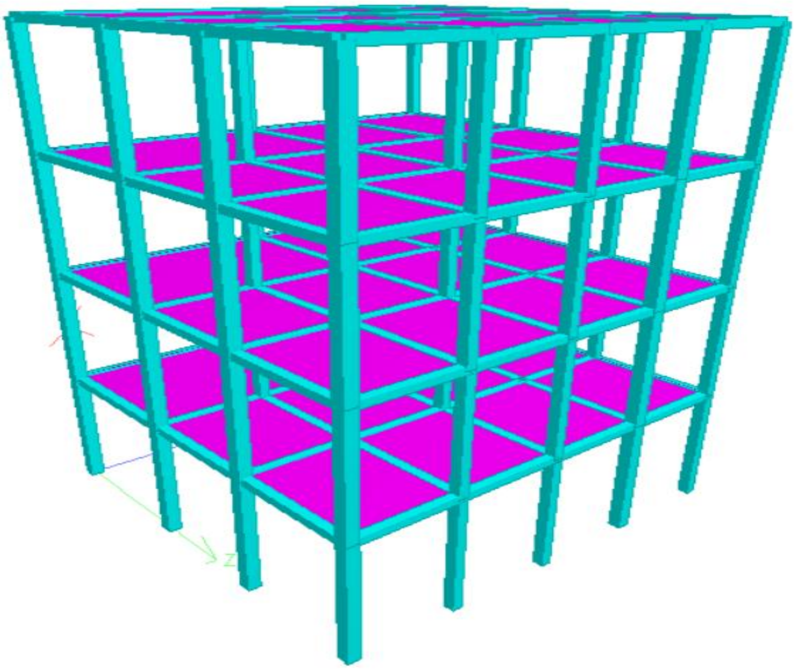
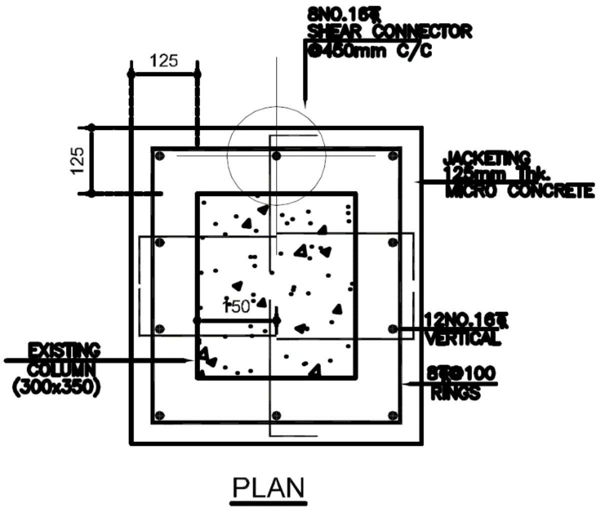


Figure No. 4.6 column jacketing for the strengthening of columns.

Recommendation:

Based upon all the Test results it is recommended to repair damaged area as with the help of column jacketing for the strengthening of columns.



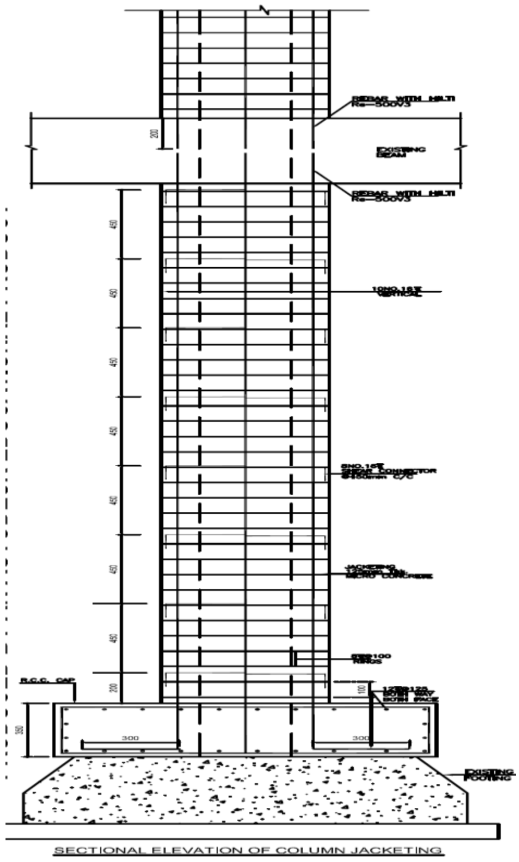


Figure No. 4.7 Detailing of column jacketing 1.

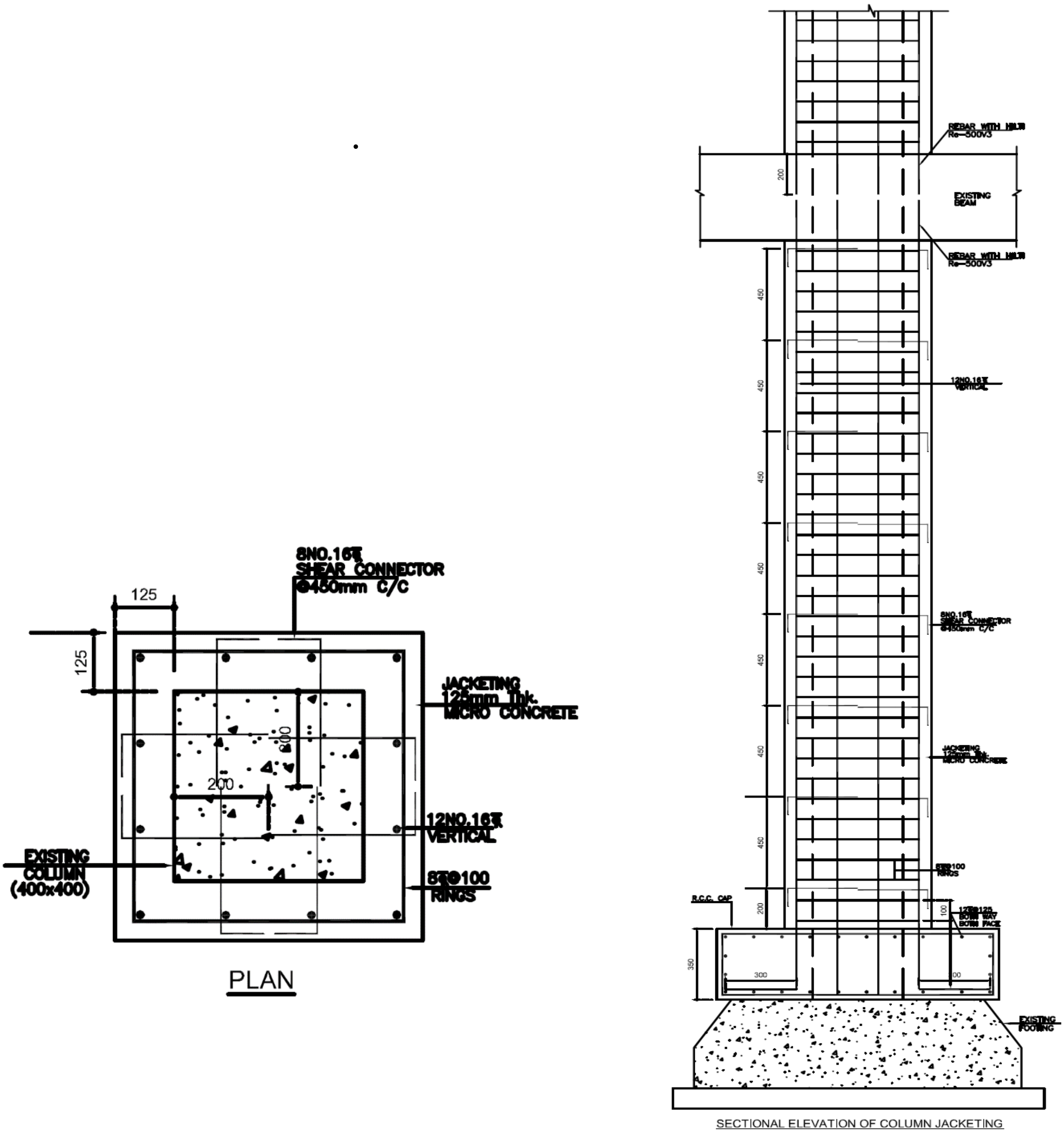


Figure No. 4.8 Detailing of column jacketing 2

5. CONCLUSIONS

- In all three cases after fire the concrete in the tested area loses strength nearly 60% of its actual load carrying capacity.
- Most of the structure gets heavily damaged and as by the NDT tests results it had to be demolished due to its unstable condition.
- As per Non-Destructive test the concrete got porous, the strength is reduced heavily, the reinforcement got corroded, the carbonation depth reached to reinforcement level and the compressive strength of concrete is also got reduced.
- As per the visual observations some part of ground floor looks very damaged and can't be helped but to demolish and the first floor looks visually great though the NDT tests results shows poor results but it can be retained with help of column jacketing going upwards with decrease in thickness of jacketing.
- After STAAD pro analysis of the existing structure the structure looks unstable.
- So, column on ground floor got jacketed with 150mm thickness up to first floor level with reduced thickness of 125 mm up to second floor level.
- Post analysis of the structure with column jacketing shows that some part of the structure can be retained and the absolute maximum bending moment in pre analysis can be reduced easily,
- After comparative analysis of Pre and Post Strengthening it is seen that the Bending Moments are reduced nearly to 80%.

6. STRENGTHENING SCHEME

INTRODUCTION

On the basis of ultrasonic pulse velocity test, rebound hammer test including visual inspection it is recommended to do grouting for all the columns with Micro Fine Cement & Epoxy Resin (Non Shrink free flow low viscocity solvent free epoxy grouting required or high molecular thermo set polymer grouting) as per methodology and specification given as follows:

6.1 Environmental requirements

6.1.1 Micro Fine Cement Grout to Columns

Providing and injecting Micro Fine Cement Grout in the ratio by grouting pump at a pressure @ 3-7 Kg/Cm2 or as instructed by Engineer-in-charge etc. complete by considering 200mm x 200mm c/c grid along honeycombing areas and 150mm x 150mm c/c grid along cracks.

6.1.2 Epoxy Resin Grout to Column

Providing and injecting low viscosity solvent free epoxy in the ratio by grouting pump at a pressure @ 3-6 Kg/Cm2 or as instructed by Engineer-in-charge etc. complete by considering 200mm x 200mm c/c grid along honeycombing areas and 150mm x 150mm c/c grid along cracks.

6.1.3 Damaged Concrete Cracks

Open the cracks into "V" groove. Then providing and applying Epoxy + Silica Sand 1:2 mortar at the groove and finish at all heights, levels and surface etc. complete.

6.1.4 Micro Concrete

Providing and applying 50/100/150mm micro concrete as per specification or as instructed by Engineer-in-charge etc. complete.

6.1.5 Column Jacketing

1. Remove loose cover from concrete surface.
2. Clean the surface with wire brush and force air.
3. Fix the nozzle in column or crack surface in vertical and plan dimension and grout the nozzles with microfine cement grout and epoxy.
4. Drill the holes for fixing shear connectors. Clean the holes with force air and grout the shear connector with Hilti HY200 or Hilti Re-500V3 or equivalent rebar chemical.

5. After fixing shear connectors clean the column surface with force air. Place the vertical and reinforcement and rings as per drawings.

6. Apply new and old epoxy base bonding agent to existing column before doing new concrete (Micro concrete + Aggregate).

7. New jacketing concrete must be cured for minimum of 10 days.

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8. PUBLICATIONS

Sr. No.	Title	Journal	Remark
1	Case study of condition assessment and structural audit of fire damaged building	Alinteri Journal of Agricultural Science (Web of Science)	Submitted

Table No. 8.1 Publication