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DIAGNOSIS AND PERFORMANCE EVALUATION OF REINFORCED CONCRETE AND FRP RETROFITTED COLUMNS OF EXISTING BUILDINGS

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1. ABSTRACT

Structural Health Monitoring is relatively new concept across the worldwide and very recent for India. It has proved to be effective and fruitful in many countries, now being practices often, and has a great potential and usefulness for India. India has a rich cultural and historical background which is very well reflected in the varied amount of historical structures. These structures are very well built and have withstood the test of time. But due to their historical importance it becomes very important to assess health condition of these structures, so that appropriate steps may be taken before it is too late. In the present work, Structural Health Monitoring of 62 years old hostel building situated in Walchand College of

Engineering, Sangli is carried out along with the performance analysis of building in ETABS and identifying defects in the structure which may cause the instability. This research work pertains to identify and retrofit the major structural components such as columns with the help of advanced techniques (CFRP Confinement). Furthermore, the provided CFRP confinement is validated through the FEA based (ABAQUS) simulation of columns. From, the result it is observed that strength and ductility of the column is increased by 30-50% by using such CFRP confinement.

KEYWORDS: RCC Column, ETABS, ABAQUS, CFRP confinement.

2. INTRODUCTION

As new materials and technologies are discovered, buildings get taller, bridges get longerspans and the designs of structures become more ambitious, but more complex. In view, of these developments, there is an increased requirement to providing both the costs savings with regard to maintenance and a safer environment for by preventing structural failures. Apart from old buildings there are high rise buildings made of steel and concrete which have started to make their way in India and as they need extensive modelling, design details andanalysis before and during construction it becomes important and good to know about whathas been made and its behavior in future.The objective of SHM is to monitor the in-situ behavior of a structure accurately andefficiently, to assess its performance under various service loads, to detect damage or deterioration, and to determine the health or condition of the structure. The historical beauty of our nation plays a spirited role in tourism. Very few countries are taking part to maintain and continues their cultural and historical background by structural health monitoring.

Ageing phenomenon of concrete is very difficult to predict and this can lead to accidents and losses.India is one of the country having rich cultural and historical background, which is very well reflected in the varied amount of historical structures. These structures are very well built and have withstood the test of time. But due to their historical importance it becomes very important to assess health condition of these structures, so that appropriate steps can be taken before it is too late.

2.1 Benefits of SHM

Structural health monitoring gives information regarding the damages, position of damage and not last but the least is severity of damage. Early detection of performance degradation can save lives and property in time by stopping exploitation and access to the structure. This guarantee the safety of the structure and its users. It also gives us a way to assess the possible damages after a natural calamity or any other type of major event which can affect the structural properties and condition. The main purpose of structural health monitoring is to give ample warning against sudden failures of structures which interns saves the lives of peoples and economy of the country. Economically Structural health monitoring process is also very reasonable and is synonymous to buying an insurance policy for your health. One protects the individual, his/her depending family and finally gives a peace of mind. The same is true for SHM Policy, which gives a much more personal, local and national image for sustainability. A need for SHM arises with the fact that properties of both concrete and steel depend on large number of factors which are often hard to predict in practice. The representative parameters selected for health monitoring of a structure in general can be of mechanical, physical and chemical in nature.

Research Gap

Many researchers/authors had retrofitted the structures based on the SHM of existing building eitherby experimental work using non-destructive testsor by analytical work based on the analysis and design software's. But very few of them had retrofitted the structures by comparing the experimental results with the analytical one, which are obtained from the analysis and design software's such as ETABS, STAAD etc. In this present work, structural health monitoring of hostel building of walchand college of engineering, sangli had done on the basis of visual inspection and by non-destructive tests such as rebound hammer test, ultrasonic pulse velocity test and rebar locator test.Existing hostel building modelled on "ETAB-2015" and analyse on the basis of information obtained from the visual inspection and non-destructive tests. Observe the columns and checkwhether the columns in the load carrying capacity of column has reduce. The same new building modelled and analyse by using actual mechanicalproperties used during construction. By comparing the results, columns which are on the verge of failure is retrofitted by carbon fiber reinforced polymer wrapping to achieve their original strength.

Objectives

- Structural Health Monitoring of Reinforced Concrete Columns of Existing (G+2) Hostel Buildings Using Latest Techniques.
- Evaluation of Static and Seismic Performances of the Existing Structure Using.

ETABS

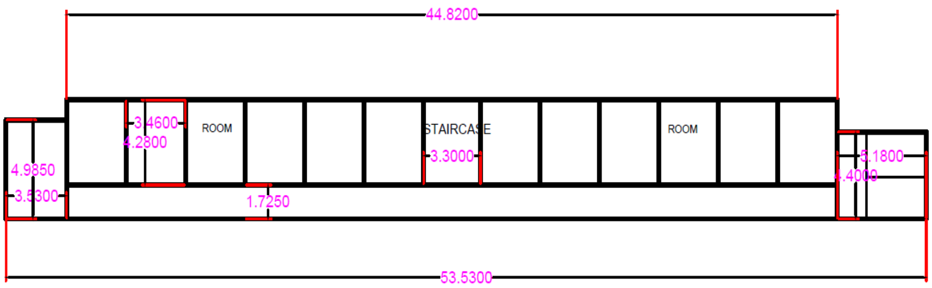
- Comparison of these Performances with Similar New Structure.
- Probable FRP Retrofitting of RC Columns in the Structure.
- Performance Evaluation and Comparison of the Retrofitted Structures.

3. CASE STUDY

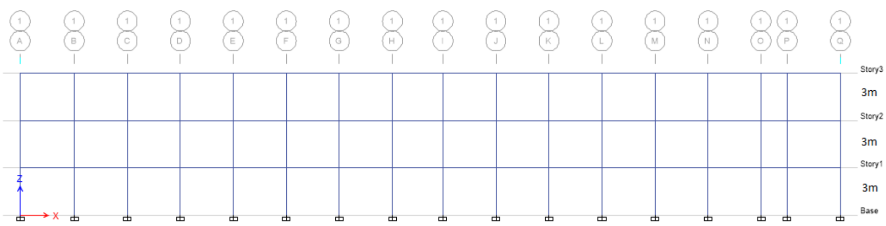
3.1 Visual Inspection

Property Name: Walchand College of Engineering, Sangli.

Fig. 1: Hostel building (D8) in WCE, Sangli.



Centre Line Plan



Elevation

Fig. 2: Plan and Elevation of Hostel Building.

3.1.1 Inspection of Building

Inspection date: 15 July 2016 to 15 August 2016.

This inspection comprised a visual assessment of the property to identify major defects and to form an opinion regarding the condition of the property at the time of the inspection. The purpose of this inspection is to provide advice regarding the condition of the property at the time of the inspection.

Visual Inspection Report

Property Description:

1. Building type: G+2 Story RCC Frame Structure.
2. External walls constructed from: Brick masonry having thickness

a) 450 mm

b) 300 mm

c) 100 mm

3. Roof is covered with: Mangalore tiles
4. Existing grade of concrete: M15
5. Grade of steel: Mild 250.
6. Size of building: 53.53 x 6 (m^2)
7. Sizes of columns: 1) Col.185x575 2) Col.300x400 3) Col.320x530
8. Sizes of beams: 1) Beam230x375 2) Beam250x500 3) Beam270x625 4) Beam300x450
9. Longitudinal bar dia.:10 mm
10. Confinement bar dia.: 6 mm

3.1.2 Visual condition of building components

Condition of Columns: Condition of most of columns in D8 hostel building are generally fair. Some of columns in the verandah are very poor. Reinforcement of those columns are exposed to the atmosphere due to the degradation of concrete. Therefore, the bars are corroded up to the 40%. Most of columns gets cracked. Columns require maintenance.

Fig. 3: Condition of Columns C2 and C13.

Condition of Beam: Condition of beams in D8 hostel building is poor. Few beams get cracked due to ageing and degradation of concrete and some of them are exposed to atmosphere.

Fig. 4: Condition of Beams.

Condition of Walls: Interior walls are very good in strength as well as in appearance. Very few walls have hair line cracks due to ageing and degradation of concrete. Overall strength of interior walls is good. On the other side, exterior walls have some major cracks and the overall strength of exterior walls is fair.

Fig. 5: Condition of wall.

Condition of Slab: condition of slab in hostel building is generally fair. Reinforcement is exposed to the atmosphere and corroded up to 20%. Overall strength of slab is not good, it requires maintenance.

Fig. 6: Condition of slab.

Table 1: Problem Formulation.

Existing hostel building properties				
Type of Structure	G+2 RCC Frame Structure			
Plan Dimension	53.53m x 6m			
Story Height	3 m			
Grade of Concrete	M15			
Grade of Steel	Fe250			
Column Sizes	Col.185x575	Col.300x400		Col.320x530
Beam Sizes	Beam230x375	Beam250x500	Beam270x625	Beam300x450
Wall Sizes	450 mm	300 mm		100 mm
Slab Thickness	125 mm			

New Hostel Building Properties				
Type of Structure	G+2 RCC Frame Structure			
Plan Dimension	53.53m x 6m			
Story Height	3 m			
Grade of Concrete	M20			
Grade of Steel	Fe415			
Column Sizes	Col.185x575	Col.300x400	Col.320x530	
Beam Sizes	Beam230x375	Beam250x500	Beam270x625	Beam300x450
Wall Sizes	450 mm	300 mm	100 mm	
Slab Thickness	125 mm			
Response Reduction Factor	5			

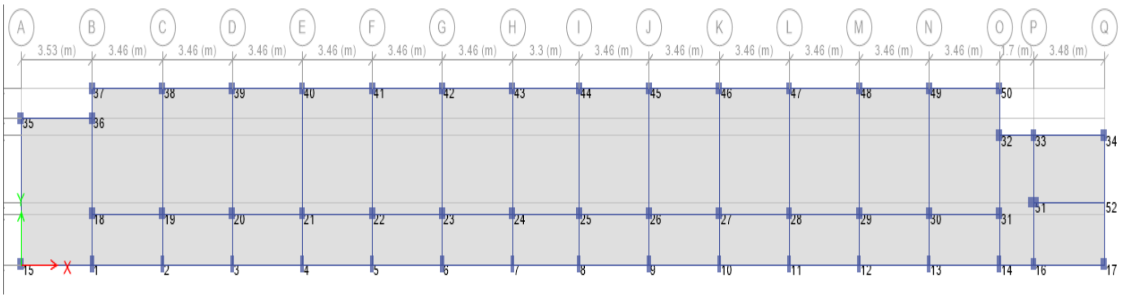


Fig. 7: Highlighting all column nodes of hostel building.

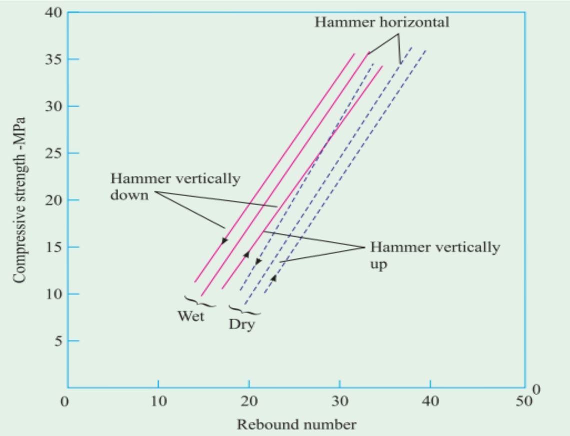
4. RESULTS

From visual inspection of hostel building it was observed that all column except C2 and C13 are safe.

4.1 Non-destructive Test Results

Table 2: Rebound hammer test. Table 3: Ultra-sonic Pulse Velocity Test.

Column No.	Avg. Rebound No.	Compressive Strength(N/mm^2)	Column No.	Dist. between probes (mm)	Time required to travel (μsec)	Velocity (m/s)
C2	22.7	15.7	C2	185	80	1947.36
C13	24.8	18.7	C13	185	95	2312.5



Pulse Velocity in m/s	Condition
4575	Excellent
3660 - 4575	Good
3050 - 3660	Questionable
2135 - 3050	Poor
2135	Very poor

Table 3: Rebar Locator Results.

No. of bars in column	**8**
Cover	35 mm

From the non-destructive test results,it is seen that column C2 and C13 are on the verge of failure. We found that, the reinforcement of column gets degraded and bar dia. Reduced to 6 mm which was earlier 10 mm at the time of construction. So, to analyse these two columns inETABS it is found that these two columns had corroded as maximum of 40% and after degradation the grade of column gets reduced to M10.

Modelling of Hostel Building

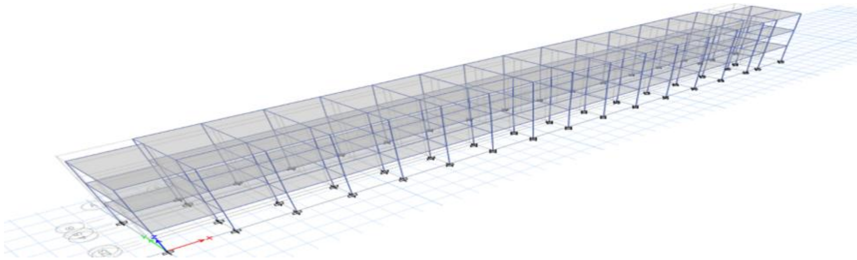


Fig. 8: 3D model in ETABS.

4.2 Analysis Results

Table 4: Mode and its Time Period.

Existing Building New Building

Mode Shape	Time Period	Mode Shape	Time Period
1	0.57	1	0.53
2	0.46	2	0.428
3	0.42	3	0.397
4	0.19	4	0.184
5	0.17	5	0.164
6	0.14	6	0.138

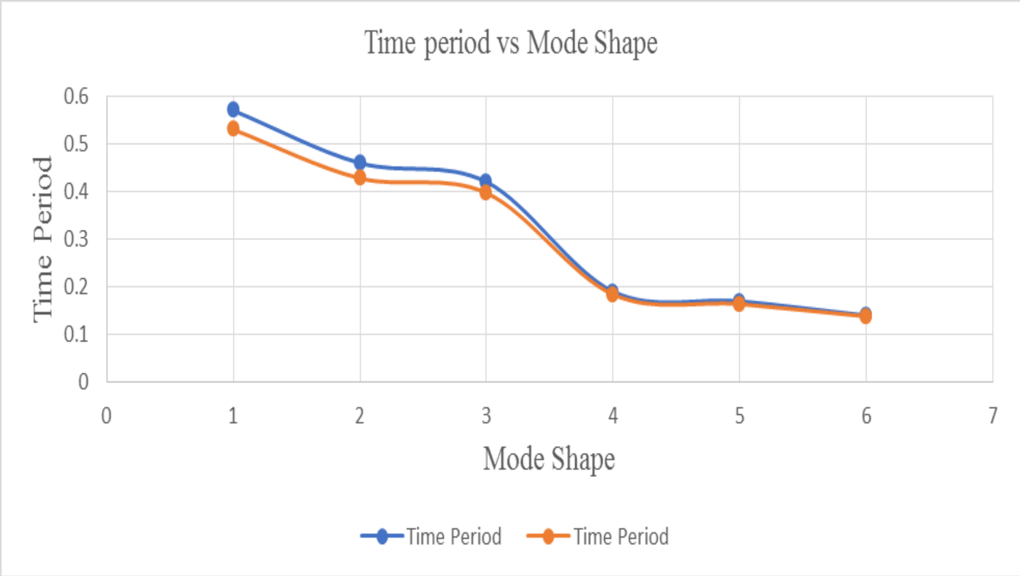


Fig. 9: Time Period Vs Mode Shape.

Table 5: Design Axial Forces.

Column	Design Axial Force (kN)				
	New Building		Existing Building		
	Static Analysis	Seismic Analysis	Static Analysis	Seismic Analysis	Static After Corrosion
C1	219.2189	111.292	301.88	89.8633	301.88
C2	160.1689	53.1717	197.61	32.907	197.61
C3	159.9306	55.4114	199.26	35.92	199.26
C13	191.73	65.94	202.2	48.91	191.73
C14	162.5168	66.1184	210.53	46.5413	210.53
C15	228.6035	170.8987	368.62	160.8512	368.62
C16	218.5213	120.1343	299.43	103.2681	299.43
C17	223.5716	158.4328	352.18	144.1056	352.18

Table 6: Design Moments.

Column	Design Moment (kN-m)									
	New Building				Existing Building					
	Static analysis		Seismic analysis		Static analysis		Seismic analysis		Static analysis After Corrosion	
	Mu2	Mu3	Mu2	Mu3	Mu2	Mu3	Mu2	Mu3	Mu2	Mu3
C1	1.11	7.69	-4.56	-3.91	-14.5	-0.37	-15.01	-52.69	-14.47	-0.37
C2	-0.06	9.85	-5.41	-5.48	10.45	-0.87	13.18	-51.98	10.45	-0.87
C3	0.06	9.72	-5.44	-5.46	-10.5	-1.25	-13.34	-51.42	-10.54	-1.25
C13	6.338	4.68	-5.35	-4.75	-10.7	-0.8	-13.1	-44.23	10.14	3.69
C14	0.32	7.98	-5.36	-3.46	-9.86	-0.45	-14.15	-43.95	-9.86	-0.45
C15	-3.86	18.24	-13.35	3.7	-15.4	19.27	36.57	-39.31	-15.37	19.27
C16	-1.72	10.66	-15.88	-6.08	5.98	-0.19	38.95	-28.78	5.98	-0.19
C17	3.68	17.59	-7.54	3.61	14.66	17.57	-37.26	-32.83	14.66	17.57

Table 7: % Rebar and Demand /Capacity Ratio.

Column	% Rebar and Demand /Capacity Ratio							
	New Building		Existing building					
	% Rebar		% Rebar			Demand/capacity ratio		
	Static analysis	Seismic analysis	Static analysis	Seismic analysis	Analysis after corrosion	Static analysis	Seismic analysis	Analysis after corrosion
C1	0.8	0.8	0.65	0.65	0.65	0.547	1.155	0.547
C2	0.8	0.8	0.65	0.65	0.34	0.414	1.7	0.438
C3	0.8	0.8	0.65	0.65	0.65	0.391	1.685	0.391
C13	0.8	0.8	0.65	0.65	0.34	0.423	1.461	0.47
C14	0.8	0.8	0.65	0.65	0.65	0.414	1.541	0.414
C15	0.8	0.8	0.8	0.8	0.8	0.507	1.435	0.507
C16	0.8	0.8	0.8	0.8	0.8	0.293	1.561	0.293
C17	0.8	0.8	0.8	0.8	0.8	0.478	1.417	0.478

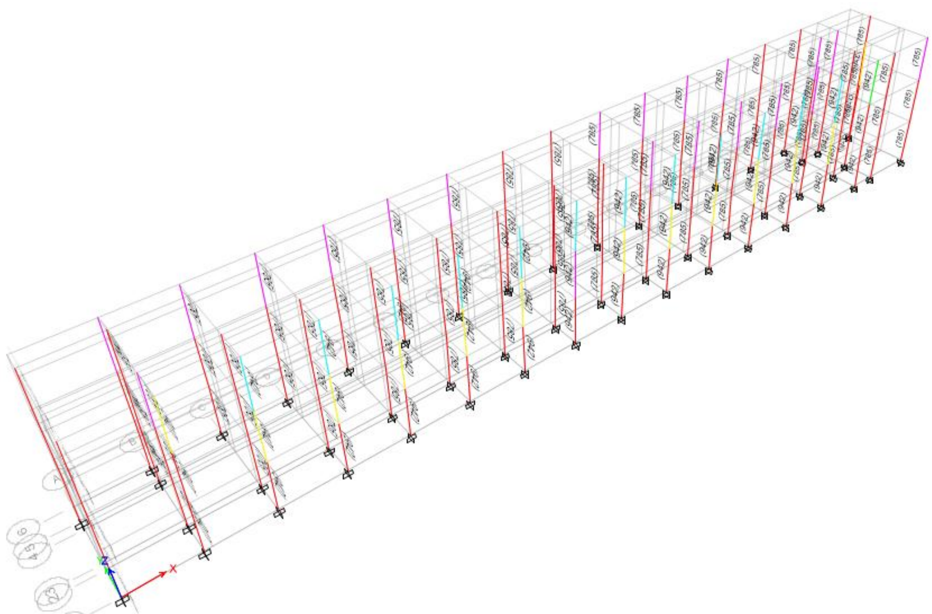


Fig. 10: Columns fails in seismic analysis.

Existing building was not designed for seismic analysis so, all the columns are failed while performing seismic analysis as capacity of members are very less than demanded. From the analysis of existing building it is seen that, for column C2 and C13, % reinforcement is to be decreased from 0.65% to 0.34%. Therefore, from the analysis and non-destructive test results it is found that the column C2 and C13 must have to be retrofitted to avoid sudden collapse.

5. CFRP Design

- As per limit state method the load carrying capacity of existing column was 741.32 kN. Where f_{ck} = 15 N/mm^2 and f_y = 250 N/mm^2.

- Load carrying capacity after corrosion is 487.08 kN. Where f_{ck} = 10 N/mm^2 and f_y = 250 N/mm^2, corrosion of steel = 40%
- % Decrease = $\frac{741.32-487.08}{741.32}$*100 = 34.29 % So, to regain 34.29% of capacity column has to confine by FRP wrapping.

5.1 CFRP Properties given by the Manufacturerare

1. Ultimate tensile strength (f_{fu}^*) = 3792 mpa
2. Rupture strain (ε_{fu}^*) = 0.0167 mm/mm
3. Modulus of elasticity (E_f) = 227527 mpa
4. No. of plies = 6
5. Environmental reduction factor (C_E) = 0.85
6. Design ultimate tensile strength (f_{fu}) = C_E* f_{fu}^* = 3223.2 mpa
7. Design rupture strain (ε_{fu}) = C_E* ε_{fu}^* = 0.0141

5.2 Column Cross Section Details

1. Column no.C2
2. B = 185 mm and d = 575 mm
3. After corrosion % rebar = 0.21%
4. After corrosionf_{ck} = 10 mpa and fy = 250 mpa
5. Required radius of column edges (r_c) = 25.4 mm

5.3 Design

1. Axial capacity of the Unstrengthen Column (ACI 440)

$P_{n\ (avail)} = 0.80\ [0.85\ f_c^1\ (A_g - A_{st}) + f_y\ A_{st}]$ = 996.66 kN

Where fc^1=10 N/mm^2, f_y=250 N/mm^2, Ast= 382.95 mm^2

2. Required axial capacity

$P_{n(req.)} = P_{n(avail.)}$ + 34.29% x $P_{n(avail.)}$ = 1338.41 kN

3. Required Additional Compressive Strength of Concrete (f_{cc}^1)

$P_{n(req.)} = 0.80\ [0.85\ f_{cc}^1\ (A_g - A_{st}) + f_y\ A_{st}]$ f_{cc}^1= 17.50 N/mm^2

4. Maximum Confining Pressure Caused due to FRP Jacket (f_1)

$$f_1 = \frac{fcc1 - fc1}{3.3\ x\ ka}\text{, where } ka = \frac{Ae}{Ac} \text{ x } \left(\frac{b}{h}\right)^2 \quad \frac{Ae}{Ac} = \frac{1 - \left\{\frac{\left(\frac{b}{h}\right) * (h-2rc)2 + \left(\frac{h}{b}\right) * (b-2rc)2}{3*Ag}\right\} - \rho g}{1-\rho g}$$

$\frac{Ae}{Ac}$ = 0.54 and ka = 0.0565

Therefore, confining pressure (f_1) = 13.40 N/mm^2

5. Thickness of FRP Plies

Assuming 6 no. of plies,

$t_f = \frac{f1 \ * \sqrt{b^2 + h2}}{2 * Ef * n * \varepsilon fe}$ = 0.215≈ 0.22 mm

6. Check for Confinement

$\frac{f_1}{f_c^1}$ = 1.16 > 0.08 (ok)

7. Check for Ultimate Axial Strain in Confined Concrete (ε_{ccu})

$\varepsilon_{ccu} = \varepsilon_c^1[1.5 + 12\ K_b * \frac{f1}{fc1} * (\frac{\varepsilon fe}{\varepsilon c1})^{0.45}] \leq 0.01$

Where, $\varepsilon_c^1 = \frac{1.71 * fc1}{Ec}$ and $K_b = \frac{Ae}{Ac} \times (\frac{h}{b})^{0.5}$

By substituting above calculated values, we get

ε_c^1= 0.0010 and K_b= 0.95

Therefore, ε_{ccu} = 0.012 ≈ 0.01.

Hence its ok.

6. Application of Cfrp On Column In Abaqus

6.1 Modelling of Actual Column

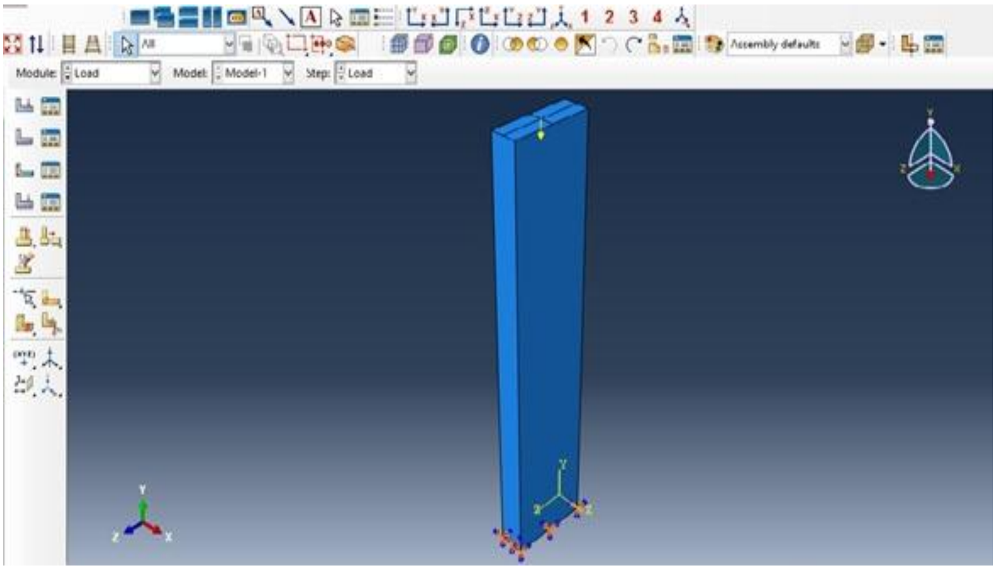


Fig. 11: 3D Model of Column C2 in ABAQUS.

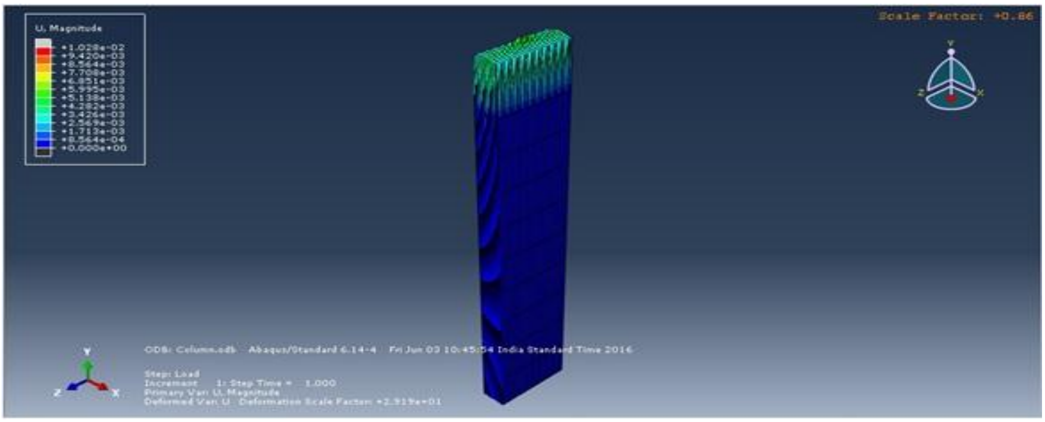


Fig. 12: Analysis of Column before CFRP Wrapping.

6.2 Application of CFRP

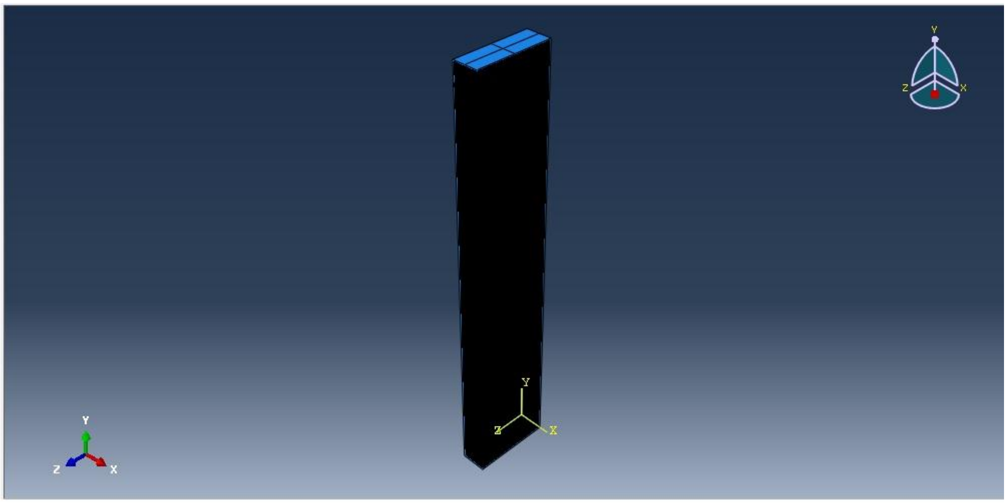


Fig. 13: Application of CFRP on Column.

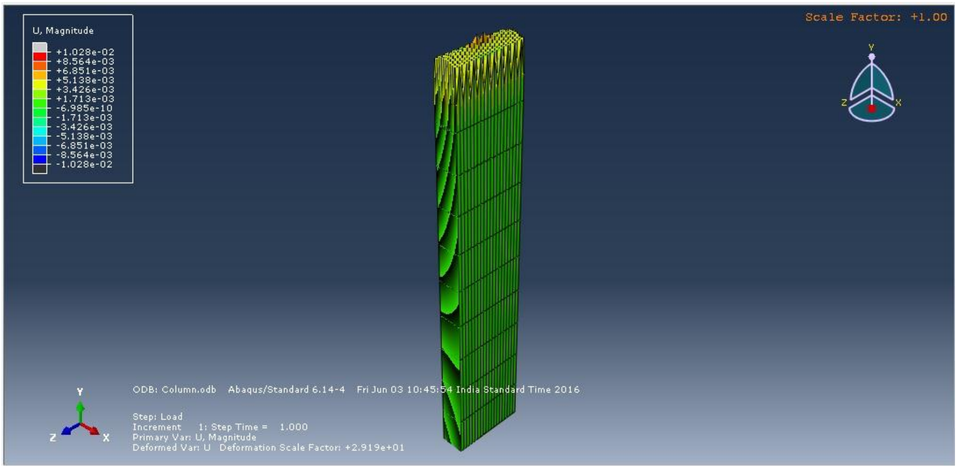


Fig. 14: Analysis of Column after CFRP Wrapping.

6.3 Analysis Result of Column after Application of CFRP

1. Required axial load carrying capacity = 741.32 kN

2. After application of CFRP, axial load carrying capacity is 742.20 kN
3. Required confining pressure = 13.40 N/mm^2
4. Confining pressure after application is 14.021 N/mm^2
5. Axial strain in confined concrete is 0.012, which is nearly equals to allowable axial strain in confined concrete.

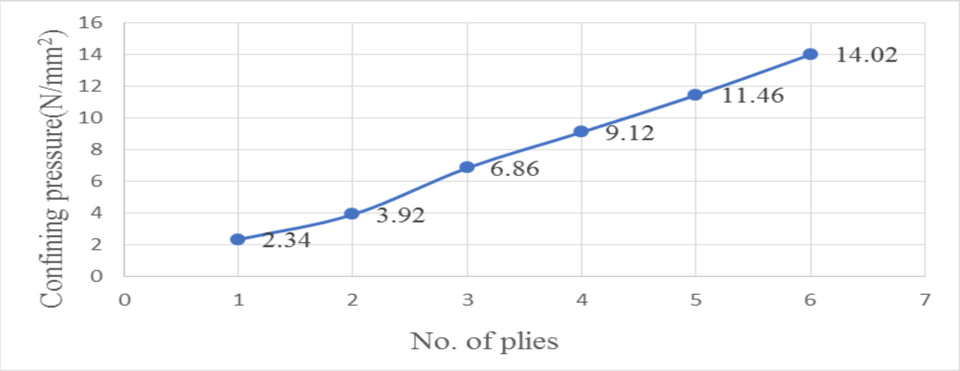


Fig. 15: Increase in Confining Pressure with No. of Plies.

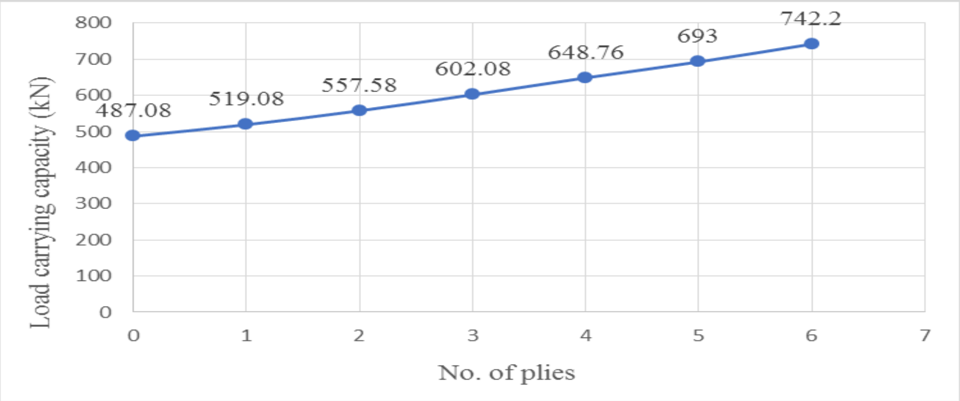


Fig. 16: Increase in Load Carrying Capacity with Plies.

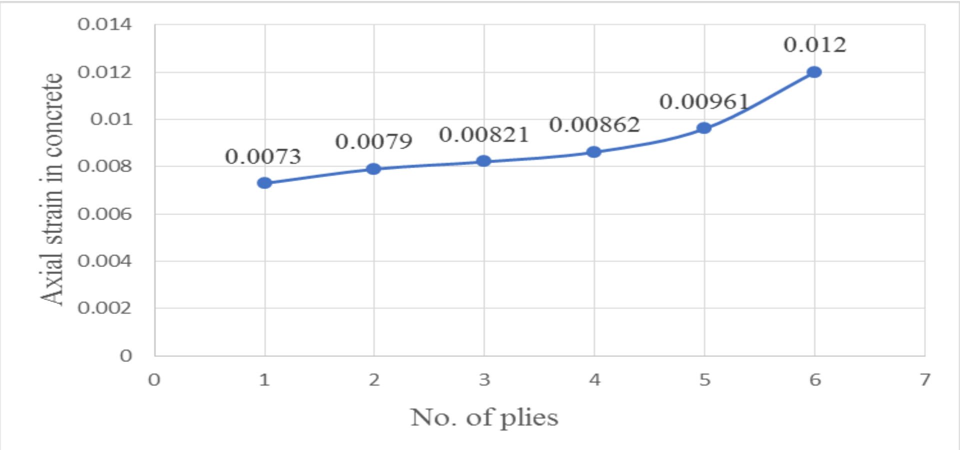


Fig. 17: Increase in Axial Strain in Concrete with Plies.

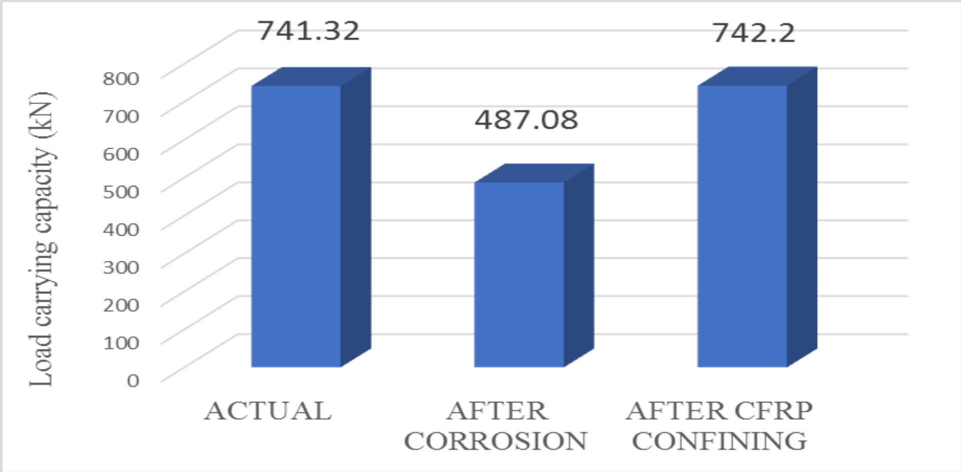


Fig. 18: Comparison between Load Carrying Capacities.

7. CONCLUSIONS

1. Thorough diagnosis of the Hostel Building has been carried out, it is found that the columns are found structurally weak in many places. Critically Columns which are exposed to atmosphere are deteriorated and the reinforcement is opened up. The grade of concrete is deteriorated around 40-60% whereas the reinforcement is corroded almost about 40%.
2. With above properties of existing material the performance simulation under worst load combinations. There is a stability issue at weak sections of the column if not retrofitted on urgent basis.
3. From analysis, it was found that to achieve actual strength of column 13.40 N/mm^2 confining pressure is required, hence, high pressure CFRP confining for these columns are proposed.
4. The CFRP 6 plies of 0.22 mm thickness are proposed to achieve the retrofitted strength.
5. The ABAQUS simulated results for columns before and after retrofitting are compared and found 50% reduction in deflection. And the strength is increased for the column by 50%
6. Therefore the CFRP retrofitting should be adopted for confinement of RC columns. From the present study, it was found that despite their cost to weight ratio, application of CFRP is beneficial to retrofit the existing structure.

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