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RESEARCH ARTICLE

Analysis of Reinforced Concrete Structures Beams-Columns Joints using Finite Element Modellings

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ABSTRACT

Various structures in many nations, including Portugal, were not completely installed for earthquake protection in recent past. As a result, buildings constructed in the 1960s using RC Beam-Column Joints used less reinforcing steel than those constructed in line with more current standards. As a result, determining the soundness of ancient RC Beam-Column joints is critical in determining the future requirement for retrofitting and the intervention's goals. As a result, a building is deemed typical of the stock constructed in the 1960s in Lisbon, Portugal, in order to place a value on contemporary modelling methods for the assessment of existing jerry-made RC Beam-Column joints. SAP 2000 is utilised to determine the important joints of the structure. Pushover analysis is done since it is an ancient structure that needs restoration. Push the structure till it reaches its maximum capacity to disfigure, as the name suggests. It aids in comprehending the disfigurement and breaking of a structure in the case of an earthquake, as well as providing reasonable knowledge of building deformation and the creation of plastic hinges in the structure. The structure is then modelled in STAAD. Pro in accordance with IS requirements. The structure was simulated in order to determine the forces on the circular beam column joints based on the SAP 2000 analysis. Finally, crucial beam-column junctions are rectified using a retrofit technique such as FRP wrapping in Abaqus, and graphs are displayed to show that if the retrofitting had been done sooner, the beam-column joint failure might have been avoided.

Keywords: RC Beam-Column joint, Staad pro, Sap2000, Abaqus, FRP wrapping, FEM.

INTRODUCTION

Earthquakes have the potential to cause the collapse of reinforced concrete structures, as well as the loss of lives and valuable property. The vast majority of structures constructed throughout the world in accordance with non-seismic standards of practise are incapable of withstanding even small earthquake stress. It is essential that the reinforced concrete structure has sufficient lateral resistance strength to prevent brittle fracture in seismic conditions. Because dismantling and rebuilding such RC buildings is so expensive, it may be more cost-effective to upgrade the main structural components in order to ensure the building's and people's safety in the first place. There may be non-ductile reinforcing components at the beam-column joint region, with inadequate or no shear reinforcement, as well as short anchor lengths of bottom steel bars that run down the longitudinal beam in these early RC structures. Furthermore, because of the strong beam design, the joint may be capable of withstanding considerable resistance. When a bond slide or joint shear failure occurs, the overall strength of the structure is significantly decreased.

Details of Building

The proposed site is an eight-story structure (ground floor +seven storys), with measurements of 36.80m in X-directions and 10.85m in Y-direction. The structure stands at a height of 27m. The structure was planned and constructed in the 2020s

Objective of the projects

Through the use of a pushover analysis on both the beam and the column, the researchers hope to discover the critical beam-column junction in this investigation. A critical beam-column junction is investigated using the finite element method in this research, which involves the application of total deformation and stress to the junction. It is therefore necessary to adjust the joints in order to compare the behaviour of different joints in terms of total deformation and stress distribution. The pushover research was carried out with the assistance of the SAP2000 software. ABAQUS version 6.13 is utilised to do the Finite Element Analysis, in addition to the other software.

Forces acting on a Beam Column Joint

The pattern of forces acting on a joint is dictated by the configuration of the joint as well as the kinds of loads pushing on the joint. Loads acting on the three types of joints are investigated in terms of stresses and the fracture patterns that occur as a consequence of these stress and fracture patterns. The forces acting on an internal joint as a result of gravity loading are shown in Figure 2. a. formalised Loads from the beam ends, as well as axial stresses from the columns, may be transmitted directly via the joint. When lateral (or seismic) loading occurs, the equilibrating forces from beams and columns cause diagonal tensile and compressive stresses to develop inside the joint, as shown in Fig. 2. (b). Fractures occur perpendicular to the stress diagonal A-B of the joint and at the joint's faces, where the beams act as a frame for the joint. Unlike tension ties, compression struts are shown with dashed lines, while tension ties are depicted with solid lines. The use of transverse reinforcements to bridge the plane of failure and resist diagonal tensile forces is necessary due to the weakness of concrete under tension.

FRP Composites

Since the mid-1980s, fibre-reinforced polymer reinforcing systems have been used to strengthen weak concrete structural components and to restore damaged or deteriorated concrete structures, mostly in the construction industry. Composites were first utilised in RC bridges as flexural strengthening materials and as confining reinforcement in RC columns, and they have since become more popular. Since the inception of the research, the range of possible applications has expanded to include beams, slabs, columns, shear walls, chimneys, vaults, domes, and trusses, among other things.

The term composite material (also known as composite) refers to a well-balanced combination of two or more elements that results in a product that is more efficient than the sum of its parts. Composite materials are used in a variety of applications. One of the components is the reinforcing or fibre phase (which provides strength), while the other is the matrix phase (in which the fibres are embedded). Through its shear transfer capability, the matrix acts as a binder, keeping the fibres in place and contributing to the structural integrity of the composite material in general. The matrix also has the additional function of protecting the fibre from the external environment in which the composite is placed. Continuous fibres are used in FRP products for structural engineering since they are endlessly long and therefore are referred to as continuous fibres. Fibre-reinforced polymers get their name from the fact that these fibres are used in relatively large quantities (ranging from 20 to 60% of the total volume of the polymer resin) to reinforce the polymer resin (FRP). When two distinct materials are mixed, the outcome is a component that has enhanced strength, stiffness, and toughness over and beyond the properties of the individual materials used in the construction. Fibrous fibres such as glass, carbon, aramid, and boron are the most common types of fibres used to create strong sheets and fabrics, and they are also the most expensive.

BEAM-COLUMNJOINT

A beam-column junction is the place where beams and columns of a reinforced concrete construction are connected. Due to the passage of a high number of forces between them (i.e. beams and columns), they are important areas in a reinforced concrete moment resistant frame. The standard design practice does not include a design assessment for beam-column joints. However, the collapse of similar frameworks during previous earthquakes throughout the globe has shown the significance of joint stresses. Shear at the joints leads to the structure collapsing. Only in the last several decades has detailed research into the joints for such structures been conducted. The fundamental criterion for a junction in a reinforced concrete structure to function well is:

- A joint's service load performance should be comparable to that of the member it joins.
- The strength of a joint should be equal to or higher than the strength of the most unfavourable load combination that the adjacent component can bear, repeated as many times as necessary to ensure that the joint is strong.
- he structure's strength should not be determined by the joint's strength, and its behaviour should not impede the growth of the neighbouring member's full-strength capability.

Types of Joints in a Frame

- Interior Beam-Column Junction — An interior joint is one that connects four beams to a single column.
- Exterior Beam-Column Connection – An exterior joint is formed when three perpendicular beams are joined to the vertical face of a single column.
- Corner Beam-Column Joint – Corner joints are the joints that can be seen on the frame's corner edges and are formed by the joining of two beams and two columns. When two beams meet at a corner junction, the vertical face of a single column becomes the connecting point.

FINITEELEMENTANALYSIS

Certain engineering problems cannot be solved analytically owing to the unpredictability of material properties, limit conditions, and the structure itself. This is especially true for structural issues. In engineering, the Finite Element Method, also known as Finite Element Analysis, is a method for finding approximate solutions to a wide range of boundary value or field value problems that may be solved numerically. In its most basic form, FEM divides or displays the structure into small finite components, which are then combined to form the final structure. There are a number of subdomains in the issue domain as a result of this division. Overall, this is a hypothesised technique, and the final findings must be widely known before it can be implemented successfully. Whenever it comes to the analysis of systems, finite element modelling (FEM) is a reliable technique for estimating the displacements, stresses, and traces in a structure under a collection of masses. Using the Finite Element Method, elliptic fractional differential situations are transformed into hard and fast arithmetical standards that are difficult to answer. Initial value problems involving an illustrated or hyperbolic differential condition, as well as the underlying circumstances, cannot be fully resolved using the finite detail method (other than the restriction conditions). When dealing with parabolic or hyperbolic differential equations, time is one of the independent variables. The Finite Element Method and the Finite Difference Method are needed in order to provide a solution to a preliminary fee issue.

METHODOLOGY

- Finding critical beam-column joints. SAP2000
- Modelling of joint and carrying out the required rectification process. ABAQUS
- Determining the forces in the critical beam column joints. STAAD PRO

SAP-2000

In the initial phase, the structure was modelled and built in SAP 2000, with Pushover Analysis used to identify key beam-column intersections. SAP2000 is a powerful structural design programme that may be used to investigate and plan an auxiliary structure. It is possible to exhibit fundamental and advanced frameworks in a natural protest-based displaying condition that simplifies and reorganises the engineering process. The frameworks can range from 2D to 3D and from simple to intricate geometry, and they can be dissected, composed, and advanced using this method. The major joints of the construction are identified with the help of SAP 2000. Because it is an ancient structure in need of renovation, a pushover analysis is performed.

STAAD. Pro

STAAD. Using the Pro software package, you may conduct traditional first order static analysis, 2nd order p-delta analysis, geometric nonlinear analysis, Pushover analysis (Static-Nonlinear Analysis), and buckling analysis, to name a few applications. It may be utilised in combination with a variety of dynamic analysis methods, such as modal extraction, time history analysis, and response spectrum analysis, among others Thedimensions ofmembers usedin the structure are as follows:

Columns sizes
700 mm X 300 mm
500 mm X 250 mm
400 mm X 250 mm
300 mm X 250 mm
Beams sizes
650 mm X 250 mm
650 mm X 300 mm

M30 concrete was utilized in the construction of the structure. Fe415 steel was utilized in the construction. The results are acquired in STAAD. Pro, and the crucial beam column joints are modeled in ABAQUS with the forces taken into account, and the results are observed.

ABAQUS

Under transient loads, a finite-element analyser uses an explicit integration technique to solve extremely nonlinear systems with many complicated connections. The fundamental task of ABAQUS is to design and assess the building structure's essential beam-column joints. The SAP 2000 results are utilised to replicate the real joint deflections and forces. ABAQUS is primarily used for beam-column joint analysis due to its Finite Element modelling, which produces more accurate results than other software and also has the ability to provide more detail about the model developed.

RESULTS

SAP2000 RESULTS

The modelling of the structure is completed, and the section attributes of the sections are established. Following the application of various load instances and various load combinations, the result is produced in the three axes ("+x," "-y," and "+y," respectively), which are the crucial joints.
The figure below shows the result received after applying the Dead Load on the system.

STAAD PRO RESULTS

According to the SAP2000 , there are 9 important nodes along various push axes.

ABAQUSRESULTS

The fundamental task of ABAQUS is to design and assess the building structures essential beam-column joints. The SAP2000 and STAAD PRO results. It was used to model actual joint deflection and forces. Using the table above, we can compare stress and displacement values with and without FRP Wrapping, and we can also compare with and without FRP Wrapping. Below are graphs that show the stress and displacement reductions that happened as a consequence of the rectification process. Node of Critical Importance-A node of critical importance is a node that has a lot of (B,2,4). The beam column joint is wrapped in FRP and rectangle meshing is performed, enhancing the beam column joint's strength and load bearing capacity and thereby correcting it.

As can be observed in the two tables above, the stress and displacement values obtained with and without FRP Wrapping are similar in both directions. The table that show how the rectification process reduces the amount of stress and displacements that occur as a consequence of the operation clearly illustrate how the rectification process reduces the amount of stress and displacements that occur as a consequence of the operation.
Critical Node–(C,2,8)

Fig 10 After analysis, the Critical Node (C,2,8) The same section is cut for further steps; the section is zoomed in view of the points chosen. The same section is cut out after the FRP Wrapping is applied; the section is zoomed in on the cut-out section; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping. The stress and displacement values are shown in the table above with and without FRP Wrapping, as well as with and without FRP Wrapping. In the following graphs, the stress and displacement reductions that occurred as a result of the rectification procedure are shown in more detail.

CONCLUSION

- If the beam-column joint had been modified and repaired in a timely manner, the failure of the beam-column joint could have been avoided. The loads on the structure were more than the members' bearing capacity, resulting in the condition known as "weak column, strong beam."
- The use of Carbon Fiber Reinforced Polymer, or CFRP, in the construction of the members reduced stresses on them by about 10% on average, which is a considerable improvement over the members' prior state of construction.
- The displacement values of non-retrofitted members were reduced by roughly 10-15% when compared to CFRP-wrapped members.
- Carbon Fiber Reinforced Polymer, or CFRP, is also a cost-effective option since the mass required per beam-column joint is quite low, and the stress and displacement values are reduced very well when compared to retrofitting procedures.

- When the building was modified with CFRP, it would have avoided a "Soft Storey" collapse that occurred on the ground and first levels. This will result in a low-cost facility that will be available for usage in the future.

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Table 1: STAAD. Pro employs the following load combinations, which are listed in the following table:

Load combination No.	Multiplying factor of Loads				
	DL	LL	WL(+Z)	WL(-Z)	TH
1	1.5	1.5	0	0	0
2	1.2	1.2	1.2	0	0
3	1.2	1.2	0	1.2	0
4	1.2	1.2	-1.2	0	0
5	1.2	1.2	0	-1.2	0
6	1.2	1.2	0	0	1.2
7	1.2	1.2	0	0	-1.2
8	1.5	0	1.5	0	0
9	1.5	0	0	1.5	0
10	1.5	0	-1.5	0	0
11	1.5	0	0	-1.5	0
12	1.5	0	0	0	1.5
13	1.5	0	0	0	-1.5
14	0.9	0	0	0	1.5
15	0.9	0	0	0	-1.5

DL: Dead Load, LL: Live Load, WL: Wind Load

Table: 2 Critical Node Points and Reinforcement Details

Node No.	Location	Connected Members	Reinforcement
1	A,2,2	B-63	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-79	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-80	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-101	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-92	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-145	Main:6# 25Ø; Ties:6Ø @250mm c/c
2	A,2,3	B-116	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-132	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-133	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B154	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-145	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-198	Main:6# 25Ø; Ties:6Ø @250mm c/c
3	B,2,2	B-59	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-73	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-99	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-88	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-141	Main:6# 25Ø; Ties:6Ø @250mm c/c
4	C,2,2	B-60	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-74	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-75	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-100	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-89	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-142	Main:6# 25Ø; Ties:6Ø @250mm c/c
5	B,2,3	B-112	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-126	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-152	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-141	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-124	Main:6# 25Ø; Ties:6Ø @250mm c/c
6	C,2,3	B-113	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-127	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-128	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-153	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-142	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-195	Main:6# 25Ø; Ties:6Ø @250mm c/c
7	B,2,4	B-165	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-179	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c

		B-205	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-194	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-247	Main:6# 25Ø; Ties:6Ø @250mm c/c
8	A,2,8	B-375	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-376	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-389	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-390	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-405	Main:6# 25Ø; Ties:6Ø @250mm c/c
9	C,2,8	B-378	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-392	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-393	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		B-418	Top:3# 16Ø; Bottom: 3# 16Ø; Stirrups; 2legged 6Ø;@300mm c/c
		C-407	Main:6# 25Ø; Ties:6Ø @250mm c/c
		C-412	Main:6# 25Ø; Ties:6Ø @250mm c/c

Table 3:Results of FRP wrapping details with Abaqus

S.no	STANDARD		FRP	
	STRESS (N)	DISPLACEMENT (mm)	STRESS-FRP (N)	DISPLACEMENT- FRP(mm)
1	371.882	6.174	371.975	6.046
2	372.459	6.162	370.503	6.058
3	379.508	6.097	361.714	6.017
4	371.466	6.068	370.907	6.013
5	369.326	6.042	368.732	6.009
6	368.732	6.026	366.587	6.017
7	364.153	6.026	363.199	6.011
8	364.345	6.038	363.038	5.999
9	366.828	6.054	364.768	5.991
10	369.211	6.070	368.897	5.983
11	371.377	6.099	371.021	5.986
12	378.330	6.127	366.350	5.991
13	379.892	6.194	361.215	6.032
14	372.152	6.027	361.215	6.021

FRP: Fibre-Reinforced Polymer

Table 4: Results of Cut section of FRP wrapping details with Abaqus

S.no	STANDARD		FRP	
	STRESS (N)	DISPLACEMENT (mm)	STRESS-FRP (N)	DISPLACEMENT-FRP(mm)
1	782.997	-2.974	781.720	-2.895
2	794.351	-2.967	770.675	-2.898
3	800.803	-2.955	765.462	-2.896
4	792.800	-2.946	799.332	-2.898
5	798.074	-2.939	769.233	-2.901
6	780.088	-2.933	779.979	-2.904
7	777.459	-2.927	777.263	-2.909

8	777.233	-2.922	777.473	-2.914
9	780.102	-2.917	779.945	-2.919
10	788.641	-2.925	774.774	-2.913
11	797.177	-2.933	769.874	-2.910
12	791.177	-2.941	780.414	-2.908
13	799.161	-2.953	767.175	-2.910
14	783.124	-2.960	781.562	-2.907

FRP: Fibre-Reinforced Polymer

Table 5: Results of final Analysis of FRP wrapping details with Abaqus

S.No	STANDARD		FRP	
	STRESS (N)	DISPLACEMENT (mm)	STRESS-FRP(N)	DISPLACEMENT-FRP(mm)
1	899.087	1.296	899.794	1.276
2	899.087	1.297	898.013	1.278
3	913.016	1.300	897.863	1.279
4	915.673	1.302	901.161	1.282
5	920.905	1.304	905.012	1.284
6	922.049	1.306	907.838	1.286
7	922.173	1.308	909.072	1.288
8	921.822	1.311	909.164	1.290
9	919.197	1.313	908.118	1.293
10	916.590	1.316	905.490	1.295
11	913.917	1.319	901.818	1.298
12	907.798	1.321	898.443	1.301
13	899.328	1.324	898.193	1.304
14	897.559	1.328	899.730	1.306

FRP: Fibre-Reinforced Polymer

Fig 1:Existing Building

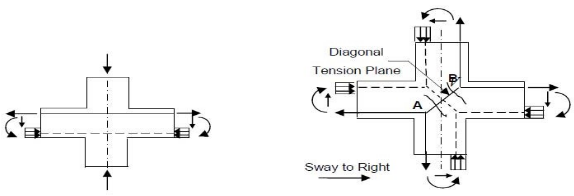

Fig 2:Interiorjoint of RC Beam-Column

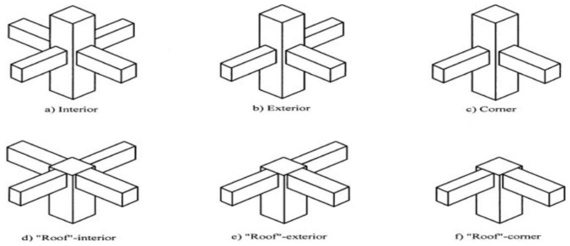

Fig 3: Beam - column joints in frames come in a variety of shapes and sizes.

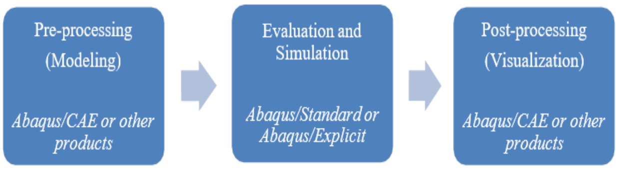

Fig 4: ABAQUS software order of use

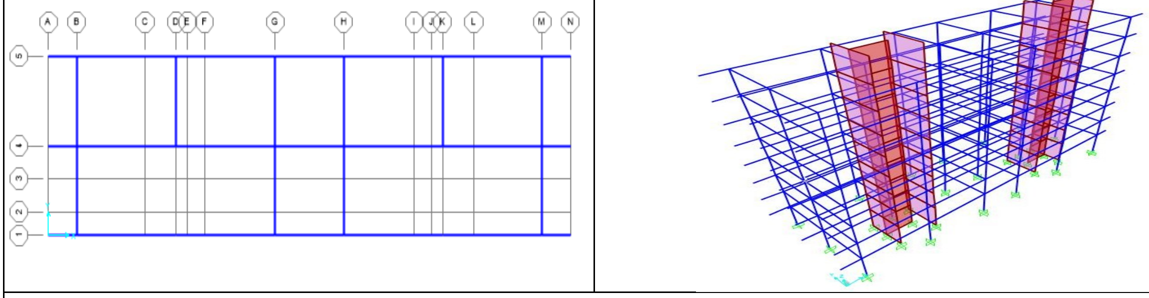

Fig 5: 3D view of the structure

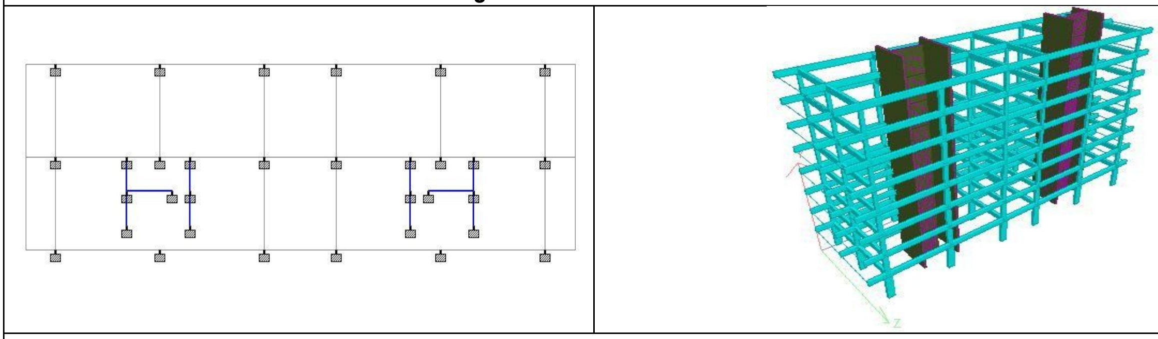

Fig 6 : STAAD. Pro Shear walls and other structural components may be seen in a 3D generated picture of the structure.

+X	+Y	-Y
☐	☐	☐
☐ Node - (A,2,2)	☐ Node - (B,2,2)	☐ Node - (A,2,8)
☐ Node - (A,2,3)	☐ Node - (B,2,3)	☐ Node - (C,2,8)
	☐ Node - (B,2,4)	☐ Node - (C,2,2)
	☐ Node - (C,2,3)	

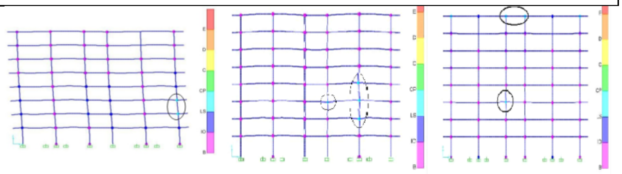

Fig 7:Critical Nodes

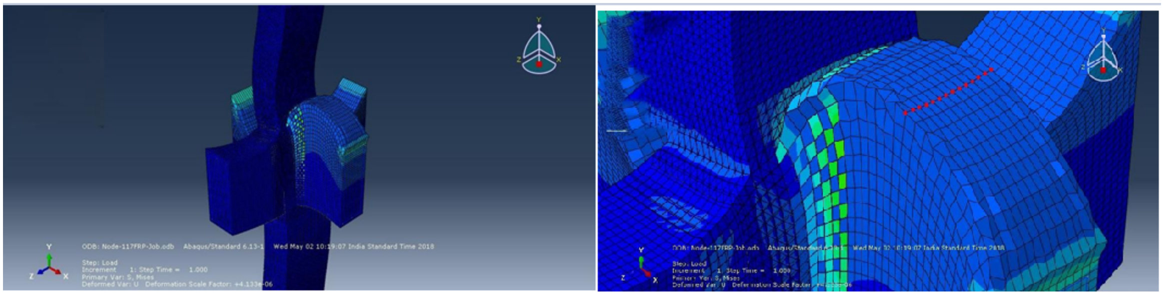

Fig. 8. Deformation after FRP Wrapping with zoomed

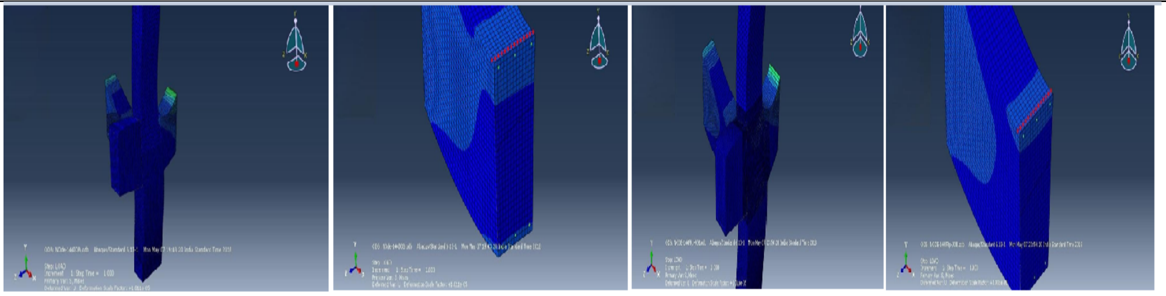

Fig 9: Node of Critical Importance (B,2,4) FRP, after an analysis and a zoomed-in image of the locations selected, Beam Column Joint with Wrapped Beam and After Correction, Zooming in on the Spots.

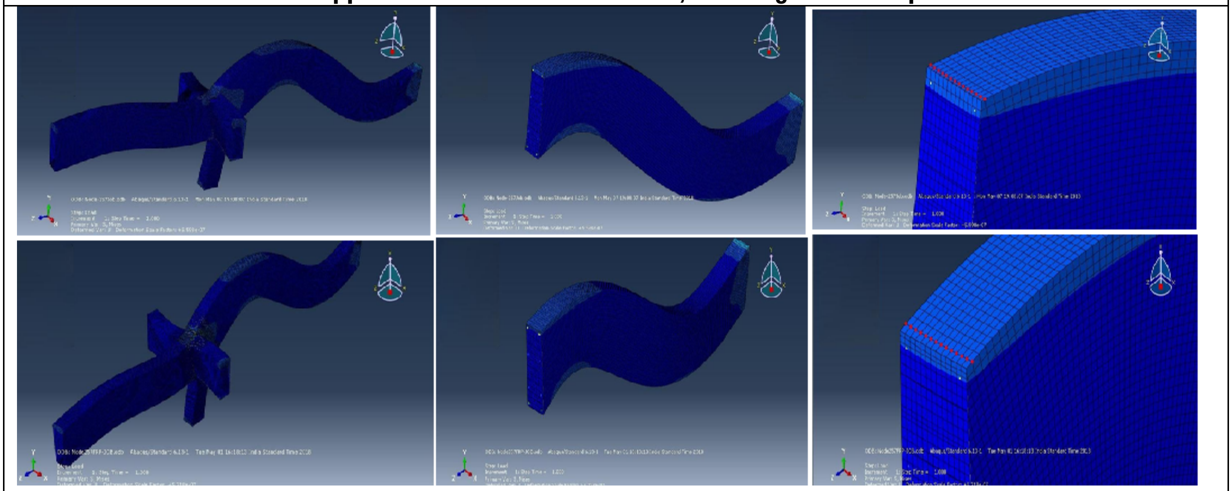

Fig 10 After analysis, the Critical Node (C,2,8) The same section is cut for further steps; the section is zoomed in view of the points chosen. The same section is cut out after the FRP Wrapping is applied; the section is zoomed in on the cut-out section;FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping; FRP Wrapped Beam Column Joint after FRP Wrapping.