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ANALYSIS OF BUILDING RETROFITTING WITH CFRP LAMINATES.

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ABSTRACT
Construction procedures in India lead to major problems that make retrofitting much more difficult. Structural engineers prioritize infrastructure that can withstand higher permitted loads and environmental hazards throughout the course of their service lifetimes. Some of the techniques used in retrofitting include fiber-reinforced polymer wrapping, steel jacketing, concrete jacketing, steel plating, and external pre-stressing. FRP systems are highly advantageous because to their low weight, non-magnetic nature, resistance to corrosion, and high tensile strength. We performed a Response Spectrum Analysis in our study to evaluate the effect of FRP wrapping on the deflection, bending moment, and shear force of reinforced concrete beams, as well as its impact on story drift and displacement in various seismic zones. According to the findings, FRP retrofitting significantly reduces story drift, displacement, and beam deflection in zones II and V. It also raises the bending moment and shear force carrying capability of FRP wrapped beams. These results also imply that, in general, zone-V continues to be the most successful seismic zone for CFRP retrofitting.

Key Word: Response Spectrum Analysis, FRP wrapping, ETABS.

1.Introduction

India's existing buildings are severely deficient against earthquake forces, with the number growing rapidly. Retrofitting these buildings is a complex task that requires skill, especially for reinforced concrete (RC) buildings due to their complex behaviour during earthquakes. The behaviour of the buildings depends on the size of members, reinforcement amount, and reinforcement placement and detailing. Construction practices in India result in severe defects, making retrofitting even more difficult. Structural engineers prioritize withstanding infrastructure in higher permissible loads and environmental hazards during their service life. Retrofitting can be done through concrete jacketing, steel jacketing, steel plating, external pre-stressing, and Fiber reinforced polymer wrapping.

These materials are popular due to their higher ultimate strengths, lower density, lesser self-weight, faster, easier, and economic installation, and higher durability. These composite materials can be added to structurally deficient members of reinforced concrete building structures. Fiber reinforced polymer (FRP) systems are lightweight, non-corrosive, non-magnetic, and have high tensile strength. They consist of carbon, glass, or aramid fibers and a polymer adhesive like epoxy, polyester, or vinyl-ester. The fibers and adhesive work together to absorb load from the original structure. FRP composites are suitable for retrofitting buildings due to their high tensile strength.

1.1 Carbon Fiber Reinforced Polymer (GFRP)

This composite material, combining carbon fibre strength with a polymer matrix, is used in various industries such as aerospace, automotive, medical, construction, and sports equipment. It offers high strength-to-weight ratio, high hardness, excellent corrosion resistance, electrical and thermal insulation, and low thermal expansion. However, it requires special fabrication techniques.

2.Literature

Abdulkhalik J. Abdulridha's (2024) study focused on the seismic response of a basement column part of an RC frame reinforced with carbon fiber reinforced plastic (CFRP). A computer model was developed to simulate the installation of CFRP sheathing on ground floor columns of multi-story RC structures. A detailed finite element (FE) model was created using ETABS commercial software, which was then used to apply external bonded FRP strengthening techniques in the reinforcement of beam column systems with CFRP sheets. The seismic performance of the structure was evaluated using non-linear time-history analysis. Four different structural models were verified, and experiments were conducted during the Irpinia-Basilicata, Loma Prieta, and Kobe earthquakes. The study also considered optimizing the thickness of CFRP sheets to improve column reinforcement. The results showed that CFRP significantly improved the seismic performance of RC structures, reducing maximum and residual displacements.

Natraj R. Kirthiga and S. Elavenil (2023), conducted a study on both multi-storey buildings having shear walls and without. The shear walls, which were crucial for the resistance of the lateral loads, needed a check on the drift, displacement, and time of storey movement. External bonded FRP techniques had been used in strengthening weakened beams and columns to improve their performance. This was achieved by retrofitting the concrete surfaces with Carbon Fibre Reinforced Polymer sheets. The findings revealed that these shear walls do indeed contribute significantly to reducing lateral sway, thereby reducing the potential for structural injuries. Additionally, it was observed that both drift and displacement of the storeys were within acceptable limits. By and large, the retrofitted beams produced a very high increase in moment resistance, while an improved load-carrying capacity was recorded for the newly added column.

Rain, Subedi, and Chaudhary (2023) uses the ETABS numerical tool to evaluate the performance of reinforced concrete beams. The study found that the moment-curvature behaviour of control, CFRP sheet jacketing, reinforced concrete (RC) jacketing, and steel jacketing beams can be used as retrofitting techniques after an earthquake. The moment carrying capacity of the beam increased with CFRP sheet, 100mm RC jacketing, and equal angle steel jacketing. The beam with RC jacketing had the maximum moment carrying capacity. Steel jacketing had slightly less capacity but good ductility. When retrofitted with CFRP sheet, the moment-carrying capacity increased but had a brittle failure. The study is significant for researchers and design engineers in structural engineering to accurately evaluate seismic performance and design reinforced concrete structures with suitable retrofitting techniques.

Amjad Al-Mudhafer's (2021) study evaluated inter-frame wall structures retrofitted using materials like FRP and steel jackets to assess their resilience in earthquakes. He used four models: Simple, Brick, FRP, and Steel Jacket, to determine the best column retrofitting method for half-interframe walls. The results showed that short shafts wrapped in steel jacketing or FRP fibers significantly increased shear strength and earthquake resistance by 3% to 40%. Brick walls also enhanced column load-carrying capacity against static and seismic loads by absorbing and damping some loads, reducing the risk of column damage during sudden loads. The study concluded that FRP and steel jacket retrofits near and at the ends of column spans over concrete frames are the best states for retrofitting, not only minimizing column damage susceptibility but also enhancing static and seismic resistance, improving structural safety and resilience.

K.P. Adhikari G.P. Lamichhane K. Lamichane, and C. Gimire (2021), conducted a project to develop iron concrete and glass-plastic coverings for collapsed columns in an existing building in Nepal. The research aimed to compare the efficiency of modernization techniques and establish the effectiveness of two different techniques in strengthening weakened elements. Traditional buildings in Nepal are easier to damage, and proper construction supervision during post-earthquake inspections is crucial. Strategic planning was necessary for the design and analysis of the building, considering economy, safety, financial losses, and project completion delays. The study assessed the strength and properties of the structural elements, recommending retrofitting measures with concrete jacketing and fiber wrap polymers to improve the capacity of deficient columns. The data collected was analyzed using finite element programs and ETABS 2017. The most appropriate retrofitting techniques were found to be concrete jacketing and FRP sheets, with columns divided based on their capacity for specific retrofitting techniques.

Anuj Chandra and Ganesh Jaiswal (2021) conducted research on the characteristics of composite materials and their applications in enhancing the strength and durability of existing structures through retrofitting. They found that fiber-reinforced composite materials have a longer life than steel-reinforced ones, and therefore, they prefer using fiber-reinforced materials. The least stiff composite material is fiber-reinforced polymer, while the stiffest is steel-reinforced. Fiber-reinforced polymer composite material excels in story displacements and drifts, but may exceed steel in base shear lateral loads. The researchers evaluated the mechanical properties and structural behaviour of retrofitted structures using the ETABS software. Their study compares the effectiveness of steel retrofitting with composite materials in strengthening existing structures.

Hussein Kareem Sultan and Alaa T. Mohammed (2020) discuss the role of Fiber-reinforced polymer (FRP) in strengthening reinforced concrete structures. They suggest that designers should understand the response modification factor (R) and ductility coefficient (μ) to improve the strength and efficiency of reinforced beams. The study tested a formula for measuring plasticity in concrete structures using three concrete moment frames with and without composite FRP reinforcement. FRP plates and repair tools were found to increase beam capacity, strength, and service life, reducing beam failure primarily due to main reinforcement fracture. FRP significantly altered behaviour for high-rise structures, enhancing seismic performance and making it a critical requirement for improved safety and structure performance.

Sabrin and Siddique (2018) used ETABS v.9.6.0 to analyse seismic performance criteria for moment-resisting RC frames retrofitted with different levels of FRP additions. The results showed significant improvements in load-carrying capacity and displacement at failure compared to frames without FRP addition. The inter-story drift index at any floor level was significantly reduced for retrofitted frames with the same base shear capacity as the bare frame. The study recommends selecting a retrofitting scheme based on project or design engineer needs. However, localized failures may decrease displacement capacity at failure, so retrofitting schemes should avoid localized collapse scenarios. Inter-story drift indexes remained within the life safety performance level for any selected frame. Engineers should evaluate different retrofitting schemes before making decisions.

Theint Thu Soe, San Yu Khaing (2014), is primarily concerned with the renovation of a twelve-story building made of reinforced concrete. Zone 2B is the location of the building under plan, and ETABS was utilized for both the design and analysis. Due to a stronger seismic force in zone 3, the retrofitting target for the building's seismic resistance capabilities is set. Externally bonded fiber-reinforced polymer, or FRP EBR, is used to reinforce weak beams and columns in shear, flexural, and confinement scenarios utilizing FRP analysis software. The ETABS software provides the necessary data for FRP analysis through an interface between the programs. The data that is created includes cross-section geometry, concrete mean strength, and additional shear. The foundations for reinforcing weakened columns and beams include simple installation, low weight, strong resistance, durability, and resistance to corrosion.

3.Objectives

- To analyse the influence of FRP wrapping on the phenomenon of storey drift and displacement of storeys for different earthquake zones.
- To assess the impact of FRP wrapping on the deflection of beams, bending moment and shear force of reinforced concrete beams for different earthquake zones.

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4.Methodology

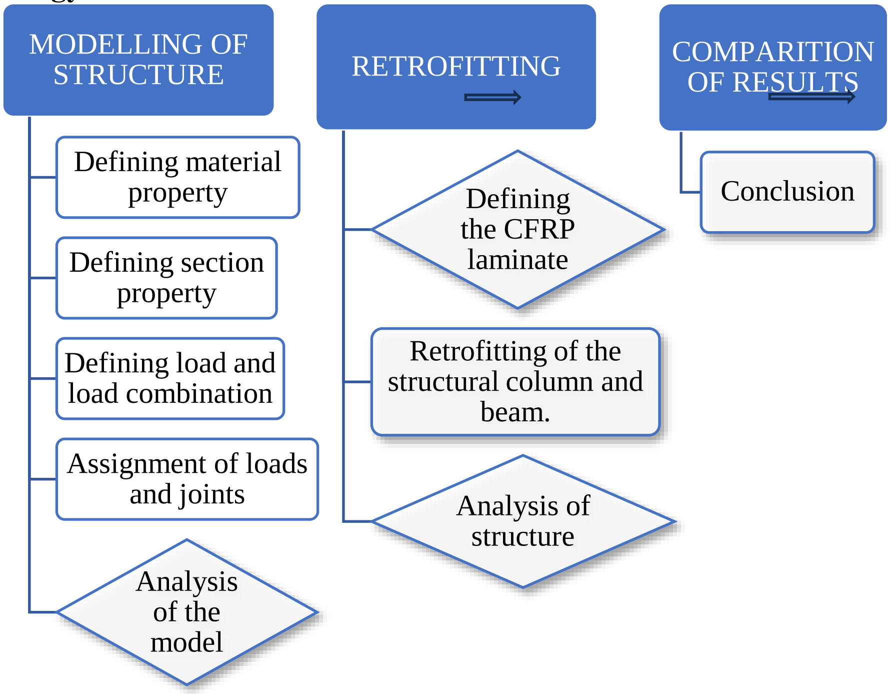

Fig.-1: Flow chart of methodology.

4.1 Details of model considered

Table -1: Structural details considered in this work

1	Building type	RCC framed structure
2	No. of storeys	G+6
3	Plan area	20 X 24 m
4	Height of storey	3.15 m
5	Beams B1 B2	 750x300 mm 300x300 mm
6	Columns C1 C2 C3	 300X600 mm 300x900 mm 300x1000 mm
7	Type of structure	Commercial building

Table -2: Load considered as per IS 875:2015

1	Dead load	Self-weight of Beam, Column and Slab
2	Live load on slab	4 kN/m^2
3	Floor finish	1.5 kN/m^2
4	Wall load	12 kN/m^2
5	Parapet wall load	6 kN/m^2

Table -3: Seismic Loads as per IS 1893:2016

No	Zone	Zone Factor	Response Reduction Factor	Importances Factor	Soil type
1	II	0.10	3 (OMRF)	1.5	II
2	V	0.36	3 (OMRF)	1.5	II

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Table -4: Wind Load as per IS 875:2015 Part-III

Terrain category	2
Wind speed	33 m/s
Risk coefficient factor	1
Topography factor	1
Importance factor	1

4.2 Modelling of RCC framed structure

Following are the steps involved in the process of modelling the structure.

- Model initialization.
- Defining grid system data.
- Defining the story data.
- Defining the material property data.
- Defining section property data.
- Assigning section property.
- Defining the load pattern.
- Defining the response spectrum.
- Analysing the structure for defined load cases.

4.3 Response Spectrum Analysis (RSA)

Response Spectrum Analysis (RSA) principle is to find the maximum response for each mode of the structure and combine those responses using a suitable method like SRSS, resulting in the required response for the entire structure. Structural analysis can be linear or non-linear, with linear analysis focusing on the direct relationship between force and deformation. It can be static or dynamic, with static analysis indicating constant external force or load over time, while dynamic analysis involves force varying over time. Static analysis is considered equivalent in most building codes, while dynamic analysis is used for seismic loading. Response spectrum analysis (RSA) is a useful and recommended method for non-symmetrical structures in building codes.

The response spectrum analysis in ETABS involves the following steps.

1. Modelling of structure.
2. Define load cases for RSA.
3. Run the analysis.
4. Check the model results.
5. Compare the results.

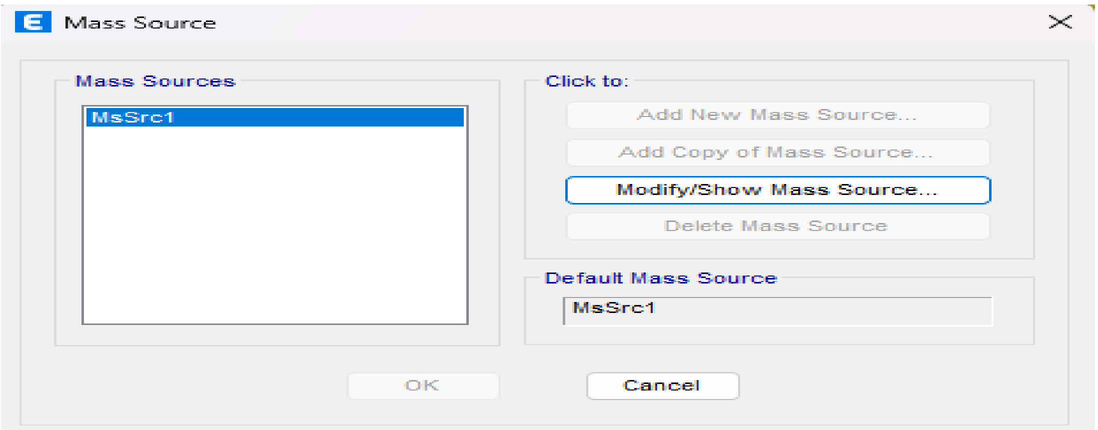

Fig.-2: Definition of mass source

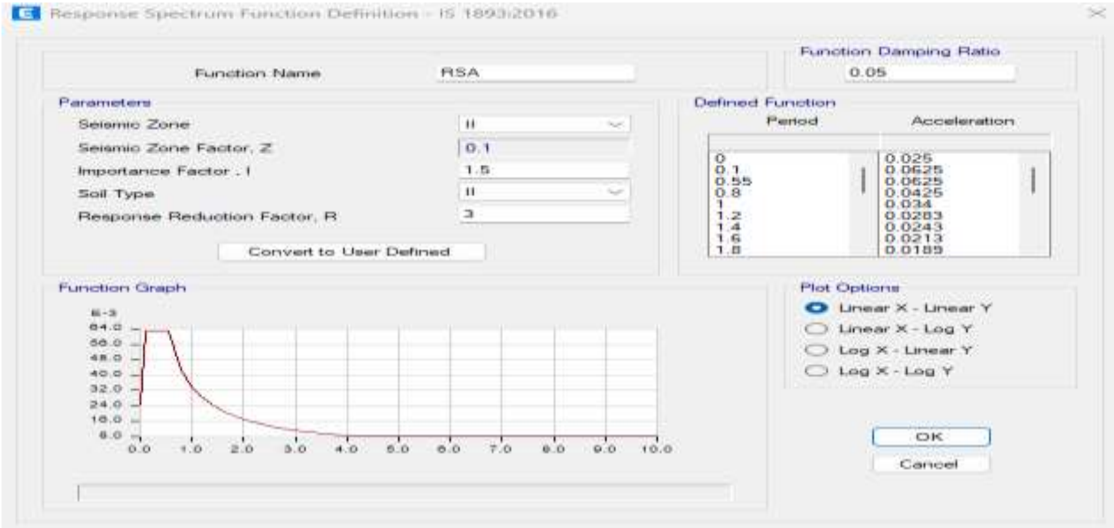

Fig.-3: Response Spectrum Function definition

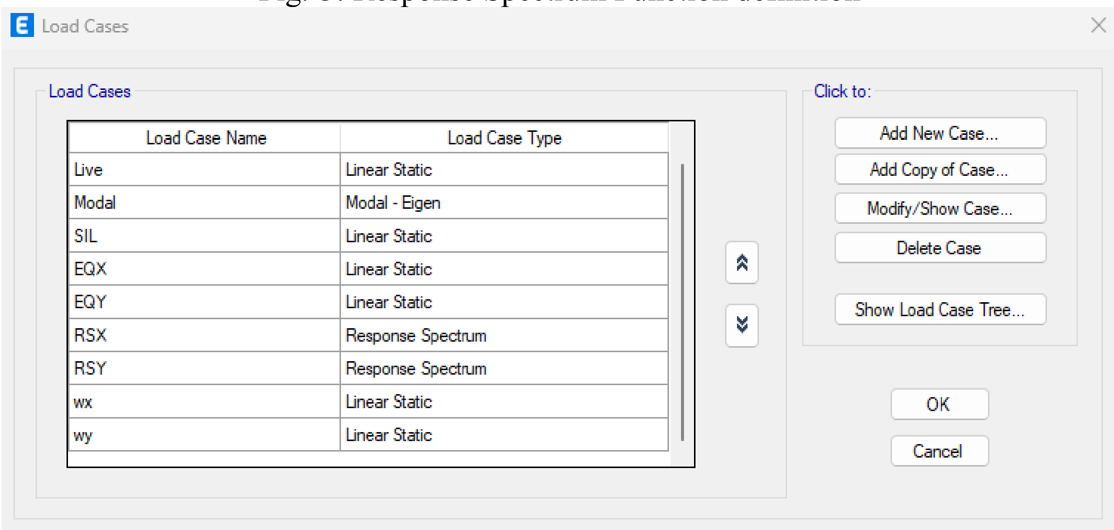

Fig.-4: Load cases for Response Spectrum Analysis

4.4 Retrofitting of RCC framed structure

Retrofitting of the structures involves the following steps:

1. Defining the FRP material.
2. Retrofitting of section using section designer

Following are the material properties of the CFRP laminate using in this project.

Table -5: Material properties of CFRP laminate

Fiber	Thickness (mm)	Weight density (Kg/m^3)	Tensile Strength (MPa)	Young's Modulus (MPa)	Shear Modulus (MPa)	Fiber Elongation (%)
CFRP	1.2	2000	1034	227500	76900	2.1

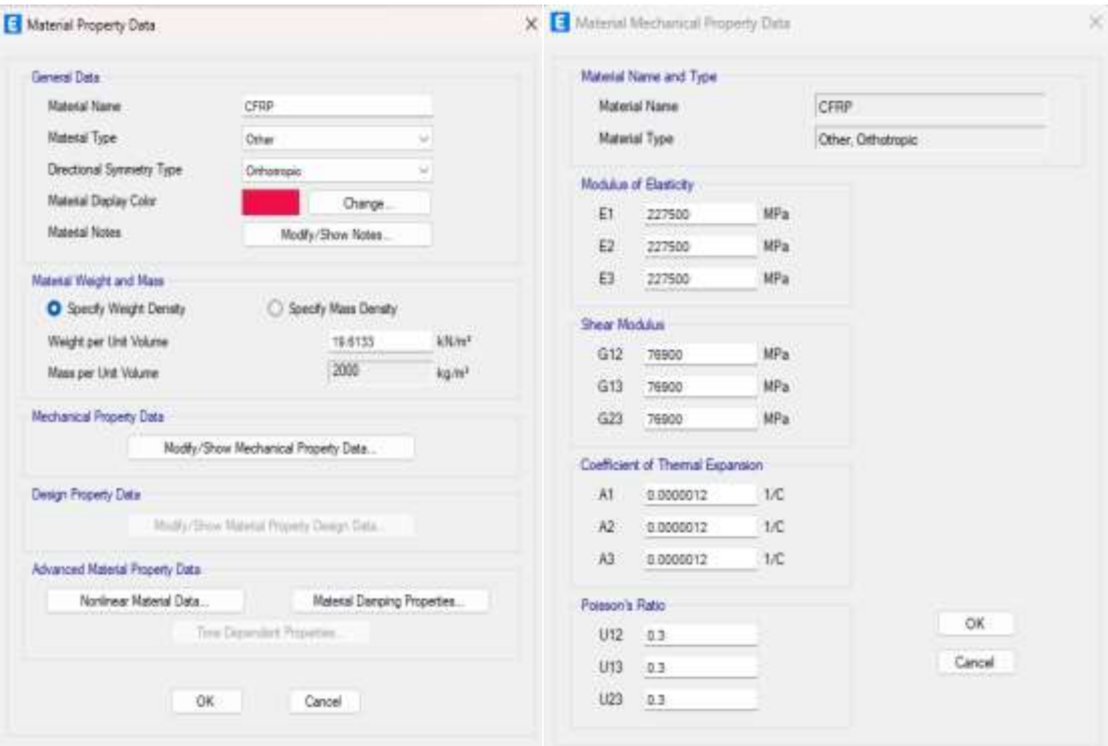

Fig.-5: Material properties of CFRP laminate

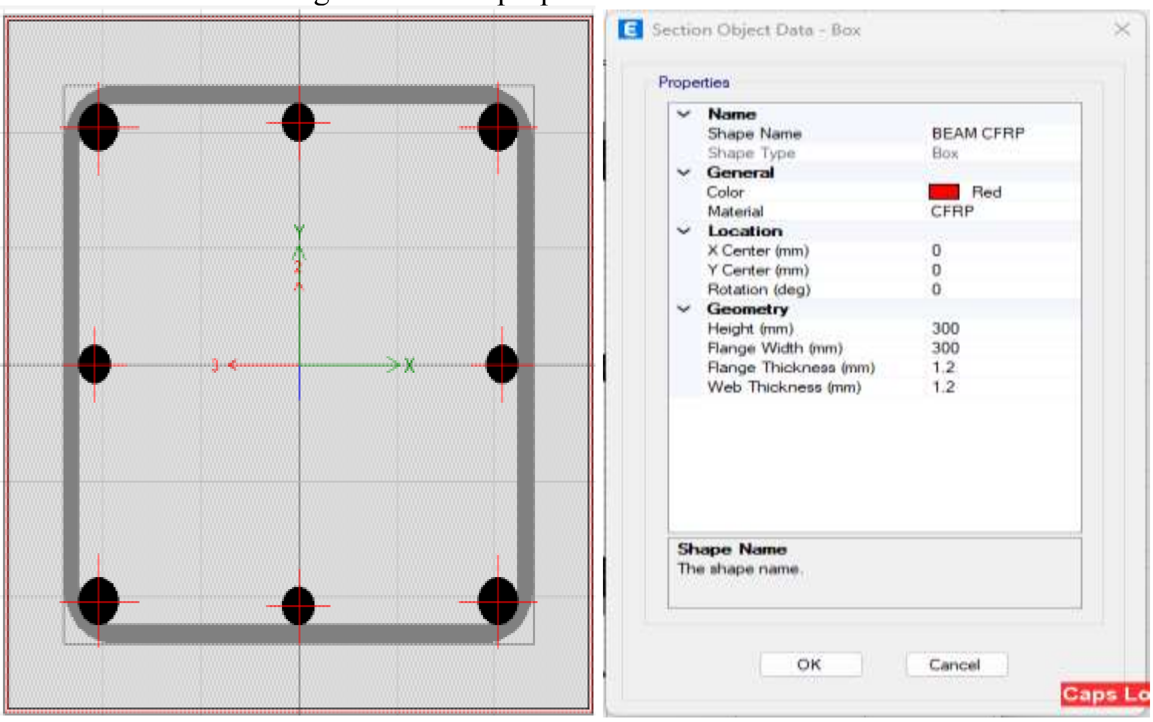

Fig.-6: Retrofitting of section using section designer

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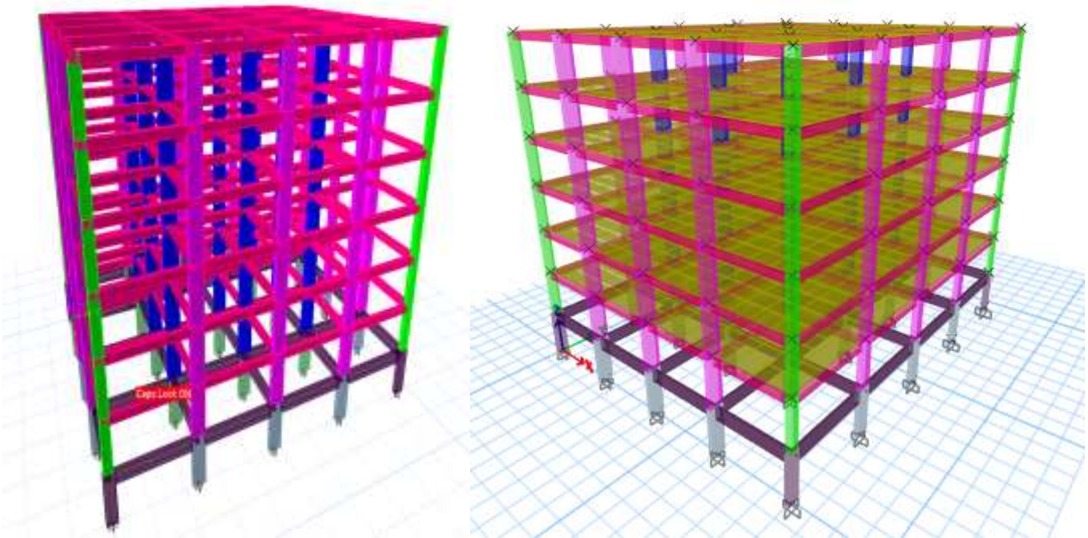

Fig.-7: Rendered viewe of FRP wrapped structure

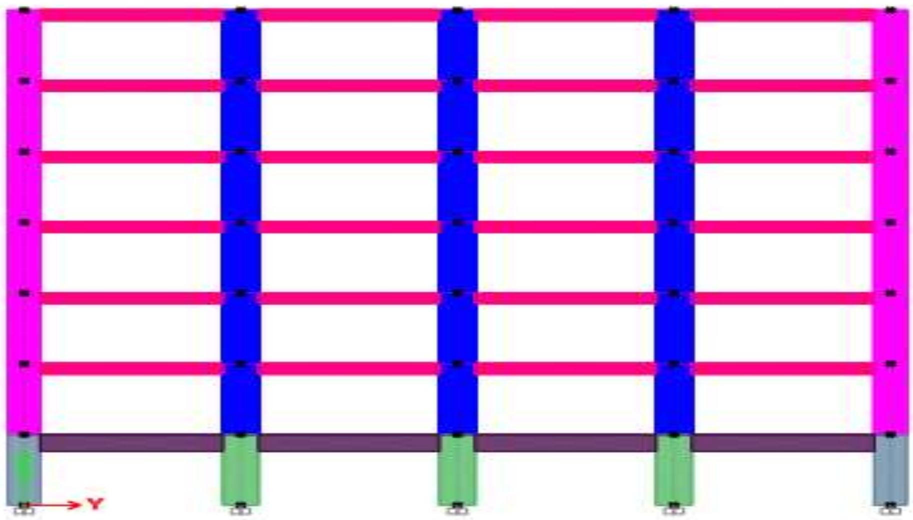

Fig.-8: Elevation at C-C

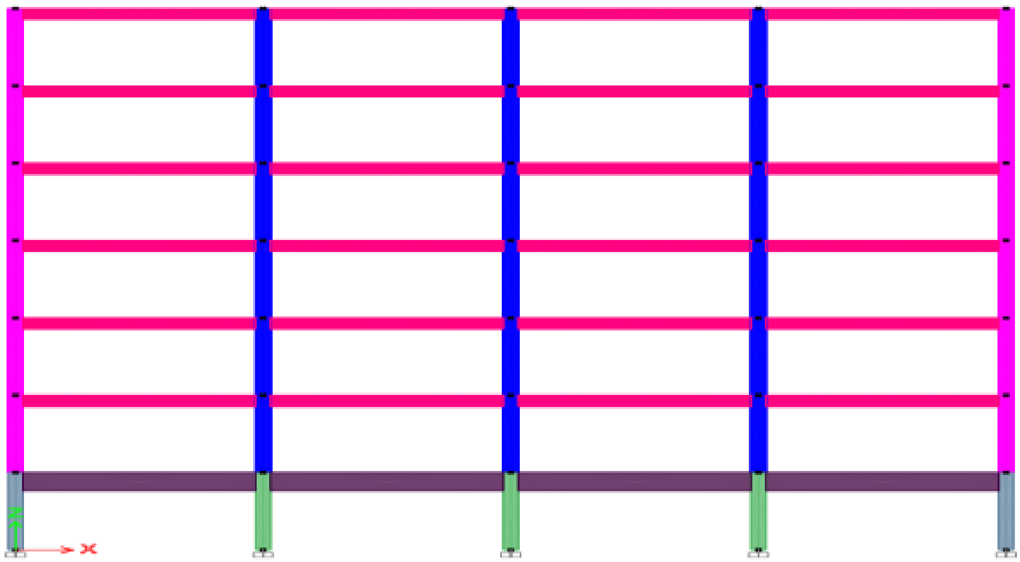

Fig.-9: Elevation at 3-3

5.Results and discussion

Following tables shows the comparison of story results obtained from the models with and without FRP wrapping after performing the response spectrum analysis in zone -II

Table -6: Maximum storey displacement in zone - II

Story	X-Direction		Y- Direction	
	With FRP	Without FRP	With FRP	Without FRP
Story6	11.286	11.837	9.102	9.613
Story5	10.574	11.063	8.062	8.401
Story4	9.311	9.711	6.721	6.926
Story3	7.541	7.802	5.094	5.186
Story2	5.361	5.45	3.308	3.316
Story1	2.66	2.945	1.413	1.59
GF	1.002	1.081	0.351	0.439
Base	0	0	0	0

Table -7: Maximum storey drift in zone-II

Story	X-Direction		Y- Direction	
	With FRP	Without FRP	With FRP	Without FRP
Story6	0.000255	0.000283	0.000341	0.000397
Story5	0.000435	0.00047	0.000436	0.00048
Story4	0.000587	0.000638	0.000524	0.000561
Story3	0.000706	0.000764	0.000571	0.000598
Story2	0.000768	0.000802	0.000541	0.000549
Story1	0.000599	0.000607	0.000374	0.000368
GF	0.000356	0.000343	0.000143	0.000139
Base	0	0	0	0

Following tables shows the comparison of storey results obtained from the models with and without FRP wrapping after performing the response spectrum analysis in zone -V

Table -8: Maximum storey displacement in zone -V

Story	X-Direction		Y- Direction	
	With FRP	Without FRP	With FRP	Without FRP
Story6	39.93	42.612	32.51	34.605
Story5	37.424	39.826	28.823	30.245
Story4	32.977	34.961	24.06	24.934
Story3	26.745	28.087	18.267	18.669
Story2	19.063	19.62	11.896	11.937
Story1	10.602	10.601	5.832	5.722
GF	4.091	3.892	1.649	1.579
Base	0	0	0	0

Table -9: Maximum storey drift in zone -V

Story	X-Direction		Y- Direction	
	With FRP	Without FRP	With FRP	Without FRP
Story6	0.000896	0.001017	0.001208	0.001429
Story5	0.001528	0.001694	0.001548	0.001729
Story4	0.002067	0.002296	0.001863	0.002018

Story3	0.002487	0.00275	0.002036	0.002152
Story2	0.002706	0.002886	0.001935	0.001978
Story1	0.002119	0.002186	0.001348	0.001325
GF	0.001299	0.001236	0.000523	0.000501
Base	0	0	0	0

Comparison of beam results at zone – II

Table -10: Comparison of shear force before and after wrapping in C-C direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Increase
B9	66.19	81.26	22.7678
B10	63.27	78.36	23.8502
B11	62.766	78.04	24.3348
B12	81.53	95.38	16.9876

Table -11: Comparison of shear force before and after wrapping in 3-3 direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Increase
B29	72.54	87.48	20.5955
B30	68.56	83	21.0618
B31	68.95	83.41	20.9717
B32	74.74	88.01	17.7549

Table -12: Comparison of bending moment before and after wrapping in C-C direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Increase
B9	28.98	37.47	22.6581
B10	22.41	32.09	30.1652
B11	22.41	32.09	30.1652
B12	28.96	37.47	22.7115

Table -13: Comparison of bending moment before and after wrapping in 3-3 direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Increase
B29	25.95	34.65	25.1082
B30	23.49	30.51	23.0088
B31	23.49	30.51	23.0088
B32	25.95	34.65	25.1082

Table -14: Comparison of deflection before and after wrapping in C-C direction.

Beam	Without FRP Wrapping	With FRP Wrapping	% Decrease
B9	3.56	2.13	40.1685
B10	2.59	1.5	42.0849
B11	2.593	1.55	40.2237
B12	3.58	2.16	39.6648

Table -15: Comparison of deflection before and after wrapping in 3-3 direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Decrease
B29	2.65	1.6	39.6226
B30	1.868	1.12	40.0428
B31	1.79	1.09	39.1061
B32	2.65	1.58	40.3774

Comparison of beam results at zone – V

Table -16: Comparison of shear force before and after wrapping in C-C direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Increase
B9	96.42	116.41	20.7322
B10	92.8	113.16	21.9397
B11	92.38	112.95	22.2667
B12	107.24	125.49	17.0179

Table -17: Comparison of shear force before and after wrapping in 3-3 direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Increase
B9	108.9	131.8	21.0285
B10	103.27	125.04	21.0807
B11	104	125.85	21.0096
B12	109.41	129.22	18.1062

Table -18: Comparison of bending moment before and after wrapping in C-C direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Increase
B9	29.14	42.24	31.0133
B10	23.39	36	35.0278
B11	23.39	36	35.0278
B12	29.14	42.24	31.0133

Table -19: Comparison of bending moment before and after wrapping in 3-3 direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Increase
B9	32.51	47.34	31.3266
B10	24.14	36.56	33.9716
B11	24.14	36.54	33.9354
B12	32.51	47.34	31.3266

Table -20: Comparison of deflection before and after wrapping in C-C direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Decrease
B9	3.49	2.09	40.1146
B10	3.56	2.15	39.6067
B11	3.56	2.19	38.4831
B12	3.49	2.08	40.4011

Table -21: Comparison of deflection before and after wrapping in 3-3 direction

Beam	Without FRP Wrapping	With FRP Wrapping	% Decrease
B29	3.109	1.85	40.4953
B30	3.24	1.95	39.8148
B31	3.244	1.96	39.5808
B32	3.109	1.85	40.4953

Graphical representation of storey response in zone - II

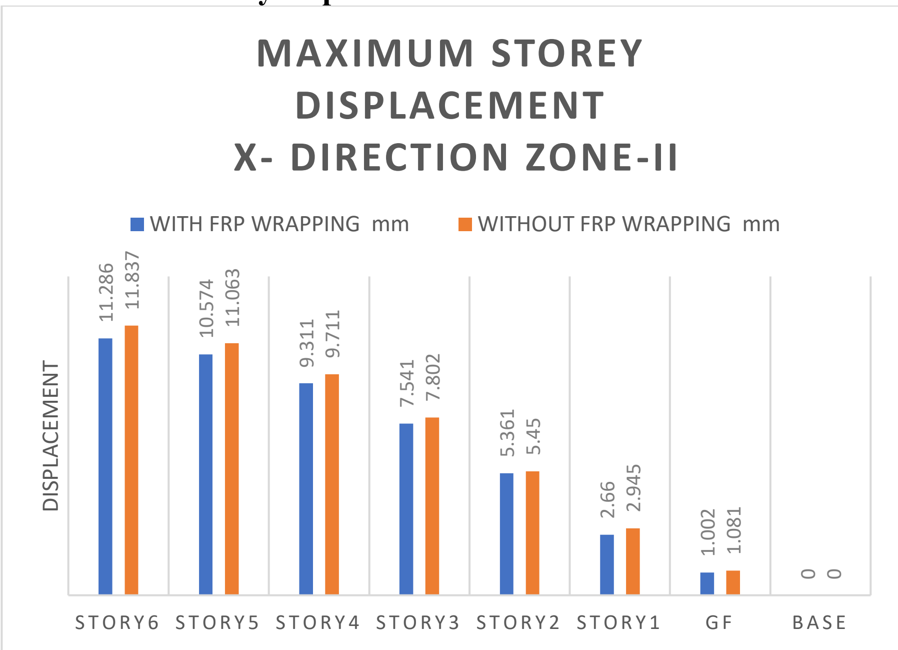

Fig.-10: Maximum storey displacement in X-direction at zone – II

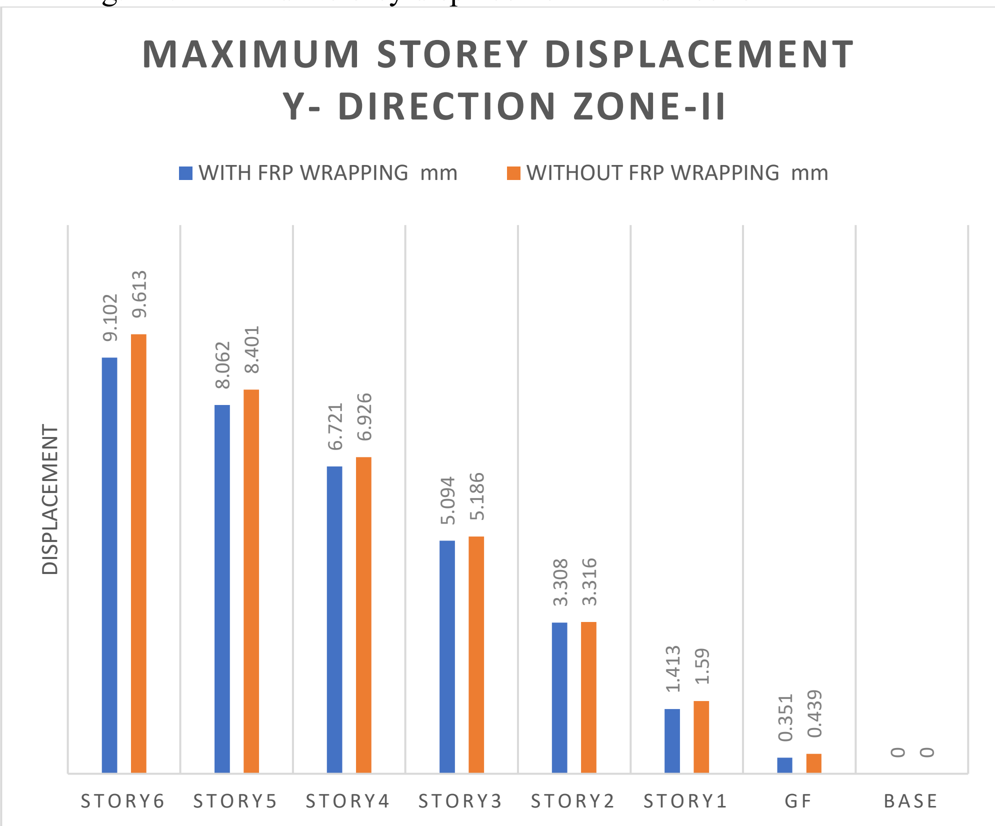

Fig.-11: Maximum storey displacement in Y-direction at zone – II

Table-6 indicates that the structure with FRP wrapping had a lower maximum storey displacement in both the X and Y directions than the structure without FRP wrapping. This is seen in Figures 10 and 11.

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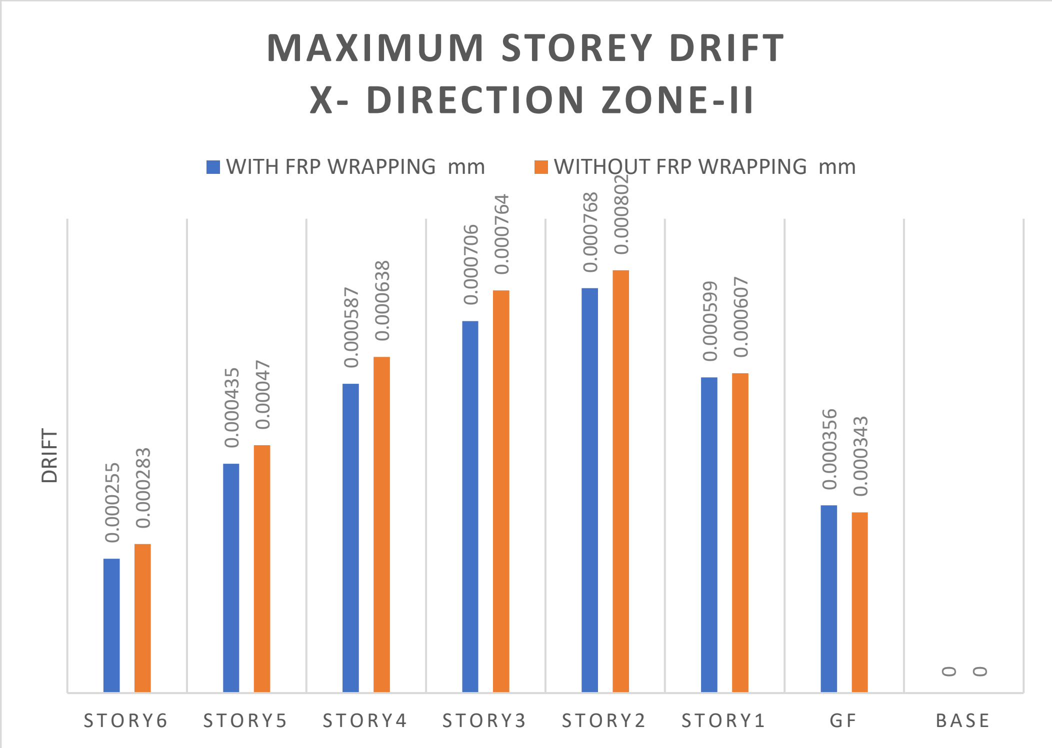

Fig.-12: Maximum storey drift in X-direction at zone - II

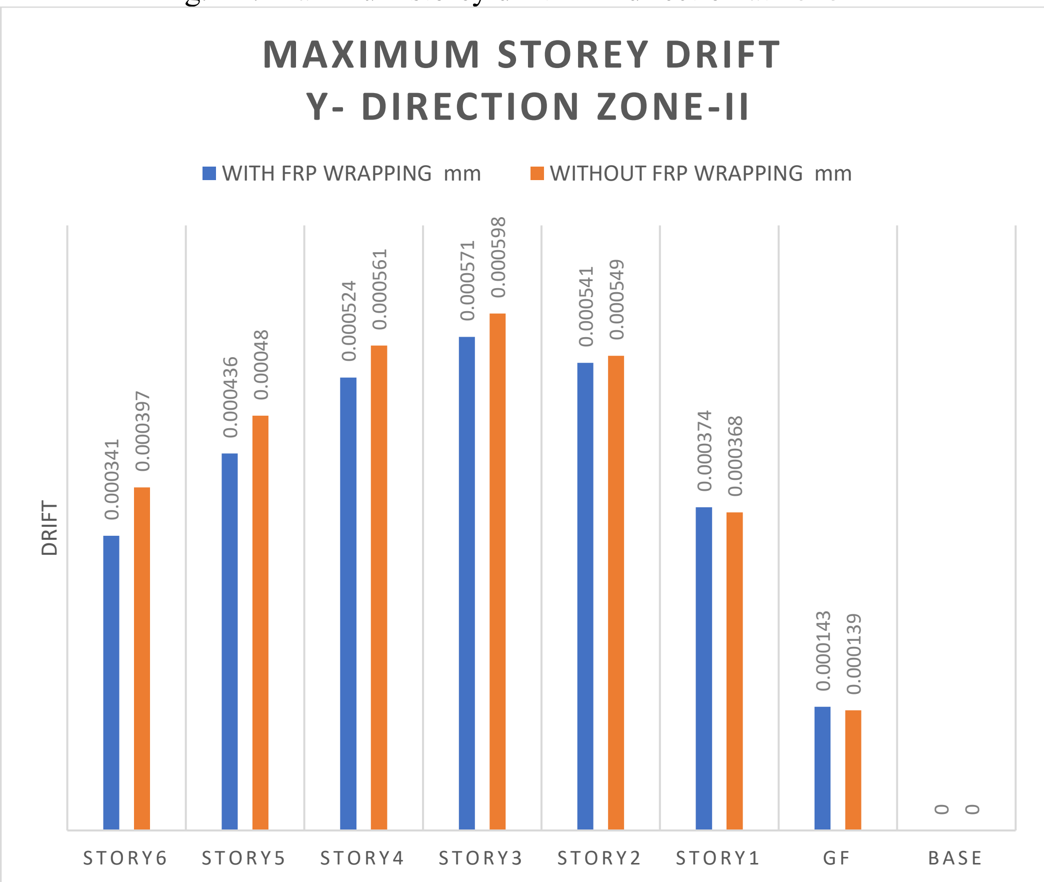

Fig.-13: Maximum storey drift in Y-direction at zone – II

Table 7 shows that, in comparison to the structure without FRP wrapping, the structure with FRP wrapping exhibited a reduced maximum storey drift in both the X and Y directions. Figures 12 and 13 show this.

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Graphical representation of storey response in zone - V

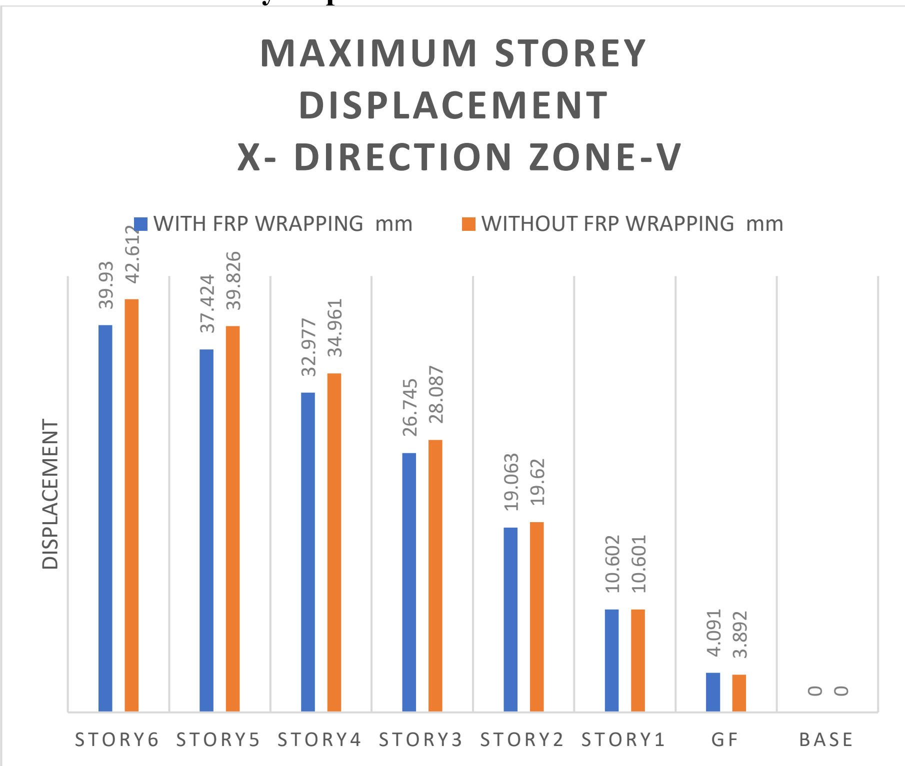

Fig.-14: Maximum storey displacement in X-direction at zone – V

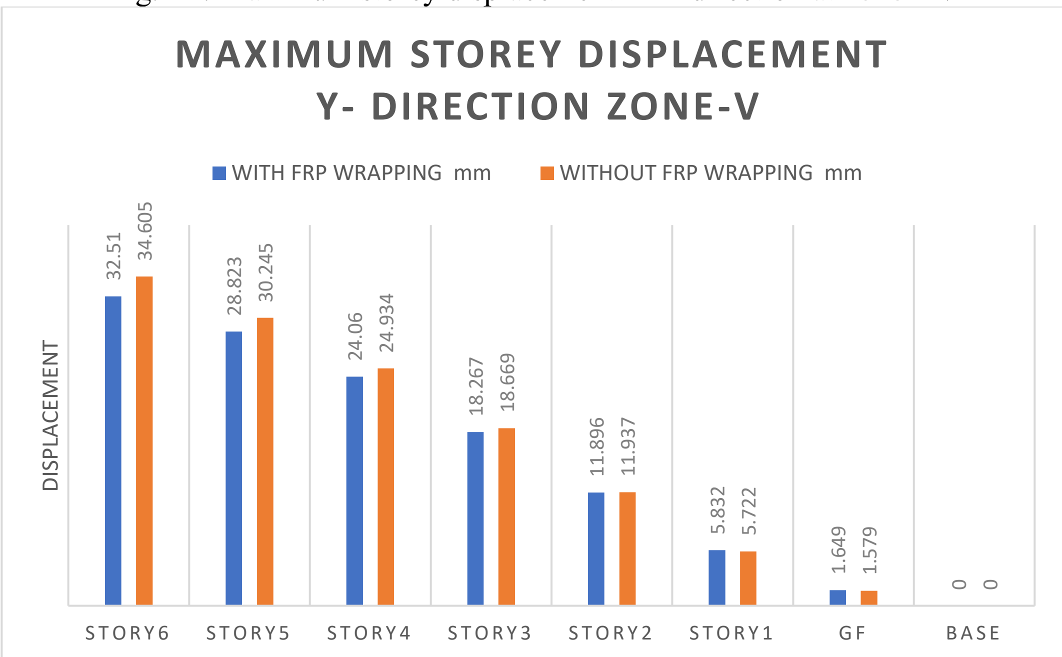

Fig.-15: Maximum storey displacement in Y-direction at zone – V

Table 8 shows that the maximum storey displacement of the FRP-wrapped building was less than that of the non-wrapped structure in both the X and Y directions. The figures 14 and 15 illustrate this.

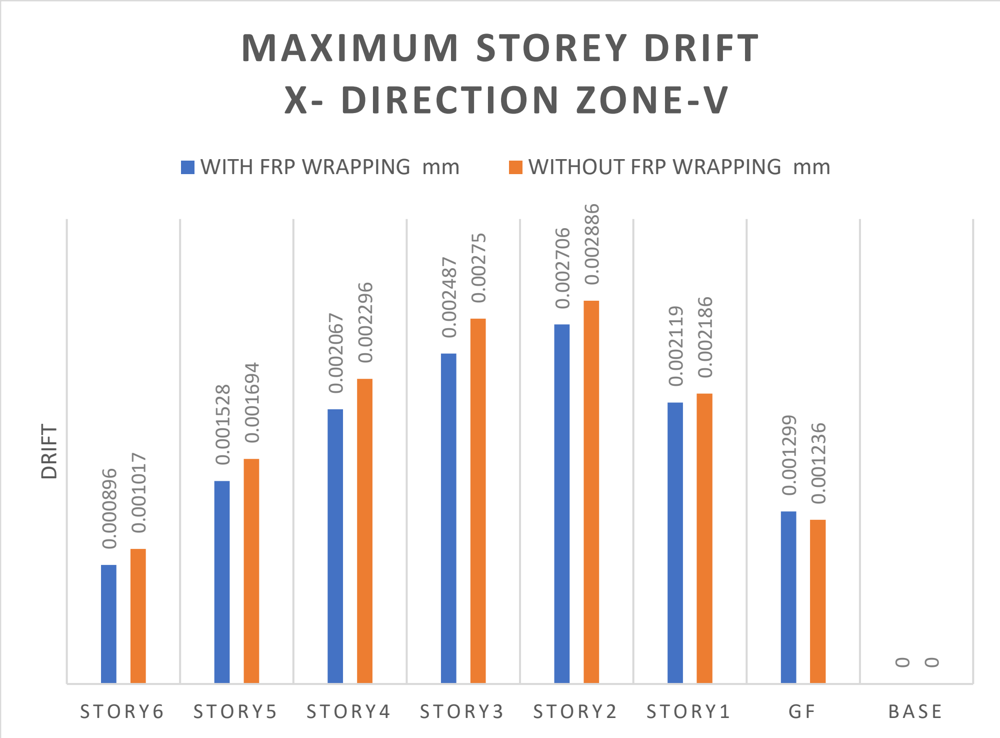

Fig.-16: Maximum storey drift in X-direction at zone – V

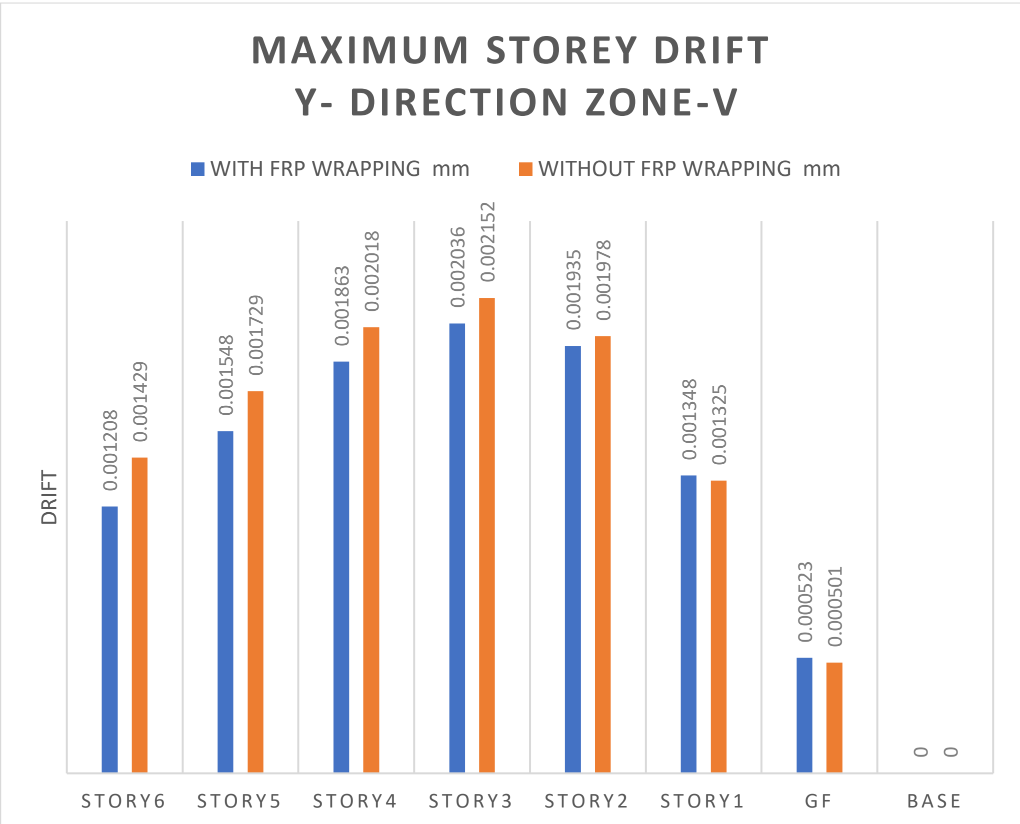

Fig.-17: Maximum storey drift in Y-direction at zone – V

Table 9 demonstrates that, in both the X and Y directions, the structure with FRP wrapping showed a decreased maximum storey drift in comparison to the building without FRP wrapping. This is given in Figures 16 and 17.

Graphical representation of beam results in zone - II

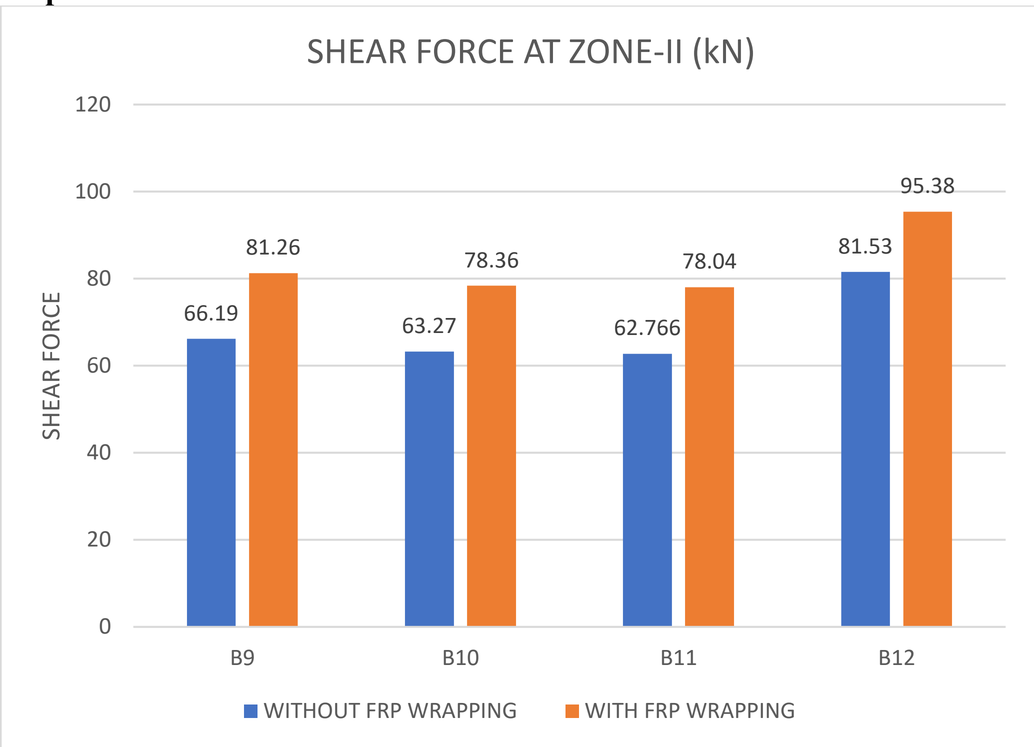

Fig.-18: Comparison of shear force before and after wrapping in C-C direction

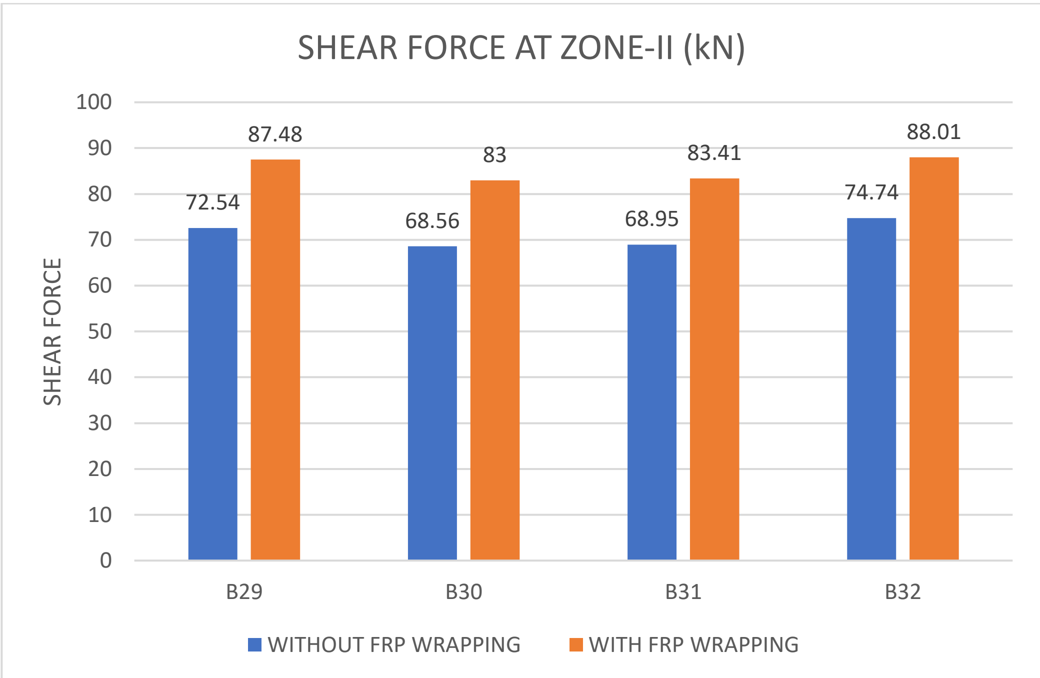

Fig.-19: Comparison of shear force before and after wrapping in 3-3 direction

Figures 18 and 19 illustrate the amount of shear force that is enhanced in the beam with FRP wrapping in zone II as compared to the beam without FRP wrapping, as indicated by Tables 10 and 11. In the beam at section C-C, the average increase in shear force is 20.98%, while in the beam at section 3-3, it is 20.09%.

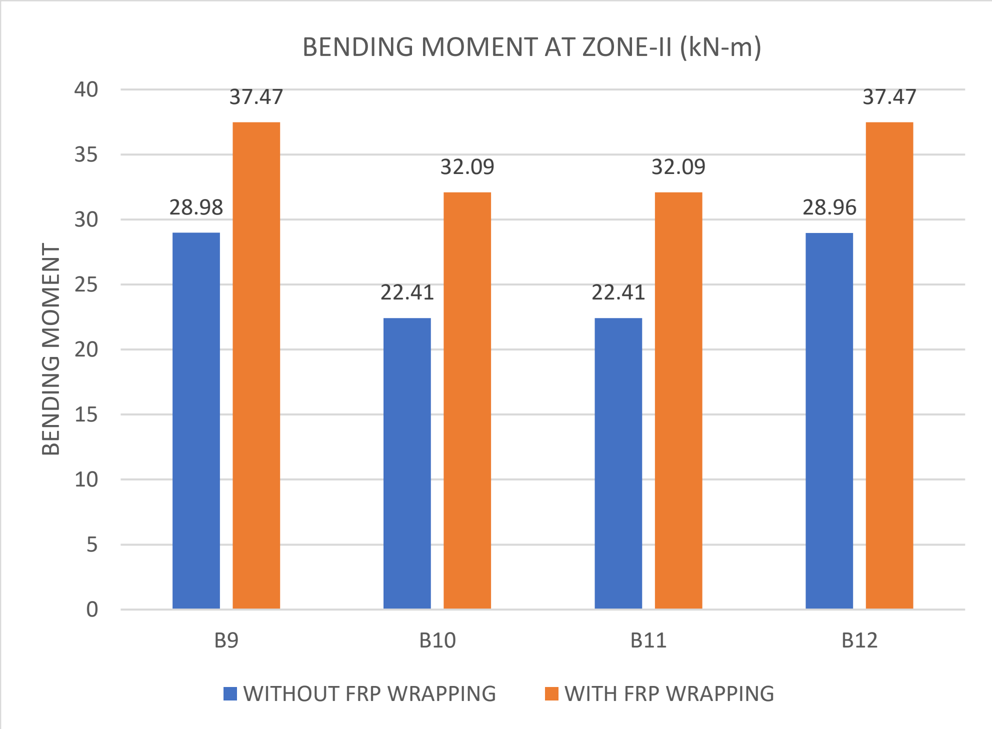

Fig.-20: Comparison of bending moment before and after wrapping in C-C direction

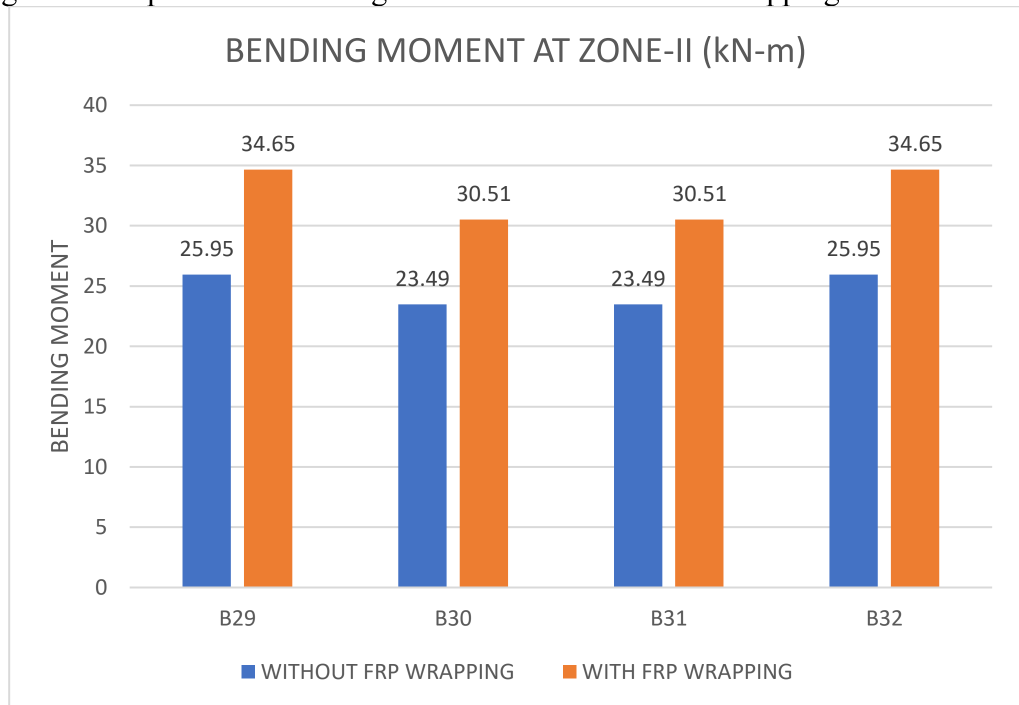

Fig.-21: Comparison of bending moment before and after wrapping in 3-3 direction

The amount of bending moment that is enhanced in the zone II beam with FRP wrapping compared to the beam without FRP wrapping is displayed in Table 12 and 13, as well as in Figures 20 and 21.the average bending moment increase in the beams at sections C-C and 3-3 was 26.42% and 24.05%, respectively.

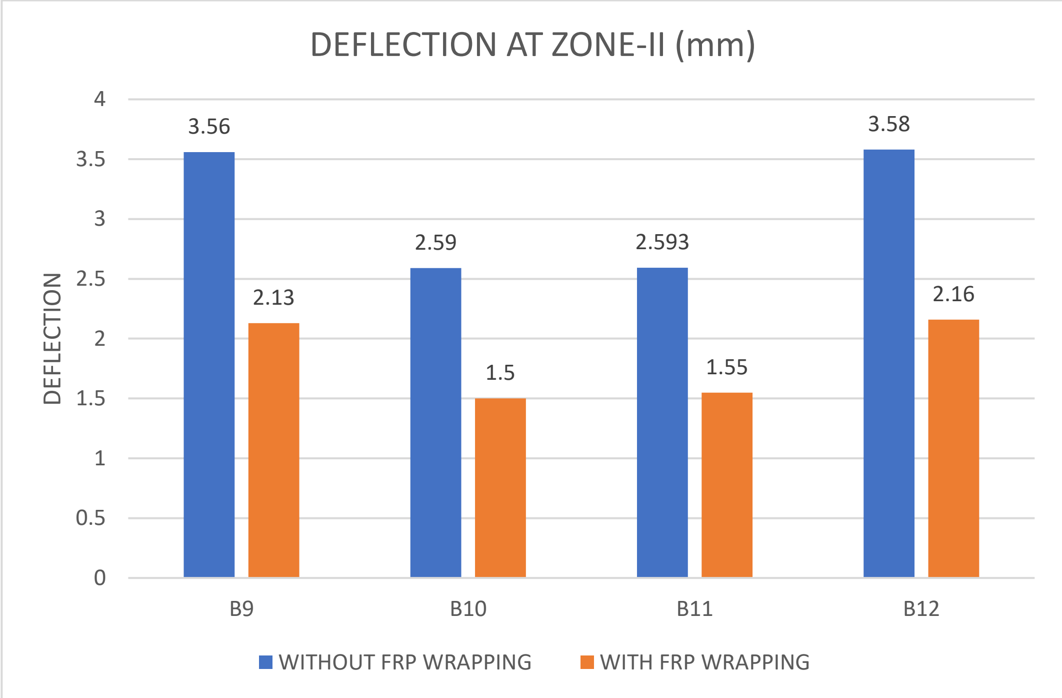

Fig.-22: Comparison of deflection before and after wrapping in C-C direction

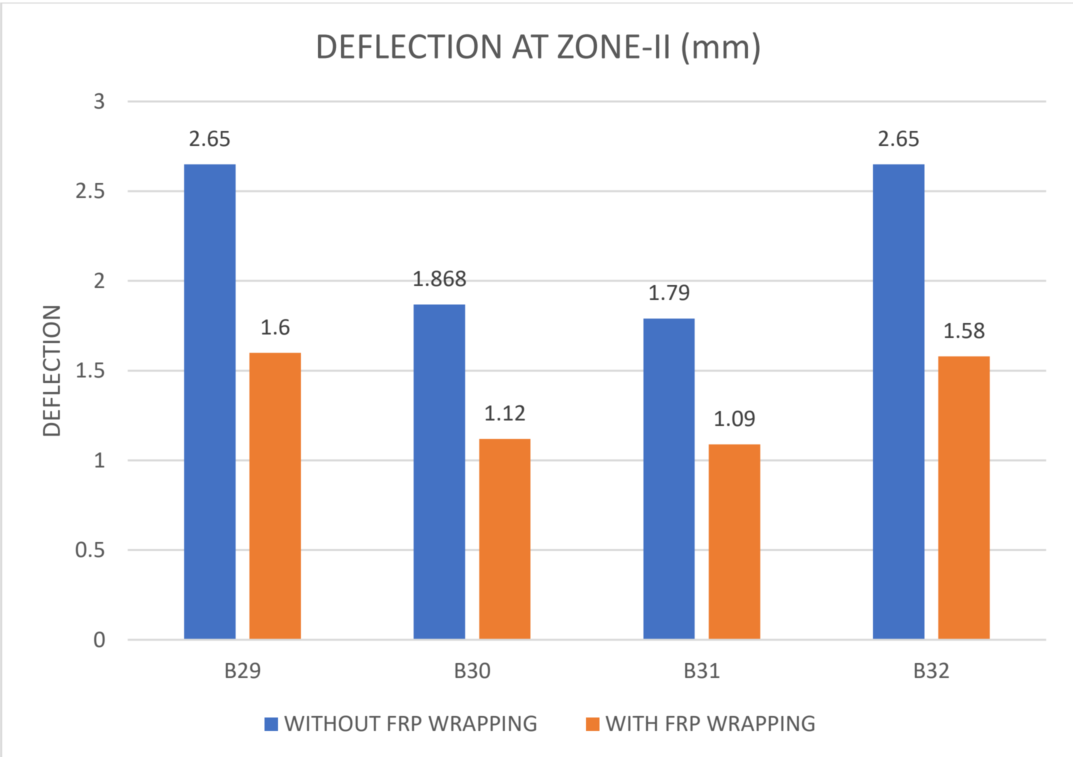

Fig.-23: Comparison of deflection before and after wrapping in 3-3 direction

Figures 22 and 23 depict the amount of deflection that is decreased in beams with FRP wrapping in zone II when compared to beams without FRP wrapping, as indicated by Tables 14 and 15.the average deflection decrease was 40.09% in the beam at section 3-3 and 39.65% in the beam at section C-C.

Graphical representation of beam results in zone - V

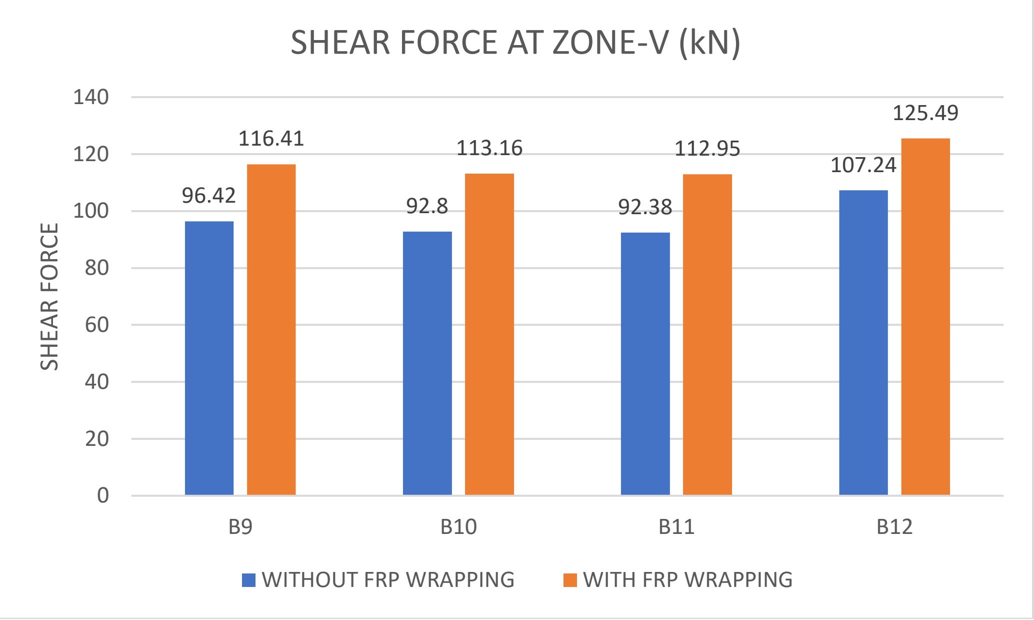

Fig.-24: Comparison of shear force before and after wrapping in C-C direction

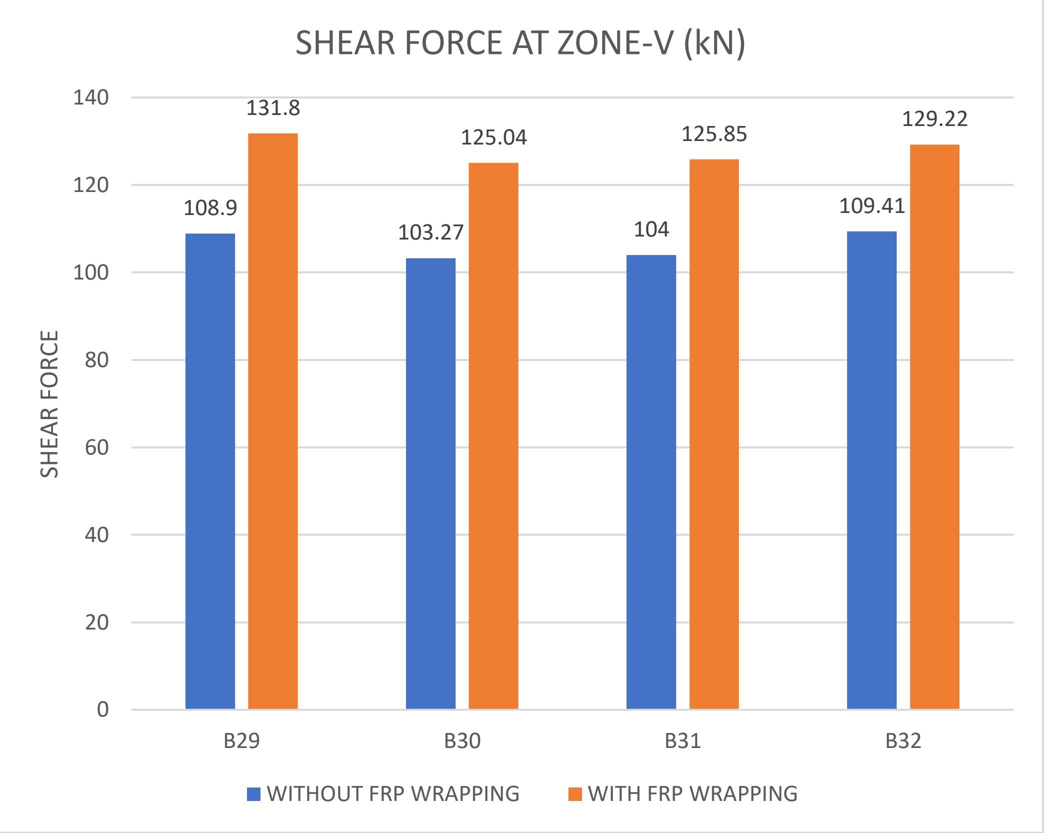

Fig.-25: Comparison of shear force before and after wrapping in 3-3 direction

Tables 16 and 17 show the amount of shear force that increases in the zone V beams with FRP wrapping compared to the beam without FRP wrapping, as shown in Figures 24 and 25. The average increase in shear force in the section C-C beam is 20.49%, whereas the section 3-3 beam has an increase of 20.28%.

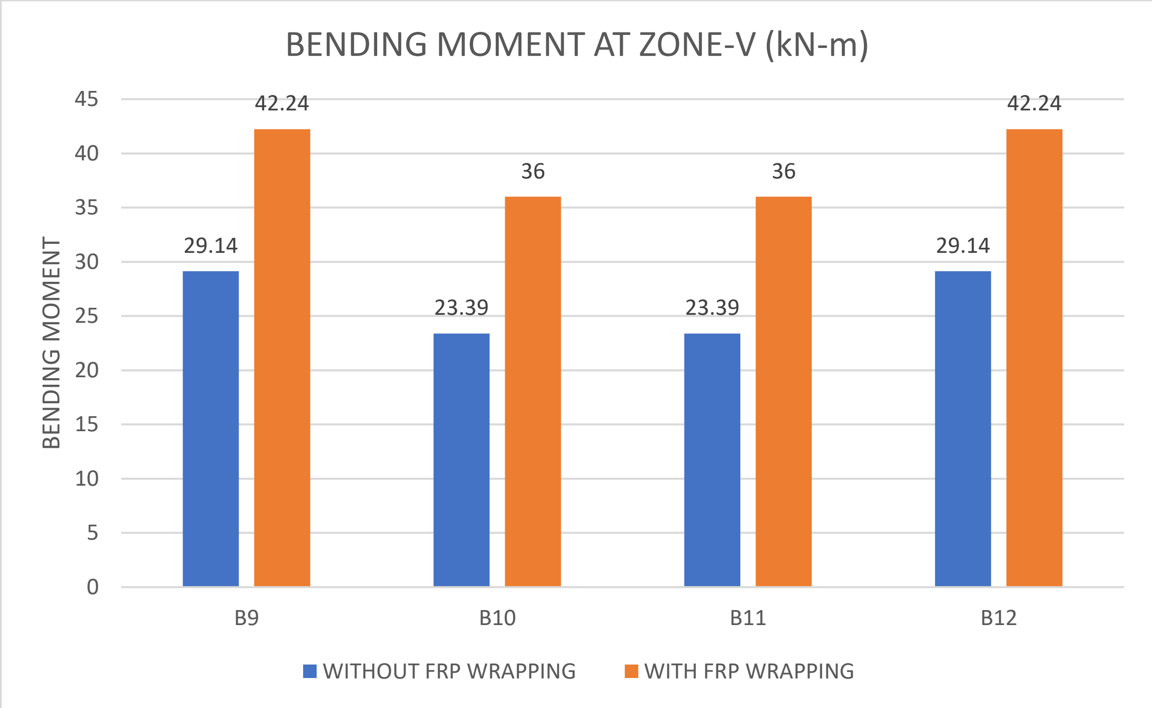

Fig.-26: Comparison of bending moment before and after wrapping in C-C direction

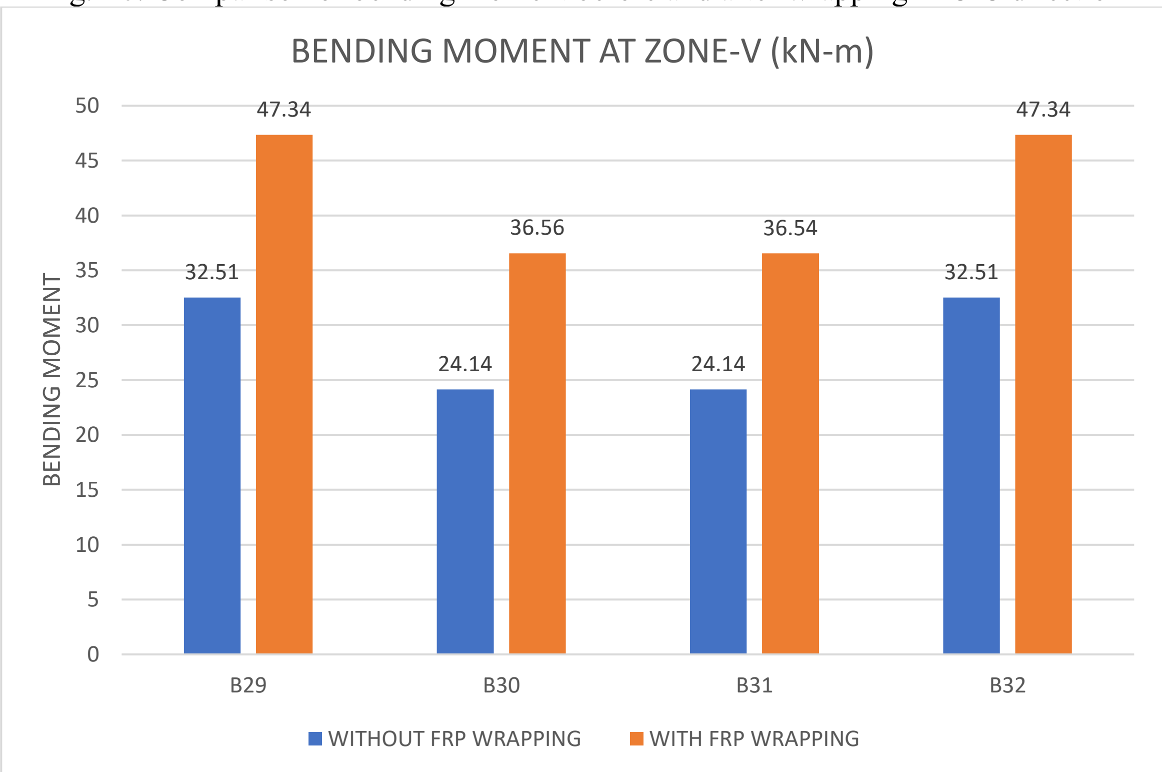

Fig.-27: Comparison of bending moment before and after wrapping in 3-3 direction

Tables 18 and 19, as well as Figures 26 and 27, show how much more bending moment is enhanced in the zone-V beam with FRP wrapping than in the beam without FRP wrapping. For the beams at sections C-C and 3-3, the average increase in bending moment was 32.64% and 33.015%, respectively.

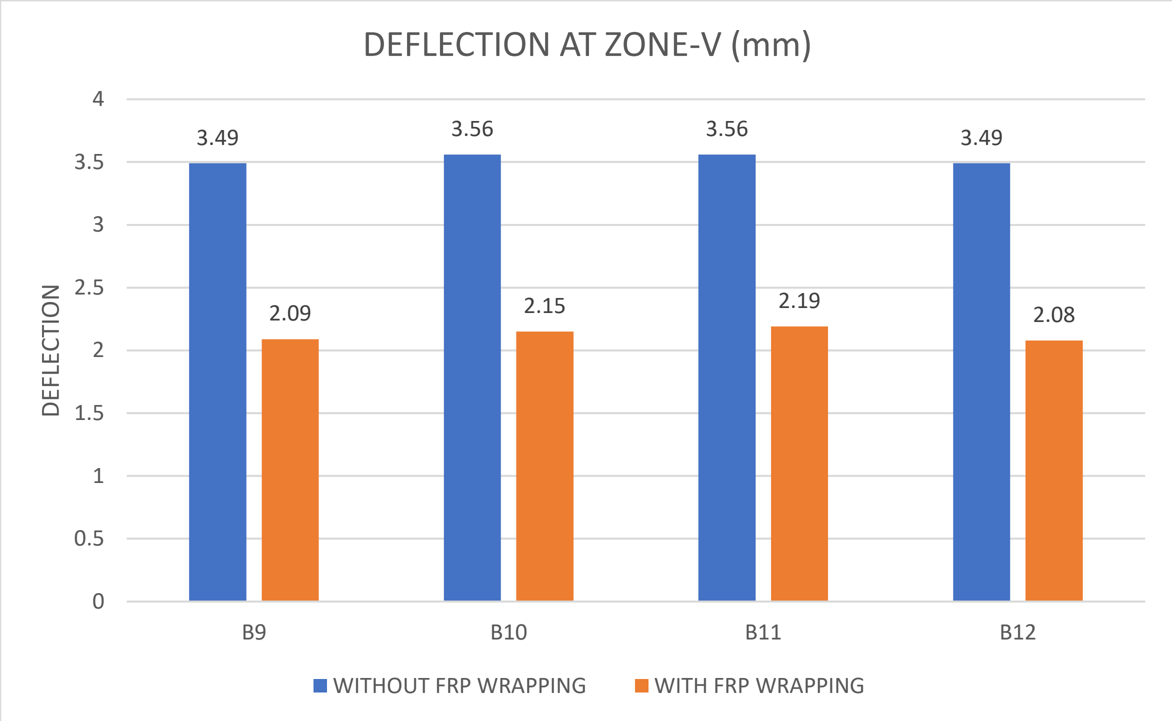

Fig.-28: Comparison of deflection before and after wrapping in C-C direction

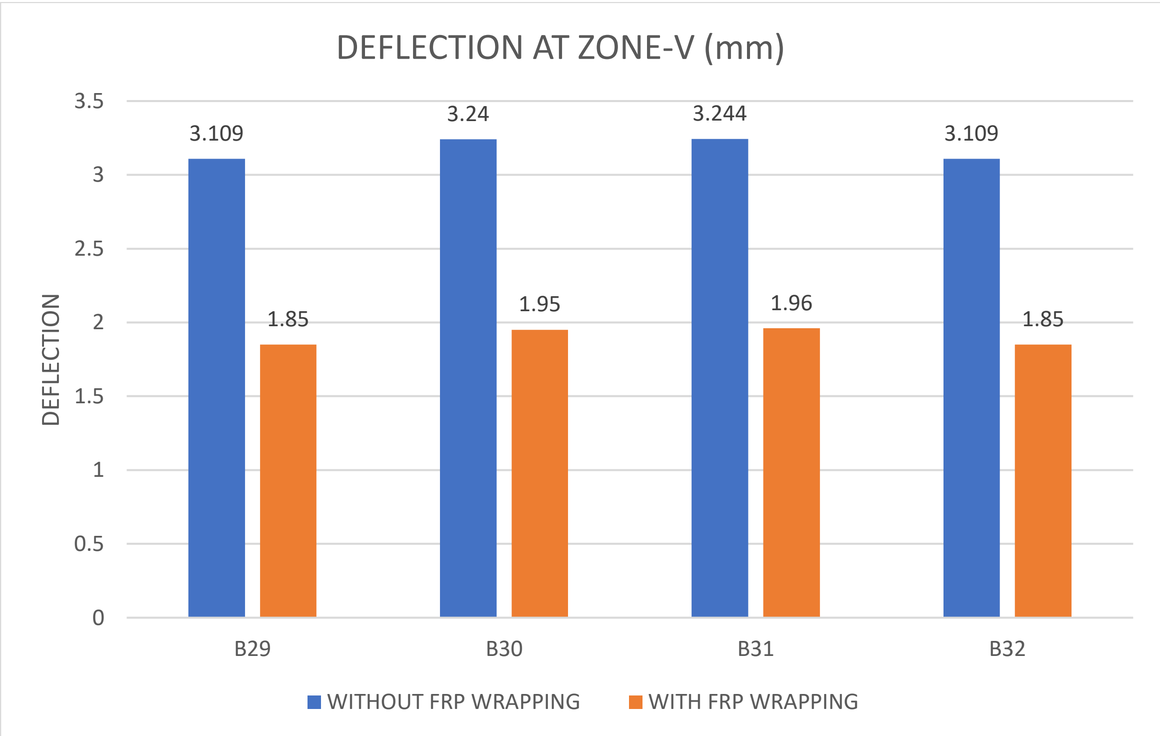

Fig.-29: Comparison of deflection before and after wrapping in 3-3 direction

According to Tables 20 and 21, the amount of deflection that is reduced in beams with FRP wrapping in zone-V compared to beams without FRP wrapping is shown in Figures 28 and 29. In the section 3-3 beam and section C-C beam, the average deflection decrease was 40.53% and 39.78%, respectively.

6.Conclusion

In this study we conducted Response Spectrum Analysis to analyse the influence of FRP wrapping on storey drift and displacement in different earthquake zones and the impact of FRP wrapping on the deflection, bending moment, and shear force of RC beams.

From the results of the study, we conclude that.

1. CFRP retrofitting leads to an effective reduction in story drift and story displacement in both zones II and V.
2. The shear force capacity of beams with FRP wrapping at grid C-C and at 3-3 increased by 20.98% and 20.09%, respectively, in zone II, and 20.49% and 20.28% in zone-V.
3. The maximum bending moment capacities of beams with FRP wrapping at grid C-C and at 3-3 was increased by 26.42% and 24.05% respectively in zone II and by 33.015% and 32.64% in zone-V.
4. In addition, beam deflection with FRP wrapping was significantly reduced by 39.65 % and 40.09 % at grid C-C and 3-3, respectively, in zone II, and by 40.53 % and 39.78 % in zone V, in comparison to beams without FRP wrapping.
5. These findings further suggest that, relatively speaking, among all seismic zones, zone-V remains the most successful where CFRP retrofitting is conducted.

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List of codes

[1] IS:1893-2016 (part-I) Indian Standard Code of practice for criteria for Earthquake Resistant Design of structures.
[2] IS:875–1987 (part-I) Indian Standard Code of practice for dead loads for buildings and structures.
[3] IS:875-1987 (part-II) Indian Standard Code of practice for live load for buildings and structures.
[4] IS:875-1987 (part-III) Indian Standard Code of practice for wind load for buildings and structures.
[5] IS 800-2007 Indian Standard Code of practice for general construction in steel.
[6] IS:456-2000 Indian Standard Code of practice for Plain and Reinforced Concrete.
[7] IS:13920-2016 Indian Standard Code of practice for Ductile and detailing of Reinforced Concrete Structure.