JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

ANALYSIS OF DIFFERENT TYPES OF FRP STRENGTHENING FOR RC BEAM COLUMN JOINT AND RC SHEAR WALL

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ABSTRACT

The global awareness of sustainability initiated human innovativeness for identifying and implementing more environmental solutions such as the use of fibre-reinforced polymers (FRP) to reduce greenhouse gas emissions and energy consumption associated with unnecessary structural labour. The use of fibre-reinforced polymers gained popularity because of their advantageous properties such as lightweight, high strength and corrosion resistance. Reinforced concrete beam-column joints are generally recognised as critical zones which experience severe deformations during earthquakes as well as Reinforced concrete shear walls are widely used in medium to high rise buildings to provide the lateral strength, stiffness, and energy dissipation capacity required to resist lateral loads caused by wind or earthquakes. Due to bad effect of Environmental changes, pollution, carbonation, and corrosion in a structural part cause the structure to collapse.

This paper aims to introduce the retrofitting of different types of FRP strengthening for RC Beam Column joint and RC Shear Wall under axial and cyclic loading. The FEM Analysis is done using ANSYS Software. The equivalent stresses and the total deformation generated are calculated and compared with each other to determine which will be more effective in the field of construction.

Keywords: Beam column joint, shear wall, finite element analysis, cyclic loading, FRP

1. INTRODUCTION

Earthquakes are a natural occurrence that can happen anywhere, at any time, and they have destroyed a lot of infrastructure and taken many lives. As a result, the buildings must be constructed in a way that ensures their safety in the event of such an incident. To prevent partial or complete collapse during earthquakes, the majority of reinforced concrete structures will require significant repairs soon. One of the biggest problems that civil engineers nowadays are dealing with is retrofitting old structures. New retrofitting solutions have had to be developed as a result of the upgrading of many cities and towns in the nation to higher seismic zones. To provide a ductile response of reinforced concrete structures during earthquakes, careful reinforcing details is of the utmost importance. The detailing is done to make sure that, even under the worst conditions that an earthquake may bring about, the entire strength of the reinforcing bars acting as either the major flexural reinforcement or the transverse reinforcement can be developed.

The use of Fibre Reinforced Polymer (FRP) materials in civil engineering field has continuously expanded since their initial notable debut in practice approximately three decades ago. Despite the fact that many academics and professionals have shown that FRP systems offer a great deal of potential for a variety of civil engineering applications, they have largely risen to the top among the alternatives for the refit and rehabilitation of reinforced concrete structures. FRP material outperforms other traditional materials in strengthening applications due to its clearly defined material properties, high strength-to-weight and stiffness-to-weight ratios, resistance to electrochemical corrosion, and ease of handling.

FRP strengthening in RC beam column joint

RC Beam-column joints are regarded as one of the most vulnerable and critical structural elements. According to research, the inadequacy of existing structures has often been brought to light by severe damage or complete collapse brought on by earthquakes. In actuality, many RC structures were only intended to withstand the effects of static gravity loads, with no attention paid to the lateral strength needed to withstand the inertial forces generated by the structure's mass. Additionally, poor seismic performance is typically the result of a lack of ductility, which is a result of two significant design process flaws: inadequate reinforcement details and a lack of design philosophy. To lessen the susceptibility of existing structures and improve occupant safety for future earthquake events, it is imperative to develop efficient and affordable repair solutions. As a result, several techniques for strengthening have been adopted, including jacketing, shotcrete, post-tensioning, etc., all of which have some drawbacks and restrictions. FRP is one of them and is currently frequently utilised because of its attributes and availability.

FRP strengthening in RC Shear Wall

Reinforced concrete (RC) shear walls are the most common systems resisting lateral loads in concrete buildings. Because they lessen floor movement in large concrete buildings, RC shear walls are crucial in decreasing the severity of seismic damage during an earthquake. The RC shear walls' easy construction and inexpensive cost are additional benefits that make them a popular lateral load resisting solution. In order to prevent brittle failure when subjected to heavy lateral loads, RC shear walls must be properly built to have not only enough strength but also enough flexibility. Many RC shear walls all around the world are in urgent need of rehabilitation because they have been damaged by prior earthquakes, have inadequate design detailing, or have construction flaws. Many designed shear walls include flaws such insufficient stiffness, insufficient reinforcements, and unfavorable wall dimensions, which impacts how well RC walls operate when subjected to lateral loading. In order to prevent brittle shear failure of RC walls, appropriate ductility must be given in addition to sufficient stiffness. Investigating strengthening techniques while taking into account different factors is crucial for retrofitting existing RC shear walls. Both experimental observations and numerical studies can be used to examine strengthening techniques. These days, steel components and fibre reinforced polymer (FRP) layers are widely used as effective methods for boosting the performance of concrete structures.

1.1 Fibre Reinforced Polymer (FRP)

Fibre Reinforced Polymer (FRP) materials are composite materials that typically have strong fibres embedded in a resin matrix. The fibres give the composite material strength and stiffness and typically support the majority of the applied loads. The matrix functions to bind and safeguard the fibres and to enable the passage of stress from fibre to fibre through shear stresses. Glass, carbon, and synthetic fibres are the most prevalent types. FRP composites are nonconductive, noncorrosive, and lightweight materials with exceptionally high strength properties.

These materials have advantageous electrical, magnetic, and thermal properties, a high strength-to-density ratio, outstanding corrosion resistance, and all-around usefulness. They are fragile, though, and the rate of loading, temperature, and environmental factors can all have an impact on their mechanical characteristics.

1.2 Types of Fiber Reinforced Polymer used in this study:

- Carbon Fiber Reinforced Polymer (CFRP)
- Glass Fiber Reinforced Polymer (GFRP)
- Basalt Fiber Reinforced Polymer (BFRP)
- Aramid Fiber Reinforced Polymer (AFRP)

1.3 Properties of different types of FRP

Table 1. Properties of FRP's

NAME	YOUNG'S MODULUS	POISSON'S RATIO
CARBON	76.35 GPa	0.26
GLASS (S2 GLASS)	86.9 GPa	0.22
BASALT	83 GPa	0.2
ARAMID (KEVLAR 49)	151.7 GPa	0.35

2. RC BEAM COLUMN JOINT

2.1 Modeling of beam column joint

T shape is modeled in Ansys workbench. The column had a cross section of 200 mm x 200 mm with an overall length of 1600 mm. The beam had a cross section of 200 mm x 200 mm with a cantilevered portion of length 600 mm. The column portion was reinforced with 4 numbers of 12 mm diameters and the beam portion was reinforced with 2 numbers of 16 mm diameters in the tension zone and 2 numbers of 16 mm diameters in the compression zone. The main reinforcement had yield strength of 415 MPa. The lateral ties in the columns were 6 mm diameter at 180 mm center to center spacing and the beams had vertical stirrups of 6 mm diameter at 120 mm c/c.

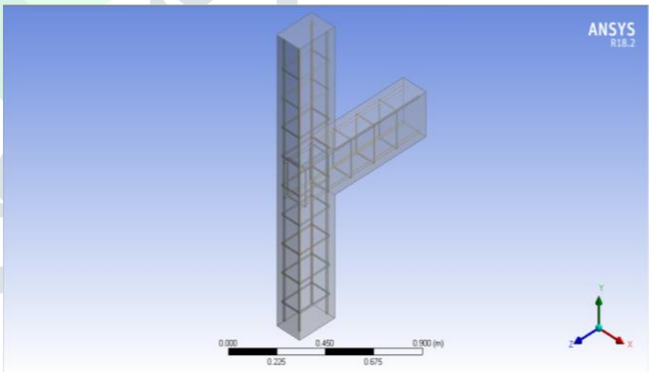

Fig.1. Geometry of beam Column Joint

2.2 Material properties

The table below shows the material properties. The concrete and steel bar properties are given in table 2 and table 3 respectively.

Properties of Concrete

Table 2. Properties of Concrete

Density	2300 kg/m3
Compressive Ultimate Strength	41 MPa
Tensile Ultimate Strength	5 MPa
Young's Modulus	30000 MPa
Poisson's Ratio	0.18

Properties of Structural steel

Table 3. Properties of Structural Steel

Density	7850 kg/m3
Compressive Ultimate Strength	250 MPa
Tensile Ultimate Strength	460 MPa
Young's Modulus	200000 MPa
Poisson's Ratio	0.3

2.3 Modeling of FRP retrofitted specimen

Four different types of FRP (i.e., Carbon, Glass, Basalt, Aramid) are applied to the beam column joint. FRP Sheets were applied to the beam face for horizontal distance of 400 mm and vertical distance of 200 mm. Also 600 mm in the vertical direction and 200 mm in the horizontal direction to the face of column.

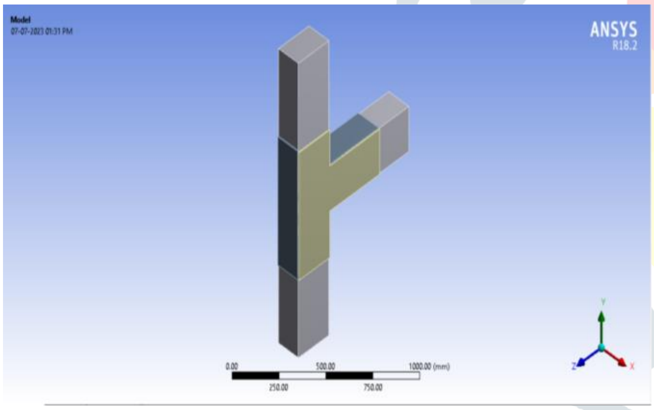

Fig.2. Application of FRP to beam Column Joint

2.4 Meshing

Meshing is done before and after application of FRP. Fine mesh property is being used and the size of the mesh is selected as default. Fig. 3 shows meshing of beam column joint with FRP.

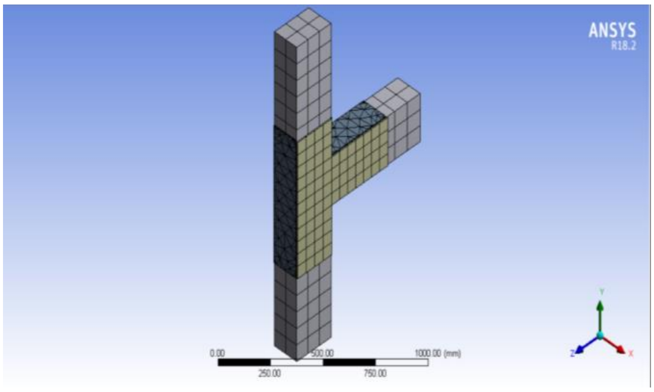

Fig.3. Meshing on beam column joint

2.5 Loading and boundary conditions

A constant axial load of 100 kN was applied to the column. And cyclic load was applied to the beam tip. The graph of cyclic loading is as shown below in fig.4. Beam column joint has a cantilever beam and column is hinged at top and bottom.

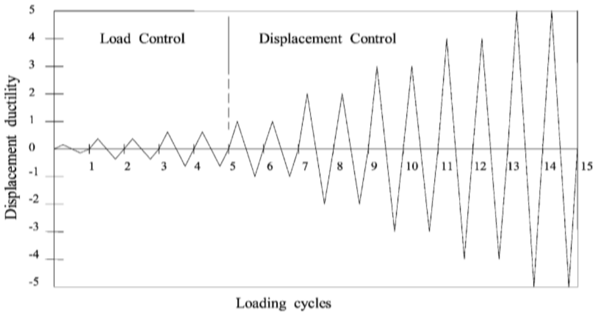

Fig.4. Cyclic loading pattern

2.6 Analysis and Results

The comparison is made between the non-retrofitted and retrofitted beam column joint. The total deformation and equivalent stresses are found out for all specimens by using Ansys software.

2.6.1 TOTAL DEFORMATION

Total deformation of Rc beam column joint with and without FRP's are observed. Maximum deformation is obtained at the tip of the beam in all specimens.

The results obtained after analyzing for total deformation are as follows:

- Total deformation of beam column joint without FRP is 25.677 mm.
- Total deformation of beam column joint with CFRP is 23.639 mm.
- Total deformation of beam column joint with GFRP is 21.584 mm.
- Total deformation of beam column joint with BFRP is 22.612 mm.
- Total deformation of beam column joint with AFRP is 20.045 mm.

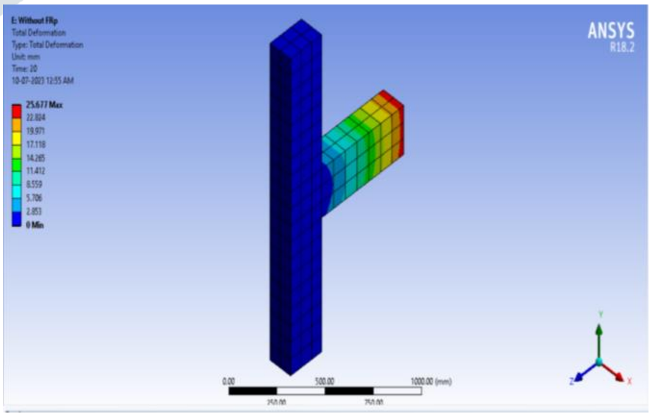

Fig.5. Total Deformation of Rc Beam Column joint without FRP

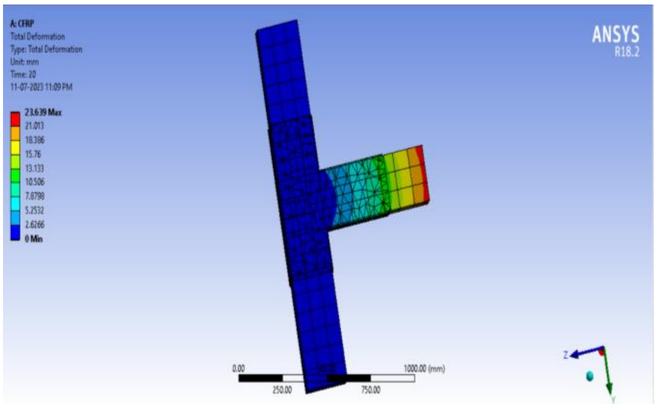

Fig.6. Total Deformation of Rc Beam Column joint with CFRP

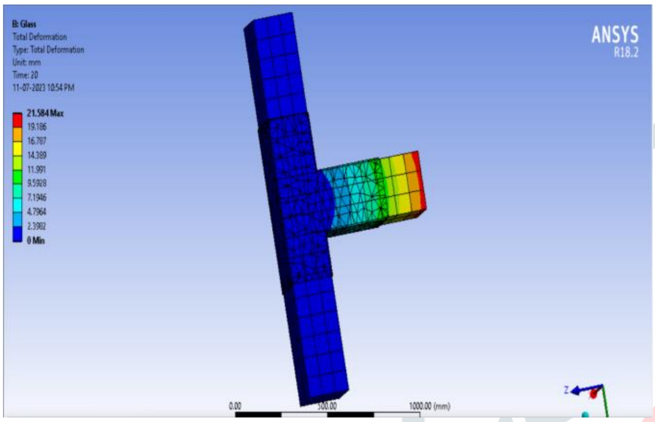

Fig.7. Total Deformation of Rc Beam Column joint with GFRP

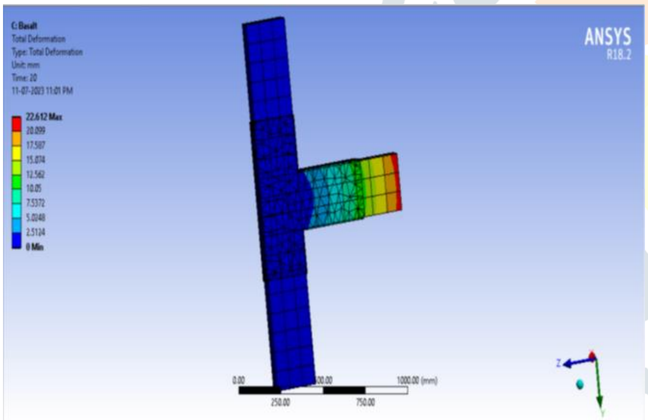

Fig.8. Total Deformation of Rc Beam Column joint with BFRP

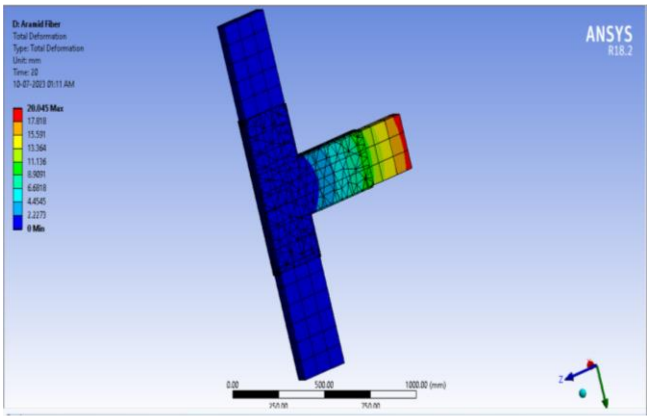

Fig.9. Total Deformation of Rc Beam Column joint with AFRP

2.6.2 EQUIVALENT STRESSES

Equivalent stresses of Rc beam column joint with and without FRP's are observed. Maximum equivalent stresses can be seen at junction of Beam and column.

The results obtained from the equivalent stress can be summarized as:

- The equivalent stress for beam column joint without FRP is 291.92 MPa.
- The equivalent stress for beam column joint with CFRP is 243.06 MPa.
- The equivalent stress for beam column joint with GFRP is 180.26 MPa.
- The equivalent stress for beam column joint with BFRP is 201.54 MPa.
- The equivalent stress for beam column joint with AFRP is 174.49 MPa.

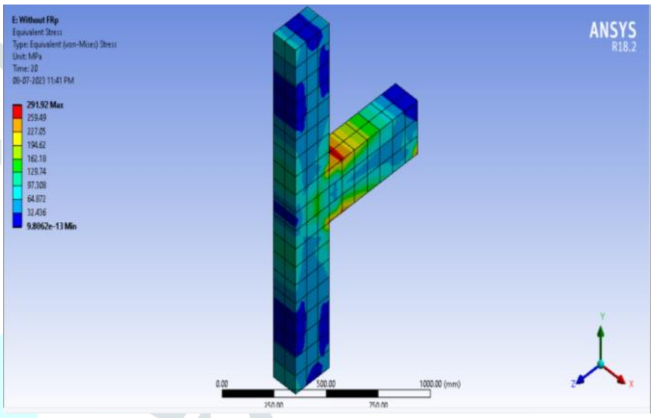

Fig.10. Equivalent stresses of Rc Beam Column Joint without FRP

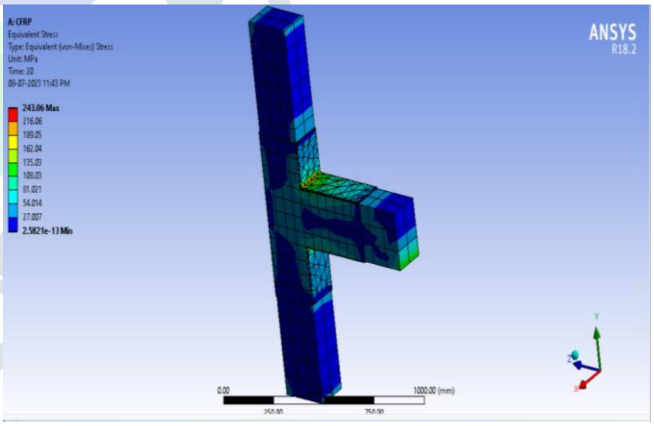

Fig.11. Equivalent stresses of Rc Beam Column Joint with CFRP

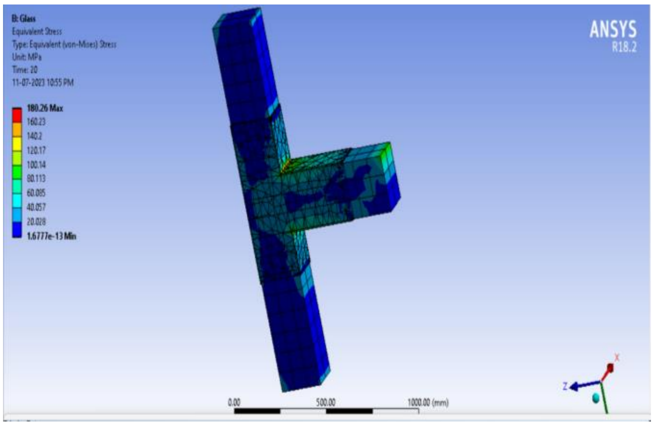

Fig.12. Equivalent stresses of Rc Beam Column Joint with GFRP

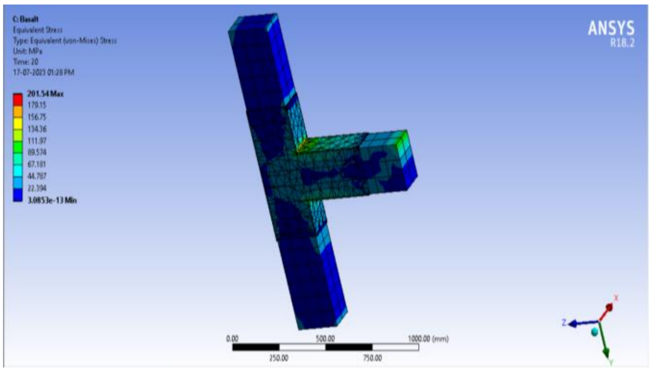

Fig.13. Equivalent stresses of Rc Beam Column Joint with BFRP

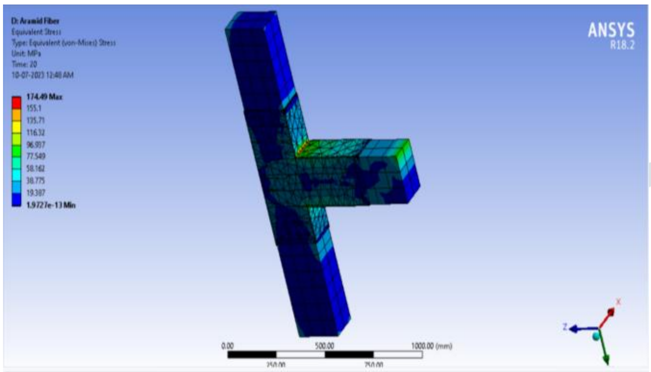

Fig.14. Equivalent stresses of Rc Beam Column Joint with AFRP

3. RC SHEAR WALL

3.1 Modeling of Rc shear wall

Shear wall consist of (1) the head beam, (2) the wall panel and (3) the foundation beam. The length, height, and thickness of wall were l = 1000 mm, h = 1600 mm, and t = 120 mm, respectively. The aspect ratio of the wall was 1.6. The web reinforcement consisted of a double orthogonal grid of 8 mm diameter bars vertically and laterally with spacing 110 mm, and 150 mm, respectively. The 225 mm x 120 mm boundary elements were reinforced with six bars of 10 mm diameter. Confinement in the boundary element was provided by 8 mm diameter closed stirrups spaced at 150 mm.

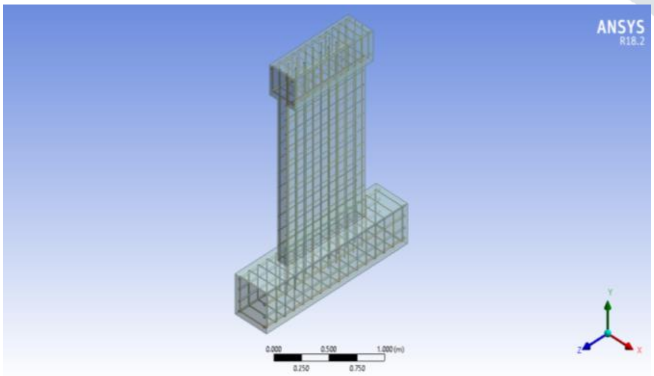

Fig.15. Geometry of Shear Wall

3.2 Material Properties

Concrete of M30 grade and structural steel is used. Properties of concrete and structural steel are given in table 2 and table 3 respectively.

3.3 Modeling of FRP retrofitted specimen

Four different types of FRP (i.e., Carbon, Glass, Basalt, Aramid) are applied to the shear wall. Three 300 mm wide lateral strips, spaced at 350 mm, as shown in fig.16.

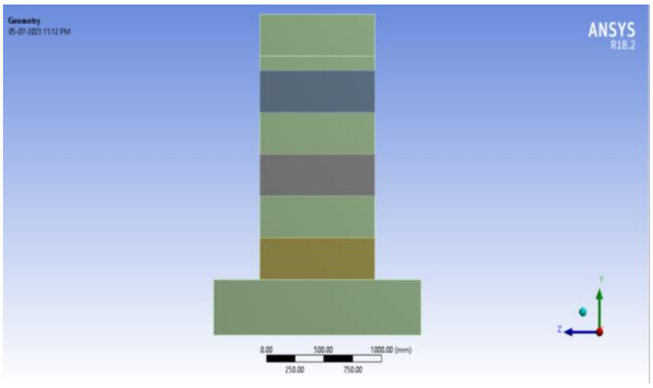

Fig.16. Application of FRP on shear Wall

3.4 Meshing

Meshing is done before and after application of FRP. Fine mesh property is being used and the size of the mesh is selected as default. Fig.17 shows meshing of shear wall with FRP.

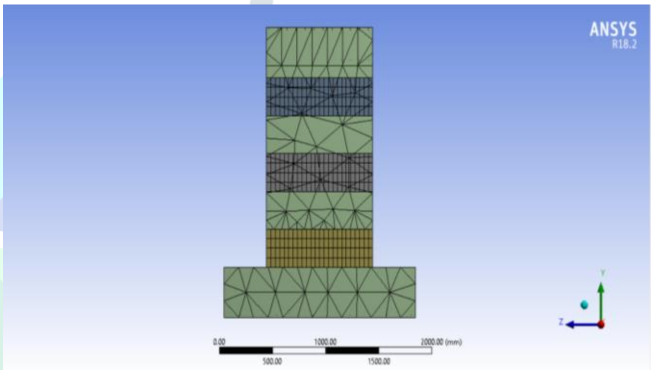

Fig.17. Meshing on shear wall

3.5 Loading and Boundary conditions

The wall was subjected to a constant axial load of 325.0 kN and cyclic load at head beam of shear wall. Cyclic loading is given as per fig.18. Cantilever wall has a fixed support at the bottom.

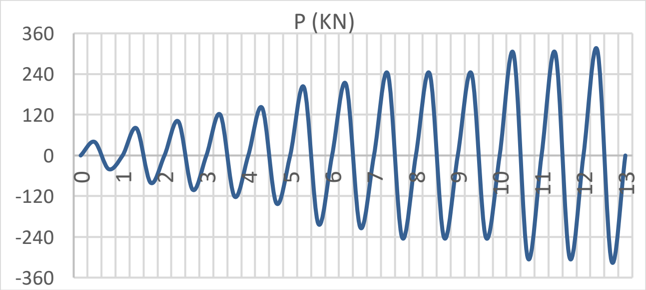

Fig.18. Load cycle History

3.6 Analysis and Results

The comparison is made between the non-retrofitted and retrofitted shear wall. The total deformation and equivalent stresses are found out for all specimens by using Ansys software.

3.6.1 TOTAL DEFORMATION

Total deformation of Rc Shear wall with and without FRP's are observed. Maximum deformation is obtained at the head beam of shear wall in all specimens.

The results obtained after analyzing for total deformation are as follows:

- Total deformation of shear wall without FRP is 33.587 mm.
- Total deformation of shear wall with CFRP is 30.282 mm.
- Total deformation of shear wall with GFRP is 28.838 mm.
- Total deformation of shear wall with BFRP is 29.237 mm.
- Total deformation of shear wall with AFRP is 26.847 mm.

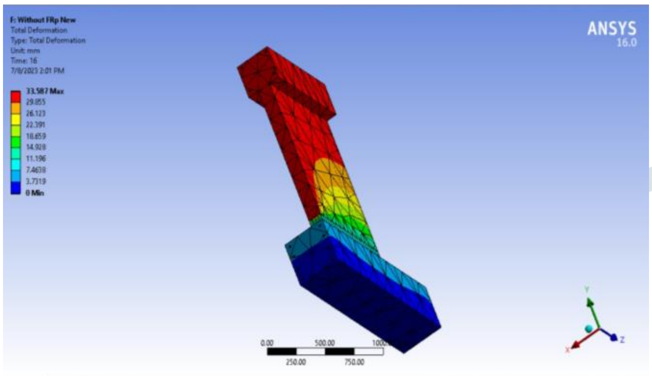

Fig.19. Total deformation of Rc Shear Wall without FRP

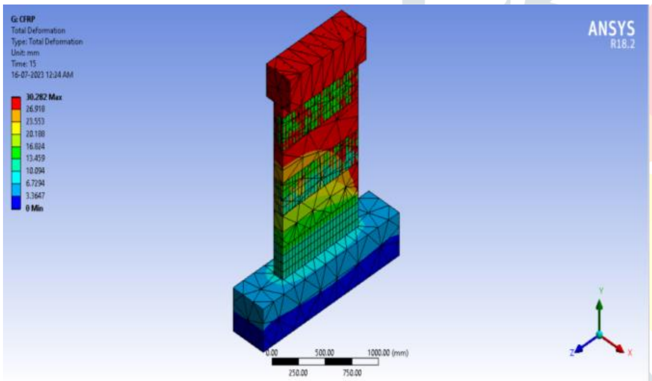

Fig.20. Total deformation of Rc Shear Wall with CFRP

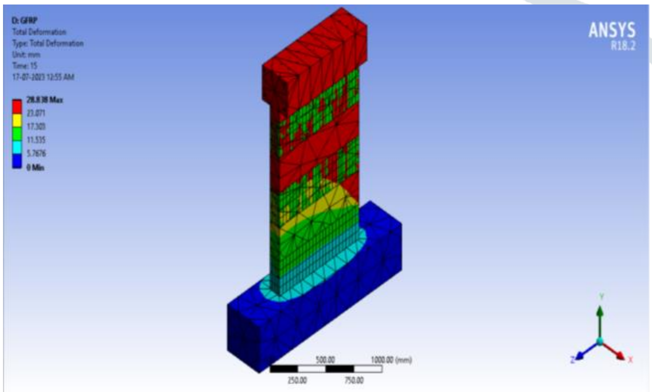

Fig.21. Total deformation of Rc Shear Wall with GFRP

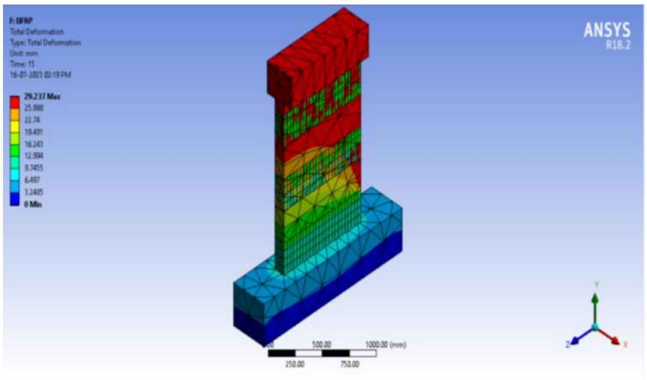

Fig.22. Total deformation of Rc Shear Wall with BFRP

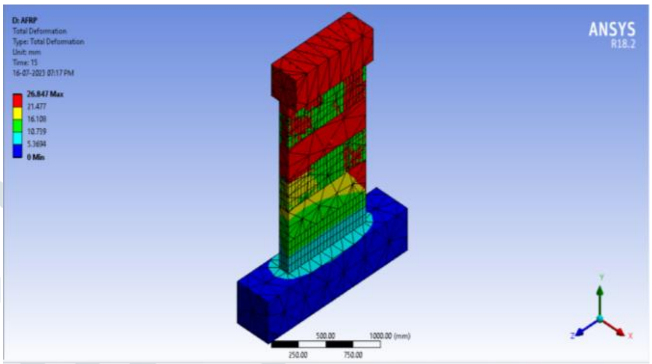

Fig.23. Total deformation of Rc Shear Wall with AFRP

3.6.2 EQUIVALENT STRESSES

Equivalent stresses of Rc shear wall with and without FRP's are observed. Maximum equivalent stresses in shear wall can be seen at junction of wall panel and foundation beam.

The results obtained from the equivalent stress can be summarized as:

- The equivalent stress for Shear wall without FRP is 443.35 MPa.
- The equivalent stress for Shear wall with CFRP is 368.36 MPa.
- The equivalent stress for Shear wall with GFRP is 325.99 MPa.
- The equivalent stress for Shear wall with BFRP is 347.96 MPa.
- The equivalent stress for Shear wall with AFRP is 306.73 MPa.

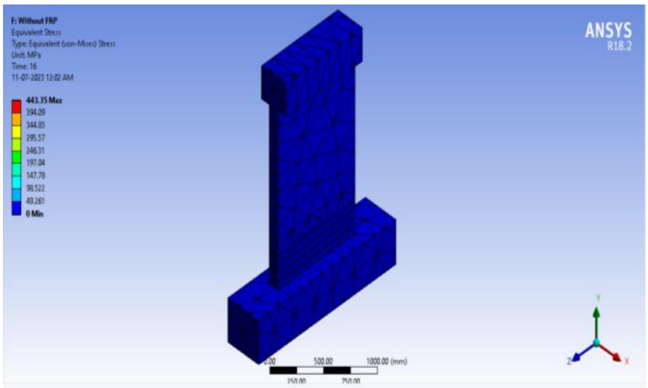

Fig.24. Equivalent stresses of Rc Shear Wall without FRP

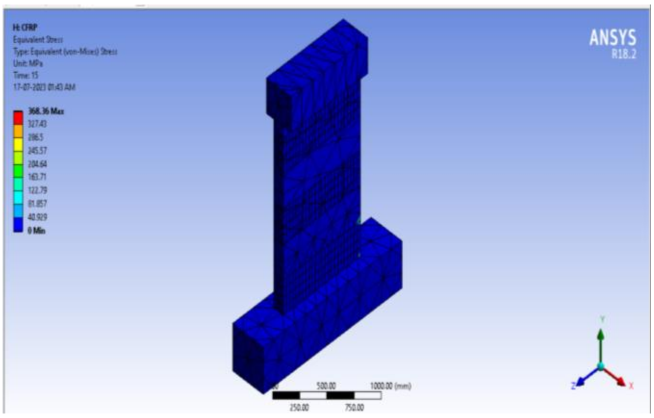

Fig.25. Equivalent stresses of Rc Shear Wall with CFRP

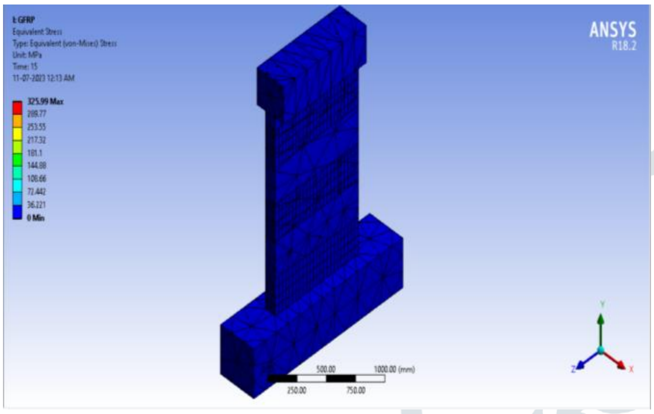

Fig.26. Equivalent stresses of Rc Shear Wall with GFRP

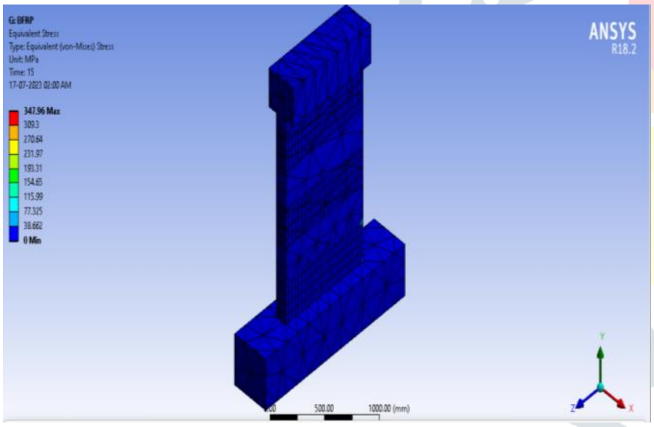

Fig.27. Equivalent stresses of Rc Shear Wall with BFRP

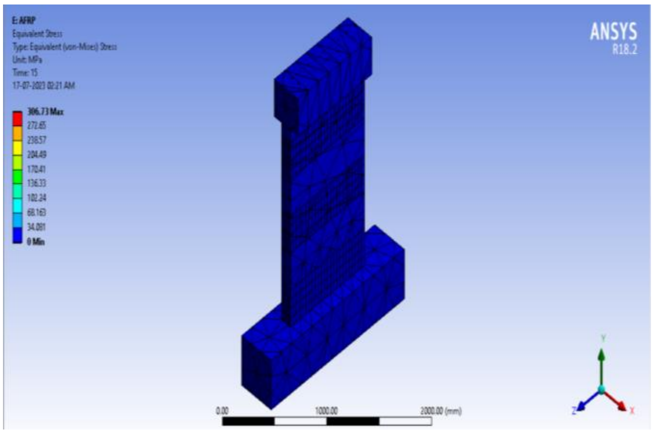

Fig.28. Equivalent stresses of Rc Shear Wall with AFRP

4. CONCLUSION

Analysis of different types of FRP strengthening for Rc beam column joint and Rc shear wall was studied using finite element analysis software, Ansys. Total deformation and equivalent stresses were obtained and Properties of different types of FRP were studied.

The result concludes that the maximum deformation occurs at the specimen without FRP and least deformation occurs at the specimen with aramid fibre reinforced polymer as compared to the other retrofitted specimens.

It can be concluded that the application of FRP can provide additional strength and stiffness to structural elements. FRP can enhance the flexural and shear capacity of specimen, by increasing the load carrying capacity, FRP can reduce the deformation experienced under a given load. FRP has high modulus properties, which means it is stiffer than many conventional construction materials. When applied to a specimen, FRP can increase the overall stiffness. This increase stiffness can help to reduce deformation. FRP can also provide confinement to concrete elements, preventing or delaying the occurrence of concrete cracking and spalling. By confining the concrete, FRP can limit the extent of deformation in the specimen. All the above factor resulting in less total deformation compared to an unstrengthen specimen.

From the figure 29 and figure 30, We can easily compare Total Deformation of RC Beam column joint and RC shear wall, without and with FRP.

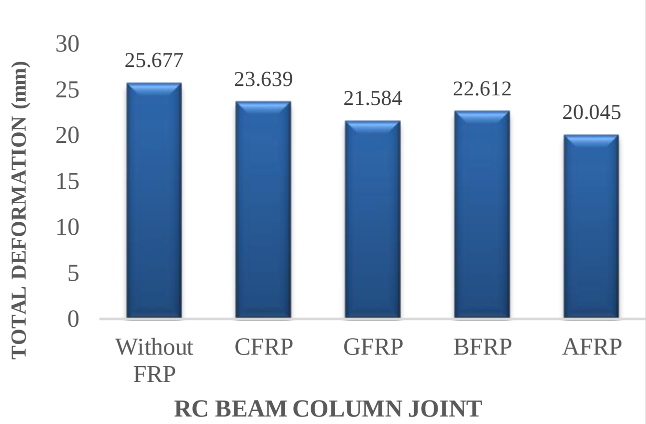

Fig.29. Total Deformation of Rc beam column joint

Fig.30. Total Deformation of Rc Shear wall

From the results, it can be concluded that maximum equivalent stresses developed at the specimen without FRP and least equivalent stresses developed at the specimen with aramid fibre reinforced polymer as compared to the other retrofitted specimens.

When it comes to the equivalent stresses, by using the different types of FRPs the equivalent stresses in the concrete got reduced. The reduction is basically due to the fact that the FRP is acting like an external reinforcement to the beam column joint and shear wall, the stresses generated is taken by the FRPs. Hence it resulting in less equivalent stresses compared to an unstrengthen specimen.

From the figure 31 and figure 32, We can easily compare equivalent stresses of Rc beam column joint and Rc Shear Wall, without and with FRP.

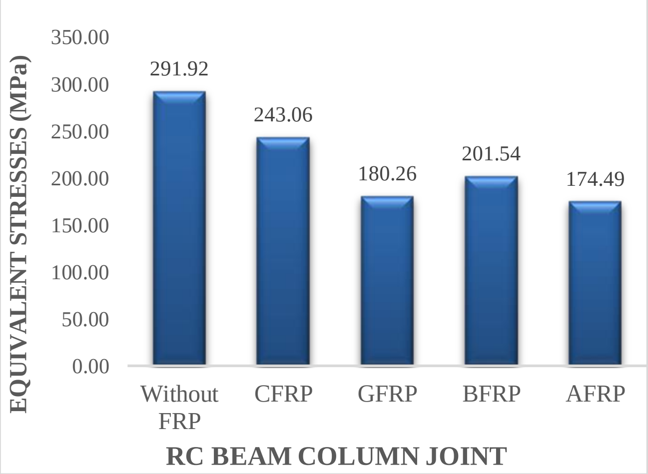

Fig.31. Equivalent Stresses of Rc beam column joint

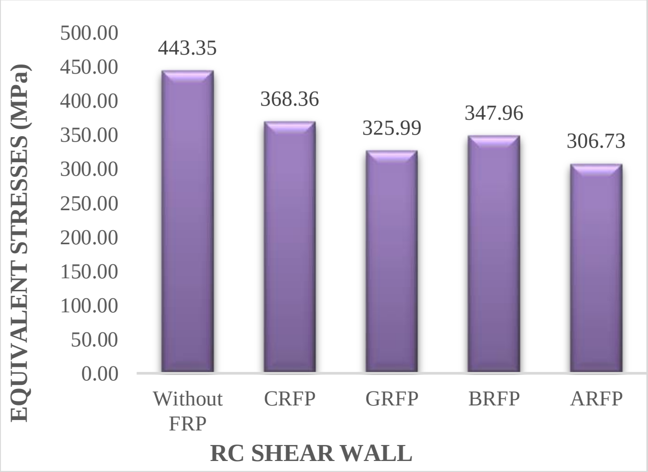

Fig.31. Equivalent Stresses of Rc Shear wall

While strengthening the structural elements using FRP composites, it has been proved that it gives an increase in strength but the % of increase varies from 5% to 70% which depends on parameters considered like width of wrap, length of wrap, size of substrate, available reinforcement, size of specimen considered for testing, grade of concrete, grade of reinforcement steel used in the structural member.

Different types of FRPs have different modulus of elasticity and different Poisson's ratio. Therefore, the variation is observed.

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