ANALYTICAL INVESTIGATION OF BEAM-COLUMN JOINT RETROFITTED WITH CFRP

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Abstract – *Retrofitting of structures has become a major issue worldwide due to increase in the applied loads, human error in initial construction, legal requirement to comply with updated versions of existing codes, or the loss of strength due to deterioration over time. FRP has tremendous potential and has great advantages over conventional materials and techniques of retrofitting of RC structures. As the failure of the beam-column joints leads to the failure of the structure, an analytical study has been carried out to investigate the behaviour of beam-column joint with different CFRP strengthening schemes. CFRP materials such as CFRP sheets, laminates and rods are considered. The suitability of Near Surface Mounting (NSM) technique at beam-column joint is also explored in this study. A typical Multi storey RC building is selected and seismic analysis (Time history analysis) is performed and the critical beam column joint is found out. The peak shear force (208.630 KN) and peak moment (202.9411 KN-m) of the selected beam-column joint obtained from the time history analysis is applied to the retrofitted beams. The finite element program ANSYS has been used to study the behaviour of beam-column joint. It is found that all the six retrofitting techniques have reduced the deflection at free end of the beam. Use of Laminates with mechanical anchorages showed better performance. NSM technique of retrofitting beam-column joint is effective in reducing the deflection. Considering the stresses near the beam-column joint, application of NSM technique in beam is found to be ineffective. Use of CFRP sheet, laminates, laminates with mechanical anchorage is found to be effective with respect to stresses near the joint. The study shows that CFRP laminate with mechanical anchorages is the most efficient retrofitting scheme.*

Key Words*: *Beam-column joint, Retrofitting, Analytical Investigation, Carbon Fibre Reinforced Polymer, Near Surface Mounting, ANSYS

1. INTRODUCTION

The need of retrofitting is increasing day by day due to different reasons such as increase in seismic activity, natural calamities, increase in the live loads over old structures etc. The behaviour of a structure depends on the nature of behaviour of column-beam joint, hence the need of strengthening the column beam joint is important. Different retrofitting schemes such as providing steel bracing's, providing steel plates at tension zones etc are available. Apart from all those conventional retrofitting systems, Fibre Reinforce Polymer (FRP) has major advantage i.e. high strength to low weight ratio. Fibre had been used as a reinforcement of structural components for millenniums. There are biblical references dating back to 2000 b.c or earlier, use of straw reinforced mud bricks and composite bow are few examples. In India use of FRP material has taken shape around 1960s. The major constituents of a fibre reinforced composite material are reinforcing fibre, matrix, coupling agent, coating and fillers. Different composites materials of Carbon, Glass fibre, Aramid, Boron and Ceramic fibres are available now a days in the market. For retrofitting purpose most efficient among is the CFRP material. The behaviour of beam-column joint after retrofitting using CFRP sheets, laminates, rods at different configurations is investigated in this study. A static load of 208.630KN and moment of 202.9411 KN-is applied at the free end of the beam. The forces are obtained from the analysis of a multi storey building subjected to seismic forces.

2. FINITE ELEMENT ANALYSIS

Finite element analysis has been carried out to investigate the behaviour of CFRP materials at beam column joint. Different schemes of retrofitting considered in the study are listed below.

1. Control Specimen
2. CFRP sheet at beam and column
3. CFRP laminates at beam and column
4. Laminates having anchorage at beam only
5. NSM at beam bottom only
6. NSM at beam top and bottom
7. NSM at beam and CFRP sheet at column

2.1 Material properties

The properties of CFRP materials used are given in the tables 1 to 6.

Table 1 Concrete Property

	Properties	Value
1	Young's Modulus	30000Mpa
2	Poisson's Ratio	0.18
3	Density	2500Kg/m^3

Table 2 Steel Reinforcement Property

	Properties	Value
1	Young's Modulus	2e05Mpa
2	Poisson's Ratio	0.3
3	Density	7850Kg/m^3

Table 3 CFRP sheet Property

	Properties	Value
1	Young's Modulus X direction	73300Mpa
2	Young's Modulus Y direction	4613.8Mpa
3	Young's Modulus Z direction	4613.8Mpa
4	Poisson's Ratio XY	0.31
5	Poisson's Ratio YZ	0.39
6	Poisson's Ratio XZ	0.02
7	Shear Modulus XY	1761Mpa
8	Shear Modulus YZ	1660Mpa
9	Shear Modulus XZ	1761Mpa

Table 4 Epoxy Property

	Properties	Value
1	Young's Modulus	1.65e05Mpa
2	Poisson's Ratio	0.22
3	Tensile yield strength	30Mpa
4	Compressive ultimate strength	95Mpa

Table 5 CFRP Laminate Property

	Properties	Value
1	Young's Modulus	1.65e05Mpa
2	Poisson's Ratio	0.183
3	Tensile yield strength	2800 Mpa
4	Tensile Ultimate strength	3050Mpa

Table 6 CFRP bar Property

	Properties	Value
1	Young's Modulus	122.52Mpa
2	Poisson's Ratio	0.2
3	Tensile Ultimate strength	1408Mpa

3. Modelling of Beam-Column joint

3.1 Control specimen

The beam-column joint considered for analysis consist of a cantilever beam portion and column portion as shown in figure 2. The column has a cross section of 500mm x 500mm with an overall length of 1500mm and the cantilever portion has cross sectional dimensions of 300mm x 400mm with a span of 1000mm. The column portion was reinforced with 4 numbers of 12mm diameter Fe415rebars and the beam portion was reinforced with 2 numbers of 12mm diameter rebars at tension and compression side of beam. Lateral ties of 8mm diameter with a spacing of 150mm and 146mm are provided at beam and column. The ends of the column are fixed at both sides. The figure below shows the beam-column joint and the reinforcement detailing.

Cross section details:

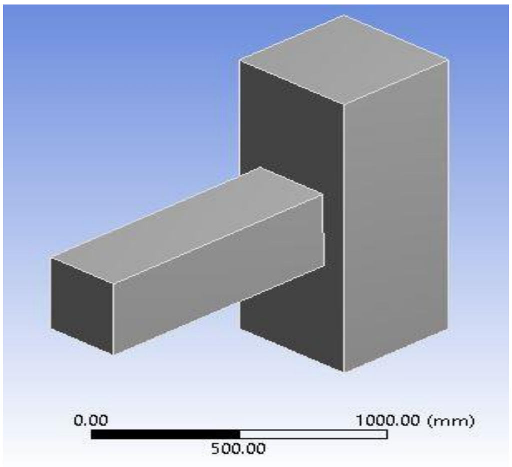

Fig. 3.1 Beam-Column Joint

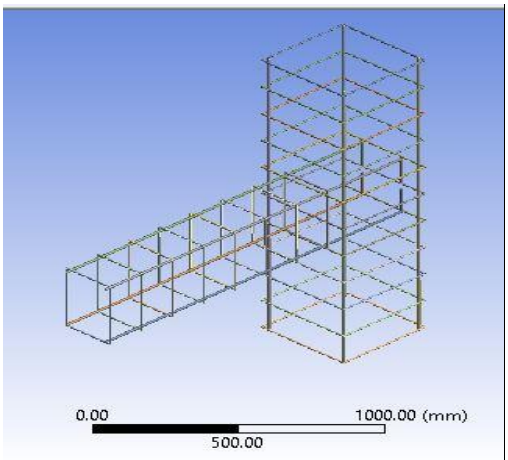

Fig. 3.2 Reinforcement Detailing

3.2 Modelling of Retrofitted specimens

The epoxy materials used to bond the CFRP material had a thickness of 2mm. CFRP sheets had a thickness of 0.117mm which is wrapped throughout the beam-column joint. CFRP laminates had a thickness of 3mm, width of 100 mm and a length of 600mm at beam portion and 1200mm at column portion. CFRP rods had a diameter of 8mm and a length of 600mm at beam portion. In NSM technique of retrofitting, a groove of 30mm depth is created and epoxy is applied and the CFRP bar of 8mm diameter is placed inside and again a layer of epoxy is applied to fill the groove. The images of different retrofitting schemes are shown below in figures 4 to 10.

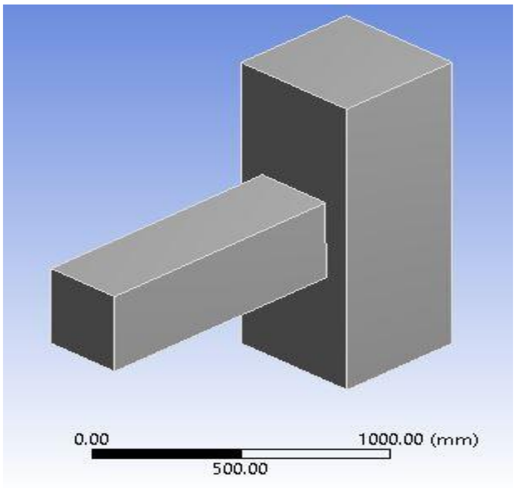

Fig. 3.3 Control specimen

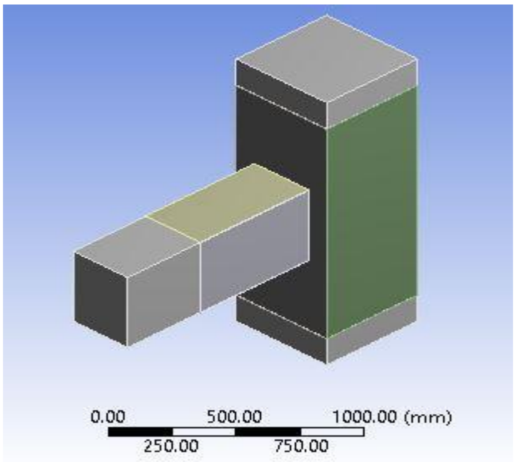

Fig. 3.4 CFRP sheet

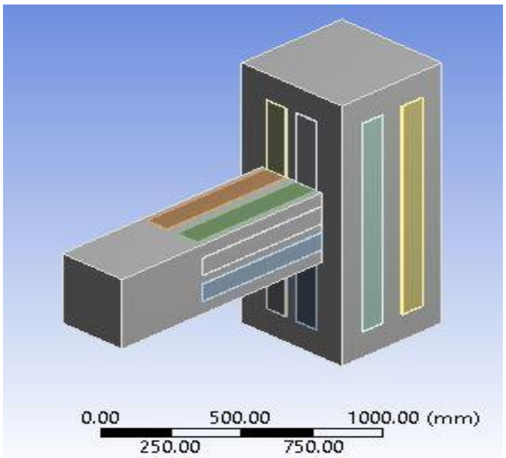

Fig. 3.5 CFRP laminate

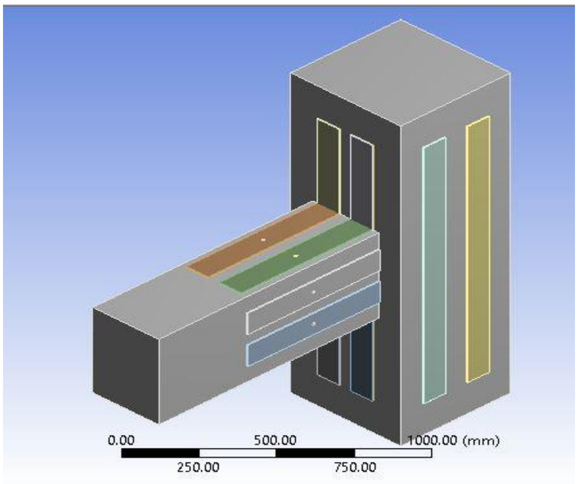

Fig. 3.6.CFRP laminate with anchorage at beam

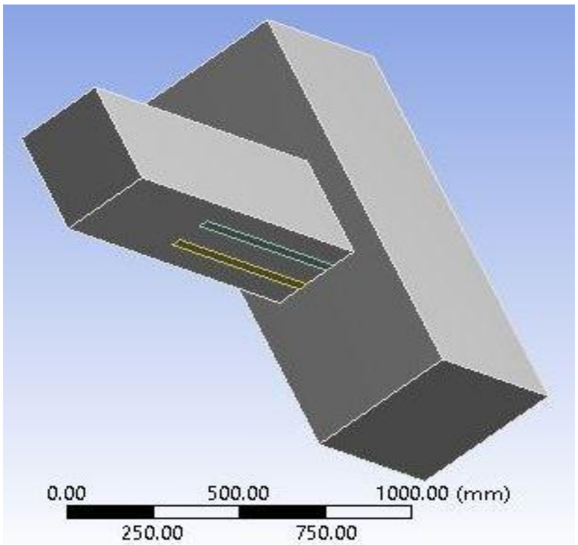

Fig. 3.7 NSM at beam bottom

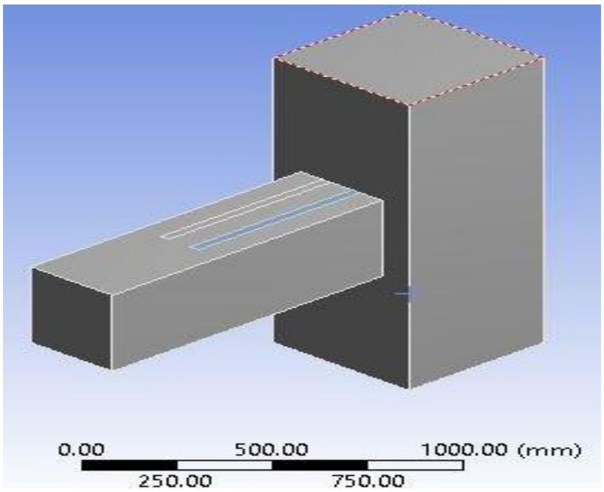

Fig. 3.8 NSM at top and bottom of beam

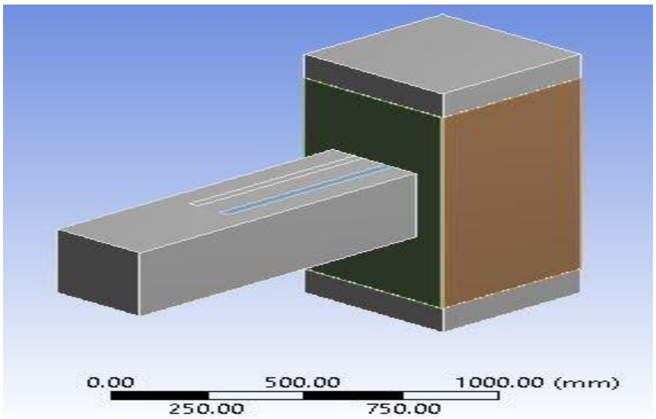

Fig. 3.9 NSM at beam and CFRP sheet at column

Shear force of 208.630KN and moment of 202.9411KN-m is applied at the free end of beam spanning 1000mm from the beam-column joint. The beam-column joint has been analysed for deflection and stresses. The results are discussed in the following section and deformation at free end of beam is compared for different scheme. The analysis results are depicted in figures.

4 RESULTS & DISCUSSIONS

4.1 Deflection at the free end of the cantilever portion.

Deformation at free end of beam are compared for different schemes in figures 4.1 to 4.7

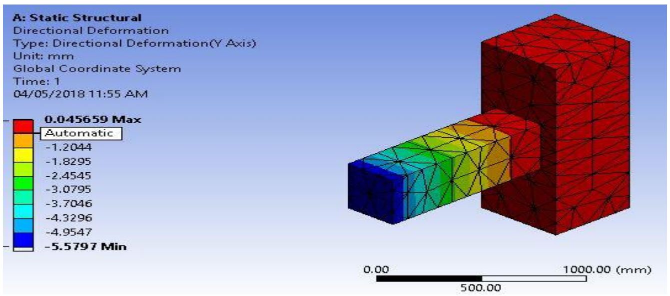

Fig. 4.1 Deformation of Control Specimen

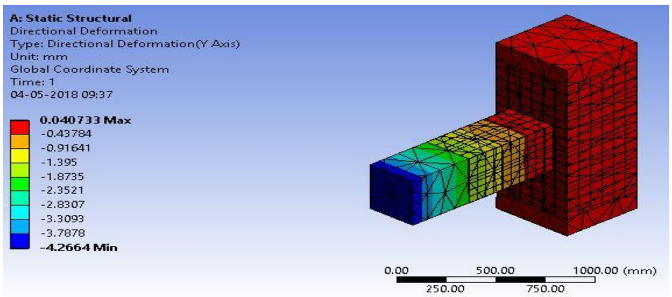

Fig. 4.2 Deformation of FRP sheet retrofitted beam-column
joint

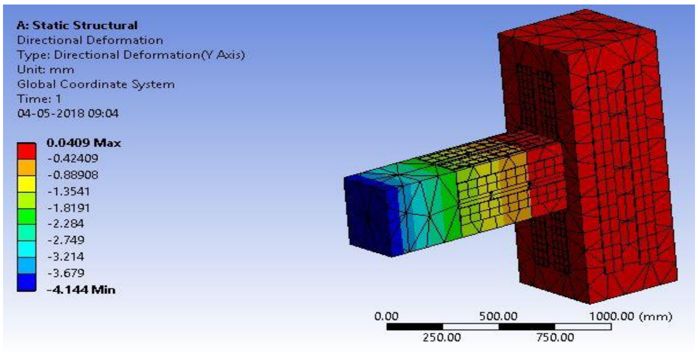

Fig. 4.3 Deformation of FRP laminates retrofitted column-beam joint

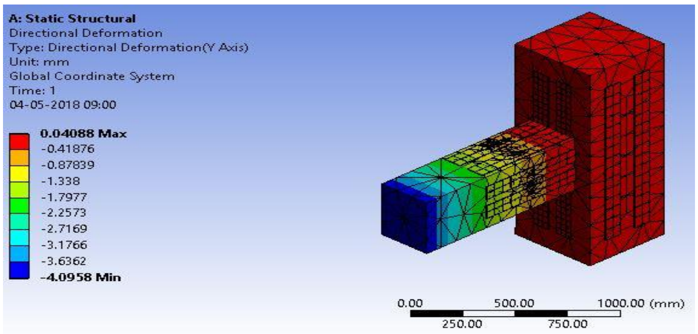

Fig. 4.4 Deformation of FRP laminates with anchorage at beams

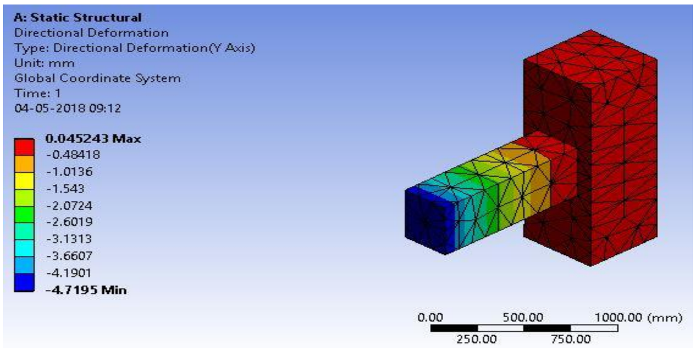

Fig. 4.5 Deformation of NSM at beam bottom only

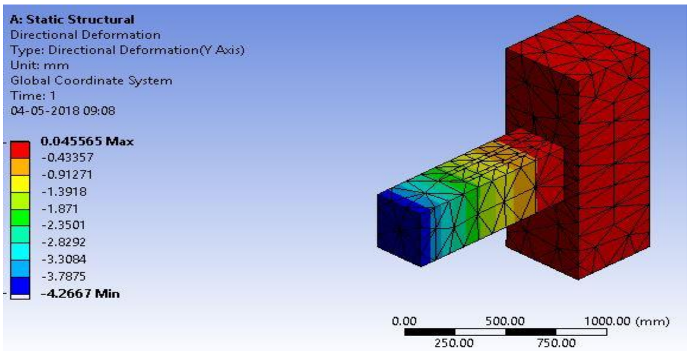

Fig. 4.6 Deformation of NSM at top and bottom of beam

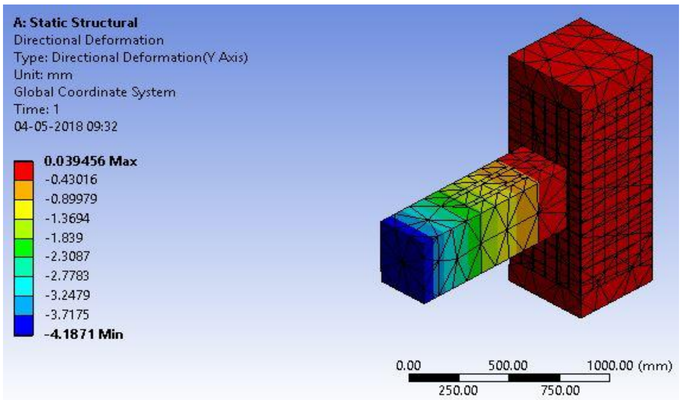

Fig. 4.7 Deformation of NSM at Beam and sheet at column

The deflection of beams with different retrofitting schemes is compared in table 7.

Table 7. Deflection comparison

Case	Retrofitting Schemes	Deflection at free end (mm)	% Decrease in deflection as with respect to control specimen
C	Control specimen	5.5797	-
S	CFRP sheets	4.266	23.54%
L	CFRP Laminate	4.144	25.73%
LA	CFRP Laminate with anchorage at beam	4.0958	26.59%
NB	NSM technique at bottom of beam	4.7195	15.416%
NTB	NSM technique at top and bottom of beam	4.2667	23.53%
NTBS	NSM technique at beam bottom and CFRP sheet at column	4.1871	24.96%

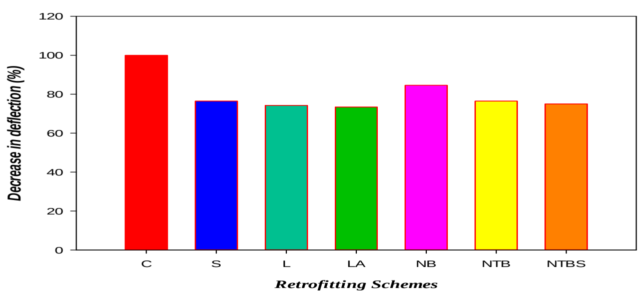

Chart 1. Comparison of deflection of beam with different retrofitted schemes

FRP sheet retrofitted specimen shows a reduction in deflection of about 23.54% as compared to the control specimen and CFRP laminates shows a reduction in deflection of about 25.73% CFRP laminates with anchorages shows a lower deflection as compared to the CFRP laminate retrofitted specimen without anchorages. The variation in deflection with and without anchorage is about 1.16%. Providing sufficient number of anchorages may increase considerable amount of strength there by reducing the deflection. Delamination failure mechanism may be minimised by providing sufficient number of anchorages. NSM technique of retrofitting is good for flexural strengthening of beam. On the basis of decrease in deflection, CFRP laminate retrofitted beam-column joint with mechanical anchorages is found to be more effective.

4.3 Stresses at the beam- column Junction.

The variation of Von-Mises stresses are plotted and depicted in figures 4.9 to 4.15

4.3.1 CONTROL SPECIMEN

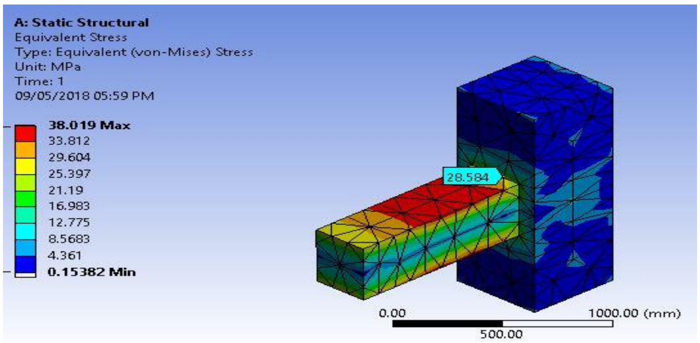

Fig. 4.8 Von-Mises stress of Control Specimen at the joint

4.3.2 CFRP SHEET AT BEAM AND COLUMN

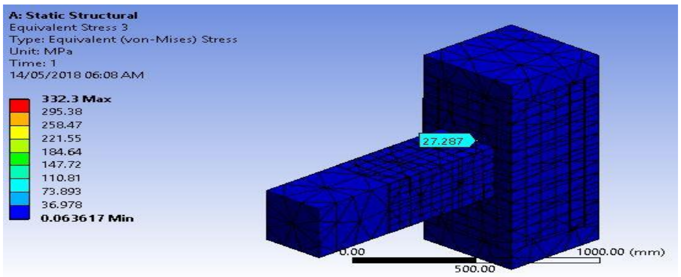

Fig. 4.9 Von-Mises stress of CFRP retrofitted sheet Specimen at the joint

4.3.3 CFRP LAMINATES AT BEAM AND COLUMN

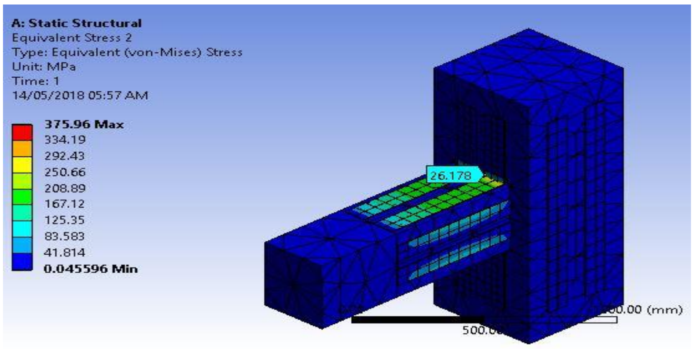

Fig. 4.10 Von-Mises stress of CFRP laminate retrofitted Specimen at the joint

4.3.4 CFRP LAMINATE HAVING ANCHORAGE AT BEAM ONLY

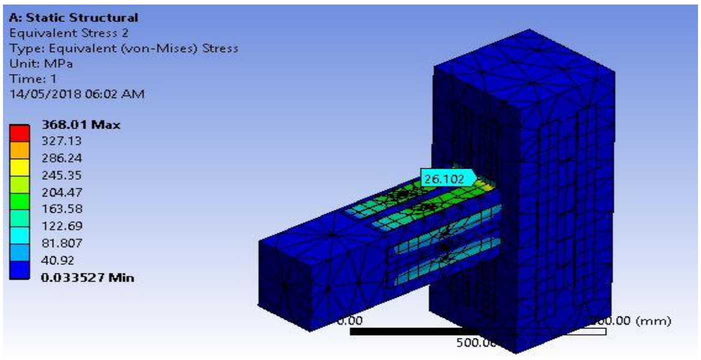

Fig. 4.11 Von-Mises stress of CFRP laminate with anchorage retrofitted Specimen at the joint

4.3.5 NSM AT BEAM BOTTOM ONLY

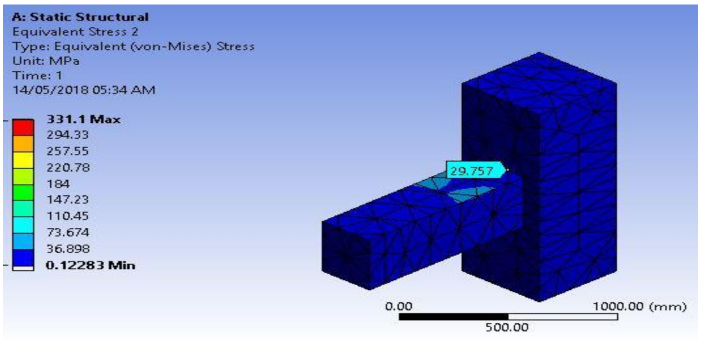

Figure 4.12 Von-Mises stress of NSM retrofitted beam-column joint at bottom of beam only

4.3.6 NSM AT BEAM TOP AND BOTTOM

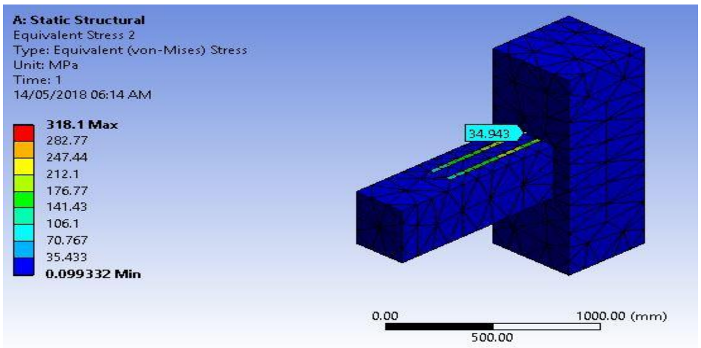

Figure 4.13 Von-Mises stress of NSM retrofitted beam-column joint at top & bottom of beam only

4.3.7 NSM AT BEAM AND CFRP SHEET AT COLUMN

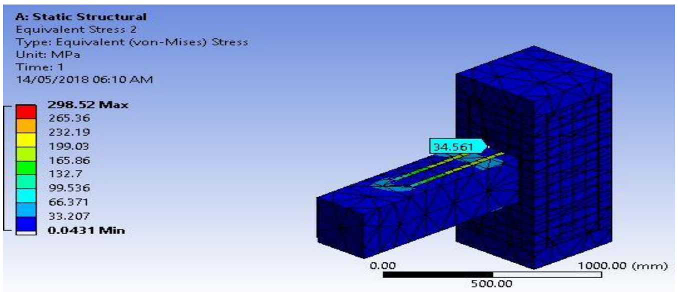

Figure 4.14 Von-Mises stress of NSM at beam and CFRP sheet at column retrofitted beam-column joint

4.4 COMPARISON OF STRESS RESULTS

For stress comparison the failure stress at the beam-column joint is considered. The table bellows shows the stress variation in concrete near-beam column junction.

Table 8 Von-Misses stress near beam-column junction

Case	Retrofitting Schemes	Von-Misses stresses in concrete at beam-column junction (Mpa)	% Icrease/decrease in stresses
C	Control specimen	28.584	
S	CFRP sheets	27.287	-4.54%
L	CFRP Laminate	26.178	-8.42%
LA	CFRP Laminate with anchorage at beam	26.102	-8.68%
NB	NSM technique at bottom of beam	29.757	+4.10%

NTB	NSM technique at top and bottom of beam	34.943	+22.25%
NTBS	NSM technique at beam bottom and CFRP sheet at column	34.561	+20.91%

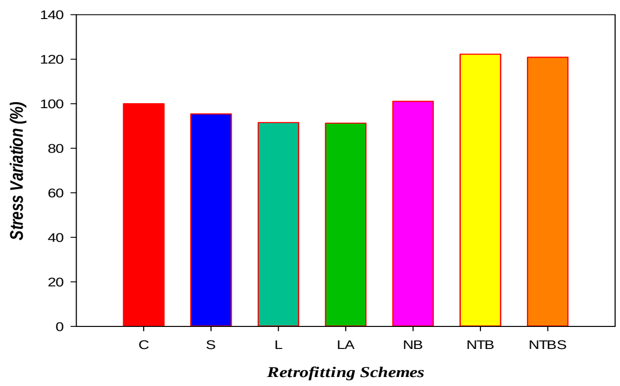

Chart 2. Comparison of stresses for different retrofitted schemes

The increase in stress on the surface of concrete at the beam-column joint after retrofitting indicates decrease in strength of joint. Hence NSM retrofitting technique is found to be ineffective in strengthening beam-column joint. It may be due to the delamination failure happens due to the yielding of epoxy material. Use of CFRP laminate with mechanical anchorage is found to be more effective among the selected retrofitting schemes. Appling CFRP laminate with mechanical anchorage shows increase in strength of about 8.68%. Hence most efficient retrofitting scheme according to stresses near beam-column joint is by CFRP laminate with mechanical anchorages.

5. CONCLUSION

Retrofitting of beam-column joint using CFRP material is efficient in strengthening the joint. All the retrofitting schemes adopted for the study have reduced the deflection of beam at free end. Considering the stresses near the joint, use of CFRP laminates with mechanical anchorages is found to be more effective. Mechanical anchorages also prevent the delamination failure at beam-column joint. Providing sufficient number of mechanical anchorages increases strength at the interface of the CFRP specimen. NSM technique of retrofitting can be used for decreasing the deflection of beam but with respect to strength aspect NSM retrofitting technique fails at beam-column joint. Numerical modelling using ANSYS software can be used effectively for the beam analysis. Most efficient retrofitting scheme from the study is by using CFRP laminate with mechanical anchorages.

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