Analytical Study on CFRP Strengthened Steel Column under Transverse Impact Load

Sreehari K S, Parvathy Anand Menon

Abstract— Naturally, steel has high strength and stiffness, which makes it harder to strengthen compared to materials such as concrete and wood. When steel is strengthened with a material whose Young's modulus is lower, the strengthening should only be effective after the steel yields. To solve the issues of conventional methods, there is a need for accepting a long-lasting, cost-effective material. A possible solution is the use of carbon fibre reinforced polymer (CFRP) plates. This paper deals with the numerical simulation of the strengthened square hollow section (SHS) steel columns under transverse impact loading and analysis was carried out using ANSYS 18.1. Parametric studies are conducted to find out the impact load capacity of CFRP strengthened SHS column under transverse impact load, by providing CFRP layer of various thickness, lengths and providing the CFRP layer on multiple sides (1, 2 and4 sides) of the column are used for CFRP distributions. The impactor is modelled as a rigid mass using 8-node brick element with dimensions of 89 x 89 x 90 mm. The density of the impactor was adjusted to achieve a specific mass of 170-kg with initial impact velocity of 7m/s. A series of detailed analyses on the impact behaviour of CFRP-strengthened steel columns was performed using the validated finite-element model to provide further insight.

Index Terms— Carbon fiber reinforced polymer; Transverse impact; Steel SHS column; Finite-element analysis.

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1. Introduction

Large part of infrastructure today consists of steel structures, which may need to be strengthened for increased loading The strengthened member of course will continue to be susceptible to corrosion and fatigue. Bolting or welding additional plates is the conventional method for retrotting or strengthening a steel member. The strengthened member of course will continue to be susceptible to corrosion and fatigue. Adding plates also increases the area of the column as well as the dead weight, which could cause issues for some projects. Naturally, steel has high strength and stiffness, which makes it harder to strengthen compared to materials such as concrete and wood. When steel is strengthened with a material whose Youngs modulus is lower, the strengthening should only be effective after the steel yields. To solve the issues of conventional methods, there is a need for accepting a long-lasting cost-effective material. A possible solution is the use of carbon bre reinforced polymer (CFRP) plates. Though they originally may have a larger material cost than steel, the material cost alone is normally small compared to the total cost of the project.

Majid M. A. [1] conducted a series of tests was conducted to gain insight into the effect of impact load on such beams. The parameters examined in the experiments were the thickness and length of the CFRP layers.

Alam, M.I. [4] studied the strengthening of metallic structures using carbon fibre reinforced polymer (CFRP) has become a smart strengthening option over the conventional strengthening method. Transverse impact loading due to accidental vehicular collision can lead to the failure of existing steel hollow tubular columns. However, knowledge is very limited on the behaviour of CFRP strengthened steel members under dynamic impact loading condition. This paper deals with the numerical simulation of CFRP strengthened square hollow section (SHS) steel columns under transverse impact loading to predict the behaviour and failure modes. The transverse impact loading is simulated using finite element (FE) analysis based on numerical approach.

Al-Thairy [2] studied a numerical simulation of the behaviour and failure modes of axially compressed steel column subjected to transverse impact by a rigid mass at different impact speeds and locations is presented.

Almost all of existing studies focused on investigating the behaviour of CFRP layer under axial and impact loading ; Studies are limited in the using of CFRP layer under axial loading and impact load without any specific CFRP distributions. Imapct capacity of those steel structures for various length and thickness are not studied in detail and corresponding optimum distribution not found. Hence this paper aims to conduct a study on impact capacity of square hollow section tubular columns strengthen by various CFRP distribution under transverse impact by finite element analysis using ANSYS 18. software.

2. FINITE ELEMENT ANALYSIS

Two paper was selected for validation. Majid M. A. et.al (2019) numerically investigate the impact behavior of the CFRP-strengthened steel beams. Beam was modeled using linear three-dimensional four-node shell elements, thesametypeofelementwas used to model the CFRP layer. While the other parts such as the impactor and the striking system were modeled by eight-node three-dimensional elements. In addition, the density of the impactor was adjusted to achieve a specific mass. The impact velocity was imposed using the PREDEFINED FIELD option available in ANSYS 18.1. Specimen was 0.85 m in length Two end plates (140 x 140 x 12 mm) range of CFRP thicknesses was investigated including 1.2, 2.4, 3.6 and 4.8 mm. In addition,

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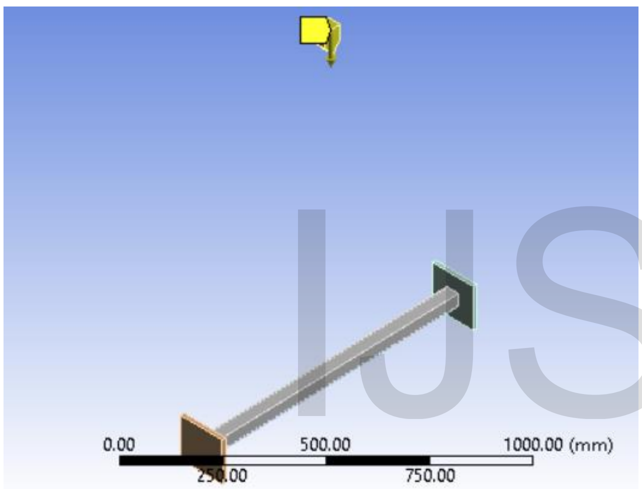
the effect of CFRP length (while maintaining constant overall CFRP volume) was further investigated to find the optimumCFRPdistribution. Finally, the effect of varying the impact-energy generated by two velocities 4.43 and 6.26 m/s and masses 91 and 182 kg was examined numerically. The steel beams used in the tests were Grade S355 SHS 40 x 40 x 3 mm (square hollow sections). Finite Element Modeling is done using ANSYS 18.1. The model developed is shown in Figure 1. . Results from the analysis of beam strengthened with CFRP under impact loading taken from the paper are used for comparison. Figure 2. Shows the graphical comparison of the results. The percentage error is approximately 4%.

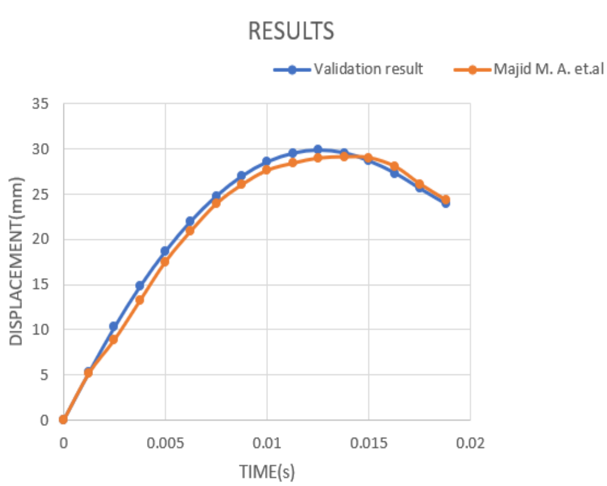
Fig. 1. Boundary conditions applied to CFRP strengthened beam

Fig. 2. Time deformation response comparison

Second paper selected for validation was M. I. Alam, S. Fawzia et.al et.al (2015), A 3-D finite element model of CFRP



strengthened columns with sectional dimension of 89 x mm x 89 mm 3.2 mm and length of 2380 mm are developed in ANSYS 18.1. The impactor is modelled as a rigid mass using 8-node

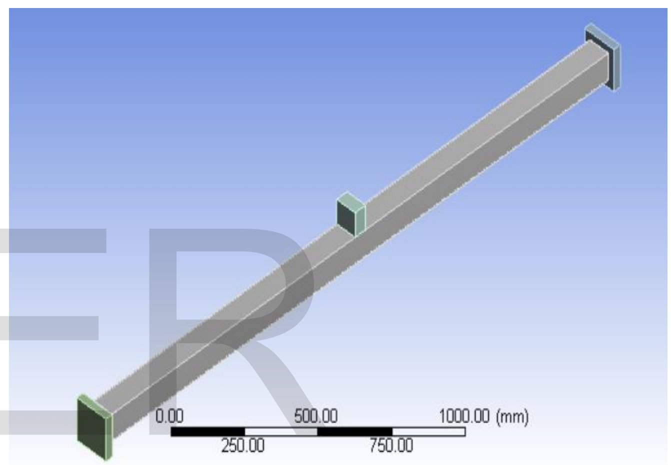


brick element with dimensions of 74 x 74 x 700 mm. The density of the impactor cube is calculated using its volume and expected mass. The initial impact velocity is generated at the outer surface of the impactor to create an impact collision at the mid height of the column. The thickness of CFRP and GFRP lamina are assigned as 0.54 mm and 1.46 mm. The steelbeams used in the tests were Grade S355 SHS 40x40x3mm (square hollow sections). The model developed is shown in Figure 3. Impact loading is provided. Results from the analysis of column strengthened with CFRP under transverse impactloading taken from the paper are used forc omparison. Figure 4. shows the graphical comparison of the results. The percentage error is approximately 7%.

Fig 3. Boundary conditions applied to CFRP strengthened column

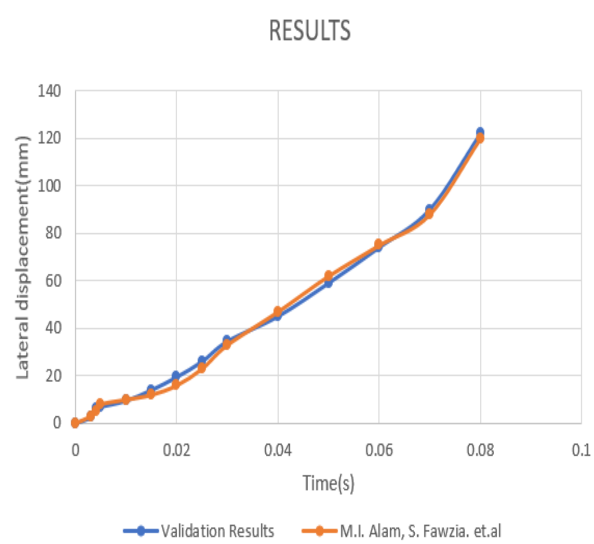
Fig. 4. Time deformation response comparison

3. NUMERICALMODELLING



3.1 Details of test specimens

Three - dimensional finite element model of square steel tubular columns with sectional dimension of 89 x mm x 89 mm x 3.2



mm and length of 2380 mm are developed in ANSYS 18.1. The impactor is modelled as a rigid mass using 8-node brick element with dimensions of 89 x 89 x 90 mm. The density of the

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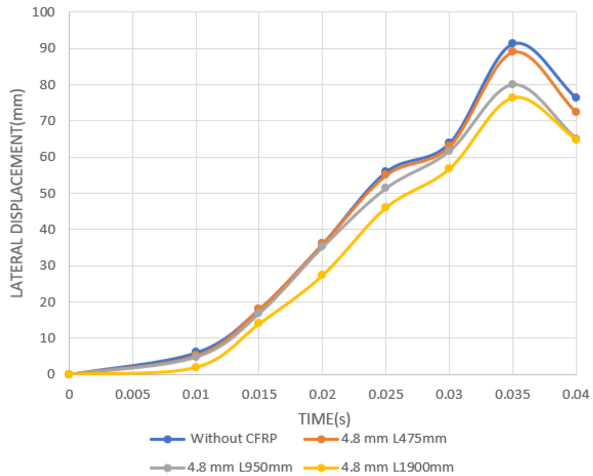

8	1900x89x2.4
9	1900x89x4.8

3.2 Material properties

Properties of the steel and CFRP layer used for modeling the specimens are as specified in Table 2 and Table 3 respectively.

TABLE 2
PROPERTIES OF STEEL

Youngs modulus (GPa)	200GPa.
Tensile strength (MPa)	611 MPa
Average yield stress of steel	538 MPa
Poisons ratio of steel	0.3

TABLE 3
PROPERTIES OF CFRP PLATE

Youngs modulus (GPa)	105.3 GPa
Tensile strength (MPa)	1,397.8 MPa
Strain to failure	0.01404

4. PARAMETRIC STUDY

In order to provide a comprehensive conclusion with the behavior of the CFRP strengthened steel columns subjected to transverse impact load, a set of parameters will be considered for the strengthened steel columns. Various thickness and length will be investigated numerically. Similarly, by providing CFRP on multiplesides, it will be examined in the numerical model and the optimum distribution is also investigated.

4.1. Effect of CFRP thicknesses

Influence of the CFRP thickness on the impact performance of the strengthened steel columns. Several CFRP thicknesses were examined in this section including 1.2, 2.4 and 4.8 mm. All col-

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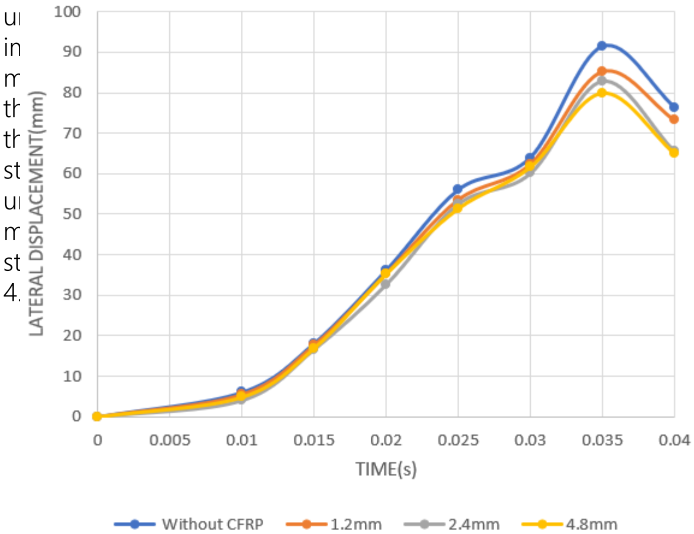
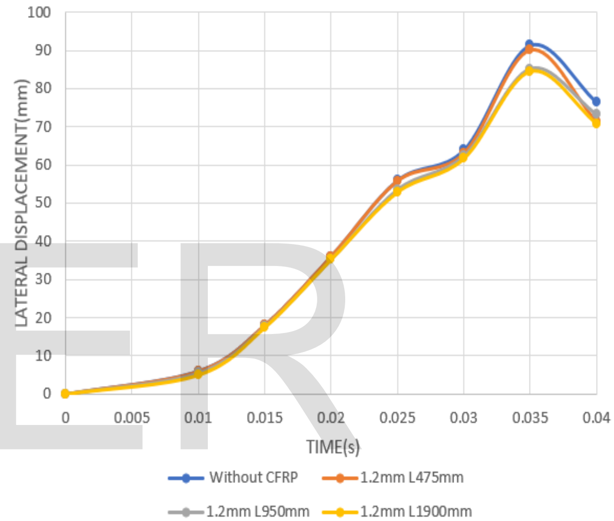




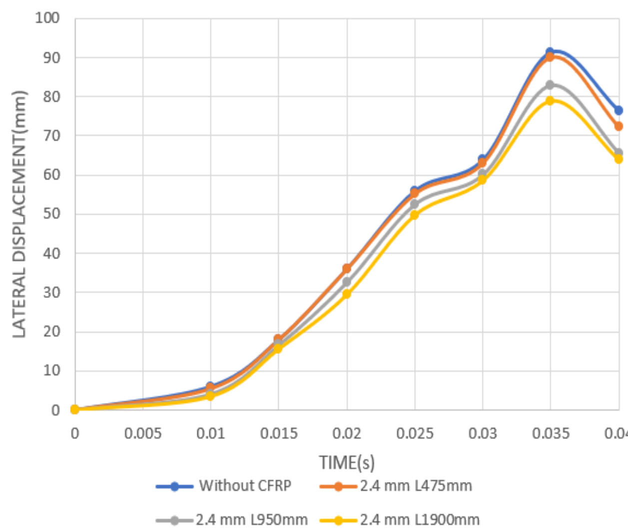


Fig. 7. Lateral displacement vs time graph for L1900 mm

Using a 1.2mm ,2.4mm and 4.8mm for L475mm CFRP layer reduces the maximum lateral displacement by around 1% ,2%, 4% respectively.Using a 1.2mm ,2.4mm and 4.8mm for L950mm CFRP layer reduces the maximum lateral displacement by around 5% ,6%, 12% respectively.Using a 1.2mm ,2.4mm and 4.8mm for L1900mm CFRP layer reduces the maximum lateral displacement by around 8% ,10%, 18% respectively.

4.2. Effec to CFRP lengths

Influence of the CFRP length on the impact performance of the strengthened steel columns was investigated. Several CFRP length were examined, including 475mm, 950mm and 1900mm. All columns were simulated under the same boundary conditions and impacted with the same kinetic energy. Thickness of CFRP was maintained constant during this investigation. In addition to the reduction in maximum transverse displacement of the strengthened columns compared with unstrengthened columns.

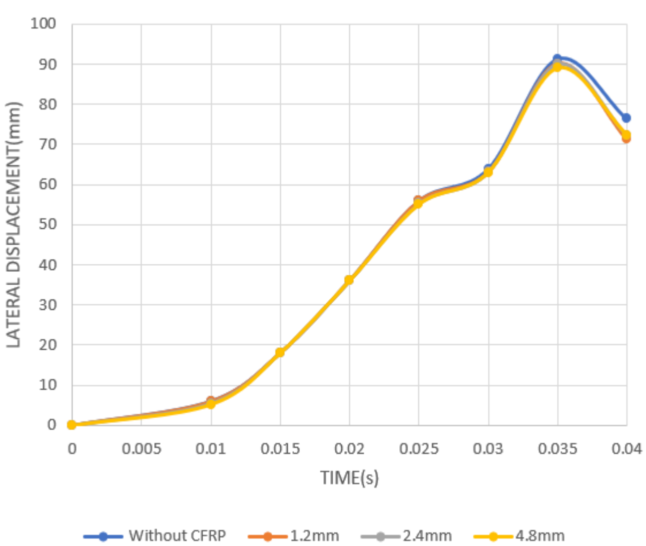
Fig.8 Lateral displacement vs time graph for T1.2 mm

Fig. 9 Lateral displacement vs time graph for T2.4 mm

Fig. 11 Lateral displacement vs time graph for T4.8 mm

Figure 9,10 and 11 summarizes the maximum transverse displacement for the strengthened and unstrengthened columns under various length of 475, 950 and 1900mm for thickness of 1.2, 2.4 & 4.8mm CFRP plate.

Using a 1.2-mm thick (T1.2mm) CFRP layer with for L475mm, L950 mm and L1900mm reduce the maximum lateral displacement by around 1% , 5% and 8% respectively.Using a 2.4-mm(T2.4 mm) thick CFRP layer with for L475mm, L950 mm and L1900mm reduce the maximum lateral displacement by around 2% , 6% and 10% respectively. Using a 4.8-mm(T4.8 mm) thick CFRP layer with for L475mm, L950 mm and



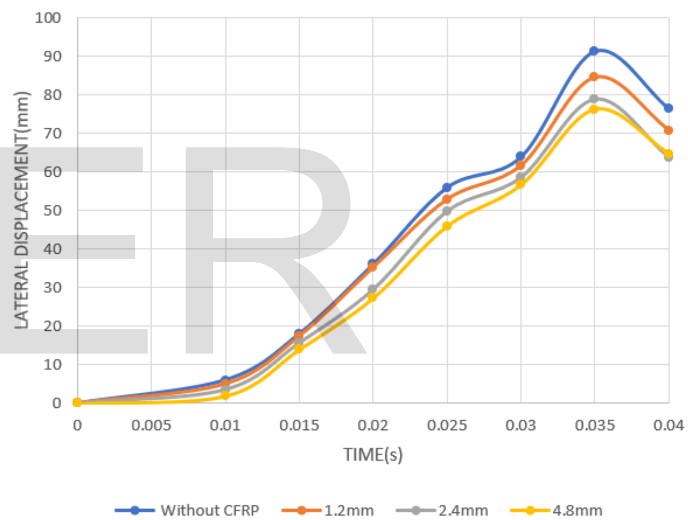
L1900mm reduce the maximum lateral displacement by around 4% , 12% and 18% respectively.

Table 5 shows comparison of the percentage of reduction in maximum lateral displacement for varying length and thickness of CFRP layer with constant volumes(A1 A2, A3) by changing the area.

TABLE 5

PERCENTAGE OF REDUCTION IN MAXIMUM LATERAL DISPLACEMENT OF CFRP DISTRIBUTIONS WITH CONSTANT VOLUME

Volume No.	Thickness (mm)	Length (mm)	% of reduction in lateral displacement
A1	2.4	475	2%
	1.2	950	5%
A2	4.8	475	4%
	2.4	950	6%
	1.2	1900	8%
	4.8	950	12%
	2.4	1900	10%



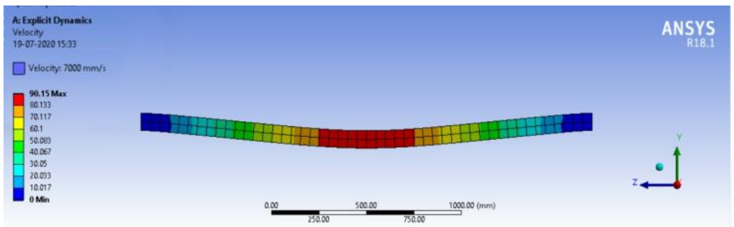
4.3. Effect of CFRP by providing CFRP plate on different sides

Influence of the CFRP by providing different sides on the impact performance of the strengthened steel columns .CFRP plate on 1, 2 and 4 sides were examined. All columns were simulated under the same boundary conditions and impacted with the same kinetic energy.Length and thickness of CFRP was maintained constant during this investigation. In addition to the reduction in maximum transverse displacement of the strengthened on 1, 2 and 4 side of columns were compared. Table 6 summarizes the maximum transverse displacement for the strengthened columns CFRP layer of 475, 950 and 1900mm for thickness of 1.2, 2.4 & 4.8mm CFRP plate strengthened on 1, 2 and 4 side of columns.

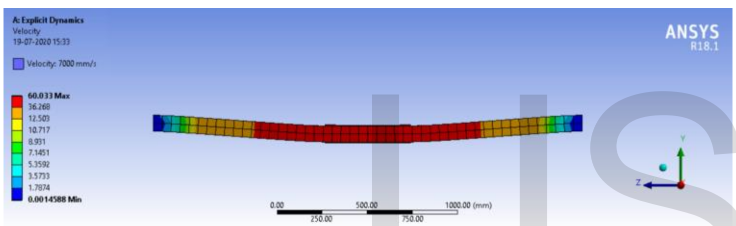
TABLE 6

PERCENTAGE OF REDUCTION IN LATERAL DISPLACEMENT

Length (mm)	Thickness (mm)	No. of sides	% of reduction in lateral displacement
475	1.2	1	1%
		2	4%
		4	26%
	2.4	1	2%
		2	11%
		4	35%
	4.8	1	4%



		2	12%
		4	37%



950	1.2	1	5%
		2	16%
		4	52%
	2.4	1	6%
		2	17%
		4	58%
	4.8	1	12%
		2	27%
		4	64%
1900	1.2	1	8%
		2	32%
		4	51%
	2.4	1	10%
		2	25%
		4	60%
	4.8	1	18%
		2	35%
		4	74%

4.4. Effect of CFRP distributions

Aimed at finding the most appropriate distribution of the CFRP to provide the maximum transverse displacement reduction. The quantity or volume of the CFRP is kept constant, change is made to the thickness and length or area of the CFRP layer to find the optimum distribution of the CFRP.

Table 7 shows the percentage of reduction in maximunum transverse displacement of strengthened columns for various CFRP distributions with constant volume(V1, V2, V3, V4, V5).

TABLE 7

PERCENTAGE OF REDUCTION IN LATERAL DISPLACEMENT FOR VARIOUS CFRP DISTRIBUTIONS WITH CONSTANT VOLUME

No.	Thickness (mm)	Length (mm)	No. of sides	% of reduction in lateral displacement
V1	2.4	475	1	2%
	1.2	950	1	5%
	1.2	475	2	4%
V2	4.8	475	1	4%
	2.4	950	1	6%
	1.2	1900	1	8%
	2.4	475	2	11%
	1.2	950	2	16%
	1.2	475	4	26%
V3	4.8	950	1	12%
	2.4	1900	1	10%
	4.8	475	2	12%
	2.4	950	2	17%
	1.2	1900	2	32%
	2.4	475	4	35%
	1.2	950	4	52%
V4	4.8	1900	1	18%
	4.8	950	2	27%
	2.4	1900	2	25%
	4.8	475	4	37%
	2.4	950	4	58%
	1.2	1900	4	51%
V5	4.8	1900	2	35%
	4.8	950	4	64%
	2.4	1900	4	60%

Fig. 12 Deformation of column CFRP (L475mm and T4.8mm) strengthened on 1 side

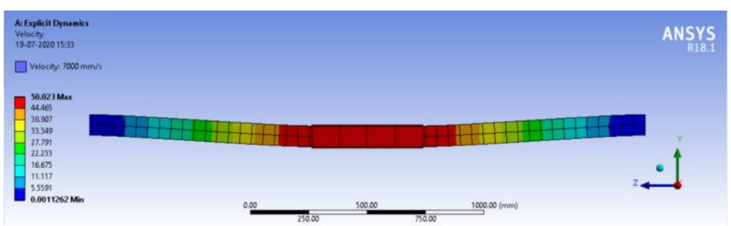
Fig. 13 Deformation of column with CFRP(L475mm and T4.8mm) strengthened on 2 side

Fig. 14 Deformation Of Column With CFRP(L475mm And T4.8mm) Strengthened On 4 Side

5 Conclusion

This paper is aimed at investigating the behavior of CFRP-strengthened steel columns subjected to transverse impact load. The following conclusions can be drawn from this investigation:

- CFRP-strengthening technique showed a good performance in enhancing the steel column against transverse impact load.
- Using a thicker CFRP layer can increase the effectiveness of the CFRP in strengthening the steel columns.
- Using a 4.8-mm CFRP thickness layer, reduction in the maximum lateral displacement nearly 3 times more than of a 1.2mm thick layer.
- By using alonger CFR Player, it can also increase the strength of the column under transverse impact.
- Using 1900 mm CFRP length layer instead of 475 mm, the reduction in the maximum transverse displacement nearly increases 4 times.
- From the parameter of length and thickness, comparing the percentage of reduction in maximum lateral displacement with constant volume but different area, for A1, the CFRP layer of L950 with T1.2 mm gives the maximum reduction in lateral displacement of 5%.
- For volume A2, the CFRP layer of L1900 with T1.2mm gives the maximum percentage of reduction of 8%.
- For volume A3, the CFRP layer of L950 and T4.8mm gives the percentage of reduction in lateral displacement of 12%.



- By providing CFRP on different sides, reduction in the lateral displacement increases with increase in length and thickness.
- It was found that using a 4.8mm and 1900mm CFRP layer on the 4 sides reduces the maximum transverse displacement by around 74%.
- It was found that using constant volume (V2) and changing the area of the CFRP layer, the maximum reduction in lateral displacement is increase from 4% to 26%.
- Using constant volume (V3) and changing the area of CFRP plates, the maximum reduction in lateral displacement is increase from 10% to 52%.
- It was found that using constant volume (V4) and changing the area of CFRP plates, the maximum reduction in lateral displacement is increase from 18% to 58%
- It was found that using constant volume (V5) and changing the area of CFRP plates, the maximum reduction in lateral displacement is increase from 35% to 64%.
- The distribution of the CFRP quantity (thickness and length) plays a significant role in an effective strengthening design.

The following are some recommendations for future study on this topic, Comparative study by changing the shape of the cross section of the column can be considered.Numerical study by changing the length of the column can be conducted. Numerical study by changing the impact load.Experimental study on present work can be conducted.

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