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Numerical Studies on CFRP Strengthened Cold formed Steel built-up Columns

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Abstract: This paper reports the numerical investigation carried out on the Cold-formed steel (CFS) built up columns strengthened with a Carbon fiber-reinforced polymer (CFRP) by using Finite element software ABAQUS/CAE. The CFS sections used in the investigation are built-up Cold formed box sections connected together by screws. Totally 24 columns are considered for the analysis in that twelve columns used are plain CFS and other 12 columns used are CFRP strengthened CFS columns. The geometric properties of the materials considered as 0.6 mm, 0.75 mm and 1 mm thickness with 300 mm, 500 mm and 700 mm depth respectively. All the built-up columns were modeled and analysed using ABAQUS software. From the analysis results, the Ultimate load capacity, buckling behavior and Load-lateral displacement of the Plain and CFRP strengthened columns are obtained and presented in this paper. It is also noted that the numerical results obtained from the ABAQUS software is in good agreement with the experimental results.

Keywords: Finite element method, built-up section, cold-formed steel, CFRP, buckling

1. Introduction

The use of Cold-formed steel sections is increased in recent days for structural and non-structural items such as beams, columns and built-up sections. The CFS columns are subjected to axial loads resulting in deformation and buckling. Hence, to decrease the deformation and buckling, different types of retrofitting methods are used. To come out of this problem, CFRP strengthening is one of the most promising techniques which is used in this study. There were numerous researchers conducted on experimental and numerical studies on CFS sections. But there is very a smaller number of research work carried on numerical analysis of CFS built-up columns strengthened using CFRP.

Several experimental and numerical investigations were carried out on CFS and CFRP strengthened sections. Urmi Devi et.al conducted a numerical investigation on the CFRP strengthened steel hallow columns. In this study it is observed that, for the higher slenderness ratio, CFRP Strengthening is effective and adding more CFRP layers (1-5) will increase the axial strength columns up to 20% [1]. Yanan Sun et. al reported a numerical investigation on the C-shaped steel channel columns subjected to the axial compression loads by varying CFRP thickness, CFRP reinforced

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layers to determine the ultimate strength of channel shaped columns by developing models using Abaqus Software. The results show that for a short column with transversely orientated CFRP wrapping is more effective than for individual web or flange regions [2]. Nuno Silvestre et.al conducted experimental and numerical investigation on the lipped columns strengthened by CFRP. Here, for short columns the ultimate load increased up to 15% and for long columns 20% increased [3]. M.Shahraki et. al reported the experimental and numerical analysis on CFRP-strengthened square hallow steel columns. The experiments were carried out for 3 columns, to know the behavior of columns subjected to axial loads. The results show that by CFRP strengthening, there was 82% increase in strength [4]. Galal M. Al-Mekhlafi et.al conducted experimental and numerical analysis on steel tubular columns with CFRP. These columns were tested experimentally and numerical analyses were done by Abaqus Software. Results shows that the columns with partial CFRP wrapping possess lesser strength compare to full wrapping. Further parametric studies were carried out by using finite element models, these studies show that strengthening increases with decreasing tubes diameter [5]. A. Shabani Ammari et.al conducted experiment and numerical analysis on short columns. Upon loading in the short column, defects were produced in 3 different places such as middle, top and bottom of the columns. The results show that at middle part horizontal deficiency is more compare to other parts of the member [6].

The numerical investigation on the plain CFS columns by Ehab Ellobody et. al. In this study geometric properties were taken into the account to know the buckling behavior of the columns. Different column length of fixed ends analysis were done and validated by using the experimental results. Both experimental and numerical results were in good agreement [7]. Krishanu Roy et.al done a numerical investigation on the steel channel sections. There were 36 models analysed by varying the slenderness ratio of the columns. The results show that, the spacing of the fasteners effect the load bearing capacity of columns [8]. S. Narayanan conducted an experimental and numerical investigation on 15 columns of medium length under axial compressive load. The obtained results show the residual stress effect on ultimate load is less in CFS column of medium length [9].

The researches have been done for the built-up CFS columns. Davide C. Fratamico et.al. conducted the numerical investigation using abaqus software on the built-up CFS columns to know the buckling behavior. In this work, the spacing of the fastners affects the column buckling behavior under axial load was observed [10]. Krishanu roy et.al did experimental and numerical investigation on built-up columns connected back-to-back. The experimental investigation was carried out on 40 columns by varying the slenderness ratio, the ratio was between 1.08 to 1.16 mm. The results shows that the design according to AISI specification conservative by as 53% [11]. Mohamed Imran et.al done an experimental and numerical analysis for SHS columns by taking seven columns with CFRP wrapping by taking end conditions. It is found that from numerical and experimental investigation after CFRP wrapping ultimate load increased 2.6 times compared to plain CFS [12].

The researches have been carried out experimental investigation on the CFRP strengthened Cold formed steel sections. Sreedhar kalavagunta et.al done experimental investigation on the CFRP stengthened cold formed sections. The results show, CFRP strengthening columns shows that 16.75% increase in the ultimate load capacity [13]. Nahushananda Chakravarthy et.al conducted experimental investigation on the built-up CFS columns with CFRP Strengthened. The results shows that percentage increase in the ultimate load after CFRP wrapping for columns found 13.77% and CFRP wrapping controls the lateral displacement [14]. Majid M.A. Kadhim et.al conducted experimental investigation of column strengthened with CFRP subjected to preloads result shows that local buckling is reduced by placing fibre in transverse direction and also by using CFRP, displacement of column was reduced [15]. Jimmy Haedir et.al conducted the experiments on CFRP strengthened steel tubular columns. The results show that by using longitudinal CFRP in a column, the axial compression capacity was increased with lesser displacement. The obtained results are compared with the AS/NZS 4600 [16].

From this literature study, it is observed that there is less numerical investigation is carried out on the built-up CFS box section columns strengthened with CFRP. In this paper numerical analysis investigation is carried out by using finite element software ABAQUS. Here, built-up columns of various thickness and length are chosen to determine the ultimate load bearing capacity, percentage of increase in strength after CFRP wrapping, buckling behavior and load-lateral displacement of the Plain and CFRP strengthened columns.

2. Summary of Experimental Investigation

For the present study, a recent experimental investigation [17] has been taken to validate with finite element model of built-up CFS box section column strengthened using CFRP. Two channel sections are represented by C75 and C100 where C is the channel section, 75 and 100 is the depth of web sections respectively. For C75 sections the length of the flanges are 41 mm and 38 mm with 8mm is the lip. For C100 sections the length of the flanges are 51 mm and 49 mm with 12 mm lip. These sections were formed by connecting two C sections front-to-front using screws of diameter 5.43 mm. The thickness of CFS members used in the experiment are 0.6 mm, 0.75 mm and 1 mm with a column height of 300 mm, 500 mm and 700 mm respectively. Screws were placed at 50 mm from the edges and 200 mm from centre to centre to connect channel sections.

From the tensile coupons test, material properties of the CFS used in the experiments were determined. The results were obtained from a universal testing machine of 1000 kN capacity with a 10 N preload and a 3 mm/min test speed by attaching extensometer over a guage length obtained an Initial Young's modulus of cold formed steel and CFRP were 207 GPa and 251 GPa respectively. The Proof stress at 2% is 659 MPa for Cold formed steel and 4983.8 MPa for CFRP. The tensile strength was 671.4 MPa for cold formed steel and 4986.9 MPa for CFRP. The Elongation at break was 9.0% and 2.1% for Cold formed steel and CFRP respectively. Further, tests were conducted using hydraulic testing machine of 300 kN capacity. All specimens were tested at a displacement rate of 0.1 mm/min to determine the ultimate strength, modes of failure axial shortening, lateral displacement of the columns.

3. Finite Element Model

3.1 Abaqus Software

In the current study of numerical investigation, Finite element software ABAQUS/CAE is used for the analysis. ABAQUS 6.10 software is used for modeling and analysis of structural components and to visualize the finite element model results [18]. By using Finite element software built-up box section of CFS column and CFRP strengthened columns are modeled. The sizes of columns sections are as mentioned in the section 2. Finite element software model analysis includes three steps. First step is pre-processing, In this step model is created to its dimensions and material properties are assigned. Second step is processing, in this step model is subjected to analysis, where job is created to run the model. Third step includes post-processing, where visualization of the model was made [18]. In an Abaqus software two types of analysis can be done. First one is buckling analysis, which is for linear material properties and another one is static general analysis for non-linear properties. Present study is about non-linear analysis, hence static general analysis is used.

3.2 Material Modeling

In the material modeling by using creation of parts two C-sections are created. Fig 1 shows the part creation of C-section from the Abaqus Software. For the present study 24 columns are modeled for different thickness of 0.6 mm, 0.75 mm and 1 mm with depth 300 mm, 500 mm and 700 mm. After creation of parts, the material properties of CFS is assigned in which Young's modulus as 207 GPa, Poisson's is 0.3. The stress-strain graph obtained from the experimental results is used for the modeling. The stress-strain graph is as shown in the Fig 2, which used to assign the material properties. After assigning the properties the two separate C-sections are assembled together to form built-up box section by using bolts of diameter 5.43 mm at 50 mm distance from the edges and 200 mm center to center. Further, Static general analysis has been done with an increment of 1000 and with a time period of 1.

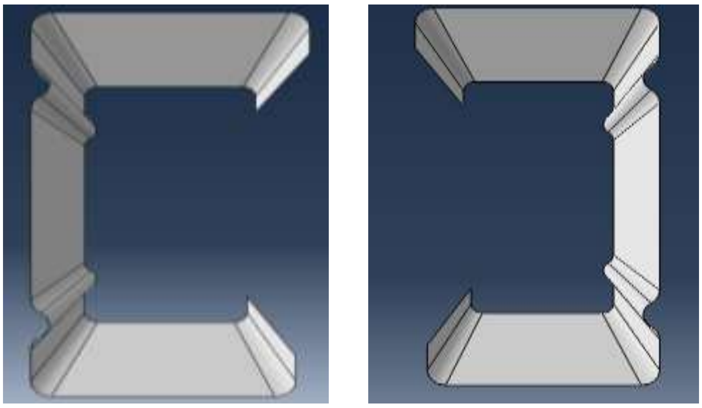

Fig. 1 - C-Sections modeled in Abaqus Software

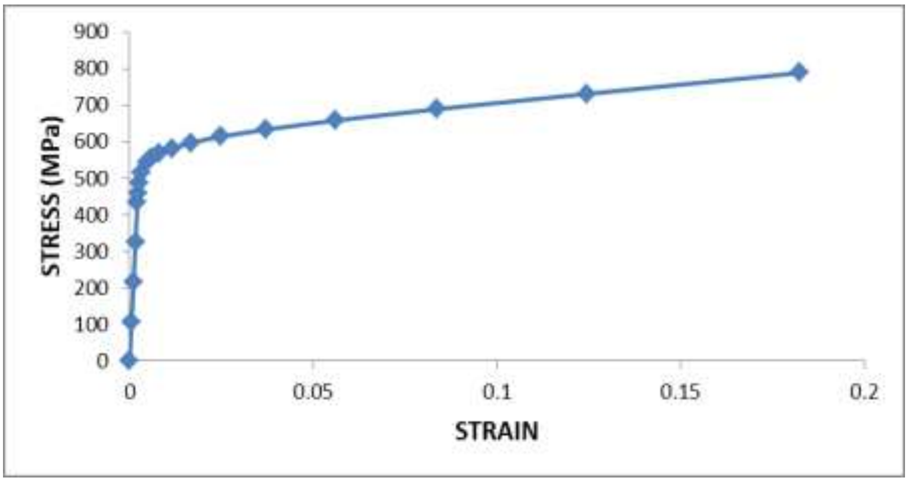

Fig. 2 - Stress-strain curve

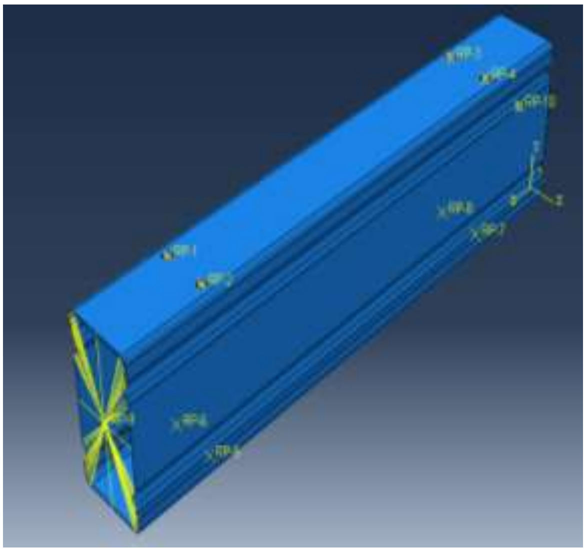

Fig. 3 - Application of kinematic coupling

After the selection of type of analysis coupling and contact is applied for the built-up section for interaction. Fig 3 shows the coupling application on the built-up section. The type of coupling selected for the analysis is Kinematic coupling. Three types of buckling can be applied such as Kinematic coupling, Distributive coupling and Structural distributing [18]. Kinematic coupling have rigid nature to hold two sections but distributive coupling have flexible nature it is not fully rigid nature. Coupling is given mainly to transfer the loads. In the interaction section contact is given for the surfaces of two C-sections where it overlaps.

3.3 Boundary Conditions and Loading

The built-up box section of CFS used in the analysis is subject to the boundary conditions of fixed type. Fig 4 shows the boundary conditions application at RP (Reference Point) 10 at the lower end. In Abaqus Software, Encastre options is selected for the fixed boundary conditions. After applying boundary condition the Concentrated load is applied on the built-up box section at a RP 9 from the upper end with a displacement of 20 mm. Fig 5 shows the application of concentrated load at RP 9.

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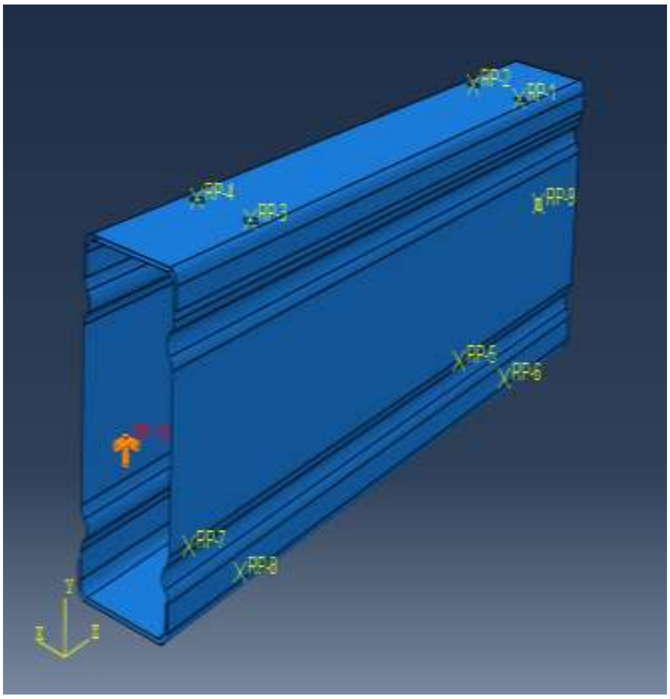

Fig. 4 - Fixed boundary condition at RP 10 (Lower end)

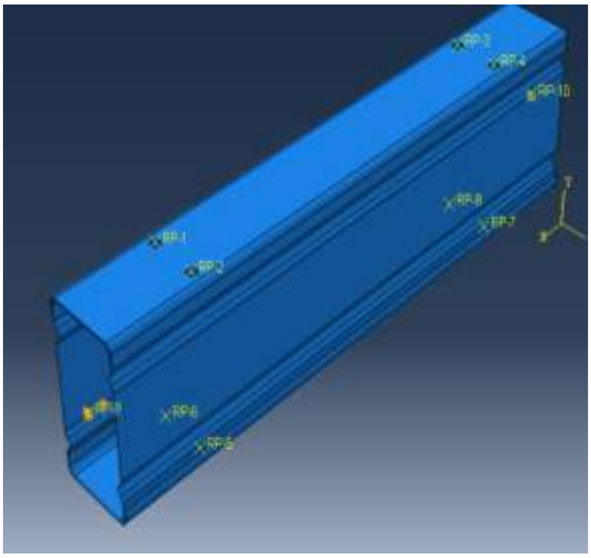

Fig. 5 - Application of concentrated load at RP 9 (Upper end)

3.4 Meshing of Finite Element Model

Meshing is carried out to develop the model to obtain accurate results. If the size of the mesh is small then the accuracy of the results obtained in the analysis is more [18]. For a Finite Element model meshing of a section is done by selecting an approximate global size as 5, 10 and 15 for different channel section having different depth of 300 mm, 500 mm and 700 mm respectively. In this study element type selected for meshing is Quadrilateral. In finite element software meshing is done by selecting a part separately. Fig 6 shows the meshing of built-up column section. After meshing, job is created with the help of a job module to run the model. After running of a job, model is prepared for visualization.

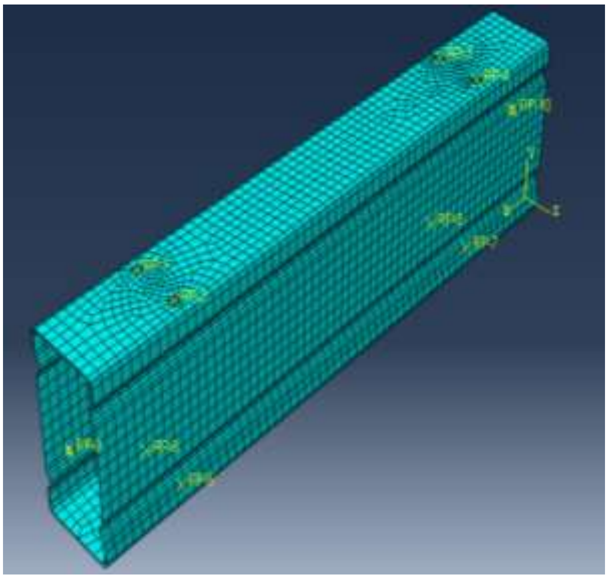

Fig. 6 - Meshing of a built-up box section

3.5 CFRP Assemble on Cold formed Built-up Column

CFRP is used to strengthen the built-up cold formed steel columns. The thickness of the CFRP used in the experimental and numerical analysis is 0.164 mm. For the material properties of CFRP young's modulus used as 251 GPa and Tensile strength as 4986.9 MPa. Number of CFRP layers used in the analysis is one in a vertical direction. Meshing of a CFRP is done of quadrilateral element shape with an approximate global size of mesh is 5 x 5. In an assembly section CFRP layer is assembled on a plain cold formed built-up steel column. Fig 7 shows the CFRP layer on a cold formed column.

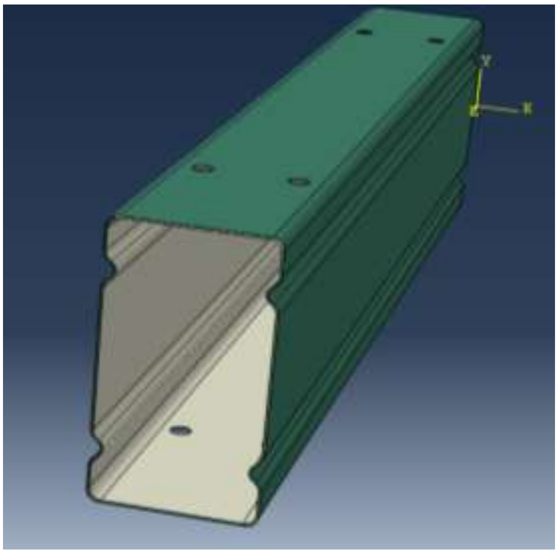

Fig. 7 - CFRP wrapping on cold form steel column

4. Results and Discussion

From the numerical investigations carried out using Abaqus Software on a built-up CFS columns with CFRP strengthening. The obtained results such as ultimate strength, Buckling modes and Load-lateral displacements are discussed as follows:

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4.1 Ultimate Strength

The results obtained from the Abaqus software; it is noted that there is a percentage increase in an ultimate strength up to 13.05% after CFRP wrapping. From the experimental investigation [17], percentage increase in an ultimate load after CFRP wrapping of built-up CFS columns was 13.77%. The results show that there is good agreement between experimental and numerical analysis results. The obtained results are compared with experimental results in Table 1.

Table 1 - Ultimate strength from numerical analysis comparing with experimental results

Sections	Experimental Ultimate Strength Plain (kN)	Numerical Analysis Ultimate Strength Plain (kN)	Experimental Ultimate Strength CFRP (kN)	Numerical Analysis Ultimate Strength CFRP (kN)	Experimental % increase Plain to CFRP	Numerical Analysis % increase Plain to CFRP
C7560x300	45.3	44	49.4	48	9.05	9.09
C7560x500	43.2	43	49.9	49.9	15.50	14.76
C7560x700	40.1	41	46.2	47	15.21	14.63
C7575x300	64.7	64	70.9	68	9.58	6.25
C7575x500	59.9	60	70.3	71	17.36	18.33
C7575x700	53.2	52	61.9	60	16.35	15.38
C7510x300	104.9	101	116.9	113	11.43	11.88
C7510x500	99.0	95	111.5	110	16.66	15.78
C7510x700	96.3	95.5	109.6	109	13.81	14.13
C10010x300	134.6	107	148.4	118	10.25	10.28
C10010x500	134.4	110	147.6	119	9.82	8.18
C10010x700	123.1	100	148.1	118	20.3	18
Mean					**13.77%**	**13.05%**

4.2 Buckling

The experimental results show that there was a local buckling failure in test results. Similarly, the numerical results also show the local buckling failure in the box shaped columns. Here, one the flanges of the channel hold the another flange, the flanges fit firmly one over the other. Moreover, flanges were connected with screws. Hence, only in the web region local buckling was observed. The modes of failure are as shown in the Fig 8.

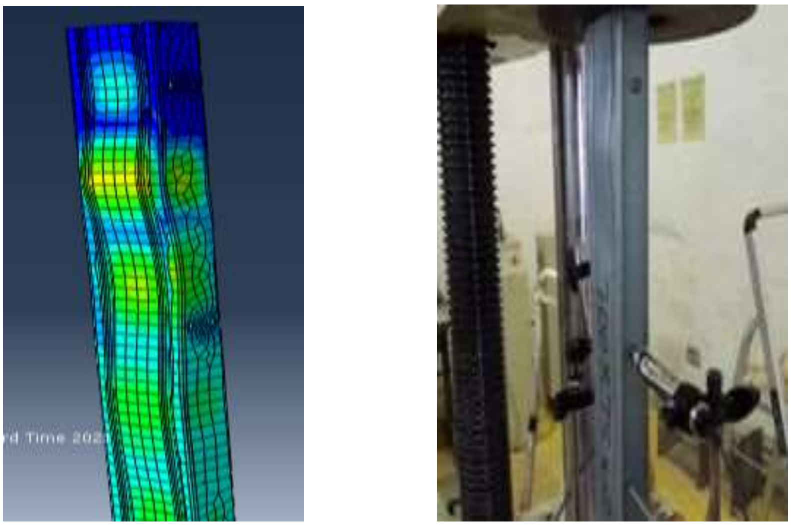

Fig. 8 - Local buckling from numerical and experimental results

4.3 Load-Lateral Displacement

From the numerical analysis the load-lateral displacement of plain and CFRP strengthened column is obtained as shown in a Fig 9. When column in subjected to axial compressive loads, there will lateral displacement in the columns. Due to firm contact of CFRP and the cold formed steel, there is reduction in lateral displacement in the columns. Hence CFP plays a major role in controlling lateral displacement. In Fig.9 lateral displacement for plain column is 2.5 3mm and CFRP strengthened column is 1.3 mm. Similar behavior observed in other sections also.

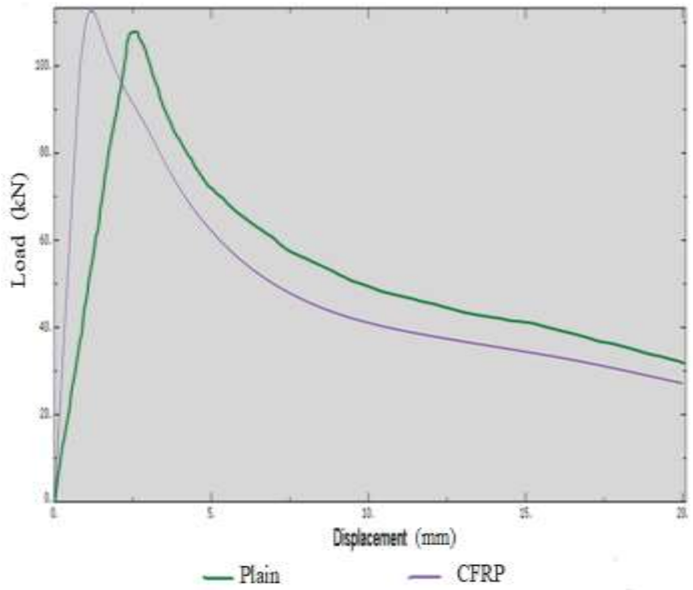

Fig. 9 - Load-lateral displacement of column

5. Conclusions

By using finite element software ABAQUS/CAE numerical investigation is carried out for a 24 built-up cold formed steel of box section with and without CFRP. The results were validated with a previous experimental investigation. From the numerical analysis, it is noted that 13.05 % increase in ultimate strength of plain to CFRP Strengthened column. Whereas experimental ultimate strength was 13.77%. The local buckling was observed both in experimental and numerical analysis. From the Load-lateral displacement graphs it was observed that the plain columns experienced lesser displacement compared to the CFRP Strenghened CFS Columns. Hence, there is a close matching of experimental and numerical results. So, Abaqus software can be used effectively for validating experimental results in CFS.

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