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Numerical Investigation and Structural Performance of Hollow Flanged Corrugated Web Tapered Slender Columns

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Abstract - *This research aims to develop numerical investigation and structural performance of hollow flanged corrugated web tapered slender columns. Tapered steel member offers a better cross section utilization along the member, which makes them an interesting and more economical alternative to prismatic ones. In this paper the investigation is carried on I section with the combination of hollow flange and corrugated web. Firstly, non-prismatic columns with different tapering conditions are investigated under axial loading. Out of best tapered ratio, investigating non prismatic column with flat flange effects. From the best width of flange, investigation for various shapes of hollow flanges. After that investigating the effect of double web in this column. Finally, lateral load resisting capacity of non-prismatic column is investigated. Finally push over analysis is carried out with the single storey frame for the different factor's ductility performance, strength factor etc. Above objectives are done for axial loading condition to check the performance of strength, critical buckling load and stiffness of the column.*

Key Words: Non prismatic column, NPC, Tapered column, Hollow flange, Corrugated web, Axial loading, Lateral loading, Finite element analysis

1. INTRODUCTION

A tapered column in a building system provides the widest possible span without the need for interior supports. They are more economical on larger clear span designs than straight column framing. Tapered steel member offers a better cross section utilization along the member, which makes them an interesting and more economical alternative to prismatic ones. A non-prismatic column (NPC) is the column whose cross section is not constant along its entire length. Corrugated sections are normally high strength fabricated steel sections. These are mainly used in industrial, commercial and residential buildings. Hollow flange sections are cold formed & welded from either hot rolled, cold rolled, pre-galvanized or stainless steel. They have different shape & size. The study investigates the effect of non-uniform crossection on the behavior of composite columns subjected to eccentric and axial load.

In this present study hollow flanged non prismatic corrugated web slender structures structural behavior is explained. Firstly, the investigation of non-prismatic Column with different tapered ratio. Out of best tapered ratio investigation for flat flange effect under constant weight as well as section constant condition. After that, out of best flange width investigation of Non-Prismatic Column with various shapes of hollow flange. From the best shape, investigating Non-Prismatic Column with hollow flange effects. Then investigating the effect of double web Non-Prismatic Column. Finally, lateral load resisting capacity of Non-Prismatic Column is investigated. Above objectives are done for axial loading conditions to check the performance of strength, critical buckling load, stiffness of the column and type of buckling effect. Finally push over analysis is carried out with the single storey frame. the different factors like ductility performance, strength factor etc.

2. FINITE ELEMENT MODELLING

2.1 General

The main objective of this paper is to perform numerical investigation and structural performance of hollow flanged corrugated web tapered slender column and lateral load resisting capacity of the structure was done by ANSYS 16.0

2.2 Scope

The work is limited to modelling and analysis of columns using ANSYS16.0. Improve the structural stability of non-prismatic columns by changing its parameters like web, flange & taper ratio. Easy to install in construction site and cost effective. It is an effective method in construction field in terms of ductility, durability, stiffness etc. Introducing corrugated web, double web concept and hollow flange concept for non-prismatic columns. The Axial Loading performance is carried out to evaluate buckling load, axial shortening, stiffness and its failure capacity is also determined. Lateral loading performance is also carried out to investigate the seismic factors like target displacement, lateral stiffness, and lateral strength.

2.3 Geometry NPC with different tapered ratio

Non prismatic columns were considered for analysis. V and L shaped I section steel column with corrugated web and flat flange with different tapered ratio under constant weight as well as constant section were taken for analysis. There are 12 models, 6 models with constant weight (L and V shape) and 6 models with constant section (L and V shape). The length of the column is taken as 6000mm. The thickness of corrugated web is taken as 3mm. The width and thickness of flange is 100mm and 10mm respectively. The structural characteristics of steel section including Density, Young's modulus and Poisson's ratio are 7850 kg/m^3, 2.01x10^5 MPa and 0.3 respectively. Bilinear isotropic hardening is used to reproduce plastic behavior of materials. In above cases weight remain constant as well as section remain constant are analysed. Table -1 shows sectional dimensions of V shape with different TR under constant weight. The geometry of V and L shaped column connected with corrugated steel plate in the Finite Element Modelling under constant weight is shown in figure1.

Table -1-Sectional dimensions of V shape with different TR under constant weight.

TAPER RATIO	H_max (mm)	H_min (mm)	WEIGHT (Kg)
2	320	160	40.5
3	360	120	40.5
4	400	100	40.5

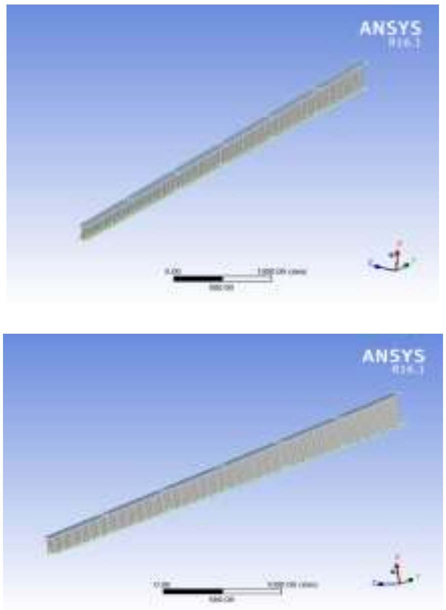


Fig -1 Geometry of V and L shaped I section steel column.

2.3.1 Meshing

Selected three-dimensional model of V and L shaped I section steel column was developed by finite element software to demonstrate the behavior properly. Figure 2 shows meshing of V and L shaped I section steel column with TR 2 under constant weight. In the finite element analysis fine mesh was adopted for accuracy. so that, solid model with given dimensions is formed into a Finite Element Model.

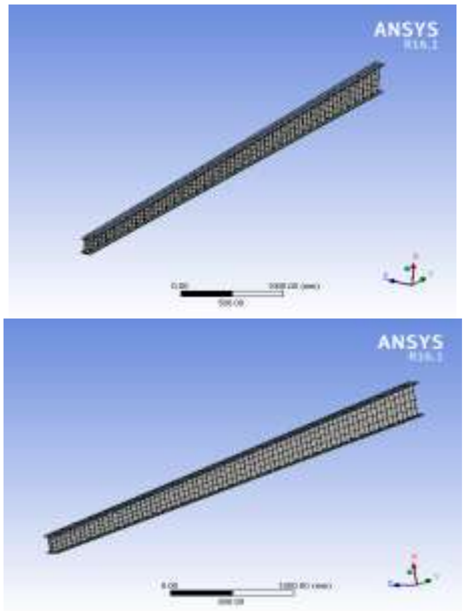


Fig - 2 Meshing of V and L shaped I section steel column.

2.3.2. Loading and boundary conditions

To simulate the real condition, V and L shaped I section steel column were analyzed with hinged support at both ends. Lateral support is provided at each 1m. The load was given at one end of tapered I section column. Column is subjected to axial loading condition. Rotation was allowed along the X and Z axis and load was applied only in one direction. Behavior of columns under axial loading was studied by ANSYS. Figure 3 shows loading and boundary conditions of V and L shaped I section steel column with TR 2 under constant weight.

2.3.3. Results and discussions

The web tapered I section steel column with the geometrical dimensions and material properties as described in the previous sections was analyzed in ANSYS Workbench 16.1. The load and corresponding deformation of V and L shaped I section steel column with TR 2 under constant weight and section are analyzed. Figure 4 shows deformation diagram of V shaped I section steel column with TR 2 under constant weight and constant section and Figure 5 shows deformation diagram of L shaped I section steel column with TR 2 under constant weight and constant section.

According to this analysis taper ratio 2 has more performance compared to other taper ratios. Here taper ratio 2 has more performance and maximum load carrying capacity compared to other taper ratios in both conditions i.e. weight constant as well as section constant. Chart 1 shows comparison of load carrying capacity. From this it is concluded that V shape has more load carrying capacity other than L shape under constant weight condition.

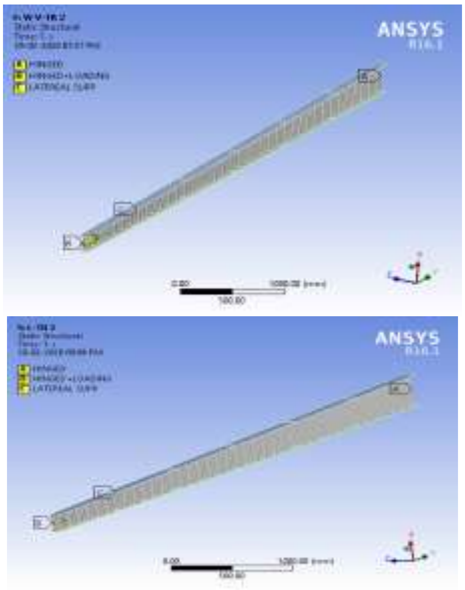


Fig -3 Loading and boundary condition.

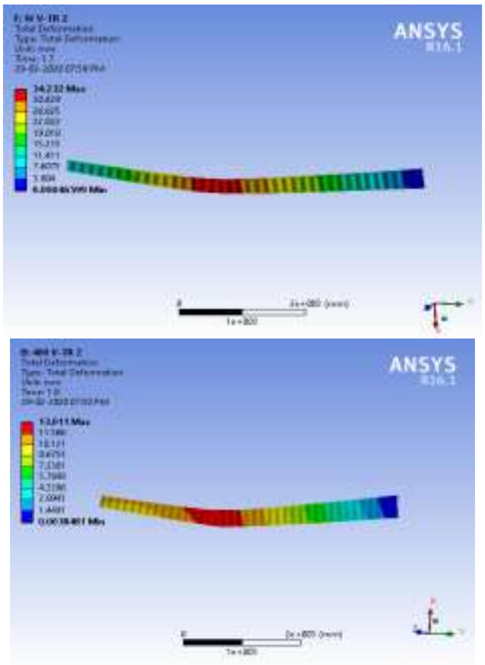


Fig – 4 Deformation of steel column.

2.4 Investigation of flat flange effects

V – shaped steel column with corrugated web and flat flange with taper ratio 2 under constant weight as well constant thickness are taken for analysis. The length of the column is taken as 6000mm. The thickness of corrugated web is taken as 3mm. The width and thickness of flange is varying. The structural characteristics of steel section including Density, Young's modulus and Poisson's ratio are 7850 kg/m^3 2.01x105 MPa and 0.3 respectively. Bilinear isotropic hardening is used to reproduce plastic behavior of materials. Here effect of flange is determined by applying different width for flanges. To simulate the real condition, tapered I section steel column were analyzed with hinged support at both ends. Lateral support is provided at each 1m. The load was given at one end of tapered I section column. Column is subjected to axial loading condition.

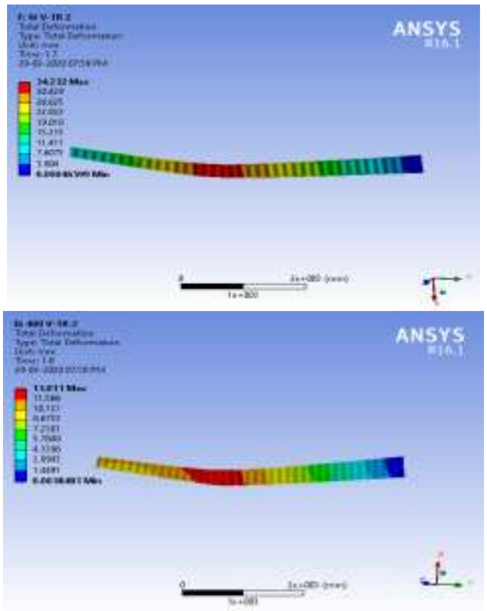


Fig - 5 Deformation of steel column.

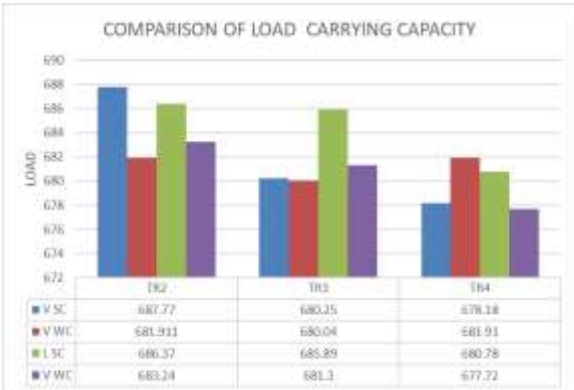


Chart -1: Comparison of load carrying capacity.

2.4.1. Results and discussions

The web tapered I section steel column with the geometrical dimensions and material properties as described in the previous sections was analyzed in ANSYS Workbench 16.1. The load and corresponding deformation of tapered I section steel column with TR 2 and different flange width under constant weight and section are analyzed. The load and corresponding deformation of steel column with TR 2 under constant weight is shown in table 2. Fig- 6 shows deformation diagram of tapered I section steel column with TR 2 with flange width 100mm under constant weight. According to this analysis taper ratio 2 with flange width

100mm under constant weight has more performance compared to other flange widths. Here flange width 100mm has more performance and maximum load carrying capacity compared to other flange widths in both conditions i.e. weight constant as well as section constant. In this load carrying capacity is increasing in case of weight is not constant but at the same time weight is increasing so that it is not economical. By comparing these values flange width with 100 mm under both conditions shows same performance. But flange with 200mm to 300mm load capacity is decreasing and they are not feasible under both conditions. Therefore, flange with 100mm width under constant weight has better performance.

Table.2- Maximum load-deflection values of different width of flanges under constant weight.

WEIGHT CONSTANT			
		DEFORMATION(mm)	LOAD(KN)
T=10MM	F100	12.002	678.54
T=5MM	F200	10.259	668.68
T=3.3MM	F300	13.038	431.38

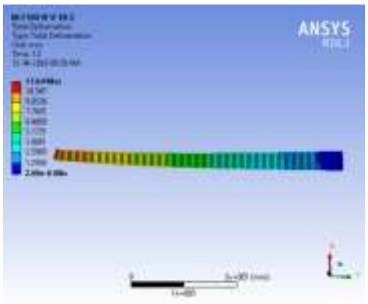


Fig - 6 Deformation of tapered steel column.

2.5 Investigation of hollow flange effects with different geometries

I sections are built-up sections and they are not available as standards. Here by previous analysis we can conclude that taper ratio 2 with V shape and flange width 100mm under constant weight has more performance. Hollow flanged corrugated web tapered I section under constant weight are taken for analysis. Here the hollow flange effect is analysed in different geometries. For that we are choosing different shapes for hollow flange. Rectangle, trapezoid, and semi-circular shapes are used for analysis. Figure 7 shows hollow flange with trapezoidal, rectangular and semi-circular shape. Here rectangular hollow flange has 3.33mm thickness and 100mm width. Loading and boundary conditions are given same as above.

2.5.1. Results and discussions

Hollow flanged corrugated web tapered I section steel column with the geometrical dimensions and material properties as described in the previous sections was analyzed in ANSYS Workbench 16.1. The load and corresponding deformation of tapered I section steel column with taper ratio 2 and different shapes of hollow flange under constant weight are analyzed.

Figure 8 shows deformation diagram of rectangular, trapezoidal and semicircular hollow flanged steel column under constant weight respectively. Maximum load and corresponding deformation of steel column with TR 2 under constant weight is shown in table 3.

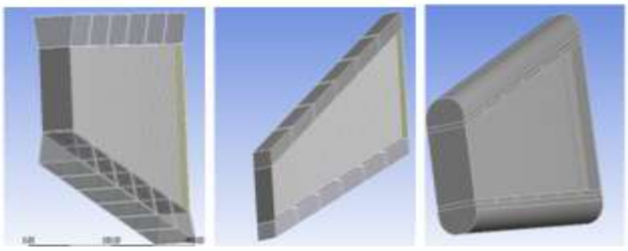
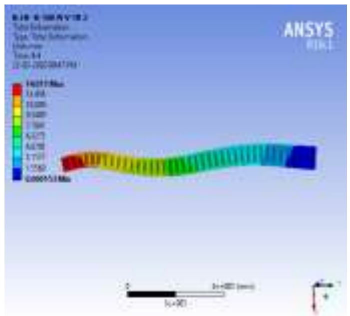
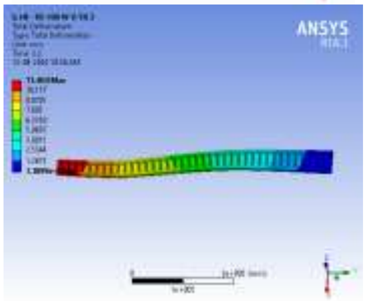


Fig - 7 Hollow flange with trapezoidal, rectangular and semi-circular shape.

Table.3 Maximum load-deformation values of different shapes of hollow flanges.

FLANGE	DEFORMATION(mm)	LOAD(KN)
RECTANGLE	11.948	699.44
TRAPEZOID	10.93	693.35
SEMI CIRCLE	9.4369	671.78
FLAT FLANGE	12.14	678.19





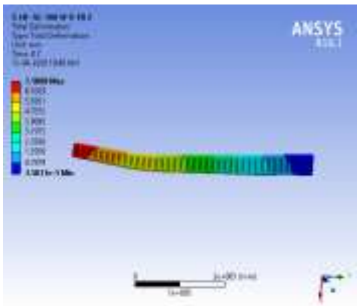


Fig-8 Deformation of steel columns.

The load vs. deformation graph is given in chart 2. According to this analysis taper ratio 2 with rectangular hollow flanged corrugated web steel column under constant weight has more performance compared to other shapes of hollow flange Therefore, hollow flange with rectangular shape under constant weight has better performance.

2.6 Investigation of double web effect

From the previous analysis we can conclude that taper ratio 2 with V shape and rectangular hollow flange with width 100mm under constant weight has more performance. Hollow flanged corrugated web tapered I section under constant weight are taken for analysis.

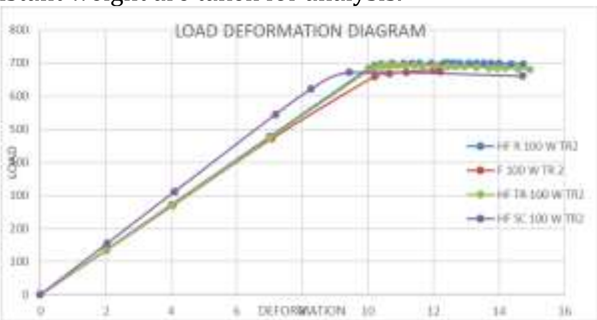


Chart -2 Load-deformation curve.

Here single corrugated web is changed to double corrugated web without changing the thickness of web. The length of the column is taken as 6000mm. The thickness of corrugated webs is taken as 1.5mm each. The gap between two webs is taken as 40mm.The structural characteristics of steel section including Density, Young's modulus and Poisson's ratio are 7850 kg/m^3, 2.01x105 MPa and 0.3 respectively. Bilinear isotropic hardening is used to reproduce plastic behavior of materials. Here the hollow flange with double web effect is analyzed and compared with single web effect. Figure 9 shows a corrugated double web steel column and geometry of rectangular hollow flanged corrugated double web steel column in the Finite Element Modelling under constant weight.

2.6.1. Results and discussions

Hollow flanged corrugated double web tapered I section steel column with the geometrical dimensions and material properties as described in the previous sections was analyzed in ANSYS Workbench 16.1. The load and corresponding deformation of tapered I section steel column with taper ratio 2 and hollow flange with corrugated double web under constant weight are analyzed. Table 4 shows maximum load-deformation values of hollow flanged double web and flat flange single web under constant weight. Figure 10 shows deformation diagram of rectangular hollow flanged corrugated double web and single web steel column under constant weight.

The load vs. deformation graph is given in chart 3. According to this analysis taper ratio 2 with rectangular hollow flanged corrugated double web steel column under constant weight has more performance compared to flat flange corrugated web steel column. Here rectangular hollow flange with corrugated double web has more performance and maximum load carrying capacity compared to flat flange.

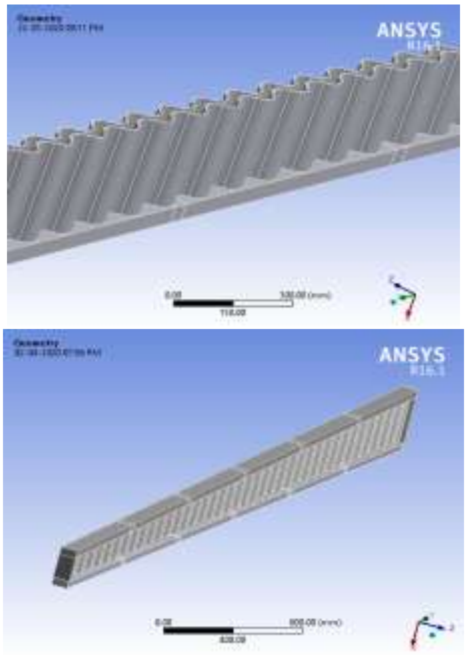


Fig -9 Corrugated double web and Geometry of rectangular hollow flanged corrugated double web steel column

Table-4 Maximum load-deformation values.

FLANGE	DEFORMATION(mm)	LOAD(KN)
FLAT FLANGE SINGLE WEB	12.14	678.19
HOLLOW FLANGE DOUBLE WEB	12.316	699.97

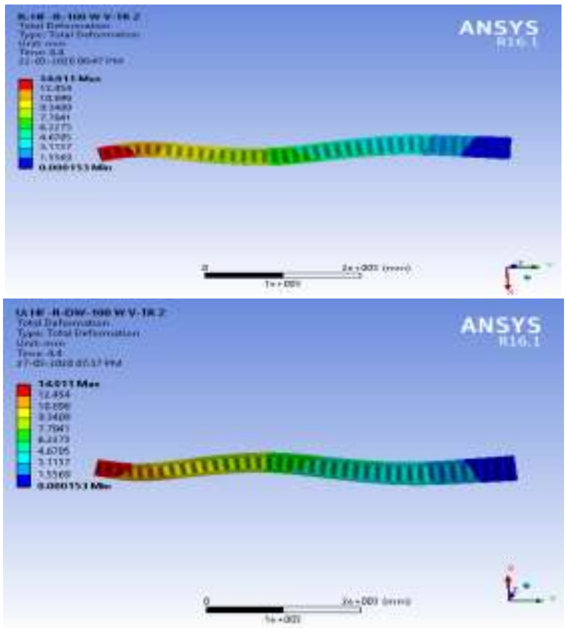


Fig-10 Deformation of single and double web steel column.

As it has constant weight, they are economical and cost effective as like normal I section but have more strength and load carrying capacity. Therefore, double web sections have more performance than single web sections under constant weight.

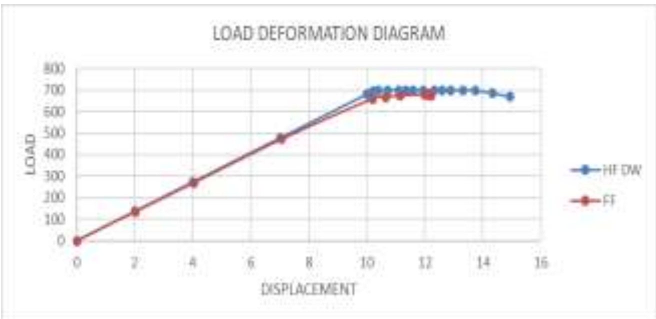


Chart -3 Load-deformation curve.

3. HOLLOW FLANGED CORRUGATED TAPERED WEB FRAMES

3.1 Investigation of single web and double web frame

3.1.1 Geometry

Hollow flanged corrugated web tapered I section under constant weight are taken for analysis. Here single corrugated web section is used and is combined to form a frame. It consists of 2 columns connected with a beam element. The length of the columns is taken as 6000mm. The thickness of corrugated webs is taken as 3mm each.

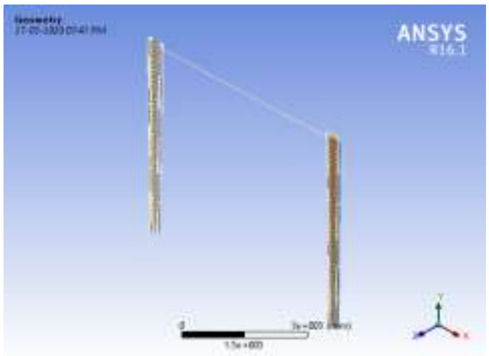


Fig 11 Geometry of steel frame

Next is double corrugated web section is used and is combined to form a frame. It consists of 2 columns connected with a beam element. The length of the columns is taken as 6000mm. The thickness of corrugated webs is taken as 1.5mm each. The gap between two webs is taken as 40mm.The width and thickness of flange 100mm and 3.33mm respectively. The structural characteristics of steel section including Density, Young's modulus and Poisson's ratio are 7850 Kg/m3, 2.01x105 MPa and 0.3 respectively. Bilinear isotropic hardening is used to reproduce plastic behavior of materials.

The geometry of rectangular hollow flanged corrugated single web and double web steel frame in the Finite Element Modelling under constant weight is shown in figure 11. Figure 12 shows meshing of rectangular hollow flanged corrugated single web and double web steel frame under constant weight. In the finite element analysis fine mesh was adopted for accuracy. so that, solid model with given dimensions is formed into a Finite Element Model. Figure 13 shows loading and boundary conditions of rectangular hollow flanged corrugated double web steel frame under constant weight.

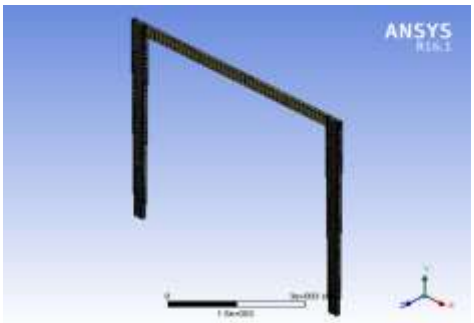


Fig 12 Meshing of steel frame

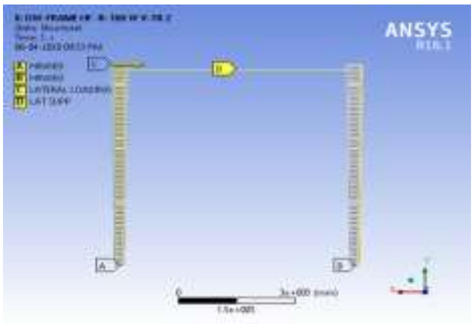


Fig 13 Loading and boundary condition of steel frame

3.2. Results and discussions

Hollow flanged corrugated single and double web tapered I section steel frame with the geometrical dimensions and material properties as described in the previous sections was analyzed in ANSYS Workbench 16.1. The load and corresponding deformation of tapered I section steel frame with taper ratio 2 and hollow flange with corrugated single web under constant weight are analyzed. Figure 14 shows deformation diagram of rectangular hollow flanged corrugated single and double web steel frame under constant weight. For the load applied on the frame the stress result was observed for the different model. The typical stress distribution of rectangular hollow flanged corrugated single web steel frame under constant weight are shown in fig 15.

Hollow flanged corrugated single and double web tapered I section steel frame with the geometrical dimensions and material properties as described in the previous sections was analyzed in ANSYS Workbench 16.1. The load vs. deformation graph is given in chart 4. Table. 5 shows maximum load-deformation values of hollow flanged single and double web under constant weight. According to this analysis rectangular hollow flanged corrugated double web steel frame under constant weight has more performance compared to hollow flanged corrugated single web steel frame under constant weight but approximately they have equal performance. Here rectangular hollow flange with corrugated double web has more performance and maximum load carrying capacity compared to hollow flanged corrugated single web steel frame. As it has constant weight, they are economical and cost effective as like normal I section but have more strength and load carrying capacity. Therefore, double web steel frame has more performance than single web frames under constant weight.

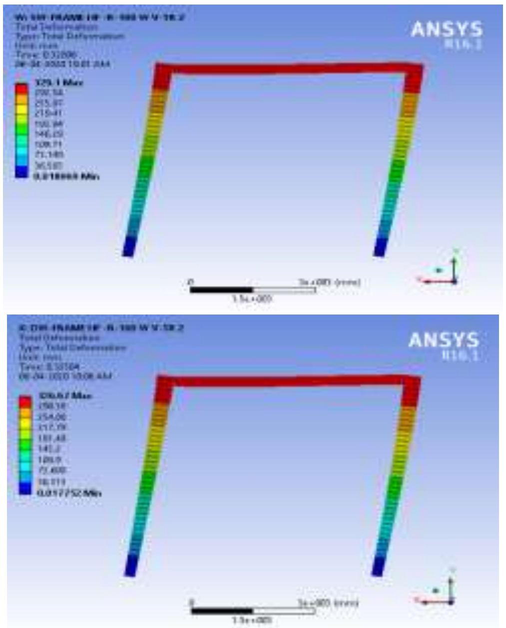


Fig 14 Deformation of steel frames.

Table.5 Maximum load-deformation values of single and double web frame.

	DEFORMATION(mm)	LOAD(KN)
HOLLOW FLANGE SINGLE WEB FRAME	330.12	528.04
HOLLOW FLANGE DOUBLE WEB FRAME	327.69	530.16

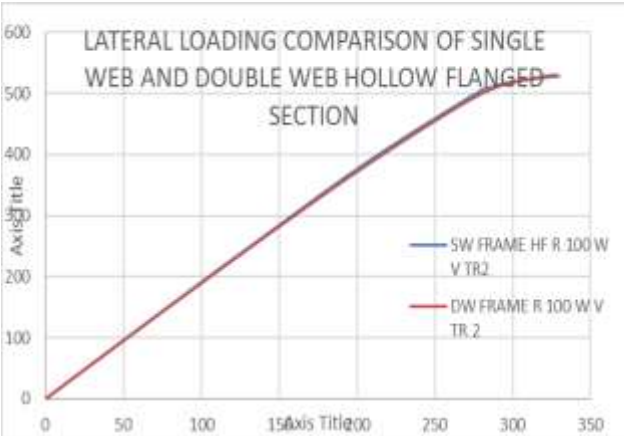


Chart -4 Load-deformation curve.

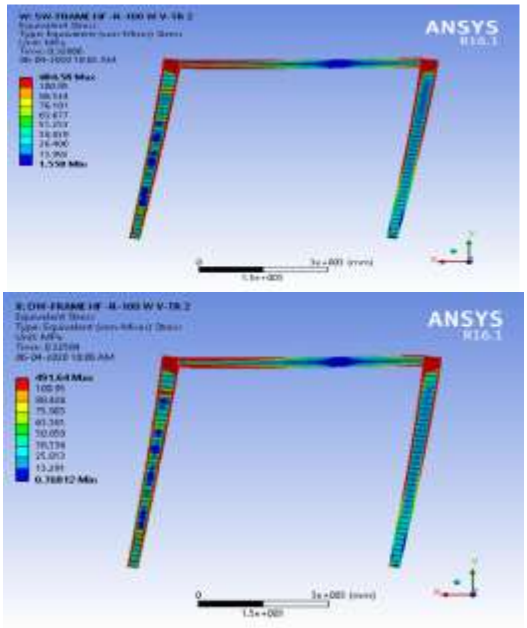


Fig. 15 Stress distribution of steel frames.

4. SUMMARY OF RESULTS

4.1 Summary of hollow flange effect

Hollow flanged corrugated web tapered I section steel column is much stronger than the conventional flat flange steel section. Because all load values of hollow flanged corrugated web tapered, I section steel column is comparatively larger than the conventional flat flange steel section. The strength of steel section is increased when using the corrugated web. The structural performance and load carrying capacity of hollow flanged corrugated web tapered I section steel column is much better and hence the life of slender structure is more. Comparison of ultimate load values of different shapes of hollow flanges are shown in chart 5. Comparison of ultimate load values of flat flange with single web and hollow flange with double web column are shown in chart 6. Comparison of ultimate load values of hollow flange with single and double web frame are shown in chart 7.

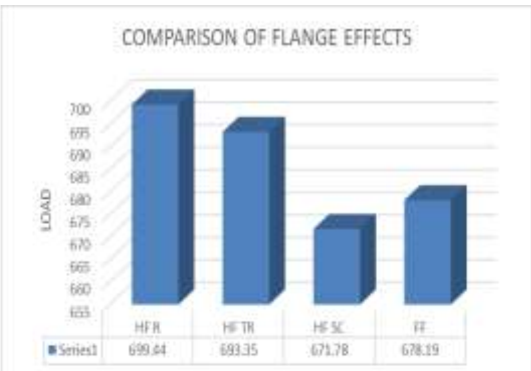


Chart -5 Comparison of load carrying capacity.

Chart -6 Comparison of load carrying capacity.

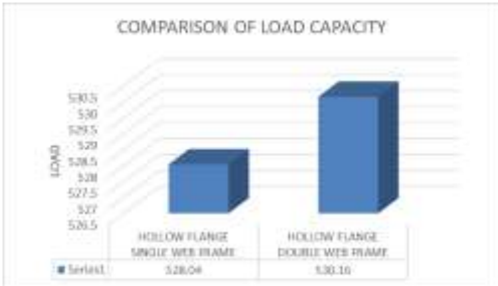


Chart -7 Comparison of load carrying capacity.

5. CONCLUSIONS

A tapered column in a building system provides the widest possible span without the need for interior supports. They are more economical on larger clear span designs than straight column framing. Tapered steel member offers a better cross section utilization along the member, which makes them an interesting and more economical alternative to prismatic ones. Non-prismatic members are popular nowadays as the fabrication costs are considerably reduced. Therefore, this research aims to develop numerical investigation and structural performance of hollow flanged corrugated web tapered slender columns. In this paper the investigation is carried out with the combination of hollow flange and corrugated web is used in I section. Non prismatic columns with different tapering conditions are investigated under axial loading conditions.

The main conclusions of this paper are as follows.

- According to the analysis of different taper ratio, the section having taper ratio 2 with V shape has more performance.
- According to the analysis of flange width effect, the section with flange width 100mm under constant weight has more performance.
- Based on the analysis of different shapes of hollow flange sections, rectangular hollow flanged section has more performance.
- Considering the double web effect, the rectangular hollow flanged corrugated double web steel column under constant weight has more performance than flat flange single web steel column.

- In view of the lateral load effect of frames, rectangular hollow flanged corrugated double web steel frame has more performance compared to single web steel frames.
- Hollow flanged corrugated web columns showed greater load carrying capacity and stiffness compared to flat flanged sections.
- Therefore, it can be recommended as a good basis future development in the area of stability design.

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