Flexural Behaviour of Delta Hollow Flange Steel Beam with and without stiffeners

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***Abstract:** In recent years of construction, steel has been considered as the most commonly used construction materials. Cold Formed steel has many structural benefits like high strength, greater stiffness, high ductility with excellent structural properties and fire resistance. The Cold formed steels are usually used in day by day in residential, commercial and industrial buildings around world. It also reduce the cross section of an element. Steel structure are faster in construction. The main aim of this paper is to study new steel beam. Rather than normal I-shaped beam, it is innovated to form Triangular Hollow Flange Beam (THFB) with slender web using required welded connection to improve the flexural capacity. THFB is also called as Delta Hollow Flange Beam (DHFB). Hollow Tubular Flange Beam provide more strength, stiffness, and stability than a flat plate flange with the same amount of steel. Flanges resist the applied moment, whereas web plates resist the induced shearing force. To improve the flexural resistance the use of the stiffeners also plays an important role, hence the flexural behavior of DHFB with the addition of transverse stiffeners has been investigated in this research work. Initially the section for the research has been chosen, Ultimate load has been calculated manually, Weld used for the sections are designed and they were analyzed through the Finite Element software called 'ANSYS'. Later, five different specimen which includes specimen with and without stiffeners has been tested experimentally. The flexural test was carried out, along with that other properties like Ductility properties also calculated. From both analytical and experimental study DHFB shows positive results. They were highly used in various application which includes purlins, girts, portal frames and steel frame structures. Steel structure are faster in construction.*

***Keywords:** DHFB, ANSYS, Flexural strength, Stiffeners, Ductility factors*

I. INTRODUCTION

Steel members are strong in Tension. Hence they are used in various applications. Generally, structural steels are of two types, namely Hot Rolled steel and Cold Formed steel. The major difference between these two steels are in the manufacturing process. Cold formed steel has 20% higher strength than Hot rolled steel and the finishing of the surface in cold formed steel are better. And the major advantage is, it is easy to bend in any desirable shapes with high strength to weight ratio. Hence they can be used in various day to day application in residential, commercial, industrial buildings, etc., Triangular Hollow Flange Beam (THFB) is otherwise known as Delta Hollow Flange Beam (DHFB). Hollow Flange Beams are more efficient than normal flange Bean. The Same strength with same mass of solid section can be achieved with lesser mass of Hollow section that is Strength to weight ratio is higher for Hollow section, and the resistance against torsion is high in Hollow Sections. This DHFB can be used mainly in bridge applications and Gantry Girders. The objective of the paper is the flexural-torsional resistance is increased with increase Moment of Inertia.

Based on the literature study, the strength of DHFB is further more increased by using vertical stiffeners to improve the buckling capacity of the slender beam. As to make the study cost effective, stiffener are placed at largely spaced distance. Five different specimens with and without stiffeners were analyzed. The analytical process has been done using the FEA software ANSYS. Different parameters like stress, strain, deflection and buckling properties are studied.

A. Element of Tubular Hollow Flange Beam

The following are the elements of a typical Delta Hollow Tubular flange Beam,

- Web
- Flanges
- Stiffeners

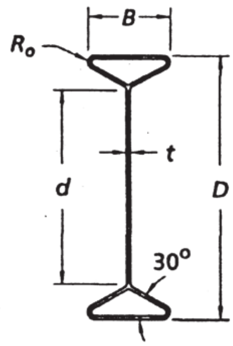

Fig. 1. Cross Section of Delta Hollow Flange Beam

B. Webs

In I-shaped steel Beam, the slender, tall and vertical portion is called web. It will resist all the shear in the beam and to provide separation for the coupled forces of bending. Webs of adequate depth and thickness are generally provided to distance the two flange plates and they resist the shear force in the beam.

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C. Flange

The Horizontal sections of the I-Beam are called Flanges. It will resist the bending and web will resist the shear force. Wide flange beam makes the element a lighter building material. Flanges with adequate with and thickness can resist bending moment on the beam by developing compressive force in one flange and tensile force in another flange.

D. Stiffeners

Stiffeners are the secondary plates used in beam to its web or flanges to strengthen them against out of plane deformations. Mainly all type of bridge beams will have stiffeners. There are two types of stiffeners namely,

- Longitudinal stiffeners
- Transverse stiffeners.

Most of the bridge beam will have only transverse stiffeners. It is also called as vertical stiffeners. Deep beams will have longitudinal web stiffeners. Flange stiffeners can be used in some cases like large span box girder bridges. Generally web is subjected to shear force which leads to web buckling when the height of the web exceeds the limits. In that cases, web stiffeners are used. Longitudinal stiffeners are also called as Horizontal stiffeners. If the depth of the web increases the buckling also increases more rapidly and in such cases provision of largely spaced vertical stiffeners are good and economical.

E. Objective

- It is aimed to study a new innovative cold- formed steel section called Delta Hollow Flange Beam (DHFB).
- To study different concepts regarding DHFB published in different papers were studied.
- To analyze the model using ANSYS software.
- To determine the stress, strain, deformation and ultimate load carrying capacity of the five different section through experimental investigation.
- To find the use of stiffeners in DHFB.
- The results obtained from ANSYS software were compared with experimental results.

F. Inference from Literature Review

I shaped beam with tubular flange includes large local buckling resistance, lateral stability, large torsional stiffeners and reduce web slenderness. Reinforced by transverse stiffeners will eliminate the web crippling. Three stiffeners can increase about 20%-25 % strength compared to unstiffened girders. If the transverse stiffeners are closely spaced the mechanism involves web strength as well as flange strength. Transverse stiffeners were welded to supports and at load points in order to prevent web buckling or web crippling or web crushing.

II. SPECIFICATION

The Beam section selected for the analysis is taken from the paper published by P.Avery and M. Mahendran [6]. Delta Hollow Flange section is not available in IS codal provisions. The following section is taken by the Authors from Australian code. The Authors were analyzed beam sizes from depth of 200mm to 450mm. I have selected the depth size of 400mm depth cross section because the experiment work is not done for that size.

B1 – Conventional I Steel Beam
B2 – Hollow Flange at top and bottom with Stiffeners
B3 – Hollow Flange at top and bottom without stiffeners
B4 - Hollow Flange at top only with stiffeners
B5 – Hollow Flange at top only without stiffeners

Table I Stiffener Specification

Number of stiffener	3
Position of stiffener (From Left End)	0.3m, 0.6m, 0.9m
Thickness of stiffener	3 mm
Connection used	Welding

III. SOFTWARE ANALYSIS

A. ANSYS Workbench

FEA is one of the most widely used method to analyze a structural member. In FEA, the member is analyzed by dividing the element into infinitely small elements, so that the result accuracy is more. In this paper, ANSYS is used to analyze various parameters of Delta Hollow Flange Beam. Mainly, the stresses in a body is uniformly distributed which can be clearly shown through FEA. The stress concentrated Area can be clearly located. Models with complex geometry can be easily analyzed through ANSYS.

The analysis focuses on

- Geometry creation and optimization
- Attaching existing geometry
- Setting up the finite element model
- Solving and reviewing results

B. Geometry of the section

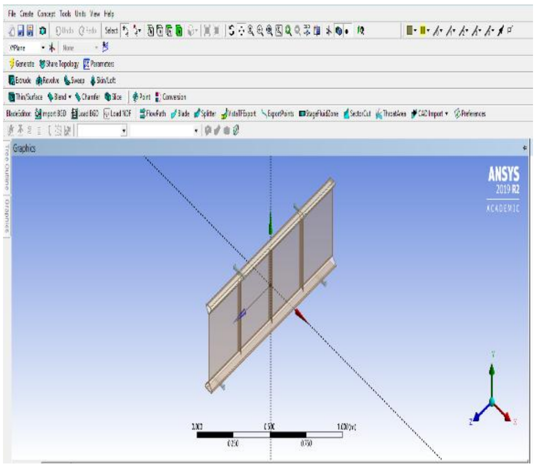

Fig. 2 Geometry of B2

C. Meshing of the section

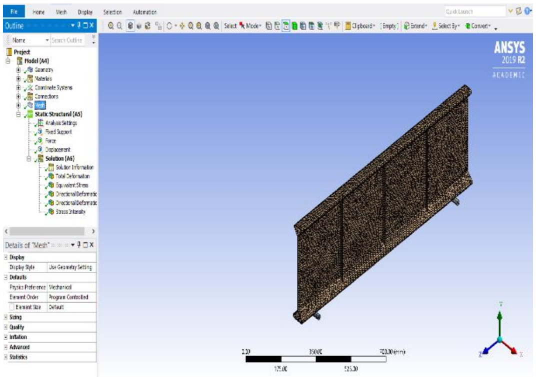

Fig.3 Meshing of B2

D. Total Deformation of the section

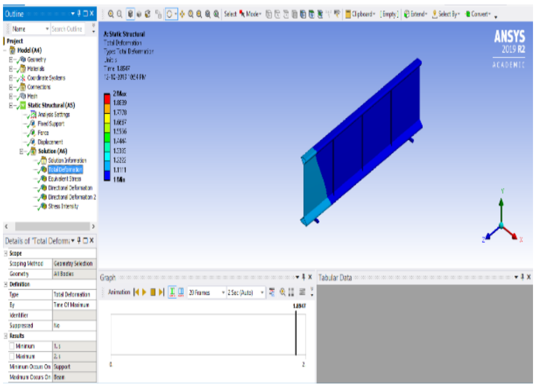

Fig. 4 Total Deformation of B2

E. Equivalent Stress of the section

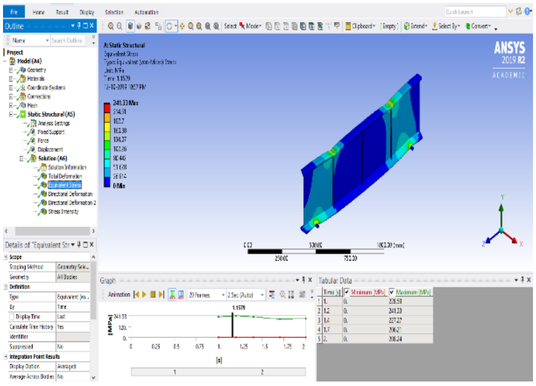

Fig. 5 Equivalent stress of B2

IV. RESULTS FROM ANSYS

Table 2 Total Deformation (mm) obtained from ANSYS

	B1	B2	B3	B4	B5
Min	0	1	0.35	-3.6	0
Max	1.18	2	3.26	1.55	1.39

Table 3 Equivalent Stress (M Pa) obtained from ANSYS

	B1	B2	B3	B4	B5
Min	0.017	0	0.037 8	0.018 5	0.045 0
Max	0.020	0.064	0.049	0.055	0.031

	8	2	8	2	1

Table 4 Equivalent Strain obtained from ANSYS

	B1	B2	B3	B4	B5
Min	0	0	0	0	0
Max	0.0025	0.0008 9	0.0288	0.011	0.0052

Table 5 Y Directional Deformation (mm) obtained from ANSYS

	B1	B2	B3	B4	B5
Min	-1.185	-0.17 0	-3.123	-3	-1.344
Max	0.0019 1	0.057	0.0313	1.55	0.0175

Table 6 Stress Intensity (M Pa) obtained from ANSYS

	B1	B2	B3	B4	B5
Min	0.021 3	0.0519	0.0413	0	0.0180
Max	0.240	0.0698	0.0558	0.0593	0.0367

Table 7 Buckling (mm) obtained from ANSYS

	B1	B2	B3	B4	B5
Min	0	0	0	0	0
Max	2.009	1.002 9	1.004	1.075	1.085

From the above table it is found that the maximum deformation is found on both hollow flanges without stiffener (B3) which is 3.266mm. Among five specimen B3 is having the high load carrying capacity so that it has higher equivalent stress and strain. The Deformation gets reduced when the stiffener is added. Meanwhile the load carrying capacity is also reduced. Considering buckling behaviour the buckling value get reduced for the beam with stiffeners. Hence to reduce buckling effect stiffener can be provided. And it is clearly shown that Hollow flanges are better than solid I section.

V. EXPERIMENTAL INVESTIGATION

A. Fabrication of Test Specimens

Five Specimens were fabricated at Cold formed steel fabrication yard. 4mm Sheets were fabricated into the desired beam shape and size. First the model of the specimen was fabricated and then the actual beams were fabricated. Arc welding is the type of welding used for the fabrication.

Three number of stiffeners were used for two specimens. 3mm Sheets was used for the stiffeners. Stiffeners were provided at both sides of the beam. One conventional beam with same dimensions of DHFB is also fabricated to compare the DHFB with the normal Conventional I shaped steel Beam. After Completion of fabrication, the specimens were painted to prevent them from rusting.

B. Test Setup

The beams were tested under monotonic loading up to failure using a hydraulic machine of 1000 KN capacity with simply supported conditions. The loads were measured using a digital meter attached to the hydraulic jack. Two point loading conditions have been applied to the beams and testing has been carried out. Firstly, for two-point loading condition, two beams were placed in the frame with 1000mm clear span between the roller supports and secondly, single concentrated load was applied on the beam at a mid-span. A Spandrel Beam has been used to distribute the load to the actual specimen. The longitudinal and transverse strains of the specimens were measured by two different methods such as linear variable differential transducers (LVDT) and electric strain gauges. The strains were measured at the mid span of the Beam. 120ohm of 5mm Strain gauge was used to measure the strain value. Deflection were measured at a distance of 0.333m, 0.666m and 0.999m.

Fig.6 Experimental Test Setup

C. Test Outcomes

Yield load, Ultimate load, Strain and Deflection have been obtained from the experimental testing. From the results obtained, other results like Yield stress, ultimate stress, Moment and other properties like Moment factor, Ductility Factor, Deformation factor, curvature factor, Deflection factors and Young's Modulus. All the above results were calculated and compared for five different specimens and they were also compared with the ANSYS analysis. The results were analysed by plotting graph between stress and strain and Load and deflection. As per the objective the beams with stiffeners carries higher load compare with unstiffened beams. So the aim of the study is achieved by the results. Similarly all other factors for stiffened beams gave better results than Unstiffened and conventional beam. The DHFB are comparatively effective in Load, stress, strain and ductility factors than the conventional I beam. DHFB without stiffeners also effective than conventional beam.

VI. RESULTS AND DISCUSSIONS

A. Flexural Strength Test

Flexural strength evaluates the tensile strength of the specimen indirectly. It tests the ability of the beam to withstand failure in bending. The Flexural test was conducted by using Universal Testing Machine (UTM). The Capacity of the UTM is about 1000kN. The Results obtained from the Test is given in the following table.

Table II Experimental Results of Beam 1 – Conventional I beam

Load kN	Moment kN-m	Stress N/mm^2	Strain 10^{-6}
10	1	0.0126	-10
20	2	0.0252	-14
30	3	0.0378	-17
40	4	0.0505	-26
45	4.5	0.0568	-87

Table III Experimental Results of Beam 2 – Hollow Flanges at both top and bottom with stiffeners

Load kN	Moment kN-m	Stress N/mm^2	Strain 10^{-6}
10	1	0.00933	-14
20	2	0.0186	-24
30	3	0.0207	-37
40	4	0.037	-43
50	5	0.0466	-50
60	6	0.0559	-53
70	7	0.0653	-74
80	8	0.0746	-88
90	9	0.0839	-108
100	10	0.093	-126
110	11	0.102	-143
120	12	0.111	-171
130	13	0.1213	-214

Table IV Experimental Results of Beam 3 – Hollow Flanges at both top and bottom without stiffeners

Load kN	Moment kN-m	Stress N/mm^2	Strain 10^{-6}
10	1	0.01	-3
20	2	0.02	-8
30	3	0.0304	-15
40	4	0.0406	-34
50	5	0.0507	-67
60	6	0.0609	-111
70	7	0.071	-168
80	8	0.0812	-178
90	9	0.0913	-249
100	10	0.1015	-349
110	11	0.1116	-410

Table V Experimental Results of Beam 4 – Hollow Flanges at Top only with stiffeners

Load kN	Moment kN-m	Stress N/mm^2	Strain 10^{-6}
10	1	0.0102	10
20	2	0.0202	6
30	3	0.0307	10
40	4	0.041	11
50	5	0.0512	14
60	6	0.0615	17
70	7	0.0717	6
80	8	0.082	-19
90	9	0.0922	-25
100	10	0.1025	-75

Table VI Experimental Results of Beam 5 – Hollow Flanges at Top only without stiffeners

Load kN	Moment kN-m	Stress N/mm^2	Strain 10^{-6}
10	1	0.0112	-73
20	2	0.025	-135
30	3	0.0337	-185

B. Load Vs Deflection Graph

A graph in which increasing flexural loads on a beam are plotted along the vertical axis, and deflections resulting from these loads are plotted along the horizontal axis. The Load vs Deflection for the five specimens were given below.

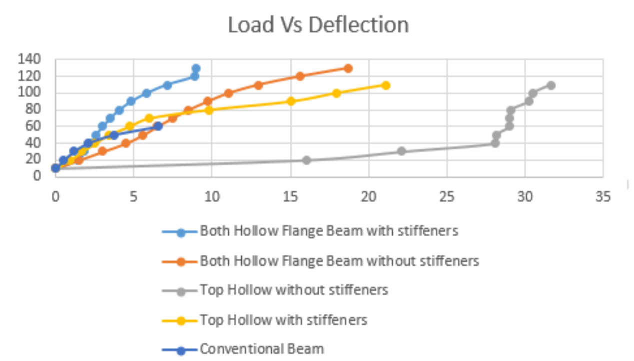

Fig.7 Load vs Deflection Curve

C. Failure Of The Specimens

The failure pattern of all five specimen were along the web. B1, the conventional beam was failed at 45kN, web crippling is happened. B2, the beam with hollow flanges at both top and bottom with stiffener is the specimen which carries high load that all other 4 specimen. B2 carries load of 130kN and the failure in the web is controlled by the stiffeners and the failure is started at the loading points. B3, beam with hollow flanges at both top and bottom without stiffeners carries almost equal load like B2. It carries about 110kN. Beam with hollow flange at top with stiffener carries 100kN and beam with hollow flange at top without stiffeners carries a load of 30kN which is the lowest load among all the five specimen. From the above results it is found that B2, B3 and B4 are almost carries equal amount of loads. It is found that Hollow Flange Beam carries about 40% of higher load than normal I Beam. Mostly all five specimens fails by torsion. The web crippling can be controlled by the use of stiffeners. But it does not create more variation in the beam with hollow flange without stiffeners.

Fig. 8 Failure of B1

Fig.9 Failure pattern of B2

Fig. 10 Failure pattern of B3

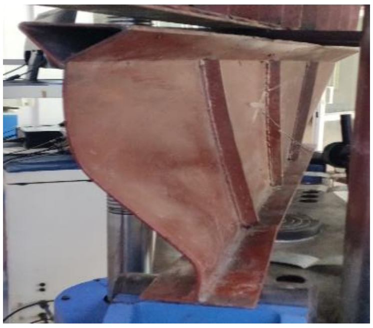

Fig.11 Failure pattern of B4

Fig.12 Failure pattern of B5

D. Ductility Performance

Ductility can be defined as the “ability of material to undergo large deformations without rupture before failure”. Mild steel is an example of a ductile material that can be bent and twisted without rupture. Member or structural ductility is also defined as the ratio of absolute maximum deformation to the corresponding yield. This can be defined with respect to strains, rotations, curvature or deflections. Strain based ductility definition depends almost on the material, while rotation or curvature based ductility definition also includes the effect of shape and size of the cross-sections. Each design code recognizes the importance of ductility in design because if a structure is ductile it ability to absorb energy without critical failure increases. Ductility behavior allows a structure to undergo large plastic deformations with little decrease in strength. Ductile detailing is provided in structures so as to give them adequate toughness and ductility to resist severe earthquake shocks without collapse.

Ductility is an important stage where external energy is transformed into internal energy by providing high strain. The ductility performance of the beams was determined by finding out the following parameters such as moment factor, deflection factor, curvature factor and deformability factor. Each term is explained below. All the Ductility factors for the specimen B2 is calculated as follow.

Moment factor is the ratio of moment at yield load to the moment at ultimate load.

Moment at Yield Load = 6 kN m Moment at Ultimate load = 13kN m

Moment Factor = 6/13 = 0.46

Deflection factor is the ratio of deflection at yield load to the deflection at ultimate load

Deflection at yield load = 7.47mm Deflection at Ultimate Load = 23.01

Deflection Factor = 7.47/23.01 = 0.324

Curvature factor is the ratio of curvature at yield load to the curvature at ultimate load

Curvature at yield load = Deflection / Strain = $\frac{7.47}{-53x10^{-6}}$ = -140943.39

Curvature at ultimate load = $\frac{23.01}{-214x10^{-6}}$ = -107523.36

Curvature Factor = 1.3108

Deformability factor is the product of moment factor and curvature factor

Deformability factor = 0.461/1.3108 = 0.352Ductility ratio is defined as the ratio of the curvature at ultimate moment to the curvature at yield.

Ductility factor = 1/1.3108 = 0.7633

Similarly the different ductility factors for other specimens were calculated and all they were listed in the following table.

Table VII Moment Factor

Specimens	Moment factor
B1	0.888
B2	0.461
B3	0.636
B4	0.8
B5	0.33

Table VIII Deflection Factor

Specimens	Deflection Factor
B1	0.561
B2	0.324
B3	0.458
B4	0.711
B5	0.57

Table IX Curvature Factor

Specimens	Curvature factor
B1	1.878
B2	1.3108
B3	1.695
B4	2.8
B5	1.445

Table X Deformability Factor

Specimens	Deformability factor
B1	0.472
B2	0.352
B3	0.375
B4	0.285
B5	0.394

Table XI Ductility Factor

Specimens	Ductility factor
B1	0.532
B2	0.7633
B3	0.589
B4	0.357
B5	0.691

E. Analytical Vs Experimental Results

From the Paper [3] it is taken that 170 kN is the ultimate load taken by the DHFB and it is given for the analytical analysis. The Highest Ultimate Load from the Experimental analysis is 130 kN. Comparing the two results, 76% of analytical load is carried by the experimental results. Hence the comparison of analytical and experimental work gave us a successful results. The other objective of the study is to use the DHFB Economically and efficiently, it is also fulfilled by the experimental results. In the experimental work, B2 and B3 carried the highest load which are DHFB at both top and bottom. Meanwhile, the B4 that is the DHFB at top with stiffener gives about 77% of same result like B2 and it is 45% higher than Conventional Beam. So Hollow Flange at top with stiffener (B4) is considered as the most efficient and economically better specimen among all five specimens. Comparing B2 and B3, 85% of the result was same, can carry about more or less equal load like DHFB with stiffeners. Comparing the failure from analytical and experimental work it is seen that, the failure in Analytical works are mostly seen in flanges, but in case of experimental work the failure is seen along the web. By using stiffeners the failure in web such as web crippling can be reduced.

VII. CONCLUSION

1. The Delta Hollow Flange Beam (DHFB) carries 45% higher load than normal I shaped steel beam with same dimension.
2. Among all five specimen it is found that B2, B3 and B4 carried better loads and they all good in their ductility factors.
3. 76% of results were same while comparing the Analytical and experimental works.
4. As the main objective of the study is to prove that DHFB are better than normal conventional beam, it is proved that Delta Hollow Flange at Top alone with stiffeners can give the better results than the conventional beam.
5. Here, stiffeners also plays a vital role in load and ductility factors. B2 and B4 specimens are the specimens with stiffeners and both the beams carries 130kN and 100kN respectively.
6. In this study the stiffeners are economically used. Only three stiffeners were provided so they are largely spaced stiffeners. Hence usage of stiffeners is economical and effective.
7. 6mm weld is provided for all the specimens, and most of the failures of DHFB are not at the welding joints. So it is effective to use weld connections in DHFB.
8. For B2, the failure is seen in the flange where the support is given and the web does not shows any failure. Meanwhile, B3 specimen failed by web torsion due to the absence of stiffeners.
9. In B4, the failure is found at the bottom of the specimen where it is flat flange. Comparatively the failure is low in the top flange as it is Delta Hollow Flange.
10. It is found that Delta Hollow Flange will transmit the load equally to the web and will reduce the possibility of failure than normal solid section.
11. Ductility factor of DHFB with stiffener is 71% higher than the Conventional beam. So it is concluded that DHFB is better than conventional beam in all aspects.
12. Finally it is concluded that DHFB are high in flexural resistance than normal I section. Such DHFB can be used in thin walled structures, truss construction and in bridge applications.

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