ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE) Vol. 4, Issue 1, January 2018

SHEAR BEHAVIOUR OF DELTA HOLLOW FLANGE BEAM WITH AND WITHOUT WEB STIFFENER

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***Abstract* — A Delta Hollow Tubular Flange Beam(DHTFB) is an I-shaped steel beam with the addition of two continuous diagonal plates welded to the compression flange and web to form a two-celled continuous triangular. When compared to the I-shaped steel beam 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 in addition to maintaining the relative distance between the top and bottom flanges. I-shaped steel beam have the thickness of the web plate is much smaller than that of the flanges. Consequently, the web panel buckles at a relatively low value of the applied shear loading. Hence stiffeners are introduced in the DHTFB. Stiffeners are used to bear high loads and to increasing the shearing capacity of Hollow Tubular Flange Beam. Their parametric study examined the effect of stiffeners, geometrical imperfections, and the shear strength of HTFGs. The selected beam is analyzed for concentrated loading and simply supported condition by using ANSYS software. The shear strengths and displacement of the hollow tubular flange plate girders are determined from the finite element models and then compared to the experimental study. Graphs will be plotted for each condition to get comparative results.**

***Index Terms*— I-shaped, Stiffeners, Shear strength, Tubular flange.**

I. Introduction

A. GENERAL

Historically, the triangular hollow flange beam (THFB) was the first beam with tubular flanges to emerge as a structural member .These THFBs were formed from slender elements [1]. After that, a number of different types of girders with hollow tubular flanges have been developed for bridges and buildings. These THFBs have different shapes. They were initially proposed for increasing the flexural–torsional resistance of the girders by replacing the flat flanges by different shapes tubes, so that the radius of gyration of compression flange is increased [3].

The triangular hollow flange beam (THFB) also called as delta hollow flange beam which comprises a basic plate girder section - web, top and bottom flanges - with the addition of two continuous diagonal plates welded to the compression flange and web to form a two-celled continuous triangular, or delta-shaped, box.

Stiffeners are used to increasing the shearing capacity of Hollow Tubular Flange Beam (HTFB) I-section plate girders (IPGs), are generally fabricated by welding together two flanges, a web and a series of transverse stiffeners. Flanges resist the applied moment, whereas web plates resist the induced shearing force in addition to maintaining the relative distance between the top and bottom flanges.

B. ELEMENTS OF TUBULAR FLANGE BEAM

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

- Web
- Flanges
- Stiffeners

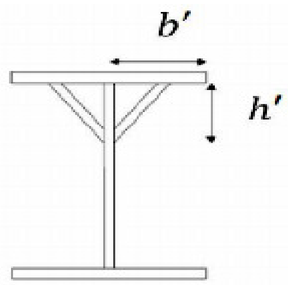

Figure 1.1 Delta Girders

Webs of required depth and thickness are provided to keep the flange plates at required distances and to resist the shear in the beam.

Flanges are required width and thickness are provided to resist bending moment acting on the beam by developing compressive force in one flange tensile force in another flange.

Stiffeners are provided to safeguard the web against local buckling failure and web buckling due to shear when the height of the web exceeds certain limits.

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ISSN (PRINT): 2454-9762
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International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE) Vol. 4, Issue 1, January 2018

C. TYPE OF STIFFENERS

The web is subjected to shear force which tends to web buckling when the height of the web exceeds certain limits. In such cases, web stiffeners are provided. The stiffeners may classify as

- Transverse stiffeners
- Longitudinal stiffeners

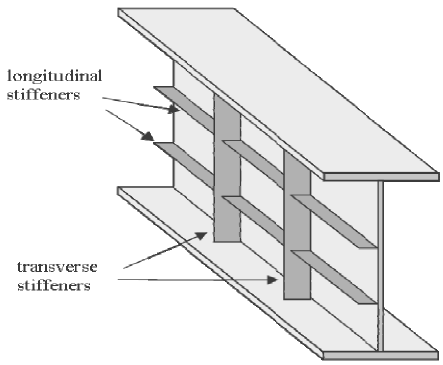

Figure 1.2 Types of Stiffeners

Transverse stiffener also known as web vertical stiffeners their main purpose is to prevent web buckling [16]. The vertical stiffeners will be subjected to bending moment about the center of the plate if the load is not in the plane of the web, or a transverse to the bending moment .The shear flow between them must be effectively resisted by the connection.

Longitudinal stiffener also known as horizontal stiffeners. As the depth of the web increases the web buckling tendency increase more rapidly and provision of closely spaced vertical stiffeners may not be a good or economical situation.

Transverse stiffeners are classified as below;

- Bearing stiffener
- Intermediate stiffener

End bearing stiffeners are provided to transfer the load from beam to support. If concentrated loads are acting on the beam, intermediate bearing stiffeners are required [13].

D. FINITE ELEMENT ANALYSIS

The Finite element Method (FEM) is a numerical technique to find approximate solutions of partial differential equations. In a structural simulation, FEM helps in producing stiffness and strength visualizations. It also helps to minimize material weight and its cost of the structures. FEM has an in built algorithm which divides very large problems (in terms of complexity) into small elements which can be solved in relation to each other. The solution is obtained by eliminating the spatial derivatives from the partial differential equation.

i. ANALYSIS SOFTWARE-ANSYS

ANSYS is a general-purpose finite-element modeling package for numerically solving a wide variety of mechanical problems. These problems include static/ dynamic, structural analysis (both linear and nonlinear), heat transfer, and fluid problems, as well as acoustic and electromagnetic problems.In general, a finite-element solution may be broken into the following three stages.

- Preprocessing
- Solution
- Post processing

The major steps in preprocessing are;

- Define key points/lines/areas/volumes,
- Define element type and material/geometric properties
- Mesh lines/areas/ volumes as required.

Assigning loads, constraints, and solving. Here, it is necessary to specify the loads, constraints, and finally solve the resulting set of equations.

Post processing means reviewing the results of an analysis. It is probably the most important step in the analysis, because you are trying to understand how the applied loads affect your design, how good your finite element mesh is, and so on.

II. METHODOLOGY

A. GENERAL

The methodology is the general research strategy that outlines the way in which research is to be undertaken and, among other things, identifies the methods to be used in it. It is the systematic, theoretical analysis of the methods applied to a field of study.

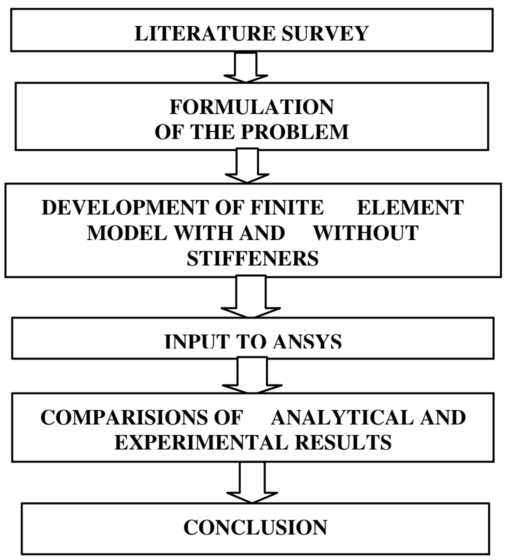

Fig 2.1 Flow chart for methodology

III. Design Of Delta Hollow Flange Beam

A. GENERAL

I shaped steel plat girders are normally designed to support heavy loads over long spans in situations where it is necessary to produce an efficient design by providing girders of high strength to weight ratio [2]. Transverse stiffeners improve the shear buckling resistance.

Plate elements do not collapse when they buckle; they can possess a substantial post-buckling reserve of resistance. For an efficient design, any calculation relating to the ultimate limit state should take the post-buckling action into account [3]. This is particularly so in the case of a web plate in shear where the post-buckling resistance arising from tension field action can be very significant.

B. DESIGN CONSIDERATIONS

The principal functions of the main components found in plate girders may be summarized as follows:

- Flanges resist moment
- Web resists shear
- Delta stiffeners resist longitudinal shear at interface
- Vertical stiffeners improve shear buckling resistance

C. DESIGN OF DELTA STIFFENER

I shaped steel beam welded with two diagonal plates that is called delta stiffener. That is this will be stiffen by like this means it will be joined like this and this will be joined like this right. So, this is called delta girder right. And this improves the lateral rigidity improves lateral rigidity. The advantage of this is to improve the lateral rigidity. So, these are some typical welded connected plate girder right. Failure modes of Delta girder depend on the thickness and situation of Delta stiffeners.

Generally, failure mode is one of the following or combine of these modes: (a) Lateral deformation, (b) Elesto-plastic deformation at Delta portion of section. Delta Stiffeners could be used as efficient stiffening methodfor girders in comparison with longitudinal stiffeners or I-shaped girders with thicker web. But, optimum values for cross sectional parameters should be considered with respect to modes of failure.

Weld connecting the flanges angles and the web will be subjected to horizontal shear and sometimes vertical loads which may be applied directly to the flanges for the different cases such as depending upon the directly applied load to the either web or flange and with or without consideration of resistance of the web.

D. DESIGN OF TRANSVERSE STIFFENERS

Intermediate transverse stiffeners are provided to prevent out of plane buckling of web at the location of the stiffeners due to the combined effect of bending moment and shear force. Intermediate transverse stiffeners must be proportioned so as to satisfy two Conditions;

1) They must be sufficiently stiff not to deform appreciably as the web tends to buckle.

2) They must be sufficiently strong to withstand the shear transmitted by the web.

Since it is quite common to use the same stiffeners for more than one task (for example, the stiffeners provided to increase shear buckling capacity can also be carrying heavy point loads), the above conditions must also, in such cases, include the effect of additional direct loading.

E. SPACING OF STIFFENERS

To achieve an effective design, i.e. a plate girder of high strength/weight ratio, it is usually necessary to provide intermediate transverse web stiffeners [21]. An Indian standard only allows the application of the tension field method to give a significantly enhanced load resistance, when the web is stiffened. The IS 800 also specifies that such stiffeners must be spaced such that the stiffener spacing/web depth ratio (a/d) is within the following range:

$$1{,}0 \leq a/d \leq 3{,}0$$

Transverse stiffeners play an important role in allowing the full ultimate load resistance of a plate girder to be achieved. In the first place they increase the buckling resistance of the web; secondly they must continue to remain effective after the web buckles, to provide anchorage for the tension field; finally they must prevent any tendency for the flanges to move towards one another.

F. DESIGN FOR SHEAR STRESSES

Let us take the case of a 'Delta hollow flange beam' subjected to the maximum shear force (at the support of a simply supported beam). The external shear '*V*' varies along the longitudinal axis '*x*' of the beam with bending moment as $V=dM/dx$. While the beam is in the elastic stage, the internal shear stresses τ , which resist the external shear, V, can be written as,

$$\tau = VQ/It$$

Where;

V = shear force at the section

I = moment of inertia of the entire cross section about the neutral axis

Q = moment about neutral axis of the area that is beyond the fiber at which τ is

Calculated and't' is the thickness of the portion at which τ is calculated. Web carries a significant proportion of shear force and the shear stress distribution over the web area is nearly uniform. Hence, for the purpose of design, we can assume without much error that the average shear stress as

$$\tau av=V/tw.dw$$

Where;

tw = thickness of the web

dw = depth of the web

The nominal shear yielding strength of webs is based on the Von Misses yield criterion, which states that for an un-reinforced web of a beam, whose width to thickness ratio is comparatively small (so that web-buckling failure is avoided), the shear strength may be taken as

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE) Vol. 4, Issue 1, January 2018

$$\tau y = 0.58 fy$$

Where;
fy = yield stress.

When the shear capacity of the beam is exceeded, the 'shear failure' occurs by excessive shear yielding of the gross area of the webs. The factored design shear force *V* in the beam should be less than the design shear strength of web.

IV. ANALYTICAL AND EXPERIMENTAL RESULTS

A. *MODELLING AND ANALYSIS*

Analysis is the process of breaking a complex topic or substance into smaller parts by mathematics or logic in order to gain a better understanding of it. The shear performance of steel beam with and without web stiffener is analyzed using ANSYS15 software. Totally 4 models were analyzed to find shear stress and displacements for different sections.

1.Top tubular flange beam with stiffener.
2.Top tubular flange beam without stiffener.
3.Bottom tubular flange beam with stiffener.
4.Bottom tubular flange beam without stiffener.

These FE Models are analyzed with respect to the maximum shear stress and the total deformations**.** An elastic perfectly-plastic material is used for the steel. In the elastic range, Young's modulus is 200 GPa and Poisson's ratio is 0.3. In the inelastic range, Von Mises yield criteria is used to define isotropic yielding. The current study contains four HTFB models generated by ANSYS FE program covering the following parameters;

1. Span length (L); 4m
2. Tubular flange depth (Df); (100mm)
3. Thickness of web (tf); (11.2mm)
4. Thickness of flange (21.3mm)

These different cross-sections for the tubular hollow flanges as well as top tubular and bottom tubular flanges are used in the current modeling. Simply supported boundary conditions are applied to the end sections. At each end section, the vertical displacement of the nodes of the bottom wall of the bottom tube, the lateral displacements of all nodes along the line through the web mid-surface, and the twist rotations about 2-axis of all nodes on the section are restrained.

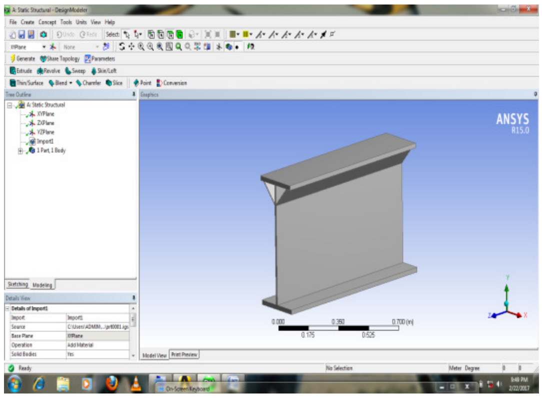

Fig4.1 Model of Delta Hollow Flange beam without web stiffener

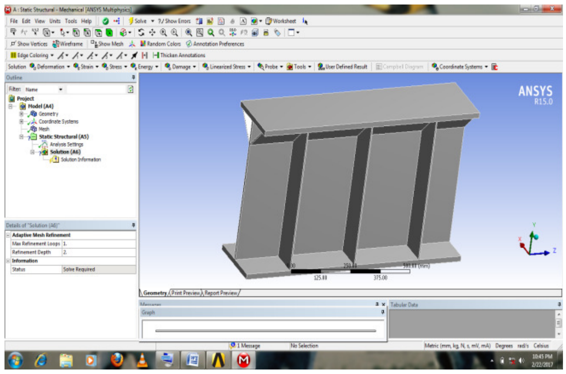

Fig4.2 Model of Delta Hollow Flange beam with web stiffener

i. Shear Stress

Shear stress is a stress that causes shear. When the shear capacity of the beam is exceeded, the 'shear failure' occurs by excessive shear yielding of the gross area of the webs. The design resistance for shear (VS) for un stiffened or stiffened webs is the sum of the contributions from the web and the flanges. Hence, the authors believe that the use of hollow tubular flanges instead of flat plates will increase their contribution in the final design shear resistance (VS) of the HTFPGs.

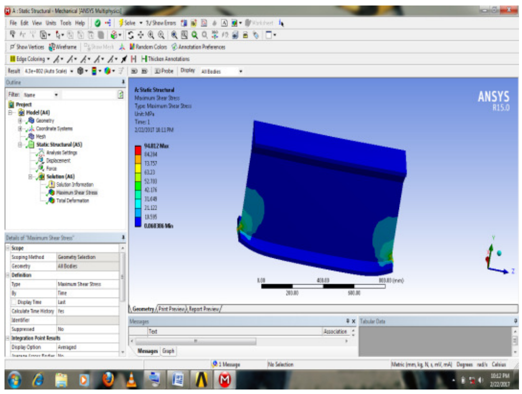

Figure 4.3 Shear stress of Top tubular Delta Hollow Flange beam without web stiffener

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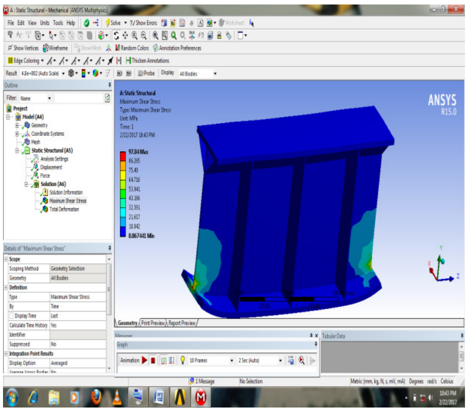

Figure 4.4 Shear stress of Top tubular Delta Hollow Flange beam with web stiffener

Top tubular flange beam is a type of steel beam with a hollow tubular cross section. Top portion of the beam has hollow section which is known as top tubular flange beam. Bottom portion of the beam has hollow section which is known as bottom tubular flange beam.

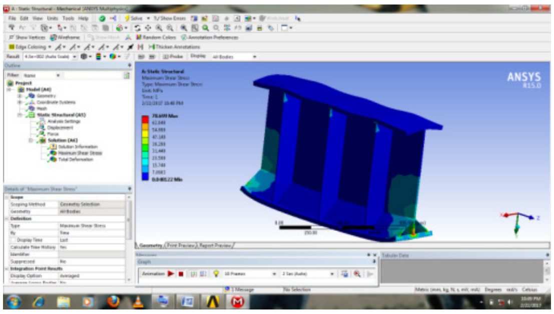

Figure 4.5 Shear stress of Bottom tubular Delta Hollow Flange beam with web stiffener

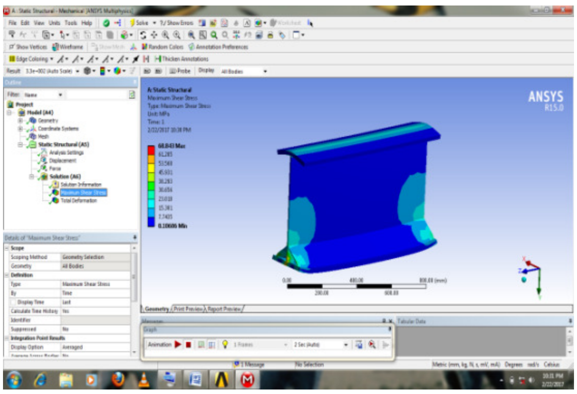

Figure 4.6 Shear stress of Bottom tubular Delta Hollow Flange beam without web stiffener

These different cross-sections for the tubular hollow flanges as well as top tubular and bottom tubular flanges are used in the current modeling. Simply supported boundary conditions are applied to the end sections.

ii. Results for Shear Stress

Shear force and shear resistance of the current DHTFBs are studied. Top tubular flange beam well than the bottom tubular flange beam. DHFBs with stiffener great shear resistance 5% than the without stiffeners.

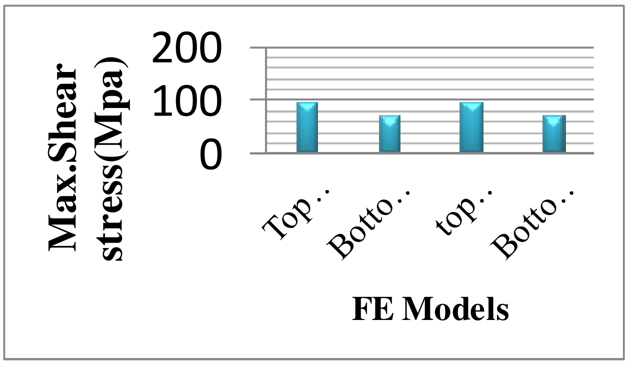

Figure 4.7 Shear stress for various models

iii. Displacement

Displacement is the degree to which a structural element is displaced under a load. It may refer to an angle or a distance. The displacement distance of a member under a load is directly related to the slope of the deflected shape of the member under that load, and can be calculated by integrating the function that mathematically describes the slope of the member under that load. Displacement can be calculated by virtual work method, direct integration method, Castiglione's method, Macaulay's method or the direct stiffness method. The displacement of beam elements is usually calculated on the basis of the Euler – Bernoulli beam equation.ANSYS- 15 introduced to create FE models. Four models developed for the present study which is differentiated by stiffeners and by the tubular sections. Simply supported boundary conditions are applied to the end sections.

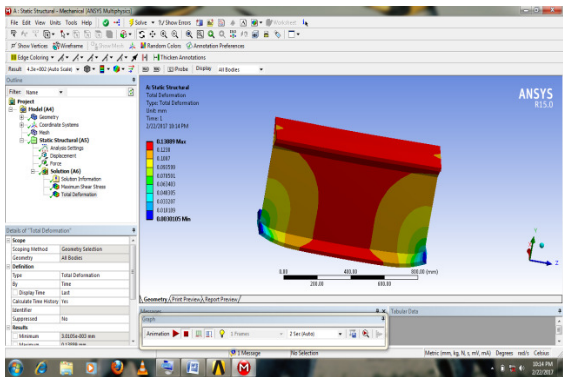

Figure 4.8 Deformation of Top tubular Delta Hollow Flange beam without web stiffener

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International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE) Vol. 4, Issue 1, January 2018

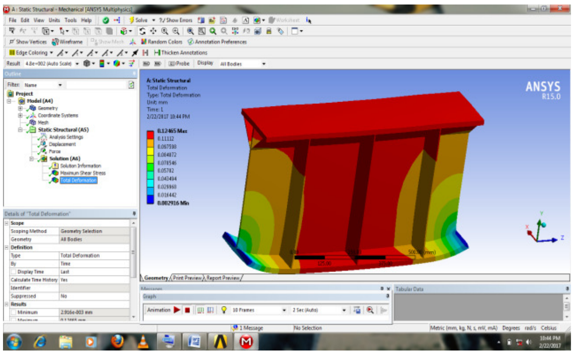

Figure 4.9 Deformation of Top tubular Delta Hollow Flange beam with web stiffener

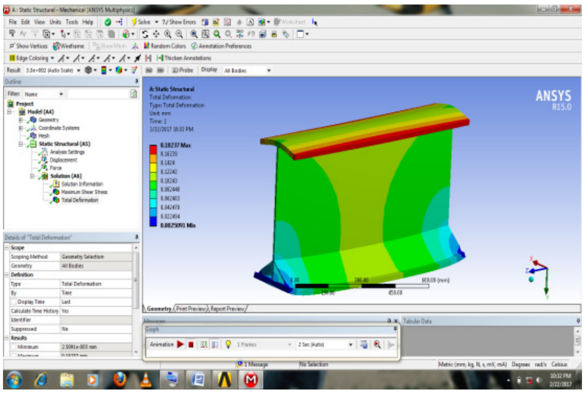

Figure 4.10 Deformation of Bottom tubular Delta Hollow Flange beam without web stiffener

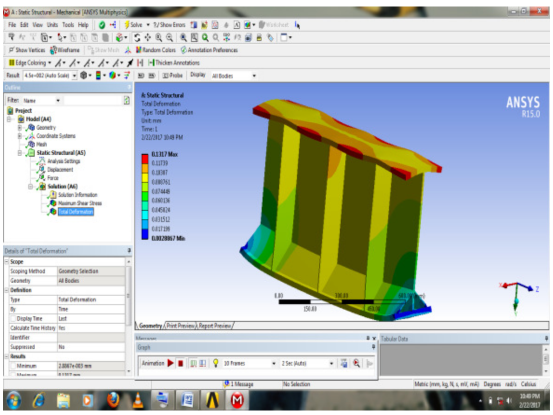

Figure 4.11 Deformation of Bottom tubular Delta Hollow Flange beam with web stiffener

iv. Results for Deflection

Top tubular flange beam has more shear strength rather than the bottom tubular flange beam. Bottom tubular flange beam has more deflection than the top tubular flange beam.

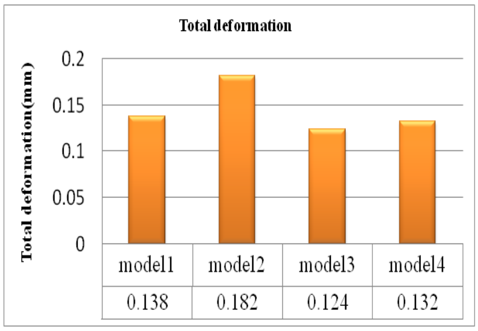

Figure 4.12Deformation for various models

B. EXPERIMENTAL INVESTIGATION

In this chapter experimental details also enumerated. The shear stress, deflection, and shear capacity were studied. Two type of models were experimentally tested which are top tubular flange beam with web stiffener and top tubular flange beam without web stiffener. Based on the analytical results bottom tubular flange beam had more deflection hence top tubular flange beam only tested under simply supported condition.

i. Experimental Test Procedure

The models are tested by using loading frame. The steel beam models are made of rolled wide flange profile. The one of the model beam welded with web stiffener. The top tubular flange beam with and without web stiffener model were experimentally tested. Material properties of the steel beam taken from the code book (SP: 6(1)-1964).

The test specimen is set in the loading frame with concentrated load under simply supported end condition. The constant vertical point load applied at the centre of the beam by the testing machine.

Deflection of the beam increased with respect to the application of load by adjusting the hydraulic jack. Deflection of the beam measured by the dial gauge and the load-deflection curve was plotted by the measurements.

The top tubular flange beam with and without web stiffener model were experimentally tested. Load-deflection curves for the two models were obtained from the measurements.

Figure 4.13 Deformation of Top tubular Delta Hollow Flange beam without web stiffener

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
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Figure 4.14 Deformation of Top tubular Delta Hollow Flange beam with web stiffener

ii. EXPERIMENTAL EVALUATION

The models experimentally tested under simply supported condition. The models are experimentally tested by reducing the scale 1:4 ratio. Four models as top and bottom tubular flange beam with and without stiffeners are tested under axial load. When applying load the stiffeners prevented twist at the support, and connected the HFB specimen to the top plate, allowing rotation about the minor axis without lateral deflection. The stiffener also transmitted the reaction force from the web directly to the support, preventing local bearing failure of the bottom flange. When the DHFBs under simply supported end condition maximum shear stresses calculated from the expression;

$$\tau = VQ/It$$

Where,

V=Shear force

I=Moment of inertia

The factored design shear force *V* in the beam should be less than the design shear strength of web.

iii. EXPERIMENTAL TEST RESULTS

The deformed shapes displayed how the top and bottom hollow tubular flanges deform in a way similar to a simple beam with a slight difference in the initial rotation between them; the top flange relatively rotates more than the bottom one. This differential rotation results in a shear deformation near the support, which finally leads to the formation of shear plastic hinges.

Table 4.1 Experimental Test Results

MODELS	SHEARSTRESS	DEFORMATION
With stiffener	96Mpa	0.1mm
Without stiffener	92.1Mpa	0.14mm

The top tubular flange beam with and without web stiffener model were experimentally tested. When applying load at the centre of the beam, deflection is increased. Maximum deflection of the beam is measured under maximum applied load.

C. COMPASRISION OF RESULTS

In this section analytical and the experimental results are compared with one another. The two parameters such as shear stress and deflection of the delta hollow flange beam investigated analytically and experimentally. Comparison results about experimental and analytical results are clearly explained in this chapter.

Shear stress and deflection of the delta hollow flange beam investigated analytically and experimentally. Model 1 is the top tubular flange beam without web stiffener. Model 2 is the top tubular flange beam with web stiffener.

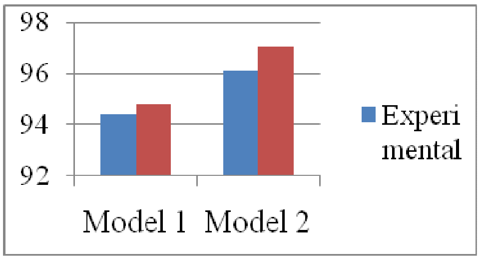

Figure 4.15 Comparison results for Shear stress

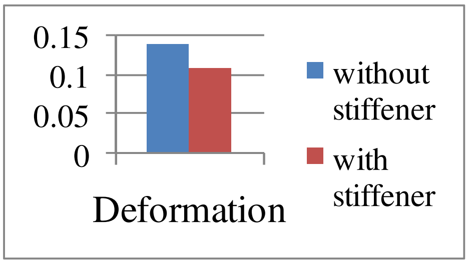

Figure 4.16 Comparison results for Deflection

Top tubular flange beam 20% better shear capacity than the bottom tubular flange beam. Without stiffener bottom tubular flange beam has 10% more deformation than the others.Bottom tubular flange beam has 26% more deflection than the top tubular flange beam.However, the comparative results .From the average values, it could be observed that the percentage of increase of the shear stress is higher than the corresponding percentage of the increase of the whole cross sectional area. Hence, the shear amount carried by the girder is increased more than the increased amount of steel. The analysis of the results indicated that reducing the aspect ratio of the flange increases the shear carried by the HTFPGs. Furthermore, the shear strengths of them rise by reducing the spacing between the transversal stiffeners.

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE) Vol. 4, Issue 1, January 2018

V. CONCLUSION

In this project, Delta Hollow Tubular Flange Beam (DHTFBs) with and without transverse stiffeners was analyzed with the help of analyzing software ANSYS15 and experimentally also tested. The variation in shear stress and displacement, while changing the tubular section of the flange was studied. The stress results from Models were checked with the design criteria, and the results from experimental study were compared and checked with the design criteria. Also the variation of stress concentration and the effects of stiffeners had studied. The HTFPGs instead of IPGs is a powerful tool to increase the shear strength of the girders provided by the additional vertical flange elements that share in bearing the shear. Experimental results are compared with the analysis results. That result has slight variations between them. Delta stiffeners have better shear resistance than the transverse stiffeners. Top tubular flange beam 20% better shear capacity than the bottom tubular flange beam. Without stiffener bottom tubular flange beam has 10% more deformation than the others. Bottom tubular flange beam has 26% more deflection than the top tubular flange beam. It's concluded that the Delta Hollow Tubular Flange Beam with web Stiffeners is well accepted for heavy loaded industrial buildings, long span girders and multistoried structures, where generally span is more satisfactory shear performance than I shaped steel beam.

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