Design, Analysis of Varying Cross Sectional Beam with Trapezoidal Web for Gantry Crane

#1Kavita R. Kapadni, #2Mr. S. G. Ganiger,
1kapadni.kavita@gmail.com
2somu.ganiger@gmail.com

12Department of Mechanical Engineering, Jspm’s ICOER, Wagholi, Pune India.

ABSTRACT

Gantry cranes are one of the most common material handling equipments available in industries. Recently, designers and analysts have shown their interest in optimization of such cranes. This paper deals with achieving modified improved design of gantry crane beam with considered different parameters having varying trapezoidal web shapes, thickness and loading capacity. The aim of this study includes an investigation of the stresses, bending, deflections, shear capacity and lateral-torsional buckling behavior of regular I section beam of gantry crane which is subjected to a uniformly distributed load (self-weight) and a concentrated load at the intermediate section of the simply supported beam. The lateral torsional buckling and lateral bending is the main failure mode that controls the design of beam. The thickness of the web is taken as 4.5 mm and 5.5 mm for all specimens with length 5000 mm and 500 Kg load lifting capacity. In this study it is observed that not only the web thickness, but also the shape of web and cross section of simply supported beam influences the resistance to lateral torsional buckling and bending. Currently proposed work is being carried out to improve the strength structure of crane beam which reduces the effects of lateral torsion buckling and bending effects as possible by changing parameters and developing a trapezoidal corrugated web shape in the beam design. These efforts help to overcome gantry crane beam failure. By using Finite Element Analysis (FEA) software offers inexpensive solution to failure problems. It is concluded that steel beam with modified design tapered flange shape and trapezoidal web section has higher resistance to lateral torsional buckling and lateral bending as compared to conventional I section beam design.

Keywords- a Gantry crane, lateral torsion buckling, bending, Finite Element Analysis

ARTICLE INFO

Article History
Received :18th November 2015
Received in revised form : 19th November 2015
Accepted : 21st November 2015
Published online : 22nd November 2015

I. INTRODUCTION

A crane with a movable bridge is used for lifting and lowering a load vertically and moving it horizontally and that has a hoisting mechanism as an integral part of it. Crane beams are structural elements made from steel material, while very efficient in terms of the structural strength and stiffness to weight ratios can be susceptible to highly complex instability phenomena where the length is the main parameter of the beam axis denoted in longitudinal direction. Now a day in industry material handling equipment like crane which consist hoisting mechanism slides over the crane beam carries large heavy load causes bending, warping and lateral torsion buckling.

Because of this effects hoist can’t move through the middle span of the beam. To overcome this serious issue new modified design is required to reduce these effects. Hence this research is adopted a different methodologies and focused on new modified design which can be possible to implement in industry to engulf the problem during carrying large load. When uniformly distributed load and concentrated load (self load) both applied over the long span of the simply supported I section beam which causes
deflection of the beam which results in torsional bending, due to lateral displacement and twisting of a member lateral torsional buckling has occurred. Due to this beam changes its equilibrium position and permanent deformation occurs at the intermediate span section which is known as deflection. Because of same the trolley carrying a load stuck up at the center of crane. Several solutions have to be incorporated to eliminate the above issues such as varying cross section beam, different sizes and shapes of web. In this study, simply supported beam I-section is selected for symmetrical shape. All the sections will run for spans of 5000 mm with varying web thickness of 4.5 mm and 5.5 mm in ANSYS software and related results for deflection, slope, stresses, lateral torsional buckling will procure.

A. Lateral Torsion Buckling
When beams are loaded in bending about their strong axis, instability can occur due to buckling of the top part of the beam that is under compression. Because the bottom part is in tension, it will offer some resistance to the lateral movements of the compressed upper part. This results in a combined lateral and torsional movement of the beam. This phenomenon is known as lateral-torsional buckling. Lateral torsional buckling is one of the important failure modes for crane beam. When the magnitude of the load acting on the beam reaches to a critical level, the beam experiences global buckling in which the beam is twisted and laterally buckled. Due to large heavy load carried by the steel beam it gets twisted from its equilibrium position.

B. Lateral Bending
The lateral bending of the section creates restoring forces that oppose the movement because the section wants to remain straight. Two parameters which are fundamentally important to the design of beams are shear force and bending moment. These quantities are the result of internal forces acting on the material of a beam in response to an externally applied load system.

The bending force induced into the material of the beam as a result of the external loads, span, own weight, causes lateral bending. Beam theory shows that I-shaped section is a very efficient form for carrying both bending and shears loads into the plane of the web. In construction application, the flanges support the major external loads while the web usually bears most of the compressive stress and transmits shear in the beam.

II. LITERATURE SURVEY
This section elaborates literature survey on the substantial achievement in optimized design of simply supported beam to reduce the effect of lateral bending and lateral torsion buckling and improves shear capacity and buckling strength. Hong-Xia Wan et al. (2015) this paper has presented the details of an investigation into the combined bending and torsion behavior of a hollow flange channel beam known as Steel beam using experiments and finite element analyses. Experimental study included three LSB sections tested to failure under a mid-span eccentric load. Simple boundary conditions were accurately simulated by suitable test supports in a special test rig that was used to simulate different loading eccentricities. Finite element models of tested LSBs were developed using ANSYS, and their ultimate strengths, failure modes, load, displacement curves were obtained and compared with corresponding test results. The results from FEA and tests agreed well and thus validated the developed finite element models. Parametric studies were also conducted using the validated finite element models of LSB to investigate the effects of the location and eccentricity of the applied load, and spans. The results showed that the bending moment capacity reduces significantly as the loading eccentricity increases. This paper presents the details of the tests, finite element analyses, and parametric study of LSBs subject to combined bending and torsion, and the results.[1]

Jiho Moon et al. (2009) This paper presents the results of the theoretical and finite element analyses of the lateral–torsional buckling of I-girders with corrugated webs under uniform bending. In this paper, previous studies on the bending and torsional rigidities of the I-girder with corrugated webs are first discussed. Then, approximated methods for locating its shear center and calculating the warping constant are proposed. Using the proposed methods, the lateral–torsional buckling strength of I-girder with corrugated webs under uniform bending can be calculated.
A series of finite element analyses are conducted and their results are compared with those of the proposed methods. Based on these comparisons, the proposed methods are successfully verified. Finally, the effects of the corrugation profiles of the web on the lateral–torsional buckling strength of the I-girder with corrugated webs are further discussed. The effects of the corrugation profiles of the web on the lateral–torsional buckling strength of the I-girder with corrugated webs are also investigated in this study. From the results, it is found that the warping constant of the I-girder with corrugated webs is larger than that of the I-girder with flat webs, while the shear modulus of the corrugated plates is smaller than that of the flat plates. [2]

Fatimah Denan et al. (2010) this paper represents experimental and numerical study on lateral torsional buckling behavior of steel section with trapezoid web. Comparison is made with conventional beams and flat web. In the experimental work, sections with nominal dimension 200 x 80 mm and 5000 mm length were loaded vertically while the lateral deflection were unrestrained to allow for the lateral torsional buckling. In the analytical study, Eigenvalue buckling analysis in the finite element method was used to determine the critical buckling load. The result shows that corrugation thickness influences the resistance to lateral torsional buckling. From the experimental and analytical study on the lateral torsional buckling on trapezoid web section, it can be concluded that Steel beam with trapezoidal corrugated web section have higher resistance to lateral torsional buckling compared to that of section with flat web. Higher value of moment of inertia about minor axis for the section with thicker corrugation contributes to the higher resistance to lateral torsional buckling. [3]

Ismail Gerdemeli et al. (2010) In this study first of all, the main characteristics as the height of the crane, the distance between the rails, the lifting height, speed of the crane and speed of the trolley are determined. After that, the geometry of all parts, and the features of the power and transmission components are specified. The construction geometry is analyzed by Abaqus Software program. First, three dimensional geometry of the crane is built with a CAD program, and then this geometry is modeled by using finite element method. The crane is tested under the effects of its self weight, the weight of the load, the hook and the trolley, and also the wind load and the dynamic loads occurring with the movement of the crane. In this study, the stress values on wrinkle supports which are employed for safety against wrinkle proves that they do not carry load and they do not provide strength for tension, compression and bending. Considering the data obtained from the analyses, the material waste can be prevented in crane design. The construction is now more reliable, light and durable. This is crucially important in means of low cost production and low design duration [4]

III. METHODOLOGY

There must be need to reduce the warping, bending and lateral torsion buckling effect of beam, hence work done on the analysis of lateral torsional buckling in various ways such as analytically an experimentally by using CAE softwares, etc. Suitable methodology will be developed for experimental validation of results obtained by FEA. For validation; comparison will enact between finite element analysis and experimental result. Failure analysis of regular beam for point loading & eccentric loading simply supported beam need to Study & analyse for various change in parameters of trapezoidal web and taper beam for the evaluation of deflection by ANSYS software.

A. Material selection

When designing a crane beam structure, it is necessary to decide which material is most suitable for the design. Cost is commonly the controlling element; however, other considerations such as weight, strength, constructability, availability, sustainability, and fire resistance will be taken into account before a final decision is made. Steel material is specifically used for general structural purpose which is a very reliable material because of its ductility, high tensile strengths and low costs. The properties of structural steel use in design may be taken as given below.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>MATERIAL PROPERTIES OF GANTRY CRANE BEAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Modulus of Elasticity (E) N/mm²</td>
</tr>
<tr>
<td>IS:2062-1999</td>
<td>2.0 x10⁵</td>
</tr>
</tbody>
</table>

B. Design Modelling

CATIA is fully integrates the cross-discipline modeling, simulation and verification needed for developing complex products. This software provides advanced technologies for mechanical surfaceing enables the creation of 3D parts. In this study CATIA software is used to create three dimensional solid models of regular and modified symmetrical 1 section beam cross section. This solid model is imported to ANSYS software for further analysis are defined in terms of geometric features that must be subdivided into finite elements for solution. This process of sub division is called meshing. Mesh datasets contain information about element types, element discretisation and mesh type.
The I-beam models were assigned ungraded mild steel for its material property with Young’s modulus, \( E = 2.1 \times 10^5 \) N/mm\(^2\), shear modulus, \( G = 79 \times 10^3 \) N/mm\(^2\) and Poisson ratio of 0.3. The convergence of the mesh was established by independently increasing the mesh density in each part of the model beam section.

C. FEA of straight and trapezoidal web section

Finite element analysis prior to the experimental work a FEA will be carried out to predict the stress patterns and deflection of a straight web and trapezoidal web I-Section beam. In this section finite element models of trapezoid web steel section was built up by welding flanges and a web of trapezoidal corrugated profile as shown in fig. 5 were first developed to simulate the behaviour and strength of tested Steel beams subject to combined bending and torsion. Appropriate parameters were chosen in these models for the geometry, mechanical properties, loading and support conditions, initial geometric imperfections, and residual stresses.

Finite element model is developed to simulate the behaviour of steel beams having a I-shaped cross-section. Solid Model is imported to ANSYS 14.0 software which provided useful information in the form of failure loads, failure modes, load–lateral deflection curves and load–strain curves that could be used in developing finite element models. Geometrical details of analyzed beams are simulated using the hexahedral eight-node solid element. A steel beam is selected and analyzed for constant loading and support condition by using ANSYS software and the stress and deflection pattern at the centre of beam is studied for different parametric conditions by changing section of beams.

D. Parameter selection

Different parameters like Length of mid span, load carrying capacity, thickness, width, overall height of Web and flange, weight of the beam Shape and size of the beam Trapezoidal web angle Cross section of simply supported beam is considered during the design process to improve the conventional design and reduce the bending and lateral buckling effect.

E. Finite element analysis models

Finite element analysis is carried out in ANSYS software For the regular straight I section beam section for 5000mm length with 4.5mm and 5.5 mm web thickness.

We obtained the FE analysis models of both the cross section which are having translator motion in x, y and z direction and forming a angle of twist due to lateral torsion buckling. Deflection is also occurring due to loads applied over the span of beam.

F. Result & Discussion

The effect of some geometric properties on the performance of beam loaded with point load at the centre such as effect of web thickness (\( t_w \)), corrugation angle (\( \theta \)), length of Infill Corrugated Plates (b), and width of corrugated web (h), other geometric parameters such as B = 100 mm, D = 200 mm and \( t_f =10 \) mm are considered. In the following paragraphs, the results of these parameters are presented in detail. For trapezoidal web some parameters are considered for FEA analyses are,

1. Corrugated Web Plate Thickness (\( t_w \))

The influence of web thickness on the performance of a trapezoidal web section is investigated in this study. The web thicknesses that are considered in this study are 4.5 mm, 5.5 mm. The results of analysis are shown in table IIII & table IVVI and graphical presentation of effect of thickness.

a) Effect on LTB in Z-axis

**TABLE VII**

| LTB IN Z-AXIS (FOR 5000 MM SPAN WITH THICKNESS 4.5 & 5.5 MM) |
The influence of corrugation web angle ($\theta$) on the performance of a trapezoidal web section is investigated in this study. The web corrugation angles that are considered in this study are $30^\circ$, $45^\circ$, $60^\circ$, and $75^\circ$. The results of analysis are shown in table IV & table V and graphical presentation of effect of thickness.

a) Effect on LTB in Z-axis

b) Effect on bending

2. Corrugated web angle ($\theta$)

The influence of corrugation web angle ($\theta$) on the performance of a trapezoidal web section is investigated in this study. The web corrugation angles that are considered in this study are $30^\circ$, $45^\circ$, $60^\circ$, and $75^\circ$. The results of analysis are shown in table IV & table V and graphical presentation of effect of thickness.

a) Effect on LTB in Z-axis

b) Effect on bending

3. Length of Infill Corrugated Plates (b)

The influence of length of infill corrugated plates (b) on the performance of a trapezoidal web section is investigated in this study. The lengths of infill corrugation plates that are
considered in this study for web corrugation angles are 30°, 45°, 60°, and 75°. The results of analysis are shown in table VI & table VII and graphical presentation of effect of thickness.

a) Effect on LTB (in Z-axis)

**TABLE VI**

<table>
<thead>
<tr>
<th>LTB in Z-axis (5000 MM SPAN FOR CORRUGATION PLATE LENGTH 300 &amp; 350 MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span (mm)</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>500</td>
</tr>
<tr>
<td>350</td>
</tr>
</tbody>
</table>

Fig. 12 LTB in Z-axis for 5000

b) Effect on bending

**TABLE XVIII**

<table>
<thead>
<tr>
<th>Bending in X-axis (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapezoidal Beam</td>
</tr>
<tr>
<td>TW 30°</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>500</td>
</tr>
<tr>
<td>350</td>
</tr>
</tbody>
</table>

Fig. 14 LTB in Z-axis for 5000 mm span for corrugated width 20 & 30 mm

4. Width of corrugated web (h),

The influence of width of corrugated web (h) on the performance of a trapezoidal web section is investigated in this study. The width of corrugated web that are considered in this study are 20mm, 30mm and the web corrugation angles are 30°, 45°, 60° with keeping length of in filled corrugated plate constant i.e 30 mm. The results of analysis are shown in table VXIVVXXVI & table XIXXIX and graphical presentation of effect of thickness.

a) Effect on LTB (in Z-axis)

**TABLE XXI**

<table>
<thead>
<tr>
<th>LTB in Z-axis (5000 MM SPAN FOR WIDTH OF CORRUGATED WEB IS 20 &amp; 30 MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span (mm)</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>5000</td>
</tr>
<tr>
<td>300</td>
</tr>
</tbody>
</table>

Fig. 14 LTB in Z-axis for 5000 mm span for corrugated width 20 & 30 mm

b) Effect on bending

**TABLE XXIX**

<table>
<thead>
<tr>
<th>Bending in X-axis (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapezoidal Beam</td>
</tr>
<tr>
<td>TW 30°</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>500</td>
</tr>
<tr>
<td>350</td>
</tr>
</tbody>
</table>

Fig. 14 LTB in Z-axis for 5000 mm span for corrugated width 20 & 30 mm
A finite element analysis is carried out to study the deflection and lateral torsion buckling behavior in straight beam and trapezoidal web steel section. From the tabular and graphical representation following results are observed.

1. Trapezoidal web steel section has higher resistance to bending and lateral torsional buckling compared to that of section with straight web section simply supported beam.
2. Trapezoidal web thicknesses, web angle, length of infill corrugated plate, width of corrugated web influences the resistance to bending and lateral torsional buckling resistance of a cantilever beam,
   a. Higher trapezoidal web thickness gives the higher resistance.
   b. With trapezoidal corrugated web angle 45° and 75° will get higher resistance to bending and lateral torsional buckling.
   c. Increasing lengths of infill corrugated plate reduce the resistance to bending and lateral torsional buckling.
   d. Increasing width corrugated web increases the resistance to bending and lateral torsional buckling.

I. PROPOSED EXPERIMENTAL SET UP

Modified designed beams will be tested in the Heavy Structures Laboratory in the industry of crane beam manufacturer. The bending strains along the beam will measure using six uni-directional strain gauges. The locations of the gauges are shown in Figure 16. Three more strain gauges will install at the mid-span and 400 mm before and after the mid-span of the beams in order to determine the location and the magnitude of the maximum stress.

IV. FUTURE SCOPE

Economical design of structural steel sections normally requires thin webs to increase the shear buckling strength. The conventional method which uses intermediate stiffeners welded to web to allow the use of thin webs has two disadvantages i.e. high cost of fabrication and reduced service life of the element. The use of corrugated trapezoidal web shape sheets to replace straight web sheets to eliminate both disadvantages. In addition, it reduces the total weight of the structure, thus allowing longer spans and savings in foundation design. Previous researches have been carried out to study the performance of trapezoid web section in shear in web, secondary bending moment in flange, bending, and axial buckling.

V. CONCLUSION

This paper investigated a promising satisfactory design which ensures that the beam is stable and has enough
strength and stiffness against the applied loads. For steel beams having I-shaped cross sections, buckling and bending are typical modes of instability. It is observed that when regular I section beams are loaded with large capacity of concentrated and uniform distributed load they may deflect and laterally buckled which can be reduce by adopting suitable methodologies and change in varying cross section of the beam. A new design approach of beam shape is proposed to solve the problems of deflection, shear capacity and lateral torsional buckling of beam due to loading. In the depth study of the research shows that trapezoidal web I section beam is more capable and also the web thickness, shape of the web and varying cross section of beam influences the resistance to lateral torsional buckling and bending with high shear capacity for a given load as compared to regular I section simply supported beam. Finite element can be used to determine the lateral deflection and lateral torsional buckling moment of the section.

**ACKNOWLEDGMENT**

It gives me a great sense of pleasure and satisfaction to present this paper on “Design, analysis of varying cross sectional beam with trapezoidal web for gantry crane”. Most especially to my family, friends and God, who made all things possible. I would like to also thank to Prof S. G. Ganiger for his valuable contribution.

**REFERENCES**


