

Study on the Behaviour of Plate Girder with Plane Web and Corrugated Web

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Abstract

The corrugated steel plate is a widely used structural element in many fields of application because of its numerous favourable properties along with being more economical than the conventional rolled sections. In addition, profiling of the web generally avoids failure of the section due to loss of stability before the plastic limit-loading for the web is reached. To increase the shear capacity of web of large steel plate girders, the web with different patterns such as tapered web, haunches, corrugations of different shapes are now being used for different applications. Present paper deals with the study of behaviour of plate girder with the plane web and rectangular corrugated web under different loading conditions. The finite element analysis of the plate girder is carried out using ANSYS software. The results obtained from the analysis are then compared with the plate girder with plane web of uniform depth. It is concluded that the corrugated web plate has high buckling strength and sufficient reduction in weight with light gauge elements, than plate girder with plane web.

Keywords: Corrugated, Steel, Plate, Girder, Structural, Web

1. INTRODUCTION

Plate girder is basically an I- beam built up from plates which are joined together by angles and rivets, with or without stiffeners to obtain the desired size. They are also known as deep flexural members which are capable of carrying heavy loads. Plate girder provides maximum flexibility and economy in design. They offer a unique flexibility in fabrication and the cross section can be uniform or non-uniform along the length. It is possible for providing the exact amount of steel required at each section along the length of the girder by changing the flange areas and keeping the same depth of the girder. In other words, it can be shaped to match the bending moment curve itself. Thus, plate girder offers limitless possibilities to the creativity of the engineer.

Usually, the web of the plate girder is subjected to bending, shear or a combination of the two. In construction application, the web usually bears most of the compressive stress and transmits shear in the beam while the flanges support the major external loads. Also, since the plate girders have the maximum moment carrying capacity than any other rolled sections, the section has to be slender. But *slender sections are susceptible to web buckling. This led to the need of slender sections which could be provided by using corrugations along the web section. The use of corrugations eventually replaced the use of stiffeners.* The main benefit of providing these corrugations is to increase the buckling resistance of the web thereby reducing the thickness of the web and also the overall weight of the section. Furthermore, studies have shown that the use of thinner webs results in lower material cost, with an estimated cost savings of 10-30% in comparison with conventional fabricated sections and more than 30% compared with standard hot rolled universal beams.

In our present study, a web with rectangular corrugations is used. The main objective of this project is to determine the buckling strength of corrugated web subjected to shear for different loading conditions. Two plate girders, one with a flat web and another with a corrugated web are designed, analysed and the results are compared. Further the finite element models of plane web as well as corrugated webs are developed and analysis is performed by using ANSYS software.

2. LITERATURE REVIEW

Most of the earlier studies on plate girders with corrugated webs addressed the issues related to rectangular corrugated webs in which the failure of webs may be govern either by shear buckling in the plate parts of the folds or by shear buckling in several folds over a part of girder depth or by shear buckling spread across several folds [1]. Perhaps research on corrugated plates dates back to the late sixties when Easley and McFarland [2] studied the buckling of light-gauge corrugated metal shear diaphragms.

Easley [3] derived, based on the orthotropic plate buckling theory, a set of formulae for buckling loads. Several experimental as well as theoretical investigations on girders with corrugated webs have been carried out since then by a number of researchers. The finite strip method was employed by Luo and Edlund [10] for buckling analysis of corrugated panels. Subsequently, trapezoidally corrugated webs were examined by Luo and Edlund for ultimate strength under patch loading [11] and later for shear capacity. [4]

Experimental investigations have been carried out by Elgaaly et al. in order to study the ultimate load behaviour of girders with corrugated webs subjected predominantly to shear loading [5] or to uniform bending [6] or to partial compressive edge loading [7]. Elgaaly and Seshadri [7] employed nonlinear finite element modeling to analyse the girders under different types of loading and, the behaviour up to failure; failure mode and ultimate capacity could be predicted with sufficient accuracy. Y.A. Khalid [9] investigate the bending behaviour of mild steel beams with semicircular web corrugation, determine the effects of corrugated web and the corrugation direction to the beam's load-carrying capability.

Later, Jamali [8] investigated on the torsional properties, that is torsional constant and warping constant that could influence the lateral torsion capacity of trapezoid web profile section. She also performed lateral torsional buckling tests on two beams with normal flat web and two beams with trapezoid web profile.

3. SCOPE AND OBJECTIVES

The scope and objectives of this study are as follows: Study on the behaviour of welded plate girder for variation in geometry of corrugation and thickness of web plate. Preparation and study of the model in ANSYS. Perform the static and buckling analysis. Calculate the buckling strength and weight of corrugated web plate girders. Comparative study of plane web plate girder without stiffeners.

4. NEED FOR CORRUGATIONS

For making the cross section efficient to resist in plane bending it is required that maximum material is placed as far away from neutral axis as possible. As the depth of section increases, depth of web increases and it becomes slender, premature failure of girder due to web buckling in shear might be occur. Hence to reduce the slenderness ratio created by high depth and small thickness of web, instead of using stiffeners, the corrugated web is the possible way to give stability against the elastic buckling of web. Present study deals with rectangular corrugations.

5. OUTLAY OF STUDY

In this dissertation the finite element models of plane web as well as corrugated webs are developed and analysis is performed by using ANSYS software. The results obtained from analysis are then compared with plane web plate girders and corrugated web plate girders.

6. DESIGN

6.1. MANUAL DESIGN OF PLANE WEB PLATE GIRDER

Before analytical work a selected plate girder is first checked as per IS 800-2007. [12]

6.1.1. SECTION SPECIFICATION

Breadth of flange plate b_f = 600mm,

Thickness of flange plate t_f = 40mm,

Thickness of web plate t_w = 16mm,

Depth of web plate d = 1950mm

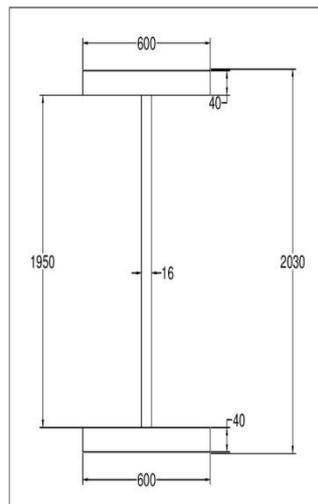


Figure 1 . Dimensions of Plate Girder with Plane Web

6.1.2. DESIGN PROCEDURE

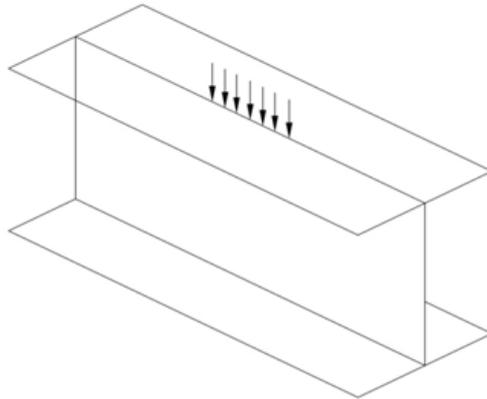


Figure 2 . Plate Girder Section with Applied Load

Assume a concentrated load of 250 KN acting at the midspan of the section,

Maximum bending moment = 6250KNm

Shear force V= 1250KN

From I.S Code, Resistance to shear buckling for a web without stiffeners shall be verified by

$$\frac{d}{t_w} > 67 \epsilon = \frac{1950}{16} \quad (1)$$

$$= 121.875 > 67$$

Flange outstand,

$$b = \frac{b_f - t_w}{2} \quad (2)$$

$$= 292 \text{ mm}$$

$$\frac{b}{t_w} = \frac{292}{40} \quad (3)$$

$$= 7.3 < 8.4$$

Therefore, flanges are plastic.

Plastic modulus of the section

$$\begin{aligned} Z_p &= 2b_f t_f \left[\frac{D}{2} - \frac{t_f}{2} \right] \quad (4) \\ &= 2 \times 600 \times 40 \times \left[\frac{2030}{2} - \frac{40}{2} \right] \\ &= 47.76 \times 10^6 \text{ mm}^3 \end{aligned}$$

Moment carrying capacity of the section

$$\begin{aligned} M_d &= \frac{\beta f_y Z_p}{\gamma_{m0}} \quad (5) \\ &= \frac{1 \times 250 \times 47.76 \times 10^6}{1.1} \\ &= 10854.5 \text{ kNm} > 6250 \text{ kNm} \end{aligned}$$

$$\begin{aligned} \frac{d}{t_w} &= \frac{1950}{16} \quad (6) \\ &= 121.875 \text{ (less than 200)} \end{aligned}$$

Shear capacity of the web

As per I.S code the elastic critical shear stress of the web is calculated by using the formula

$$\begin{aligned} \tau_{cr,e} &= \frac{K_v \pi^2 E}{12(1 - \mu^2) \left[\frac{d}{t_w} \right]^2} \quad (7) \\ &= \frac{5.35 \times \pi^2 \times 2 \times 10^5}{12(1 - 0.3^2)(121.875^2)} \\ &= 65.11 \text{ N/mm}^2 \end{aligned}$$

Non-dimensional web slenderness ratio,

$$\begin{aligned}\lambda_w &= \sqrt{\frac{f_{yw}}{\sqrt{3} \times \tau_{cr,e}}} & (8) \\ &= \sqrt{\frac{250}{\sqrt{3} \times 65.11}} \\ &= 1.489 > 1.2\end{aligned}$$

Shear stress corresponding to web buckling,

$$\begin{aligned}\tau_b &= \sqrt{\frac{f_{yw}}{\sqrt{3} \times \lambda_w^2}} & (9) \\ &= \sqrt{\frac{250}{\sqrt{3} \times 1.489^2}} \\ &= 65.10 \text{ N/mm}^2\end{aligned}$$

Shear force corresponding to web buckling

$$\begin{aligned}V_{cr} &= A_v \tau_b & (10) \\ &= 1950 \times 16 \times 65.10 \\ &= 2031.12 \times 10^3 \text{ N} > 1250 \text{ N}\end{aligned}$$

Hence the assumed section satisfies all the requirements of IS 800-2007.

6.2. MANUAL DESIGN OF PLATE GIRDER WITH CORRUGATED WEB

For the same section, the web of the girder is replaced with the rectangular corrugated web with varying thickness and designed accordingly.

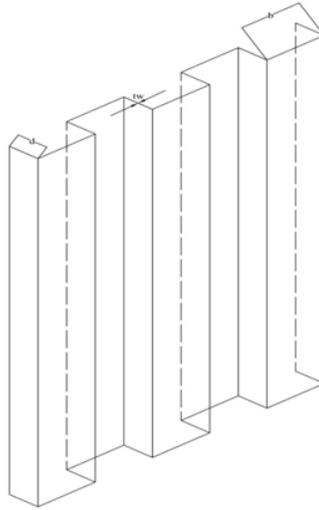


Figure 3 . Dimension of Rectangular Corrugation

6.2.1. DESIGN PROCEDURE FOR 10mm THICK PLATE

The shear stress is calculated using the formula,

$$\tau_{cr} = \frac{K_s \pi^2 E}{12(1 - \nu^2)} \left(\frac{t_w}{b} \right)^2 \quad (11)$$

Where,

E Young's modulus of elasticity

ν Poisson's ratio

b width of corrugated webs

t_w thickness of web

$$K_s = 5.34 + 4 \left(\frac{b}{h_w} \right)^2 \quad (12)$$

Where,

b width of corrugated webs

h_w height of corrugated webs

$$= 5.34 + \left(4 \left(\frac{200}{1950} \right)^2 \right)$$

$$= 5.38 \text{ (KS is same for all the conditions)}$$

Therefore shear stress

$$= \frac{5.38 \times \pi^2 \times 2 \times 10^5}{12(1 - 0.3^2)} \left(\left(\frac{10}{200} \right)^2 \right)$$

$$= 2431.24 \text{ N/mm}^2$$

The shear force is calculated using the formula,

P= Stress x Area

$$= 2431.24 \times 1950 \times 10$$

$$= 47409.18 \times 10^3 \text{ N}$$

The Elastic lateral–torsional buckling strength (moment carrying capacity) of I-girder with rectangular web corrugations is calculated using the formula,

$$M_{ocr} = \left(\frac{\pi}{L_b} \right) \sqrt{EI_{yc}G_cI_c} \sqrt{1 + W_c^2} \quad (13)$$

Where,

E Young's modulus of elasticity

G_c shear modulus of elasticity of corrugated plates

J_c pure torsional constant of I-girder with rectangular web corrugations

J pure torsional constant of I-girder with flat webs

L_b lateral buckling length of the I-girder with rectangular web corrugations

I_{y,c} moments of inertia of I-girder with rectangular web corrugations

W_c beam parameter of the I-girder with rectangular web corrugations

The shear modulus of elasticity of corrugated plates is calculated using the formula,

$$G_c = \frac{a+b}{a+c} G \quad (14)$$

Where,

G is the shear modulus of the flat plates and (a+b) is the projection length of the actual length (a+c)

$$G = \frac{E}{2(1+\nu)} \quad (15)$$

$$= \frac{2 \times 10^5}{2 \times (1 + 0.3)}$$

$$= 76923.07$$

Therefore G_c

$$= \frac{200 + 0}{100 + 200} \times 76923.07$$

$$= 51.283 \times 10^3 \text{ (Gc is same for all conditions)}$$

The moment of inertia I_{yc} can be calculated using the formula,

$$I_{yc} = \frac{t_f b_f (2t_f b_f^3 + t_w h_w b_f^2 + 12d^2 t_w h_w)}{6(2t_f b_f + t_w h_w)} \quad (16)$$

=

$$\frac{(40 \times 600)(2 \times 40 \times 600^3 + 10 \times 1950 \times 600^2 + 12 \times 100^2 \times 10 \times 1950)}{6(2 \times 40 \times 600 + 10 \times 1950)}$$

$$= 1578.67 \times 10^6 \text{ mm}^4$$

The torsional constant is calculated using the formula,

$$J_c = \frac{2b_f t_f^3 + h t_w^3}{3} \quad (17)$$

$$= \frac{2 \times 600 \times 40^3 + 1950 \times 10^3}{3}$$

$$= 26.25 \times 10^6$$

The beam parameter W_c is calculated using the formula,

$$W_c = \left(\frac{\pi}{L_b}\right) \sqrt{\frac{EC_{w,c}}{G_c J_c}} \quad (18)$$

Where,

L_b lateral buckling length of the I-girder with rectangular web corrugations

J_c pure torsional constant of I-girder with rectangular web corrugations

E Young's modulus of elasticity

$C_{w,c}$ warping constant of I-girder with rectangular web corrugations

$$C_{w,c} = \frac{h_w^2 t_f b_f (6 t_f b_f^3 + t_w h_w b_f^2 + 12 d^2 t_w h_w)}{24 (6 t_f b_f + t_w h_w)} \quad (19)$$

$$\frac{1950^2 \times 40 \times 600 (6 \times 40 \times 600^3 + 10 \times 1950 \times 600^2 + 12 \times 100^2 \times 10 \times 1950)}{24 (6 \times 40 \times 600 + 10 \times 1950)} = 1.423 \times 10^{15}$$

Therefore W_c

$$\begin{aligned} &= \left(\frac{\pi}{1000}\right) \sqrt{\frac{2 \times 10^5 \times 1.43 \times 10^{15}}{51.283 \times 10^3 \times 26.25 \times 10^6}} \\ &= 4.579 \end{aligned}$$

The moment carrying capacity M_{oc} of the I section with rectangular corrugated web,

$$\begin{aligned} &= \left(\frac{\pi}{1000}\right) \sqrt{(2 \times 10^5 \times 1578.67 \times 10^6 \times 51.283 \times 10^3 \times 26.25 \times 10^6) \sqrt{1 + 4.579^2}} \\ &= 30361.72 \times 10^6 \text{ Nmm} \\ &= 30361.72 \text{ kNm} \end{aligned}$$

Similarly, for 20mm thick plate

The shear stress is calculated using the formula,

$$\tau_{cr} = \frac{K_s \pi^2 E}{12(1 - \nu^2)} \left(\frac{t_w}{b}\right)^2 \quad (11)$$

$$\begin{aligned}
 &= \frac{5.38 \times \pi^2 \times 2 \times 10^5}{12(1 - 0.3^2)} \left(\left(\frac{20}{200} \right)^2 \right) \\
 &= 9724.99 \text{ N/mm}^2
 \end{aligned}$$

The shear force is calculated using the formula,

P= Stress x Area

$$= 9724.99 \times 1950 \times 20$$

$$= 379274.79 \times 10^3 \text{ N}$$

The Elastic lateral–torsional buckling strength (moment carrying capacity) of I-girder with rectangular web corrugations is calculated using the formula,

$$M_{ocr} = \left(\frac{\pi}{L_b} \right) \sqrt{EI_{yc}G_cI_c} \sqrt{1 + W_c^2} \quad (13)$$

The moment of inertia I_{yc} can be calculated using the formula,

$$I_{yc} = \frac{t_f b_f (2t_f b_f^3 + t_w h_w b_f^2 + 12d^2 t_w h_w)}{6(2t_f b_f + t_w h_w)} \quad (16)$$

$$\begin{aligned}
 &= \frac{(40 \times 600)(2 \times 40 \times 600^3 + 20 \times 1950 \times 600^2 + 12 \times 100^2 \times 20 \times 1950)}{6(2 \times 40 \times 600 + 20 \times 1950)} \\
 &= 1655.17 \times 10^6 \text{ mm}^4
 \end{aligned}$$

The torsional constant is calculated using the formula,

$$\begin{aligned}
 J_c &= \frac{2b_f t_f^3 + h t_w^3}{3} \quad (17) \\
 &= \frac{2 \times 600 \times 40^3 + 1950 \times 20^3}{3} \\
 &= 30.8 \times 10^6
 \end{aligned}$$

The beam parameter W_c is calculated using the formula,

$$W_c = \left(\frac{\pi}{L_b}\right) \sqrt{\frac{EC_{w,c}}{G_c J_c}} \quad (18)$$

Where,

$$C_{w,c} = \frac{h_w^2 t_f b_f (6 t_f b_f^3 + t_w h_w b_f^2 + 12 d^2 t_w h_w)}{24(6 t_f b_f + t_w h_w)} \quad (19)$$

$$= \frac{1950^2 \times 40 \times 600 (6 \times 40 \times 600^3 + 20 \times 1950 \times 600^2 + 12 \times 100^2 \times 20 \times 1950)}{24(6 \times 40 \times 600 + 20 \times 1950)}$$

$$= 1.466 \times 10^{15}$$

Therefore W_c

$$= \left(\frac{\pi}{1000}\right) \sqrt{\frac{2 \times 10^5 \times 1.466 \times 10^{15}}{51.283 \times 10^3 \times 30.8 \times 10^6}}$$

$$= 4.28$$

The moment carrying capacity M_{ocr} of the I section with rectangular corrugated web,

$$= \left(\frac{\pi}{1000}\right) \sqrt{(2 \times 10^5 \times 1655.17 \times 10^6 \times 51.283 \times 10^3 \times 30.8 \times 10^6) \sqrt{1 + 4.28^2}}$$

$$= 31574.33 \text{ kNm}$$

Similarly, for 30mm thick plate

The shear stress is calculated using the formula,

$$\tau_{cr} = \frac{K_s \pi^2 E}{12(1 - \nu^2)} \left(\frac{t_w}{b}\right)^2 \quad (11)$$

$$= \frac{5.38 \times \pi^2 \times 2 \times 10^5}{12(1 - 0.3^2)} \left(\left(\frac{30}{200}\right)^2\right)$$

$$= 21881.24 \text{ N/mm}^2$$

The shear force is calculated using the formula,

P= Stress x Area

$$= 21881.24 \times 1950 \times 30$$

$$= 1280052.44 \times 10^3 \text{ N}$$

The Elastic lateral–torsional buckling strength (moment carrying capacity) of I-girder with rectangular web corrugations is calculated using the formula,

$$M_{ocr} = \left(\frac{\pi}{L_b} \right) \sqrt{EI_{yc}G_cI_c} \sqrt{1 + W_c^2} \quad (13)$$

The moment of inertia I_{yc} can be calculated using the formula,

$$\begin{aligned} I_{yc} &= \frac{t_f b_f (2t_f b_f^3 + t_w h_w b_f^2 + 12d^2 t_w h_w)}{6(2t_f b_f + t_w h_w)} \quad (14) \\ &= \frac{(40 \times 600)(2 \times 40 \times 600^3 + 30 \times 1950 \times 600^2 + 12 \times 100^2 \times 30 \times 1950)}{6(2 \times 40 \times 600 + 30 \times 1950)} \\ &= 1703.66 \times 10^6 \text{ mm}^4 \end{aligned}$$

The torsional constant is calculated using the formula,

$$\begin{aligned} J_c &= \frac{2b_f t_f^3 + h t_w^3}{3} \quad (17) \\ &= \frac{2 \times 600 \times 40^3 + 1950 \times 30^3}{3} \\ &= 43.15 \times 10^6 \end{aligned}$$

The beam parameter W_c is calculated using the formula,

$$W_c = \left(\frac{\pi}{L_b} \right) \sqrt{\frac{EC_{w,c}}{G_c J_c}} \quad (18)$$

$$C_{w,c} = \frac{h_w^2 t_f b_f (6 t_f b_f^3 + t_w h_w b_f^2 + 12 d^2 t_w h_w)}{24 (6 t_f b_f + t_w h_w)} \quad (19)$$

$$= \frac{1950^2 \times 40 \times 600 (6 \times 40 \times 600^3 + 30 \times 1950 \times 600^2 + 12 \times 100^2 \times 30 \times 1950)}{24 (6 \times 40 \times 600 + 30 \times 1950)} = 1.5 \times 10^{15}$$

Therefore W_c

$$= \left(\frac{\pi}{1000}\right) \sqrt{\frac{2 \times 10^5 \times 1.5 \times 10^{15}}{51.283 \times 10^3 \times 43.15 \times 10^6}}$$

$$= 3.65$$

The moment carrying capacity M_{ocr} of the I section with rectangular corrugated web,

$$= \left(\frac{\pi}{1000}\right) \sqrt{(2 \times 10^5 \times 1703.66 \times 10^6 \times 51.283 \times 10^3 \times 43.15 \times 10^6) \sqrt{1 + 3.65^2}}$$

$$= 32646.96 \text{ kNm}$$

Comparison of Shear and Moments

Table I. Comparison of Shear and Moments of Plate Girder with and without Corrugated Web Plate

t_w	Shear kN	Moment kNm
10	47409.34	30361.72
20	379274.79	31574.33
30	1280052.44	32646.96
Without Corrugation (10 mm Thick Plate)	2031.12	10854.5

7. FINITE ELEMENT ANALYSIS USING ANSYS

ANSYS is a finite element based software to simulate the combined geometric and materials nonlinear response. To analyze and get the precise results of any structure in ANSYS software it required some inputs like material property, element type, boundary conditions, proper meshing etc.

7.1 FLOW CHART

The following flow chart describes the methodology for the software design and analysis of plate girders with and without corrugated webs.

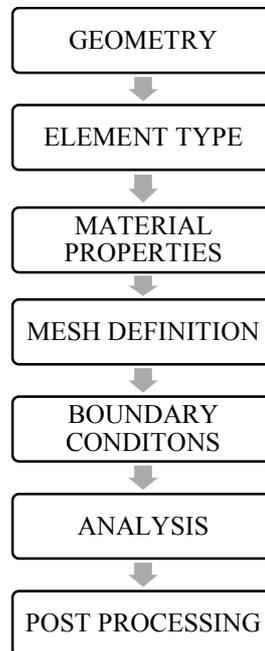


Figure 4. Flowchart for Analysis

7.2 DRAWING PROCEDURE

- 1) The section is drawn using **Creo parametric software**.
- 2) A suitable plane is chosen and the dimensions of the section are given.
- 3) Normal command is used to change the distance.
- 4) Extrude command is used for giving the thickness of the various sections.
- 5) To repeat the number of corrugations assembly command is used.
- 6) After drawing the I section and the corrugations assembly → coincide command is used to join the I section and corrugations.
- 7) The file is saved in .igs format.

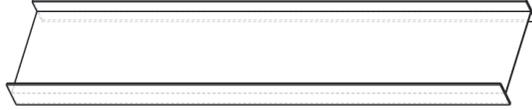
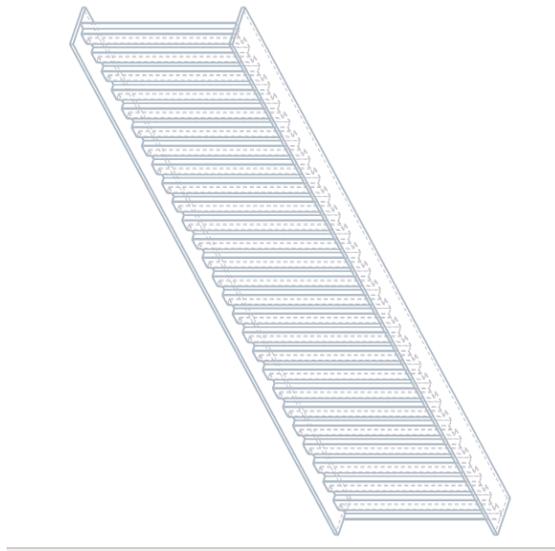
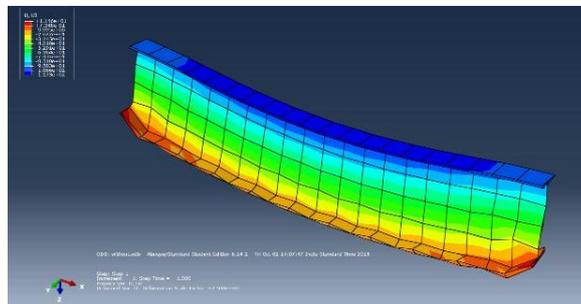
7.3. ANALYSIS OF PLATE GIRDER WITH PLANE WEB

- 1) The saved file is first imported
- 2) In the pre-processor command click the element option and click add solid.

- 3) For giving the material properties click on the material model command and choose structural →linear→ isotropic. Here the value of Young's modulus and Poisson's ratio are given.
- 4) The meshing is provided by clicking on the meshing tool command and choosing global→ 1 →pick all option.
- 5) Click on the analysis type option and click on new analysis→ static.
- 6) For giving support conditions, click on the key points option and choose node option. After giving these commands on the bottom face of the section click the four corner node which denotes the simply supported condition.
- 7) For defining loads click on define loads option and choose apply structural on area→ force and moment→ center of section →250kN on the top face.
- 8) Click on the solution option and click on solve→ current L.S and ok.
- 9) Finally click on the general preprocessor command and click on the plot result→ nodal solution →contour plot→ Von mises stress to get the results.

7.4. ANALYSIS OF PLATE GIRDER WITH CORRUGATED WEB

- 1) The saved file is first imported.
- 2) Click on the modeling option and choose operate→ Boolean →add volume→ select all and click ok to connect the section as a whole mass.
- 3) In the preprocessor command click the element option and click add solid.
- 4) For giving the material properties click on the material model command and choose structural→ linear →isotropic. Here the value of Young's modulus and Poisson's ratio are given.
- 5) The meshing is provided by clicking on the meshing tool command and choose global→ 1 →pick all option.
- 6) Click on the analysis type option and click on new analysis static.
- 7) For giving support conditions click on the key points option and choose node option. After giving these commands on the bottom face of the section click the four-corner node which denotes the simply supported condition.
- 8) For defining loads click on define loads option and choose apply structural on area→ force and moment→ center of section →250kN on the top face.
- 9) Click on the solution option and click on solve→ current L.S and ok.
- 10) Finally click on the general preprocessor command and click on the plot result→ nodal solution→ contour plot →Von mises stress to get the results

7.5. ANALYSIS RESULTS**Figure 5.** Plate Girder With Plane Web**Figure 6.** Plate Girder With Corrugated Web Plate**Figure 7.** Deformation Of Plate Girder With Plane Web After Application of Load

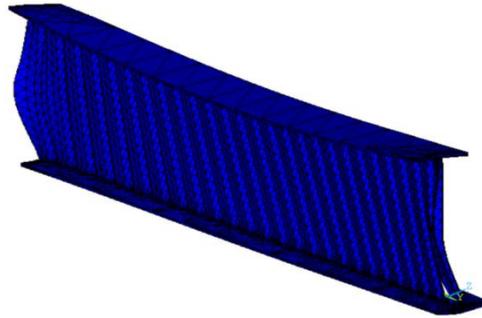


Figure 8. Deformation Of Plate Girder With 10mm Thick Corrugated Plate



Figure 9. Deformation Of Plate Girder With 20mm Thick Corrugated Plate

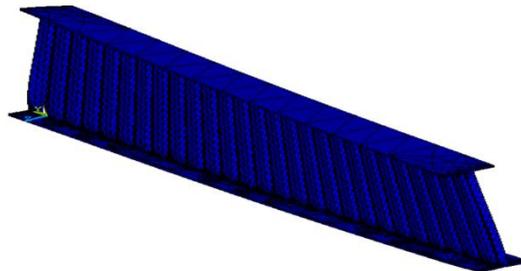


Figure 10. Deformation Of Plate Girder With 30mm Thick Corrugated Plate

8. CONCLUSION

Both shear force and moments of varying web thickness are compared. From the results, it is found that plate girder with corrugated webs are more efficient than the plate girder with plane web. The moment carrying capacity of the plate girder with corrugated web is found to be 64% higher in the case of 10 mm thick plate than that of the plate girder with plane web. Similar results were obtained with varying thicknesses of the plates. Moreover the shear taking capacity of the plate girder with corrugated web is significant when compared with the plate girder with plane web.

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