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Buckling Analysis of Plate Girders with Corrugated Web

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Abstract: "Plate girders became popular in the late 1870's, when they were used in construction of railroad bridges. The plates were joined using angles and rivets to obtain plate girders of desired size. By 1940's welded plate girders replaced riveted and bolted plate girders in developed world due to their better quality, aesthetics and economy. The corrugated steel plates are widely used structural elements in many fields of application because of its numerous favourable properties. To increase the shear capacity of web for large steel plate girders, the web with different types such as tapered web, haunches, corrugations of different shapes are used. Corrugated steel panels have been recognized as excellent load carrying members". In this project the stiffness of plate girders with different corrugation parameters were compared and it was established that corrugated web plate girders are better than plane web plate girder.

Keywords: Buckling Strength, Corrugated Web, Finite Element Analysis, Plate Girder.

I. Introduction

In present study webs with rectangular corrugations were used [11]. The main objective of this project was to compare the buckling strength of corrugated web plate girders with different corrugation parameters [15]. Also to compare the stiffness of plate girders with corrugated web [18].The "corrugated webs were not commonly used in India they were used commonly in foreign countries. As we know, plate girders have the maximum moment carrying capacity than any other rolled sections used. To carry the moments, the sections have to be slender and the slender sections are susceptible to web buckling. So the webs lose its buckling strength. Hence to avoid this buckling and to gain maximum strength we provide corrugations to the web. The purpose of using corrugated web is that it permits the use of thin plates without the need of stiffeners; hence it considerably reduces the cost of beam fabrication and improves the fatigue life. Also it gives good aesthetics to structures". In this thesis the finite element models of corrugated webs were developed and analysis was performed by using ANSYS 14 software. The literature available on application of corrugated web is less. "The results of available studies indicate that the stiffness of these girders can be higher as compared to girders with stiffened or un-stiffened web".

Case 3:- Compare the stiffness of plane web plate girder with corrugated web plate girder with highest buckling strength.

II. Scope Of The Study

"The corrugated steel plate is a widely used structural element in many fields of application because of its numerous favourable properties. 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 used. Corrugated steel panels have been recognized as excellent load carrying members". The scope of this project is to compare the stiffness of plate girders with different corrugation parameters and to establish that corrugated web plate girders are better and economical than plane web plate girder.

III. Outlay Of The Study

In this study the finite element models of corrugated webs with different corrugation parameters were developed and analysis was performed by using ANSYS 14 software. The results obtained from analysis were then compared to find the plate girder with highest stiffness.

During this study following cases were taken into account.

Case 1:- Compare the stiffness of plate girders with corrugated web plate girder based on different corrugation parameters.

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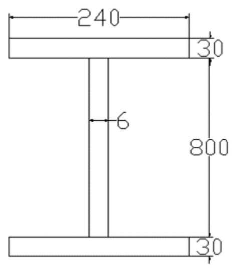
IV. DESIGN OF PLATE GIRDER AS PER IS 800-2007



Data: Length = 6000 mm
Load = 100 kN/m

Maximum bending moment = $\frac{w\,l^2}{8}$

$= \frac{100 \times 6^2}{8} = 450$ kNm

Shear force = $\frac{wl}{2} = \frac{100 \times 6}{2} = 300$ kN

Check for bending strength

$Z_{pz} = \frac{b_f \times t_f \times (D - t_f)}{2}$

$= \frac{2 \times 240 \times 30 \times (860-30)}{2} = 5.98 \times 10^6\ mm^3$

$M_d = \frac{\beta_b \times z_{pz} \times f_y}{\gamma_{mo}}$ (cl 8.2.1.2)

$= \frac{1 \times 5.98 \times 10^{\wedge}6 \ \times 250}{1.1}$

= 1359×10 kNm > 450 kNm

Hence OK.

Shear capacity of web

$\frac{d}{t_w} > 67\varepsilon$ (for web without stiffener, cl 8.4.2.1)

$\frac{d}{t_w} = \frac{800}{6} = 133.33 > 67\varepsilon$, shear buckling occurs and the web fail due to shear buckling.

Shear buckling resistance

τ_{cr} = critical shear stress of the web

$= \frac{K_V \times \pi^2 \times E}{12\,(1-\mu^2)(\frac{d}{t_w})^2}$

$K_V = 5.35$ (Cl 8.4.2.2)

$\lambda_w = \sqrt{\frac{f_y}{\sqrt{3} \times \tau cr}} = \sqrt{\frac{250}{\sqrt{3} \times 68.4}} = 1.45 > 1.2$

$\tau_{cr} = \frac{5.35 \times \pi^2 \times 2 \times 10^5}{12\,(1-.3^2)(133.33)^2} = 68.4\ N/mm^2$

$\tau_b = \frac{f_y}{\sqrt{3} \times {\lambda_w}^2} = \frac{250}{\sqrt{3} \times 1.45^2} = 68.65\ N/mm^2$

TABLE II

Shear force, $V_{cr} = A_V \times \tau_b$

$= 0.8 \times 0.006 \times 68.65$

$= 330.52$ kN > 300 kN

Selected plate girder satisfies all the conditions as per IS 800-2007.

Section classification as per IS 800-2007

$\frac{d}{t_w} = \frac{800}{2} = 400 > 126\varepsilon$, therefore web is slender.

$\frac{d}{t_w} = \frac{800}{4} = 200 > 126\varepsilon$, therefore web is slender.

$\frac{d}{t_w} = \frac{800}{6} = 133.33 > 126\varepsilon$, therefore web is slender.

$\frac{b}{t_f} = \frac{240}{30} = 8 < 8.4\varepsilon$, therefore flange is plastic.

V. FINITE ELEMENT ANALYSIS

Plate girders of corrugated web with different corrugation parameters were modelled in AutoCAD 2012 and exported to finite element software ANSYS 14 for analysis.

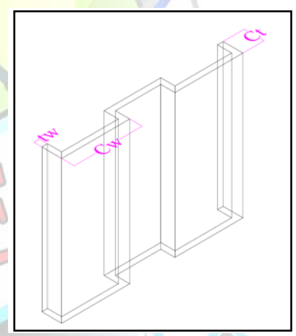


Fig. 1 Corrugation Parameters

TABLE I
VARIATION IN CORRUGATION PROPERTIES

Web thickness (t_w) (mm)	Corrugation Width (C_w) (mm)	Corrugation Thickness (C_t) (mm)		
2	100	10	20	30
	200	10	20	30
	400	10	20	30
4	100	10	20	30
	200	10	20	30
	400	10	20	30
6	100	10	20	30
	200	10	20	30
	400	10	20	30

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GEOMETRIC PARAMETERS OF PLATE GIRDERS WITH CORRUGATED WEB

Web height (h) (mm)	Web thickness (t_w) (mm)	Flange width (b_f) (mm)	Flange thickness (t_f) (mm)	Corrugation Width (C_w) (mm)	Corrugation Thickness (C_t) (mm)	Overall depth (H) (mm)	Length (L) (mm)
800	2	240	30	100	10	860	6000
	4			200	20		
	6			400	30		

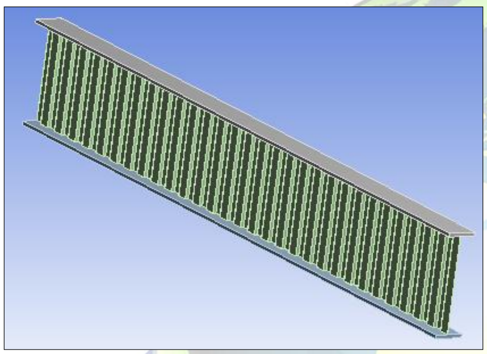

Fig. 2 Corrugated Web Plate Girder Model

A. *Analysis of Corrugated Web Plate Girder*

Buckling analysis:-

- "Buckling loads are critical loads at which certain types of structures become unstable. Each load has an associated buckled mode shape; the shape that the structure assumes in its buckled condition".
- Buckling depends upon the loading conditions and the geometrical and material properties of the structure.
- Buckling analysis gives the buckling strength and buckling behavior of girders.
- The stiffness is obtained by dividing the buckling strength with the deflection, both obtained from the analysis results.

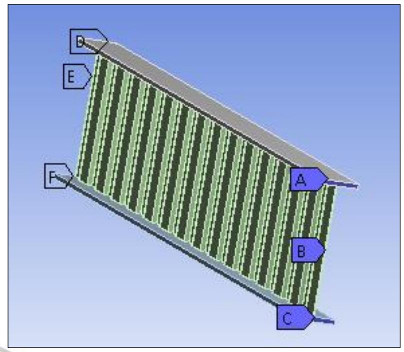

Fig. 3 Boundary Condition Application in Software

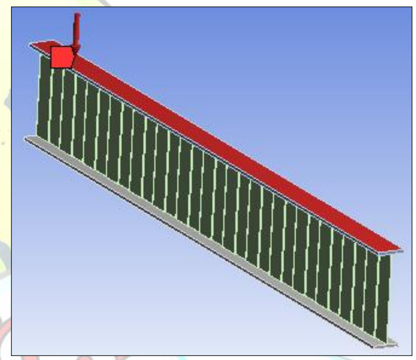

Fig. 4 Load Application in Software

B. *Analysis Results*

Typical deformation pattern of a corrugated web plate girder with the following geometric parameters is given below:

Web height, h = 800 mm
Web thickness, t_w = 2 mm
Flange width, b_f = 240 mm
Flange thickness, t_f = 30 mm
Length, L = 6000 mm
Corrugation width, C_w = 100 mm
Corrugation thickness, C_t = 10 mm

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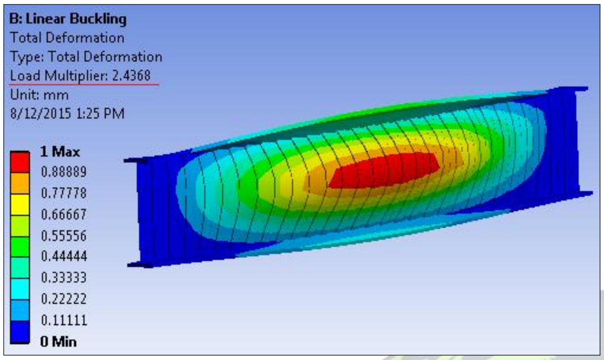

Fig. 5 Buckled Shape of Corrugated Web Plate Girder

C. Stiffness Comparison

(i) For t = 2 mm

TABLE III
STIFFNESS ($\times 10^3$ kN/mm) FOR t_w = 2 mm

Parameters	C_w = 100 mm	C_w = 200 mm	C_w = 400 mm
C_t = 10 mm	3.51	2.75	0.28
C_t =20 mm	7.11	5.21	0.39
C_t =30 mm	11.42	8.65	8.55

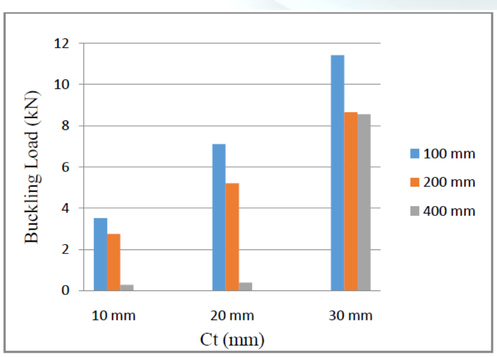

Fig. 6 Graph Representing Variation in Stiffness

(ii) For t = 4 mm

TABLE IV
STIFFNESS ($\times 10^3$ kN/mm) FOR t_w = 4 mm

Parameters	C_w = 100 mm	C_w = 200 mm	C_w = 400 mm
C_t = 10 mm	4.38	3.43	1.12
C_t =20 mm	10.01	6.86	1.84
C_t =30 mm	15.53	14.78	12.37

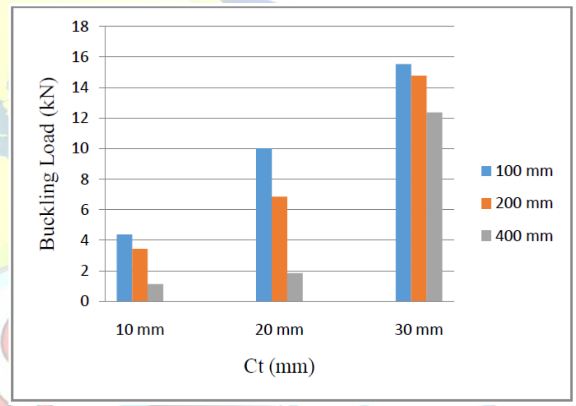

Fig. 7 Graph Representing Variation in Stiffness

(iii) For t = 6 mm

TABLE V
STIFFNESS ($\times 10^3$ kN/mm) FOR t_w = 6 mm

Parameters	C_w = 100 mm	C_w = 200 mm	C_w = 400 mm
C_t = 10 mm	6.19	4.78	2.78
C_t =20 mm	12.79	11.39	4.23
C_t =30 mm	18.66	17.90	15.03

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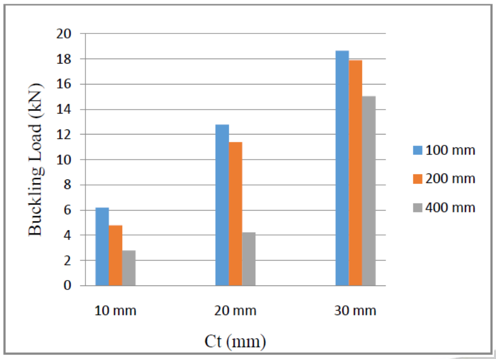

Fig. 8 Graph Representing Variation in Stiffness

From the above graphs it is seen that the plate girder with corrugated web of 6 mm thickness, corrugation width of 100 mm and corrugation thickness of 30 mm have the highest stiffness. So it is observed that stiffness increases with decrease in corrugation width.

VI. Comparison Of Corrugated Web Plate Girder With Plane Web Plate Girder

A plane web plate girder with and without stiffeners were modelled and analysed in the finite element software. The weight of the corrugated web of 6 mm thickness, corrugation width of 100 mm and corrugation thickness of 30 mm, for which highest buckling strength was obtained from the analysis, was calculated and this equivalent weight was used to obtain the thickness of the plane web plate girder.

A. Weight and Thickness Calculation for Plane Web Plate Girder

(i) Weight Calculations

Data: Length, L = 6000 mm
Web height, h = 800 mm
Web thickness, t_w = 6 mm
Corrugation width, C_w = 100mm
Corrugation thickness, C_t = 30 mm
Corrugation length,
C. L.= (60 × 100) + (61 × 30)= 7830 mm
Self weight of corrugated web
= 7.83 × 0.006 × 7850 × 0.8 = 295.03 kg
Weight of stiffeners
= 0.12 × 0.012 × 0.8 × 7850 × 6
= 54.26 kg

(ii) Thickness calculation

(a) Without stiffeners

$$295.03 = 6 \times t_w \times 7850 \times 0.8$$
$$t_w = 7.82 \text{ mm} \sim 8 \text{ mm}$$

(b) With stiffeners at Both Ends and in the Middle

$$(295.03 - 54.26) = 6 \times t_w \times 7850 \times 0.8$$
$$t_w = 6.39 \text{ mm} \sim 6.4 \text{ mm}$$

B. Analysis of Plane Web Plate Girder

(a) Without stiffeners

Load multiplier obtained for plate girder with plane web = 1.9097
The buckling load was obtained by multiplying this load multiplier with the flange area.
Stiffness obtained = 2.75 × 10^3 kN/mm

(b) With stiffeners at Both Ends and in the Middle

Load multiplier obtained for plate girder with plane web = 1.7888

The buckling load was obtained by multiplying this load multiplier with the flange area.
Stiffness obtained = 2.58 × 10^3 kN/mm

TABLE VI
STIFFNESS (× 10^3 kN/mm) COMPARISON FOR PLANE AND CORRUGATED WEB

Parameter	Plane Web		Corrugated Web	% increase	
	Without Stiffeners	With Stiffeners		Without Stiffeners	With Stiffeners
Stiffness (× 10^3 kN/mm)	2.75	2.58	18.66	85.26 %	86.20 %

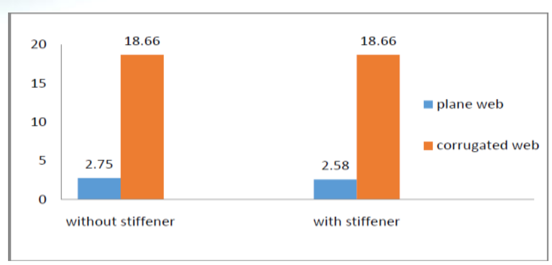

Fig. 9 Graph Representing Variation in Stiffness

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From the above graph it can be concluded that the stiffness of corrugated web plate girder is much more than that of a plane web plate girder.

VII. CONCLUSIONS

1) In this thesis the stiffness of corrugated plate girders with different corrugation parameters were studied. The variation in stiffness of these plate girders were plotted with the help of a bar chart and it was observed that the stiffness of corrugated web plate girder with 6 mm web thickness, corrugation width of 100 mm and corrugation thickness of 30 mm have the highest stiffness. So, it can be concluded that stiffness also increases with decrease in corrugation width.
2) The buckling strength of plane web plate girders with and without stiffeners was also studied. The weight of the corrugated web of 6 mm thickness, corrugation width of 100 mm and corrugation thickness of 30 mm, for which highest buckling strength was obtained from the analysis, was calculated and this equivalent weight was used to obtain the thickness of the plane web plate girder. From the stiffness obtained it was concluded that the corrugated web plate girders have much more stiffness than plane web plate girders.

   Thus it can be concluded that the stiffness of corrugated web plate girder increases with decrease in corrugation width, also, corrugated web plate girder have more stiffness than plane web plate girder. So, corrugated web plate girder is much better than plane web plate girder.

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REFERENCES

[1]. Masahiro Kubo, Yuhshi Fukumoto, "Lateral-Torsional Buckling of Thin Walled I-Beams", *J. Struct. Eng*., (1988), 114:841-855.

[2]. K. Baskar, N. E. Shanmugam, V. Thevendran, "Finite-Element Analysis of Steel–Concrete Composite Plate Girder", *J. Struct. Eng*., (2002), 128:1158-1168.

[3]. N. E. Shanmugam, K. Baskar, "Steel–Concrete Composite Plate Girders Subject to Shear Loading", *J. Struct. Eng*., (2003), 129:1230-1242.

[4]. Sherif A. Ibrahim, Wael W. El-Dakhakhni and Mohamed Elgaaly, "Fatigue of Corrugated-Web Plate Girders: Experimental Study", *J. Struct. Eng*., (2006), 132:1371-1380.

[5]. Bong-Gyun Kim and Richard Sause, "Lateral Torsional Buckling Strength of Tubular Flange Girders", *J. Struct. Eng*., (2008), 134:902-910.

[6]. Joseph Yura, Todd Helwig, Reagan Herman, Chong Zhou, "Global Lateral Buckling of I-Shaped Girder Systems", *J. Struct. Eng.*, (2008), 134:1487-1494.

[7]. Mahendrakumar Madhavan, James S. Davidson, "Theoretical Evaluation of Flange Local Buckling for Horizontally Curved I-Girders", *J. Bridge Eng*., (2009), 14:424-435.

[8]. Hartmut Pasternak, Gabriel Kubieniec. "Plate Girders with Corrugated Webs", *Journal of Civil Engineering and Management*, (2010), (2): 166–171.

[9]. M. M. Alinia, A. Dibaie, "Buckling and failure characteristics of slender web I-column girders under interactive compression and shear", *Comp. Meth. Civil Eng*., (2012), Vol. 3, 1:15-34.

[10]. hris R. Hendy, Rachel P. Jones, "Lateral buckling of steel plate girders for bridges with flexible lateral restraints or torsional restraints", (2013).

[11]. Limaye A. A, Alandkar P. M, "Strength of welded plate girder with corrugated web plate", *Int. Journal of Engineering Research and Applications*, (2013), Vol. 3, 5:1925-1930.

[12]. Sung C. Lee, Doo S. Lee and Chai H. Yoo, "Flexure and Shear Interaction in Steel I-Girders", *J. Struct. Eng.*, (2013), 139:1882-1894.

[13]. B. Saddek, "Theoretical Investigation of Shear Buckling for Hybrid Steel Plate Girder with Corrugated Webs", *World Applied Sciences Journal*. (2015), 33 (2): 284-302.

[14]. Sachin K.G, Sowjanya G.V, "Buckling Strength and Bending Performance of Plate Girder with Flat Web and Corrugated Web", *International Journal of Civil and Structural Engineering Research*, (2015), Vol. 2, Issue 2, pp: (1-11).

[15]. Sujit P. Naikwadi, S.B.Kandekar, R.S Talikoti, "Numerical Analysis of Buckling Strength of Welded Plate Girder with Corrugated Web Plate Girder", *International Journal for Scientific Research & Development*, (2015), Vol. 3, Issue 1, pp: (728-731).