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Strength Of Welded Plate Girder With Corrugated Web Plate

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ABSTRACT
The corrugated steel plate is a widely used structural element in many fields of application because of its numerous favorable 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. Present paper deals with the determination of buckling strength of a plate girder considering rectangular corrugated web plate. The finite element analysis of a plate girder is carried out using ANSYS. The results obtained from analysis are then compared with the plate girder with plane web of uniform depth. Various parameters like buckling strength and weight are compared. 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* -** Buckling strength, corrugated web, finite element analysis, moment carrying capacity, plate girder

I. INTRODUCTION

In present research a web with rectangular corrugations is used [1]. The main objective of this project is to determine the buckling strength of corrugated web subjected to shear for transverse loading at mid span [4]. Also to check the economy and compared it with plane web plate girders. Though the corrugated webs are not commonly used in India but are used commonly in foreign countries. As we know, plate girders have the maximum moment carrying capacity than any other rolled sections. To carry the moment’s section has to be slender and the slender sections are susceptible to web buckling. So the web loses its buckling strength. Hence to avoid this buckling and to gain maximum strength we are focusing on providing corrugations to the web. The purpose of using corrugated web is that it allows the use of thin plates without the need of stiffeners thus it considerably reduces the cost of beam fabrication and improves the fatigue life. Also it improves the aesthetics of structures. In this research the finite element models of plane web as well as corrugated webs are developed and analysis is performed by using ANASYS software. There is less literature available on application of corrugated web. The result of available studies indicates that the strength of these girders can be higher as compared to girders with stiffened or un-stiffened web.

I.1 Scope of work

In present study, an attempt has been made to study following aspects

1) Study of behavior of welded plate girder for variation in geometry of corrugation and thickness of web plate.
2) Preparation and study of model in ANSYS.
3) Perform the static and buckling analysis.
4) Calculate the buckling strength and weight of corrugated web plate girders.
5) Comparative study of plane web plate girder without stiffeners.

I.2 Purpose of corrugations

For making the cross section efficient to resist in plane bending it is required that max 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.

I.3 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 ANASYS software. The results obtained from analysis are then compared with plane web plate girders.

During this study following cases are taken into account.

Case 1:- Compare the buckling strength of standard plate girder with corrugated web plate girder based on different corrugation properties.

Case 2:- Compare the weight of standard plate girder with corrugated web plate.

II. MODELLING OF PLATE GIRDER USING ANSYS

II.1 Problem statement

In the present study following cases are considered for comparison.

1) To determine the buckling strength of corrugated web subjected to shear for transverse loading at mid span by finite element method using “Ansys”.

2) To check the economy.
3) Weight comparison.

Table II.1.1 Variation in corrugation properties

Web Thickness (mm)	C_w (mm)	C_t (mm)		
2 mm	200	10	20	30
	400	10	20	30
	500	10	20	30
4 mm	200	10	20	30
	400	10	20	30
	500	10	20	30
6 mm	200	10	20	30
	400	10	20	30
	500	10	20	30

Where, C_w = Width of corrugation
C_t = thickness of corrugation

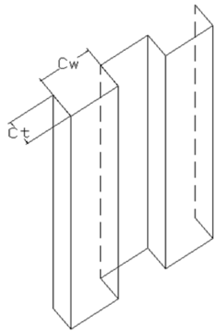

Fig. II.1.1 Rectangular corrugated web

Flange plate properties are considered same in all above the cases.

II.2 Design of plate girder as per IS 800-2007

Before analytical work a selected plate girder is first checked as per IS 800-2007 (16)

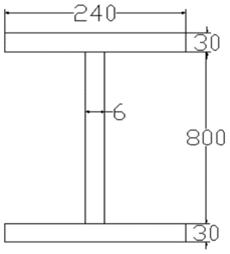

Fig. II.2.1 Dimensions of plate girder

Data –
Length = 10m
Load = 100 kN (point load at center)

Maximum bending moment = $\frac{wl^2}{4} = \frac{100x10^2}{4}$

= 250 kNm

Shear force = $\frac{w}{2} = \frac{100}{2}$ = 50kN

Check for bending strength

$Z_{pz} = \frac{bf\ tf\ (D-tf)}{2} = \frac{2x240x30\ (860-30)}{2}$ = 5.98 x 10^6 mm^3

$M_d = \frac{\beta_b Z_{pz} f_y}{\gamma_{mo}}$ = 1538 x 10^6 kNm > 250 kNm

hence ok ……………………… clause 8.2.2

Shear capacity of web

$\frac{d}{t_w}$ = 133.33 > 6.7ε ……….. clause 8.4.2.1

As $\frac{d}{t_w}$ > 6.7ε, shear buckling need to consider i.e. web is fail by shear buckling. Thus shear buckling resistance as per clause 8.4.2. 2 IS 800: 2007 (16) is calculated as

$\tau_{cr} = 5.35 \frac{\pi^2 2x10^5}{12(1-0.3^2)(133.33)^2}$ = 101.03 N/mm^2

$\lambda_w = \frac{f_{yw}}{\sqrt{3}\tau_{cr}}$ = 1.42 > 1.2

$\tau_b = \frac{f_{yw}}{\sqrt{3}\lambda_w^2}$ = 71.58 > 50 hence ok

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

II.3 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 required some inputs like material property, element type, boundary conditions, proper meshing etc.

II.3.1 Flow chart showing analysis in ANSYS

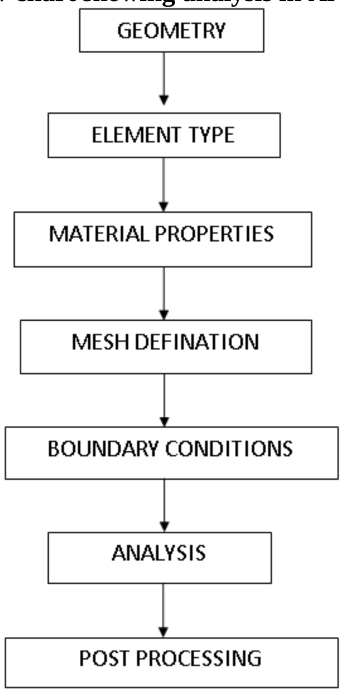

Figure II.3.1 & II.3.2 shows plane web plate girder and corrugated web plate girder modelled using Ansys.

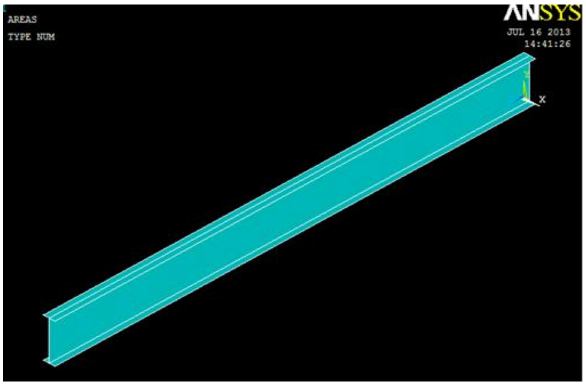

Fig. II.3.1 Plane web plate girder

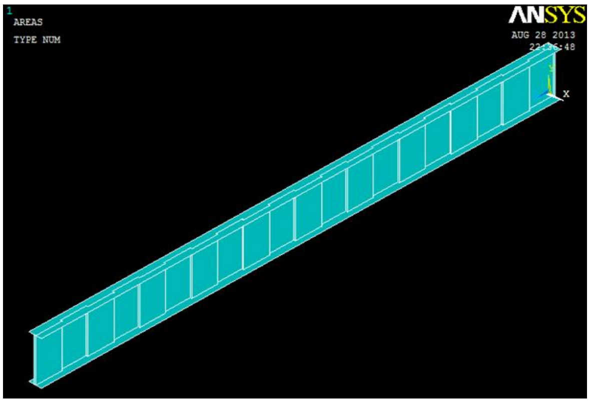

Fig. II.3.2 Corrugated web plate girder

The geometric properties required for modelling are given as below. The flanges are considered as plastic and web is considered as slender as per IS800-2007 (16) for both cases.

Table II.3.1 Geometric parameters for plane web plate girders

Web Height (h)	Web thickness (t_w)	Flange width (b_f)	Flange thickness (t_f)	Overall depth (H)	Length	Fy N/mm^2
800 mm	2mm,4mm 6 mm	240 mm	30 mm	860 mm	10000 mm	250

Section classification as per IS 800-2007 (16)
b/t_f = 240/30 = 8 < 8.4ε therefore flange is plastic.
d/t_w = 800/6 = 133.33 > 126ε therefore web is slender.
b = Outstand of flange, d = depth of web

Table II.3.2 Geometric parameters for corrugated web plate girders

Web Height (h)	Web thk. (t_w)	Flange width (b_f)	Flange thk.(t_f)	Corrugation width(C_w)	Corrugation thk. (C_f)	Overall depth (H)
800mm	2,4, 6mm	240mm	30mm	200,400, 500mm	10,20,30 mm	860mm

Section classification as per IS 800-2007
b/t_f = 240/30 = 8 < 8.4ε therefore flange is plastic.
d/t_w = 800/2 = 400 > 126ε therefore web is slender.
d/t_w = 800/4 = 200 > 126ε therefore web is slender.
d/t_w = 800/6 = 133.33 > 126ε therefore web is slender.

The thickness of structure is negligible (i.e. area element) as compared to its length and width. Hence "SHELL 63" element is suitable. "SHELL 63" has both bending and membrane capabilities. Also it has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. For this element type it is necessary to specify the proper real constants (r) such as area, diameter, wall thickness etc. Here the thickness is given to both the flanges and web as mentioned in table II.3.1 & II.3.2."SHELL 63"element also requires some material properties such as modulus of elasticity, Poisson's ratio etc. In present study the material property Young's modulus 'E' is assigned as $200kN/mm^2$ and Poisson's ratio 'µ' defaults to 0.3 for any steel section. After giving the material properties proper meshing is to be done for both flange and web with a proper mesh size. After meshing it is required to give proper boundary conditions. For both the models, both ends are fixed and the web is restrained in Ux direction along the length as shown in figure II.3.3

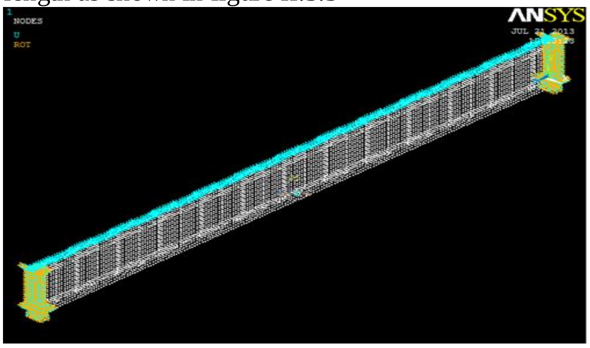

Fig. II.3.3 Boundary conditions

After proper meshing and boundary conditions the loading is to be assigned.

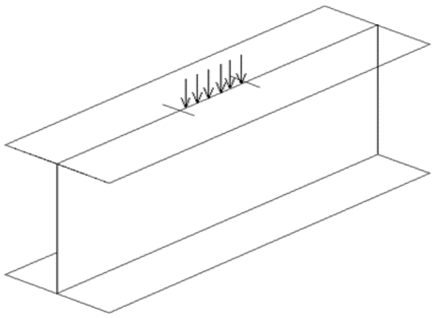

Fig. II.3.4 Loading

Here for analysis unit load per node is considered as shown in figure II.3.4 for getting required buckling/bending values from software itself.

III. ANALYSIS AND WEIGHT COMPARISON

III.1 Analysis using ANSYS

During analysis following cases are taken into consideration

Case 1:- Compare the buckling strength of plane web plate girder with corrugated web plate girder based on varying thickness of plane web and corrugation properties.

- The thickness of plane web and corrugated web plate is varied as 2mm, 4mm and 6mm.
- The thickness and width of corrugation is varied.

Case 2:- Compare the weight of plane web plate girder with corrugated web plate.

There are two types of analysis performed viz.

1) Static analysis –

- Structural analysis is the process to analyse a structural system to predict its responses and behaviours by using physical laws and mathematical equation.
- The main objective of structural analysis is to determine internal forces, stresses and deformation of structures under various load effect.
- ANSYS shows the proper initial bending shape for given loading.

2) Buckling analysis –

- Buckling loads are critical loads where certain types of structures become unstable. Each load has an associated buckled mode shape; this is the shape that the structure assumes in a buckled condition.
- Buckling is depends upon the loading conditions and on its geometrical and material properties.
- Buckling analysis gives buckling strength and buckling behavior of girder for different modes.

Different models with varying corrugation width and corrugation thickness are analysed and the results are compared with plane web plate girder. For comparison only first buckling mode is consider for both cases.

III.2 Weight comparison

Considering the buckling resistance, self-weight of both the girders are calculated and compared.

1) For plane web plate girder –
Web plate thk. = 6 mm
Total length = 10m
d = 800 mm
Buckling Resistance = 283.37 kN
SELF WEIGHT =
10 x 0.006 x 7850 x 0.8 = 376.8 kg

2) For corrugated web plate girder –
Web plate thk. = 4 mm
Total length = 10 m
d = 800 mm
Cw = 400 mm, Ct = 30 mm
C.L = 25 x 400 + 26 x 30 = 10780 mm
Buckling Resistance = 309.39 kN
SELF WEIGHT =
10.78 x 0.004 x 7850 x 0.8 = 270.8 kg

IV. RESULTS AND DISCUSSION

The comparison between the plane web plate girder and corrugated web plate girder for their buckling strength is shown in Figure IV.1 when thickness of web plate is 2mm.It shows that as the corrugation width (C_w) increases (from 200 to 500 mm) there is considerable increase in buckling strength for corrugation thickness (C_t) (10 to 30 mm) as compared to plane web plate girder.

Table IV.1 Comparison of buckling load for t = 2mm

For t = 2mm			
Ct	200	400	500
STANDARD	12.568	12.568	12.568
10	32.375	42.831	54.77
20	33.56	45.581	65.276
30	32.185	47.113	71.318

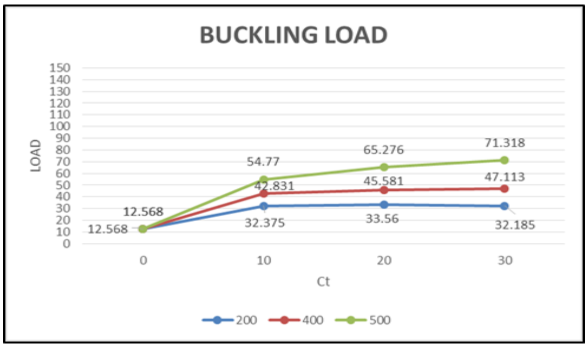

Fig. IV.1 Comparison plot for buckling load (t=2mm)

Similarly when thickness of web plate is 4mm and 6mm as shown in Figure IV.2 and IV.3 it shows that as the corrugation width (C_w) increases (from 200 to 500 mm) there is much increase in buckling resistance for corrugation thickness (C_t) (10 to 30 mm) as compared to plane web plate girder.

Table IV.2 Comparison of buckling load for t = 4mm

For t = 4mm			
Ct	200	400	500
STANDARD	93.393	93.393	93.393
10	208.69	278.34	292.73
20	217.93	300.38	418.24
30	200.01	309.39	471.46

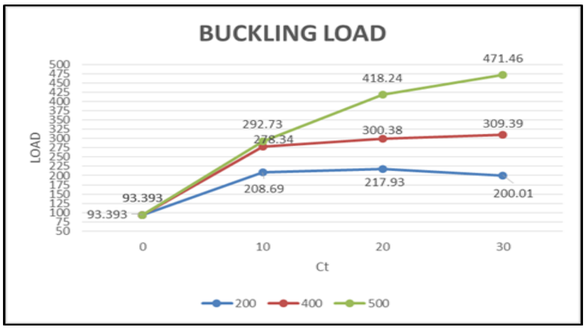

Fig. IV.2 Comparison plot for buckling load (t=4mm)

Table IV.3 Comparison of buckling load for t = 6mm

For t = 6mm			
Ct	200	400	500
STANDARD	283.37	283.37	283.37
10	545.47	794.76	662.55
20	649.85	904.38	1123
30	592.7	940.83	1359

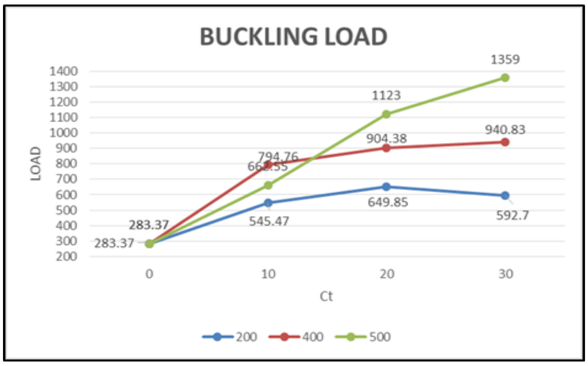

Fig. IV.3 Comparison plot for buckling load (t=6mm)

Figure IV.4 and IV.5 shows the comparison of weight when corrugation width is 200 mm to 400 mm. It shows that when the thickness of web plate is 2mm and 4mm for corrugated web plate girder there is sufficient reduction in self weight of girder for corrugation thickness (C_t) (10 to 30 mm) as compared to plane web plate girder having thickness of web plate 6mm whose buckling resistance less than that of corrugated web plate.

Table IV.4 Comparison of weight for C_w = 200 mm

For Cw = 200mm				
Weight (Kg)				
Thk.	Standard web	corrugated web		
Ct		10mm	20mm	30mm
2mm	125.6	132	138.4	144.82
4mm	251.2	264	276.82	289.63
6mm	376.8	396	415.23	434.45

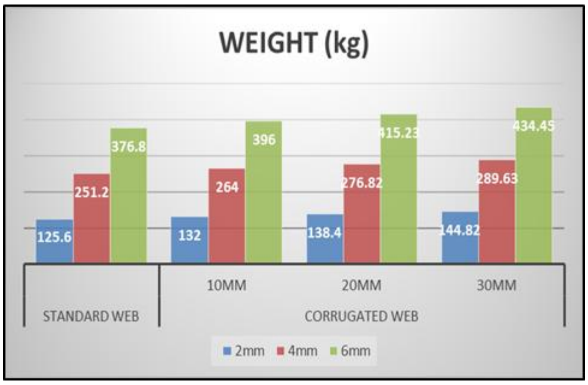

Fig. IV.4 Comparison plot for weight (C_w=200mm)

Table IV.5 Comparison of weight for C_w = 400 mm

For Cw = 400mm				
Weight (Kg)				
Thk.	Standard web	corrugated web		
Ct		10mm	20mm	30mm
2mm	125.6	129	132.13	136
4mm	251.2	258	264.3	270.8
6mm	376.8	386.6	396.4	407

Fig. IV.5 Comparison plot for weight (C_w=400mm)

Similarly when corrugation width is 500 mm as shown in Figure IV.6. It shows that when the thickness of web plate is 2mm and 4mm there is sufficient reduction in self weight of girder for corrugation thickness (C_t) (10 to 30 mm) as compared to plane web plate girder having thickness of web plate 6mm whose buckling resistance less than that of corrugated web plate. Also for 6mm plate thickness for corrugations the weight is nearly equal to that of plane web plate girder of 6mm plate thickness.

Table IV.6 Comparison of weight for C_w = 500 mm

For Cw = 500mm				
Weight (Kg)				
Thk.	Standard web	corrugated web		
Ct		10mm	20mm	30mm
2mm	125.6	128.24	130.9	133.5
4mm	251.2	256.5	261.8	267
6mm	376.8	384.7	392.6	400.5

Fig. IV.6 Comparison plot for weight (C_w=500mm)

V. CONCLUSION

The study concludes that as the width of corrugations increases from 200 mm to 500 mm the buckling strength of corrugated web increases as compared to plane web plate girder. It shows that buckling resistance of web increases with corrugation. However it is increasing for corrugation thickness up to 10% of flange width, placed symmetrically with respect to flange width. Weight of corrugated cold rolled web thickness of 2mm and 4mm is compared with standard web of 6 mm shows sufficient reduction in weight.

Thus it proves that corrugated web is economical and has sufficient buckling strength.

REFERENCES

[1] Hartmut Pasternak, Gabriel Kubieniec (2010), "*Plate Girder with Corrugated Webs",* ASCE Journal of the Structural engineering, Brandenburg University of Technology, Germany,

[2] Ezzeldin Yazeed Sayed-Ahmed, *"Design aspects of steel girders with corrugated web plate",* Professor, Structural Engineering Department, Ain Shams University, Egypt.

[3] C.Graciano, E.Casanova, J.Martinez (2010-11), *"Imperfection sensitivity of plate girder webs subjected to patch loading",* Universidad Simon Bolivar, Venezuela.

[4] Sedky Tohamy, Osama Mohamed Abu El Ela, Ahmed Ibrahim Mohamed (2013), *"Efficiency of plate girder with corrugated web versus plate girder with flat web"*, Minia Journal of Engineering and Technology, (MJET), Vol. 32, No 1, Egypt.

[5] M.H Abu Hassan, A. Ibrahim, H. Abdul hamid, B.S. Mohamed (2008), *" Effect of web and flange thickness of profiled web girder by using LUSAS"* , ICCBT 2008 - C - (45) – pp515-528, Malaysia.

[6] Y.A. Khalid , C.L. Chan, B.B. Sahari, A.M.S. Hamouda (2003-04) *"Bending behavior of corrugated web beams",* Department of Mechanical and Manufacturing Engineering, University Putra Malaysia, Malaysia.

[7] Johnson R.P and Cafolla J. (1997) *"Local flange buckling in plate girders with corrugated webs",* Proc. ICEB, Vol. 122 (2), 148-156.

[8] Jiho Moon, Jong-WonYi, ByungH.Choi, Hak-EunLee (2007-08*) "Lateral torsional buckling of beam with trapezoidal web",* Steel Structure research laboratory, South Korea.

[9] Izni Syahrizal Ibrahim, Mohd Hanim Osman and Fathoni Usman (2008*) "Buckling analysis of plate girder with trapezoid web subjected to shear loading",* university of technology, Malaysia.

[10] M.F. Hassanein, O.F. Kharoob *"Behavior of bridge girders with corrugated webs: (I) Real boundary condition at the juncture of the web and flanges",* Department of structural engineering, Tanta University, Egypt.

[11] Ulrike Kuhlmann (2010), Thesis on *"Patch loading resistance of girders with corrugated web",* Professor Budapest University of Technology and Economics, Hungary.

[12] Nikolaus Ljungstrom, Olof Karlberg (2010), Thesis on *"Girder with trapezoidally corrugated web under patch loading",* Professor Chalmers University of technology, Sweden.

[13] S.K Duggal *"Limit state design of steel structures",* Tata McGraw Hill Education Private Limited, New Delhi.

[14] M.R. Shiyekar *"Limit state Design in Structural Steel",* PHI Learning Private Limited, New Delhi.

[15] N. Subramanian "*Steel Structures Design and Practice",* Oxford University Press, New Delhi.

[16] IS 800:2007, Code of practice for general construction in steel, Bureau of Indian Standards, New Delhi.