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A COMPARATIVE ANALYSIS OF WEB BUCKLING RESISTANCE: STEEL PLATE GIRDERS – GIRDERS WITH CORRUGATED WEBS

BY

CĂTĂLIN MOGA, ALEXANDRA-DENISA DANCIU[*] and MIRCEA SUCIU

Technical University of Cluj-Napoca
Faculty of Civil Engineering

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Abstract. In this paper we present a comparative analysis regarding the shear web resistance between five types of steel plate girders and a girder with corrugated webs.

The web buckling resistance of steel plate girders is established in accordance with EN 1993-1-5: *Plated Structural Elements*-§5.3.

In the case of girders with corrugated webs, the background for the shear resistance of the web and the beam verification is the Annex D to EN 1993-1-5: *Plate Girders with Corrugated Webs*.

Key words: steel plate girders; girders with corrugated webs; comparative analysis; Euronorm EN 1993-1-5: *Plated Structural Elements*.

1. Introduction

It is well known that in the case of steel plate girders the shear force is preponderantly taken over by the girder web, the contribution of the flanges

[*]Corresponding author: *e-mail:* alexandra.stan@cfdp.utcluj.ro

being almost insignificant and the shear is integrally taken over by the corrugated webs in the case of girders with corrugated webs.

As the web is corrugated, it has no ability to sustain longitudinal stresses so, the conventional assumption is to ignore its contribution to the bending moment resistance (Åkesson, 2007).

In this paper we present a comparative analysis regarding the shear web resistance between five types of steel plate girders and a girder with corrugated webs (Johansson *et al*., 2007; Moga *et al*., 2012).

The web buckling resistance of steel plate girders is established in accordance with EN 1993-1-5: *Plated Structural Elements*-§5.3.

In the case of girders with corrugated webs, the background for the shear resistance of the web and the beam verification is the Annex D to EN 1993-1-5: *Plate Girders with Corrugated Webs* (SR EN 1993-1-1, 2006; SR EN 1993-1-5, 2006; ESDEP, 1994).

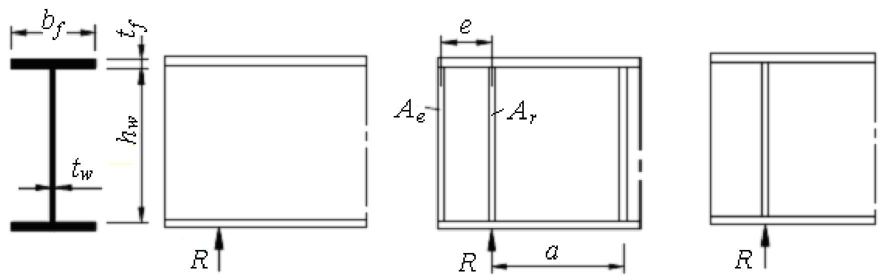
The obtained results can be useful in the optimal design of such type elements.

2. Resistance to Shear

2.1. Web Shear Resistance of Steel Plate Girders

The contribution of a stiffened or unstiffened plate web (Fig. 1) to the shear buckling resistance is given by

$$V_{bw.Rd} = \chi_w \frac{f_{yw}}{\sqrt{3}\,\gamma_{M1}} h_w t_w \,. \tag{1}$$



a *b* *c*

Fig. 1 – End supports: *a* – no end post; *b* – rigid end post; *c* – non- rigid end post.

For webs with transverse stiffeners at supports only and for webs with either intermediate transverse stiffeners or longitudinal stiffeners or both, the factor χ_w for the contribution of the web to the shear buckling resistance should be obtained from Table 1.

Table 1
Factor χ_w

	Rigid end post	Non-rigid end post
$\bar{\lambda}_w < 0.83/\eta$	η	η
$0.83/\eta \le \bar{\lambda}_w < 1.08$	$0.83/\bar{\lambda}_w$	$0.83/\bar{\lambda}_w$
$\bar{\lambda}_w \ge 1.08$	$1.37/\left(0.7+\bar{\lambda}_w\right)$	$0.83/\bar{\lambda}_w$

The slenderness parameter, $\bar{\lambda}_w$, should be taken as

$$\bar{\lambda}_w = \sqrt{\frac{f_{yw}/\sqrt{3}}{\tau_{\mathrm{cr}}}} = \frac{h_w/t_w}{37.4\varepsilon\sqrt{k_\tau}}, \tag{2}$$

where: f_{yw} is the yielding steel stress in the web; $\tau_{\mathrm{cr}} = \dfrac{\pi^2 E}{12\left(1-\mu^2\right)} k_\tau \left(\dfrac{t_w}{h_w}\right)^2$ – the critical elastic shear stress; k_τ – the shear buckling resistance obtained as follows:

a) transverse stiffeners at supports only, $k_\tau = 5.34$;

b) transverse stiffeners at supports and intermediate stiffeners

$$k_\tau = 5.34 + \frac{4}{(a/h_w)^2}, \text{ when } (a/h_w) \ge 1;$$

$$k_\tau = 4.00 + \frac{5{,}34}{(a/h_w)^2}, \text{ when } (a/h_w) < 1.$$

2.2. Shear Resistance of Corrugated Webs

The shear resistance, V_{Rd}, of a trapezoidal or sinusoidal corrugated web (Fig. 2) should be taken as

$$V_{Rd} = \chi_c \frac{f_{yw}}{\gamma_{M1}\sqrt{3}} h_w t_w. \tag{3}$$

The reduction factor, χ_c, is the lesser of the values of reduction factors for local buckling, $\chi_{c.\ell}$, and global buckling, $\chi_{c.g}$, obtained from

$$\chi_c = \min \begin{cases} \chi_{c.\ell} = \dfrac{1.15}{0.9 + \bar{\lambda}_{c.\ell}} \le 1, \\ \chi_{c.g} = \dfrac{1.5}{0.5 + \bar{\lambda}_{c.g}} \le 1, \end{cases} \tag{4}$$

where the quantities in eq. (4) are given by relations

$$\overline{\lambda}_{c.\ell} = \sqrt{\frac{f_{yw}}{\tau_{cr.\ell}\sqrt{3}}}\ , \tag{5}$$

$$\tau_{cr.\ell} = \begin{cases} \left(5.34 + \dfrac{a_3 s}{h_w t_w}\right)\dfrac{\pi^2 E}{12(1-\nu^2)}\left(\dfrac{t_w}{s}\right)^2 - \text{for sinusoidal corrugated webs,} \\ 4.83 \cdot E\left(\dfrac{t_w}{a_{\max}}\right)^2; \quad a_{\max} = \max\,[a_1; a_2] - \text{for trapezoidal corrugated webs,} \end{cases} \tag{6}$$

$$\overline{\lambda}_{cr.g} = \sqrt{\frac{f_{yw}}{\tau_{cr.g}\sqrt{3}}}; \quad \tau_{cr.g} = \frac{32.4}{t_w h_w^2}\sqrt[4]{D_x D_z^3}\ , \tag{7}$$

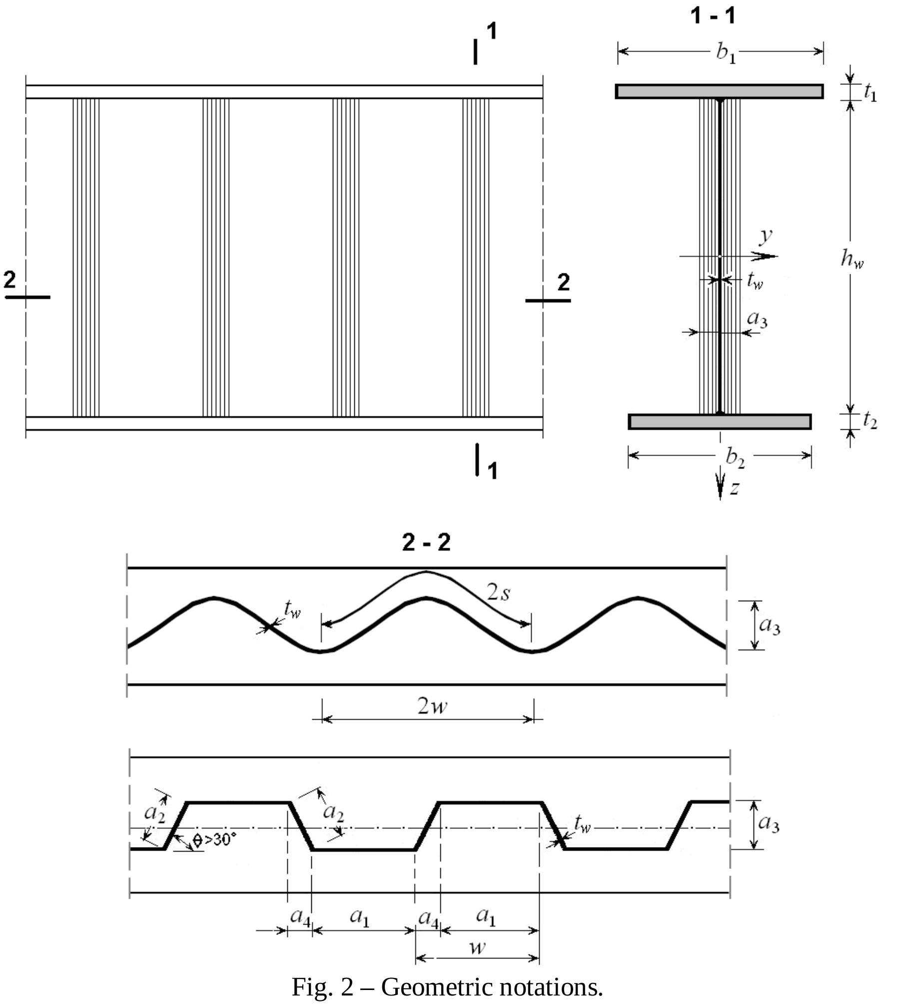


Fig. 2 – Geometric notations.

where D_x and D_z are given by relations

$$D_x = \begin{cases} \dfrac{Et_w^3}{12\left(1-\nu^2\right)} \cdot \dfrac{w}{s} \text{ – sinusoidal corrugated webs,} \\ \dfrac{Et_w^3}{12\left(1-\nu^2\right)} \cdot \dfrac{a_1+a_4}{a_1+a_2} \text{ – trapezoidal corrugated webs;} \end{cases} \tag{8}$$

$$D_z = \begin{cases} \dfrac{EI_z}{w} \text{ – sinusoidal corrugated webs webs,} \\ \dfrac{Et_w a_3^2}{12} \cdot \dfrac{3a_1+a_2}{a_1+a_4} \text{ – trapezoidal corrugated webs;} \end{cases} \tag{9}$$

I_z – second moment of area of one corrugation of length *w*, (Fig. 2).

3. Comparative Analysis

In what follows, we conduct a comparative analysis regarding the shear web resistance between five types of steel plate girders and a girder with corrugated webs.

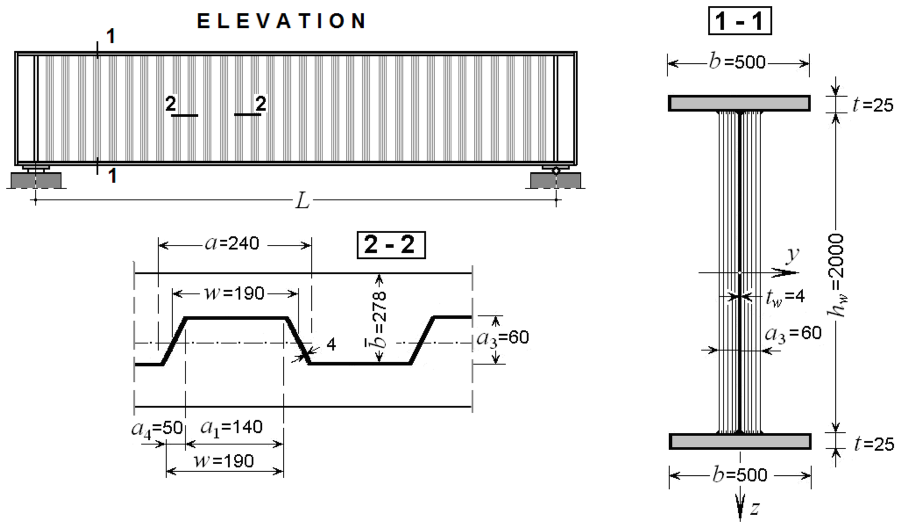


Fig. 3 – Constructive solution of case 1: girder with trapezoidal corrugated web (TC).

The following cases are analysed:

a) C a s e 1: *Girder with trapezoidal corrugated web (TC)*

Design data:

Steel: S235;

Constructive solution of girder (Fig. 3).

b) C a s e 2: *Steel plate girder (GP)*

Five types of plate girders are analysed (GP.1,...,GP.5), with the following design data:

Simple supported girder, made of steel S 235.

Web dimensions: $h_w \times t_w = 2{,}000 \times t_w$; t_w = 6; 7 and 8 mm.

Girders with transverse stiffeners only, at a distance of a = 1,400; 1,500 and 2,000 mm.

3.2. Case 1 Solution: Girder with Trapezoidal Corrugated Web (TC)

The solution is presented in the following eqs.

$$\tau_{\text{cr}.\ell} = 4.83E\left(\frac{t_w}{a_{\max}}\right)^2 = 4.83\times 2.1\times 10^6\left(\frac{4}{140}\right)^2 = 8{,}280\ \text{daN/cm}^2, \quad (10)$$

$$\bar{\lambda}_{c.\ell} = \sqrt{\frac{f_{yw}}{\tau_{\text{cr}.\ell}\sqrt{3}}} = \sqrt{\frac{2{,}350}{8{,}280\sqrt{3}}} = 0.40, \quad (11)$$

$$D_x = \frac{Et_w^3}{12\left(1-\nu^2\right)}\cdot\frac{a_1+a_4}{a_1+a_2} = \frac{2.1\times 10^6\times 0.4^3}{12\,(1-0.3^2)}\cdot\frac{140+50}{140+78} = 10{,}727\ \text{daN.cm}, \quad (12)$$

$$D_z = \frac{Et_w a_3^2}{12}\cdot\frac{3a_1+a_2}{a_1+a_4} = \frac{2.1\times 10^6\times 0.4\times 6^2}{12}\cdot\frac{3\times 140+78}{140+50} = 965.35\times 10^4\,\text{daN.cm}, \quad (13)$$

$$\tau_{\text{cr}.g} = \frac{32.4}{t_w h_w^2}\sqrt[4]{D_x D_z^3} = \frac{32.4}{0.4\times 200^2}\sqrt[4]{10{,}727(965.35\times 10^4)^3} = 3{,}569\ \text{daN/cm}^2, \quad (14)$$

$$\bar{\lambda}_{\text{cr}.g} = \sqrt{\frac{f_{yw}}{\tau_{\text{cr}.g}\sqrt{3}}} = \sqrt{\frac{2{,}350}{3{,}569\sqrt{3}}} = 0.62. \quad (15)$$

The reduction factor is

$$\chi_c = \min\begin{cases}\chi_{c.\ell} = \dfrac{1.15}{0.9+\bar{\lambda}_{c.\ell}} = \dfrac{1.15}{0.9+0.40} = 0.88 < 1; \\[2ex] \chi_{c.g} = \dfrac{1.5}{0.5+\bar{\lambda}_{c.g}} = \dfrac{1.5}{0.5+0.62} = 1.34 > 1,\end{cases} \quad (16)$$

consequently $\chi_c = 0.88$.

The web shear buckling resistance is

$$V_{Rd} = \chi_c\frac{f_{yw}}{\gamma_{M1}\sqrt{3}}h_w t_w = 0.88\frac{2{,}350}{1.1\sqrt{3}}200\times 0.4\times 10^{-2} = 868\ \text{kN}. \quad (17)$$

3.2. Case 2 Solution: Steel Plate Girder (GP)

In Table 2 the design parameters and the values of the web shear buckling resistance, V_{Rd}, are presented for each of five girders.

Table 2
Design Parameters and Values of V_{bw}, [kN]

Type	h_w, [mm]	t_w, [mm]	a, [mm]	k_τ	$\overline{\lambda}_w$	χ_w	V_{bw}, [kN]
GP.1	2,000	6	2,000	9.34	2.92	0.38	562
GP.2	2,000	7	2,000	9.34	2.50	0.43	743
GP.3	2,000	8	2,000	9.34	2.18	0.48	947
GP.4	2,000	7	1,400	14.90	1.98	0.51	880
GP.5	2,000	7	1,500	13.49	2.08	0.49	846

4. Conclusions

Steel girders with corrugated webs can be advantageous from an economic point of view in comparison with steel plate girders having transverse or transverse and longitudinal stiffeners.

Table 3 presents some data showing the structural efficiency of steel girders with corrugated webs in comparison with steel plate girders.

Table 3
Efficiency Parameters

Girder type		Web weight, g kg/m^2	$g_{\text{GP}.i}$ / g_{TC}	V_{bw}, [kN]	$V_{bw}^{\text{TC}} / V_{bw}^{\text{GP}.i}$
TC		36	1.00	868	1.00
Plate girder	GP.1	≈ 50	1.39	562	1.54
	GP.2	≈ 52	1.44	743	1.17
	GP.3	≈ 65	1.80	947	0.92
	GP.4	≈ 56	1.56	880	0.99
	GP.5	≈ 57	1.58	846	1.03

It can be observed that at the same shear resistance the weight of the web of a plate girder is about 50%...55% greater than that of a corrugated web.

At the same time some disadvantages of the girder with corrugated webs can be mentioned: a higher manufacture to build up such elements; the automatic welding is difficult to be applied; the corrugated webs have no ability to sustain longitudinal stresses, so, the conventional assumption is to ignore its contribution to the bending moment resistance; the joints with other members are more complicated.

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ANALIZĂ COMPARATIVĂ PRIVIND REZISTENȚA LA VOALARE: GRINZI PLANE – GRINZI CU INIMA DIN TABLĂ CUTATĂ

(Rezumat)

Se prezintă rezultatele unei analize comparative privind rezistența inimii la voalare din forfecare a grinzilor metalice realizate în soluția uzuală de grinzi cu inimă plină, respectiv grinzi cu inima din tablă profilată – tablă cutată sau tablă ondulată.

Rezistența inimii la voalare din forfecare este stabilită în conformitate cu normativul SR EN 1993-1-5/2006. Eurocod 3: *Proiectarea structurilor de oțel*. Partea 1-5: *Elemente din plăci plane solicitate în planul lor.*

Baza de calcul teoretic este însoțită de o analiză comparativă numerică, în urma căreia au putut fi formulate unele concluzii și observații utile în activitatea de proiectare a unor elemente metalice de tip grindă, solicitate la eforturi de forfecare importante.