COMPARATIVE ANALYSIS OF THE SHEAR FORCE RESISTANCE OF WELDED STEEL SECTIONS WITH FLAT WEBS TO CORRUGATED WEBS STEEL CROSS SECTIONS

Daniel Taus[546]
Dorin Radu[547]

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Summary: *One of the major concerns of the steel structures field is the defining of methods for reducing material consumption, and obtaining safe structures in service using elements with cross sections which does not require manual labor and can have a reduced steel quantity. An economical way to reduce the weight of steel elements is to decrease the thickness of the web of welded profiles required to bend and the profile of the web.*
The present paper proposes to perform a comparative analysis on the shear web resistance of the steel plate girders and girders with corrugated webs (trapezoidal and sinusoidal web).

Key words: *Corrugated beam webs, sinusoidal corrugated webs, trapezoidal corrugated webs.*

1. INTRODUCTION

One of the major concerns of the steel structures field is the identification of methods for reducing material consumption, and obtaining safe structures in service using elements with cross sections which does not require large volumes of manual labor.

Welded cross sections with flange made of thick steel sheets with profiled webs made of corrugated steel sheets are structural systems introduced in the field of steel structures as an alternative to profile type beams or welded steel plate girders.

Fig. 1. Some examples of corrugated steel sheet web beams type

In case of sections made of steel plate webs the shear force is taken over by the beam web, the contribution of the flanges being almost insignificant and the shear is integrally taken over by the corrugated webs in the case of SIN cross sections. Also, in the case of corrugated web, the

[546] Transilvania University of Brașov, Faculty of Civil Engineering, Turnului 5, Brașov, Romania
[547] Transilvania University of Brașov, Faculty of Civil Engineering, Turnului 5, Brașov, Romania

possibility of the local buckling is significantly reduced, which leads to the possibility of using steel sheets with reduced thicknesses, leading to the reduction of the steel consumption.

Compared with similar elements, structures made of these profiles types were found to be more economical, considering the lower steel consumption. The studies shown that the double T welded sections with corrugated webs, also known as SIN profiles are 15% ÷ 45% lighter compared to the same structures made of laminated profiles, with I and / or H transversal section shapes.

The paper is presenting a comparative analysis, considering the shear web resistance resulting from the condition of web buckling for the three cases: welded sections with full, plan web, welded sections with trapezoidal corrugated web and welded sections with sinusoidal corrugated web. The conclusions show the significant shear resistance of the SIN profile type profiles.

2. SIN PROFILES SHEAR RESISTANCE

Regarding the denomination of these elements, SIN profile name consists of a group of three letters and three groups of numbers: three letters groups symbolize the heart thickness, as follows:

WTO - tw = 1.5 mm WTA - tw =
2.0 mm WTB - tw = 2.5mm WTC - tw = 3.0 mm, and tw = web thickness.

The first group of numbers represents the height of the web expressed in *mm*. The machine that produces the double T sections of thick plates welded with corrugated webs, can produce steel webs with different heights like: h_w = 333 *mm*, 500 *mm*, 625 *mm*, 750 *mm*, 1000 *mm*, 1250 *mm*, 1500 *mm* and h_w = web heights.

The second group of numbers represents the width of flanges (b_f). These have values between: b_f = (200 ÷ 450) mm. The third and last group of numbers represent the flanges thickness (t_f) and can have values between 10÷30 mm. An relevant example for noting a SIN sections is: WTB – 500 x 220 x 12.

2.1. WEB SHEAR FORCE RESISTANCE OF STEEL CROSS SECTION WITH FLAT WEBS

The contribution of a stiffened or unstiffened plate web (Fig. 2) to the shear buckling resistance [5] is given by :

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

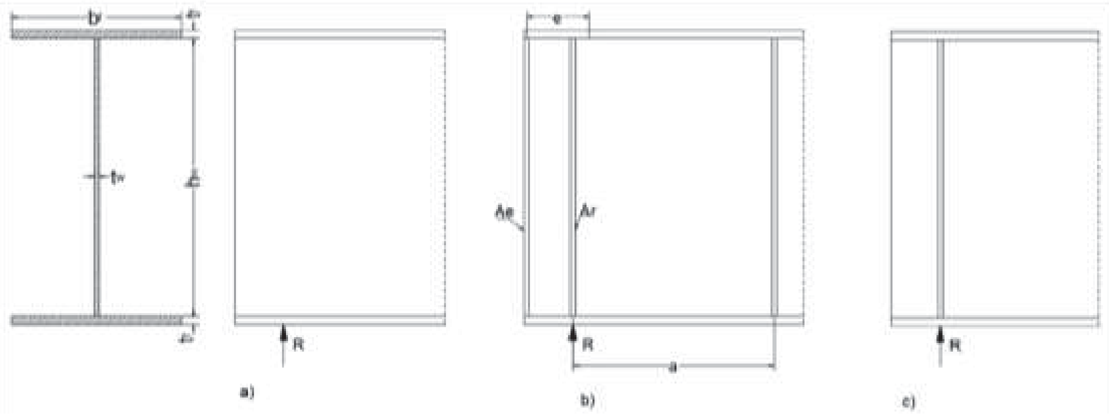

Fig. 2: a) End supports; b) rigid end post; c) non-rigid end post

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

Table 1. Contribution of the web to shear buckling resistance

	Rigid end post	Non-rigid end post
$\lambda < 0.83/h$	h	h
$0.83/h \leq \overline{\lambda_w} < 1.08$	$0.83/\lambda$	$0.83/\lambda$
λ 1.08	$1.37/(0.7+\lambda$	$0.83/\lambda$

The slenderness parameter, $\overline{\lambda_w}$, is determined by the formula (2)

$$\overline{\lambda_w} = \sqrt{\frac{f_{yw}}{\tau_{cr}\sqrt{3}}} = \frac{h_w/t_w}{37.4\epsilon\sqrt{k_\tau}} \tag{2}$$

where: f_{yw} is the yield steel stress in the web and τ_{cr} is the critical elastic shear stress [5]:

$$\tau_{cr} = \frac{\pi^2 E}{12(1-\mu^2)} k_\tau \left(\frac{t_w}{h_w}\right)^2 \tag{3}$$

The shear buckling resistance obtained as follows k_τ a) transverse stiffeners at supports only, k_τ=5.34, b) transverse stiffeners at supports and intermediate stiffeners

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

$$k_\tau=4.00+5.34/(a/h_w)^2\text{, when } (a/h_w)<1 \tag{5}$$

2.2. SHEAR RESISTANCE OF CORRUGATED WEBS

The expression to establish the shear resistance is:

$$V_{Rd} = \chi_c \frac{f_{yw}}{\gamma_{M1}\sqrt{3}} h_w t_w \tag{6}$$

where: V_{Rd} = the shear strength of the web; h_w = web height; t_w = webs tickness; f_{yw} =steel yield stress, for steel type used for the web; γ_{M1}=partial safety factor for element buckling resistance; and χ_c = the lowest value of the reduction coefficient, applicable to local buckling $\chi_{(c, l)}$, and to the global value $\chi_{(c, g)}$.

$$\chi_c = \min\left\{\chi_{c,l} = \frac{1.15}{0.9+\overline{\lambda_{c,l}}} \leq 1{,}0 \;\; ; \; \chi_{c,g} = \frac{1.5}{0.5+\overline{\lambda_{c,g}^2}} . \leq 1.0 \right\} \quad (7)(8)$$

$$\overline{\lambda_{c,l}} = \sqrt{\frac{f_y}{\tau_{cr,l}\sqrt{3}}} \quad (9)$$

where: $\overline{\lambda_{c,l}}$= relative slenderness for local buckling.
The critical shear stress value for local buckling $\tau_{cr,l}$ is obtained as following:

$$\tau_{cr,l} = \left(5.34 + \frac{a_3 s}{h_w t_w}\right) \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t_w}{s}\right)^2 \quad (10)$$

where: w = a half-wave length (see Figure 1); d= a half-wave length developed (see Figure 1); =Poisson's coefficient; E= longitudinal elastic modulus;
The relative slenderness for the global value is:

$$\overline{\lambda_{c,g}} = \sqrt{\frac{f_y}{\tau_{cr,g}\sqrt{3}}} \quad (11)$$

$$\tau_{cr,g} = \frac{32.4}{t_w h_w^3} \sqrt[4]{D_x D_z^3} \quad (12)$$

where: $\tau_{cr,g}$ = critical shear stress value to global buckling ;

$$D_x = \frac{E t_w^3}{12(1-\nu^2)} \frac{w}{s} \quad (13)$$ for sinusoidal corrugated webs

$$D_x = \frac{E t_w^3}{12(1-\nu^2)} \frac{a_1+a_4}{a_1+a_2} \quad (14)$$ for trapezoidal corrugated webs

$$D_z = \frac{E I_z}{w} \quad (15)$$ for sinusoidal corrugated webs

$$D_z = \frac{E t_w a_3^2}{12} \frac{3a_1+a_2}{a_1+a_4} \quad (16)$$ for trapezoidal corrugated webs

where: I_z = moment of inertia of a wave of w length (see figure 3);
The dimensions used for sinusoidal and trapezoidal webs are presented in figure 3.

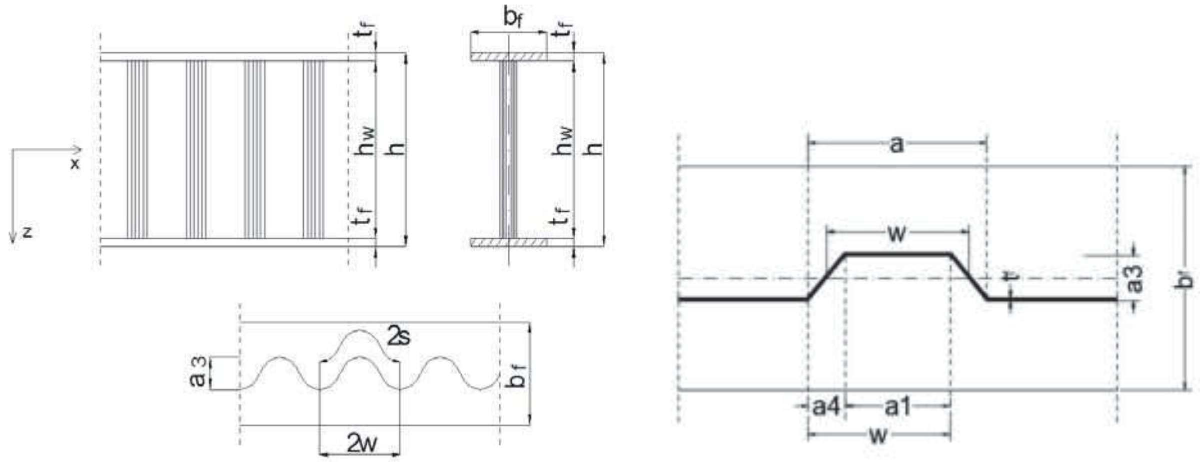

Fig.3. The dimensions used for sinusoidal webs

3. COMPARATIVE ANALYSIS

The comparison was needed in order to determine the shear resistance value of four types of steel cross sections with flat steel web, a welded cross section with trapezoidal corrugated web and a welded cross with sinusoidal corrugated web (SIN section);

The constructive solutions taken into account are:

a) steel cross sections with flat steel web

Four types of elements GP1, GP2, GP3 si GP4 are analyzed, with the following design data:

•Simple supported girder, made of steel S 235.

•Web dimensions $h_w x\ t_w$ are: GP1 (500x6), GP2 (500x7), GP3, GP4 (500x8),

•Girders with transverse stiffeners only, at a distance of a =1,500and 2,000 mm. In Table 2 are presented the design parameters and the values of V_{bw}.

Tabel 2 – Design parameters and the values of V_{bw}

Name	h_w [mm]	t_w [mm]	a [mm]	k_t	$\overline{w}$	Cw	V_{bw} [kN]
GP1	500	6	2000	5.59	0.80	1.04	38
GP2	500	7	2000	5.59	0.94	0.88	44.8
GP3	500	8	2000	5.59	0.70	1.18	58.4
GP4	500	8	1500	5.78	0.67	1.19	58.9

b) *welded cross section with trapezoidal corrugated web (TC)*

- Simple supported girder, made of steel S 235.
- Web dimensions $h_w x\ t_w$=500 x 4 mm

The results obtained are presented in Tabel 3.

Tabel 3 – Design parameters andthe values of V_{bw}

Name	h_w [mm]	t_w [mm]	$\bar{\lambda}c,l$	$\bar{\lambda}c,g$	Cw	V_{bw} [kN]
GTC	500	4	0.4	0.71	0.88	271.1

c) *welded cross with sinusoidal corrugated web (SIN section);*

- Simple supported girder, made of steel S 235, WTA-500-300x12 section
- Web dimensions h_wx t_w =500 x 2 mm

The results obtained are presented in Table 4.

Tabel 4– Design parameters and the values of V_{bw}

Name	h_w [mm]	t_w [mm]	$\bar{\lambda}c,l$	$\bar{\lambda}c,g$	Cw	V_{bw}[kN]
SIN	500	2	0.42	2.21	0.87	107.3

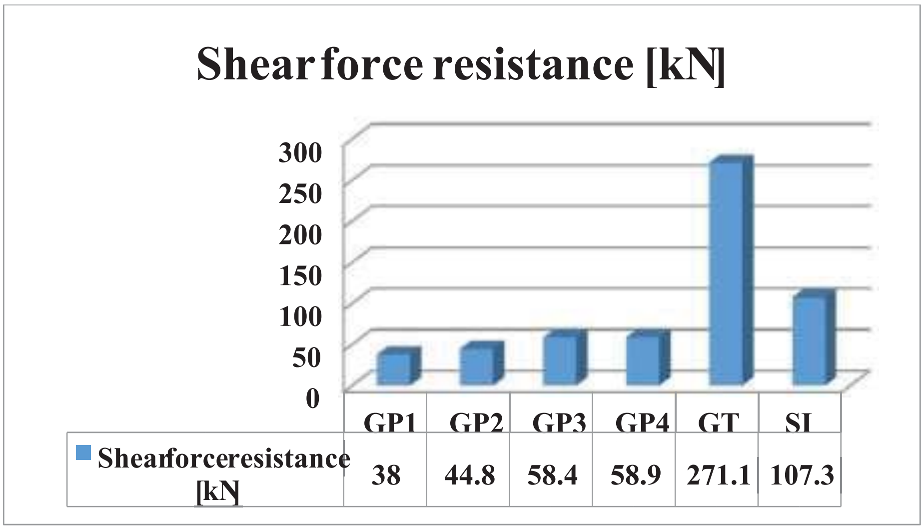

Fig.4. Shear force resistance for studied webs

The importance and efficiency of corrugating the webs of steel elements on the shear force resistance can be observed by dividing the shear force resistance to the thickness of the web for each studied case, as shown in figure 5.

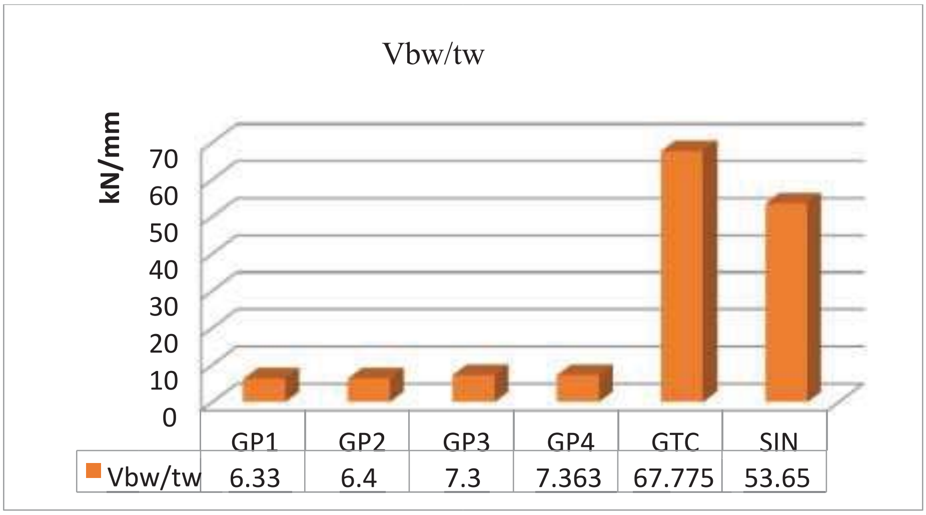

Fig.5. The ratio between the shear force resistance and the webs thickness

4. RESULTS AND CONCLUSIONS

Using steel elements with double T sections of welded steel thick plates with corrugated webs leads to lower consumption of steel compared to elements with double T welded steel sections with thick steel sheets webs. This advantage is due to the fact that these webs move away the material from the neutral axis becoming more efficient against local buckling. Considering this aspect, the same shear resistance value can be obtained using webs having less thickness compared to the thickness of straight webs made from steel sheets.

Comparing the capable shear forces resulting from the shear resistance condition in all studied situation analyzed can be observed that in the case of the corrugated webs V_{bw} has a significantly higher values than plane web, even if their thickness is less than half of the plane webs.

A disadvantage of the double T cross section steel elements with corrugated webs is that they can be manufactured only with machineries built special for this purpose. Those machineries have a large gauge and have a high acquisition and maintenance cost.

Assis. eng. ***Daniel TAUS,*** *PhD.*
University Transilvania from Brasov
Graduate of the Civil Engineering Faculty of Transilvania University in 2007. After finising University he started to work in Civil Engineering Department of The Faculty of Constructions of Transilvania University. PhD in steel structure design.
The research topics in steel design of industrial structures and welding.

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