Lateral Torsional Buckling Of Partial Corrugated Web Steel Beams

Mohammed Abbas, Sherif M. Ibrahim and Mohamed Mostafa Korashy

Abstract- A Partial corrugated web (PCW) steel beam is built up by welding flanges and a web composed of trapezoidal corrugated profile and flat web parts in the longitudinal direction of the beam. The shape of the beam web plate leads to the increase of the beam lateral stiffness when compared to flat web beams. This research presents the results of the theoretical and finite element analyses of the lateral torsional buckling of beams with partial corrugated webs under uniform bending. In the theoretical part, an equation of the warping constant is derived analytically. Using this proposed equation, the lateral torsional buckling strength of PCW steel beams under uniform bending can be effortlessly calculated. The predicated lateral torsional buckling moment is validated through comparison with both linear and non-linear finite element analyses. The effect of different geometrical configurations of the PCW steel beams on the bending capacity using proposed equation and finite element analysis is presented.

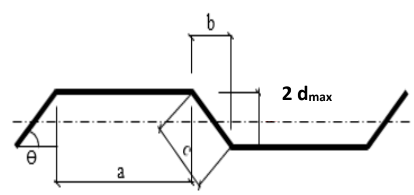
Index Terms- Partial Corrugated web, I-beam, lateral torsional buckling, bending behavior, warping constant, Finite Element Analysis.

1 INTRODUCTION

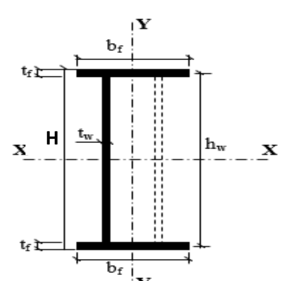
Corrugated steel webs have been widely used in various structures due to their several advantages [1]. Firstly, they can be used to replace the stiffened steel plates in plate girders as they reduce out-of-plane displacements and prevent out-of-plane buckling of web. Secondly, corrugated steel webs improve the performance of beams specially the out-of-plane strength such as lateral torsional buckling resistance. However, there are problems in transverse connections to the web and the fabrication will take more time than flat web (FW) beams due to the increase in welding path. The main difference between partially corrugated web (PCW) and fully corrugated web (FCW) steel beams is the presence of flat part of web between corrugation panel as shown in Fig. 1. The ratio of partial corrugation is expressed in terms of the total length of the corrugated part projected on the beam longitudinal axis to the beam total length. PCW steel beams would have advantages over FCW steel beams by reducing the welding path and providing a flat portion in the web to facilitate connections of transverse beams. With the advanced fabrication technology, fabrication of partial corrugation in the web is not a challenging task. Currently, a research project is undergoing at Ain Shams University to investigate the potential applications of PCW steel beams. One of the main aspects in understanding the behavior of PCW steel beams is to calculate their strength against the occurrence of lateral torsional buckling (LTB) and to estimate the gain in bending strength due to the utilization of partial corrugated web profile. The main aim of the current paper is to present an analytical procedure to evaluate the elastic and the inelastic bending strength of PCW steel beams considering LTB. The presented procedure is validated through numerical modelling by both linear and non-linear finite element (FE) analyses.

i-Fully corrugated web steel beam

ii- Partially corrugated web steel beam



iii- Corrugation notations beam



iv- Cross section notations

Fig. 1: A typical shape of FCW and PCW steel

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2 Background

Many researchers have carried out studies on corrugated steel webs [1–7]. These studies on the flexural and torsional behavior of the I-girder with corrugated webs are discussed in this section. Elgaaly et al. [1] concluded that the contribution of the web to the ultimate moment capacity of a beam with corrugated webs is negligible and the ultimate moment capacity should be based on the flange yield stress. Abbas et al. [2,3] showed that I-girder with corrugated webs in flexure cannot be analyzed using the conventional beam theory alone. Under the action of in-plane loads, a torsional moment is produced and an I-girder with corrugated webs twists out-of-plane simultaneously as it deflects in-plane. The in-plane bending behavior is therefore analyzed using the conventional beam theory, whereas the out-of-plane torsional behavior is analyzed as a flange transverse bending problem. Lateral-torsional buckling is one of the main design aspects of the flexural members composed of thin-walled I-girders [4]. Lindner [5] studied lateral-torsional behavior of steel I-girders with trapezoidal web corrugations. The study concluded that the torsional section constant (J_c) for an I-girder with trapezoidal web corrugations does not differ from those of a beam with flat web and that the warping section constant (C_w) is different. Sayed-Ahmed [6] showed that resistance to lateral torsion–flexure buckling of I-girders with trapezoidal web corrugations is 12% to 37% higher than that of the resistance of plate girders with traditional plane webs to lateral torsion–flexure buckling.

Divahar and Joanna [7] experimentally studied the lateral buckling behavior of corrugated web steel beams. In that research, an increase in the out-of-plane stiffness was observed and it was attributed to the corrugations. They tested 6 specimens under two-point bending. The specimens consisted of beams with flat and corrugated webs. The corrugation angles used were 30° and 40°. The applied loads were at a distance of one-third from the supports under load control mode. Based on these experiments, Divahar and Joanna [7] concluded that: corrugated web beams have higher resistance to lateral buckling compared to the one with normal web shape, the average load carrying capacity of steel beams with 30° corrugated webs are higher by 25% than the beam with normal web and there is an only marginal increase in load carrying of beam with 30° corrugated web than that of beam with 45° corrugated web.

The warping constant can be determined by considering the section to be composed of a series of interconnected plate elements [8]. Moon et al [4] derived an equation to calculate the warping constant of FCW steel beams. In their analysis they ignored the contribution of web due to the accordion effect. Based on this assumption, their equation for warping constant was presented at general location of web at an offset distant, d, from the center of flanges as follows:

$$C_{w(Moon)} = C_{w(Flat)} + I_w d^2 \quad (1)$$

where, $C_{w(Flat)}$ is the warping constant of flat web (FW) beam and I_w is the web moment of inertia about major axis and they are given as follows:

$$C_{w(Flat)} = \frac{I_y}{4} h_w^2 = \frac{b_f^3 t_f}{24} h_w^2 ,$$

$$I_w = \frac{t_w h_w^3}{12} \text{, and}$$

h_w is the beam web height.

The value of $C_{w(Moon)}$ varies along the longitudinal axis of the beam due to the variation of the web location along the corrugation path. Moon et al [4] proposed an average value for the warping constant for the full beam by using an average value of, d, in Eq. 1 and this average value is given as follows:

$$d_{avr} = \frac{(2a+b)}{2(a+b)} d_{max} \quad (2)$$

where d_{max} is the maximum offset of the corrugated web from the center of flanges as shown in Fig. 1.

Nguyen et al. [9] neglected the accordion effect between the flanges and the web when calculating the cross section properties and warping constant for FCW steel beams.

The shear center in this case is located at a distance Xc from the outside of the corrugated web as shown in Fig. 2 and it was given by Nguyen et al. [9] as follows:

$$X_c = \left(\frac{6 b_f t_f}{6 b_f t_f + h_w t_w}\right) d = K\, d \quad (3)$$

$$\text{where, } K = \frac{6 b_f t_f}{6 b_f t_f + h_w t_w} \quad (4)$$

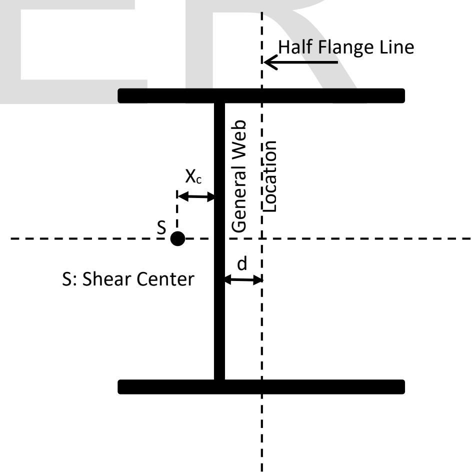

Fig. 2: Location of shear center of corrugated web beams

The general equation deduced by Nguyen et al [9] for warping constant at any cross section with the web located at distance, d, from the center of the flanges is given as follows:

$$C_{w(Nguyen)} = \frac{{h_w}^2}{24} {b_f}^3 t_f + \left(\frac{{h_w}^3 t_w}{12}\right)\left(\frac{6 b_f t_f}{6 b_f t_f + h_w t_w}\right) d^2 \quad (5)$$

By substituting for $C_{w(Flat)}$, I_w and K, the warping constant can be expressed as

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$$C_{w(Nguyen)} = C_{w(Flat)} + I_w K d^2 \quad (6)$$

Nguyen et al [9] proposed to calculate the warping constant as the average value at d = 0 and at d = d_{max}.

Ibrahim [10] derived an expression for the average warping constant of FCW steel beam with unsymmetrical section by integrating warping constant along the corrugation path of the web in the longitudinal direction and dividing it by the beam length.

Samanta and Mukhopadhyay [11] proposed a reduced shear modulus G_c of the corrugated plates is defined as

$$G_c = \frac{(a+b)}{(a+c)} G \quad (7)$$

where G is the shear modulus of flat plates, the term (a + b) is the projected length and the term (a + c) is the actual length of the corrugated plate as shown in Fig. 1.

3 Analytical Approach for Elastic Lateral Buckling of PCW Steel Beam

Fig. 3 shows a plan of a PCW steel beam. The part from point 1 to 5 represents a typical part of PCW beam which is repeated along the span. The total projected length of the corrugated part is (a+b) while the total flat part is expressed as α(a+b), where α is the flat part parameter. The case that α equals to zero would represents a FCW steel beam. Any value of $\alpha > 0$ represents a PCW steel beam and for example $\alpha = 1$ represents 50% partial corrugation. Thus the percent of partial corrugation (p) can be expressed as follows:

$$p = \frac{1}{\alpha+1} \times 100 \quad (8)$$

As shown in Fig. 3, the web offset, d, from the center line of flanges (i.e. axis z) varies from point 1 to 5 from zero to d_{max} about the longitudinal axis z. Consequently, the warping constant varies from a minimum value equals to ($C_{w(Flat)}$) at point 1 to a maximum value equals to ($C_{w,max}$) at point 2 for the inclined fold with projected length 0.5b. The value of the warping constant equals to a maximum value from point 2 to 3. For the inclined fold from point 3 to 4 with projected length 0.5b, the value of the warping constant varies from a maximum value equals to ($C_{w,max}$) at point 3 to a minimum value equals to $C_{w(Flat)}$ value at point 4. For the flat part from point 4 to 5 the warping constant is uniform with a value equals to $C_{w(Flat)}$. An average value of the warping constant for the whole PCW steel beam can be derived by integrating the variable value of the warping constant along the beam length from point 1 to 5 and dividing this integration by the beam length from point 1 to 5. Thus the average value of the warping constant for PCW steel beam can be expressed as follows:

$$C_{w,PCW} = \frac{1}{(\alpha+1)(a+b)} [A + B + C] \quad (9)$$

where

$$A = 2 \int_0^{0.5b} F(C_W) dZ \quad (10)$$

$$B = \int_{0.5b}^{a+0.5b} C_{w,max}\, dZ \quad (11)$$

$$C = \int_{a+b}^{(\alpha+1)(a+b)} C_{w(Flat)}\, dZ \quad (12)$$

where, $F(C_{w,})$ is provided in Eq. 1 as a function of the web offset, d, and

$$C_{w,max} = C_{W(Flat)} + I_w d_{max}^2 \quad (13)$$

The parameter, d, can be expressed in terms of the parameter, z, from the geometrical relationship of the folded part as follows:

$$\frac{d}{Z} = \frac{2d_{max}}{b} \text{ , thus } d = \frac{2d_{max}}{b} Z$$

Thus Eq. 1 can be rewritten as follows:

$$F(C_w) = \left(C_{w(Flat)} + 4I_w \frac{d_{max}^2}{b^2} z^2\right) \quad (14)$$

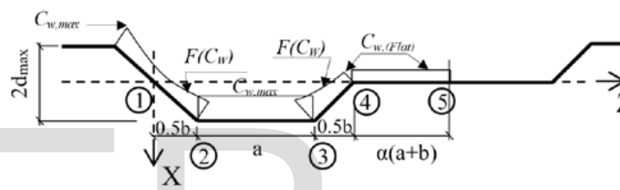

Fig. 3: The warping constant variation and integration function along the inclined fold projection

Substituting of Eq.14 into Eq. 9 and performing the integration would result in the final form of the warping constant of PCW steel beam taking into consideration the geometrical variation of the web depth as follows:

$$C_{w,pcw} = C_{W(Flat)} + \frac{a+\frac{1}{3}b}{(\alpha+1)(a+b)} (I_w d_{max}^2) \quad (15)$$

The maximum corrugation offset, d_{max}, can be expressed in terms of the flange width, b_f, and the corrugation ratio β as follows:

$$\beta = \frac{2\, d_{max}}{b_f} \quad (16)$$

Thus, Eq. 15 can be expressed in terms of the flange width and the corrugation ratio as follows:

$$C_{w,pcw} = C_{W(Flat)} + \frac{a+\frac{1}{3}b}{(\alpha+1)(a+b)} \left(I_w \frac{b_f^2}{4} \beta^2\right) \quad (17)$$

Fig. 4 shows the ratio between warping constant of PCW to that of FCW beam for different flat part parameter α and different corrugation ratios β. It is evident from this figure that the effect of partial corrugation on reducing the warping constant becomes more pronounced when the corrugation ratio increases. A beam with 50% corrugation (i.e $\alpha = 1$) has a reduction of about 18% of the warping constant compared to FCW beam at $\beta = 0.95$ while the same beam would have about 2% reduction of the warping constant at $\beta = 0.2$. Most of the reduction in the warping constant of PCW beam

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occurs when the beam changes from FCW (i.e. $\alpha = 0$) to case of 50% partial corrugation (i.e. $\alpha = 1$).

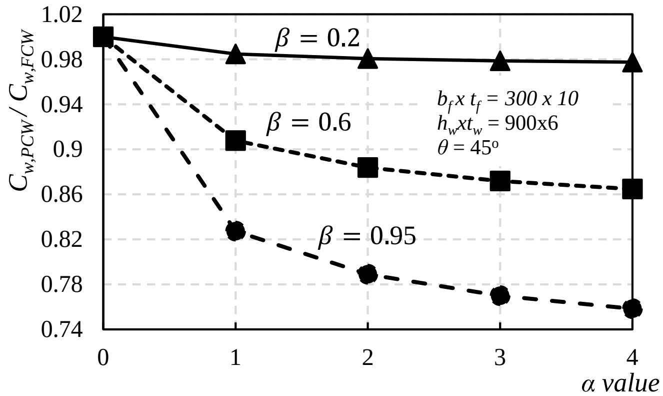

Fig. 4: Ratio of warping constant for PCW to FCW beam

Fig. 5 shows the ratio between the warping constant of PCW and FW beam for different flat part parameter α and different corrugation ratios β. It is evident from this figure that PCW beam has warping constant greater than that for FW beam. The maximum gain in the warping constant is noticeable at larger corrugation ratio (i.e. $\beta = 0.95$). With the increase of the parameter α (i.e. the increase of flat part ratio and decrease in partial corrugation ratio) the ratio ($C_{w,pcw}$ / $C_{w,(Flat)}$) becomes asymptotic to unity for all values of corrugation ratios β. At corrugation ratio of 0.2 both FCW (i.e. $\alpha = 0$) and PCW (i.e. $\alpha > 0$) have slight increase of the warping constant compared to FW beam. A noticeable increase in warping constant of PCW beam is observed at corrugation ratio $\beta = 0.6$.

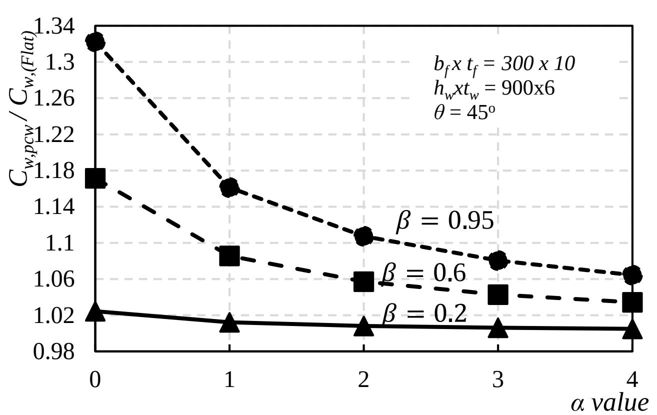

Fig. 5: Ratio of warping constant for PCW to FW beam

The warping constant expression in Eq. 17 can be incorporated into Timoshenko and Gere [12] formula for elastic lateral torsional buckling moment of beam under uniform moment. Thus, the elastic lateral–torsional buckling strength $M_{cr,\,pcw}$ of the beam with partially corrugated webs can be written as follows:

$$M_{cr,pcw} = \frac{\pi}{L}\sqrt{EI_{y,pcw}\, G_{pcw} J_{pcw}}\sqrt{1+W^2} \tag{18}$$

where

$$W = \frac{\pi}{L}\sqrt{\frac{EC_{w,pcw}}{G_{pcw}\, J_{pcw}}} \tag{19}$$

Where, L, is the lateral torsional buckling length of PCW steel beam.

The pure torsional constant, J_{pcw} of PCW steel beam is the same as that of the beams with flat webs because the pure torsional constant of a section is equal to the sum of the pure torsional constants of each individual element [5]. Therefore, J_{pcw} is given by

$$J_{pcw} = \frac{1}{3}\left(2b_f {t_f}^3 + h_w {t_w}^3\right) \tag{20}$$

The moment of inertia about y-axis is calculated based on the contribution of the flanges only and neglecting the web contribution due to accordion effect as suggested by Moon et al [4] and Ibrahim [10], therefore $I_{y,pcw}$ can be written as follows:

$$I_{y,pcw} = \frac{t_f b_f^3}{6} \tag{21}$$

The reduced shear modulus is to be calculated based on the proposed value by Samanta and Mukhopadhyay [11] as the ratio of the total projected length to the sum of horizontal and inclined parts of the repeated part which can be written as follows for PCW steel beam as follows:

$$G_{pcw} = \frac{(\alpha+1)(a+b)}{(a+c)+\alpha(a+b)}\, G \tag{22}$$

The elastic critical moment resulting from Eq. 18 based on the derived warping constant will be validated with finite element analysis described in the next sections.

4 Finite Element Analysis

A linear buckling analysis is a useful technique that can be applied to structures to estimate the maximum load that can be supported prior to structural instability or collapse. The assumptions used in linear buckling analysis are that the linear stiffness matrix does not change prior to buckling and that the stress stiffness matrix is simply a multiple of its initial value. Finite element (FE) study was carried out on FW and PCW steel beams using commercial structural analysis program "ABAQUS 6.14" [13]. Thin shell element was chosen to represent the element type in the numerical model. For this research, the numerical models are built using eight-node thin shell elements (S8R5) as shown in Fig. 6.

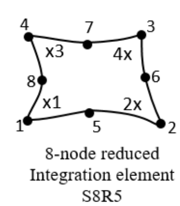

Fig. 6: Shell element geometry

All investigated steel I-beams have the following material properties: Young's modulus, E = 209 × 103 N/mm², shear modulus, G = 79 × 103 N/mm² and Poisson's ratio of 0.3. The typical loading and boundary conditions of all models are shown in Fig. 7. The Beams are considered in the numerical model as simply supported both in bending and wrapping. Displacements about directions X, Y and Z and rotation about X-axis are restrained at point (A), whereas at point (B) the displacements about directions Z and Y and rotation about X-axis are only restrained.

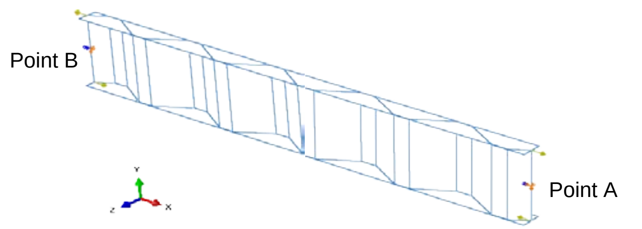

Fig. 7: Loading and boundary conditions of finite element models

The Eigenvalue buckling analysis is performed to obtain the elastic critical buckling moment, by solving the associated Eigenvalue problem. It is important to determine the value of elastic lateral torsional buckling moment for beam as it represents the true failure moment for case of long span beams (i.e. in the elastic buckling range). Moreover, elastic LTB moment is used as a base for calculating the inelastic LTB moment in some international codes such as Eurocode-3 (EC-3) [14]. In this study the result of the first buckling mode as shown in Fig. 8 is considered because it represents the lowest critical bending moment.

Buckling mode 1 Buckling mode 2 Buckling mode 3
Fig. 8: First three buckling modes

4.1 Validation of Elastic Critical moment of PCW steel beams

In this section, the elastic lateral torsional buckling moment of PCW steel beam obtained from Eq. 18, using derived warping constant from Eq. 17, is verified and compared with the results obtained using the finite element method. The study performed on two different cross sections with constant flanges 300 x 10 mm with two different web plates 900 x 6 and 1200 x 6 mm respectively. All beams have partial corrugation ratio equals to 50% (i.e. $\alpha = 1$). Two corrugation angles (θ) equals to 45° and 60° are investigated. The corrugation ratio (β) is considered as 0.2, 0.6 and 0.95 to cover all possible range. All cases are analyzed for two spans of 12 and 15 m. Tables 1 and 2 show the results of the elastic critical buckling moment from the finite element study $M_{cr,FE}$, compared with the critical elastic buckling moment capacity $M_{cr,PCW}$ using the proposed $C_{w,PCW}$ from Eq.17 for corrugation angles 45° and 60° respectively. The ratio of $M_{cr,PCW}$ / $M_{cr,FE}$ ranges from 0.98 to 1.04 as shown in Tables 1 and 2 which indicates that the proposed $C_{w,PCW}$ accurately predicts the elastic critical moment of PCW steel beams.

4.2 Comparison between PCW and FW Steel Beams

As concluded in the previous sections, the derived warping constant of PCW steel beams resulted in excellent estimate of elastic critical moment. Therefore, it is used to perform a comparative study between PCW and similar FW steel beams to demonstrate the gain in the elastic critical moment from the use of partial corrugation web.

TABLE 1
COMPARISON BETWEEN PROPOSED EQUATION AND FINITE ELEMENT ANALYSIS ($\theta = 45°$)

Beam section h_w x b_f x t_f x t_w	L_b (m)	β	$M_{cr,PCW}$ (t.m)	$M_{cr,FE}$ (t.m)	$\frac{M_{cr,PCW}}{M_{cr,FE}}$
900x300x10x6	12	0.2	31.03	31.02	1.00
		0.6	31.79	31.93	0.99
		0.95	32.62	32.63	1.00
	15	0.2	20.60	20.67	1.00
		0.6	21.09	21.46	0.98
		0.95	21.74	21.91	0.99
1200x300x10x6	12	0.2	40.49	40.28	1.00
		0.6	41.96	41.2	1.02
		0.95	43.46	41.51	1.05
	15	0.2	26.53	26.49	1.00
		0.6	27.51	27.31	1.01
		0.95	28.71	27.73	1.04

TABLE 2
COMPARISON BETWEEN PROPOSED EQUATION AND FINITE ELEMENT ANALYSIS ($\theta = 60°$)

Beam section h_w x b_f x t_f x t_w	L_b (m)	β	$M_{cr,PCW}$ (t.m)	$M_{cr,FE}$ (t.m)	$\frac{M_{cr,PCW}}{M_{cr,FE}}$
900x300x10x6	12	0.2	31.00	31.09	1.00
		0.6	31.89	32.48	0.98
		0.95	33.26	33.58	0.99
	15	0.2	20.56	20.70	0.99
		0.6	21.10	21.85	0.97
		0.95	22.01	22.82	0.96
1200x300x10x6	12	0.2	40.47	40.33	1.00
		0.6	42.21	41.76	1.01
		0.95	44.64	42.83	1.04
	15	0.2	26.51	26.52	1.00
		0.6	27.62	27.70	1.00
		0.95	29.27	28.70	1.02

The two cross sections and the two spans used in the validation study in the previous section are used herein and the range of corrugation ratio β is extended to have additional values of 0.4 and 0.8. The ratio between the elastic critical moment of PCW and FW steel beams for various corrugation ration is shown in Fig. 9 to 12.

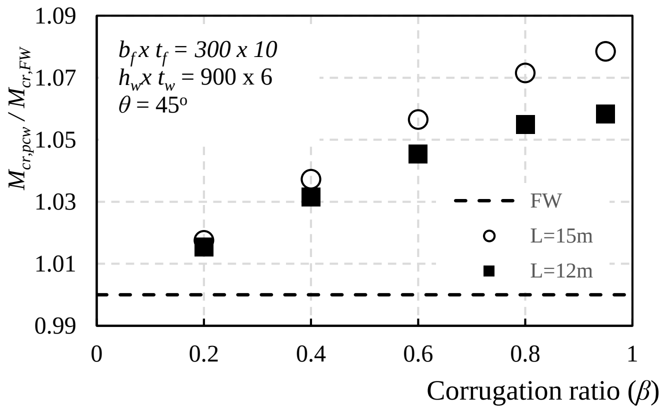

Fig. 9: Comparison between critical moment of PCW and FW beams of cross section 900x300x10x6 and θ =45º

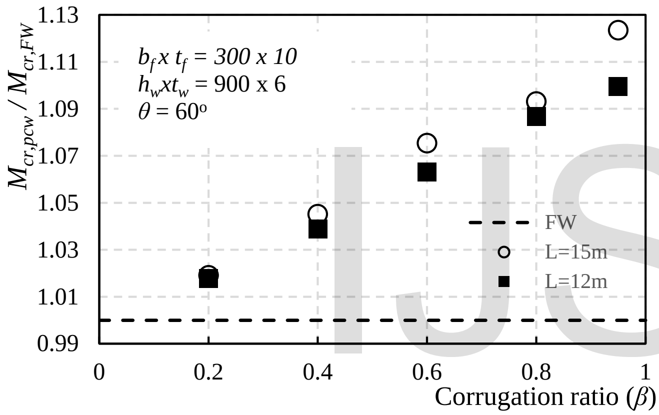

Fig. 10: Comparison between critical moment of PCW and FW beams of cross section 900x300x10x6 and θ =60º

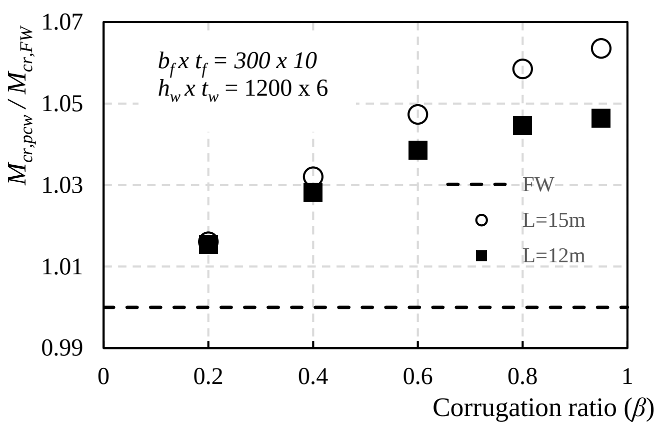

Fig. 11: Comparison between critical moment of PCW and FW beams of cross section 1200x300x10x6 and θ =45º

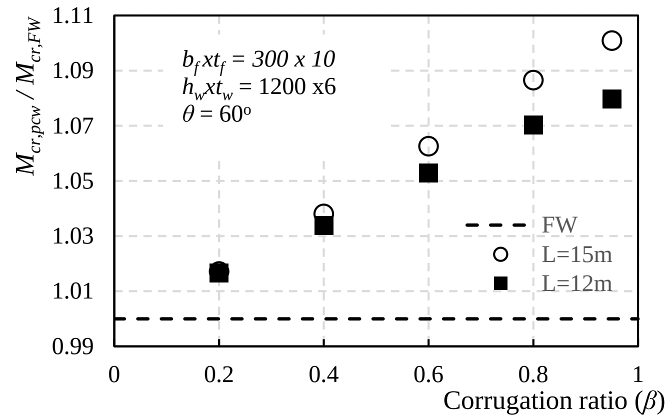

Fig. 12: Comparison between critical moment of PCW and FW beams of cross section 1200x300x10x6 and θ =60º

It is evident from Fig. 9 to 12 that the use of PCW in steel beam is effective in increasing the elastic critical moment in case of longer spans. It is evident from these figures that the ratio $M_{cr,pcw}/M_{cr,FW}$ is always larger for the 15 m span compared to the 12 m span for all cases. This can be explained as longer span is more prone to lateral torsional buckling phenomena and thus it benefits from the partial corrugated pattern of the web. It is also evident that corrugation angle of 60º results in better enchantment of the elastic critical moment compared to corrugation angle 45º for all cases. Moreover, it is evident that the gain in the elastic critical moment of PCW beam with respect to FW beam increases with increasing the corrugation ratio β. The maximum gain in the elastic critical moment is achieved at β = 0.95 with a value of approximately 13% for beam with corrugation angle 60º as shown in Fig. 10. For beams with corrugation ratio 0.2 and 0.4 minor increase in the elastic critical moment is observed. Thus, it would be a reasonable recommendation to have a corrugation ratio of at least 0.6 in order to get noticeable increase in elastic critical moment.

4.3 Ultimate Bending Resistance of PCW steel Beams

Based on the derived value of the elastic lateral torsional buckling strength, the ultimate bending resistance of PCW steel beam can be determined using procedure prescribed in EC-3 [14]. The ultimate moment resistance M_{Rd} is given according to the EC-3 as follows:

$$M_{Rd} = \chi_{LT}\ W_y \frac{F_y}{\gamma_{M1}} \tag{23}$$

Where, γ_{M1} is a partial factor representing resistance of member for instability = 1.0, W_y is the plastic section modulus for class 1 or class 2 sections, F_y is the yield strength and χ_{LT} is the reduction factor for lateral torsional buckling and is given according to the EC-3 as follows:

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$$\chi_{LT} = \frac{1}{\varphi_{LT}+\sqrt{\varphi_{LT}^2-\beta\lambda_{LT}^2}} \leq \begin{cases} 1.0 \\ 1/\lambda_{LT}^2 \end{cases} \quad (24)$$

$$\varphi_{LT} = 0.5\left[1+\alpha_{LT}\left(\lambda_{LT}-\lambda_{LT,0}\right)+B\lambda_{LT}^2\right] \quad (25)$$

$$\lambda_{LT} = \sqrt{\frac{M_P}{M_{cr}}} \quad (26)$$

Where, M_p is the cross section plastic moment and can be determined as:

$$M_p = W_y\, F_y \quad (27)$$

For models investigated in this paper, $\frac{h_w}{b_f} > 2.0$; hence buckling curve (d) is utilized and α_{LT} is an imperfection factor which is considered as 0.76 in this paper. B and $\lambda_{LT,0}$ are parameters depending on the type of beam section and EC-e recommends their values as: B= 0.75 and $\lambda_{LT,0} = 0.4$. The value of warping constant for PCW beam is obtained analytical from Eq. 17 and it can be incorporated into Eq. 18 to calculate the elastic critical moment which in turns can be utilized to evaluate the ultimate moment resistance using Eq. 23. A non-linear finite element analysis is preformed using ABAQUS software [13]. The material properties are Young's modulus $E = 209 \times 103\ N/mm^2$, Poisson's ratio of 0.3, steel grade is S355 which have $F_u=520\ N/mm^2$ and $F_y=355\ N/mm^2$. Non-linearity in material is considered using bi-linear stress strain relationship with tangent modulus equals to 1/50 of the elastic Young's modulus. The initial imperfection was considered based on the mode shape of elastic buckling analysis and scaling it with initial imperfection factor equals to 0.002 of the beam span. The results of M_{Rd}/M_p are plotted against corrugation ratio β using the proposed equation and EC-3 [14]. Fig. 13 shows the results the proposed procedure and it is evident that there is good agreement with non-linear FE results with the proposed procedure always resulting in conservative estimate of the ultimate moment resistance of PCW steel beams.

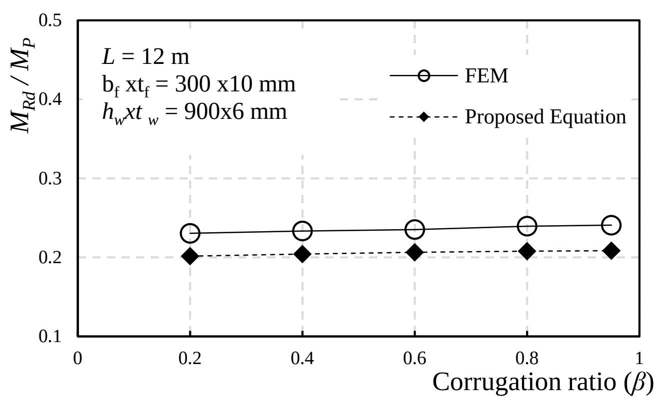

Fig. 13: Ultimate moment resistance of PCW steel beams with different values of corrugation ratios β

5 Conclusion

In this study, the lateral torsional buckling strength of partial corrugated web (PCW) steel beams subjected to uniform pure flexure moment was investigated. An analytical expression is derived for the warping constant of PCW steel beam and it was utilized to calculate the elastic lateral torsional buckling strength. Linear buckling analysis using finite element method (FEM) was performed to validate the proposed formula of the warping constant. A difference not more than 4% was observed between the proposed formula and FEM. A parametric study was conducted to investigate the effect of corrugation angle and the corrugation ratio. It was concluded that the gain in bending strength of PCW is more pronounced in beams with large spans. The increase in LTB strength depends on the corrugation angle and as this angle increases the more increase in the bending strength. The most influential parameter on the bending strength of PCW steel beams was found to be the corrugation ratio. A noticeable increase in the bending strength of PCW is observed at corrugation ratio equals 0.6.

The proposed formula for the elastic critical moment was extended to estimate the ultimate bending strength based on the procedure of Eurocode 3 and the results was compared to non-linear FEM results. A reasonable agreement between the proposed procedure for ultimate bending strength and FEM results was observed with results of the proposed procedure being always on the conservative side.

Finally, it could be concluded that the use of PCW steel beams has some potential application due to the reasonable increase value in the elastic critical moment compared to FW steel beams

6 References

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