American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-10, Issue-01, pp-290-294
www.ajer.org
Research Paper Open Access

Effect of web profile on the behaviour shear strength of plate girders with corrugated web

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ABSTRACT : Corrugations of different shapes such as tapered web, haunches are used to increase the web strength of large steel plate girders, which have many profiles such as trapezoidal, sinusoidal, rectangular, and zigzag. This paper Investigate the behavior and shear strength of corrugated web of plate girders (CWPGs) with different types of web profiles and which profile has maximum strength (optimum design). Verify the results of models built with FE with the test results carried by [15]. The load carrying capacity of plate girder with plain web is studied and compared with the load carrying capacity of beam with trapezoidal and triangular corrugated web having 30, 37 and 45 corrugations.

Keywords: *Shear strength, Plate girder, Web profile, Corrugated web*

Date of Submission: 04-01-2021 Date of acceptance: 19-01-2021

I. INTRODUCTION

The corrugated webs are designed to allow the use of thin plates without stiffeners for use in buildings and bridges. The use of larger thicknesses and stiffeners, which decreased strap weight and cost, could be eliminated. The early work was carried out by Elgaaly [1] and was further developed at a practical stage. Most of these theoretical and experimental work focused on vertically corrugated trapezoidal webs. An experimental and numerical analysis of the lateral-torsional buckling behavior of a plate girder section with a trapezoidal web, found that the steel beam with a trapezoidal corrugated web section has a higher resistance to lateral-torsional folding than that of a plain web section [2]. The efficiency of the corrugated web plate girder was analyzed numerically using ANSYS software and found that the 300 corrugated web plate girder has a higher load-bearing capacity compared to the other corrugated angle [3-4-5]. The lateral-torsional buckling of the hot-rolled steel plate girder with corrugated webs is numerically analyzed using ANSYS. It was concluded that the resistance to lateral torsional buckling is more of a corrugated web beam than a corrugated web beam [6]. Numerical study of the folding resistance of cold-formed steel beams with sinusoidally corrugated webs is studied and found that the folding failure of the web is prevented by corrugation [7]. M.F. Hassanein et al. [8] investigated the behaviour of BGCWs fabricated by HSSs to get benefits from advantages of both the BGCWs and the HSSs in one structure. They studied girders utilized in Pennsylvania demonstration bridge with corrugated web, USA. existing test results in literature. Then, extensive nonlinear parametric studies are generated considering the corrugation dimensions used in the available constructed bridges. that noticed that increasing the web thickness leads to an increase in both the ultimate shear load carried by the girder and the ultimate shear stress carried by the webs. However, this increases in the value of (tw) leads to a significant increase in web's cross-sectional area against a relatively small increase in the ultimate strength. Therefore, using small web thicknesses become more economical than large ones. While increasing the web height increases considerably the value of ultimate shear load, the ultimate shear stress decreases, meaning that the lower the (hw) value, the more efficient the steel material is. The effects of the corrugation depth (hr) and angle (α) were found to be large and a recommendation of using girders with (α) > 30 was suggested to avoid global buckling in the BGCWs formed from the HSSs. The effects of the corrugation parameters were studied by Zhang et al. [9,10] and Li et al. [11] an optimal set of parameters for fully corrugated web beams were developed based on the basic web beam optimization. The corrugated web beam also has been found to be 1.5 – 2 times higher than the web beam in the plane. Chan and et.al [12] studied the corrugated webs of arc corrugation, which the research was based on I-beams with a length of 500 mm, a flanged width of 75 mm and a depth of 127 mm. The webs with one arc and two arcs were examined in the horizontal case while the depth of the corrugated webs was controlled. The main conclusions that can be drawn from this investigation include the vertical corrugation produces higher strength than the horizontal corrugation and the plane web, at an average range of 1.8–2.1. The strength increases as the corrugation radius used increases, and The arc corrugation could be manufactured by hot rolling process, but it is important to mention that, a larger corrugation radius or angle of corrugation, when the vertical corrugated beams are compared to the original I-beams, of the same parameters, it appears that a lighter vertical corrugated beam could carry the same load of the original I-beams with 10.6% reduction in weight. The increase of the corrugation radius for the vertical corrugated webs would further reduce the weight of the beam for the same maximum load when compared to the original I-beam.

II. FINITE ELEMENT MODELING

The literature indicates that several studies in shear behavior and effect of web profile on the shear strength based on the slenderness ratio of the web plate parameter (hw/tw), have addressed their result, which is unable to account for the effect of web plate boundaries in web shear behavior. Accordingly, conducting a comprehensive study that considers the effects of the flange-to-web stiffness ratio, aspect ratio, and non-dimensional web plate slenderness parameter (λ) on the elastic and plastic shear buckling behavior is necessary. So, several FEM models for a thorough parametric study are developed here. Using these models, the effect of the above-mentioned parameters on the elastic shear buckling strength and shear strength of girders are studied. To investigate the research objectives, 200 models including 12 girders with slender, non-compact, and compact webs, along with non-compact and compact flanges were constructed using the FEM software, ANSYS® platform [14]. Shell element 181 with four nodes, each with six degrees of freedom, and a reduced integration scheme was selected. As shown in Fig. 1, Four girders with plain web with span lengths of a =1000 mm, web depth of h_w =1000 mm, and equal flange width of bf=200mm are selected, and four girders with Trapezoidal web with corrugation angle (α=37 and 45°) and four girders with triangular web with angle (α=37 and 45°), 8 models with various values of web and flange thickness are generated. The details and names of the models are presented in Table 2. Selecting a wide range of thickness and slenderness parameters provides the possibility for studying the elastic/plastic buckling behavior of slender and stocky plates.

III. MATERIAL PROPERTIES

The material behavior of the steel is assumed to be elastic-perfectly plastic. The flange material has Young's modulus E of 200GPa, the normal yield stress of 403 MPa, and Poisson's ratio of 0.3. Besides, the web plate material has Young's modulus of 200 GPa, the normal yield stress of 403 MPa, and Poisson's ratio of 0.3. It must be noted that these material properties are selected from test model in Ref. [15].

IV. VERIFICATION OF THE NUMERICAL MODELING PROCESS

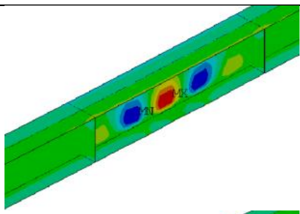
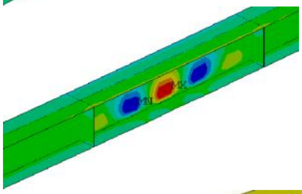
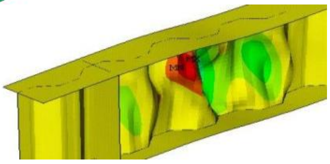
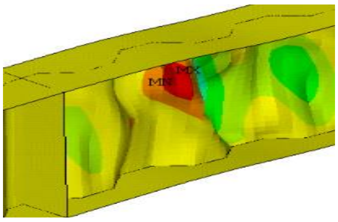
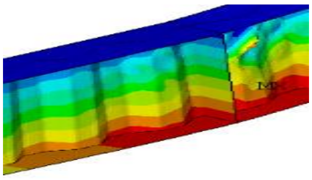
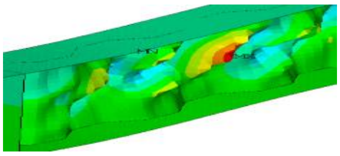
Divahar, et.al [15] conducted an experimental study of six cold-formed steel beams with plain webs and corrugated webs were tested. The load carrying capacity of cold-formed steel beam with plain web is studied and compared with the load carrying capacity of beam with trapezoidal corrugated web having 30° and 45° corrugations. The specimens were tested under two-point loading for its pure flexural behaviour. From the study, it is found that the cold-formed steel beam with trapezoidal corrugated web having 30° corrugation has higher load carrying capacity compared to the beams having plain web and 45° corrugated web.

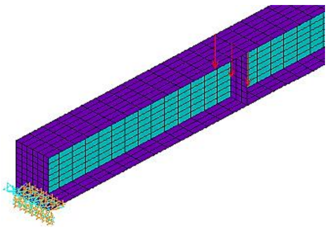
All the geometric and material properties, as well as the support and loading conditions of the aforementioned experiment, are available in Refs. [15]. In this study, to evaluate the proposed simulation technique, the six test models are selected and the results obtained from numerical analysis are compared with those of experiments.

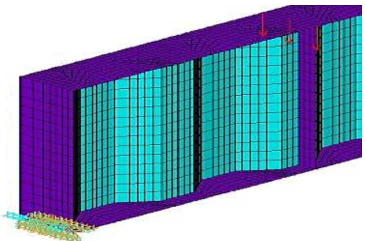
Parametric Study

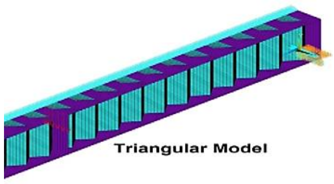
To investigate the effect of the different properties of the cross-section on calculating the critical load of the plate girder a large number of numerical analyses have been carried out on several combinations of three key geometric variables, $\frac{a_w}{h_w}$, $\frac{h_w}{t_w}$ and $\frac{t_f}{t_w}$,. The ranges of parameters examined in this study are listed in Table (2):

Table (1): Comparison between the presented FE model, theoretical analysis, and the tested model presented by Divahar, et.al [15].

Plate model	The presented FE model The elastic buckling shapes	V_{FE} (KN)	The tested model presented by Divahar, Et.al [15] The failure tested shape	$V_{Divahar[15]}$ (KN)	$\frac{V_{,FE}}{V_{Lee,Test96}}$
PWB 0°,150-1		35.1		37.15	0.95
PWB 0°,150-2		35.1		37.15	0.95
CWB 30°,150-1		44.9		46.55	0.96
CWB 30°,150-2		44.8		46.55	0.96
CWB 45°,150-1		46.68		45.55	1.02
CWB 45°,150-2		46.25		45.55	1.01







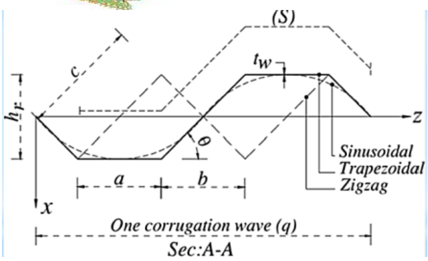


Fig. (2): FE model of flat web under shear and edge restraints.

Table:(2): Classification of Plate girder Models

Model	a_w	h_w (mm)	t_w (mm)	α	b or i	d (mm)	h_r (mm)	b_f (mm)	t_f (mm)	h_w/t_w	$\emptyset = a_w/h_w$	t_f/t_w
PLw1			4	0	-	-	-	200	20	250		5
PLw2	1000	1000		0	-	-	--	200			1	5
PLw3			5	0	-	-	-	200	20	200		4
PLw4				0	-	-	-	200				4
TZPW1				37	150	120	90	200				4
TZPW2	1000	1000	4	37	150	120	90	200	20	250	1	4
TZPW3				45	150	106.1	106.1	200				4
TZPW4				45	150	106.1	106.1	200				5
TRPW1				37	150	120	90	200				5
TRPW2	1000	1000	4	37	150	120	90	200	20	250	1	5
TRPW3				45	150	106.1	106.1	200				5
TRPW4				45	150	106.1	106.1	200				5

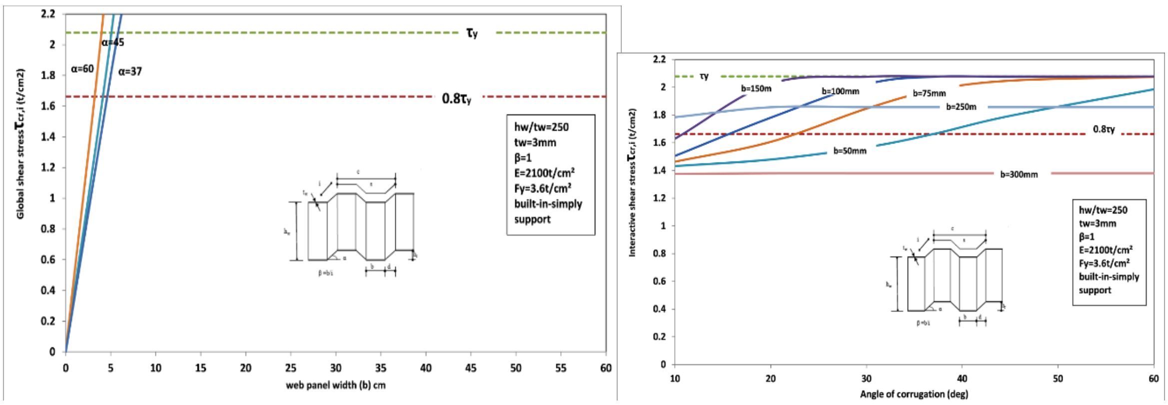


Fig (3): Effect of angle of corrugation (α) on interactive shear buckling modes for trapezoidal corrugated web.

V. RESULTS AND DISCUSSION

the effect of corrugation angle on failure criteria of corrugated webs can be explained as follows:

1. Effect on global buckling mode: Corrugation angle have a clear effect in case of small web panel width (b≤150mm). While for values of (b> 150mm) there isn't any effect on global buckling.
2. Effect on local buckling mode: Corrugation angle hasn't any effect on local shear buckling mode, the curve of local buckling appears as horizontal line [for b=250, 300mm, tw =3mm and hw/tw =400, 250].
3. Effect on interactive buckling mode: It affects the interactive buckling mode in case of small panel width (b< 150 mm), where the behavior of the corrugated web is governed by either pure global buckling or interaction between global buckling and shear yield criterion. This effect was clearly for small values of panel width (global zone effect), but for larger values of panel width (b ≥150) this effect disappeared and interactive buckling curves become one curve for all values of α considered. When (α > 60) there was a negligible effect on the interactive buckling, the curves became horizontal lines for values of (b ≥100mm). When α > 30 and small values of b (b<100mm) there is a small effect or nearly no effect on the interactive buckling, the curve approach horizontal line. When α < 30 there was a significant effect on the interactive buckling for all values of panel width considered.
4. the effect of corrugation angle on interactive, and global buckling modes for different web thicknesses and under the case of study (hw/tw=250), (b=5, 7.5, 10, 15, and 30cm), it was cleared that the corrugation angle has a clear effect on interactive, and global buckling modes for different thicknesses and; for the considered panel widths, this is true(in global buckling zone) until local buckling effect appeared (failure occurred by local buckling), in this case where local buckling is critical.
5. for case of (b=150cm, tw=3mm and hw=1200mm) corrugation angle hasn't any effect in interactive buckling mode, the curve of the interactive buckling appears as horizontal line. It is clear that the increase in angle of corrugation leads to an increase of the interactive buckling stress up to an angle

near 45 degree, in case of large value of angle α ≥45 there is no effect in interactive buckling; the curves become one horizontal line.

6. that the increases of web panel width require a decrease in the angle of corrugation with constant web thickness to achieve economic and safe section. Also, it is clear that in case of the angle is less than 10 degree the interactive buckling stress values are small and not economic. the corrugation angle effect on the panel width for 3 web thickness of trapezoidal corrugation with hw/tw ratio=250, 400 and 500. It is clear from this figure that the corrugation angle has a clear effect on web panel width in case of small angle of corrugation (α<45 degree) while in case of larger values of angle (α >45 degree) there isn't any effect. So, for practical application it was recommended that the value of corrugation angle doesn't exceed than 45, and doesn't less than 10 degree for economic and safe choice.

VI. CONCLUSION

These resulting data lead to the following conclusions:

1- The angle of corrugation (α) hasn't any effect on local shear buckling mode. It affects global buckling mode, and also affects interactive buckling mode in case of small panel widths (b). It is recommended for practical applications that the best value of corrugation angle ranged between (10 - 45) degrees to fulfil economic sections.

2- The average load carrying capacity of plate girder with 30° corrugated webs increases by 25% than the beam with plain web. But there is only a marginal increase in load carrying capacity of beam with 30^0 corrugated webs than that of beam with 45^0corrugated web.

3- Beams with plain web showed shear buckling of web, but the failure due to shear in web could be eliminated by using corrugated web.

4- The strain in the beams with corrugated web is more than that of the beams with plain web.

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