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Numerical study on the performance of corrugated steel shear walls

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Abstract. This paper examines the nonlinear behaviour of corrugated steel plate shear walls under lateral pushover load. One of the innovations in these types of walls which have used in recent years is the use of the corrugated steel shear walls rather un-stiffness plates. In the last decades many experimental studies have been done on the on the corrugated steel shear walls. A finite element analysis that includes both material and geometric nonlinearities is employed for the investigation. A comparison is made between the behaviour of steel shear walls with sinusoidal corrugated plate and trapezoidal corrugated plate. The effects of parameters such as the thickness of the corrugated plate, the corrugation depth in the corrugated plates and the corrugation length of the infill of the corrugated plates, are investigated. The results of this study have demonstrated that in the wall with constant dimensions, the trapezoidal plates have higher energy dissipation, ductility and ultimate bearing than sinusoidal waves, while decreasing the steel material consumption.

Keywords: steel shear wall; sinusoidal corrugated plate; trapezoidal corrugated plate; energy dissipation; ductility; ultimate bearing

1. Introduction

Experimental and numerical studies conducted in the past three decades have demonstrated that a steel plate shear wall is an effective and economical lateral load resisting system against both wind and earthquake forces. In recent years, it has been demonstrated that steel plate shear walls can act as an effective and economical lateral bracing system. In particular, steel plate shear walls will respond to seismically-induced loading with a high degree of stiffness, stable load versus deflection behavior, and a capacity for significant energy dissipation

A steel plate shear wall is consisted of steel in-fill plates bounded by column-beam system. When these in-fill plates occupy each level within a framed bay of a structure, they constitute a steel plate shear wall. Steel plate shear walls are well-suited for new construction and are also a relatively simple means for the seismic upgrading of existing structures. Both steel and concrete

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frame buildings can be upgraded with steel plate shear panels.(Astaneh-Asl 2001, Behbahanifard 2003).

This system with its thin plate shows a good strength against lateral loads imposed on the structure using its own post-buckling behavior. The efficiency of shear walls in resisting lateral forces induced by earthquakes or wind in multi-storey buildings has long been recognized. They are often used in multi-storey buildings if other structural elements such as moment-resisting frames are insufficient to resist the lateral forces.The benefits of this system include high ultimate bearing, perfect plasticity, high energy absorption capacity, appropriate stiffness, reduced structural weight, lower foundation construction costs, better quality and high-speed construction. A properly designed steel plate shear wall has superior ductility, high initial stiffness, stable hysteresis loops, and good energy absorption capacity (Berman *et al*. 2003).

The infill plates can be stiffened or unstiffened and the beam-to-column connections can be rigid or shear connections. In unstiffened walls, a series of flat plates with light thickness is used for utilizing the post-buckling field under overall buckling. In the second type of wall, a belt series or steel profiles are utilized as stiffeners with different arrangements – horizontal, vertical and diagonal – on one side or both sides of the wall until the energy dissipation, stiffness and ultimate bearing are increased.

The performance of steel shear walls is similar to that of the plate girder, the plates, columns and beams are the same as its webs, flanges and stiffeners, respectively (Breman *et al*. 2005, Driver 1998, Sabouri-Ghomi *et al*. 2008). Investigations into stiffened and unstiffened steel shear walls and more experimental and theoretical works have been carried out by many researchers. Some researcher that have studied in this field: analytically, experimentally and numerically (Breman 2001, Bruneau 2002, Formisano *et al*. 2006, De Matteis *et al*. 2008, Bhowmick *et al*. 2011, Chen *et al*. 2011, Choi *et al*. 2010 and Clayton *et al*. 2011, Bayat *et al*,. 2014).

Corrugated steel plates, due to their ductility and low cost, are an appropriate alternative system in these walls. On the other hand, in corrugate plates, the plate's wave function is similar to that of the stiffeners and it has appropriate stiffness too. The investigations of steel shear walls with corrugated plates are limited and more activities in this field have been done on the plate girder system. In the plate girder system, the plates are used vertically in a web. The investigations of plate girders with corrugated steel plates as a web are limited to the laboratory activities of, (Elgaaly *et al*. 1996, 1997, Usman 2001, Wang 2003, Gentilinia *et al*. 2008, Kovesdi 2010, Tanaka *et al*. 2008, Sause *et al*. 2008). Laboratory research on the steel frame with the corrugated plate is limited to the work of, (Chosa 2006, Stojadinovic *et al.* 2007), who have studied the experimental and numerical aspects of the shear steel panels with corrugated trapezoid-shaped plates under cyclic and uniform loads.

All of the above researches on steel shear walls with corrugated plates have been experimental and have examined only the overall behaviour of the walls under uniformly and cyclic lateral loading, indicating in the end the advantages of this system. According to experimental activities and the outcomes of these types of studies, the investigation has been limited to negligible components of these systems, neglecting different aspects of the corrugated plate, such as the effect of plate thickness on the walls, the effect of the height and length of the plate's wave, and other parameters on the behaviour of these walls. Hence, in this paper these parameters have been studied.

2. Failure modes of corrugated plates

Primarily, the infill plates provide the shear capacity of the frame. The control of the structure's shear strength by the steel plates comes through buckling of the plate or through it failure. Pure shear stress is the only significant stress in these structural components. In corrugated plates, the yield shear stress can be determined with Eq. (1) (Sayed-Ahmed 2005, 2007, Kiymaz *et al*. 2010)

$$\tau_y = \frac{F_y}{\sqrt{3}} \tag{1}$$

Where F_y is the yielding strength of steel.

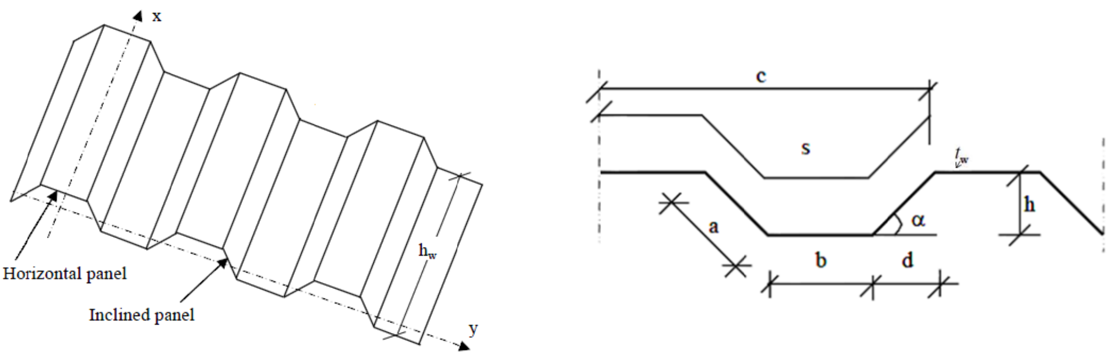


Fig. 1 Geometric properties of trapezoidal corrugated plate

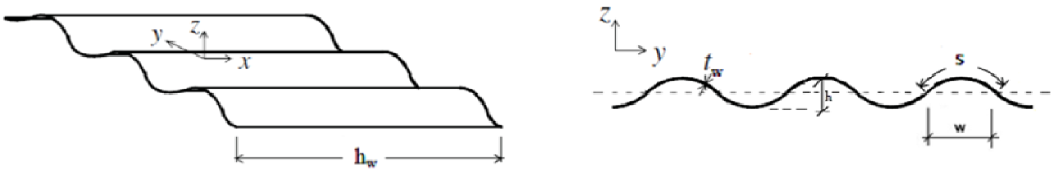


Fig. 2 Geometric properties of sinusoidal corrugated plate

Buckling control of corrugated plates is performed by overall and local buckling. The local buckling mode of the corrugated plates is formed in flat panels of the trapezoidal corrugated plates, primarily, and along the horizontal edge, as shown in Fig. 4. In this span, corrugated plates are connected to the short edges of column flange. In these conditions, the local buckling is studied in isotropic plates and the elastic critical shear stress for the local buckling mode is defined by Eq. (2) for trapezoidal and sinusoidal plates (Sayed-Ahmed 2001, 2007, Kiymaz *et al*. 2010):

$$\tau_{cr,l} = k_s \frac{\pi^2.E}{12\left(1-\nu^2\right)}.\left(\frac{t_w}{b}\right)^2 \qquad \text{Trapezoidal} \tag{2}$$

$$\tau_{cr,l} = k_s \frac{\pi^2.E}{12\left(1-\nu^2\right)}.\frac{2t_w}{s} \qquad \text{Sinusoidal} \tag{3}$$

where t_w is the corrugated plates' thickness, b is length of wave in the trapezoidal corrugated plate in which the local buckling occurs, s is the actual length of the corrugate in the plate with a sinusoidal corrugated plate, E is the modulus of elasticity, ν is the Poisson ratio of steel and k_s is the shear buckling coefficient in the local buckling mode, the value of which is dependent on boundary conditions and the panel's aspect ratio (b/h_w), such that h_w is the height of the plate. This coefficient for trapezoidal corrugated plates is defined by Eq. (4) (Galambos 1998, Sayed-Ahmed, 2005).

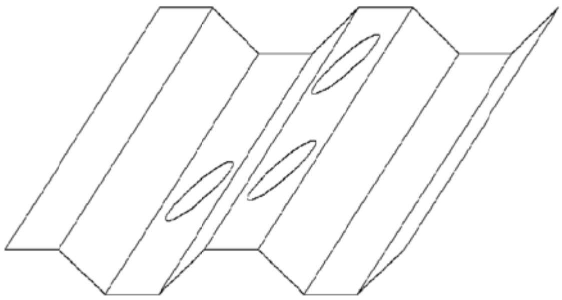


Fig. 3 The local buckling form in corrugates of plate

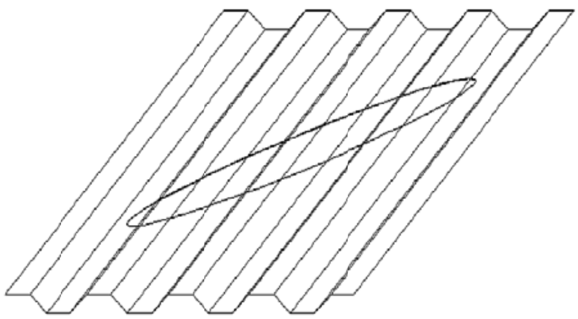


Fig. 4 Global buckling on trapezoidal corrugated plate

$$k_s = 5.34 + 4.0\left(\frac{b}{h_w}\right) \tag{4a}$$

$$k_s = 5.34 + 2.31\left(\frac{b}{h_w}\right) - 3.44\left(\frac{b}{h_w}\right)^2 + 8.39\left(\frac{b}{h_w}\right)^3 \tag{4b}$$

$$k_s = 8.98 + 5.60\left(\frac{b}{h_w}\right)^2 \tag{4c}$$

Eq. (4(a)) is used when the plate boundary conditions are simple, such as for corrugated plates that are in the web of the plate girder, while Eq. (4(b)) is used for the longer edges that are simply supported with the shorted edges clamped; Eq. (4(c)) is used when all edges are clamped. The sample of clamped boundary conditions on the short edge of the plate's corrugate is used in the composite beam, with a web of corrugated plates and concrete flanges. This system is usually used in bridge construction.

In Eq. (2), if the inclined width of the corrugated plate a is larger than the horizontal panel width of the inside trapezoidal plate *b*, it should be considered as the critical width, in which case the inclined width of the plate is the critical zone of its local buckling mode

$$k_s = 5.34 + \frac{s.h}{2h_w t_w} \qquad \text{Sinusoidal} \tag{5}$$

Where *h* is the height of sinusoidal waves.

According to the stated conditions, if $\tau_l \geq 0.8\tau_y$ then inelastic local buckling will occur on the plate; therefore, inelastic buckling stress is defined by (Galambos 1998)

$$\tau_{l,i} = \sqrt{0.8\tau_l \tau_y} \tag{6}$$

In the equation above, τ_l is shear stress due to local buckling and $\tau_{l,i}$ is shear stress due to inelastic local buckling on the corrugated plate.

According to Fig. 5, the global buckling is formed with global diagonal buckling of the multi-waves in the corrugated plate. In this case, the critical shear stress is estimated with respect to the corrugated plate as an orthotropic plate. The critical shear stress of this mode is defined by (Sayed-Ahmed 2005, 2007, Kiymaz *et al*. 2010)

$$\tau_{cr,g} = k_g \frac{(D_y.D_x{}^3)^{1/4}}{h_w{}^2.t_w} \qquad \text{Trapezoidal} \tag{7}$$

$$\tau_{cr,g} = k_g \frac{(D_x.D_y{}^3)^{1/4}}{h_w{}^2.t_w} \qquad \text{Sinusoidal} \tag{8}$$

Where k_g is the global buckling coefficient, which is a function of the panel aspect ratio and the boundary conditions. In a trapezoidal corrugated plate, it is 36 when the longer edges are simply supported and the shorted edges are clamped, such as in the web plate on a plate girder. It is 68.4 for plates where all the edges are clamped, such as in the web plate on a composite beam. In a sinusoidal corrugated plate, k_g is 32.4 for simply supported and 60.4 for clamped boundary conditions. The factors D_x and D_y are plate rigidities in the longitudinal, *x*, and traverse, *y*, direction that are given as

$$D_y = \frac{Et_w^{\ 3}}{12\left(1-\nu^2\right)} \cdot \frac{b+d}{b+a} \qquad \text{Trapezoidal} \tag{9}$$

$$D_x = \frac{Et_w . h^2}{12} \cdot \frac{3b+a}{b+d} \tag{10}$$

$$D_y = \frac{Et_w^{\ 3}}{12(1-\nu^2)} \cdot \frac{w}{s} \qquad \text{Sinusoidal} \tag{11}$$

$$D_x = \frac{EI_x}{w} \tag{12}$$

where *a* is the inclined panel width in the trapezoidal plate, *d* is the horizontal projection of the inclined panel width, *w* is the horizontal projection of the one wave on the sinusoidal plate and I_y is the second moment of the area of one wave length of the web, which has a projected length as defined by (Szilard *et al*. 2004)

$$I_y = \frac{h^2 t_w}{8}\left[1 - \frac{0.81}{1+2.5\left(h/4w\right)^2}\right] \tag{13}$$

If $\tau_g \geq 0.8\tau_y$, then inelastic buckling will happen on the plate and the inelastic critical shear stress for the global buckling mode will be as given by (Galambos 1998).

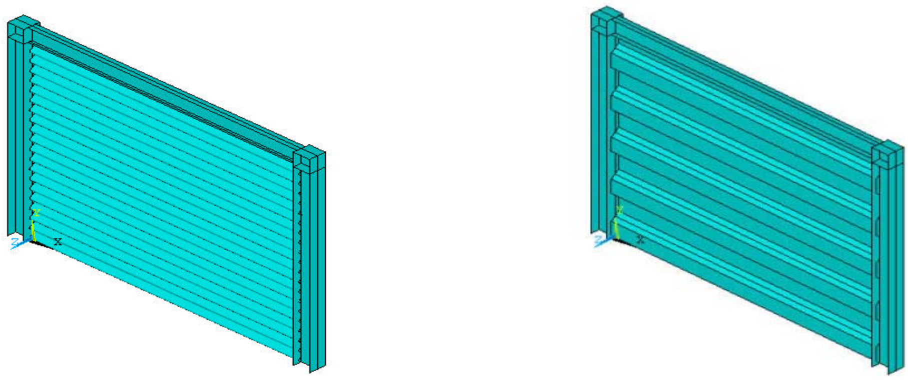
$$\tau_{I,g} = \sqrt{0.8\tau_g \tau_y} \tag{14}$$

In the equation above, τ_g is shear stress due to global buckling and $\tau_{g,i}$ is shear stress due to inelastic global buckling in the corrugated plate.

Elgaaly (1996) in his laboratory research on the trapezoidal corrugated plates has shown that if the waves of the corrugated plate are large then the local buckling can form in the horizontal portion of each corrugated plate; however, if the lengths of waves are small then the global buckling can form in the plate without control.

However, these equations above were used on a plate girder with trapezoidal and sinusoidal waves. Therefore, this paper refers to the comparison of results obtained by the finite element method.

3. Numerical Modeling and analyses of steel shear wall



(a) (b)

Fig. 5 the schematic corrugated steel shear wall with a) sinusoidal and b) trapezoidal waves

The numerical analyses were performed on one-storey and one-span wall of 3000 mm width and 2600 mm height. The boundary element was IPB180 for columns and IPE180 for beams. The infill plate used in this wall was a sinusoidal and trapezoidal corrugated plate, rigidly connected to the surrounding frame. The geometry and meshing configurations of these walls are shown in Fig. 5. The walls were supported by clamps on the bottom of the wall, giving simple support in the out-of-plane direction for the prevention of out-of-plane displacement all around the frame. In these models, an elastic-plastic material model was assumed with a yield strength value of 240 Mpa, a modulus of elasticity of 200 Gpa, a Poisson ratio of 0.3 and a tangent modulus of 3% of the modulus of elasticity. Additionally, geometric nonlinearity was used because of the large displacement.

4. Evaluation of the parametric study results

In this part, the results of the effects of some geometric properties, such as thickness of plate, depth or wave height of plate, length of wave, corrugated density and stiffness of beam and column, on corrugated steel walls were investigated. The results of these parameters are presented in detail.

4.1 The thickness effect of the corrugated plate

The thicknesses that are considered for the study of the effect of thickness on sinusoidal and trapezoidal corrugated plate are 1.5, 3, 5, 10, 15 and 20 mm. In these models, the columns and beams were considered to be IPB180 and IPE 180. The geometric properties of the applied plates are demonstrated in Figs. 2 and 3 and tables 1 and 2. In these tables, w is the horizontal projection of the single wave on the sinusoidal plate, b is the horizontal panel width in the trapezoidal plate, h is the corrugation magnitude, t_w is the plate thickness, s is the unfolded length of one corrugation in the sinusoidal plate, *a* is the inclined panel width in trapezoidal plate, *d* is the horizontal projection of the inclined panel width, *c* is the horizontal projection of one wave on the trapezoidal plate, α is the corrugation angle in the trapezoidal plate and *h/2w* and *h/c* coefficients are the corrugation density in the corrugated plates.

Table 1 Geometrical dimensions of sinusoidal plate

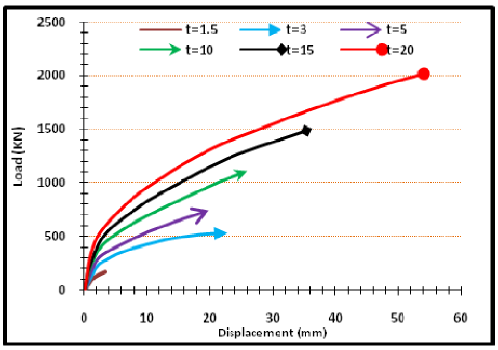
h/2w	*h*	*w*
0.16	19	60

Table 2 Geometrical dimensions of trapezoidal plate

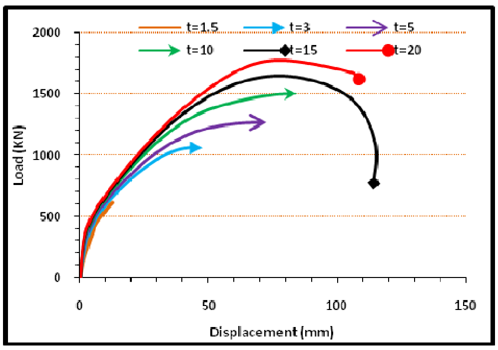
h/c	α	*d*	*a*	*h*	*b*
0.16	45	80	113	80	170

According to the results shown in Figs. 6 and 7 for sinusoidal and trapezoidal corrugated plates with six different thicknesses, the ultimate bearing capacity and energy dissipation are increased with increasing the thickness. Also, in these walls, out-of-plane deformation of the wall progresses to a plastic hinge formation in nearly all beam-to-column connections when the plate thickness increases. It is necessary to explain that the results of the increase of thickness on ultimate bearing were predictable and demonstrate the accuracy of the software's performance.

With compression, the load-displacement and energy-displacement curves in sinusoidal and trapezoidal steel corrugated plates, assuming that corrugation density is equal to 0.16 for both plates, show that corrugated plate with a trapezoidal wave has more ductility than that with a sinusoidal wave. According to the results, it therefore has higher energy dissipation. In both walls, if the plate has less thickness, then the trapezoidal plate has better performance in ultimate bearing and energy dissipation, but with high thickness of plate, the sinusoidal plate has more ultimate bearing. The sinusoidal plates yield under buckling and the trapezoidal plates yield under the plastic hinge formation on the beam.

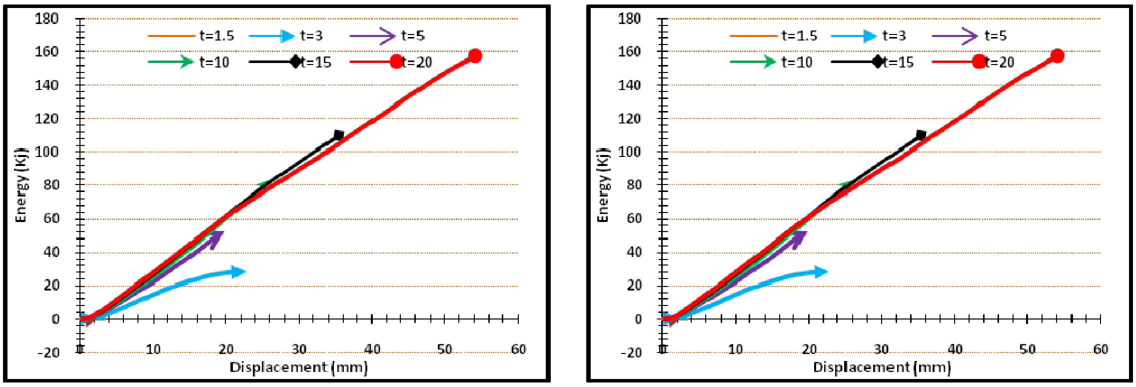


(a)



(b)

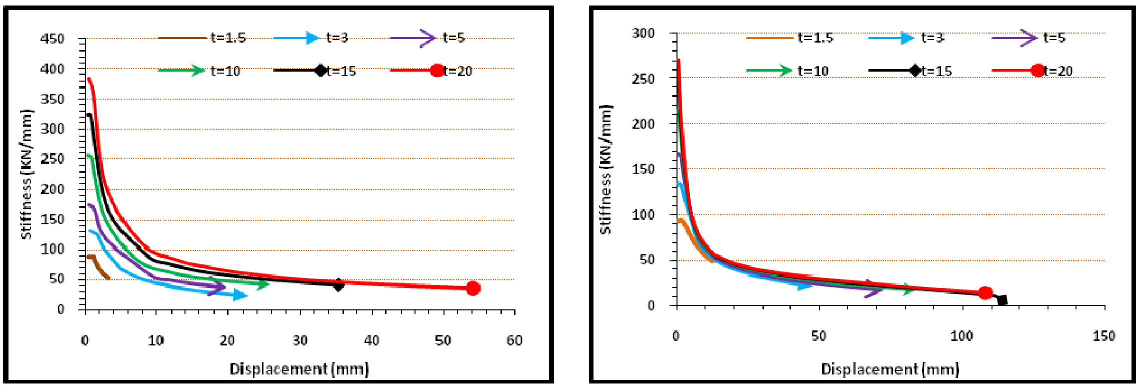
Fig. 6 Load- displacement curves of (a) sinusoidal (b) trapezoidal corrugated plates with different thickness



(a) (b)

Fig. 7 Energy- displacement curves of (a) sinusoidal (b) trapezoidal corrugated plates with different thickness

The stiffness performance of the one-storey steel shear wall system with sinusoidal and trapezoidal corrugated plate under in-plane load is shown in Fig. 8. These diagrams show that with increases in the plate's thickness, stiffness is increased in the elastic and post-elastic range. Also, the stiffness of all models is gradually decreased without any abrupt change, even at the onset of shear buckling. As shown in Fig. 8, with increased plate thickness, the sinusoidal corrugation plate has more stiffness than the trapezoidal corrugated plates. Also, the stiffness drop slope is greater in trapezoidal plates.



(a) (b)

Fig. 8 performance of stiffness in (a) sinusoidal (b) trapezoidal corrugated plates with different thickness

4.2 Corrugation depth effect in corrugated plates

The corrugation depth is one of the parameters that increased the lateral stiffness of the corrugated plates. In this part, the effect of corrugation depth is studied on steel shear wall behaviour with sinusoidal and trapezoidal corrugation. To study the effect of corrugation depth on sinusoidal corrugated plates, six specimens with different corrugation depth of 19, 30, 40, 50, 56 and 60 mm are used. The geometric characteristics of these plates are shown in Table 3.

To study the effect of the corrugation depth in trapezoidal corrugated plates, five specimens and their characteristics are demonstrated in Table 4.

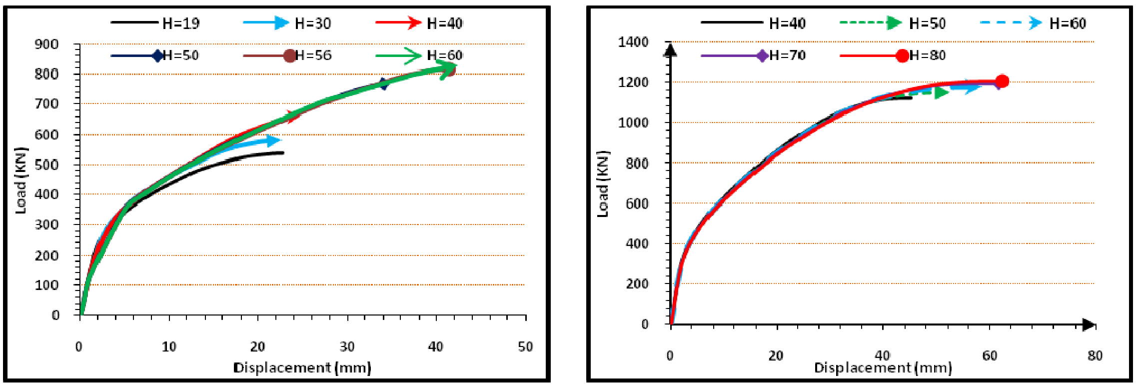
The results of these specimens under in-plane loading are shown in Figs. 9 and 10. These results demonstrate that with an increase in the corrugation depth, the ultimate bearing, energy dissipation and ductility in the sinusoidal and trapezoidal plate increased significantly. In addition, the energy dissipation shows an increasing trend. The results show that ductility is increased with increasing corrugation depth. The stiffness of wall is uniform; its approximate performance is shown in Fig. 11. According to this figure, the stiffness decrease is a result of increased ductility.

Table 3 Geometrical characteristic of sinusoidal plates with different corrugation depth (mm)

h	t_w	*w*
19, 30, 40, 50, 56, 60	3	60

Table 4 Geometrical characteristic of trapezoidal plates with different corrugation depth (mm)

d	*a*	t_w	*h*	*b*
40, 50, 60, 70, 80	113	3	80	170



(a) (b)

Fig. 9 Load- displacement curves of (a)sinusoidal (b) trapezoidal corrugated plates with different corrugation depth

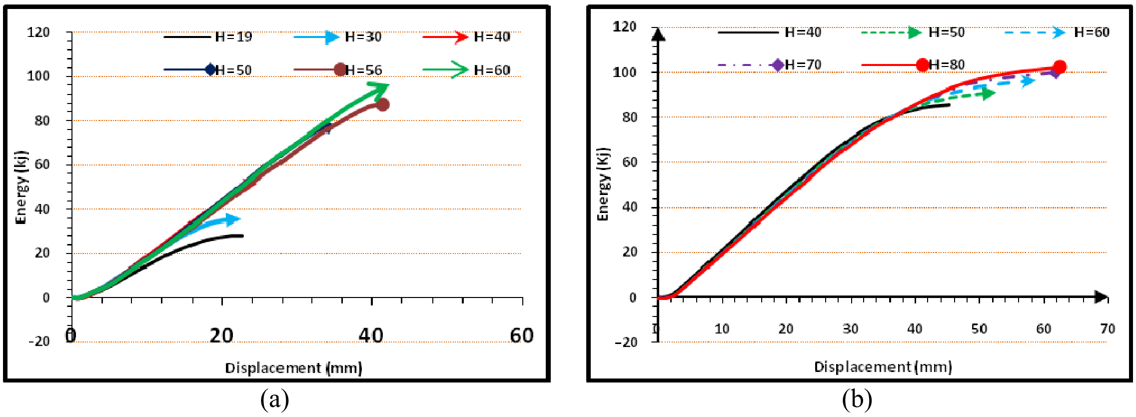


Fig. 10 Energy- displacement curves of (a)sinusoidal (b) trapezoidal corrugated plates with different corrugation depth

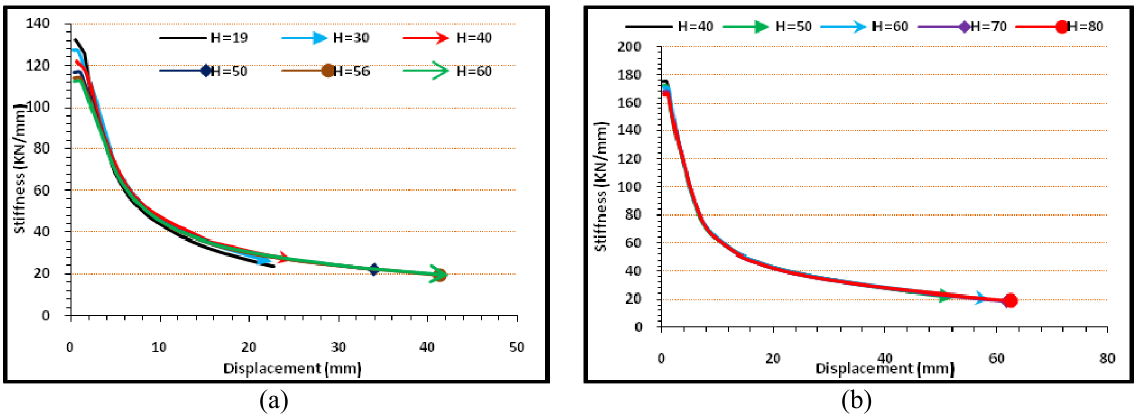


Fig. 11 Performance of stiffness curves (a) sinusoidal (b) trapezoidal corrugated plates with different corrugation depth

4.3 The Corrugation length effect of infill corrugated plates

In this part, seven specimens of sinusoidal and four specimens of trapezoidal corrugated plate were used for studying corrugation length. The geometric characteristics of these models are shown in Tables 5 and 6, where L is the corrugation length equal to w in sinusoidal plates and equal to $d+b$ in trapezoidal corrugated plates.

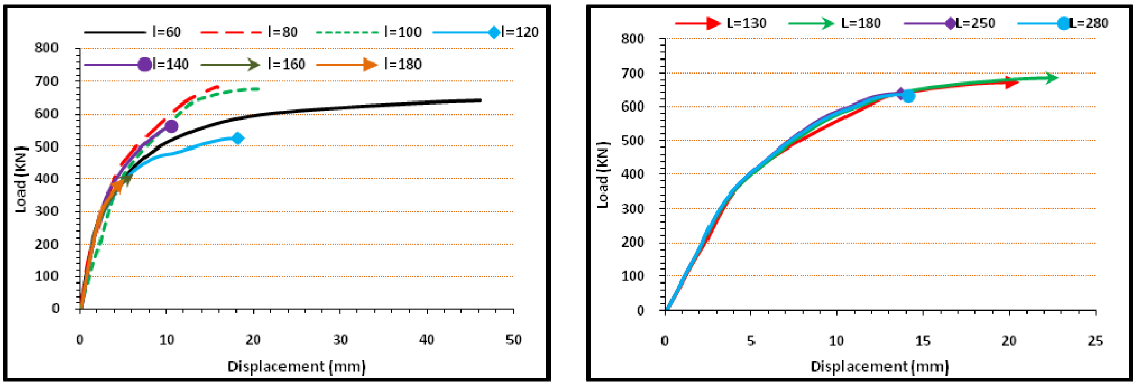
Table 5 Geometrical characteristic of sinusoidal plates with different corrugation length (mm)

h	t_w	$L=l$
19	3	60, 8, 100, 120, 140, 160, 180

Table 6 Geometrical characteristic of trapezoidal plates with different corrugation length (mm)

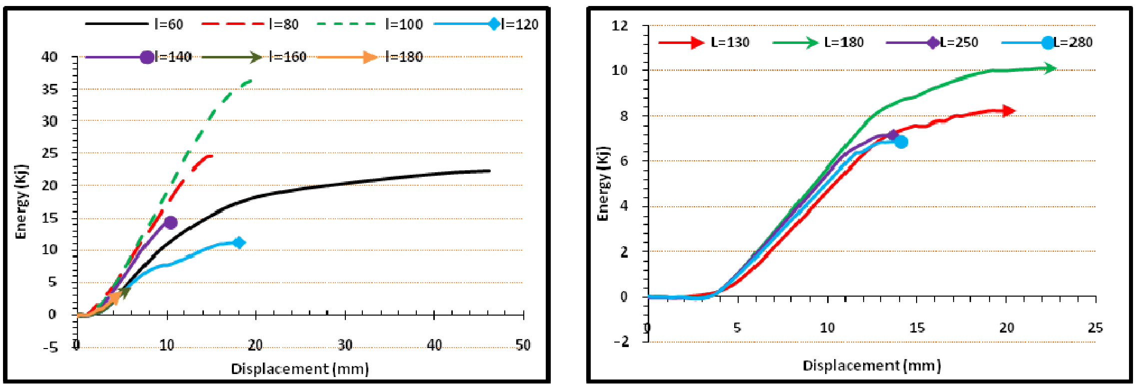
h	t_w	L
80	3	130, 180, 250, 280

Figs. 12(a), 13(a) and 14(a) show that for sinusoidal corrugated plates the ultimate bearing and energy dissipation of the wall decreased with increases in the corrugation length and the walls lost bearing due to global buckling failure. The stiffness performance of sinusoidal corrugated plate shows that the initial stiffness did not change with increased corrugation length, but the ductility of wall changed considerably.



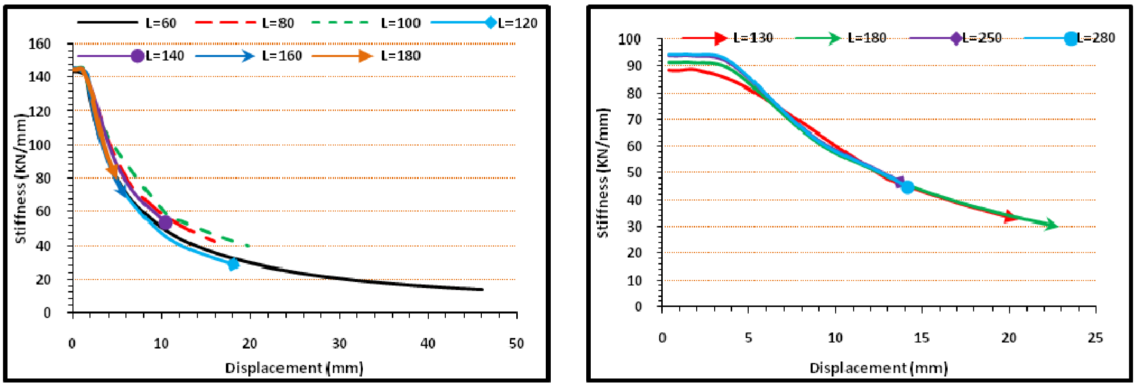
(a) (b)

Fig. 12 Load- displacement curves of (a) sinusoidal (b) trapezoidal corrugated plates with different corrugation length



(a) (b)

Fig. 13 Energy- displacement curves of (a) sinusoidal (b) trapezoidal corrugated plates with different corrugation length



(a) (b)

Fig. 14 Performance of stiffness curves of (a) sinusoidal (b) trapezoidal corrugated plates with different corrugation length

In Fig. 12(b), studies of four specimens with trapezoidal corrugated plate show that the ultimate bearing and ductility decreased with increased corrugation length of the plate. Fig. 13(b) shows that energy dissipation decreased with increased corrugation length of plate. According to Fig. 14(b), the stiffness performance increased with increased corrugation length of trapezoidal corrugated plate, but the process of losing stiffness is shorter, as is the deformation of wall. This was due to energy dissipation decreasing.

Table 7 Comparison of various factors of sinusoidal and trapezoidal corrugated plates

	Ultimate bearing (KN)		Energy dissipation (KJ)		Stiffness (KN/mm)		Ductility	
thickness	sinusoidal	trapezoidal	sinusoidal	trapezoidal	sinusoidal	trapezoidal	sinusoidal	trapezoidal
3	387.09	474.48	3.095	7.97	145.21	144	1.97	2.14
5	828.66	876.69	41.3	51.95	184.92	182.52	4.88	5.03
8	1114.64	1229.8	81.89	115.03	227.94	224.22	6.27	7.98
10	1323.76	1368.54	117.94	144.43	250.8	246.47	8.43	9.21
12	1548.32	1545.66	162.51	186	270.68	265.87	9.68	12.83
15	1749.64	1790.12	208.32	249.53	296.5	291.17	11.5	13.22

4.4 Comparison behavior of corrugated plates with similar corrugation density

Based on the results of of various factors on steel shear wall behaviour with sinusoidal and trapezoidal corrugated plates, in this part, the behaviour of two types of plate with similar depth, length and corrugation density have been compared. Sinusoidal and trapezoidal corrugated plates with different thickness of 3, 5, 8, 10, 12 and 15 mm were used for this comparison. The results for the uniform load for these specimens are shown in Table 7.

These results demonstrate that for plates with similar weight and geometric characteristics, the ultimate bearing, energy dissipation and ductility show an increasing trend with increasing plate thickness. However, comparing these plates shows that the trapezoidal corrugated plate has better behaviour as demonstrated through better ultimate bearing, ductility and energy dissipation values. Furthermore, the sinusoidal corrugated plate has slightly more stiffness than the trapezoidal corrugated plate.

5. Conclusions

In this paper, an investigation into the geometric characteristics of sinusoidal and trapezoidal corrugated one-storey steel shear wall when subject to uniform lateral load was carried out. The following results were obtained:

1. With increasing corrugated plate thickness in steel shear walls, the ultimate bearing, ductility and energy dissipation increase significantly. The results obtained for sinusoidal and trapezoidal types of corrugated plates with similar corrugation depths show that increasing the plate thickness in sinusoidal plates produces greater stiffness and ultimate bearing compared to trapezoidal plates, but the ductility of trapezoidal plate increased with thickness changes.
2. The other parameter investigated in this paper was the corrugated depth. The corrugated depth has greater effects on stiffness, ultimate bearing and energy dissipation of the sinusoidal plates compared to the trapezoidal corrugated plates.
3. The study of corrugation length in the corrugated plates shows that the ultimate bearing is decreased with increases in the corrugation length, but also that length has no effect on the stiffness of the sinusoidal plate. However, the stiffness of the trapezoidal plate increases with increased corrugated length and the ductility is decreased.
4. The comparison of the results obtained for sinusoidal and trapezoidal corrugated plate show that the trapezoidal corrugated plates have better performance and are the corrugated plate needed for steel shear walls with specific weight, thickness, corrugation depth and length, and will ensure better ultimate bearing, energy dissipation, ductility and stiffness.

References

Astaneh-Asl, A. (2001), *Seismic behavior and design of steel shear walls* , Steel TIPS Report

Bayat, M., Pakar, I. and Cveticanin, L. (2014), "Nonlinear free vibration of systems with inertia and static type cubic nonlinearities : an analytical approach", *Mech. Mach.Theory* , **77**, 50-58.

Behbahanifard, M.R., Grondin, G.Y. and Elwi, A,E. (2003), *Experimental and numerical investigation of steel plate shear walls*, Structural engineering report No. 254. Edmonton (Canada): Department of Civil and Environmental Engineering, University of Alberta.

Berman, J. and Bruneau, M. (2003), "Plastic analysis and design of steel plate shear walls", *J. Struct. Eng*. -

ASCE, **129**(11),1448–1456.
Berman, J.W. (2011), “Seismic behavior of code designed steel plate shear walls”, *Eng. Struct*., **33**(1), 230-244.
Berman, J.W. and Bruneau, M. (2005), “Experimental investigation of light-gauge steel plate shear walls”, *J. Struct. Eng. - ASCE*, **131**(2), 259-267.
Bhowmick, A.K., Grondin, G.Y. and Driver, R.G. (2011), “Estimating fundamental periods of steel plate shear walls”, *Eng. Struct*., **33**(6), 1883-1893.
Bruneau, M. and Bhagwagar, T. (2002), “Seismic retrofit of flexible steel frames using thin infill panels”, *Eng. Struct*., **24**(4), 443-453.
Chen, S.J. and Jhang, C. (2011), “Experimental study of low-yield-point steel plate shear wall under in-plane load”, *J. Constr. Steel Res*., **67**(6), 977-985.
Choi, I.R. and Park, H.G. (2010), “Hysteresis model of thin infill plate for cyclic nonlinear analysis of steel plate shear walls”, *J. Struct. Eng. - ASCE*, **136**(11), 1423-1434.
Chosa, K., Kashiwai, Y., Kono, S. and Watanabe, F. (2006), *Fundamental study on corrugated steel webs used as shear walls*, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan.
Clayton, P.M., Berman, J.W. and Lowes, L.N. (2011), “Seismic design and performance of self-centering steel plate shear walls”, *J. Struct. Eng. - ASCE*, **138**(1), 22-30.
De Matteis, G., Formisano, A., Panico, S. and Mazzolani, F. (2008), “Numerical and experimental analysis of pure aluminium shear panels with welded stiffeners”, *Comput. Struct.*, **86**(6), 545-555.
Driver, R.G., Kulak, G.L., Kennedy, D.J.L. and Elwi, A.E. (1998), “Cyclic tests of four-story steel plate shear wall”, *J. Struct. Eng. - ASCE*, **124**(2), 112-120.
Elgaaly, M., Hamilton, R. and Seshadri, A. (1996), “Shear strength of beams with corrugated webs”, *J. Struct. Eng. - ASCE*, **122**(4), 390-398.
Elgaaly, M., Seshadri, A. and Hamilton, R. (1997), “Bending strength of steel beams with corrugated webs”, *J. Struct. Eng. - ASCE*, **123**(6), 772-782.
Formisano, A. (2006), “Experimental-numerical investigation on stiffened aluminum shear panels”, *Pollack Periodica*, **1**(3), 57-77.
Galambos, T.V. (1998), *Guide to stability design criteria for metal structures*, 5th Ed., John Wiley and Sons, NY, USA
Gentilinia, C., Seffenb, K.A., Guest, S.D. and Nobile, L. (2008), “On the behavior of corrugated plates in bending”, *Procedia Eng*., **1**, 79-82.
Kiymaz, G., Coskun, E., Cosgun, C. and Seckin, E. (2010), “Transverse load carrying capacity of sinusoidally corrugated steel web beams with web openings”, *Steel Compos. Struct*., **10**(1), 69-85.
Kovesdi, B. (2010), *Patch loading resistance of girders with corrugated webs*, Doctor of Philosophy Thesis, University of Stuttgart, Germany.
Qu, B., Bruneau, M., Lin, C.H. and Tsai, K.C. (2008), “Testing of full-scale two-story steel plate shear wall with reduced beam section connections and composite floors”, *J. Struct. Eng. - ASCE* , **134**(3), 364-373.
Sabouri, G.S. and Gholhaki, M. (2008), “Ductility of thin steel plate shear walls”, *Asian J. Civil Eng.* (Building and housing), **9**(2) 153-166
Sause, R. and Braxtan, T.N. (2011), “Shear strength of trapezoidal corrugated steel webs”, *J. Constr. Steel Res*., **67**(2), 223-236.
Sayed-Ahmed, E.Y. (2001), “Behaviour of steel and/or composite girders with corrugated steel webs”, *Can. J. Civil Eng*., **28**, (4). 656-672
Sayed-Ahmed, E.Y. (2005), “Plate girders with corrugated steel webs”, *Eng. J. AISC*, **42**(1), 1-13.
Sayed-Ahmed, E.Y. (2007), “Design aspects of steel I-girders with corrugated steel webs”, *Electronic J. Struct. Eng*., **7**, 27-40**.**
Stojadinovic, B. and Tipping, S. (2007), *Structural testing of corrugated sheet steel shear walls*, Research report University of California, Berkeley.
Szilard, R. (2004), *Theories and applications of plate analysis*, Published by John Wiley & Sons, Inc
Tanaka, Y., Ichioka, Y., Kono, S., Ohta, Y. and Watanabe, F. (2008), “Precast prestressed portal frames with corrugated steel panel dampers”, *Proceedings of the14th World Conference on Earthquake Engineering,*

China.

Usman, F. (2001), *Shear buckling of trapezoidal plate*, Master of Science thesis, university technology Malaysia.

Wang, X. (2003), *Behavior of steel members with trapezoidally corrugated webs and tubular flanges under static loading*.

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