Wang
Journal of Engineering and Applied Science (2024) 71:120
https://doi.org/10.1186/s44147-024-00454-2

Journal of Engineering and Applied Science

RESEARCH **Open Access**

Investigating the effect of changing the geometric characteristics on the seismic behavior of the yielding shear panels

Chuncha Wang[1*]

*Correspondence: WCC12485@163.com

[1] Fujian Chuanzheng Communications College, Fuzhou 350007, China

Abstract

The use of different types of shear panels as a large group of yielding dampers has been investigated. Acceptable seismic behavior such as stiffness and high deformation capacity, appropriate lateral resistance, ease of construction, and use in the structure are among the most important. Different types of these dampers have been developed, and yield shear panel device (YSPD) dampers are one of them. This research investigates the effects of changes in the geometric dimensions of this type of damper on their seismic behavior. For this purpose, nonlinear finite element models of dampers under cyclic loading were analyzed. The obtained results showed that the simultaneous use of side plates and stiffeners can create suitable conditions for directly controlling the dimensions of the damper. Local buckling in the side plates may concentrate deformations in this part of the damper element, affecting the hysteresis behavior with pinching. In addition, increasing the thickness of the side plate linearly has increased the yield strength and ultimate strength of these dampers. Finally, it was found that the increase in shear plate stiffness can directly increase the energy absorbed by this type of damper, effectively improving the seismic capacity of YSPD dampers.

Keywords: Shear panel, Hysteretic behavior, Deformation, Strength, Energy absorption

Introduction

Yielding dampers as passive devices in seismic control of structures have been widely developed in recent decades [1]. These types of dampers, installed in the structures, dissipate the input energy caused by the earthquake by yielding in a different state, such as cutting or bending. Therefore, these elements act like a fuse and prevent damage to structural members [2].

One of the usual mechanisms to control the behavior of yielding dampers is the use of sections under bending. The known added stiffness and resistance dampers (ADAS) are one of them. This type of dampers can experience many loading cycles without a decrease in resistance or stiffness [3]. A different kind of damper with bending behavior can be considered a box-shaped damper (BSD). This type of damper can withstand large deformations by changing the shape of the cross-section plates [4]. Other types of dampers, such as pipe dampers, are affected by the shear load. The bending due to the geometry causes a lot of energy absorption and ductility in them [5, 6].

Another mechanism in controlling the behavior of yielding dampers is sectioned under shear load. These types of dampers are known as shear panel dampers (SPD) [7]. Rectangular plates that are loaded in shear are generally used to build these dampers. As a result of in-plane shear loading, these dampers yield and can dissipate large amounts of seismic energy. To achieve this yield in shear panel dampers, two connection methods of using braces or master columns are more common methods [8].

The appropriate seismic capacity of SPD is necessary to prevent the inelastic buckling of the damper plates effectively. In the usual case, vertical and horizontal stiffeners control buckling [9]. However, due to problems such as the need for a long welding length, the performance of the damper is affected, and the heat caused by welding can affect the performance of the plastic and cause brittleness of the metal of the damper plates [9]. In addition, under the influence of shear loading, due to the geometry of the plates used in the damper, which is usually rectangular, significant amounts of stress concentration are created at the corners of the plates, which leads to sheet tearing in these parts [10].

Much research has been done on modifying the behavior of these dampers to increase ductility and energy absorption. Ductile metals such as pure aluminum and steel with low yield stress can be considered one of them [11–19]. Another method of modifying the behavior of this type of damper can be regarded as the use of additional components [20–23]. In these methods, the shear plates are usually enclosed in a hollow section, or bending parts are used perpendicular to the damper"s shear plane to increase the damper's seismic capacity while preventing the shear plate's buckling. However, one of the methods presented in this field is the use of side plates to improve the seismic performance of these dampers, which Deng suggested as a means of absorbing energy in the restrainer of bridges. The geometry of the side plates with appropriate thickness increases their plasticity and strength. Also, it creates a suitable support for connecting the stiffeners to prevent the buckling of the shear plate effectively.

Because the geometrical conditions have a great influence on the behavior of these dampers, dimensional ratios should be considered to achieve acceptable seismic behavior. However, a complete investigation has not been done on the effect of using shear and side plates with different geometrical conditions on the seismic behavior of yielding shear panels. Therefore, this research investigates the change in the geometry and thickness of the side and shear plates and its effects on the control of the seismic behavior of this type of shear panels.

Research method

The nonlinear finite element method based on ABAQUS software has been used to investigate the behavior of these dampers. This software has the appropriate ability to consider nonlinear behavior in various materials, including steel, which can well include the effects of plastic behavior and hardening behavior in addition to complex geometric nonlinearity in modeling.

Geometric configuration

In this research, the behavior of the shear panel proposed by Deng et al. has been investigated; therefore, the geometry used in this damper is based on this research. Also, the simultaneous effect of the change in the shear and side plate geometry has been investigated. Figure 1 shows the overall geometry of the investigated shear panel.

As seen in Fig. 1, the geometric characteristics include the thickness of the side plates and the width and thickness of the shear plate, which can determine the seismic performance of the damper. In addition, horizontal and vertical stiffeners are needed to prevent buckling of the shear plate, which depends on the dimensions of the shear plate. In this research, by considering the width of the shear plate is at least 30% less than its height, vertical stiffeners were not used, and only horizontal stiffeners were added for every 150 mm of damper height in G.1 and G.2 group and 100 mm in G.3 and G.4 groups. Based on geometric configurations, shear dampers are divided into four groups; in each group, the width of the shear plate is constant, but its thickness changes along with the thickness of the side plate. It should be noted that in order to investigate the effect of the width of the plates on the behavior of the damper, its value is 50 mm more in the first group than in the second. This value has been repeated for the third and fourth groups as well. Table 1 shows the general characteristics of the studied dampers.

Steel properties

As mentioned in the previous sections, the type of steel effectively changes the performance of this type of damper. For this reason, in this research, steel with yield stress LY-235 was used to model the dampers. Figure 2 shows the stress–strain curve of this steel.

It should be noted that in order to model the behavior of steel with a modulus of elasticity equal to 210 GPa, Poisson's ratio is considered equal to 0.3. Also, isotropic hardening based on Deng's research, which is calibrated to model this type of damper, has been used in the modeling.

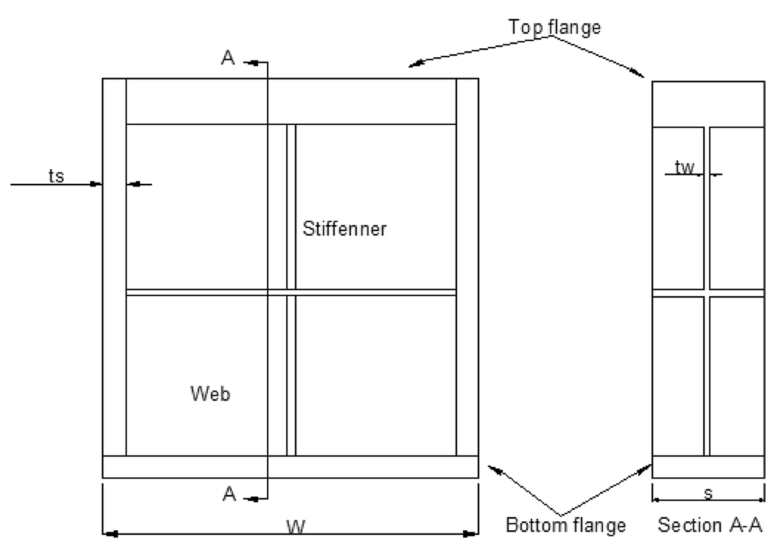


Fig. 1 Scheme of the proposed shear panel

Table 1 Geometry of selected dampers for analysis

Group	Name	h (mm)	w (mm)	tw (mm)	s (mm)	ts
G.1, G.2, G.3, G.4	10X30	300, 400	200, 150, 250, 200	30, 35	200	10
	10X35					10
	15X30					15
	15X35					15
	20X30					20
	20X35					20
	25X30					25
	25X35					25

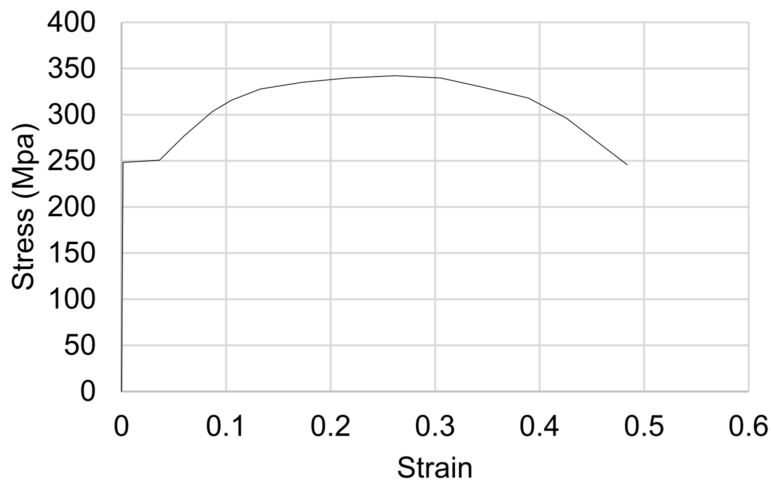


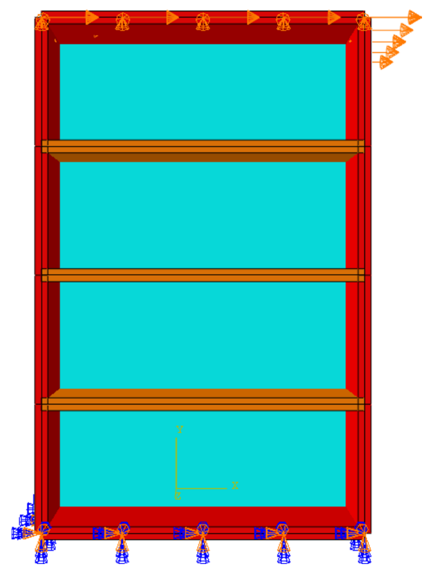
Fig. 2 Stress-strain of LY-235 steel

Finite element modeling consideration, loading, and boundary condition

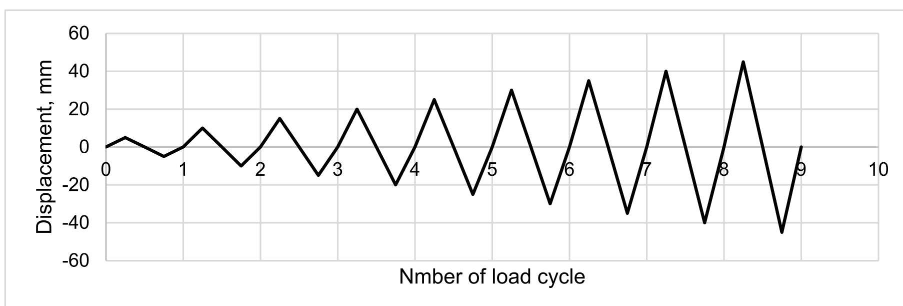
Shell elements have been used to model these dampers. These elements are suitable for modeling steel sections with low thickness, and according to the dimensions of this type of damper, these conditions can be considered for these types of dampers. In addition, S4R elements have been used for meshing these different parts of the damper, which is based on the 4-noded shell-type element with 6 degrees of freedom at each point and has been reduced by integration. For shear loading on the damper, it is assumed that the load is applied on the upper face of the damper. Fixed conditions were considered for the bottom plate of the damper to show the nonlinear behavior of the damper by cyclic loading. Figure 3a shows the boundary condition apllied to the models. For cyclic nonlinear loading, a loading history similar to Fig. 3b is used.

Verification

To check the accuracy of the modeling, experimental specimen S4 spiceman was selected for modeling. Generally, this type of shear panel was modeled in the research of Deng et al. [22]. The nonlinear behavior of this type of shear panel dampers is very sensitive to the relative dimensions of their side and shear plates. Local buckling in the plates will likely occur if these ratios exceed a specific value. To control these conditions,



a. boundary condition applied to models



b. Applied cyclic loading history

Fig. 3 **a** Boundary condition applied to models; **b** Applied cyclic loading history

researchers consider one of the main characteristics. However, the specimen with the lowest aspect ratio among the examined test samples has shown the most stable behavior. This study uses this specimen (S4) to control the software's modeling accuracy. In this laboratory specimen, the damper's overall height is 300 mm. The shear plate (W) has a width of 200 mm and a thickness (tw) of 5 mm. The side plate's width (S) is also 200 mm, but its thickness (ts) is 20 mm. The model of this damper was conducted in ABAQUS and analyzed under cyclic loading and, its results are compared with the results of the experiment in Fig. 4.

Results and discussion

Deformation shape

As Fig. 5 shows, the values of the maximum plastic strain are generated in the horizontal shear plate of the damper, which occurs due to shear loading, which shows the nonlinear behavior of shear panel dampers. The initial behavior of this damper, like all shear panel dampers, occurs under the influence of the shear yielding of the horizontal plate, as shown in the models of the first and second groups. In the models

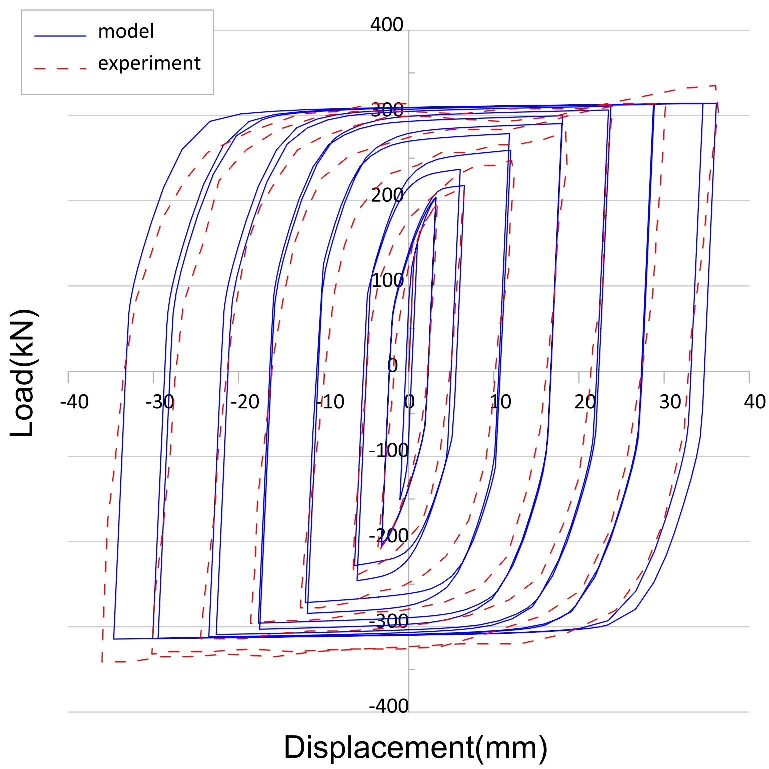


Fig. 4 Comparison between experiment and model

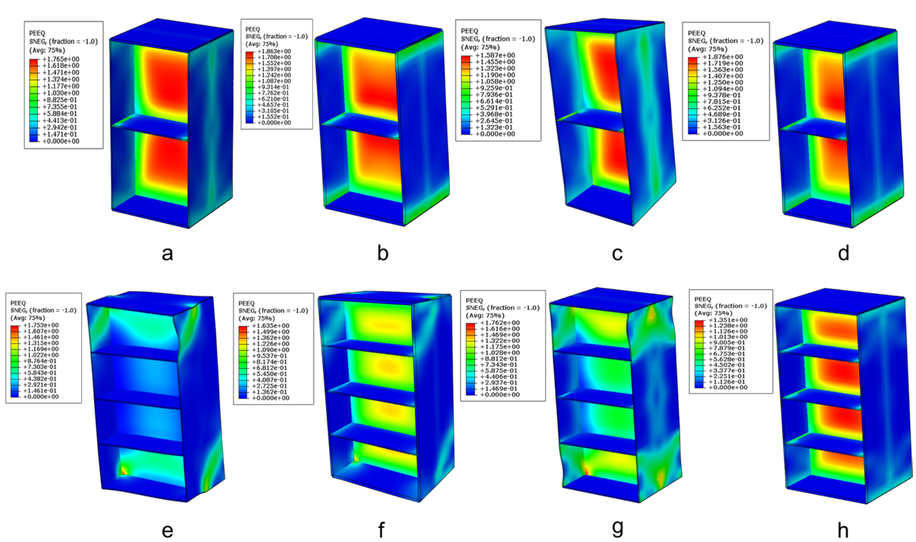


Fig. 5 Deformation of some models at a displacement of 40 mm. **a** G.1-15X30. **b** G.1-25X30. **c** G.2-15X35. **d** G.2-25X35. **e** G.3-10X35. **f** G.3-25X35. **g** G.4-10X30. **h** G.4-20X30

of these two groups, the use of a vertical sheet has caused a limited range of strain to be seen at the top and bottom of the plate and, to some extent, at the junction of the horizontal and vertical side plates. The flexural yielding of these plates increases its accumulation in the said parts with the increase of the loading range. However, the amount of these strains is far less than the strains created in the shear plate, which shows that the effect of side plates is much less than the shear part of the damper, and the use of vertical sheets shows the role of reinforcement. Models b and d show that the increase in the thickness of the vertical side plate has reduced the accumulation of strains in the upper and lower parts of the plate, which seems that the increase in bending stiffness has caused this behavior. A comparison of strains in models G.1 and G.2 generally shows that increasing the width of the horizontal shear plate strengthens the shear behavior and causes the strain to increase more strongly in the middle of the shear plate, so the ratio of the dimensions of the horizontal shear plate should be influential on the overall behavior of the damper compared to the vertical side plate.

The comparison between models G.3 and G.4 shows a different effect of the vertical side plate dimensions on the damper's overall behavior. In these two groups, with the increase in the overall height of the vertical side plates damper, there has been local slenderness, which has caused the buckling of these sheets due to the loading of the damper. The deformation of models e, f, and g in the top and bottom side plates and the asymmetric strain distribution in these parts confirm this. Of course, with the increase in the thickness of the plate, the buckling is limited to a large extent, and it has been completely avoided in model h in G.4. This problem also shows the effects of the relative dimensions of the sheet on the behavior of the damper.

Due to the use of horizontal stiffeners, a general comparison of strain local buckling does not occur in the shear plate. These stiffeners are added for every 100 mm according to the height of the damper. For this reason, the stiffener sheets have effectively bound the horizontal sheet, which, by simultaneously connecting it with the vertical sheet, has created an almost rigid area around the stiffener sheet, which can effectively limit buckling. Plastic strains in these plates, except for the limited values in the corners, do not show a specific change, which indicates the elastic behavior of these parts in loading on these components.

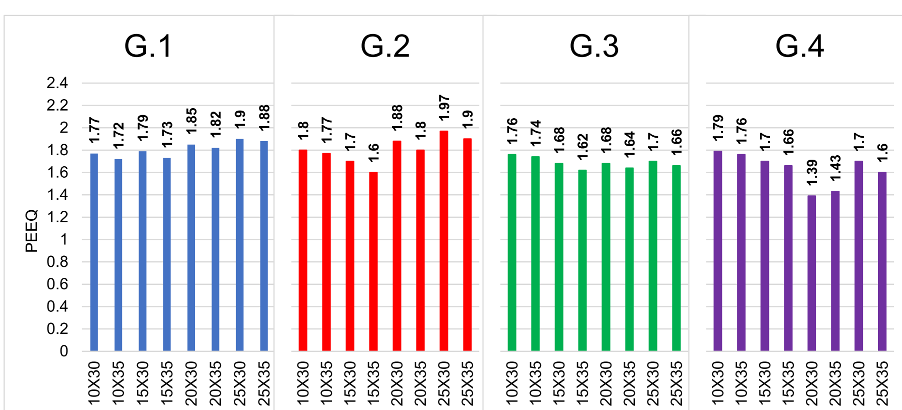


Fig. 6 Maximum plastic strain equivalent of the analyzed models

Maximum plastic strain equivalent

Figure 6 shows the maximum plastic strain equivalent (PEEQ) values at the end of loading as an indicator of the deformation demand in the damper elements.

As Fig. 6 shows, due to the similarity of the geometric configuration of G.1 and G.2, the PEEQ values in these two groups are close to each other. Similar conditions occur for G3 and G.4. Considering that the overall height of the damper element in the G.1 and G.2 groups is equal to 300 mm and for the G.3 and G.4 groups with an increase of 33%, it is equal to 400 mm, so the PPEQ values in these groups are close to each other. Considering this condition, it can be said that the increase in height of the damper has caused a decrease in PEEQ. For example, PEEQ in 25X30 models in G.1 and G.3 is equal to 1.9, and G.3 is equal to 1.9 and 1.7, respectively, which shows an increase of 12%.

The change in the thickness of the horizontal shear plate has the opposite relationship with PEEQ. By increasing the thickness of the shear plate, the stress concentration in this part has decreased, which has led to a decrease in PEEQ values. Of course, these changes are less than the impact of other variables. The value of PEEQ in 15X30 models in G.1 and G.2 is equal to 1.79 and 1.7, respectively, which shows an approximate increase of 5%. However, PPEEQ in similar models G.3 and G.4 is equal to 1.68 and 1.7, respectively, which represents an approximate decrease of 1%. The value of PEEQ in all groups decreased with the increase in side plate thickness. This result can be seen more clearly, especially in the models where the thickness of the shear plate is higher. Therefore, the plastic strains have increased with the increase in thickness in G.1 and G.2. But in G.3 and G.4, the relationship has occurred in reverse. That is, PEEQ values have decreased with increasing thickness. Therefore, a significant relationship between PEEQ and the thickness of the shear plate in the damper cannot be considered.

Hysteretic behavior

As can be seen in Fig. 7, the hysteretic behavior of all the models shown is quite stable. That is, up to the maximum displacement and before failure, the resistance drop is not seen in the graphs. This shows that this geometry of the shear panel damper exhibits nonlinear behavior up to a large nonlinear displacement without significant change in loading, which can satisfy the ductility demand well. In addition, the general shape of the graphs does not show a drop in stiffness in any case, which causes the formation of hysteretic loops with a large area. Therefore, high levels of damping are created in this type of shear panel.

Displayed graphs, such as G.3-10X35 and G.3-20X30, show a pinching in the hysteresis graphs. As mentioned, the occurrence of buckling in the side plates causes this reduction. However, with the increase in the thickness of the side plates, the pinching has disappeared, which is not seen in the graphs of G.4, which is largely similar to G.3. Based on this, it can be said that although the most nonlinear behavior is caused by the shear performance of the horizontal plate, buckling in the side plates can affect the hysteretic behavior of the damper. So, this shows that in order to control the behavior of this damper, the effects of the dimensions of the horizontal and side plates should be considered.

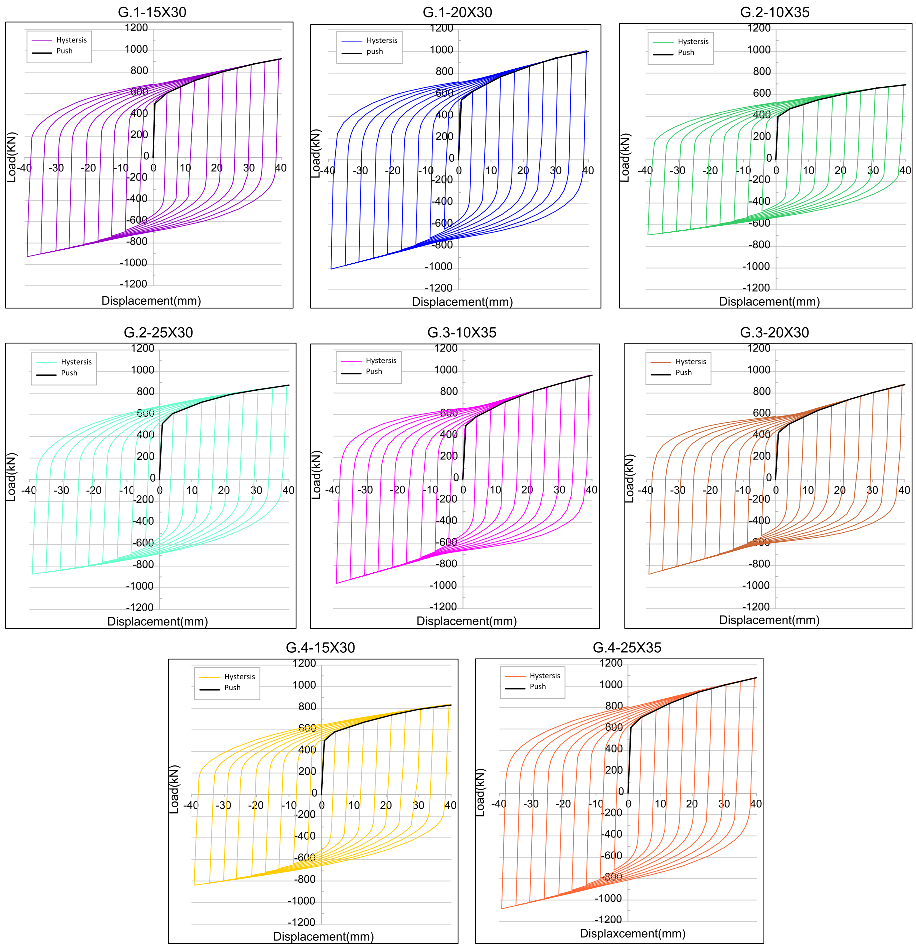


Fig. 7 Hysteretic behavior of some analyzed models

In addition to the side plate buckling effects on the overall behavior of the dampers, the increase in its thickness has caused a change in the hysteretic loops. The comparison between G.1-15X30 and G.1-20X30 graphs shows this phenomenon well. Also, the effect of increasing the thickness of the shear plate is noticeably more significant than that of the side plates. Comparing the hysteretic behavior of G.2-10X35 and G.2-25X30 shows the changes made in the behavior. In addition, the simultaneous effects of increasing the shear and side plate thickness can be seen in the conduct of G.4-15X30 and G-4-25X35, which indicates a significant increase in this variable.

The change in the width of the shear plate also shows a particular effect on the hysteretic behavior. Increasing the plate width in these models due to the limitation of shear buckling has caused an apparent increase in the hysteresis loops. This increase is clearly seen in the comparison between the G.1-20X30 and G.2-25X30 models, where even the thickness of the side plate is greater. Therefore, the width and thickness of the shear plate are the most important variables affecting the cyclic behavior of this type of damper.

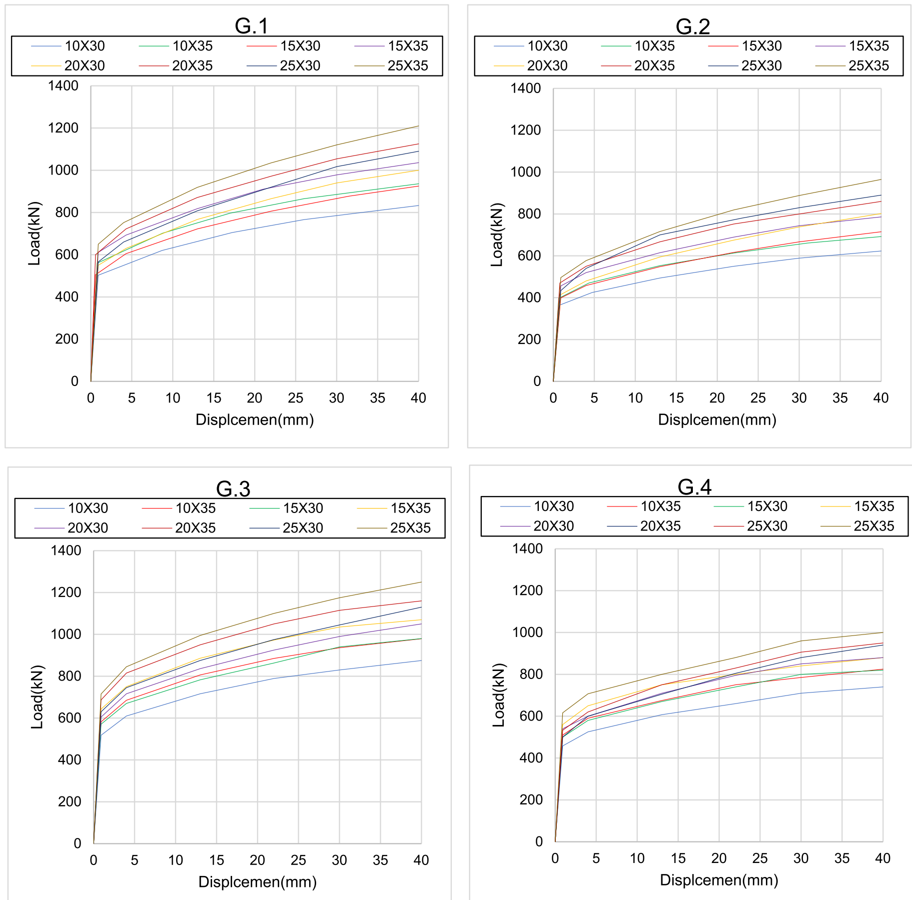


Fig. 8 Push diagram resulting from the cyclic behavior of models (skeleton curves) based on the different analyzed groups

Overall nonlinear behavior

Overall, the behavior of models is controlled with skeleton curves. These curves are obtained by connecting the points with the maximum loading capacity in the positive direction of the hysteretic diagram. Figure 8 shows the graphs resulting from push hysteresis (skeleton curves) as an essential measure of the overall behavior of the models.

As Fig. 8 shows, the stability in the general behavior of the models can also be seen in the skeleton curves. Until yielding occurs, no clear difference can be seen in the shape of the graphs, which indicates the behavioral stability of this type of shear panel damper due to high shear stiffness. After the occurrence of yielding, with an almost certain slope, until reaching the maximum displacement, they have increased the resistance bending. The increase in the geometric dimensions has caused an increase in the level under the graphs as a measure of resistance. Therefore, based on the shape of the diagrams shown in this section concerning the cyclic behavior of all models, this type of shear panel has a high capacity for nonlinear deformations.

Furthermore, as it is known, the increase in the thickness of the shear plate in all groups has caused the skeleton diagrams to rise in all groups. With the increase in thickness, the place of yielding changes, and the final shift in place shows an apparent increase, which has increased the level of the skeleton diagrams. In G.1 to G.4, the

20X35 models show an increase in resistance of 12, 3, 14, and 2%, respectively, in the displacement of 22 mm, compared to the 20X30 models. This increase is more evident in G.1 and G.3, which shows that other geometric characteristics can have a more significant effect in combination with the behavior of these dampers.

The other results show that the side sheets' thickness has also increased the level of the skeleton diagrams, which can be seen in all four groups of models. In this way, with the increase in thickness in each step, the surface of the diagram increases until it is almost equal to the diagrams in which the thickness of the cutting sheet is greater. This phenomenon shows that the increase in the thickness of the side plates has an effect almost equal to the increase in the thickness of the shear plates. In groups G.1 and G.3, the 20X35 models are 5% and 8% higher than the 25X30 models. But groups G.2 and G.4 show lower values of 3 and 5%, respectively. Accordingly, increasing the thickness of the side plate in combination with other specifications can change the overall behavior of the damper.

Finally, these result shows increasing the width of the horizontal shear sheet has a significant effect on the overall behavior of the skeleton curves, which can be seen well in the comparison between the groups G.1 and G.2, as well as G.3 and G.4. The width of the horizontal shear sheet in G.1 is almost 30% more than G.2. This value has reached 25% in the comparison between G.3 and G.4 groups. Accordingly, in the G.1 group, the level of the skeleton diagram of the 25X35 model is almost 30% higher than that of the similar model in the G.2 group. Comparing the skeleton diagram of this model in group G.3 shows a 28% increase compared to group G.4. Therefore, the width of the sheet has affected the general behavior of the examined models almost linearly.

Yield and ultimate strength

Several variables play a fundamental role in determining the behavioral characteristics of the damper elements, which must be carefully considered. Yield and ultimate resistance and the ratio between them have a significant impact on the behavior of dampers. Therefore, changing the geometric characteristics of the models based on these variables has

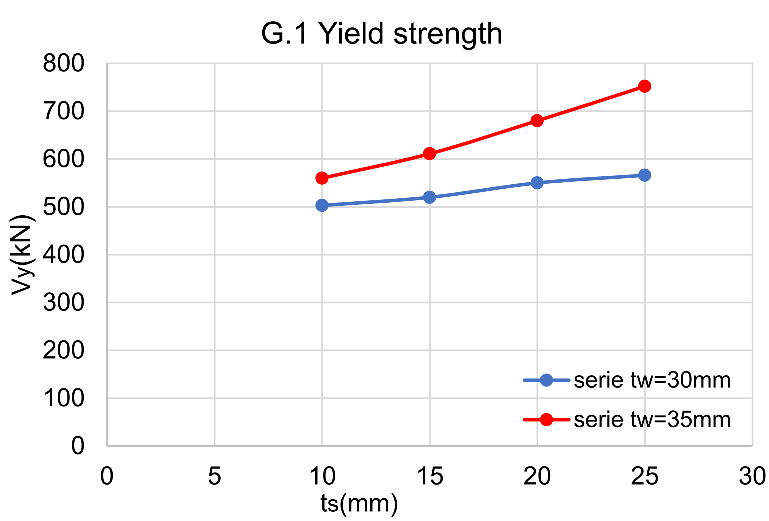


Fig. 9 Yield strength of G.1

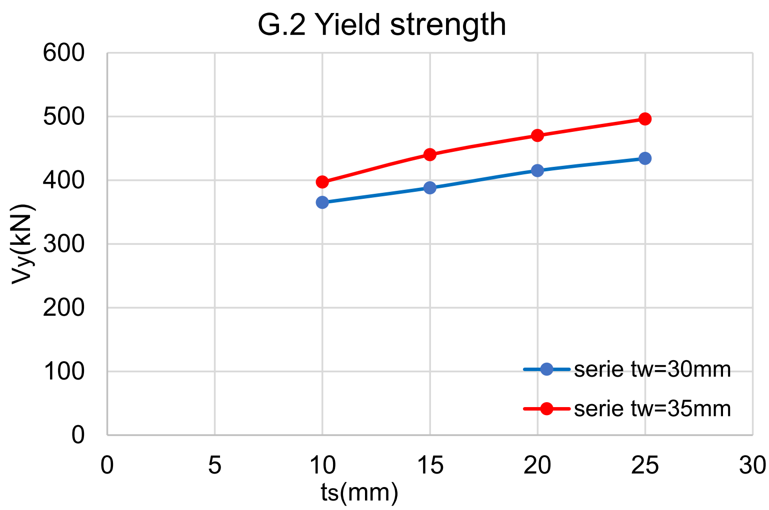


Fig. 10 Yield strength of G.2

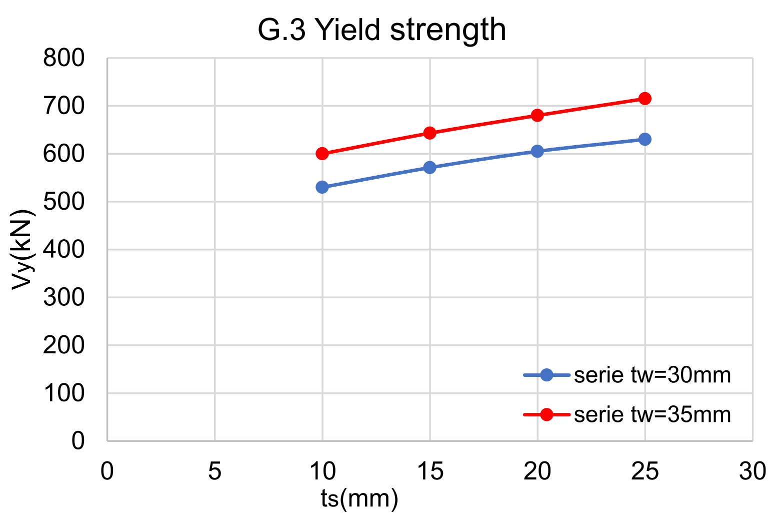


Fig. 11 Yield strength of G.3

been investigated. Figures 9, 10, 11 and 12 show the change in the shear-yielding force of the models based on different groups and the thickness subgroup of the horizontal shear plate.

As shown in Figs. 9, 10, 11, and 12, the yield strength in each group has generally changed linearly with the increase in the thickness of the side sheets. The change in the thickness of shear sheets of the horizon shows similar conditions. Only in G.1 are the differences slightly different due to the more significant effect of the side sheets and horizontal shearing simultaneously.

In addition, based on these results, increasing the thickness of the horizontal shear sheet in all groups has increased the yield strength. As can be seen, the graphs related to the subgroup Tw = 30 mm are consistently lower than those of Tw = 35 mm. Increasing the thickness of the side plates linearly in each subgroup has increased the yield strength of the models. These changes are more in G.1 and when Tw = 35 mm,

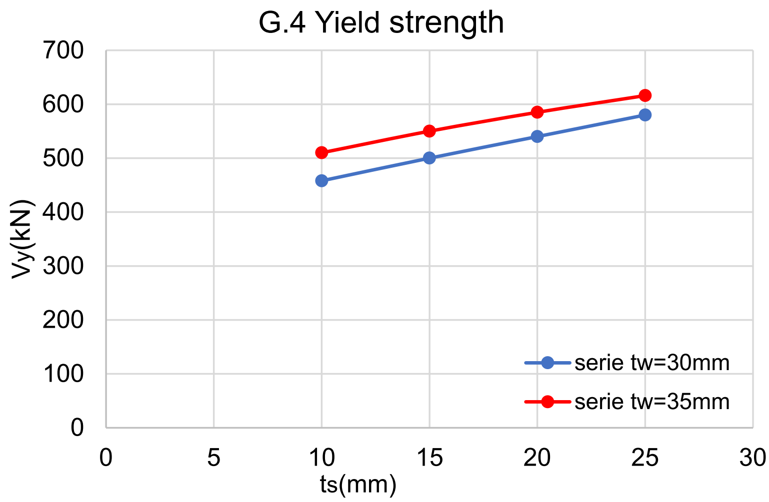


Fig. 12 Yield strength of G.4

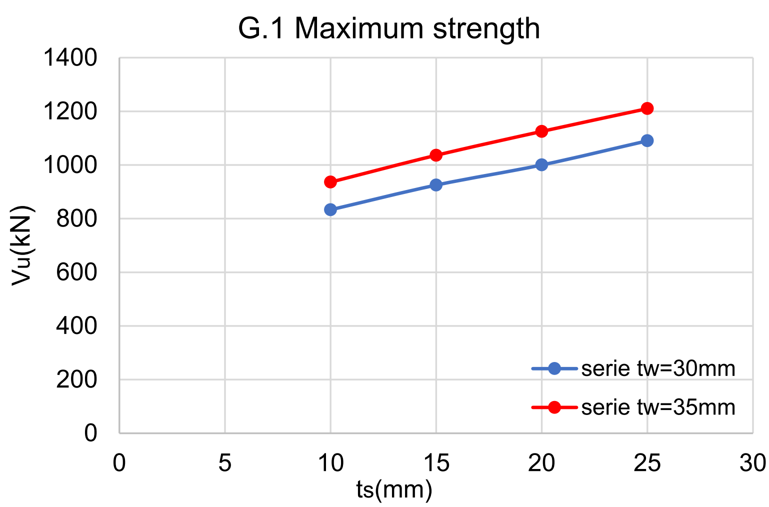


Fig. 13 Maximum strength of G.1

but in other subgroups, the resistance increase slope is almost constant. Increasing the width of the horizontal shear sheet has an apparent effect on increasing the yield strength. A comparison between G.1 and G.2 illustrates this well. The yield strength of the G.1-15X30 model is almost 38% higher than G.2-15X30.

Figures 13, 14, 15, and 16 show the changes in the maximum strength of the models with the change in the thickness of the side plate and according to the thickness of the horizontal shear plate as a subgroup.

As shown in Figs. 13, 14, 15, and 16, the changes in the maximum resistance are linear to the changes in the thickness of the side plate and similar to the yield strength. The maximum resistance also increases with the increase in the thickness of the side plate. However, the intensity of the changes in the final resistance is less than that, and the slope of the resistance increase line is also less.

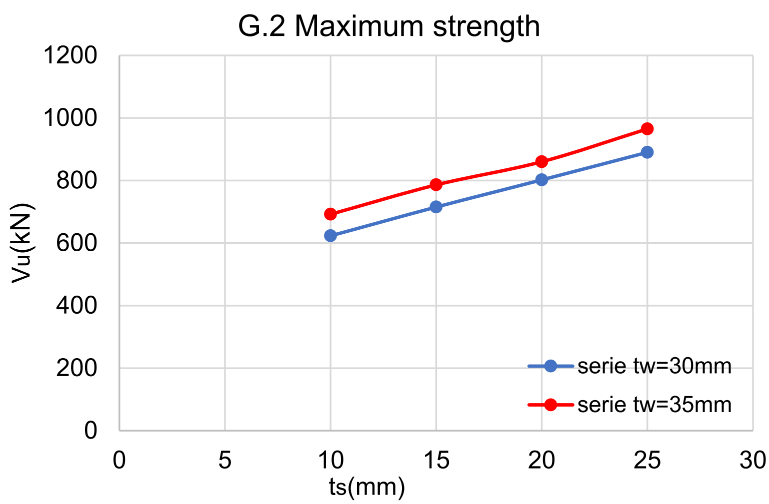


Fig. 14 Maximum strength of G.2

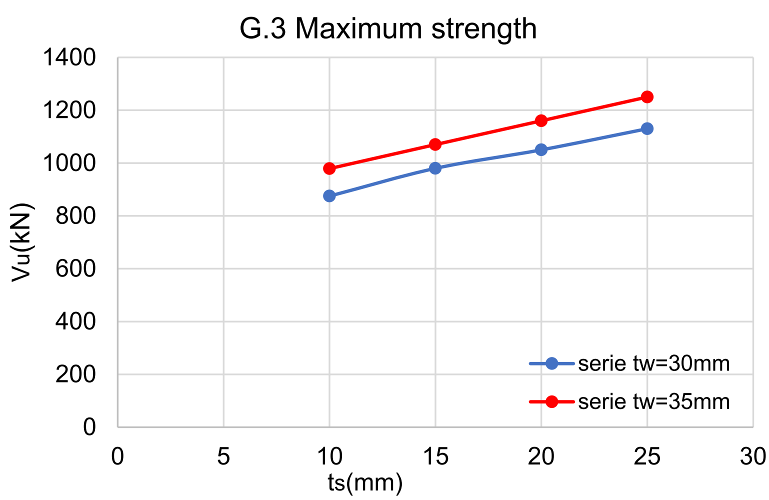


Fig. 15 Maximum strength of G.3

Increasing the thickness of the horizontal shear sheet has generally increased the maximum strength. That is, in this case, the graphs of the subgroup Tw = 30 mm are lower. In addition, the examination of the width of the sheet also shows that increasing the width of the horizontal shear sheet increases the final strength.

Energy absorption

Yielding damping elements as an energy-absorbing tool is effective when they can absorb significant amounts of seismic energy. For this reason, the energy absorbed by these dampers has been investigated as an influential factor in the seismic behavior of this type of shear panel. Figure 17 shows the energy absorbed by the studied dampers in each group.

Figure 17 shows that the energy absorbed in all groups has increased with the increase of nonlinear loading cycles. The increase in the amount of energy absorbed by these

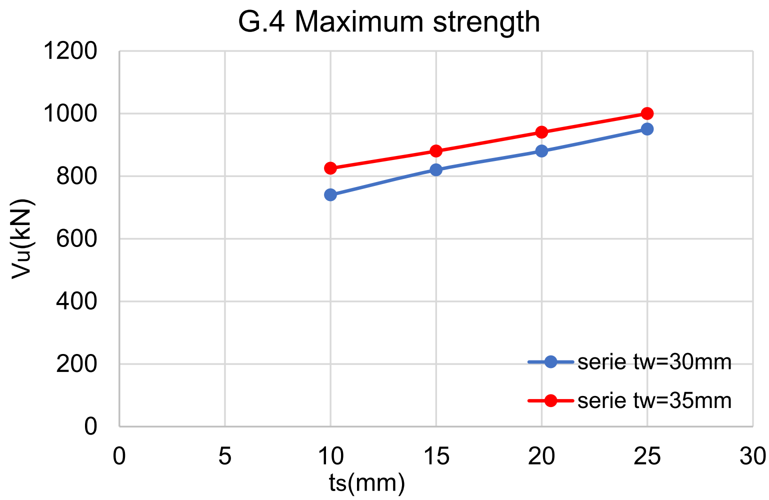


Fig. 16 Maximum strength of G.4

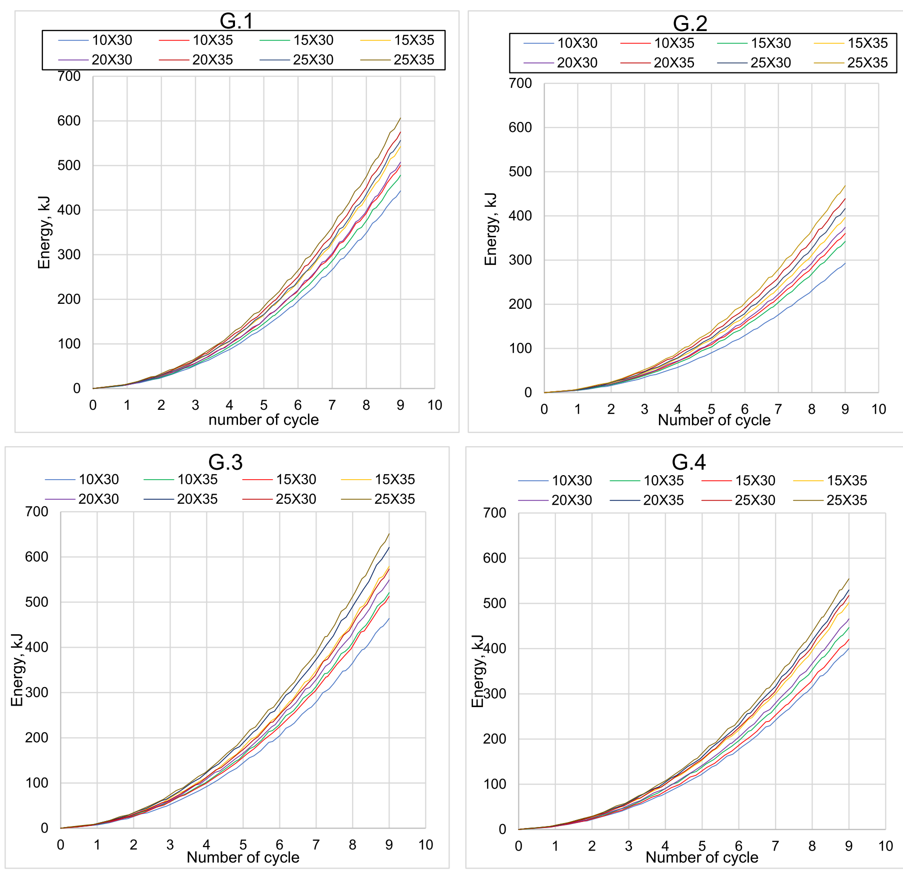


Fig. 17 Energy absorption of different groups of models

dampers indicates the high capacity of energy absorption by this type of shear panel, which can be used well for seismic control of structures. In the lowest case, the amount of absorbed energy reaches 296 kJ, and with the increase in geometric dimensions, the amount of absorbed energy has increased by more than two times to 602 kJ.

Increasing the thickness of the side sheets in each group has effectively increased energy absorption. This increase is significantly higher in G.2 due to the damper geometry's overall effect on energy absorption. Increasing the thickness of the horizontal shear sheet has a significant impact on energy absorption. This increase can be seen especially in models where the thickness of the side sheet is less. Therefore, increasing one of the thickness parameters of the shear or lateral sheet can effectively improve the energy absorption capacity. Increasing the width of the shear plate greatly increases the energy absorption of these dampers, which can be seen from the comparison between groups G.1 and G.2 as well as G.3 and G.4 together. The difference between the 25X35 models that absorb the most energy, G.1 and G.2, has reached 26%, which shows the effect of this variable on the energy absorption of the damper.

Conclusions

This study investigated the effect of geometric characteristics on the nonlinear behavior of a specific type of shear panel dampers (YSPD) in cyclic loading. The analyzed variables included the change in the thickness of the horizontal shear sheet and the side sheet, the width of the shear sheet, and the overall height of the section. For this purpose, the nonlinear finite element method was used, and 32 models with different geometrical conditions were analyzed under cyclic loading. Their deformations, maximum plastic strains, hysteretic behavior, skeleton curves, ultimate yield strength, and energy absorption were investigated, and the obtained results showed the following:

1. Lateral loading on shear panels causes the horizontal sheet to yield at the beginning of loading, and nonlinear behavior occurs in this type of damper. As the loading range increases, bending deformation occurs in the side plates, so the overall behavior of this type of damper can be controlled. The possibility of buckling in the side sheets can concentrate the deformation in this part instead of the shear sheet, which can create the reliability of this type of shear panel.
2. With the increase in the thickness of the shear and side plates, the PEEQ increases, and this increase does not have a linear relationship with these variables and is less. However, increasing the cross-section height of the damper has a significant effect on reducing PEEQ. By choosing the damper's overall height according to the structure's drift conditions and behavior to reach the shear capacity of the damper, the displacement of the structure can also be controlled.
3. The hysteretic behavior of the models is entirely stable, and its nonlinear behavior continues several times of yield displacement. Increasing the thickness of the shear and side plates directly affects the hysteretic behavior and causes the formation of hysteresis loops with a large area. However, the possibility of buckling in the side plates shows the effects of pinching in the hysteresis diagrams, which is not suitable for the overall behavior of the damper. Therefore, choosing the correct dimensions

for the shear and side plates to prevent buckling achieved the proper resistance and stable hysteresis behavior in the structures where this damper is used.

4. The observed overall behavior of the dampers based on the skeleton curves also shows an entirely stable behavior in all models. After the yielding, an almost definite slope increases until the maximum resistance location change is reached. The shape of the graphs gives a high nonlinear capacity for this type of shear panel. Increasing the thickness of the shear and side plates has directly affected the skeleton diagrams.
5. The yield and maximum strength in different groups of models increase linearly with an increase in the thickness of the side plate. Increasing the thickness of the shear plate directly increases the yield and ultimate strength. Increasing the width of the sheet has a significant effect and can increase the yield strength by 38%. Because the dimensions of the shear sheet have a more significant effect on the ultimate yield strength of the damper, it is necessary to design this part first and then design the side plates to prevent buckling and increase the final capacity of the damper.
6. Increasing the dimensions of the damper, such as the thickness of the shear and side plates, directly increases the energy absorption of these dampers. The increase in the amount of energy absorbed by these dampers indicates the high capacity of energy absorption by this type of shear panel. Increasing the thickness of the horizontal shear sheet has a significant effect on energy absorption. This increase can be seen especially in models where the thickness of the side sheet is less. Therefore, increasing one of the thickness parameters of the shear or lateral sheet can effectively increase the energy absorption capacity. This result shows that by choosing appropriate relative dimensions for the shear and side plates, the energy absorption capacity of the damper can be optimally increased, which can be used well in controlling the energy input to the structure during earthquakes.

Acknowledgements
I would like to take this opportunity to acknowledge that there are no individuals or organizations that require acknowledgment for their contributions to this work.

Authors' contributions
CW performed data collection, simulation, and analysis. Also, he evaluated the first draft of the manuscript, editing, and writing.

Funding
This work was sponsored in part by Education Science Research Project of China Transportation Education Research Association for 2022–2024 (JT2022YB215).

Availability of data and materials
Data can be shared upon request.

Declarations

Competing interests
The author declares no competing interests.

Received: 13 February 2024 Accepted: 12 May 2024
Published online: 20 May 2024

References

1. Soong TT, Dargush GF (1997) Passive energy dissipation systems in structural engineering
2. Symans MD, Charney FA, Whittaker AS, Constantinou MC, Kircher CA, Johnson MW, McNamara RJ (2008) Energy dissipation systems for seismic applications: current practice and recent developments. J Struct Eng 134(1):3–21

3. Tsai KC, Chen HW, Hong CP, Su YF (1993) Design of steel triangular plate energy absorbers for seismic-resistant construction. Earthq Spectra 9(3):505–528
4. - Shirinkam, M. R., & Razzaghi, J (2020) Experimental and analytical investigation on the behavior of metallic box-shaped dampers (BSD). In Structures (Vol. 23, pp. 766–778). Elsevier
5. Maleki S, Mahjoubi S (2013) Dual-pipe damper. J Constr Steel Res 85:81–91
6. Maleki S, Mahjoubi S (2014) Infilled-pipe damper. J Constr Steel Res 98:45–58
7. Nakashima M, Iwai S, Iwata M, Takeuchi T, Konomi S, Akazawa T, Saburi K (1994) Energy dissipation behaviour of shear panels made of low yield steel. Earthquake Eng Struct Dynam 23(12):1299–1313
8. Javanmardi A, Ibrahim Z, Ghaedi K, Benisi Ghadim H, Hanif MU (2020) State-of-the-art review of metallic dampers: testing, development and implementation. Arch Comput Methods Eng 27:455–478
9. Chen Z, Ge H, Usami T (2006) Hysteretic model of stiffened shear panel dampers. J Struct Eng 132(3):478–483
10. Ambur DR, Jaunky N, Hilburger MW (2004) Progressive failure studies of stiffened panels subjected to shear loading. Compos Struct 65(2):129–142
11. Rai DC (2002) Inelastic cyclic buckling of aluminum shear panels. J Eng Mech 128(11):1233–1237
12. Jain S, Rai DC, Sahoo DR (2008) Postyield cyclic buckling criteria for aluminum shear panels
13. De Matteis G, Mazzolani FM, Panico S (2007) Pure aluminium shear panels as dissipative devices in moment-resisting steel frames. Earthquake Eng Struct Dynam 36(7):841–859
14. De Matteis G, Mazzolani FM, Panico S (2008) Experimental tests on pure aluminium shear panels with welded stiffeners. Eng Struct 30(6):1734–1744
15. De Matteis G, Formisano A, Panico S, Mazzolani FM (2008) Numerical and experimental analysis of pure aluminium shear panels with welded stiffeners. Comput Struct 86(6):545–555
16. Xu LY, Nie X, Fan JS (2016) Cyclic behaviour of low-yield-point steel shear panel dampers. Eng Struct 126:391–404
17. Yao Z, Wang W, Zhu Y (2021) Experimental evaluation and numerical simulation of low-yield-point steel shear panel dampers. Eng Struct 245:112860
18. Abebe DY, Jeong SJ, Getahune BM, Segu DZ, Choi JH (2015) Hysteretic characteristics of shear panel damper made of low yield point steel. Mater Res Innovations 19(sup5):S5-902
19. Zhang C, Zhu J, Wu M, Yu J, Zhao J (2016) The lightweight design of a seismic low-yield-strength steel shear panel damper. Materials 9(6):424
20. Chan RW, Albermani F, Williams MS (2009) Evaluation of yielding shear panel device for passive energy dissipation. J Constr Steel Res 65(2):260–268
21. Sahoo DR, Singhal T, Taraithia SS, Saini A (2015) Cyclic behavior of shear-and-flexural yielding metallic dampers. J Constr Steel Res 114:247–257
22. Deng K, Pan P, Su Y, Ran T, Xue Y (2014) Development of an energy dissipation restrainer for bridges using a steel shear panel. J Constr Steel Res 101:83–95
23. Li Z, Shu G, Huang Z (2019) Development and cyclic testing of an innovative shear-bending combined metallic damper. J Constr Steel Res 158:28–40

Publisher's Note