BEHAVIOR OF METALLIC SHEAR YIELDING DEVICES UNDER CYCLIC LOADS

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Abstract

Seismic design philosophy of current standards aims at allowing controlled damages in structures under design-basis earthquakes. Supplemental energy dissipation devices are used to control seismic response and to minimize the post-earthquake repairing cost of structures. Several types of energy dissipation devices have been studied in the past. Metallic energy dissipation devices are considered as more cost-effective as it requires minimum intervention to the existing structures during their installation. Owing to low yield point and high ductility of certain metallic alloys, most of the inelastic activity is confined to these devices. These metallic shear yielding devices may be easily replaced after an earthquake.

This paper presents a numerical study on metallic shear yielding devices proposed to supplement the structure during an earthquake and thus reducing demand on the primary structural elements. Objective of this paper is to evaluate cyclic behavior of metallic shear yielding devices. First, experimental results of past studies are validated by means of FE model and then validated FE model is used to study the behavior of these devices under cyclic loads. Parametric study is conducted to predict hysteretic behavior, energy dissipation potential and ductility of the metallic shear yielding devices. Effects due to change in web aspect ratio, web slenderness ratio and stiffeners on overall cyclic performance is presented in this paper. Results show that these metallic shear yielding devices have high ductility and stable hysteretic behavior under cyclic loads. Energy dissipation potential of these devices depends on web aspect ratio and web slenderness ratio of web plate.

Keywords: Metallic Shear Yielding Device; Structural Response Control; Seismic Fuse; Energy Dissipation

1. Introduction

Current seismic codes are based on prescriptive approach of designing structures for specified elastic force. It is expected to dissipate the seismic energy through controlled damage in the main structure. This results in evaluating the structure after an earthquake and then repair the damages before reusing the structure. In recent times more emphasis is being given to supplemental energy dissipation devices which are used to dissipate most of the input seismic energy and eventually reducing the seismic demand on main structure. These supplemental devices may be replaced easily after an earthquake and more importantly with less downtime.

Many such energy dissipation devices have been developed and studied recently. Some of these are buckling restrained braces (BRBs), combined metallic devices (CMDs), added damping added stiffness (ADAS) devices, steel plate shear walls (SPSWs), shear and flexural yielding devices (SAFYDs) and shear yielding devices (SYDs). This paper focusses on shear yielding devices made of aluminum plates. Aluminum has relatively low yield point than steel, this enables yielding in the devices prior to the that of primary structural elements. Aluminum also has high ductility which makes it suitable for making energy dissipation devices [1].

There has been lot of studies on metallic shear yielding devices in past. Rai et al. [2] experimentally investigated shear yielding devices made of aluminum. Dusicka et al. [3] experimentally investigated shear yielding devices made of low yield point steel (LYP steel). Chan et al. [4] experimentally investigated shear yielding devices made of steel. Since, experiments cannot be done for large number of specimens owing to costs involved, numerical investigation on finite element software is preferred for evaluating behavior of large number of specimens. In this paper, shear yielding devices made of aluminum are studied numerically to evaluate their behavior under large cyclic loading. The main objective of this paper is to numerically evaluate behavior of metallic (Al 6063 annealed) shear yielding devices and their energy dissipation potential with variations in web slenderness ratio (WSR), web aspect ratio (WAR) and number of panels.

2. Numerical Validation

Metallic (Al 6063 annealed) shear yielding devices are investigated numerically to study their behavior when subjected to cyclic loading. For carrying out parametric study, it is essential to validate the material parameters and boundary conditions against experimental testing. Jain et al. [5] conducted experiments on Al-SYD's under slow cyclic loads. In total 19 specimens were tested by Jain et al. [5] which includes variations in web slenderness ratio, web aspect ratio and number of panels. They have used two different alloys of aluminum which are Al 6063 and Al 1100. All specimens were heat treated to remove the residual stresses due to welding [5]. For numerical validation, total of four specimens are validated, in this paper, to obtain material parameters. Details of the geometry of the validated specimens are listed in Table 1. Web depth, flange width and stiffener thickness in these validated specimens are 152.4 mm, 100 mm and 6.5 mm, respectively.

Table 1 – Geometric details of specimens considered for validation

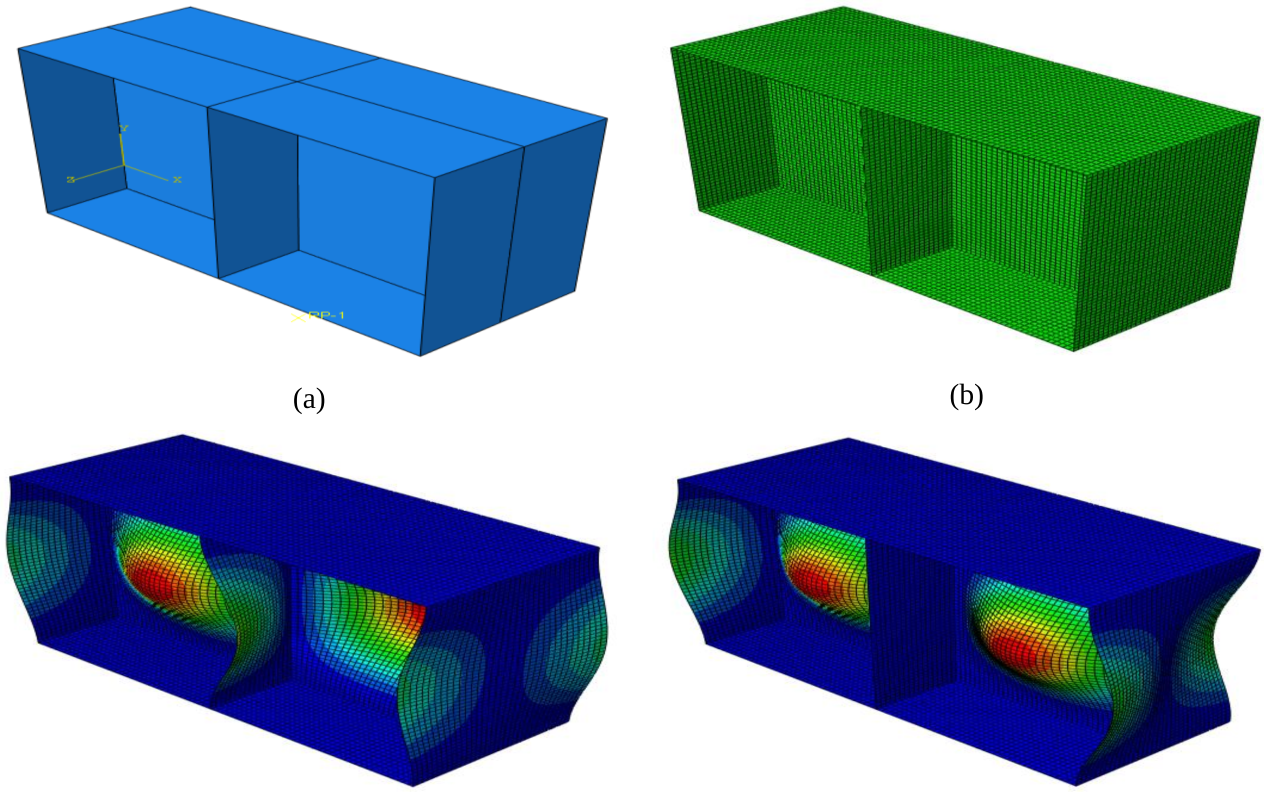
Specimen	Web Thickness (mm)	Flange Thickness (mm)	Web Slenderness Ratio	Web Aspect Ratio	Number of Panels
Sp02	4.5	6.5	33.9	0.75	2
Sp06	4.5	6.5	33.9	1.00	3
Sp08	6.5	10.0	23.4	0.75	2
Sp12	6.5	10.0	23.4	1.00	3

2.1 Modelling Technique

Finite element modelling is conducted to evaluate the specimens numerically and results are then compared with that of experiments [5]. Flanges of the specimens tested experimentally were bolted to rigid floor beam and loading beam which was connected to actuator. To represent these connections of shear yielding devices in numerical model, bottom flange of the shear yielding devices is fixed using MPC tie constraint to a reference point. Top flange of the shear yielding devices is tied to another reference point using MPC constraint. Cyclic displacement time history is applied to this reference point. Flange, web and stiffener are tied together in the numerical model. Flange, web and stiffener are modeled using S4R element available in ABAQUS.

Initial geometric imperfections are modeled by performing buckling analysis in the finite element model and then 0.1% of first mode shape is applied as initial imperfection in the model. Typical geometry, meshing and first two buckling mode shapes of the shear yielding device are shown in the Fig. 1.

Cyclic displacement time history is applied in numerical model. Three cycles each at 0.005, 0.010, 0.020, 0.050, 0.100, 0.150 and 0.200 shear strain level were applied as loading protocol.



(a) (b) (c) (d)

Fig. 1 – (a) Geometry, (b) Mesh in FEM, (c) Mode 1 and (d) Mode 2 of Sp02 specimen

2.2 Material Calibration

It is essential to validate the material parameters of test specimens under cyclic loading in numerical investigation. In this study of metallic shear yielding devices, annealed Al 6063 is used for finite element modeling. Tensile coupon test result of annealed aluminum is used for getting yield strength and modulus of elasticity. For material hardening parameters, combined hardening model which includes non-linear kinematic hardening and isotropic hardening is used. Constitutive equations for combined hardening law are given below [6-7]:

For a single backstress, kinematic hardening law is given by

$$\alpha = \frac{C}{\gamma}(1 - e^{-\gamma \varepsilon_p}) \quad (1)$$

where, C/γ is maximum change in backstress, γ is rate of change of backstress and ε_p is plastic strain.

Isotropic hardening law is defined by

$$\sigma_y = \sigma_{y0} + Q_\infty(1 - e^{-b\varepsilon_{eq}}) \quad (2)$$

where, σ_y is yield Surface size, σ_{y0} is yield stress at zero plastic strain, Q_∞ maximum change in size of yield surface, b is rate of change of yield surface and ε_{eq} is equivalent plastic strain.

Cyclic hardening parameters are calibrated and used in the numerical model. Initially, cyclic hardening parameters for nonlinear kinematic and isotropic hardening are taken in equal proportion from tensile coupon test result [8-9]. These material parameters are then used for numerical analysis and results are compared with experimental results. Iterative procedure is used to arrive at acceptable parameters. Comparison of numerical results with that of experimental results is shown in Fig. 2-4. Load-deformation behavior of all validated specimens is in reasonable match with experimental results. For Sp08, during experiment bolt slippage was observed which is reflected in the load-deformation behavior in Fig. 2. Skeleton curves of the validated specimens are also in reasonable match with experimental results. It is observed that shear yielding devices show stable hysteretic curves without pinching till 15% shear strain levels. For Sp12, at higher strains numerical results are around 10% lower than experimental results. However, cumulative energy dissipation in all validated specimens is in reasonable match with experimental results. Equivalent viscous damping at higher strain levels is around 40% to 60%.

Numerical results are reasonably matching with experimental results with varying aspect ratio, slenderness ratio and number of panels of specimens (Fig. 2-4). Thus, the modeling technique and calibrated material parameters may be used for numerical investigation of metallic (Al 6063 annealed) shear yielding devices.

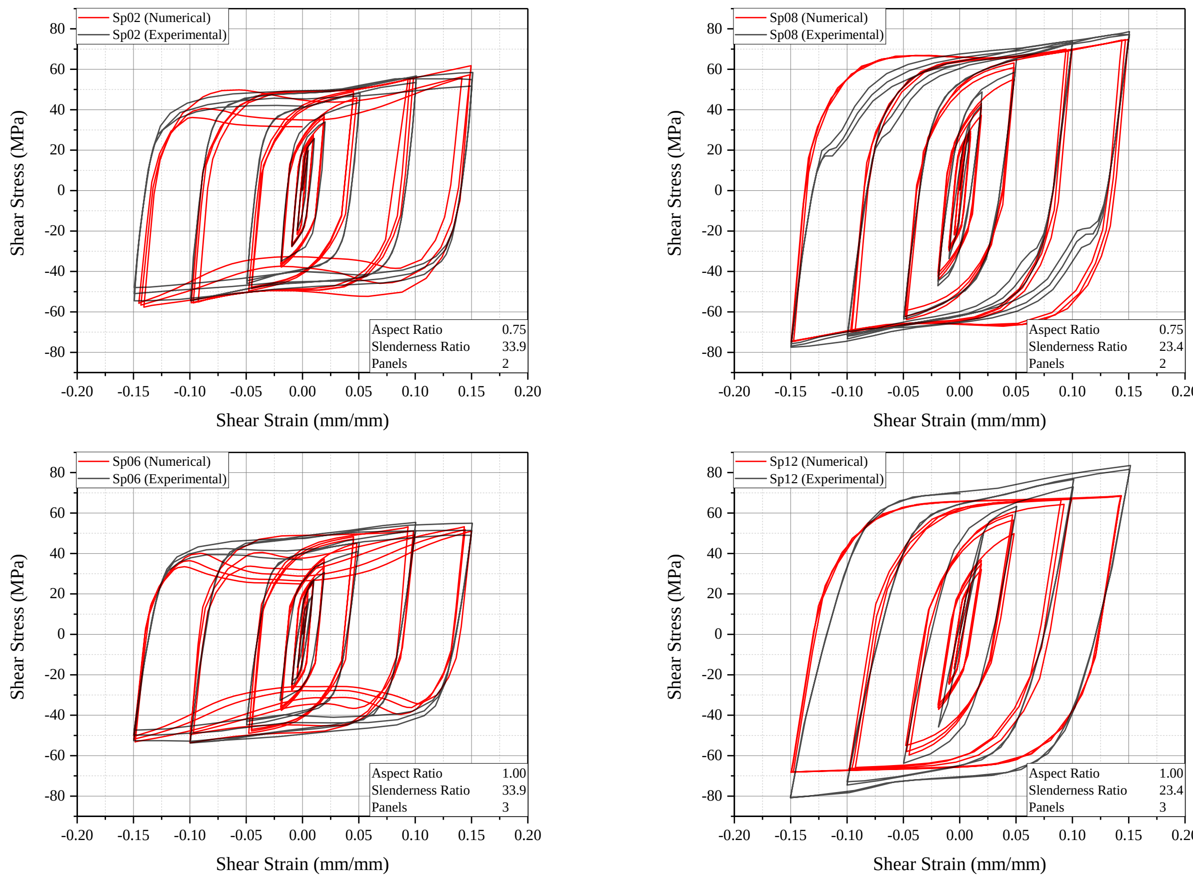


Fig. 2 – Comparison of load deformation behavior of metallic (Al 6063 annealed) shear yielding devices under cyclic loading

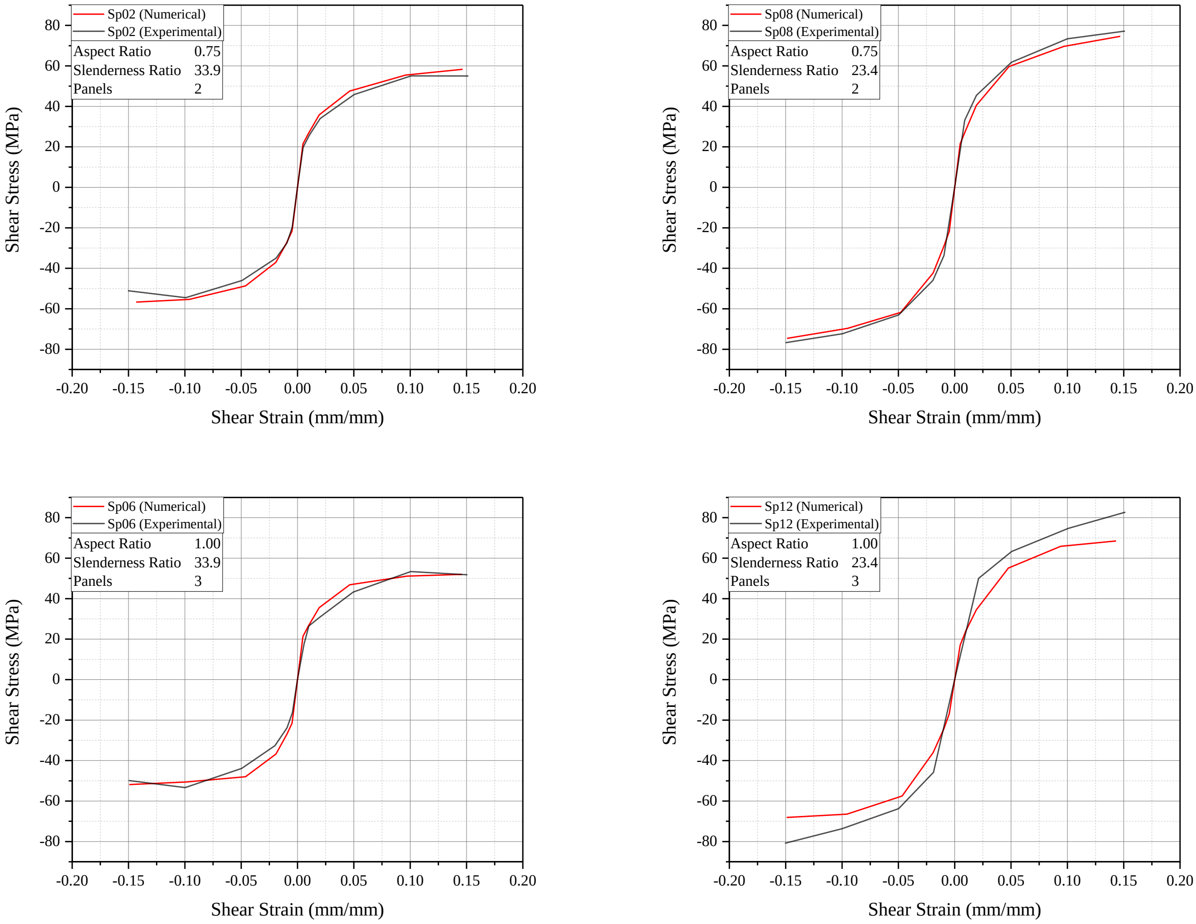
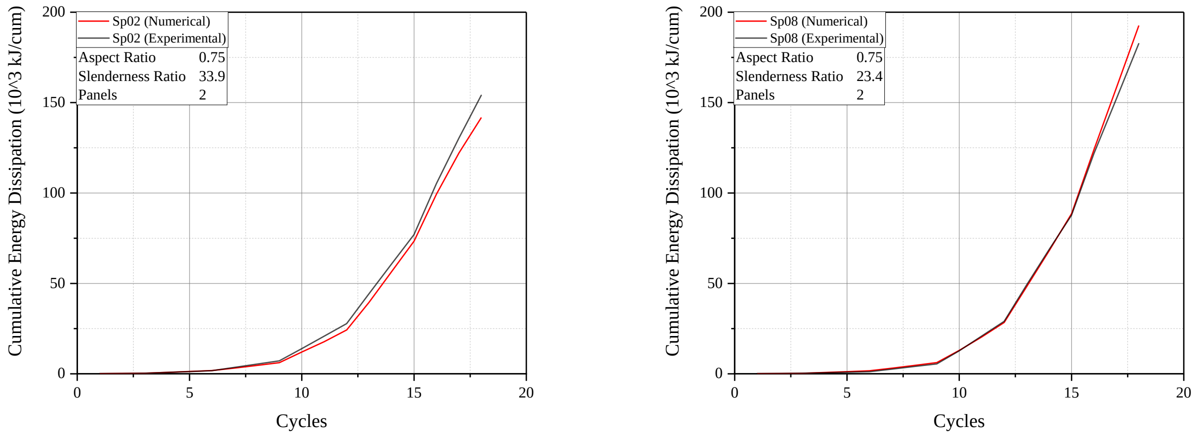


Fig. 3 – Comparison of skeleton curves of metallic (Al 6063 annealed) shear yielding devices



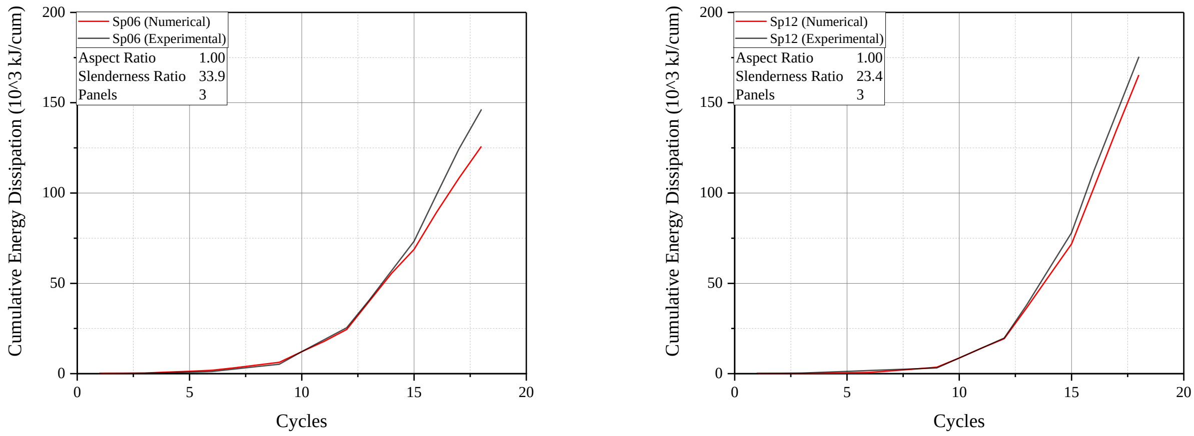


Fig. 4 – Comparison of cumulative energy dissipation of metallic (Al 6063 annealed) shear yielding devices

3. Parametric Study

3.1 General

Parametric study is done to study the behavior of metallic (Al 6063 annealed) shear yielding devices under cyclic loads. Geometry of specimens for numerical investigation is selected to take into account wide range of aspect ratio, slenderness ratio and number of panels. In the selected specimens, aspect ratio is varied in the range of 0.5-1.5, slenderness ratio is varied in the range of 20-80 and number of panels is considered as 1 to 3. Geometry of the selected specimens is given in Table 2. Web depth, flange width, flange thickness and stiffener thickness in these validated specimens are 150 mm, 100 mm, 8 mm and 8 mm respectively. Boundary conditions in numerical investigation are taken same as discussed in previous section. Material parameters are taken from numerically validated results as discussed in previous sections.

Table 2 – Details of metallic (Al 6063 annealed) shear yielding devices for numerical investigation

Specimens	**Web Thickness (mm)**	**Web Slenderness Ratio, *WSR***	**Web Aspect Ratio, *WAR***	**Number of Panels, *n***
Cypl01 to Cypl04	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	0.50	1
Cypl05 to Cypl08	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	0.75	1
Cypl09 to Cypl12	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.00	1
Cypl13 to Cypl16	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.25	1
Cypl17 to Cypl20	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.50	1
Cypl21 to Cypl24	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	0.50	2
Cypl25 to Cypl28	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	0.75	2
Cypl29 to Cypl32	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.00	2
Cypl33 to Cypl36	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.25	2
Cypl37 to Cypl40	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.50	2
Cypl41 to Cypl44	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	0.50	3

Cypl45 to Cypl48	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	0.75	3
Cypl49 to Cypl52	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.00	3
Cypl53 to Cypl56	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.25	3
Cypl57 to Cypl60	7.50, 3.75, 2.50, 1.88	20, 40, 60, 80	1.50	3

3.2 Results and Discussions

Numerical investigation is carried out to study effect of geometric variations in metallic (Al 6063 annealed) shear yielding devices. Load-deformation behavior of some specimens is shown in Fig. 5. It is generally observed that shear yielding devices show stable hysteretic behavior up to 20% shear strain. Shear yielding devices with slenderness ratio (WSR) less than 40, didn't show buckling till at least 15% shear strain. Shear yielding devices with slenderness ratio (WSR) more than 40, buckled at relatively lesser shear strain and thereafter energy dissipation takes place through tension field action. Extreme buckling and severe web deterioration are observed at large shear strain level (more than 15 % shear strain level) in specimens having slenderness ratio more than 40.

Aspect ratio (WAR) also plays an important role in performance of shear yielding devices. As it is observed in Fig. 6 energy dissipation potential is inversely proportional to aspect ratio (WAR). For aspect ratio of 0.75 or lesser, it is observed that energy dissipation of shear yielding devices increases rapidly with decreasing aspect ratio. However, for aspect ratio of 1.25 or more there is not much difference in energy dissipation, and it decreases slowly with increasing aspect ratio.

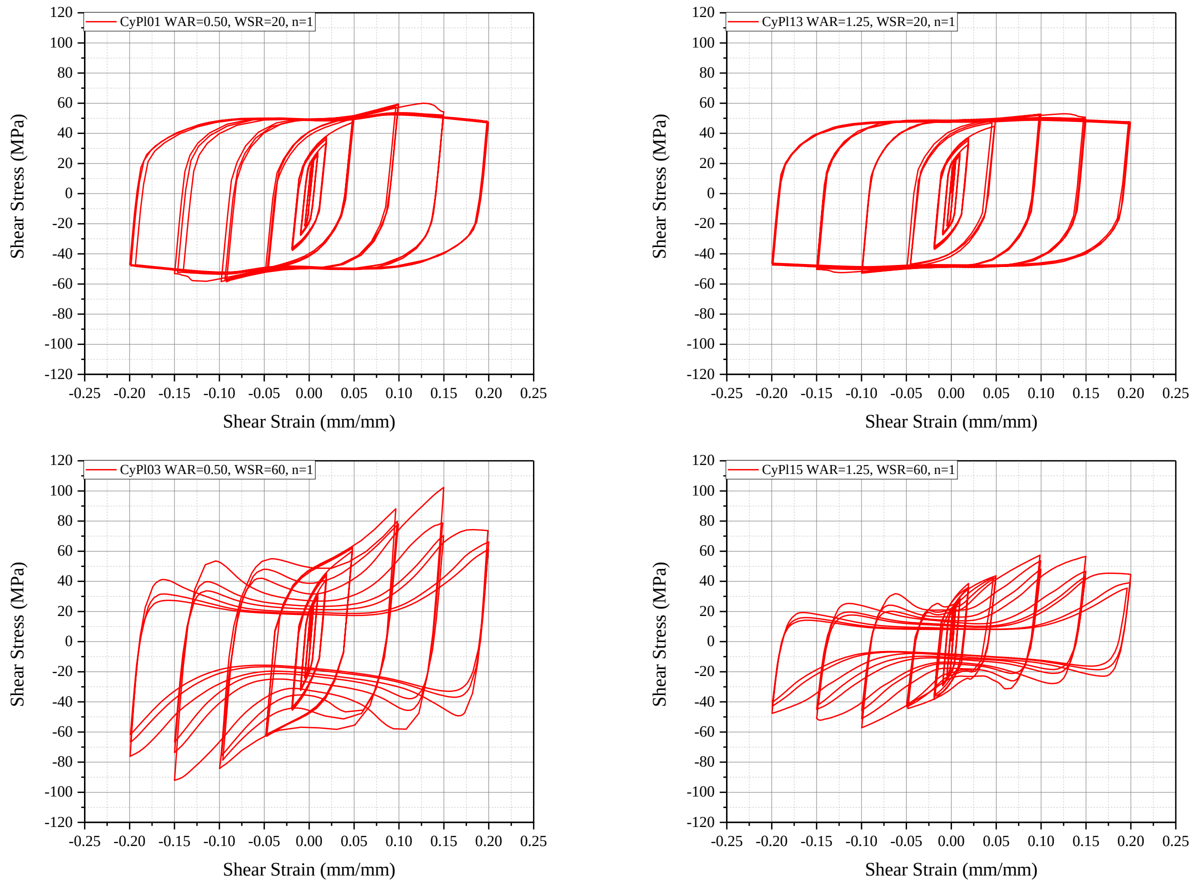


Fig. 5 – Load deformation behavior of metallic (Al 6063 annealed) shear yielding devices under cyclic loading

Number of panels didn't have much influence on energy dissipation potential of shear yielding devices. There is only small increase in energy dissipation of shear yielding devices with increase in number of panels. Equivalent viscous damping at higher strain levels is observed to be ranging from 40-60 %.

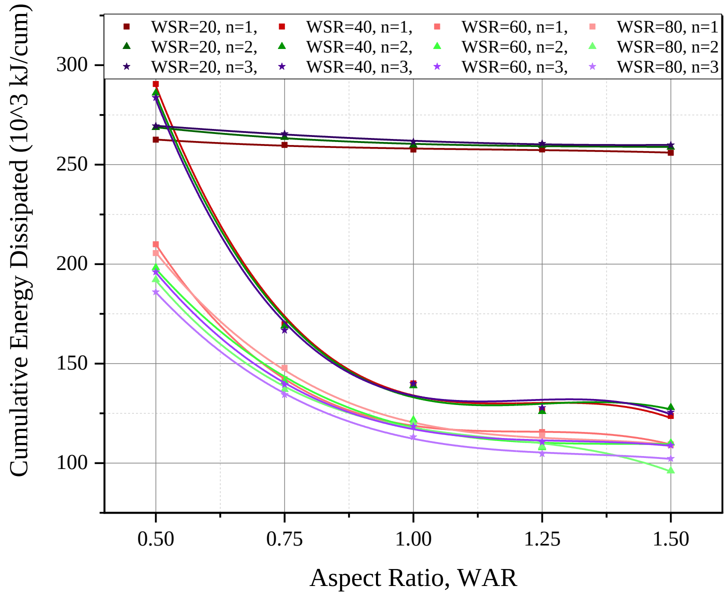


Fig. 6 – Cumulative energy dissipation of metallic (Al 6063 annealed) shear yielding devices

4. Conclusions

Based on the parametric study carried out over wide range of web slenderness ratio (WSR), web aspect ratio (WAR) and number of panels, following conclusions may be drawn.

(i) Metallic (Al 6063 annealed) shear yielding devices have stable hysteretic behavior over large shear strain levels. Thus, these devices are suitable as supplemental energy dissipation devices for structural applications.

(ii) In general, specimens with lower aspect ratio (WAR) shows more energy dissipation potential. This effect is more pronounced for slenderness ratios (WSR) of 40 or more.

(iii) Specimens with lower slenderness ratio (WSR) shows more energy dissipation potential. This effect is more pronounced for aspect ratios (WAR) of more than 0.75. For slenderness ratio (WSR) of 20, aspect ratio doesn't have much influence on energy dissipation potential of shear yielding devices.

(iv) Impact of number of panels is minimal on energy dissipation potential of shear yielding devices. However, energy dissipation increases slightly with increase in number of panels in shear yielding devices.

5. Copyrights

6. References

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