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EXTENDED ABSTRACT

Cyclic Behavior of Hybrid Honeycomb-and-Flexural Yielding Dampers in Chevron CBFs

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1. Introduction

Concentrically braced frames (CBFs) enables high lateral strength and elastic stiffness in comparison with other common systems such as eccentrically braced frames (EBFs) and moment-resisting frames (MRFs). Despite the advantages of the CBF systems, they do not provide considerable seismic energy dissipation capacity due to buckling of the braces under compressive loads. Various types of control systems, such as, friction dampers, viscoelastic dampers, metallic yielding dampers, and etc. have been proposed to mitigate the destructive action of earthquakes on buildings. Among these dampers, metallic yielding dampers are the simplest, cost-effective and easy to fabricate. Among the different metallic yielding dampers, steel plate yielding fuses are the most efficient devices which have been extensively studied by researchers. ADAS is a type of flexural dampers in which the hysteretic energy is achieved through the flexural yielding of steel plates. However, this type of damper suffers from the relatively low initial stiffness (Xia and Hanson 1992). Another type of metallic dampers is the shear link which relies on the inelastic shear deformation of metallic plates under the in-plane loading and offers high initial stiffness and stable energy dissipation (Bakhshayesh et al. 2021). A new shear damper, known as honeycomb structural fuse (HSF), was proposed and developed. The energy dissipation potential of such devices can be improved if the metallic plates are so oriented that they can undergo combined flexure and shear deformation under the action of lateral loading. In this study, a combined honeycomb-and-flexural yielding dampers are proposed as passive energy dissipation systems.

2. Methodology

2.1. Studied dampers

The configuration of the studied models is shown in Fig. 1. The models are fixed at the bottom flange and all degree of freedoms except horizontal and vertical translations of the reference point at the top flange is restrained (Fig. 1). The quasi-static cyclic load in accordance with the SAC test protocol (AISC 341-16 2016) is applied to the reference point of the top flange based on the displacement control method, as shown in Fig. 2. The numerical plan includes 15 models with different groups of dampers. The details of all dampers are enlisted in Table 1, where hybrid models, honeycomb models, and flexural ADAS models designations start with a “HA”, “H”, and “A”, respectively. The numerals in the labels of hybrid dampers indicate sequentially the number of honeycomb dampers, number of cell columns, thickness of honeycomb plate, and thickness of ADAS plates.

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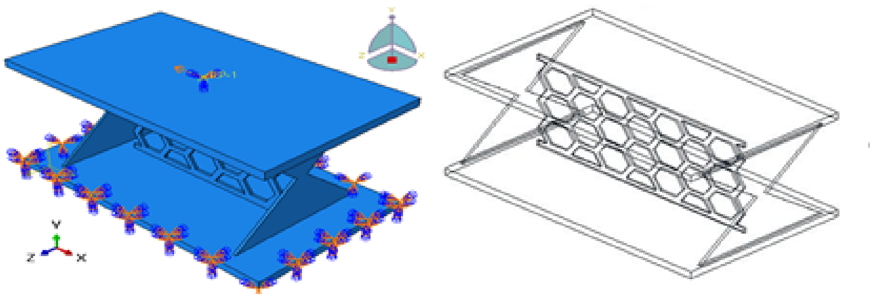


(a) (b)

Fig. 1. Hybrid honeycomb-and-flexural damper: a) Configuration, b) Boundary condition

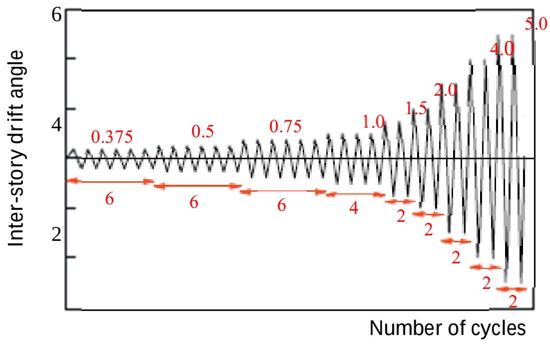


Fig. 2. Loading protocol based on SAC (AISC 341-16 2016)

Table 1. Specifications of different dampers and label of them

Row	Models	HSF							ADAS		
		t (mm)	*h* (mm)	a=t/h	*r*	*c*	T_h (mm)	*L*	*B*	T_f (mm)	*H* (mm)
1	H-1-4-4.8	11.2	37.2	0.30	3	4	4.80	418	-	-	215.69
2	H-1-3-4.8	11.2	37.2	0.30	3	3	4.80	307.1	-	-	215.69
3	H-1-2-4.8	11.2	37.2	0.30	3	2	4.80	196.1	-	-	215.69
4	HA-1-4-4.8-4.8	11.2	37.2	0.30	3	4	4.80	418	250	4.80	215.69
5	HA-1-3-4.8-4.8	11.2	37.2	0.30	3	3	4.80	307.1	250	4.80	215.69
6	HA-1-2-4.8-4.8	11.2	37.2	0.30	3	2	4.80	196.1	250	4.80	215.69
7	HA-1-3-4.8-4.8 *	11.2	37.2	0.30	3	3	4.80	307.1	250	4.80	215.69
8	HA-1-2-4.8-4.8*	11.2	37.2	0.30	3	2	4.80	196.1	250	4.80	215.69
9	A-4.8	-	-	-	-	-	-	-	250	4.80	215.69
10	HA-1-4-3.2-4.8	11.2	37.2	0.30	3	4	3.20	418	250	4.80	215.69
11	HA-1-3-3.2-4.8	11.2	37.2	0.30	3	3	3.20	307.1	250	4.80	215.69
12	HA-1-2-3.2-6.0	11.2	37.2	0.30	3	2	3.20	196.1	250	6.00	215.69
13	HA-2-4-3.2-4.8	11.2	37.2	0.30	3	4	3.20	418	250	4.80	215.69
14	HA-2-3-3.2-4.8	11.2	37.2	0.30	3	3	3.20	307.1	250	4.80	215.69
15	HA-2-2-3.2-6.0	11.2	37.2	0.30	3	2	3.20	196.1	250	6.00	215.69

* The distance between ADAS and HSF plates is limited to 20mm. In other models, the position of ADAS plates is fixed.

2.2. FE modeling

The nonlinear features of finite element ABAQUS software are exploited for the assessment of the hysteretic performance of all the models, accounting for material and geometric nonlinearities. The ABAQUS/Standard module is used to simulate the hysteretic behavior of dampers under static loading condition. The three dimensional 8-node solid elements with reduced integration (C3D8R) are used for all parts. The mesh-size used is optimized with respect to the preliminary works, considering robustness of the results, running-time and computational capacity. The general meshing size of 2mm is adopted for the honeycomb and ADAS plates, while a coarse meshing of around 62.5mm is selected for the top and bottom flanges, as typically shown in Fig. 3. "Tie constraint" is used to connect the honeycomb and ADAS plates edges to the boundary flanges. For tie constraint, the master surface is chosen for the flanges with coarser mesh, whereas the honeycomb and ADAS plates with denser mesh would be slave surfaces. The elastoplastic behavior is described by the well-known Prandtl-Reuss model, combining von Mises's yield criterion. To capture Baushinger's effect, a combined hardening model is used to define the inelastic behavior of the models. The mechanical properties of the models are listed in Table 2.

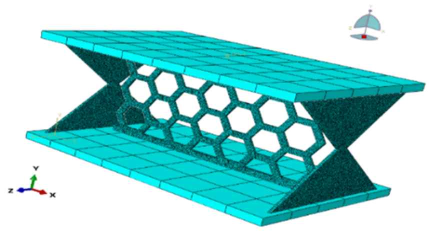


Fig. 3. Finite element meshes for dampers

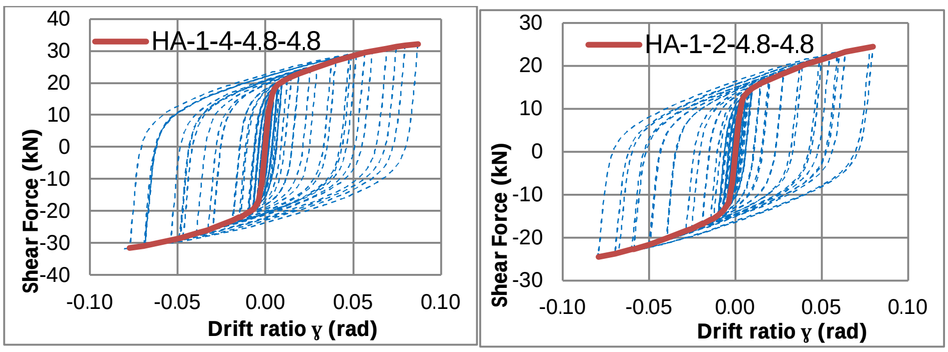
Table 2. Mechanical properties of steel material

Properties of the models	ε(%)	σ_y(MPa)	σ_u(MPa)
Top and bottom flanges	0.42	250	340
HSF	0.43	256	439
ADAS	0.198	297. 50	443.90

3. Results and discussion

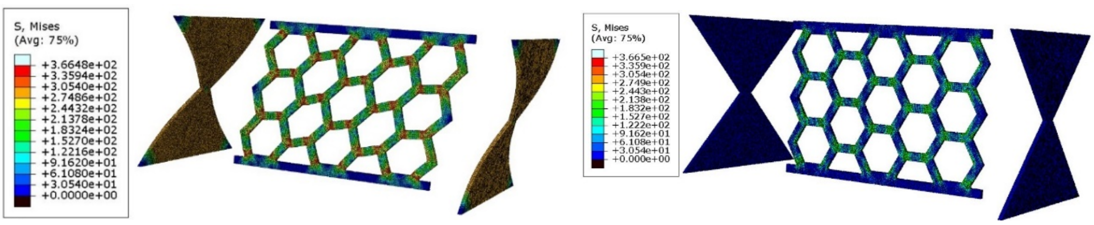
3.1. Hysteretic curves

The hysteretic curves generated from the shear force versus drift ratio curves are shown in Fig. 4 for representative dampers under cyclic loading. Generally, the models showed appropriate hysteretic behavior. All the models exhibited satisfactory cyclic inelastic performance without strength degradation up to drift of 8%. The models tend to experience parallelogram-shaped hysteresis curves. It is also found the hysteresis responses of hybrid dampers are rather stable with large energy dissipation capacity due to the application of ADAS plates. The inelastic stiffness of the hysteresis curves is promoted as the thickness of the ADAS plates increased. Using more honeycomb plates may accentuate plumpness of the hysteresis loops. Fig. 5 shows that the honeycomb cells first yielded under cyclic loading and then ADAS plates experience out-of-plane buckling at higher drift ratios.



(a) (b)

Fig. 4. Lateral force-drift hysteretic curves of the representative models: a) HA-1-2-4.8-4.8, b) HA-1-4-4.8-4.8



(a) (b)

Fig. 5. Von Mises stress distribution along with deformed shapes of HA-1-3-4.8-4.8: a) Drift ratio of 3%, b) Drift ratio of 5%

3.2. Initial stiffness, strength, and energy dissipation

The values of maximum lateral strength, initial stiffness, and energy dissipation capacities of the models are summarized in Table 3. The hybrid models HA-1-2-4.8-4.8, HA-1-3-4.8-4.8, and HA-1-4-4.8-4.8 showed strength increases by 10.5%, 18%, and 13%, respectively, with respect to the counterparts with only honeycomb dampers. Corresponding initial stiffness increases were 99%, 3%, and 2%. These can be compared to the corresponding energy dissipation increases of 23%, 13%, and 10%. ADAS dampers without honeycomb plates have the lowest strength, stiffness, and energy dissipation. Comparing hybrid dampers with one and two honeycombs, having the same geometry, it is observed that the maximum stiffness, strength, and energy dissipation increases were 118%, 87%, 96%, respectively.

A comparison between HA-1-2-3.2-6 and HA-1-2-4.8-4.8 reveal that an increase in the thickness of HSF from 3.2 to 4.8mm and a decrease in the thickness of ADAS from 6 to 4.8mm, can lead to a reduction of 35%, 67%, and 72% in strength, stiffness, and energy dissipation, respectively.

As can be seen in Table 3, the highest strength, stiffness, and energy dissipation capacity with one and two honeycombs, belong to HA-1-4-4.8-4.8 and HA-2-4-3.2-4.8 hybrid damper.

Table 3. Comparison of the initial stiffness, lateral strength, and strength degradation of the models

Row	Models	Maximum lateral strength V_u (kN)	Initial stiffness K_e (kN/rad)	Energy dissipation capacities (MJ)
1	H-1-4-4.8	22.02	5884.00	37.43
2	H-1-3-4.8	15.39	3962.78	26.11
3	H-1-2-4.8	8.90	2046.29	15.15
4	HA-1-4-4.8-4.8	24.91	5986.05	41.27
5	HA-1-3-4.8-4.8	18.22	4064.84	29.61
6	HA-1-2-4.8-4.8	18.22	4064.84	18.61
7	HA-1-3-4.8-4.8 *	18.22	4064.84	29.61
8	HA-1-2-4.8-4.8*	12.04	2148.36	11.04
9	A-4.8	3.73	102.06	0.54
10	HA-1-4-3.2-4.8	15.94	4046.31	9.14
11	HA-1-3-3.2-4.8	11.76	2742.68	6.61
12	HA-1-2-3.2-6.0	11.87	1360.16	5.28
13	HA-2-4-3.2-4.8	29.87	7990.60	17.91
14	HA-2-3-3.2-4.8	21.78	5383.34	12.76
15	HA-2-2-3.2-6.0	18.61	2961.09	8.96

4. Conclusions

In this study, a hybrid damper consisting of honeycomb and ADAS plates capable of yielding in both flexure and shear has been numerically investigated under cyclic loading. Also, the effect of various parameters including number of honeycomb plates, number of cell columns, and thickness of ADAS was studied on the hysteretic behavior. Among the interesting results, the following are noted:

- The failure mechanism of the hybrid damper is as a combination of honeycomb cells yielding and out-of-plane buckling of the ADAS plates;
- The hysteresis responses of hybrid dampers are rather stable and plump due to the application of ADAS plates. Shear strength and energy dissipation of the hybrid damper is at most 105% and 23%, more than the honeycomb counterpart dampers, respectively;
- A reduction in the number of honeycomb cell columns from four to two led to maximum 27% and 55% decreases in strength and energy dissipation capacity of the hybrid dampers, respectively;
- The strength and energy dissipation of the hybrid dampers increased up to 87% and 96%, as the number of honeycomb plates doubled. A comparison between HA-1-2-3.2-6 and HA-1-2-4.8-4.8 reveal that an increase in the thickness of HSF from 3.2 to 4.8mm and a decrease in the thickness of ADAS from 6 to 4.8mm led to a reduction of 35%, 67%, and 72% in strength, stiffness, and energy dissipation, respectively.

5. References

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