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Biaxial configuration of minimal-disturbance arm damper for seismic rehabilitation

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1. Introduction

A seismic rehabilitation technique, named minimal disturbance arm damper (MDAD)[1], was developed to reduce strain demands at the bottom flange of beams in planar steel frames [as shown in Fig. 1]. In practice, hollow structural section (HSS) columns are commonly used to resist earthquake force from any direction, thus it is desirable for MDADs to protect beam-column connections in two horizontal directions. With current configuration of MDAD, this will cost double work time and labor, and moreover increase disturbance to building users with increase of occupied space.

This paper explores and presents the new configuration of MDAD that accommodates bidirectional earthquake force. Its component-level behavior was examined by the quasi-static test of a half-scaled specimens subject to unidirectional and bidirectional loadings.

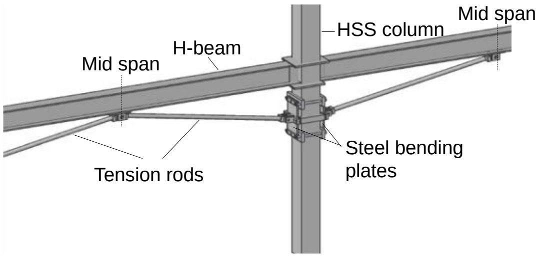
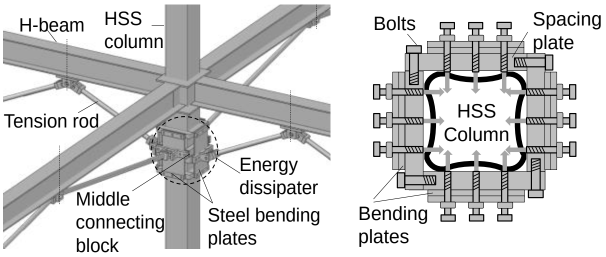


Fig. 1 Rehabilitation of planar steel frame with MDAD

2. Biaxial configuration of MDAD

Fig. 2a shows the biaxial configuration of MDAD. It consists of an energy dissipater that includes four steel bending plates, four tension rods each of which connect a bending plate with a beam and four middle connecting blocks to make a pair of steel bending plates deform together. Fig. 2b displays the detailed design of plate-column attachment. The spacing plates are connected by high-strength bolts and form two rigid rectangular frames attached on the column. Four steel bending plates are attached to the spacing plates and fixed to the column surface using bolts. These bolts provide many contact points between the energy dissipater of MDAD and the HSS column. These bolts are adjusted to accommodate unevenness of column surfaces and provide sufficient friction forces.



(a) overview (b) plate-column attachment

Fig. 2 Biaxial configuration of MDAD

3. Design equations

The biaxial configuration of MDAD is designed as a combination of two MDADs so that each component can behave independently. Thus, the design strength and stiffness of MDAD are also controlled by the beam-end rotations in each direction independently.

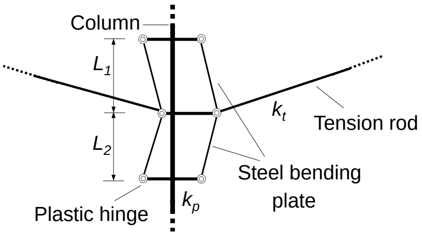


Fig. 3 Mechanical model of MDAD

Fig. 3 shows the force-resisting mechanism of MDAD. The design strength F_y and initial stiffness k_{MDAD} of MDAD are expressed as follows:

$$F_y = b^p \left(t^p\right)^2 \sigma_y^p \times \left(\frac{1}{L_1} + \frac{1}{L_2}\right) \tag{1}$$

$$k_{MDAD} = \frac{k_p k_t}{k_p + k_t} \tag{2}$$

where $k_p = 2Eb_p t_p^3 \times \left(\frac{1}{L_1^3} + \frac{1}{L_2^3}\right)$ and $k_t = \frac{EA_t}{l_t}$. b^p, t^p and σ_y^p are the width of the plates, thickness of the plates and yielding stress of the plates; L_1 and L_2 are the effective length for the two parts of the bending plates. E is the elastic modulus of steel and I is the inertia moment of steel bending plates. A_t and l_t are the sectional area and length of tension rods, respectively.

4. Quasi-static loading test

4.1 Test plan

The performance of MDAD with new configuration was examined through the quasi-static tests.

Fig. 4 shows the test setup where four exterior columns and the cruciform beam formed a rigid frame and this rigid frame supports the center column with MDAD by a biaxial pin. The two jacks in the *x* and *y* directions are fixed to the column bottom of the rigid frame and apply the displacements at the bottom of center column. Two cases of frame are formed: (1) normal case: MDAD in long span subjected to moderate out-of-plane deformation; (2) extreme case: MDAD in short span subjected to large out-plane deformation.

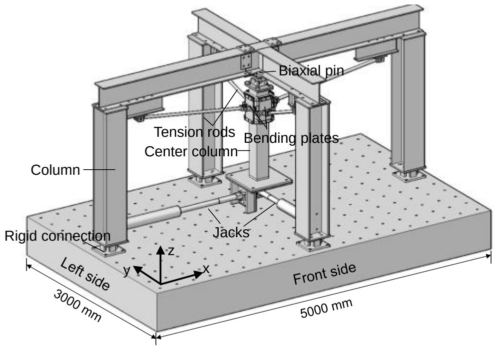
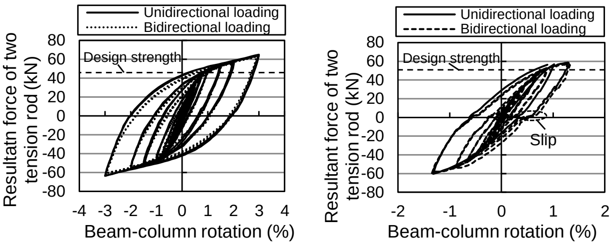


Fig. 4 Test setup

4.2 Test results

Fig. 5 compares the obtained hysteretic behavior under unidirectional and bidirectional loading. No slippage of MDAD was observed during the test thanks to the new plate-to-column attachment. In Fig. 5a, the behaviors of MDAD in unidirectional and bidirectional loadings were nearly same. There was no influence of out-of-plane deformation on the in-plane behavior. Fig 5b shows a slight slip behavior in *y* direction. In both figures, the horizontal dotted line corresponds to the design strength of specimen. The design strength and initial stiffness calculated using Eq. (1) where nearly the same with the values in test.



(a) *x* direction loading (b) *y* direction loading

Fig. 5 Test results

5. Conclusions

The biaxial configuration of MDAD was developed to accommodate the bidirectional seismic force. The main conclusions are summarized as follows:

1) The new plate-column attachment provided sufficient friction by bolts and prevented slippage of energy dissipater.

2) Design equations predicted well the strength and stiffness of MDAD.

3) The test results showed stable hysteresis behavior. In-plane behavior in the direction along each planer frame was not influenced by loading out-of-plane to the planer frame.

References

1) Kurata, M., Sato, M., Zhang, L., Lavan, O., Becker, T., and Nakashima, M.: Minimal-Disturbance Seismic Rehabilitation of Steel Moment-Resisting Frames using Light-weight Steel Elements. Earthquake Engng Struct. Dyn., 45:383-400, 2016