A04

Numerical Simulations for Seismic Rehabilitation of Steel Frames Using Minimal-Disturbance Arm Damper

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1. Introduction

Many rehabilitation techniques have been developed to improve seismic resistant capacity of seismically deficient building stock (FEMA547, 2006). As current seismic rehabilitation techniques involve large construction, often interrupt sight of users, and may include the use of heavy equipment and arduous work (welding / cutting), cost and downtime associated with construction is a major obstruct to building owners. Hence, a relatively small or partial seismic upgrading, rapidly deployable rehabilitation technique may be a good option for reducing indirect cost associated with construction.

Experience shows that large tensile strains at the bottom of flanges in composite steel beam and concrete slab sections are the weak point in steel frame structures. To reduce the demand of bottom flange directly enhance the deformation capacity of beam-column connections and eventually that of the entire frame. Thus, a supplemental load-resisting device that can reduce inter-story drifts through the stiffness and strength increase as well as reduce the bottom flange tensile strains is proposed.

2. Minimal-Disturbance Arm Damper

2.1 Schematic of Minimal-Disturbance Arm Damper

An innovative cost-efficient rehabilitation technique named Minimal-Disturbance Arm Damper (MDAD) is proposed as shown in Fig. 1.

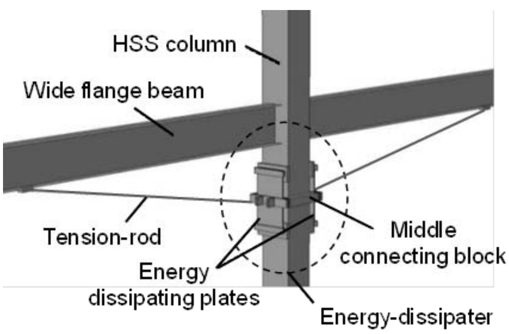

Fig. 1 Schematic illustration of MDAD

The mid-span of beams and the upper part of a column are connected with two tension rods at each side of the column and an energy dissipater. The latter consists of two steel bending plates that are attached to the two facing surfaces of the column using PC- bars. For keeping the equal deformation and yielding of two steel bending plates, middle connecting block is used to connect them. When the beam-column connection suffers the alternatively lateral load, the tension rod at the opening side of beam-column connection bears the tension force and pulls the steel bending plates while the other one keeps no force. This mechanism enables MDAD to dissipate energy with a stable bi-linear behavior examined through component-level testing.

2.2 Modeling of Minimal-Disturbance Arm Damper

Figure 2 shows the model of MDAD, in which the truss elements with tension only behavior are to simulate the tension rods and the rigid link between two springs is to simulate the middle connecting block which makes two plates bend together. The bending plates are modelled by using zero length spring elements which have a nonlinear material behavior.

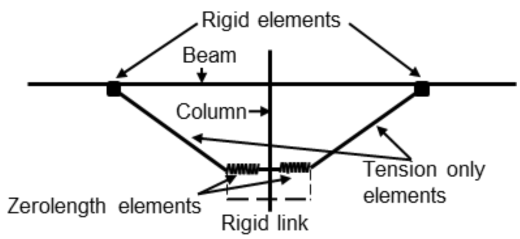

Fig. 2 Modeling of MDAD

3. Numerical Simulation of Four-story Frame

3.1 Rehabilitation plan

MDAD is applied to a four story steel moment-resisting frame. The nonlinear static analysis of this bare frame in OpenSees revealed that the damage or deformation is likely concentrated on the lower stories and thus the layout of MDADs is determined as shown in Fig. 3.

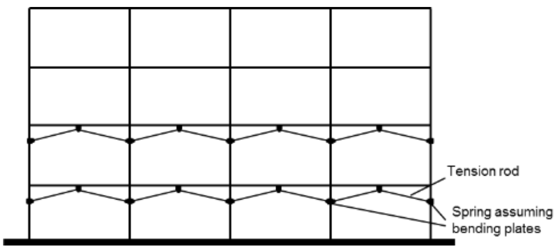

Fig. 3 Layout of MDADs

3.2 Properties design of MDAD

The MDADs increase the stiffness and strength of the bare frame as shown in Fig. 4. Another major benefit of the MDAD is the reduction of the bending moment at beam ends which are subject to positive bending moment and beam bottom flanges sustain large tensile strain. The amount of reduction in positive bending moment is controlled by adjusting the strength of MDAD. In addition, the MDADs are designed to yield earlier than the beam ends by adjusting their initial stiffness. With the target reduction of positive bending moment by 40%, the MDADs are designed to yield at a force of 330 kN and have a stiffness of 165 kN/mm.

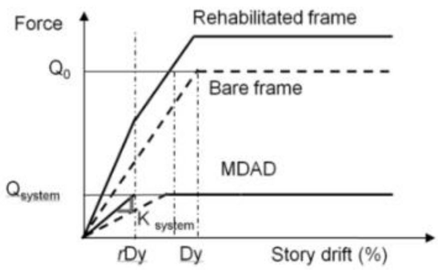

Fig. 4 Designed behavior

4. Analysis results

4.1 Pushover

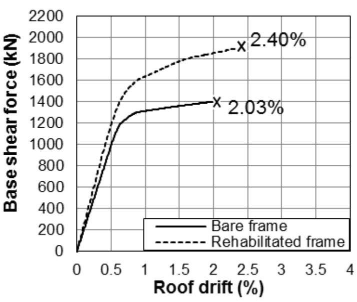

Fig. 5 Comparison of pushover

Figure 5 presents the attained pushover curves of the bare and rehabilitated frames. The displacement capacity of the frame limited by plastic rotation capacity of beam ends increased by 18%. The stiffness and the strength were increased by 22% and 43% with the deployment of the MDADs.

4.2 Response to earthquake

The ensemble of LA 10% in 50 years ground motions are used (Somerville et al., 1997). Table 1 presents the mean + standard deviation of important peak responses. The inter-story drifts of the 1st-stories and the positive plastic rotations are reduced by 13% and 43%, respectively. The MDADs were effective in decreasing inter-story drifts and reducing positive plastic rotations.

4. Conclusions

A supplemental load-resisting device that can reduce inter-story drifts through the stiffness and strength increase as well as reduce the bottom flange tensile strains is proposed. The effectiveness of the proposed device is verified in nonlinear static pushover and earthquake response analyses of a four-story steel moment-resisting frame. MDADs successfully reduced inter-story drifts and positive plastic rotations, which in turn increase apparent deformation capacity.

References

Federal Emergency Management Agency (2006): Techniques for the Seismic Rehabilitation of Existing Buildings, FEMA 547.

Somerville P, Smith N, Punyamurthula S, Sun J (1997): Development of ground motion time histories for Phase-2 of the FEMA/SAC Steel Project. Report no. SAC/BD-97-04. Sacramento (CA, USA).

Table 1 Effect of MDAD on frame under LA10-50

	Peak roof drift [%]	Peak 1st story drift [%]	Peak 1st + 2nd story drift [%]	Peak hinge positive plastic rotation [rad]
Bare frame	1.99	2.53	2.58	0.021
Rehabilitated	1.84	2.20	2.12	0.012