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Development of Design Methodology for Minimal-Disturbance Arm Damper

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1. Introduction

Minimal-disturbance seismic rehabilitation is a design scheme that aims to increase seismic capacities of existing buildings, while minimizing the disturbance to building users. Under the design scheme, a rehabilitation technique named Minimal-Disturbance Arm Damper (MDAD)[1)] was developed for steel moment-resisting frames. MDAD aims to reduce strain demands at the bottom flange of beams, which are considered as critical locations determining the deformation capacity of the frames.

The numerical study on rehabilitation of a four-story steel moment-resisting frame revealed that MDADs reduce effectively the positive plastic rotation of beam ends, which demands large strain at bottom flanges, even without considerable reduction of roof drifts[2)]. To further examine the effectiveness use of MDADs, this paper explores the development of a design procedure with the primary focus on the reduction of the plastic hinge rotation at beam ends.

2. Design of MDAD

2.1 Design development

Figure 1 shows an idealized pushover curve of a bare frame, an MDAD, and the frame rehabilitated with the MDAD. Both the bare and rehabilitated frames are assumed to have a beam-collapse mechanism. In the pushover curve, the bare frame presents a bilinear behavior, where both beam ends are expected to yield at most the same time. Meanwhile, the rehabilitated frame shows a multi-linear form.

An anatomy using the substructure model in Fig. 2 helps understanding the role of MDAD. The model assumes pinned boundary at the story mid-height and the same deformation at the column tops. When seismic force acts on the frame, the MDAD yields first at point 1 in Figs. 1 and 2. For larger force, the beam end under negative bending yields (point 2) as the MDAD reduces the positive bending moment. Finally, the beam end under positive bending (point 3) yields.

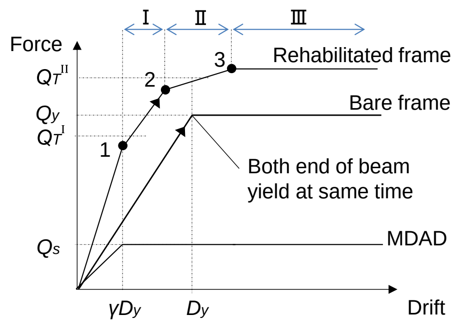

Fig. 1 Pushover curve for bare and rehabilitated frame.

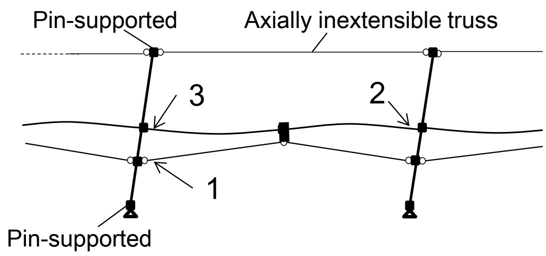

Fig. 2 Structure representative element.

The regions I and II in Fig. 1 represent the elastic stages of the beam under the positive bending, where an elastic method can be developed to evaluate the reduction in the positive bending moment under design force. Conversely, the design method proposed here intends to limit the plastic hinge rotation in stage III as it is considered more direct in enhancing the deformation capacity of existing frames. Taking the advantage of plastic analysis method, complex inelastic behavior was simplified and design equations are developed in the following sections.

2.2 Design method in plastic stage

Fig. 3 shows the substructure that approximates the condition of the beam in the frame after yielding at both beam ends. In the substructure, a one-span beam is pin-connected to a column at one end and pin-supported at the other end. At the pin near the column, the beam is subject to two counteracting bending moments, M_1, which are equivalent to the yielding moments of the beam in positive bending. The other end of the beam and the joint are both subject to the yielding moment of the beam in negative bending, M_2.

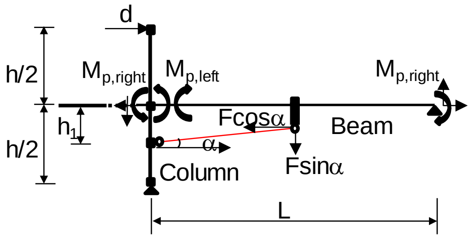

Fig. 3 Substructure for plastic design.

Based on the principle of virtual work, the positive plastic hinge rotation θ at the left beam end is related to the lateral displacement d at the column top and the MDAD strength F_y using Eq. 1. The coefficients a_1 to a_4 are the rotation θ due to a unit moment M_1 = 1, M_2 = 1, a unit damper force F_y =1 and a unit displacement d=1, respectively. These coefficients are constants computed for any frame geometries.

Rearranging and simplifying Eq. 1, Eq. 2 is derived to assess the required strength F_y of MDAD for limiting the positive plastic hinge rotation θ to a desired value at the design drift d/h.

$$\theta = a_1 \times M_1 + a_2 \times M_2 + a_3 \times F_y + a_4 \times d \qquad (1)$$

$$F_y = (-\theta + A + drift)/B \qquad (2)$$

where A=a_1×M_1+a_2×M_2, $drift$=a_4×d= d/h, and B=a_3.

3. Application of developed design

The effectiveness of the developed design was examined through earthquake response analysis for LA 10% in 50 years ground motions in the SAC steel project[3)]. The target frame and rehabilitation plan are shown in Figure 4. The detailed dimensions of the frame are reported in the reference 2). The dimensions of MDADs are designed by the plastic design and using Eq. 2 and the plastic hinge rotation at beam ends are limited to 0.015 rad or smaller.

Table 1 shows the results of the dynamic analysis. The MDAD successfully limited the positive plastic hinge rotation at beam ends within the target value by following the developed design. Although the roof drift remained almost the same, the distribution of story drift became more uniform.

4. Conclusions

A design procedure of MDADs directly limited the local deformation of the critical locations in steel moment-resisting frames, i.e. beam ends subject to large positive bending moment. The plastic design method considering substructure enabled to derive a design equation that relates the required strength of MDAD with story drift and beam end plastic rotation. The validity of the method and equation was confirmed through the numerical application to 4-story steel frame. After rehabilitation, the amount of plastic hinge rotation was successfully limited within the target in the dynamic analysis.

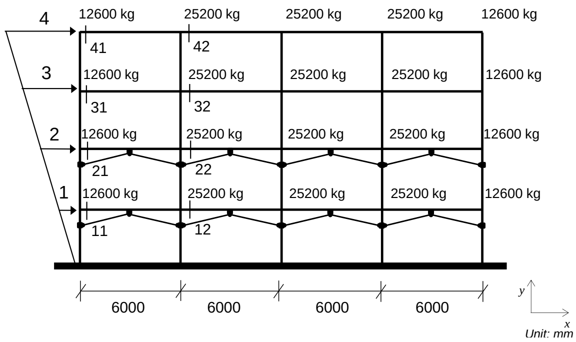

Fig. 4 Frame and layout of MDADs

Table 1 Mean plus standard deviation values for peak responses

		Bare frame	Rehabilitated
Roof drift [%]		1.91	1.88
Positive plastic hinge rotation [rad]	RF	0.002	0.005
	4F	0.009	0.013
	3F	0.018	0.014
	2F	0.020	0.013

Acknowledgments

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References

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