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Improving seismic performance of framed structures with steel curved dampers

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A B S T R A C T

Moment resisting frames possess significant ductility and thus are commonly used in earthquake-resistant designs. However, excessive deformation due to lower stiffness and structural strength limits the applicability of this system. Steel curved dampers are proposed in this study to improve this system's structural performance. The curved dampers were laser-cut from steel plates with the desired geometries and placed at the beam to column regions. The damper behavior is governed by its length and angle between the two ends. A series of cyclic loading tests were performed on steel frames with various curved damper placements to evaluate the curved damper effect on the structural performance. It was found from the test results that the frame strength was higher when the damper angle was smaller. It was also observed from test result comparisons that significant improvements in strength, stiffness and energy dissipation were achieved when the proposed curved dampers were added to the moment resisting frames. Information obtained from this preliminary investigation will be used as data for comparisons in further study of dynamic behavior of multi-story framed structures.

1. Introduction

Steel rigid frames and semi-rigid frames are commonly used for construction in areas with seismic activities [1–8]. Rigid frames possess high strength to resist lateral force induced by earthquakes. However, rigid frame design concerns have been raised due to a number of failures related to the fractures of welded beam-to-column connections under major earthquakes. Heavy stress concentration in the welds causing premature brittle failure in the connections leads to major strength deterioration and performance loss [9–15].

Semi-rigid frames are usually constructed using bolt connections between the beams and columns. This frame construction exhibits adequate deformation capability when subjected to cyclic loads. The semi-rigid higher deformation capability greatly reduces the brittle failure potential of the structures, however, excessive deformation due to lower structural stiffness and insufficient energy dissipation in the bolt connections remain concerns when adequate seismic performance is required [16–23]. Design modification in the beam-to-column regions that sustain structural strength and increase energy dissipation capability is essential [24–32].

This study focused on framed structure performance improvement by integrating semi-rigid frames with new steel curved dampers in the beam-to-column joint corner regions, as shown in Fig. 1. The proposed curved dampers were laser-cut from steel plates with the desired geometries. Curved dampers were hinged to the beams and columns to simplify the connection designs. The distance between the damper centroid and the load action axis was equivalent to a prescribed eccentricity. Therefore, the curved damper could be easily bent when an external load was applied to the structure, yielding to dissipate energy at early stage frame deformation, preventing major structural members from being damaged. A series of cyclic load tests were conducted on the steel frames with various curved damper placements. Test results obtained from this preliminary investigation, such as frame strength, stiffness and energy dissipation were compared to evaluate the proposed design method effectiveness and justify its feasibility in engineering practice.

2. Strength of curved dampers

The curved damper geometry is shown in Fig. 2. As indicated in this figure, an additional moment ($P\Delta$) due to the curved damper eccentricity will be incurred when the damper is subjected to an axial force, P. The eccentricity magnitude, Δ, can be evaluated using the following expression:

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Nomenclature

P	axial force
P_y	yielding strength of the damper
Δ	eccentricity
R	radius of the curved damper
θ	angle between the two ends of the damper
L	damper length
σ_{max}	maximum stress
σ_y	yielding stress of the material
d	depth of the damper
t	thickness of the damper
I	moment of inertia of the curved damper

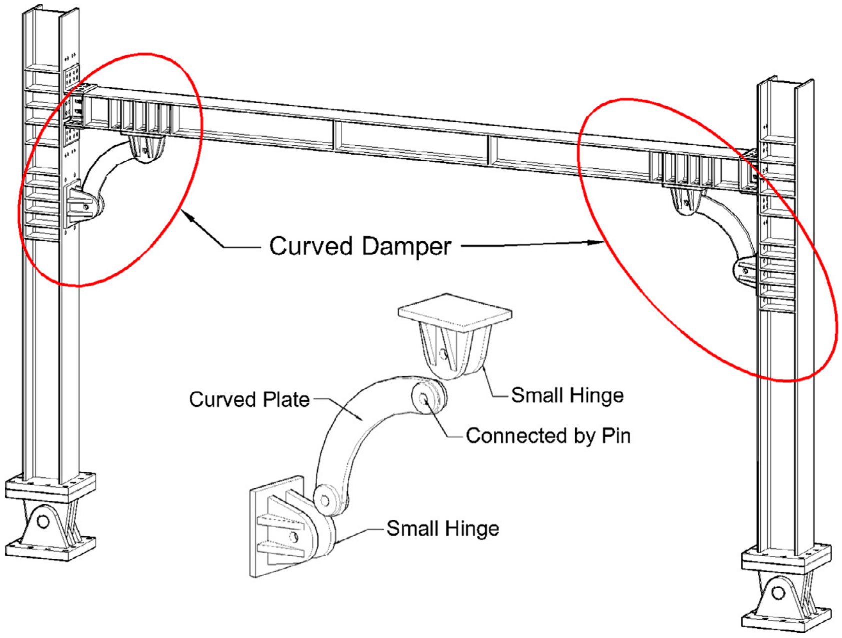

Fig. 1. Description of the design proposal.

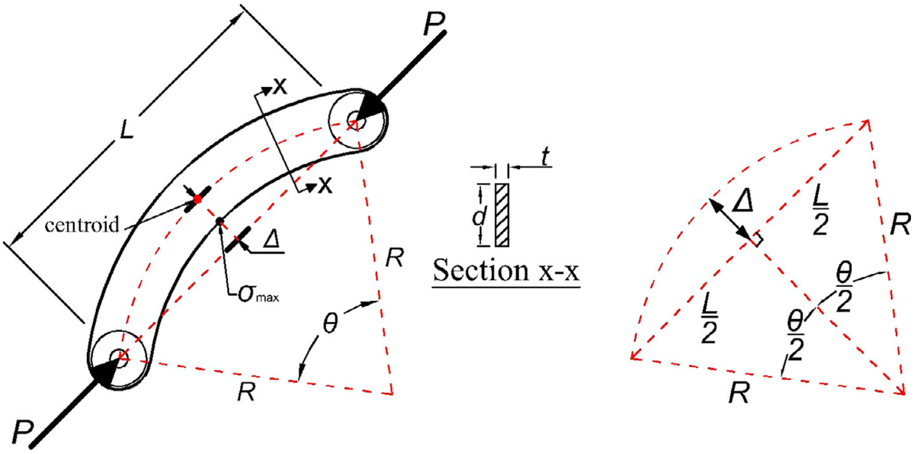

Fig. 2. Geometry of the curved damper.

$$\Delta = R - R\cos\frac{\theta}{2} \tag{1}$$

In which, R is the radius of the curved damper and θ is the angle between the two damper ends, as defined in Fig. 2. The relationship among the damper length, L, damper angle, θ, and damper radius, R, can be defined by the following:

$$\frac{L}{2} = R\sin\frac{\theta}{2} \tag{2}$$

Therefore, the curved damper eccentricity can be obtained using:

$$\Delta = \frac{L(1 - \cos\frac{\theta}{2})}{2\sin\frac{\theta}{2}} \tag{3}$$

For curved damper subject to axial force P, the maximum stress (σ_{max}) on the curved damper is located at the inner-center of the curved damper and can be evaluated using the following expression: