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Brace performance with steel curved dampers and amplified deformation mechanisms

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ABSTRACT

This study focused on the performance evaluation of new brace designs that adopted steel curved dampers with amplified-deformation mechanisms. A series of cyclic load tests on steel curved dampers and amplified-deformation braces with various damper dimensions, subjected to cyclic increasing displacement histories, were conducted. Expressions for amplified-deformation brace strength estimation were derived and proposed for engineering design references. Test results showed that significant viscous damping, approximately 25.8–36.65%, was achieved in the proposed brace, thus providing an effective mechanism to upgrade the dynamic characteristics of the structures. It was also found from the test results that the proposed braces sustained large deformation equivalent to 5% story drift without damper local buckling, exhibited stable hysteretic behavior throughout the complete load process and dissipated significant energy using amplified damper deformation, when steel curved dampers with plate depth/thickness ratios smaller than four were adopted. Simultaneous accomplishments in high strength, large deformation capability and significant energy dissipation validated the applicability of the proposed brace design to earthquake-resistant structural designs.

1. Introduction

Steel moment resisting frames (SMRFs) are adopted in framed structural designs because of the systems' significant energy dissipation at large deformation. However, excessive deformation caused by the lower structural stiffness hampers system applicability when structural drift is concerned [1–9]. Concentrically Braced Frames (CBFs) possess adequate strength and stiffness, thus are commonly used as remedies for steel frame structural seismic designs. The effective structural stiffness of CBFs prevents excessive deformation during load application [10–17]. However, the lower deformation capacity and the brace buckling under high axial load limit the application of such systems when structural ductility and economic competitiveness are concerned. A number of studies on the performance of buckling restrained braces (BRBs) subject to seismic load have been conducted [18–20]. It has been reported in these studies that the BRB performance was greatly dependent upon the adequate deformation development of the core plates. Therefore, modification to amplify the deformation of energy dissipation device in brace design is essential for structural performance improvement. To further enhance the structural performance of steel frame designs, an improved design that simultaneously sustains the significant SMRF ductility and the effective brace stiffness is proposed in this study.

This proposal combines the traditional brace member with an effective steel curved damper (SCD), previously developed by the authors [21], to form a new brace member design, shown in Fig. 1. The new brace member application to framed structure design can be explained by the scenario shown in Fig. 2. In this design the SCD can be hinged to the brace at the member center. The brace can be conveniently pin-connected to the framed system at the two device ends. It can be observed from the figure that the SCD can be easily deformed due to eccentricity between the damper and the load axis. The SCD deformation can be significantly amplified and multiply folded greater than the relative brace displacement through the lever mechanism. Since the brace is equipped with an amplified deformation damper, the proposed brace is named the A-Brace. As steel damper efficiency is greatly deformation-dependent [22–28], the amplified SCD deformation in the A-Brace provides significant energy dissipation mechanism when the framed structure is subject only to small drift.

To validate the applicability of the proposed A-Brace design, a series of cyclic load tests on the SCD and A-Brace with various damper dimensions were conducted. The test specimen responses, including strength, stiffness and energy dissipation, were compared to define the effectiveness of the proposed method and establish design references.

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Nomenclature

δ_{br}	brace deformation ratio
δ_{SCD}	SCD deformation ratio
Δ_{br}	brace deformation
Δ_{SCD}	SCD deformation
Δ	eccentricity of SCD
L_{br}	length of brace
L_{SCD}	length of SCD
L_1	length of rigid truss
L_2	distance between hinge bottom and truss joint
L_3	distance between SCD pin and truss joint
L_4	distance between intersection points on trusses
α	initial incline angle of brace
β	angle between SCD pin and rigid truss
λ	variation in brace incline angle
H_h	hinge height
P_{br}	brace yield strength
P_{SCD}	SCD yield strength
M	moment at the center of SCD
I	moment of inertia of the curved damper
d	depth of the damper
t	thickness of damper
σ_y	yield stress of the material
σ_u	ultimate stress of the material
ζ	equivalent viscous damping
E_D	total energy dissipated
P^+	maximum strength in a cycle
P^-	minimum strength in a cycle
D^+	maximum displacement in a cycle
D^-	minimum displacement in a cycle

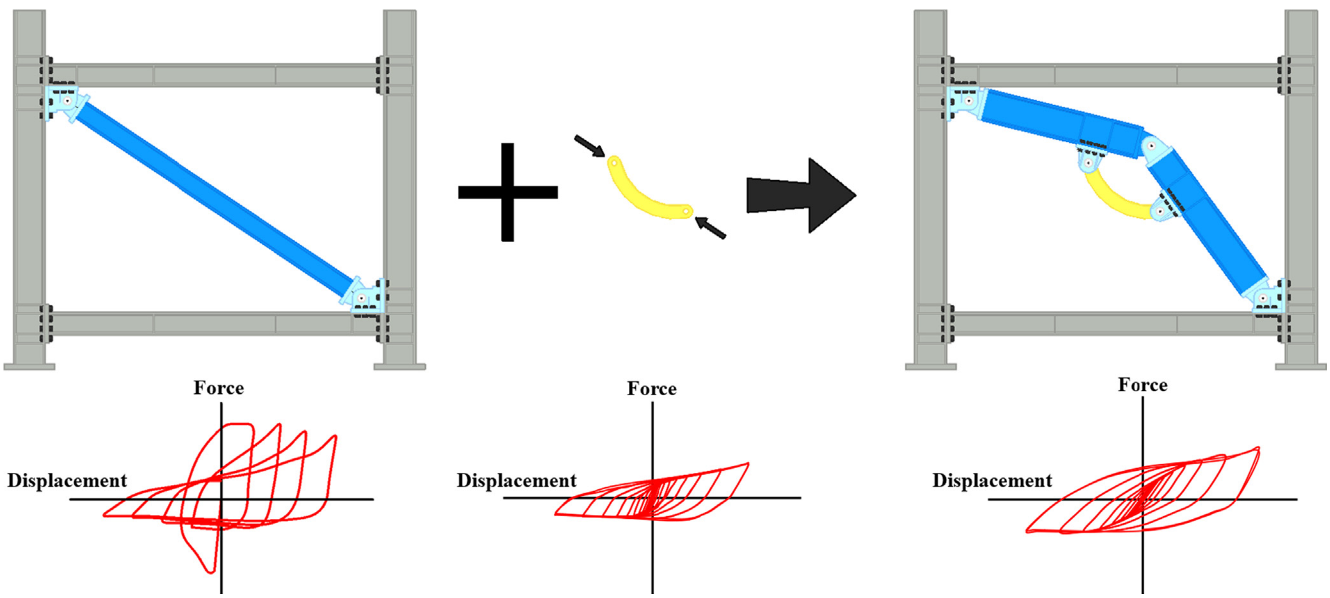

Fig. 1. Design concept of brace with steel curved dampers.

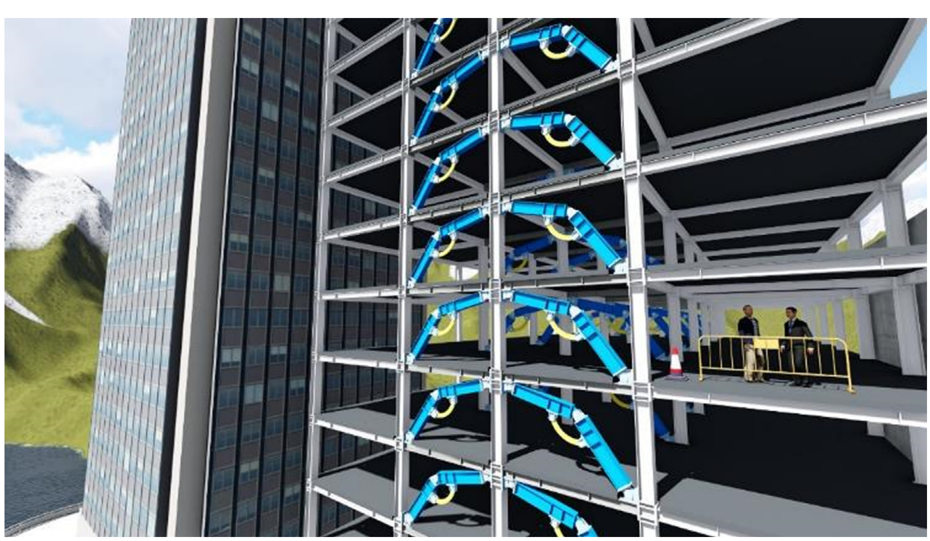

Fig. 2. Scenario for application of braces with SCD dampers to structural frame designs.