STEEL BRACE DAMPER WITH PROGRESSIVE FAILURE MECHANISM

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ABSTRACT

A new type of passive damper, consisting of energy plates, gap system, and progressive failure mechanism. The progressive failure mechanism is composed of standard bolt holes and slots with various lengths to control the initiation of various energy plates. This design not only enhanced the deformation capacity of the brace. In addition, the design provided a scheme to allow partial failure of the energy plates, thus effectively sustained the performance of the structure.

Keywords: steel; brace; damper.

A. INTRODUCTION

Fully welded steel moment frames, even though possess prequalified connection details, are known to be vulnerable to major seismic loading. This phenomenon was confirmed in the Northridge Earthquake of January 17, 1994, in which more than 150 buildings experienced brittle fractures in their welded moment connections. This premature brittle failure of welded connection was also noticed in the 1995 Hyogo-ken Nanbu (Kobe) earthquake (Abolmaali, et al., 2009.). Such fractures are difficult to detect during the post-earthquake inspection. Based on the investigation results, many types of connections have been proposed for retrofit and new design for steel moment frames in high seismicity regions. One of those is the bolted moment connections using high strength bolts, as the strength of this connection is more predictable compared with others involving welding.

Although frame with bolted moment connections possesses high ductility, the lower strength and stiffness of this structure at small deformation remains a concern. In order to enhance the performance of such structures, design with additional device such as buckling restrained brace (BRB) can be a remedy.

BRB, has become popular metallic energy dissipation device, widely used in the United States and other countries. Strength and stiffness of BRB can be adjusted independently, and can be easily installed in a frame similar to the conventional diagonal bar. However, the failure of steel core of a BRB after earthquake excitation is difficult to inspect without interrupting the braced frame (Tremblay, et al. 2006). This may require replacement of the seismic dampers of the entire building after a moderate earthquake, even though BRB still possesses adequate energy dissipation capacity to protect the main structure. In the design of BRB, the un-bonding material, due to tight fabrication tolerance, contributes largely to the manufacturing costs, thus makes it unaffordable in the design of many conventional structures (Benavent-Climent 2010). Therefore, development of brace member with higher economic competitiveness is essential.

This study proposed an effective strengthening scheme by using steel plates with progressive failure mechanism. This design simplified the replacement by separating the damper into different parts. The separate parts of the damper dissipated energy in sequence at different drift ratios, showed in Figure 1. After the earthquake, only partial replacement of the yielded plates is necessary, which effectively reduces the repairing costs and makes the design competitive. Series of cyclic loading tests on the proposed brace dampers were carried, so that the design recommendation of the proposed method could be validated.

B. LITERATURE STUDY

Evaluation of Structural Performance

A wide range of structural performancerequirements could be desired by variousbuilding owners. Four Structural Performance Levels defined in the standard of FederalEmergency Management Agency (FEMA) have been selected to correlate the mostcommonly specified structural performance requirements. The Structural PerformanceLevel of a building is usually categorized by Immediate Occupancy (S-1), Life Safety (S-3), and Collapse Prevention (S-5).

Structural Performance Level S-1, Immediate Occupancy, is defined by the postearthquake damage state that remains safe to occupy, essentially retains the preearthquake design strength and stiffness of the structure. Structural Performance Level S-3, Life Safety, defined as the post-earthquake damage state that includes damage tostructural components but retains a margin against onset of partial or total collapse.Structural Performance Level S-5, Collapse Prevention, defined as the post-earthquakedamage state that includes damage to structural components such that the structurecontinues to support gravity loads but retains no margin against collapse.

Performance Level criteria for Braced Steel Frame is also define in FEMA andis shown on Figure 2.1. This criteria relates the Structural Performance Levels to thelimiting damage states for elements of lateral-force-resisting systems. The drift valuesgiven in table are typical values provided to illustrate the overall structural responseassociated with various Structural Performance Levels.

Concentrically Braced Frame

Concentrically braced frames (CBF) can be designed to provide adequate stiffness to reduce inter-story drifts and to provide an energy dissipation mechanism in structures that can undergo severe seismic ground motions. The hysteretic behavior of CBF highly depends on the inelastic cyclic behavior of the installed steel braces.

Hysteretic loops of an axially loaded brace are usually unsymmetrical in tension and compression, when the brace buckling is exhibited. The influence of this postbuckling e behavior must be taken into account when effective structural design is considered.

C. METHODOLOGY

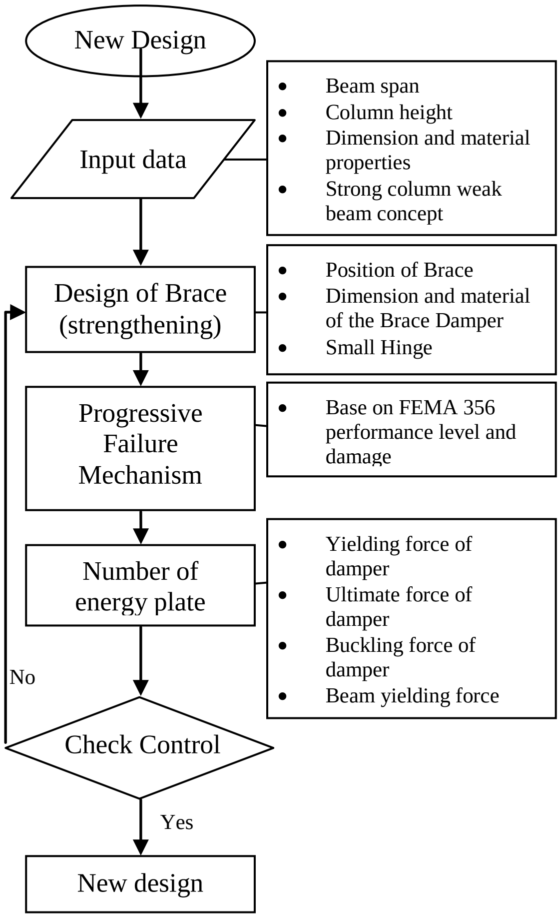


Figure 1. Design Procedure
(Source: Author)

Strength of the damper

The parameters that affect the strength of damper plate are section width (b), thickness (t), and height (x), as showed in Figure 2.

Since damper is composed of various number of plates, the strength of the damper can be estimated by the sum of the component plates. Assuming that F and n are the damper strength and number of damper plates, respectively, the shear force resisted by each plate is equal to:

$$\boldsymbol{f = \frac{F}{n}} \quad \textbf{(1)}$$

According to the boundary conditions shown in Figure 3, this shear forceincurs a linear variation of moment along the energy plate. When the plastic moment ofthe energy plate is reached at the ends of the plate, the following expressions can beobtained:

$$\boldsymbol{Mp = \frac{tb^2}{4}.\sigma_y} \quad \textbf{(2)}$$

$$\boldsymbol{f = \frac{tb^2}{4}.\frac{\sigma_y}{x}} \quad \textbf{(3)}$$

Where Mp is the plastic moment at the fixed end of the device, t is the thicknessof the plate, b is the width of the plate, x is the distance measured from the free end to thefixed end of the plate, and σ_y is the yield strength of the steel.

The specimen tests, three types of combination were used to fabricate the braced members. In which, one brace damper was designed with no gap (defined as one stage component) between the energy plate and the loading system as a reference, and two brace dampers with different number of energy plates that were designed with medium and large gaps (defined as two and three stage component which will develop progressively one after one), as shown in Table 1. This combination was made to evaluate the influence of damper design on the behavior of brace. Specimen label is also shown in Table 1. Detail of energy plate and brace damper configuration showed in figure 4 and 5, respectively.

Progressive loading Mechanism

The basic concept for the damper design is to make the energy plate consecutively working one after one. Thus, loading mechanism of the damper is composed of bolt connections with standard hole and slots with various lengths. This mechanism enables the damper plates to function at various desired drifts to achieve effective structural resilience.

In this study, the damper plates were designed to function at various drifts. That is, function of first set of damper plate at small deformation (0.5% story drift), function of second set of damper plate at 1% story drift and function of third set of damper plate at 2% story drift. Based on the structural geometries, 1% inter-story drift will incur 0.61% deformation, approximately 20 mm, on the damper plate.

D. RESULTS AND DISCUSSION

Hysteretic behavior of the test specimens are shown in Figure 7, in which, the ultimate capacity under cyclic displacements, and the extent of the plastic stage in the energy plate along the length of the brace can be compared.
It can be found from the comparison that, no strength deterioration was observed before 1% drift in all test specimen. After 1% drift, the strength of test specimens continued to increase due to tensile action of the dampers. Stable hysteretic behavior was sustained when the specimen was loaded to 2% drift as shown in Table 2. However, the specimens exhibited various responses when the drift was increased to 3%.
That is, the dampers with progressive failure mechanism remained functional in strength and energy dissipation until 3 % drift. However, the others displayed fracture in the energy plates.
Figure 6 show the set up for component test. Tests were conducted by cyclic load according to SAC-Loading Protocol until 3% drift ratio with servo-controlled hydraulic actuator.

E. CONCLUSION

By using progressive failure mechanism, the strength and energy dissipation capacity of the dampers can be progressively increased. The stiffness of the damper can be adequately sustained until large deformation.

Response comparison validated deformation capacity of framed structures was significantly improved and only partial replacement was required after the loading. This design can reduce the rehabilitation time and cost and effectively can meet the requirements for FEMA Structural Performance Design, which justified the applicability of the proposed method.

Appendix

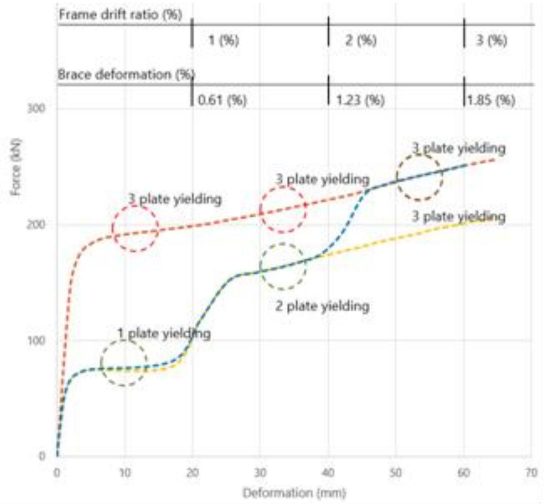


Figure 2. Rehabilitation Scheme of Brace Damper
(Source: Author)

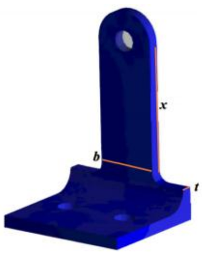


Figure 3. Detail for each section of Energy plate
(Source: Author)

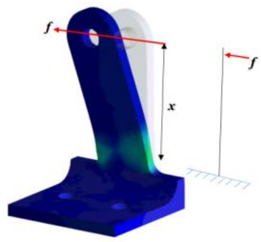


Figure 3. Plastic moment reached in the end of the energy plate
(Source: Author)

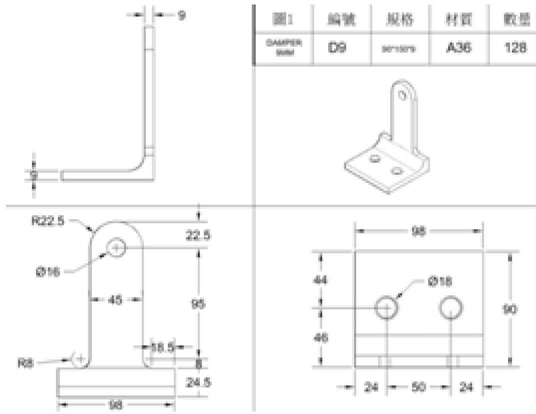


Figure 4. Energy Plate Geometry
(Source: Author)

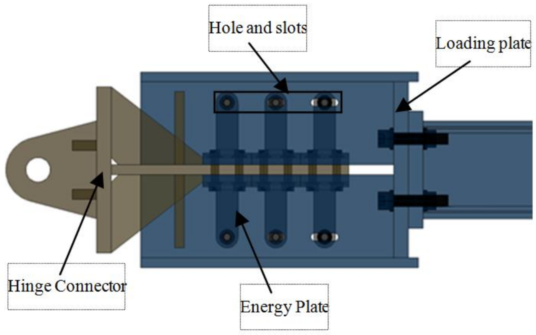
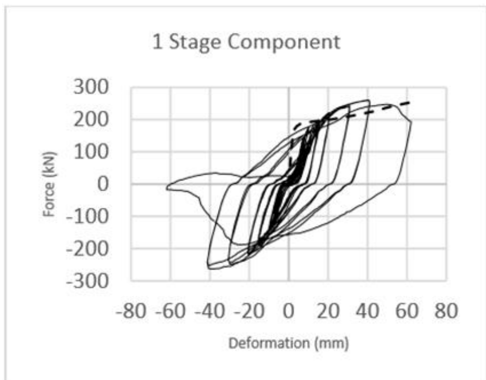
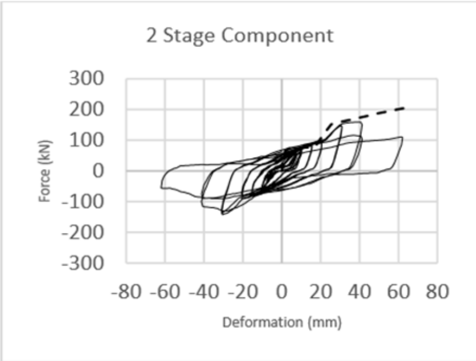


Figure 5. Detail of Brace Damper Configuration
(Source: Author)

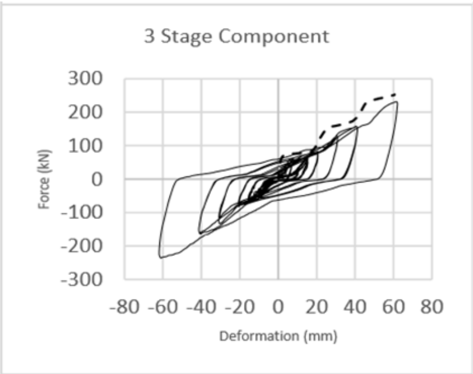
Figure 6. Set up of Component test
(Source: Author)



a)



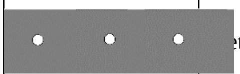
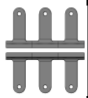
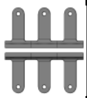
b)



c)

Figure 7. a) 1SC, b) 2SC, c) 3SC, comparison experiment result and FEM result
(Source: Author)

Table 1. Specimen Specification and Label

Specimen Label	Damper Loading Mechanism	Loading System Description	Number of set energy plate	
1-Stage Component Test (1SC)	Direct		et	
2-Stage Component Test (2SC)	Progressive		set	
3-Stage Component Test (3SC)	Progressive		set	

(Source: Author)

Table 2. Deformation Capacity of the Specimen

Specimen	Damper Yielding	Damper Initial Fracture	Damper total Fracture
1SC	0.244%	3%	3%
2SC	0.24%	2%	-
3SC	0.24%	-	-

(Source: Author)

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