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Seismic Performance Evaluation of Steel Structures with Buckling-restrained Steel Damper

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Abstract

The behavior of the steel structure with shear type steel damper can enhance the rigidity and strength of the frame together. The principle of a vibration controlled structure with a damper device is to absorb the energy by damping of the damper before the main structural member yields to reduce the damage of the whole structure. To satisfy this conditions the damper should have lower yield load or yield displacement than the structure.

In this paper, the proposed buckling-restrained steel damper is applied to improve seismic performance by increasing ductility and energy dissipation capacity. The dampers are responsible for about 15% of the average base shear of the non -seismic structure. In order to verify the hysteresis model of the proposed damper, the push-over analysis of Perform-3D was continuously performed to imitate the repeated force experiment. A total of seven seismic waves were selected from four seismic waves (El-Centro, Taft, Hachinohe, Tohoku) and three artificial seismic waves.

As a result of the comparison with experimental results on the load-displacement relationship of the buckling restrained steel damper, it is confirmed that the behavior is similar to the experimental results such as initial stiffness, secondary stiffness, yield strength, and bausinger effect.

Keywords: Non-linear time history earthquake response analysis; Buckling restrained steel panel damper (BRSD); Tri-linear hysteresis model, Story drift ratio

1. Introduction

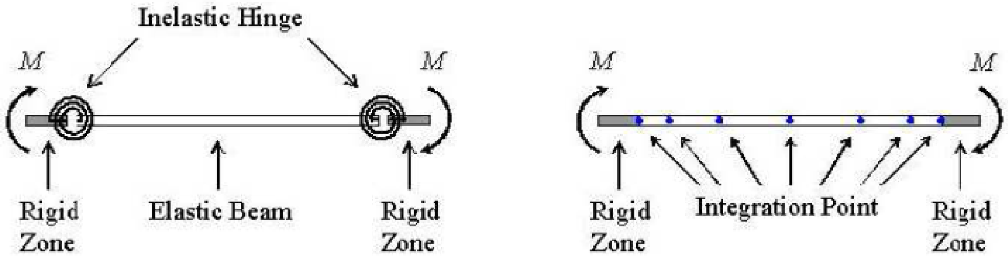
Inelastic response analysis of structures is an important technique for accurately predicting the response of structures to various levels of ground motion strength. The reliability of the results of the inelastic response analysis of the structure is highly dependent on the selection of a hysteresis model that can characterize the strength, stiffness, and energy dissipation of the member. Many types of hysteretic models have been proposed for the seismic response analysis of structures. These are usually based on specific experimental data. Therefore, when applying them to the response analysis of a specific structure, it is necessary to fully recognize the characteristics and limitations of the hysteresis model.

2. Hysteresis model for BRSD

2.1 Concept of nonlinear hinge model

The plastic behavior occurring in a structure under cyclic loads, such as the actual seismic load, also changes the position and characteristics of the plastic hinge depending on the moment distribution in the member length.

To considering this behavior, it is divided into the concentrated plastic hinge model and the distributed plastic hinge model as shown in Fig. 1. The concentrated plastic hinge model is a concept of modeling an inelastic hinge reflecting the nonlinear behavior of the entire member at the end of the member. The distributed plastic hinge model is a concept of defining the inelastic hinge characteristic of the entire member length.



(a) Concentrated plastic hinge model (b) Distributed plastic hinge model

Fig. 1 – Concept of nonlinear hinge model

Nonlinear hysteretic models can be defined by assessing how yield strength, stiffness, and reduction in strength, which can be identified from the cross-sectional or material properties, change in the case of cyclic loads such as earthquake loads. This nonlinear hysteretic model can be divided into material nonlinearity and member nonlinearity. Fiber models are generally used to account for material nonlinearities. In this paper, the distributed plastic hinge model is used as the hysteretic model used for the columns and beams of 10-story steel frame structures with Buckling restrained steel panel damper (BRSD), and the fiber model is used to consider the material nonlinearity.

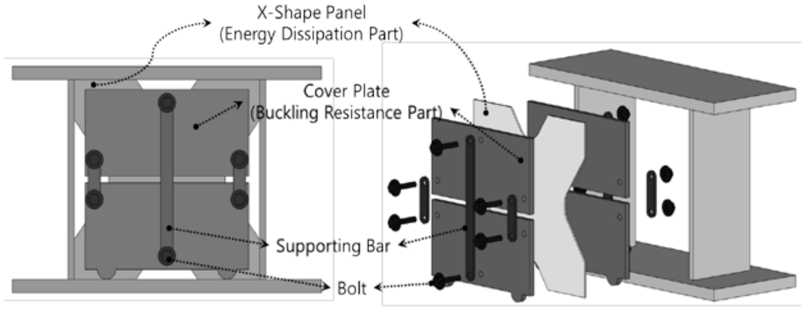


Fig. 2 Buckling restrained steel panel damper (BRSD)

2.2 Hysteretic Model of Buckling-Bound Steel Damper (BRSD)

The nonlinear material characteristics applied to the buckling-resistance steel damper (BRSD) were performed using the Seismic Isolator and Rubber Type Trilinear models of Perform-3D as shown in Figure Fig. 3. The modeling method of BRSD applied in the seismic response analysis of 10-story steel structure is shown in Fig. 4. The columns connecting the dampers are modeled on the assumption that the columns have infinite elastic stiffness. Table 1 shows the dimensions of the steel members used.

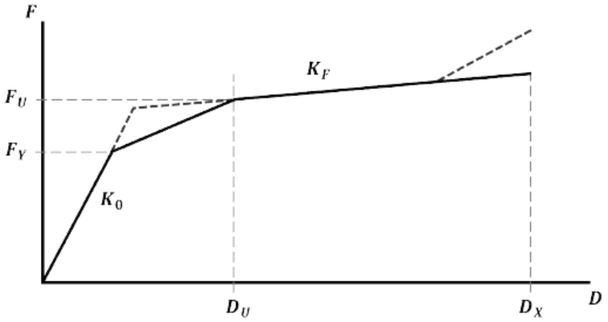


Fig. 3 – Nonlinear Material Properties of BRSD

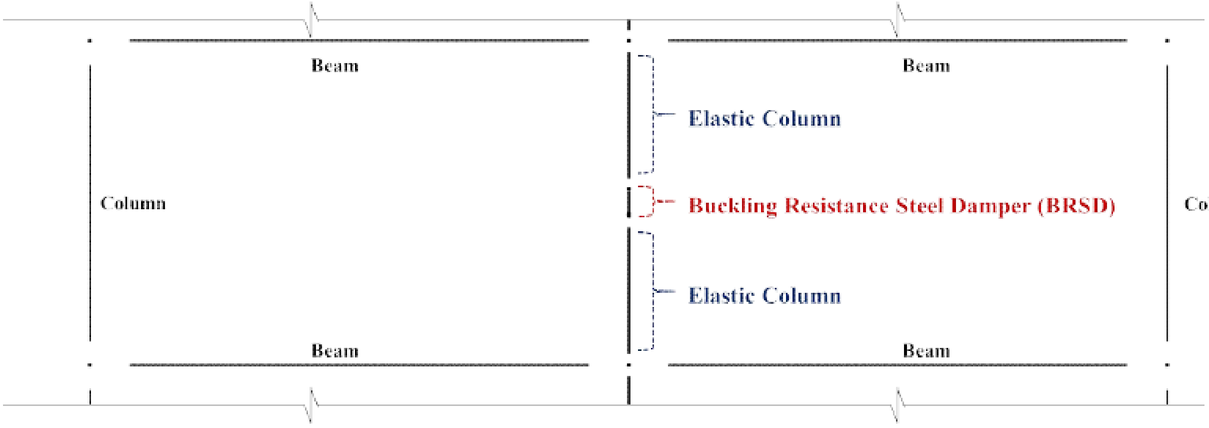


Fig. 4 – Modeling for steel frame with BRSD

Table 1 – Member List of 10-story steel frame

Member	Story	Section
Column (SS400)	1~3	H 458x417x30x50
	4~6	H 458x417x30x50
	7~10	H 428x407x20x35
Girder (SS400)	1~3	H 692x300x13x20
	4~6	H 588x300x12x20
	7~10	H 588x300x12x20

2.3 Verification of the hysteresis model for BRSD

In order to verify the hysteresis model of the BRSD proposed in this paper, the push-over analysis of Perform-3D was conducted continuously to simulate the cyclic force test. Fig. 5 shows a comparison of the experimental and analysis results for the load-strain relationship of buckling-resisting steel dampers. Experimental and analytical results, such as initial stiffness, secondary stiffness, yield strength, and bausinger effect, are quite similar.

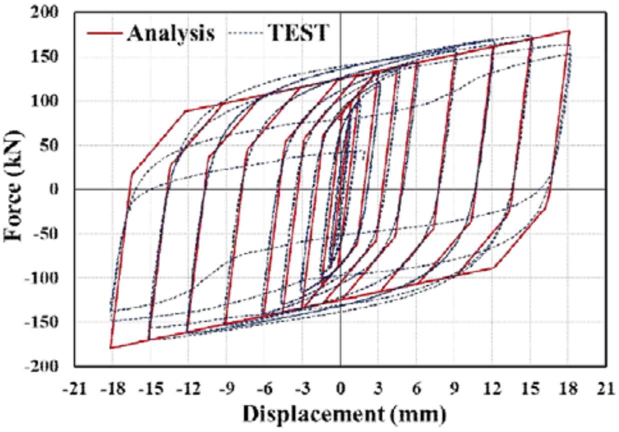


Fig. 5 – Comparison Force-displacement relationship for BRSD' hysteresis

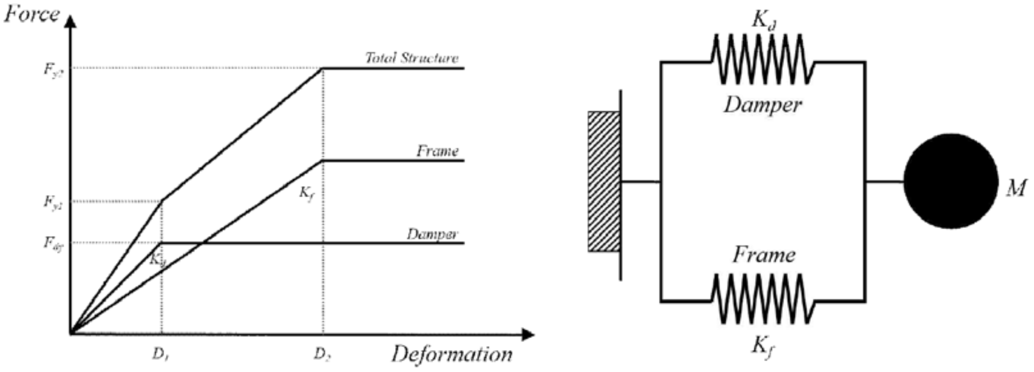


Fig. 6 – Behavior of Structures with damper devices

3. Target Structure and Input Seismic Waves

3.1 10-story steel frame

A 10-story steel structure was designed by referring to Korea Building Code (KBC2016). SS275 general structural steels were used. The basic span of the structure was planned to be 12m in the long side and 9m in the short side as shown in Fig. 7. Design load of the target structure as office facility is loaded dead load 6.8kN/m^2 for the 2nd to 10th floors, and for the roof layer, the dead load is 7.2kN/m^2 is loaded for gravity directions. For the wind load, the design basic wind speed 30m/sec, the road wind speed B, and the importance factor 1.0 were used. In this paper, to investigate the seismic response characteristics of damper reinforcement of non-seismic structures, the design of non-seismic structures without seismic loads was derived.

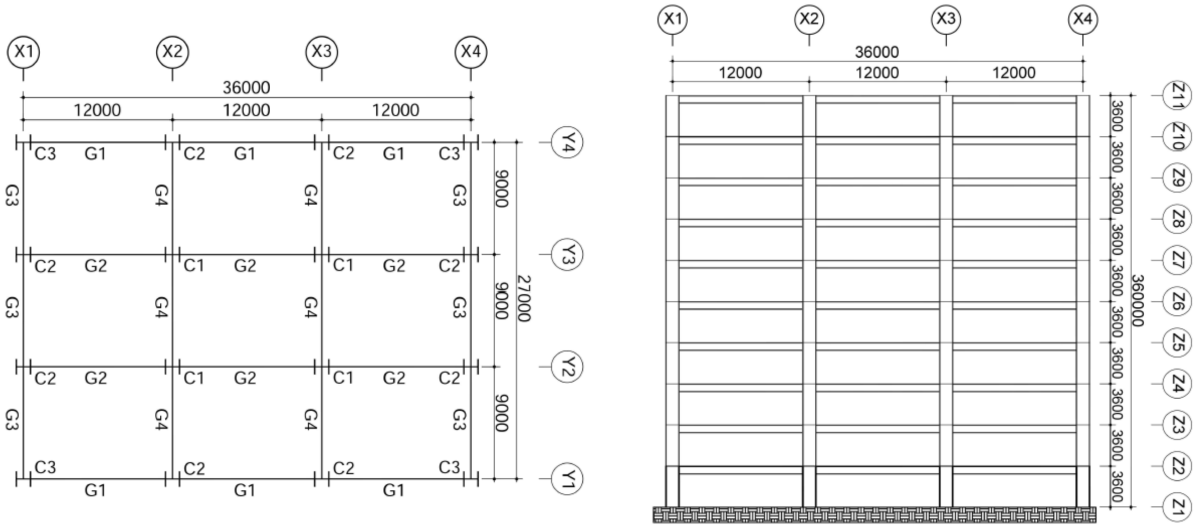


Fig. 7 – Elevation and Plane of 10-story steel frame

3.2 Input seismic wave

The seismic waves used for nonlinear time history analysis of the structure were selected from four observation waves (El-Centro, Taft, Hachinohe, Tohoku) and three artificial earthquakes. Figure 7 shows the seven seismic waves and the 5% decay acceleration spectrum used in this study. (Fig. 8)

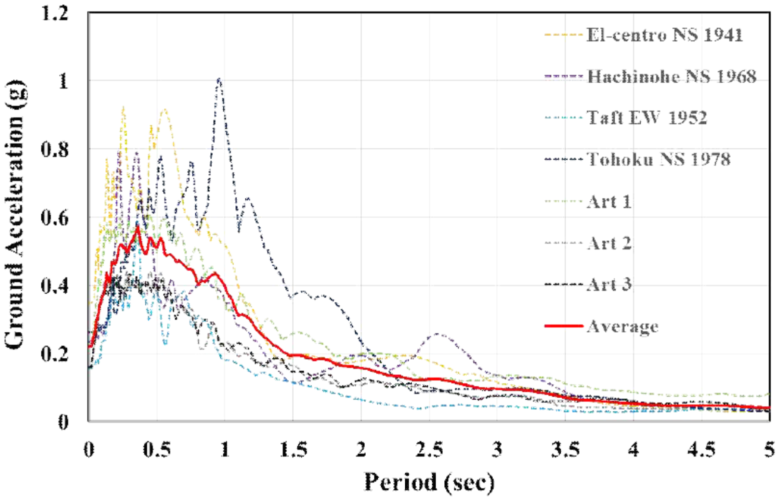


Fig. 8 – Calculation result of mean value of response spectrum

4. Result of time history nonlinear earthquake response analysis

4.1 Comparison of inter-story displacement ratio

The interlayer displacement ratio for each seismic wave of the structure without BRSD is shown in Fig. 8. The maximum mean inter-story displacement ratio was 0.0146 rad in the seventh floor. For the El-Centro seismic waves, a high inter-story displacement ratio of 0.232 rad was observed. On the other hand, in case of the structure with BRSD, the average response of the maximum inter-story displacement ratio was 0.0070 rad in the fourth floor.

In case of the structure installed by BRSD device, it was found that the design allowance of 0.015rad of inter-story drift angle was satisfied for all seismic waves (Fig. 9).

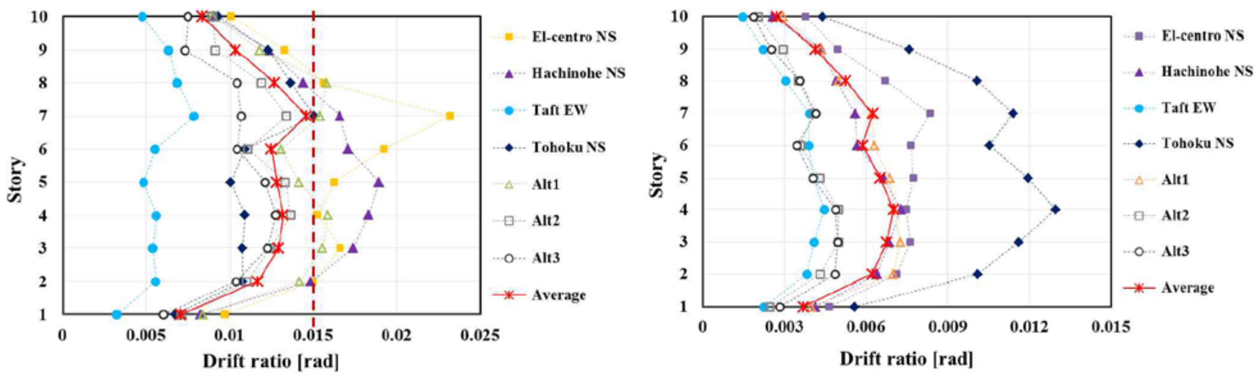


Fig. 9 – Calculation of inter-story drift ratio (left: without BRSD, right: with BRSD)

4.2 Comparison of inter-story acceleration

As shown in Fig. 10, in case of reinforced structure with BRSD device, the maximum layer acceleration average response was 0.53g at the top layer. Story acceleration was reduced by 45% based on the maximum value of vibration control damper.

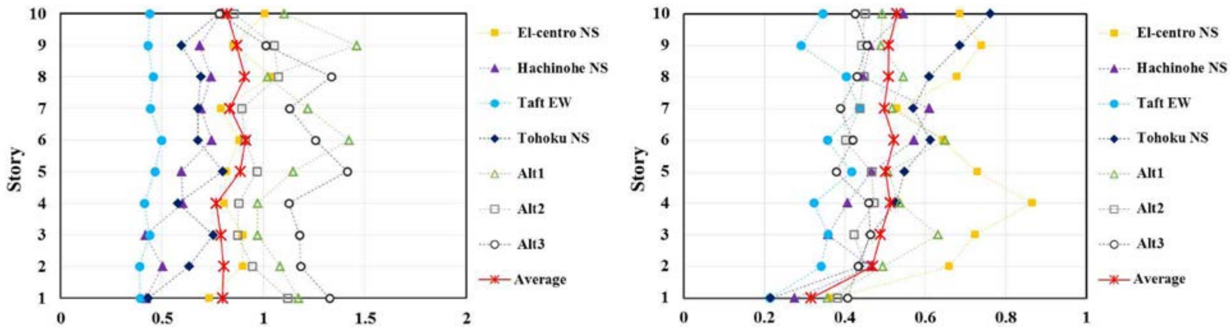


Fig. 10 – Calculation of story acceleration (left: without BRSD, right: with BRSD)

5. Conclusion

Based on the empirical results of the initial stiffness, yield strength, maximum strength, and plastic deformation capacity, we propose a method to properly simulate the hysteresis behavior during seismic response analysis and apply it to the 10-story steel frame structure for nonlinear time history analysis was performed.

In case of the structure reinforced with BRSD, displacement response that satisfies the design standard allowance was confirmed in all seismic waves, and it was confirmed that about 50% of the mean value of the inter-story displacement response was reduced compared to the structure without damper device.

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