Damping Effect of Buckling-Restrained Braces

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Modern cities are becoming more and more dependent on transportation with the rapid growth of the population and the development of the economy. As a traffic lifeline, once a bridge is damaged in an earthquake, traffic will be hindered, and restoring and rebuilding the bridge will take a long time, which will affect the daily life of drivers and locals. Therefore, bridge seismic problems cannot be ignored. One of the most widely used damping methods used to mitigate the seismic responses of bridges in recent years is the application of buckling-restrained braces (BRBs). Due to their stable mechanical properties, simple construction, and simple designs, BRBs are effective seismic dampers that are gradually being applied in the study of seismic bridges to improve their seismic capacities. With the development of engineering technology, the structure of BRBs is constantly being updated, and experimental and theoretical research on them has gradually attracted increasing attention.

buckling-restrained brace   bridge engineering   energy dissipation capacity

1. Comparison of BRB with Other Seismic Isolation Components

In recent years, seismic isolation devices have been widely used in bridge engineering [1][2][3][4]. Common seismic isolation devices include bearings (such as lead rubber bearings and sliding friction bearings), dampers (such as fluid VDs and BRBs), and limiting devices. The seismic isolation device is divided into damping and isolation methods, and the isolators will first enter the plasticity to produce a lot of damping and consume a lot of energy entering the structural system; the dampers will prevent seismic energy from entering the structure. The two working principles are different, but they will weaken the impact of the earthquake on the main structure. BRBs, as braced and energy-dissipating dampers, have demonstrated superior seismic performances compared to other seismic isolation devices.

Marco et al. [5] proposed fast design procedures for isolation systems. According to the design period and design equivalent viscous damping, three individual isolation systems (Low and High Damping Rubber Bearings, Lead Rubber Bearings, and Curved Surface Sliders) were designed. The nonlinear time history analyses demonstrated that the design procedure of a building was effective in the isolator peak displacement demand and the building base-shear response. Alper et al. [6] used curved surface sliders (CSS) in an elevated silo group. The incremental dynamic analysis demonstrated that CSS reduced the response of all parameters and the collapse risk under strong earthquakes. Young et al. [7] used rubber friction bearing (RFB) and BRB systems in the same frame. Numerical results through nonlinear time-history analysis showed that the combination of isolators and BRB systems was a good choice to safeguard the structure and minimize damage under earthquakes. Afshin et al. [8]

used nonlinear viscous dampers (NVDs), which are arranged on the first two panels from each side of the arch and connected to the truss layers. Nonlinear analysis showed that by using the proposed damping correction factor, the mechanical properties of NVDs could be selected, and the seismic requirements of the bridge could be satisfied. Li et al. [9] proposed a hybrid isolation system consisting of a BRB and a VD. This system effectively dissipated energy and protected a high-rise building under the actions of earthquakes and winds. Moreover, BRBs were combined with isolators to simultaneously mitigate the seismic responses of bridges.

Shi et al. [10] proposed a toggle BRB system that combined the structural fuse concept with toggle brace mechanisms. The system could improve the energy dissipation capacity of the BRB and keep the RC bridge bents elastic. Liu et al. [11] proposed two different hybrid isolation systems (RB (Rubber Bearing)–BRB and LRB (Lead Rubber Bearing)–BRB) on bridge piers. Based on the nonlinear time history, results demonstrated that the LRB–BRB was the most effective isolation system. Guo proposed et al. [12] a new lateral isolation system composed of elastic cables and fluid viscous damper at the girder–tower connections, and BRBs were used for lateral isolation of the piers. Numerical results through nonlinear time history analysis showed that the new system could properly control the seismic responses of the bridges. Li et al. [13] studied three different systems (without braces, with SC-BRBs, and with lock-up self-centering buckling-restrained braces (LU-SC-BRBs)), taking a continuous beam bridge as the background, as shown in **Figure 1**. Through modal analysis, it was found that the LU-SC-BRB could effectively control the pier bottom bending moment, shear force, and pier top longitudinal displacement. The LU-SC-BRB had a stronger energy dissipation capacity and a longer life cycle than other systems, and it improved the seismic capacity of the bridge.

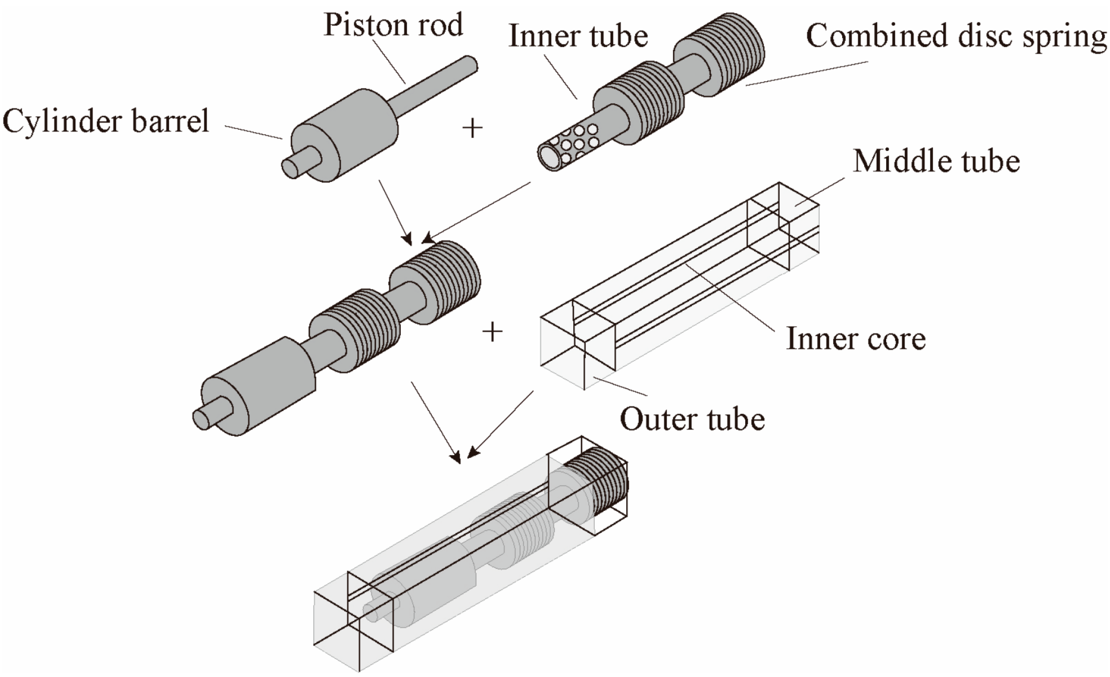

Figure 1. Composition of lock-up self-centering buckling-restrained brace (LU-SC-BRB).

Joel et al. [14][15] studied the feasibility of installing BRBs on the Vincent Thomas Bridge to reduce the maintenance cost of the bridge by replacing the problematic VDs of the original bridge. The results showed that the BRBs were effective on long-span bridges. Upadhyay et al. [16] conducted in-situ quasi-static tests on a bending bridge with two seismic retrofitting schemes involving BRBs and SCBs that were arranged diagonally on the piers. Nonlinear analysis and incremental dynamic analysis were used to compare and evaluate the performances of the two schemes and the original bridge. The results showed that both schemes improved the seismic performance of the bridge and that the BRB had a better effect in reducing the peak displacement and achieved greater cumulative energy dissipation than the SCB. However, the SCB was better at reducing the residual displacement and had a lower maintenance cost than the BRB while also improving the elasticity.

Montazeri et al. [17] studied three different seismic measures: the lead rubber bearing (LRB), friction pendulum system (FPS), and BRB (installed between three-column piers) against the background of a four-span girder bridge using nonlinear analysis and seismic fragility analysis. Based on the results, they found that all of the seismic measures effectively improved the stiffness of the bridge and that the BRB could effectively mitigate the seismic response under a strong earthquake with a high maintenance cost. Dong et al. [18] installed SC-BRBs and BRBs on reinforced-concrete double-column bridge piers and conducted large-scale quasi-static cyclic loading tests to study their hysteretic behaviors. The study found that the SC-BRBs significantly improved the strength and stiffness of the piers and reduced their residual displacements.

2. Combining BRBs with Other Seismic Isolation Components

It is crucial to choose effective seismic isolation devices in seismic design. Combining BRBs with other seismic isolation devices can meet the damping needs of bridges at different locations and orientations.

Liu et al. [19] proposed a bidirectional seismic isolation system with BRBs in the longitudinal direction and LRBs in the transverse direction with double-column piers. Their study found, through nonlinear analysis, that the combined application system was superior to the separately arranged system, which could effectively protect the piers by reducing the plastic deformation and residual displacement angle of the piers. Liu et al. [20] proposed the joint damping measures of arranging BRBs between the bottom of the main beam and the bent cap of the curved bridge and arranging lead rubber bearings at the bent cap of the pier. Three operating conditions were compared under near-fault ground motion: without BRBs, with BRBs placed between the side pier girders, and with BRBs placed between the middle pier girders. It was found that the joint damping measures with BRBs installed in the middle pier and lead rubber bearings at the abutment of the curved bridge had the best damping effect, which could effectively reduce the displacement of the main beam and the possibility of falling beams as well as mitigate the seismic response of the pier. Guo et al. studied the damping measures of a VD and a BRB center buckle on a suspension bridge. The truss stress and longitudinal beam displacement near the central buckle of the BRB decreased with the increase in the damping constant, which proved the effectiveness of the combined application. Shi et al. [21][22] proposed a damping system with a combination of bearings, SCEDBs, and BRBs between piers and beams and found that bearings could bear the rotational displacement of the beam, the BRBs reduced the horizontal displacement, and the SCEDBs controlled the residual displacement. Based on the dynamic time-history analysis of a three-span continuous railway beam arch bridge, it was found that the combined application of SCEDBs and BRBs controlled the self-recovery ratio between 0.02 and 0.15, effectively reduced the seismic response, and controlled the residual displacement under near-fault ground motion, and that the damping rate was up to 94%. Bai et al. [23] proposed a new shock absorption system, which had a BRB and a cable restrainer on simply-supported girder bridges. The results showed that the system could control the longitudinal seismic responses of girders and transition pier. However, the specific parameters need further study.

The longitudinal arrangement of other seismic isolation devices on the superstructure can reduce the displacement of the main beam, and the transverse arrangement of BRBs on the substructure can reduce the seismic response of the piers. The bidirectional seismic isolation system can play their respective roles in the longitudinal and transverse directions and maximize the overall seismic performance of the bridge.

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