Performance-based seismic design for bridge bents retrofitted with BRBs using the ductility demand spectra of SDOF oscillators with bilinear fuses

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Abstract

Reinforced concrete bridge bents with double columns are widely used in highway bridges and urban viaducts. However, past major earthquakes have shown that these substructures are vulnerable to severe damage because large lateral inertia forces from the superstructure are transferred to the columns during strong ground motions. Excessive displacement demand may lead to plastic deformation, strength degradation, residual damage, or even collapse. Therefore, effective seismic retrofit strategies are needed to control damage and improve the resilience of existing bridge bents.

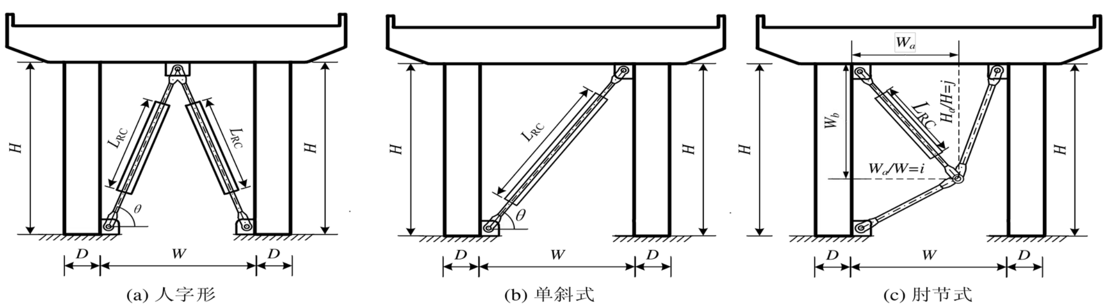
One promising approach is to use structural fuses. In such systems, replaceable energy-dissipation devices are designed to yield and dissipate seismic energy, while the primary structure is protected from excessive damage. Buckling-restrained braces (BRBs) are particularly suitable for this purpose because they provide stable hysteretic behavior, additional stiffness, and reliable energy dissipation under cyclic loading. Nevertheless, the seismic response of a bridge bent retrofitted with BRBs depends strongly on the interaction between the original bridge bent and the added BRB system. A rational design method should therefore be able to determine the properties of BRBs according to a specified seismic performance target.

The presentation in this keynote speech is about a performance-based seismic design procedure for reinforced concrete bridge bents retrofitted with BRBs. The retrofitted bent is idealized as a dual system composed of a primary structure and structural fuses acting in parallel. Two key parameters are introduced to describe their interaction: the yield displacement ratio, α, and the initial stiffness ratio, β. The product $\alpha\beta$ represents the yield strength ratio between the structural fuse and the primary structure. Based on these parameters, ductility demand factor spectra are developed for single-degree-of-freedom (SDOF) systems with bilinear fuses. These

spectra are used to relate the strength reduction factor, structural period, and displacement ductility demand.

A series of ground motion records representative of transportation engineering applications is selected to investigate the influence of α, β, and the strength reduction factor on the ductility demand spectra. The results show that structural fuses can effectively reduce the ductility demand of bridge bents, especially in the short-to-medium period range. For a given strength reduction factor, increasing the yield strength ratio generally reduces displacement ductility demand. It is also found that early yielding of the BRB is beneficial for energy dissipation, while excessively large fuse stiffness may not always improve the response of medium- and long-period structures.

What is particularly unique about this study is that three BRB configurations are considered: diagonal BRBs, inverted-V BRBs, and toggle BRB systems, as shown in Figure 1. Because these configurations have different displacement amplification effects, they lead to different axial deformation demands, stiffness requirements, steel core lengths, and steel core areas. Design equations are derived to ensure that the BRB yields before the bridge bent while maintaining sufficient deformation capacity before fracture. This requirement is essential for allowing the BRB to work as a replaceable structural fuse.



(a) (b) (c)

Figure 1- Bridge bents retrofitting with BRB: (a) Inverted-V; (b) Diagonal; (c) Toggle

The proposed design procedure begins with the geometric and material properties of the existing bent. The yield displacement, ultimate displacement, effective stiffness, yield strength, effective period, and elastic seismic force are first calculated. A target performance level is then selected in terms of displacement ductility, such as no damage, minor damage, or moderate damage. The corresponding strength reduction factor is determined, and suitable values of α and β are selected from the ductility demand spectra. Finally, the BRB configuration, axial stiffness, yield displacement, yield strength, design displacement, steel core length, and steel core area are obtained.

Among the three configurations, the toggle BRB system shows the best overall performance. Its displacement amplification mechanism allows the BRB to make fuller use of its energy dissipation capacity while requiring lower stiffness, smaller yield strength, and smaller steel core area than conventional configurations. The results indicate that BRBs, especially toggle BRB systems, can serve as effective replaceable seismic fuses for the seismic retrofitting of bridge bents.

Keywords*: Inelastic spectra; structural fuse; bridge bents; buckling-restrained braces; damage control*