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Comparative seismic performance of steel frames retrofitted with buckling-restrained braces through the application of Force-Based and Displacement-Based approaches

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ABSTRACT

This paper presents an analytical study aimed at evaluating the feasibility of using buckling-restrained braces as a retrofit scheme for existing multi-bay multi-story steel buildings. For that purpose, the seismic response of four two-dimensional frame models representative of typical steel buildings designed in a region of high seismicity was analyzed prior to and after including buckling-restrained braces as a retrofit strategy. The braces were designed following Force-Based and Displacement-Based approaches. The structural performance of the different versions of the frames was evaluated by subjecting each one to a set of twenty ground motions representative of the design earthquake with 10% exceedance probability in fifty years. It was observed that buckling-restrained braces allow for an efficient reduction in the peak drift demands in the retrofitted frames. However, since the beneficial effect of the braces cannot be fully controlled under a Force-Based design approach, it was concluded that a Displacement-Based design approach is the best option to achieve optimum structural performance.

1. Motivation

Several techniques, such as reinforced concrete and steel jacketing, as well as the addition of walls and/or braces, have been used to retrofit buildings that have experienced structural damage as a consequence of moderate or severe earthquake ground shaking, or for the seismic upgrading of outdated buildings. Among these techniques, diagonal steel bracing has been considered an attractive option to enhance the lateral strength and stiffness of existing multi-story steel buildings. Nevertheless, it should be kept in mind that traditional braces (ductile or not) tend to exhibit global buckling when subjected to compressive strains, which in turn results in local buckling, fracture of the base material, and a highly unstable behavior under cyclic loading [1,2]. Under these circumstances, adequate earthquake-resistance can only be achieved through conservative design, or more rationally, through combining the well-known efficiency of triangular sub-structures with innovative buckling-restraining mechanisms.

The idea behind a buckling-restrained brace is to fabricate a structural element that is able to work in a stable manner when subjected to compressive deformations. Because braces are normally able to behave in a stable manner when subjected to tensile forces, a buckling-restrained brace is capable of dissipating large amounts of energy in the presence of multiple yield reversals. Fig. 1 shows schematically the concept of a buckling-restrained brace and shows its different components: (A) a ductile steel core that dissipates energy through axial deformation; (B) mortar, concrete or grout fill that restricts buckling of the core; and (C) a steel jacket that confines the mortar, concrete or grout fill and provides further restriction from buckling. Under severe ground motion, only the core of the brace should yield.

Usually, the steel core is isolated from the mortar, concrete or grout fill in an attempt to minimize or eliminate the transfer of axial stresses between both materials. This is done so that the compression strength of the brace is similar to its tension strength. Further discussion regarding the concept and use of buckling-restrained braces can be found in Black et al. [3] and Uang and Nakashima [4]. Experimental testing on buckling-restrained braces indicates a highly stable behavior under severe cyclic loading.

Several studies have focused on the use of buckling-restrained braces to provide efficient seismic resistance to moment-resisting steel frames, and as a result several Displacement-Based design methodologies have been formulated [5–8]. Within this context, the effects of several parameters have been studied to better explain the dynamic nonlinear response of buildings with dual structural systems composed of steel frames and buckling-restrained braces, among them: (A) the lateral stiffness of the frames relative to that of the braces; (B) the yield strength of the steel used to fabricate the braces; (C) the number of stories; and (D) the distribution through height of braces. Although the studies have been useful in clarifying many issues in terms of the earthquake-resisting potential of buckling-restrained

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