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ORIGINAL ARTICLE

Upgrading the seismic capacity of existing RC buildings using buckling restrained braces

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Abstract Many existing RC buildings do not meet the lateral strength requirements of current seismic codes and are vulnerable to significant damage or collapse in the event of future earthquakes. In the past few decades, buckling-restrained braces have become increasingly popular as a lateral force resisting system because of their capability of improving the strength, the stiffness and the energy absorbing capacity of structures. This study evaluates the seismic upgrading of a 6-story RC-building using single diagonal buckling restrained braces. Seismic evaluation in this study has been carried out by static pushover analysis and time history earthquake analysis. Ten ground motions with different PGA levels are used in the analysis. The mean plus one standard deviation values of the roof-drift ratio, the maximum story drift ratio, the brace ductility factors and the member strain responses are used as the basis for the seismic performance evaluations. The results obtained in this study indicate that strengthening of RC buildings with buckling restrained braces is an efficient technique as it significantly increases the PGA capacity of the RC buildings. The results also indicate the increase in the PGA capacity of the RC building with the increase in the amount of the braces.

1. Introduction

Many existing buildings do not meet the lateral strength requirements of current seismic codes due to various reasons which include; (a) the design of the building according to gravity loads only, (b) subsequent updating of seismic codes and the intensity of seismic hazard in order to minimize the level of damage and repair costs after an earthquake, (c) modifications in existing buildings, (d) change in the building use, and (e) strength deterioration due to aging or previous earthquakes. Such buildings are vulnerable to significant damage or collapse in the event of future earthquakes.

Various techniques have been used for seismic strengthening of RC buildings which can be classified into two main groups: the member-level techniques and the structure-level techniques. The member-level techniques rely on section enlargement of the existing structural members by jacketing to improve flexural, axial and shear strength of these members; enhancements in ductility and stiffness are also attained. Jacketing can be performed by reinforced concrete, steel sections or fiber reinforced polymer sheets. In general, columns are regarded as the most critical structural members to be enlarged, as the failure of columns may lead to collapse [1].

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The jacketing technique may require evacuating the whole building and is labor-intensive due to the associated heavy demolition and construction works.

The structure-level techniques are mainly intended to reduce the demand on the existing structure by introducing new elements such as shear walls or conventional steel bracings. Adding concrete walls by infilling certain frame bays with reinforced concrete is an efficient strengthening approach as long as the connection between the old concrete and the new ensures monolithic behavior. The main advantages of this technique are in improving the building lateral strength and in concentrating the construction work in few places of the building. However there are several disadvantages to this approach which include the need for new foundations or strengthening of the existing ones, the added new weight to the structure and the openings and lighting difficulties.

Conventional steel braces have been used in seismic strengthening of RC buildings in areas of high seismicity. They can be more rapidly installed than other strengthening techniques and they do not add much weight to the structure. The bracing system can be attached to the perimeter frames of the building and consequently, disruptions are minimized during construction. The hysteretic behavior of conventional steel braces is un-symmetric in tension and compression. The yielding of the braces in tension under lateral loading provides a ductile plastic mechanism with a good source of energy dissipation. On the other hand, brace buckling in compression provides a poor source of energy dissipation because of the post-buckling behavior of the braces which is characterized by deterioration of strength and stiffness.

Bush et al. [2], Masri and Goel [3], Maheri and Sahebi [4] and Liu et al. [5] studied experimentally the effectiveness of using steel braces to retrofit existing RC frames. They reported that such a method allows upgrading the seismic capacity of existing structures. Their experimental results highlight the effectiveness of the steel brace strengthening technique in improving the global performance of RC structures in terms of strength, ductility and energy dissipation. Comparative studies of seismic strengthening of RC buildings by steel braces and other strengthening systems such as column jacketing and RC infill walls have been conducted by Farghaly and Abdallah [6], Alashkar [7], and Ibrahim [8]. The outcomes of these studies showed that better enhancement can be attained by using concentric steel braces than other strengthening techniques.

Buckling-Restrained Braces (BRBs) have become one of the most efficient earthquake-resistant structural systems and have been actively applied to seismic design and retrofit of building structures in regions with high seismicity. BRBs do not exhibit any unfavorable behavior characteristics of concentric braces and they require using less steel and simpler joints in comparison with other construction methods. Fig. 1 [9] shows the BRB components which consist of a steel core and external jacket. The steel core is subjected to inelastic deformations under the effect of lateral loading and the external jacket serve in restraining buckling of the steel core element. The steel core is divided into three segments: the yielding zone, transition zone and the connection zone. The yielding zone has a reduced cross section and is fully restrained to insure the occurrence of tensile and compressive yielding. The transition zones are the segments of the brace directly on either side of the yielding zone. These segments have larger cross-sectional area than the yielding zone but are similarly restrained. The connection zone is the portion of the brace that extends beyond the restraining components and is used to connect the brace to other structural elements of the frame.

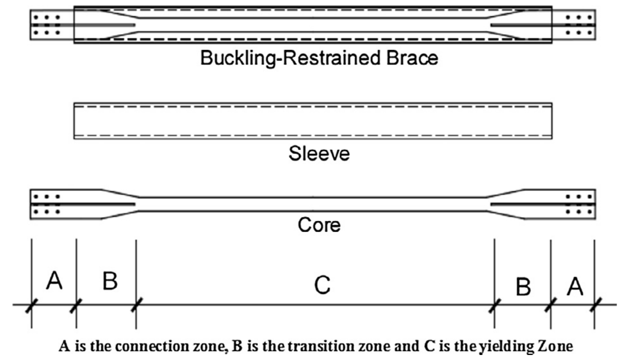

Figure 1 Schematic diagram of the BRB components [9].

The steel core can be a rod, a single plate, or a built-up section and the external jacket can be made of steel tube filled with mortar. A gap between the steel core and the mortar must be set to ensure that the axial stresses are resisted by the steel core only and not by the jacket. As shown in Fig. 2 [10], the BRBs are expected to yield in both tension and compression with a stable hysteretic behavior because of the lateral restraint provided by the external jacket.

Analytical and experimental studies carried out on structures with BRBs showed that the energy dissipation capacity of the structures increased with the installation of BRBs. Clark et al. [11] conducted a study that compared the seismic performance of a special moment resisting frame and a BRB frame. The total weight of steel in the BRB frame was reduced significantly by 50% compared to the moment resisting frame. The results indicated also that the BRB frame has larger lateral stiffness but lower yield strength as compared to the moment resisting frame. The lower yield strength of the BRB frame is because the design of the moment resisting frame was governed by drift, while the design of BRB frame was governed by strength.

Di Sarno and Manfredi [12] carried out a numerical assessment of the seismic performance of RC frame structures designed for gravity loads only and retrofitted with BRBs placed along the perimeter frames. The results of nonlinear dynamic analyses showed that at the collapse-prevention limit

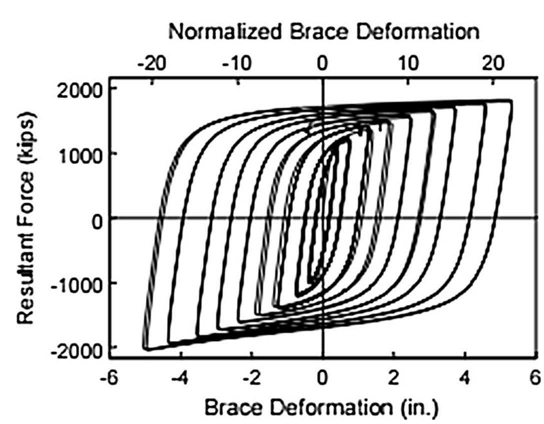

Figure 2 Axial force versus axial displacement of BRB [10].