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Evaluation of Seismic Behavior of Steel Frames Constrained with Hybrid Core Buckling-restrained Braces

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ABSTRACT: Bucking restrained braced frame (BRBF) is a special type of concentrically braced frames that the braces do not buckle in compression. As a result, it shows a desirable energy dissipation behavior. However, low post-yield stiffness of these braces causes large residual deformations at high levels of earthquake intensities. The aim of this article was evaluation of the seismic behavior of a new steel structural system known as hybrid buckling-restrained braced frame (HBRBF). Nonlinear static analysis, nonlinear time history analysis and nonlinear incremental dynamic analysis (IDA) methods were used for standard and hybrid core BRBFs with different stories. The average values of seismic behavior factor (R) for HBRBFs were obtained 10.2 and 14.7 for ultimate limit state and allowable stress design methods, respectively. In order to carry out response history analyses, past earthquakes records were used with different hazard levels. Hybrid buckling-restrained braced frames were shown to have a significant improvement over standard BRBFs in terms of behavior factor and damage measures including inter-story drift ratios and residual displacements.

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1- Introduction

Buckling restrained brace (BRB) is a special class of concentric bracing system that can yield during both tension and compression [1]. Unlike conventional concentric bracing frames (CBFs), the BRB system has nearly symmetrical behaviour in tension and compression resulting in a desirable energy dissipation capacity and much smaller unbalanced vertical brace forces [2]. The most important problem of the BRBFs is the possible large residual deformations following significant earthquakes.

The modifications to BRBs have been primarily aimed to reduce residual deformations in BRBFs [3]. One of the appropriate solutions to mitigate the permanent deformation as well as to achieve higher performance levels is using a multi-core BRB with different steel grades, called a hybrid BRB (HBRB) [4].

The main purpose of the current study was gaining further understand in whether the use of the innovative hybrid BRBs could perform better than the standard counterpart in steel buildings with varying heights. The characteristics of the seismic sequences were examined in terms of performance factors, inter-story drift ratios and residual displacements.

2- Methodology

The performance of hybrid BRBs has been investigated by means of 5-, 8- and 12-story braced frames located on a hypothetically medium soil site. The type of brace configuration in BRBFs was diagonal. Buildings were designed based on the requirement of the Iranian national building codes [5-7]. Tables 1 summarizes the details of material properties that were used in the numerical models. The superstructures were constrained at the bottom. However, the seismic performance of structures without considering the flexibility of the foundation may be significantly different from those of the actual demands [8].

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Table 1. Material properties

	A36	LYP100	HPS70W	HPS100W
F_y (MPa)	290	107	503	745
E (Gpa)	200	186	200	200

A database of seven pairs of far-field recorded ground motion time histories has been compiled [9]. Figure 1 shows the 5% damped acceleration response spectra of the ground motions for 10% in 50 years hazard level. It is worth emphasising that the earthquake ground motions close to a ruptured fault are quite different when compared to the those observed enough further away from the source [10]. According to the recent findings, seismic performance of mid-rise CBFs, designed based on Standard No. 2800, was obviously deteriorated under near-field ground motions [11].

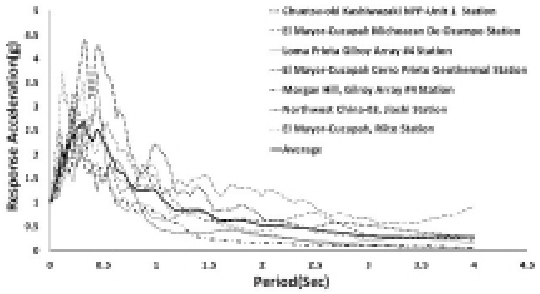

Figure 1. The single-record and the average elastic response spectra of the selected ground motions

The computational model of the perimeter braced frames were developed by using the OpenSees finite element platform [12]. Nonlinear beam–column elements with fibre sections were used to model beams and columns. A leaning column was used to model second order effects. The Giuffre-Menegotto-Pinto steel material with isotropic strain hardening, known as Steel02 was assigned to fibres. BRBs were modelled with a co-rotational truss element with yielding steel core area.

3- Results and Discussion

To illustrate the relative influence of hybridity on the seismic performance of BRBF buildings, numerous comparative nonlinear static and dynamic analyses were carried out for the different considered modelling approaches. Figure 2 shows base shear versus roof drift ratio for 5-story frames i.e. the standard and three hybrid BRBFs. As shown, the hybridity effect increaseed the post-yield stiffness of the frames due to the effect of high strain hardening in the LYP100 material, particularly in the case of the HBRB-3 model. However, the elastic stiffness and the total base shear capacity were not affected in this regard.

According to eigenvalue analyses, the fundamental periods of 5-, 8- and 12-story frames were 1.37 sec, 1.99 sec, and 2.89 sec, respectively. Hence, by using the Newmark and Hall relationships, the ductility and over-strength coefficients were employed in order to determine response modification factors (R factors) [13]. The average performance factor of HBRBFs obtained 10.2 for ultimate limit state design method. Recent code-compliant seismic designs were recommended constant value of R factor varies between 7 and 8 for standard BRBFs [2, 7, etc.]. Thus, the hybrid BRBFs had a significant improvement compared to the standard systems in terms of seismic behaviour factors and energy dissipation capacity.

The residual roof displacement was reduced as much as 71% for the 5- and 8-story HBRBFs, by increasing the seismic intensities up to collapse level (see Figure 3). However, for 12-story models, the residual displacement decreased as much as 33%, when hybrid frame is considered. On the other hand, the hybrid BRBs are not effective to reduce the inter-story drift of 5- and 8-story frames when they are compared to the standard systems. But, for the 12-story models, the inter-story drift was observed to be reduced by about 40% when the hybrid frames are subjected to the highest intensity motion. Furthermore, the comparison of the median IDA curves of the hybrid and standard BRBFs in terms of residual roof displacement showed that hybrid frames were performed better than the other one at all intensities up to collapse level, and the most hybrid frame which includes the most amount of low strength steel (LYP100) performed the best.

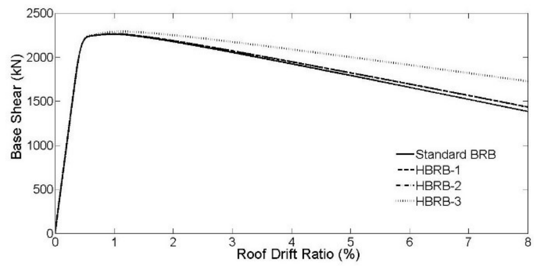

Figure 2. Base shear vs. roof drift ratio, standard and hybrid 5-story BRBFs

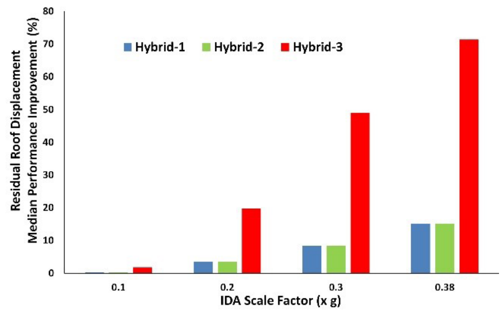

Figure 3. The median performance improvements for residual roof displacement, 8-story HBRBFs

4- Conclusions

The main analysis results are summarized as follows:

- The increase in R value of the hybrid BRBFs indicated their system performance enhancement.
- The median residual roof displacements were reduced as much as 71% for hybrid BRBFs.
- For the 12-story models, the median drift ratio decreased up to 40% when hybridity was considered.

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