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Experimental study on seismic performance of rocking buckling-restrained brace steel frame with liftable column base

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A B S T R A C T

An innovative frame system called rocking buckling-restrained brace frame (RBRBF), which is characterized by allowing the column base uplifting during strong earthquakes, has been proposed to decrease seismic damage and reduce repair cost of building structures after the disaster. According to the working mechanism and functional objectives of this new type of structure system, four buckling-restrained brace steel frames including two rocking ones were designed as half-scale specimens considering various parameters. Pseudo-static tests were conducted on the model specimens to investigate their seismic performance, the yielding mechanism and the damage mode. The experimental results illustrated that the lateral resisting capacity and initial stiffness between the rocking structural models and non-rocking ones were nearly same at the elastic stage due to the reasonable design of rocking column base. The reduced beam sections (RBS) used at the beam-column joints could effectively control the damage location, and the liftable column bases with friction dampers could improve the energy absorption capacity of the rocking structure model. Comparing with the non-rocking models, the plastic damage on rocking specimens was greatly reduced under large lateral deformation. Furthermore, there was no local buckling on the structural elements of the rocking steel frame even under 2.5% drift ratio, which showed that the rocking structures with rational design would perform well under server seismic.

1. Introduction

Buckling restrained brace frame (BRBF) as an effective lateral resisting structural system has been increasingly applied for new constructional and retrofitting of existing structures in the past years, particularly in Japan and the USA [1,2]. Because of the favorable attributes and perfect working mechanism, buckling restrained braces (BRBs) [3, 4] can not only provide necessary stiffness but also improve significant energy dissipation capacity for main structure [5]. However, when the steel core of BRBs yields, a tremendous vertical component of the axial force in the BRBs will transfer to the adjacent columns. The analysis of internal force is presented on the beam-to-column joints in two typical configurations of BRBFs when subjected to lateral force, as shown in Fig. 1. Assuming that all the BRBs framing into the beam-column joints could yield simultaneously under the lateral loading action, it is obvious to see that beam-column joints to which BRB members are attached producing identical downward and upward force along the centerlines of columns, leading to the enormous variation in the axial force of columns and foundation. With the increment of building height, the accumulated vertical tensile force in the bottom columns could exceed the self-weight of structure, resulting in the difficulties to counteract the huge tensile force in the design of structural foundation and lateral-resisting components like columns. Consequently, structural foundation and lateral-resisting components will be confronted with a potential safety hazard under the combined action of tension, bending and shearing. In general, the bottom columns and foundation in high-rise buildings are more susceptible to the effect of the accumulative vertical force induced by the BRBs than low-rise buildings. To solve the above problems, much more attention has been paid to the rocking structural systems that have been one of the hot research fields for the past several decades.

Rocking structural systems were proposed based on the observations and experience from the early earthquakes, and researchers found that the effect of rocking vibration of the structures could decrease the seismic damage of buildings when subjected to strong earthquakes. The theoretical research of various rocking structures has been developed rapidly since the concept of rocking behavior was firstly presented and investigated theoretically by Housner in 1963 [6]. Yim and Chopra studied the excited response of single-degree-of-freedom system (SDOF) supported by Winkler foundation with several sets of system parameters [7, 8]. Huckelbridge and Clough conducted a shaking table test on the scaled model of a nine-story rocking frame to investigate the seismic performance and the results showed that member forces and ductility demand of rocking frame was lower than that of the traditional pin-base frame [9]. Midorikawa [10] performed a shaking table test on a half-scale three-

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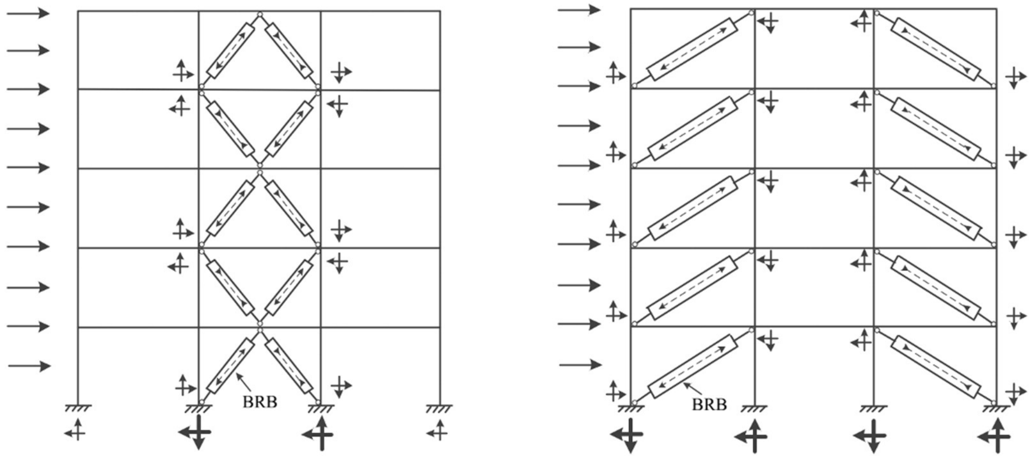

Fig. 1. Internal force of connection joints in typical BRBF configurations.

story steel braced frame equipped with steel plates at the bases of columns, which could uplift and rock after yielding of steel plates. The experimental result indicated that the shearing force of rocking frame was decreased by 52% compared to the fixed one.

With the advent of variety of innovative rocking structure systems, there were roughly two main types of rocking systems that were classified into rocking wall structure system and controlled self-centering rocking structure system during the last decade. Rocking wall structure has been successfully utilized to retrofit some existing buildings. For instance, Wada et al. [11] tactfully employed pin-supported wall-frame system in retrofitting an existing steel reinforced concrete frame to control the deformation pattern of structure, and proved its efficiency after the hit of considerable ground shaking caused by M9.0 Tohoku earthquake [12]. The controlled self-centering rocking system is an aseismic system that can virtually eliminate the residual story-drift after the structure subjected to the ground motions. Deierlein et al. has investigated the earthquake resilient steel braced frames with controlled rocking based on theoretical analysis, the overturning moments of which was provided by the post-tensioned tendons embedded in two alternative steel-braced frame configurations, and in which the steel-braced frame was designed to remain essentially elastic while concentrating inelasticity on certain replaceable fuse elements [13]. Eatherton et al. performed a series of large-scale hybrid simulation experiments to study the seismic performance of the controlled self-centering rocking steel frame. The research results indicated that the rocking steel-braced frame remained virtually elastic without residual story-drift after ground shaking [14].

According to the mechanical characteristics of the mentioned BRBFs and the practical peculiarities of the two main rocking systems narrated above, an innovative type of structural system called rocking buckling restrained brace frame system was investigated in this paper. The column bases of structure were allowed to uplift under certain level of lateral forces, aiming at reducing the remarkable axial tensile force induced in the columns of the BRBFs when subjected to major seismic events. The efficiency and feasibility of the proposed system was going to be validated through experiments.

2. Rocking buckling restrained brace frame (R-BRBF)

Fig. 2 shows the concept model of the proposed rocking system, in which the column bases of the bottom columns in the braced spans are designed in a new kind of detail. The vertical constraint of the column bases are released to be replaced with certain numbers of damping members and one compression-only spring element. In terms of this type of connection joint, the columns are allowable to uplift and rock back and forth when the axial tensile force of bottom columns exceeds

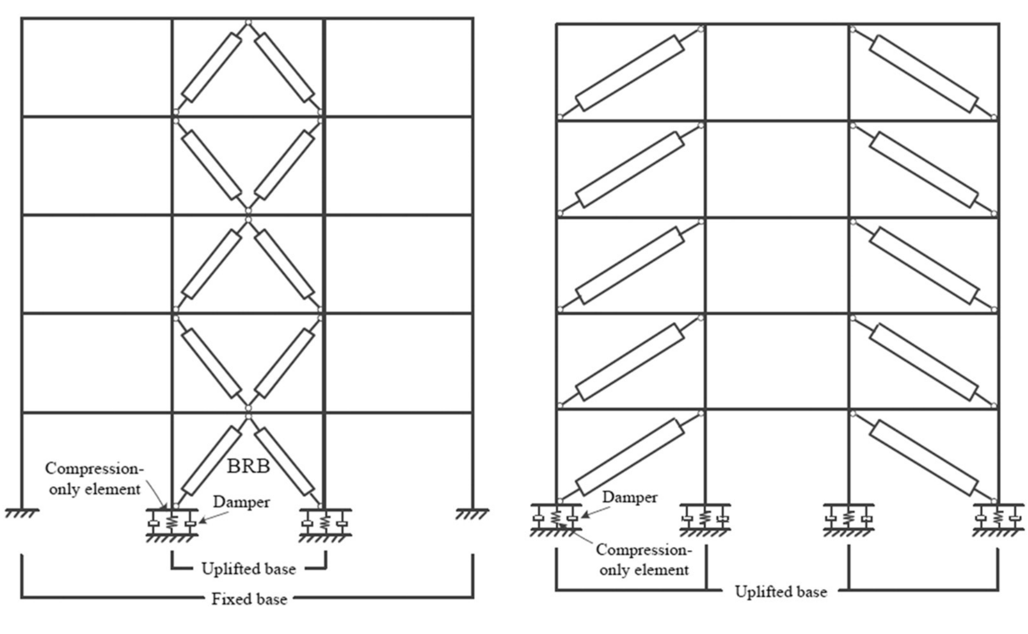

Fig. 2. Schematic diagram of rocking buckling restrained brace frame (R-BRBF).