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Case study

Investigating modeling approaches of buckling-restrained braces under cyclic loads

Rohola Rahnavard[a,*], Mohammad Naghavi[b], Maryam Aboudi[a], Mohamed Suleiman[c]

[a] Structural Engineering, Faculty of Civil Engineering, Jundi-Shapur University of Technology, Dezful, Iran
[b] Structural Engineering, Dep. of Civil Engineering, Javid Institute for Higher Education of Jiroft, Iran
[c] Lecturer of Structural Engineering, University of Tripoli, Tripoli, Libya

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ABSTRACT

The Main purpose of this paper is to present a practical method for accurate modeling and provide a simple model of buckling restrained braces (BRBs). The components of a BRB were introduced. Furthermore, two complete experimental specimens of BRBs were modeled using the ABAQUS finite element method program. The validity of these models was confirmed after comparing the results of nonlinear dynamic analysis with the experimental specimen results. An intended simple model such as steel core and springs was proposed. It was evaluated and analyzed after modeling, then a method was presented to find the spring stiffness. In this study, a comparison was made between the experimental and analytical hysteresis curves (the complete model and the simplified model) and a good agreement was observed between the two results with 5% difference. Moreover, the two-story moment frame with a BRB in both the complete details and simple states was modeled to verify the simple method of core-spring. The results showed a high accuracy of the simple model of core-spring. In addition, the use of the simplified spring-core model may significantly reduce the time of the analysis compared to the complete model.

1. Introduction

It is observed that buckling occurs at braces when pressure is exerted on them showing an undesirable behavior and is visible in most braces. This problem may cause a decrease and energy dissipation capacity of a structure due to the secondary effect of nonlinear geometric deformation. This plays an important role in cyclic loading like earthquakes due to the nature of the further reduction in hardness under dynamic seismic loads. The use of braces that have the same behavior in pressure and tension without buckling, has always been desirable to design structures [1]. The behavior of conventional buckling-restrained braces (BRBs) is shown in Fig. 1. In fact, the retrofitting corrects inappropriate behavior, such as reducing resistance, stiffness and ductility.

The idea of using submissive steel members for the energy absorption was proposed more than 30 years ago [2,3]. The new idea was that pressure member was expected to yield before buckling. It should be noted that yield has to be distributed properly that is not uniformly in local form, so that the dissipated energy reaches its greatest value during a cyclic loading such as earthquakes.

Some research was carried out based on avoiding the buckling of the compressive braces using concrete cover around it. The bearing compressive load is performed using the steel core of this type of brace and the concrete cover is only assumed to prevent buckling of the steel core.

* Corresponding author at: Faculty of Civil Engineering, Jundi-Shapur University of Technology, Dezful, P.O.Box 64615-334, Iran.
E-mail addresses: rahnavard1990@gmail.com (R. Rahnavard), mn147013@gmail.com (M. Naghavi), maryamabudi74@gmail.com (M. Aboudi), suleimmf@mail.cu.edu (M. Suleiman).

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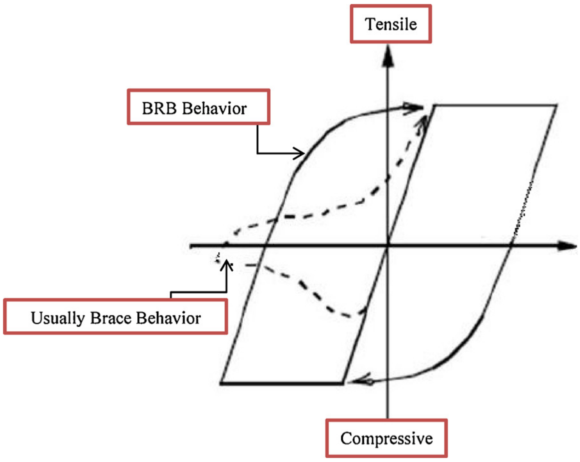

Fig. 1. Behavior of conventional buckling-restrained braces adopted from [35].

Buckling of the steel core causes lateral distribution of the internal pressure in the concrete cover. To prevent the transmission of axial compressive force from steel core to concrete cover, a thin layer of a special material is placed at common surface of steel and concrete. This layer prevents the friction between the core and concrete which causes the compressive force arising from lateral deformation of steel to transmit the core as extensive transverse load to the concrete. This way of transferring the force among components has caused this kind of brace to be called Buckling Restrained Brace (BRB).

The BRBs were widely used in the 1980s in Japan [16]. Extensive research on unbounded brace was started by researchers in the 1990s in the United States leading to the use of this type of bracing in different buildings for the seismic rehabilitation. The research is being followed in other countries including India and Taiwan. The stability analysis of a BRB was investigated by Black et al. [4] and their study demonstrated that both shear stress and shear strain at the beginning of nonlinear buckling would depend on tangential shear modulus (Gt) [5], this is due to the existence of single-axis pressure.

In 2002, for the construction of a research center at the University of California, Berkeley, the experimental studies on BRBs were performed by Lopez et al. [6] and their experimental results showed that connection plates practically cause creation of the rigid openings and rotation of nodes and should be taken into account in the analysis and design due to high rigidity in connecting plate.

A collaborative study was conducted between National Center for Research on Earthquake Engineering (NCREE) in Taiwan and a group of researchers at the University of Michigan, USA (2004) [5], the main objective of their study was to provide a convenient method for obtaining the base shear. Choi and Kim developed a design procedure for the frames with buckling-restrained brace using energy spectrum hysteresis [7]. In this procedure, it is assumed that beams and columns remain under gravity load in the elastic state and energy dissipation and its related damage occur at the BRB. Thus, this is necessary and inevitable that any new technology used in practice requires laboratory and theoretical studies. It has been suggested in the American Institute of Steel Construction (AISC 2016) that two sets of experimental tests should be conducted on braces [8]. The first series of experimental tests was only carried out on braces. Their axial behavior is carefully observed and the parameters required for the design are obtained. Another result of this series of experimental test can be the ideal shape of brace. Fahnestock et al. (2006) conducted a research program on BRBs [9]. The effect of the near-field earthquakes on structures with BRBswas studied by Shmshadyan et al. [10]. The results of the study showed that such systems had better performance on the energy dissipation [10]. A study entitled “Effect of Design Loads in Buckling Restrained Braced Frames Performance” was carried out by Shokrgozar and Asgharian. In their study, resistance, ductility and effect of design loads in buckling-restrained braced frames (BRBFs) were evaluated. For this purpose, some buildings with various stories and different configurations of braces were studied.

Static pushover, nonlinear incremental dynamic and linear dynamic analyses have been performed using the OpenSees Software. The effects of some parameters on response of the correction factor including height of a building and the bracing system were investigated and finally the vibration response of a correction factor for each braced system was separately determined in their study [11]. A research study was carried out by Almansa and Oller on the cyclical behavior of buckling-restrained brace. In their study, ductility and the connection resistance based on regulations FEMA-450 and finite element model of the studied sample were modeled, then plasticity curves and the brace strength were obtained.

In addition, cyclic behavior of a brace member using finite element methods were studied from these curves [12]. A research was conducted by Chuo and Chi-Yu to analyze and comparison of cyclic performance analysis of BRB screw connections to the beams and columns. This was performed using the Abaqus software based on changing the horizontal arrangement of connecting screws. The results obtained from the research were in accordance with the regulations AISC-LRFD for the same beam and column sections indicating the slenderness ratio for this type of brace was 2. Moreover, the results showed that distance between the screws and the connection center of the beam to column had a direct relationship to its buckling [13].

Some studies were performed by Ou and Zhao et al. to analyze and compare the cyclic performance of the BRB to the beams and columns connection as well as investigate the impact of this kind of brace on the lateral buckling. A research was also conducted on