Journal of Constructional Steel Research 105 (2015) 139–150

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Influence of design parameters of buckling-restrained brace on its performance

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ARTICLE INFO

Article history:
Received 2 April 2014
Accepted 24 October 2014
Available online 28 November 2014

Keywords:
Buckling-restrained brace
Refined finite element
Contact force
Multi-wave buckling
Core width-to-thickness ratio
Core thickness

ABSTRACT

The contact interaction between the core and external restraining members is a vital factor that affects the overall performance of buckling-restrained braces (BRBs) significantly. In this study, refined finite element (FE) model was employed to evaluate the contact force between the core and external restraining members and to investigate the BRB performance. Moreover, the influences of strength and stiffness of external restraining member, core length, and other geometric parameters on the BRB performance were also studied. On the basis of numerical results obtained in the study, the recommended values of core width-to-thickness ratio, core thickness and gap were proposed. By considering the core plasticity and the lateral restraint of external restraining member, some formulas for predicting the half-wave length of core buckling as well as contact force were also proposed while the core buckled in multi-wave form. These formulas were numerically verified and could be references in the design of BRB.

1. Introduction

Since the Northridge Earthquake (1994) and Kobe Earthquake (1995), the buckling-restrained brace (BRB) has been widely used to improve seismic performance of buildings because of its advantage in preventing core member from overall buckling under axial compression. In general, a BRB consists of the steel core member which bears the axial load, the external restraining member which provides the lateral restraint to core member and the unbonded materials or gaps between the core and external restraining members [1]. Based upon the material and components of external restraining member, BRBs are often categorized as the integrated restraining BRB [2–4] and the assembled restraining BRB [5–7], as shown in Fig. 1.

Because the external restraining member provides lateral restraint to core member, it can prevent the core from overall buckling. So the contact interaction between the core and external restraining members is important to understand the working mechanism of BRBs. To date, several investigations have been conducted on the seismic performance of BRB [4,8–15], but little work has been attempted to evaluate the contact mechanism and to consider the influences of geometric dimension on the core contact force and BRB performance. Moreover, some assumptions have been made in the previous studies. For instance, Zhao et al. [16] assumed that a two-point-contact occurs at the end of the core and external restraining members when axial forces were exerted. Guo et al. [4,5] believed that the lateral deformation of core member was consistent with that of external restraining member, and assumed the core contact force appeared as a sinusoidal distribution pattern. However, the rationality of these assumptions has not been verified yet.

The influence of design parameters on BRB performance (e.g. the strength and stiffness of external restraining member, the brace length etc.) has been involved in some researches [7,13,17,18]. Inoue et al. [17] proposed that when looking into the overall buckling of BRB, the mutual influence between the strength and the stiffness of external restraining member should be considered.

The design parameter, i.e., restraining ratio ξ [4,5] which was defined as the ratio of the overall elastic buckling load N_{cr} of BRB to the yield load N_y of core member, could reflect the lateral restraint extent of external member and the main performance in the BRB. Besides, the influence of core member dimension, such as core thickness, was also studied. Koetaka Y et al. [19] deduced the equation of the minimum half-wave length when the core deforms in a multi-wave buckling mode based on the elasticity buckling analysis of core member [Eq. (1)], but the lateral restraint influence of external member was not considered.

$$l_w = \sqrt{\pi^2 E_t I_c / N_y} \tag{1}$$

where, N_y is the core member yield load, E_t is the tangent modulus in the plastic range of steel material, and I_c is the inertia moment of core member.

This study intends to evaluate the core contact force as well as BRB performance via the refined finite element (FE) analysis, based on a simplified BRB model. The influences of the strength and stiffness of external restraining member, core member length, width-to-thickness ratio and thickness of core member on BRB performance are also researched

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http://dx.doi.org/10.1016/j.jcsr.2014.10.024
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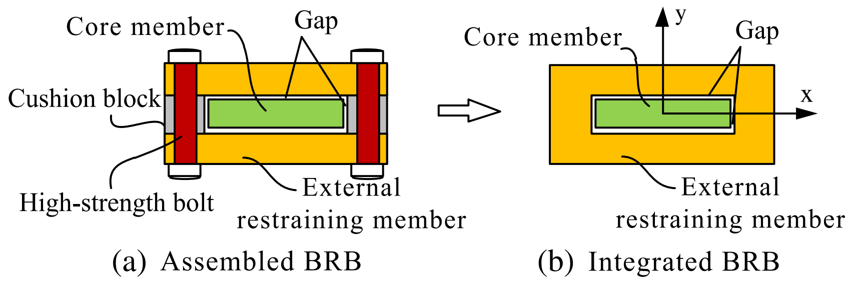

Fig. 1. Schematic diagram of BRB.

theoretically. The recommended design values of the core member and the gap are also provided in this study. Additionally, when the core deforms in the multi-wave buckling mode, the formulas for predicting the half-wave length of core member and the contact force are also proposed.

2. Finite element model

To quantify the influence of design parameters on core contact force and BRB performance, an analysis by using the refined FE method is conducted. In this study, a simplified BRB model [Fig. 1(b)] is used where the external members of BRB are integrated as a whole. In this situation, no matter what kind of material and components are used for external members, the contact interaction between the core and external members and the work mechanism of BRBs are the same. Therefore, it is assumed that the external restraining member is modeled as a square tube, and the core member is made of a steel flat plate. A gap between them is set to form an unbonded layer, as shown in Fig. 2.

Fig. 3 presents the FE numerical model of the BRB, which is solved by using the FE software ABAQUS [20]. The 8-node linear brick with reduced integration (C3D8R) element is used to model the core member, external restraining member and stopper. The contact pairs are established between the core and external restraining members, as well as between the stopper and the hole at the mid-span of the external restraining member. The tie constraint is set between the stopper and core member.

The friction forces between contact pairs are involved in the numerical analysis. It is well known that there are two kinds of contact forces between the core and external members, namely a normal contact force, and a tangential friction force. It is believed that the friction forces between the contact surfaces do not change the distribution and amplitudes of normal contact forces between the contact surfaces significantly. In order to confirm this, the effect of friction coefficient on the BRB performance has also been investigated by using numerical examples.

In general, the core yield strength is below that of external members. The yield strength of 235 MPa is taken in the core steel plate, with the hardening tangent modulus of 2% elasticity modulus in the plastic stage of core material. The elastic–perfectly plastic material with a yield strength of 345 MPa is adopted for the external restraining member and slot stiffening plate. The elasticity modulus of the members mentioned above is 206GPa.

A crossed rigid end plate is set at the end of core member for applying the axial loads conveniently, and it behaves as an ideal elasticity material. The tie constraint is also set between the end plate and the core member. The simply hinged end is assumed at the central line of both end plates, and the axial compression of the core is specified as a loading parameter of BRBs. Only the rotation around x axis of core member is concerned, and the displacements of core member in the x direction are restrained.

For simplifying numerical analysis, the length of the core is the same as the external restraining members. The web thickness of external restraining member t_1 is 70 mm, and the thickness of rigid end plate is 10 mm. The 40 mm thick wing plate is set at the core end to provide the core member with sufficient stiffness, and its plane dimension is 200 × 50 mm.

The mid-span node in core member is chosen to be an observation point in order to investigate the lateral displacement variation in the y direction during the loading process. Meanwhile, the lateral displacements on the core central line, the top flange and the bottom flange, as shown in Fig. 3, are also evaluated.

The damping factor for contact control is set to be 1E-4 to enhance the convergence of numerical analysis. The full Newton–RaPhson method [20] is adopted for the numerical solution, and the maximum increment of the loading step is set as 0.005 s.

3. Influence of strength and stiffness of external restraining member

In the design of BRBs, only external member with enough strength and stiffness can provide a proper lateral restraint and fulfill the yield of core member. Otherwise, global or local instability in the BRBs may occur before the core yields.

In this section, six BRB models of 2 m in length are analyzed numerically for investigating the influence of strength and stiffness of external restraining member on overall performance of the BRB. The influence of the friction between the core and the external members is also involved in the analysis. The gap of 1 mm at both sides between the core and the external restraining members is set, and the overall initial imperfection amplitude of $L/1000$ of the BRB is also applied, where L is the length of the external member. This amplitude of $L/1000$ results from a design code, *Chinese Code for design of steel structures GB50017* [21]. In this code, a large of number of statistic results of initial imperfection almost for all the types of solid sectional members has conducted the

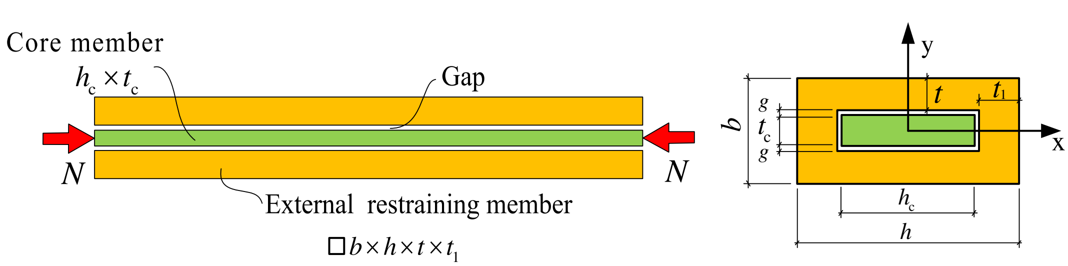

Fig. 2. Composition diagram of simplified BRB.