Journal of Constructional Steel Research 95 (2014) 106–115

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

A practical and unified global stability design method of buckling-restrained braces: Discussion on pinned connections

Junxian Zhao [a,*], Bin Wu [b], Jinping Ou [b,c]

[a] State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou 510641, China
[b] School of Civil Engineering, Harbin Institute of Technology, Harbin 150090, China
[c] School of Civil and Hydraulic Engineering, Dalian University of Technology, Dalian 116024, China

ARTICLE INFO

Article history:
Received 12 March 2013
Accepted 3 December 2013
Available online 30 December 2013

Keywords:
Buckling-restrained brace
Global stability
End bending moment
Moment amplification factor
Unified design method

ABSTRACT

The end bending moment induced by brace end rotation was recently found to have a negative effect on the global stability of buckling-restrained braces (BRBs). The proposed bending moment functions for the BRBs with traditional pinned connections, however, were found to be too complicated from practical view. Also, the relationship between the flexural behavior of BRBs and the brace end details has not yet been well understood, possibly resulting in misevaluation of BRB global stability capacity in design. In this paper, a moment amplification factor (MAF) method is proposed to simplify the bending moment function of the BRBs with traditional pinned connections, followed by parametric study on the key parameters affecting the MAF and presentation of the proposed simplified function. A unified global stability design method is proposed and implemented to the BRBs with pin-ended connections. Several future research needs for BRB global stability are presented finally.

1. Introduction

Buckling-restrained braces (BRBs) have been extensively implemented in seismic-prone areas due to their ductile performance and stable hysteretic behavior in both tension and compression [1]. With the constraining effect of outer buckling-restraining mechanism (hereafter called casing), BRBs can be used as both conventional braces without buckling and metallic yielding dampers.

According to previous studies, it is known that to increase the deformation capacity of BRBs under compression, preventing their buckling is of crucial importance. The global stability issue of BRBs has drawn much attention since the 1980s [2–12] and many useful conclusions have been obtained. Two kinds of design methods for BRB global stability can be concluded, i.e. the stiffness-based method [2–4] and the strength-based method [5–12]. To verify the commonly used strength-based method, a series of cyclic tests of sixteen BRB specimens with traditional pinned connections (see Fig. 1(a)) and pin-and-collar assembly connections (see Fig. 1(b)) were tested by the authors [13–15]. Test results confirmed that the global stability capacity of pin-connected BRBs would be overestimated from the strength-based method by 40% if end bending moments induced by the two-point contact interaction between core end and casing end developed. To consider the combined effect of end bending moment and core global buckling on the overall flexural behavior of casing, two bending moment functions for the BRBs using the two types of pinned connections were derived respectively and verified by experiments [13,16,17]. However, these functions are still inappropriate for practical use due to their complicated expressions. Although a simplified formula to predict the flexural demand on the casing for the BRBs using pin-and-collar assembly connections was presented [17], the root idea for the simplified method and the concept regarding the process of contact and deformation between steel core and casing still needs to be explained to gain further insight. Related discussion also needs to be extended to the BRBs using traditional pinned connections from design point of view. Particularly, how to consider the effect of brace end details on the overall flexural behavior of casing and unify the corresponding bending moment functions for the BRBs using pinned connections still needs to be clarified from practical view.

This paper first reviews the development for the global stability design methods of BRBs, followed by presentation of the unaddressed issues for the current design procedure of pin-connected BRBs and finally a practical and unified method to tackle these issues.

2. Brief review of the global stability design methods

2.1. The stiffness-based method

The design method by ensuring that the stiffness parameter of casing P_{eb}/P_y (defined as the Euler buckling load of casing divided by the yield force of steel core) should be no less than 1.5 was first proposed by Fujimoto et al. [2]. This design criterion was derived based on the bolt-connected BRBs using concrete filled steel tube (CFST) as the casing by assuming flexural yielding at the center of casing

* Corresponding author at: School of Civil Engineering and Transportation, South China University of Technology, 381 Wushan Road, Tianhe district, Guangzhou 510641, People's Republic of China. Tel.: +86 18027241880.
E-mail address: ctjxzhao@scut.edu.cn (J. Zhao).

0143-974X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jcsr.2013.12.001

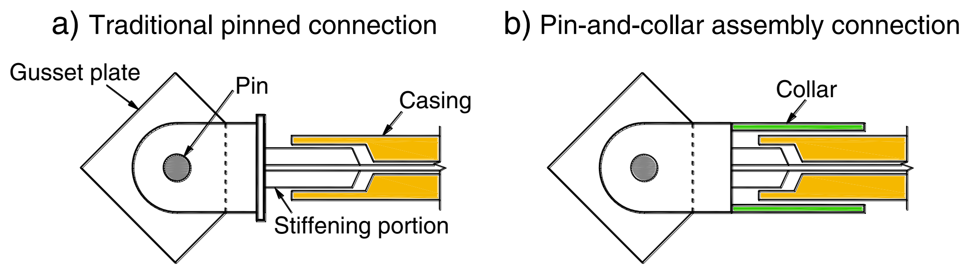

Fig. 1. Two types of BRB pin-ended connections.

and considering the effect of core imperfection and loading eccentricity. It was found that the safety factor of 1.5 is enough to ensure the global stability of the BRBs using CFST casing if the eccentricity is smaller than 1/200 of brace length. Although this method is simple for practical design, it was found overestimating the global stability capacity of the BRBs using all-steel or reinforced concrete members as the casings due to their reduced flexural strength compared with CFST [3,5]. Obviously, this method cannot be easily used to unify design of different types of BRB cross-sections due to its incomprehensive consideration of the strength of casing.

Takeuchi et al. [4] proposed a stability evaluation method of BRB by considering the out-of-plane rotational stiffness at gusset plate ends from rigid-end to pin-end. The buckling models with and without consideration of end bending moment transfer between core end and casing end were presented and the corresponding end bending moment were derived. However, this method focused on the out-of-plane stability design of connections and core extension, and the combined effect of core global buckling and end bending moment transfer from the connections on the overall flexural behavior of casing was not discussed.

2.2. The strength-based method

Considering the abovementioned problems, the stiffness-based method was developed by Inoue et al. [6] based on the flexural strength of casing. This kind of strength-based method was then further modified by Kuwahara [7] et al. and Shimizu et al. [8,9] by considering the effect of gap between the core and the casing (see Fig. 2), which can be given by

$$M_b = \frac{P(\delta_o + 2c)}{1-P/P_{eb}} < M_{yb} \quad (1)$$

where M_b and M_{yb} mean the bending moment and the yield moment at the center of casing, respectively; P and P_{eb} denote the maximum compressive force and the Euler buckling load of casing, respectively; δ_o represents the initial deflection of casing (for all-steel BRBs) or that of steel core (for the BRBs with in-filled concrete or mortar inside the casing); c means the gap between the core and the casing on each side. From inequality (1), it is seen that the contribution of both strength (M_{yb}) and stiffness (P_{eb}) of casing to the global stability could be properly reflected, which corresponded well with test results [7–9]; hence, the strength-based method has been now the commonly used global stability design criterion of BRBs and has laid basis for relevant researches [5,10–12].

Fig. 2 presents the traditional analytical model for the strength-based method, which was originally proposed by Inoue et al. [6] and then modified by Shimizu et al. [8,9]. It shows that this model considered the interaction between the constrained yielding portion and the casing only and ignored the effect of brace end rotation and possible end bending moment transfer from the connections to the casing. Hence, the boundary conditions of the casing were actually considered to be simply supported at both ends with one-point contact interaction only [2,5–12]. This assumption enables the casing to bend like a simply supported beam. In addition, it can be found from previous studies [8,9,12] that the traditional model and design criterion (inequality (1)) were validated only for the BRBs with bolted (welded) end connections and also extremely short constrained length of stiffening portion at the core ends (see Fig. 2). Hence, one-point contact interaction could be expected to occur at the core ends (see point a) only, due to the presence of gap and extremely short stiffening portion, even though significant brace end rotational deformations developed during earthquakes. This kind of contact state happened to correspond with what was assumed in the traditional model, which well explains the correspondence between the test results and the theoretical ones obtained from inequality (1) in these studies.

However, in actual application, pin-ended connections can also be used to connect BRBs to frame gussets, in which rotational deformations are easy to develop at the brace ends. It is generally recommended that the stiffening portion at the core ends be inserted into the casing with a certain constrained length to enable the steel core to yield under small earthquakes and also to improve the out-of-plane stability of gussets [4,18]. It can be expected that additional bending moments will be induced near casing ends, due to the relatively large stiffness and constrained length of the stiffening portion, when brace end rotation occurs. But the validity of the traditional model and the design criterion (inequality (1)) for the BRBs with the abovementioned brace end details was not discussed.

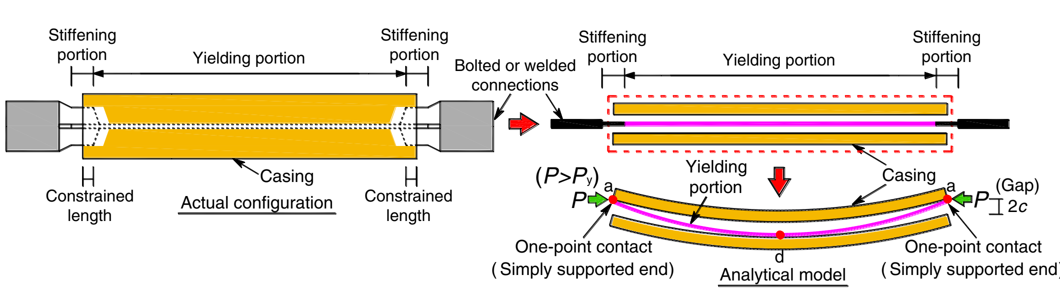

Fig. 2. Traditional analytical model for the strength-based method.