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Subassemblage tests and numerical analyses of buckling-restrained braces under pre-compression

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ABSTRACT

Pre-compression loads are conducted in BRBs if the installation of frames and BRBs are performed simultaneously. In this paper, the load-carrying and energy-dissipating behavior of BRBs under pre-compression are investigated by subassemblage tests and additional finite element (FE) analyses. A total of five specimens were tested, in which two specimens were tested by cyclic pure compression loads and three specimens were tested by hysteresis loads; four of them maintained stable load-carrying behavior during loading process. The load-carrying and energy-dissipating behavior of the specimens were satisfactorily simulated using a refined FE model with a combined isotropic and kinematic hardening rule of the core material, and the compression strength adjustment factor and the stress enhancement coefficient were well predicted by the FE analytical results with a relative error less than 3.0%. The FE analytical results of BRBs with different pre-compression strains are presented, indicating that the pre-compression in a BRB would aggravate the stress enhancement of the core material in both tension and compression, yet it would hardly influence the value of the compression strength adjustment factor.

1. Introduction

Buckling-restrained braces (BRBs), consisting of core members encased by outer restraining components, have been widely used in building structures. The core member transmits axial force and the outer part restrains the lateral displacement of the core to prevent its buckling under compression. Besides, an unbonding layer is usually installed between the core member and the restraining part to prevent the transmission of axial force between them. Therefore, the core member of BRB is able to yield in both tension and compression, thus ensuring that the BRB can achieve a stable hysteresis characteristic.

In practical design of BRBs, one of the key parameters is the restraining ratio ζ (Eq.(1)), which is defined by dividing the elastic buckling load of the whole BRB, N_{cr}, by the initial yield load of the core, N_y.

$$\zeta = \frac{N_{cr}}{N_y} \tag{1}$$

Currently, the lower limit of ζ is determined by two methods as follows: (1) getting the lower limit of ζ based on test results (e.g. $\zeta \geqslant \zeta_{\min} = 1.9$ [1]) or based on FE numerical investigations into load resistance and hysteresis responses of BRBs, and (2) deriving the lower limit of ζ theoretically according to the flexural capacity of the restraining part [2]. The former is suitable in determining the lower limit of ζ for the BRBs encased by mortar infilled steel tubes, while the latter is more suitable for all-steel BRBs.

In addition, the overstrength of core material is generally taken into consideration in design of BRBs [3] by introducing the stress enhancement coefficient of the core R_y, which is defined by dividing the maximum compression load of the core, $P_{\max}$, by N_y, and it can also be expressed as the product of β and ω (Eq. (2)).

$$R_y = \frac{P_{\max}}{N_y} = \beta \cdot \omega \tag{2}$$

Generally, BRBs are diagonally placed in frame structures, serving not only as lateral force resistance members, but also as energy-dissipation members under seismic loads. The most commonly used type of BRB is the brace encased by mortar infilled steel tube, on which a number of theoretical and experimental investigations have been performed [1,4,5], and these papers mainly focused on the hysteresis performances of BRBs. Besides, several experimental investigations were carried out by Tsai et al. [6] to examine the efficiency of different unbonding materials and the strength of the welded end-slot connections. Recent years,

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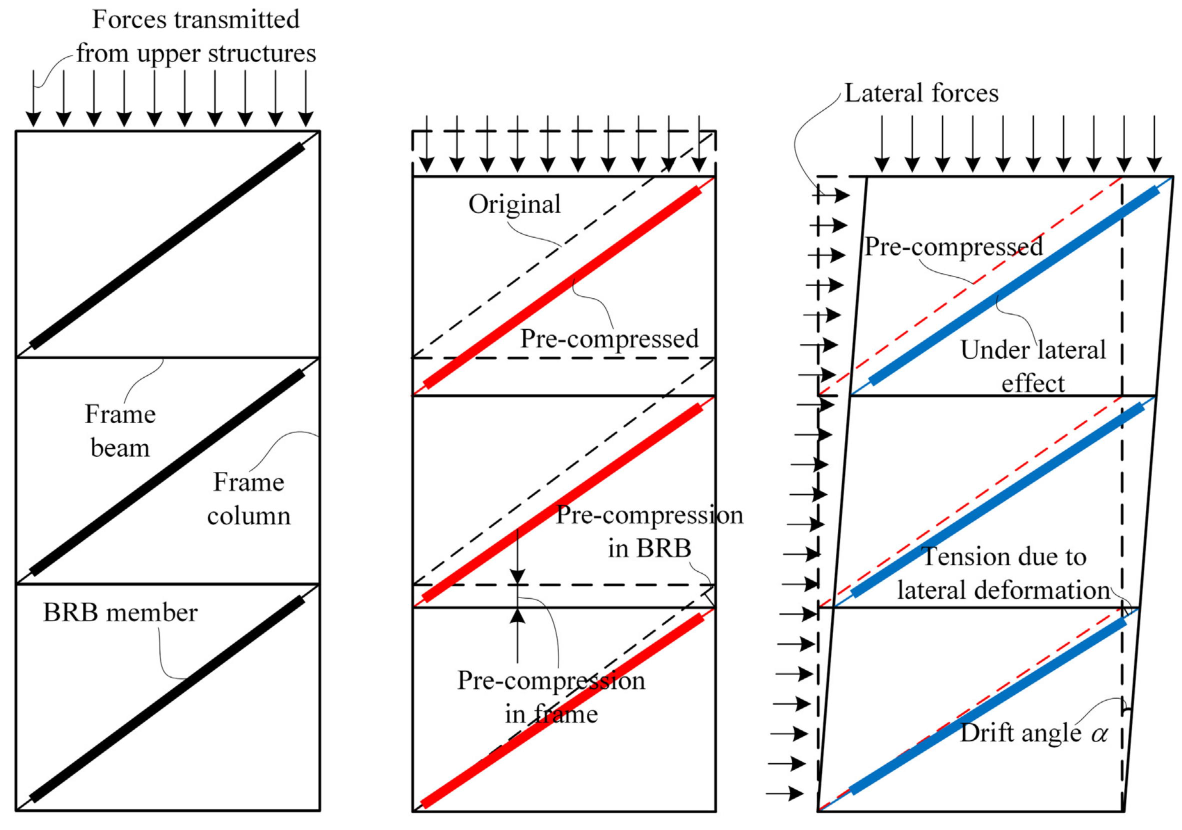
Nomenclature

A_c	cross-sectional area of the core
b	width of the confining tube
b_c	width of the core
E	Young's modulus of steel
$f_{y,t}$	yield stress of the confining tube
f_y	initial yield stress of the core
g	gap between the core and infilled concrete
g_x (g_y)	gap between the core and infilled concrete in x-direction (y-direction)
l	specimen length
l_1	length of the confining tube
l_y	length of the yield portion
N	axial load applied to the core
N_{cr}	Elastic buckling load of BRB
N_y	initial yield load of the core
$P_{\max}$	maximum compression load of the core
R_y	stress enhancement coefficient of core material
t_c	thickness of each of the four flanges of the core
$T_{\max}$	maximum tension load of the core
v_0	amplitude of the initial geometrical imperfection
w	lateral mid-span deformation
W_e	section modulus of restraining part
α	drift angle of frame
β	compression strength adjustment factor
δ	axial displacement of the core
δ_0	longitudinal space between the end plate and seal plate
ε_c	compression strain of the core
$\varepsilon_{c,\max}$	maximum compression strain of the core
ε_{pc}	pre-compression strain of the core
$\varepsilon_{t,\max}$	maximum tension strain of the core
ε_y	yield strain of the core
$\varepsilon_{y,t}$	yield strain of the confining tube
ζ	restraining ratio
$\zeta_{\min}$	lower limit of the restraining ratio
ω	tension strength adjustment factor

many new types of BRBs have been proposed and several studies of all-steel BRBs have been conducted [2,7–11]. Additionally, Khampanit et al. [12] and Palmer et al. [13] carried out experimental studies to evaluate the improvement on mechanical properties of structures by utilizing all steel BRBs.

In practical design, the construction sequence can seriously influence the loading condition of BRBs under seismic effects since: (1) if the installation of BRBs starts after the frame is finished, no pre-compression may be conducted in the BRBs, and thus the core member will be subjected to tension and compression loads alternately under seismic effects, and (2) if the installation of BRBs and the construction of frame are performed simultaneously, the BRBs will be subjected to axial pre-compression loads transmitted from their upper structures, as shown in Fig. 1. Additionally, cyclic pure compression loading condition may occur in the core under seismic effects if the pre-compression load is larger than the axial tension force resulting from lateral seismic response.

The pre-compressed condition is more common in practical engineering design since: (1) The simultaneous fabrication and installation of frames and BRB members can significantly reduce



(a) Original structure
(b) Under pre-compression due to dead loads
(c) Under pre-compression & lateral forces

Fig. 1. Deformation condition of frame structure with BRBs under construction.