Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Design method of the pinned external integrated buckling-restrained braces with extended core. Part II: finite element numerical verification

Zi-qin Jiang, Yan-lin Guo, Jing-zhong Tong, Xing Yuan

Cite this as: Zi-qin Jiang, Yan-lin Guo, Jing-zhong Tong, Xing Yuan, 2015. Design method of the pinned external integrated buckling-restrained braces with extended core. Part II: finite element numerical verification. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 16(10):793-804. [doi:10.1631/jzus.A1400326]

Highlights

- FEA is applied to verify the theoretical assumptions and the derivation results.
- Influence of 9 parameters on contact force and external member stress is conducted.
- 12 BRBs are designed to verify the rationality of the theoretical derivation.
- Some significant design recommendation of the pinned BRBs are obtained.

Theoretically derived results

Stress State of the Pinned BRBs with Core Single-wave Overall Deformation

In Part I, the following assumptions are made in a simplified model: the initial geometric imperfection of the core and the external member follow a sinusoidal pattern and the critical state when the core and the external member end start to have two-point-contact is deemed to be the initial state of the BRB. The distributed contact force appears as a sinusoidal pattern when the core has single-wave deformation, and the bending moment of the core contact region is zero.

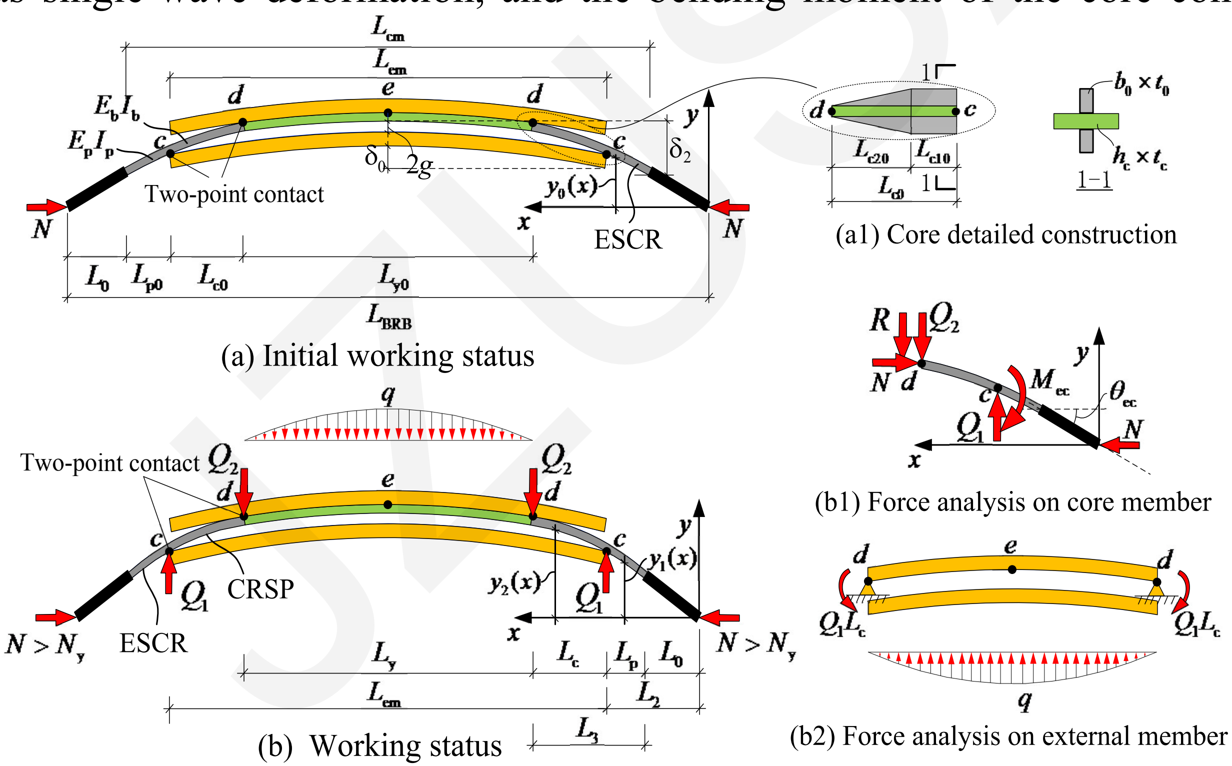


Fig. 2 Simplified force analysis for BRB with core single-wave deformation

Theoretically derived results
Stress State of the Pinned BRBs with Core Single-wave Overall Deformation

Based upon some assumptions, the force equilibrium equations of the extended strengthened core region (ESCR) and the restrained strengthened core region (RSCR) are established. By employing the deformation compatibility relationship between the core and the external member at some contact points, the maximum bending moment on the extended core region [Eq.(1)], the maximum contact force on the core member [Eq.(2)], the maximum bending moment on the external member [Eq.(3)] and the BRB's end rotation [Eq.(4)] are obtained.

$$M_{\mathrm{ec}} = c_2 N L_{\mathrm{c}} \tag{1}$$

$$Q_1 = (w_1 + c_2 w_2) N \tag{2}$$

$$M_{\mathrm{em,max}} = Q_1 L_{\mathrm{c}} + \frac{L_{\mathrm{y}}^2}{\pi^2} q_0 \tag{3}$$

$$\theta_{\mathrm{ec}} = \left(r_1 + r_2 k_1\right) \delta_2 + r_2 k_2 \left(w_1 + c_2 w_2\right) / k \tag{4}$$

Theoretically derived results
Design criteria of the BRB

Design Criteria for the External Restraining Member

As the external restraining member only offers lateral support to the core member, it is a flexural member. Accordingly, the sectional bending capacity of the external member can be considered as a control of the BRB restraining ratio in its design method.

$$\xi = \frac{\pi^2 E_b I_b}{L_{BRB}^2 N_y}$$

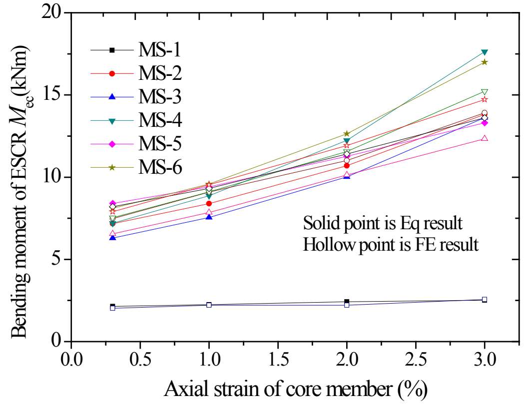
$$\xi \geq [\xi] = \frac{w L_y^2 \left(W_{em} f_{ey} + \left(\pi^2 / 8 - 1 \right) Q_1 L_c \right)}{L_{BRB}^2 \left(W_{em} f_{ey} - w N_y x_1 \delta_0 - Q_1 L_c \right)}$$

Design Recommendations for the SCR

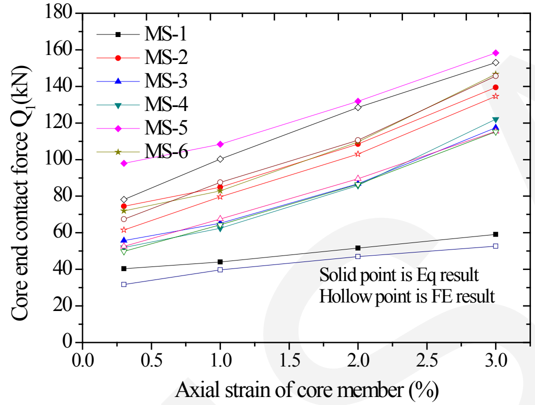
Since the ESCR behaves as a typical beam-column, its limit strength is considered as a full sectional yielding and is expressed as an interaction between axial force and bending moment.

$$\left(\frac{N}{N_{p,ec}} \right)^2 + \frac{M_{ec}}{M_{p,ec}} < 1.0$$

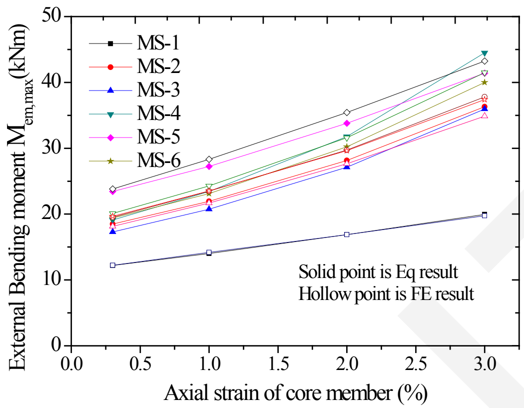
Verification for the BRB with Core Single-wave Overall Deformation



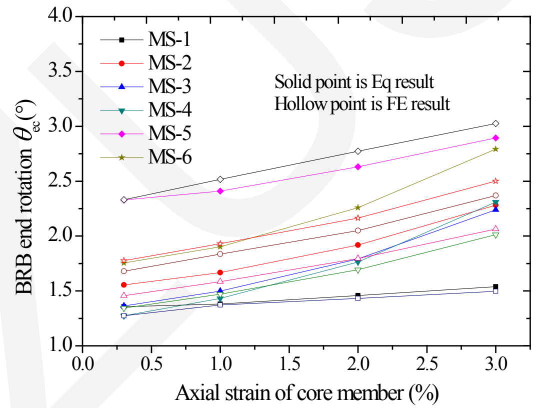
(a) Rationality verification of Eq.(1)



(b) Rationality verification of Eq.(2)



(c) Rationality verification of Eq.(3)



(d) Rationality verification of Eq.(4)

Fig. 5 FE verification of BRB with core single-wave deformation

FE analysis results shown in Fig.5 denote that the maximum bending moment of ESCR, the core end contact force, the maximum bending moment of the external member and the end rotation of BRB match well with the FE analysis results.

When the core axial strain is 3%, the equation errors can be controlled within 10%, thus meeting the engineering requirements. Also, it indicates that the basic assumptions and results in the previous theoretical derivation section are accurate.

Verification for BRB Design Method

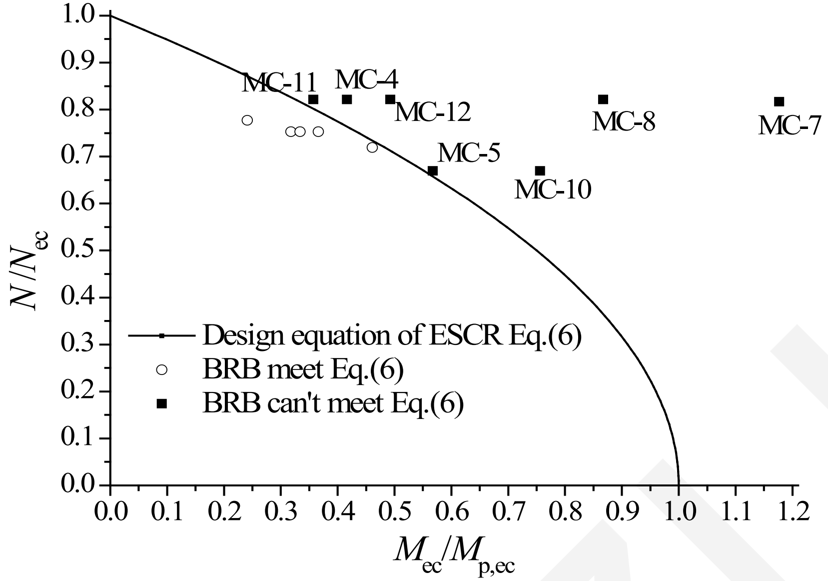


Fig. 9 ESCR Design check

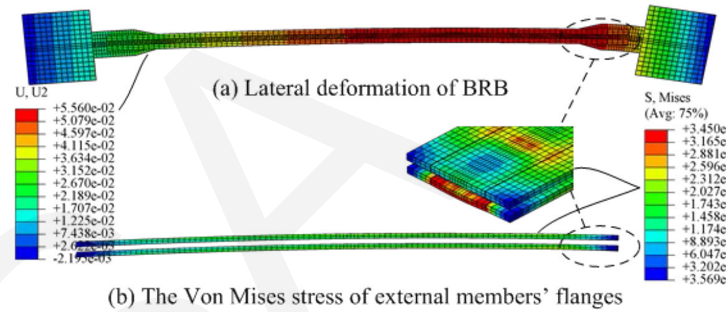


Fig. 12 FE analysis result of the BRB of MC-7

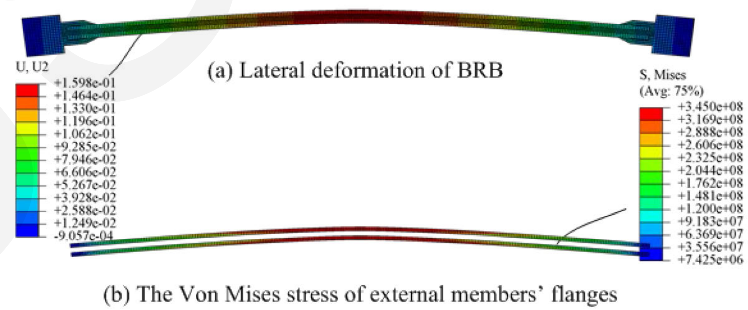


Fig. 13 FE analysis result of the BRB of MC-9

- Analysis results show that the BRBs of MC-7, MC-8, MC-9, MC-12 all lose axial load-bearing capacity.
- Generally speaking, the theoretical analysis results are consistent with the FE results, which are safe and meet the engineering design requirements.

Conclusions

- This study presents a FE numerical verification of the Part I paper. FE analysis is applied to: (1) verify the theoretical assumptions and results of Part I, as well as the accuracy and feasibility of the equations derived theoretically; (2) quantify the influence of nine parameters on the pinned BRBs' performance; (3) check the proposed strength design method of the pinned BRBs.

  The following conclusions are obtained:

- 1. FE numerical results indicate that the basic assumptions and equation derivation in the theoretical analysis of Part I are accurate, and the proposed design method of the pinned BRBs can precisely predict the BRB's overall buckling failure and bending failure in the ECSR of BRBs.
- 2. As the design of the external member and the strengthened core region directly affect the failure modes of the pinned BRBs, both sufficient rigidity and strength for the external member and the SCR are required.
- 3. Although the design parameters such as the external member's initial imperfection, external member length, the RSCR length with uniform section and the height of wing-plate of SCR can't be reflected directly in the restraining ratio, these parameters can be all considered in the proposed design method of the pinned BRBs.

Conclusions

- This study presents a FE numerical verification of the Part I paper. FE analysis is applied to: (1) verify the theoretical assumptions and results of Part I, as well as the accuracy and feasibility of the equations derived theoretically; (2) quantify the influence of nine parameters on the pinned BRBs' performance; (3) check the proposed strength design method of the pinned BRBs.

  The following conclusions are obtained:

- 4. Considering the significant influence of the gap, the core width-to-thickness ratio, and the external member's initial imperfection on the core contact force acting on the external member, these parameters should be well controlled while designing them. It is also concluded that a shorter pinned connector, a relatively longer external member and the RSCR with uniform section are favorable in designing a pinned BRB, because they can minimize the core contact force and the maximum bending moment of the external member.