# Numerical Investigation on Performance of Buckling-Restrained Braces

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## 1　Introduction

The buckling-restrained brace (BRB) attracts more and more attentions, because it does not buckle in compression but yield in both tension and compression and represents an effective energy absorption mechanism for damping of engineering structures with low cost. Based on authors' past researches, the concept of high-performance BRBs (HPBRBs) is proposed that no replacement is needed during the lifecycle of bridges and it is likely to suffer three times of strong earthquakes without severe damage. During low-cycle fatigue tests of steel BRBs, the constraints of the flat core brace member, such as the stoppers used to prevent the relative displacement between the core brace and the restraining members, attracted our attentions and obviously affected the fatigue performance. So in this paper, both half and whole models with and without taking into account the symmetry of the brace member, are proposed to simulate the hysteretic behavior of steel BRBs. Summaries of experimental and analytical results are given as follows.

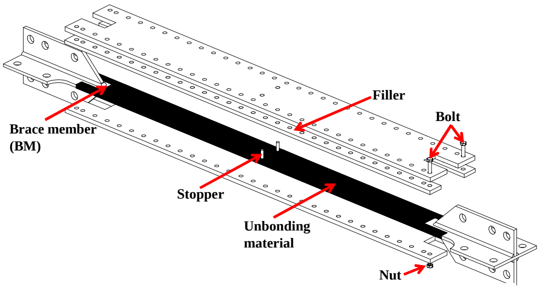


Figure 1. Assemblage of steel BRB

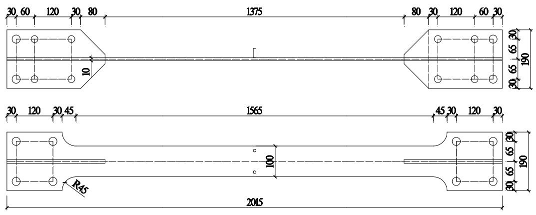

Figure 2. Dimensions of brace member

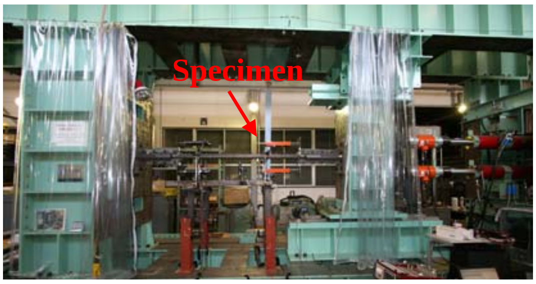


Figure 3. Testing setup

## 2　Summary of experiment

As shown in Figure 1, a steel BRB mainly consists of a steel plate brace member (BM), a pair of restraining members (RMs) connected by high-strength bolts through two filler members, and an unbonding material of 1mm in thickness stuck to the BM as the isolation material in order to reduce the friction between the BM and RMs. Dimensions of the BM are given in Figure 2 and detailed properties of the BM and RMs are presented in the references [1,2]. Furthermore, Figure 3 shows that the specimen is horizontally pinned by high-strength bolts between two rigid pillars while the BM is horizontally placed.

Table 1. Test results of BRB specimens

| Specimen | $\Delta\varepsilon/2$ | $\Delta\varepsilon$ | $N_f$ | *CID* | Failure position |
|---|---|---|---|---|---|
| FT-3.5 | 0.035 | 0.07 | 9 | 1.18 | Mid-span |
| FE-4.0 | 0.040 | 0.08 | 7 | 0.96 | Mid-span |
| FT-3.5(NS) | 0.035 | 0.07 | 5 | 0.65 | Mid-span |
| FT-4.0(NS) | 0.040 | 0.08 | 4 | 0.59 | Mid-span |

Note: $\Delta\varepsilon/2$ = strain amplitude; $\Delta\varepsilon$ =strain range; $N_f$ = number of failure cycles; *CID* = cumulative inelastic deformation.

In the present study, a tensile and compressive alternative cyclic loading pattern controlled by the constant axial strain of specimens is given. Total four BRB specimens are given in Table 1 and divided into two groups. At the center of FT-3.5 and FE-4.0 specimens' BMs, two welded stoppers of 9 mm in diameter and 30 mm in height are used to prevent the relative movement between the BM and RMs in the longitudinal direction. But there are no stoppers at the center of FT-3.5(NS) and FT-4.0(NS) specimens. As listed in Table 1, the failure cycle number $N_f$ of the FT-3.5 specimen with the

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stopper under the same 3.5% strain amplitude decreased from 9 to 5 in contrast with the FT-3.5(NS) specimen without the stopper, while $N_f$ of the FE-4.0 specimen with the stopper under the same 4.0% strain amplitude decreased from 7 to 4 in contrast with the FT-4.0(NS) specimen without the stopper. It is concluded that the stopper used to prevent the relative displacement obviously affects the low-cycle fatigue performance of steel BRBs. The same conclusion can be drawn from the *CID* values. Details of experimental stress-strain relations and failure models are given in the reference [1,2].

## 3 Proposed models

In order to simulate the mechanical behaviors of the BRBs with or without stoppers, two analytical models built in ABAQUS are given as follows.

Considering that stoppers are welded on the BM, the mechanical behavior of the BRB is symmetric. So an elastic-plastic 2D model simulating the BRB with the stoppers is proposed and illustrated in Figure 4(a), where half a BRB is modeled under the symmetry condition. Because the stoppers were not welded in the FT-3.5(NS) and FT-4.0(NS) specimens' tests, the RMs of the steel BRB, were driven by the friction at the beginning of low-cycle fatigue tests, and were stopped because of the interaction between the RMs and the cruciform section part of the BM in the axial direction. Therefore, the second elastic-plastic model of a whole BRB is presented in Figure 4(b) and the different boundary conditions of the RMs are given. The four nonlinear springs are used to simulate this movement. In order to compare with each other conveniently, the first model is called *Half Model*, and the second model is called *Whole Model*. Further details of both models are given in the reference [2].

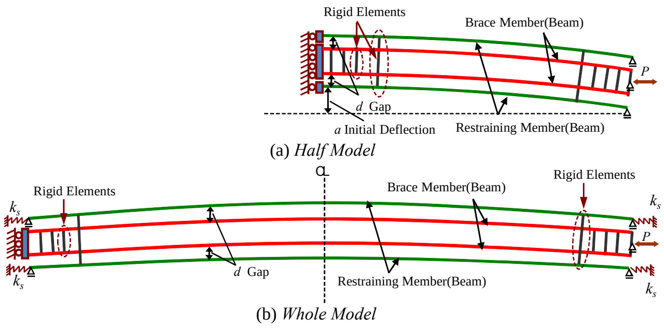


Figure 4. Analytical models based on beam element

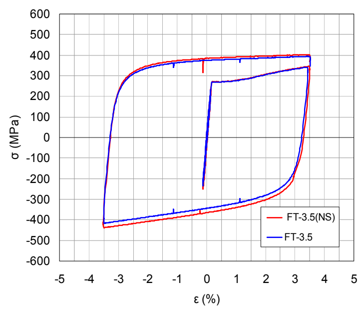


Figure 5. First loops of experimental stress-strain relations

## 4 Comparison with test results

In this section, low-cycle fatigue test results of the FT-3.5 and FT-3.5(NS) specimens will be conducted to evaluate the proposed analytical models. As shown in Figure 5, the maximum absolute compressive stress at the first loop of the FT-3.5(NS) specimen is about 5% larger than the FT-3.5 specimen. It is considered that the difference of the first loop is affected by the constraint of the RM. Stress-strain relations of *Half Model* and *Whole Model* are given together with the experimental data in Figure 6. It is clear that with the proper friction coefficient, *Half Model* and *Whole Model* can effectively simulate the hysteretic behavior of the FT-3.5 and FT-3.5(NS) specimens.

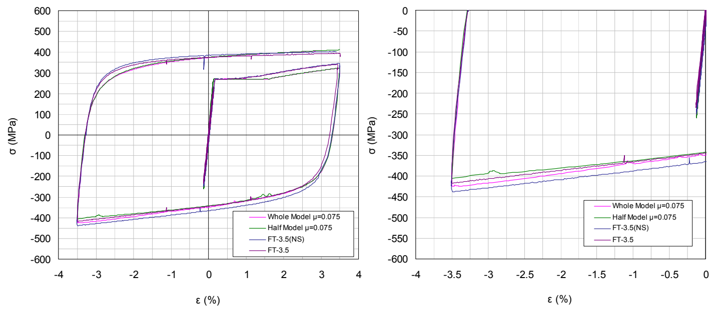


Figure 6: First loops of stress-strain relations ($\mu$=0.075)

## 5 Conclusion

In conclusion, it is clear that the low-cycle fatigue performance of BRB is affected by the constraint of the BM and proposed *Half* and *Whole Models* can effectively simulate the mechanical behavior of the BRB with or without the stoppers.

## Preference

[1] 宇佐美勉，佐藤 崇：座屈拘束ブレースの低サイクル疲労実験と照査法，構造工学論文集，Vol.56A，pp.486-498, 2010.3

[2] 舟山淳起，王春林，宇佐美勉：溶接部の仕上げによる鋼製 BRB の低サイクル疲労性能向上効果，構造工学論文集，Vol.57A，pp.565-578, 2011.3