Experimental Study on Performance Evaluation of Buckling Control Brace

Sang Ju Lee ¹,a, Sang Eul Han ²,b, Sam Young Noh ³,c

¹ Dept. of Archi. Engrg., Hanyang University, Ansan-Si, Korea, 426-791
² Dept. of Archi. Engrg., Inha University, Incheon, Korea, 402-751
³ Dept. of Archi. Engrg., Hanyang University, Ansan-Si, Korea, 426-791
a kyotolsj@empal.com, b hsang@inha.ac.kr, c noh@hanyang.ac.kr

ABSTRACT

To ensure the deformation capacity of structures, the concept of earthquake resistant design is converted into performance design. As a method of introducing this concept, research on brace system becomes very active. Brace does not only share the horizontal shearing force, as a energy absorption element--seismic resistance damper, it can also prevent the structure to be seriously damaged, it also have a big effect on increasing the deformation capacity of the structure.

Brace can be designed to be slender member because it is subjected to tensile force. Therefore it is necessary to consider buckling. We should restrict the occurrence of local buckling and improve required resistant force and deformation capacity, because the occurrence of local buckling will decrease resistant force of the element remarkably and have a big influence on stability of the whole structure.

The purpose of this research is to propose several structural systems for restricting or eliminating local buckling, and evaluate the performance of the brace systems and check their applicability on structure through experiment.

KEYWORDS: Steel Structures, Brace, Buckling, Earthquake Resistant Design, Seismic Resistance Damper, Deformation Capacity

1. INTRODUCTION

This research presents two methods to prevent local buckling by using circular tube brace, and verifies their performances through cyclic loading test. As methods to control local buckling, one is to ensure deformation capacity by setting cover plate in buckling occurred district to restrict local buckling; another is to exclude the danger of buckling under pressure by inserting a contracted element with spring in the centre of brace.

To grasp performance of these control systems, firstly, we evaluate single frame with circular tube brace which is subjected to repeated horizontal load, then verify hysteresis behavior such as buckling position, shape and buckling loads. And we would compare and analyze hysteresis behavior of experiment specimens. Apply each system to control buckling and evaluate their amplification effect on performance.
2. TESTING PLAN

We take a single steel frame with diagonal circular tube brace as experimental object. As shown in Figure 1, we apply buckling restricting device with cover plate and buckling control device consisted of spring and steel bar on brace. And we examine the effect of brace on buckling in compression through cyclic loading testing. To grasp performance of system with buckling restricting and buckling control device, we inflict repeated horizontal load on single frame with circular tube brace firstly and evaluate hysteresis behavior such as buckling position, buckling type. And we compare and analyze hysteresis behavior through experimental result of specimen which applies each buckling control system respectively, and evaluate their amplification effects on performance.

(a) device with cover plate
(b) spring-rod device

Figure 1. bucking control device

2.1 Specimen design

As shown in figure 2, specimen is fixed on supporting beam by bolted joint, and circular tube steel brace is set in diagonal line direction. Column is connected with supporting beam by bolted joint through base plate, and beam-column connection is welding joint. Apart from that, stiffener is established to exclude local buckling that may occur near beam-column connection. Both ends of brace are welded on gusset plate, and then connected with frame by bolted joint. Establish lateral bucking restraint device to prevent lateral bucking of frame. Inflict horizontal load on frame through actuator on the upper end of column so that tension and compressive force could be introduced to brace.

Figure 2. testing plan
2.1.1 Frame design

The sections of frame and brace are designed by slope deflection method and moment distribution method, and the horizontal displacement could not exceed 0.01rad (10mm if the length of element is 1m) When frame structure yields. Supposing axial stiffness of beam is very big, the relationship between displacement (uB) and horizontal force (P) on target frame structure can be expressed by slope deflection method:

\[ u_B = R_{AB} h = \frac{4 + 6\beta}{1 + 6\beta} \cdot \frac{h^2}{24EK_{AB}} P \]

\[ \beta = \frac{K_B}{K_C} \]  

Where, RAB is rotation angle of the column, \( \beta \) is relative stiffness ratio of beam and column, supposing beam is of the shear yielding type and relative stiffness ratio of beam and column is 3:2.

2.1.2 Brace design

Consider Brace as axial force subjected elements and supposing both ends are in hinge connection. Design it under conditions as follows.

1) Horizontal stiffness ratio of frame and brace is designed to be 2:1, then brace shares 1/3 of total horizontal force.
2) Brace uses steel circular tube, so it can be replaced easily.
3) Brace is designed to be three types, brace without any control (OB), brace with cover plate in central part where buckling is expected to occur (CB), and brace with spring which does not have any compression resistance ability when compressed (SB)

![Figure 3. brace design](image)

(a) brace without device(OB)  (b) cover plate(CB)  (c) spring-rod(SB)

2.1.3 Section design

The materials of column and beam adopt SS400. Design them according to the conditions described above. Table 1 and table 2 show the sizes and parameters of column, beam and brace sections.

When structure yields, frame and brace share the horizontal force by 160kN and 80kN respectively.

![Figure 4. deformation of frame and circular tube brace](image)
Table 1. Sectional parameters of column and beam

<table>
<thead>
<tr>
<th>member</th>
<th>D (mm)</th>
<th>B (mm)</th>
<th>t_w (mm)</th>
<th>t_f (mm)</th>
<th>r (mm)</th>
<th>A (cm²)</th>
<th>I (cm⁴)</th>
<th>Z_y (cm³)</th>
<th>Z_p (cm³)</th>
<th>M_y (kN·m)</th>
<th>M_p (kN·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>150</td>
<td>150</td>
<td>7</td>
<td>10</td>
<td>11</td>
<td>40</td>
<td>1640</td>
<td>219</td>
<td>246</td>
<td>45100</td>
<td>50700</td>
</tr>
<tr>
<td>BC</td>
<td>148</td>
<td>100</td>
<td>6</td>
<td>9</td>
<td>11</td>
<td>27</td>
<td>1020</td>
<td>138</td>
<td>157</td>
<td>28400</td>
<td>32300</td>
</tr>
<tr>
<td>CD</td>
<td>150</td>
<td>150</td>
<td>7</td>
<td>10</td>
<td>11</td>
<td>40</td>
<td>1640</td>
<td>219</td>
<td>246</td>
<td>45100</td>
<td>50700</td>
</tr>
</tbody>
</table>

Table 2. Sectional parameters of brace

<table>
<thead>
<tr>
<th>D (mm)</th>
<th>D (mm)</th>
<th>A_r (mm²)</th>
<th>I (mm⁴)</th>
<th>Z_y (mm³)</th>
<th>N_y (kN)</th>
<th>M_y (kN·m)</th>
<th>Z_p (mm³)</th>
<th>M_p (kN·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.5</td>
<td>2.8</td>
<td>508</td>
<td>212,000</td>
<td>7,000</td>
<td>119</td>
<td>1.64</td>
<td>9,320</td>
<td>2.19</td>
</tr>
</tbody>
</table>

2.2 Loading and measurement plan

In this experiment, loading ability of actuator is 500kN, and beam-column connection is pin-jointed. Apply repeated displacement loading on it. Loading control displacement is based on horizontal displacement for elements rotation angle of column which correspond to fully plastic moment calculated by tension experiment results, and loading cycle is increased steadily by 2, 3, 4 times of loading amplitude. Loading repeats 2 cycles about each amplitude, and continue loading until the amplitude reaches 5 times of standard (figure 5) and ultimate state can be judged. Measure points of loading and displacement are shown in figure 6. Load is measured by rod cell which is attached on the end of actuator rod, and displacement is measured by LVDT displacement meter that is established on frame, and strain is measured by strain gauge attached on central part and both ends of the brace.

3. TESTING RESULT AND REVIEW

This chapter describes the results of cyclic loading experiment. At first, we describe buckling appearance and development situation observed in experiment, then show load-displacement relation curve. And we investigate maximum loading and deformation capacity based on load-displacement hysteresis curve.

3.1 Hysteresis behavior and failure

3.1.1 Occurrence and development of buckling

When establish general brace, as expected, buckling happens in central part of brace. It is evident that this buckling influences the lateral bucking of structure. Buckling happens when horizontal displacement is 10mm and greatly increases with the number of repeat times and horizontal displacement, finally the crack which can be evaluated as complete fracture occurs at the central part of brace. When establish cover plate for buckling restricting, with the increasing of horizontal
displacement and the number of repeat times, buckling occurs at both ends of curve plate, because the
size is big and development situation is fast, buckling restraint effect can not be evaluated. When
establish spring brace for buckling control, even if horizontal displacement and the number of repeat
times increase, buckling does not occur and shows a stable hysteresis behavior under compression or
tension.

(a) buckling at center part (OB)  (b) buckling at both end (CB)  (c) compression deformation of device

Figure 7. buckling and deformation situation of brace in compression

3.1.2 loading-displacement curve

According to load and displacement relation, the internal force will fall down when bulking occurs in
the case general brace is established, but hysteresis behavior will keep stable in the case spring brace is
established.

3.2 Maximum resistant force and deformation capacity

According to experiment results, we investigate the maximum force of experiment specimen. In the
case of OB specimen, maximum force is more than 300kN when brace is in tension and more than
240kN when it is in compression. In the case of CB specimen, it is 300kN and 200kN respectively. In
the case of SB specimen, it is 300kN and 220kN respectively. In the case of OB specimen, when in
compression, internal force will decrease if buckling occurs.

Figure 8. brace  Figure 9. restraint brace with cover plate
Figure 10. brace of spring-rod device

In the case of CB specimen, buckling occurs at the end of brace which is strengthened by cover plate, and the internal force does not increase. In the case of SB specimen, it shows that it could not stand compressive force because the internal force in compression is 60 ~ 70% level of that in tension. Decline of internal force dose not appear during experiment.

4. CONCLUSIONS

In summarize, the conclusion of this research is shown as follow.
1) In case of general brace, we can know that buckling happens on the brace will influences lateral bucking of structure greatly and decrease internal force.
2) When brace is strengthened by cover plate in the central part, due to buckling happening on both end of cover plate, internal force will decrease and serious damage will occur in this experiment. Therefore I think it must be strengthen over a wider extent for more effective prevention.
3) When establish spring in central part of the brace, it shows enough control effect and the brace displays a stable hysteresis behavior without any damage. Buckling control device is evaluated to have enough amplification effect on deformation capacity. The performance will be more perfect if we arrange brace in both direction or in plane.

ACKNOWLEDGMENTS

This work was supported by Inha University which was supported Korea Institute of Construction and Transportation Technology Evaluation and Planning (KICTEP) (05-Construction Core Technology Program C02) and Sustainable Building Research Center of Hanyang University which was supported the SRC/ERC program of MOST (R11-2005-056-04004-0)

REFERENCES