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REHABILITATION OF STEEL STRUCTURE BY MEANS OF WEDGE DEVICE

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ABSTRACT :

A wedge device consisting of a wedge, a counter-wedge and a spring, is proposed by the authors. The device is applied to earthquake-resistant elements to provide more effective energy absorption under seismic ground motion. New structural elements are also proposed: a non-slip-type column base, a non-compression brace, a self-centering beam-to-column connection and a non-compression knee-brace. An experimental study has been carried out on these structural elements subjected to cyclic loadings to clarify their earthquake-resistant performance and applicability to rehabilitation.

KEYWORDS: rehabilitation, wedge device, column base, brace, beam-to-column connection, knee-brace, loading test

1. INTRODUCTION

A wedge device is proposed to minimize slip of an anchor-bolt-yield-type exposed column base. This new column base is called a non-slip-type column base and it has many advantages over a conventional exposed column base [Takamatsu et al. 2001, 2002, 2003a, 2004, 2005a-e, 2006a, Yamanishi et al. 2007a-b]. This wedge device can also be applied to non-compression brace members to eliminate slip. These members have many advantages, including no slipping and no buckling [Kobata et al. 2006, Takamatsu et al. 2003b, 2006c, Tamai et al. 2005a-b, Yamanishi et al. 2007a]. Beam-to-column connections using the wedge device can minimize beam and column yielding and reduce residual deformation in a building after an earthquake. These connections are called self-centering connections [Kobata et al. 2006, Takamatsu 2005e, 2007a]. Finally, knee-braces with the wedge device, called non-compression knee-braces, can strengthen moment-resisting connections under an earthquake [Kobata et al. 2006, Takamatsu 2005f. 2007a-b]. Experiments were carried out on specimens with the wedge device to obtain restoring force characteristics under cyclic loadings.
Models of the restoring force characteristics are compared with experimental results to examine the applicability of the wedge device to earthquake-resistant elements.

2. NON-SLIP-TYPE COLUMN-BASE

2.1 FUNCTION OF NON-SLIP-TYPE COLUMN-BASE

The non-slip-type column base proposed by the authors is shown in Figures 1 and 2. Slip behavior is prevented by simply setting the wedge device between the nut and the base plate. Any gap generated between the nut and the base plate due to plastic elongation of the anchor-bolt can be eliminated by the wedge moving into the gap under spring compression. The restoring force characteristics of the column base show non-slip-type behavior, linear from the origin. The non-slip-type column base has the following advantages over the conventional column base. 1) No gap appears between the nut and the base plate, so that no looseness is generated in the column base. 2) Since the anchor-bolt can absorb plastic energy without pinching behavior, the column base can play the role of an energy absorption damper during earthquakes of all levels. 3) The wedge device can be easily installed in existing column bases and is thus applicable to rehabilitation of conventional column bases. 4) Since a column base with multi-rows of anchor bolts shows cyclic curves returning to the origin during unloading, unless the rotation of the column base exceeds the elastic limit of rotation, the column base has self-centering capability. Since the cyclic curves become linear from the origin, the self-centering capability can survive after any large-amplitude main shock.

2.2 EXPERIMENT

A horizontal loading apparatus was used in the experimental studies. Figures 3 and 4 show the apparatus and a specimen, respectively. The specimens were designed as anchor-bolt-yield-type column bases, in which the anchor bolts were considered as yielding elements but the base plate, the column member and the foundation were considered as elastic elements. A steel foundation was employed instead of a concrete one, and the anchor bolts were rolled thread anchor bolts standardized by the Japanese Society of Steel Construction.

2.3 RESULTS AND DISCUSSIONS

The experimental results are shown in Figure 5. The relationships between the bending moment M and the base-plate rotational angle θ of the column base are shown as the restoring force characteristics. The dotted line in the figure shows the result given by the model of restoring force characteristics, and the solid line shows the result of the loading test.

In the cyclic loading tests, the loads built up from the origin at each loading cycle, and returned to the origin during unloading. Self-centering performance was shown until the elastic limit of rotation was exceeded. The models of the restoring force characteristics showed fairy good agreement with the experimental results.

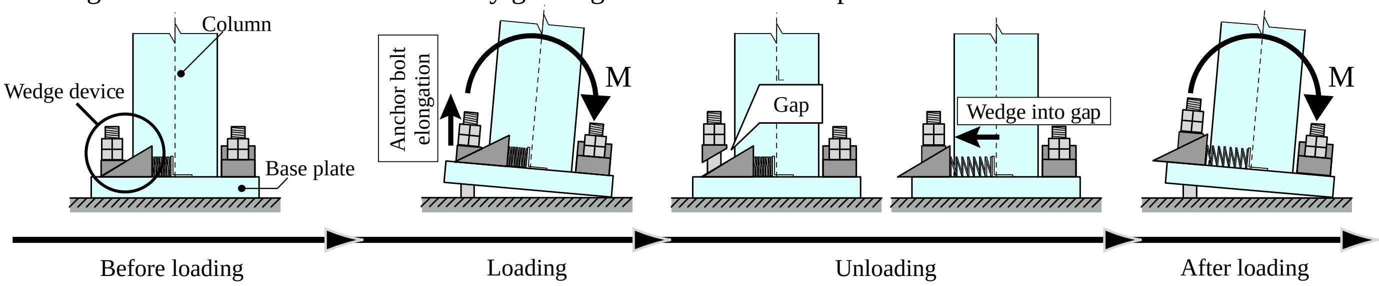
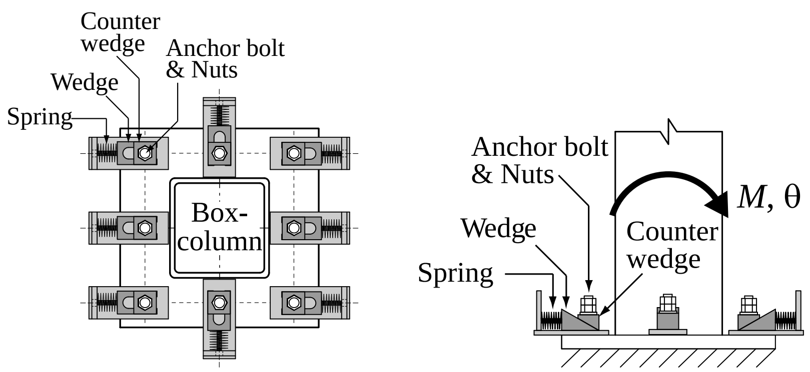
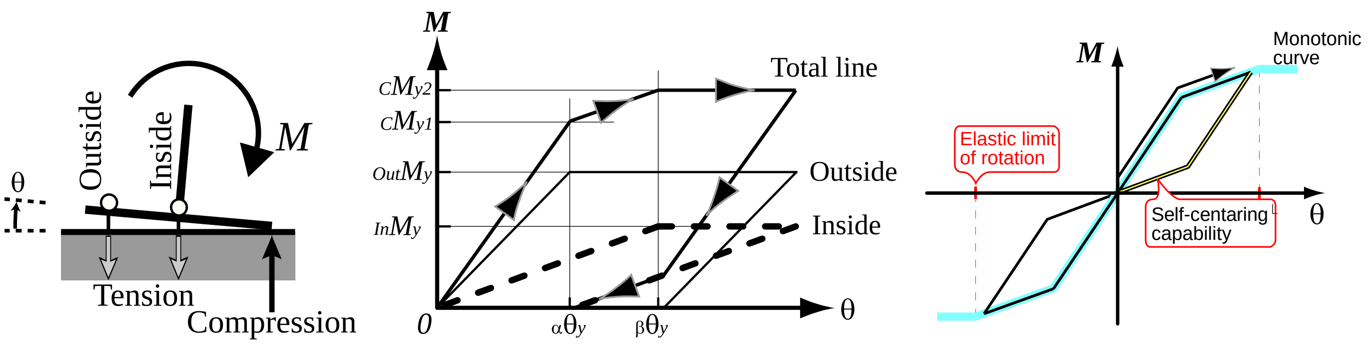


Figure 1 Function of non-slip-type column-base



(a) Arrangement of Wedge device on base plate



(b) Resistant mechanism and model under monotonic loading (c) Model under cyclic loadings

Figure 2 Restoring force characteristics

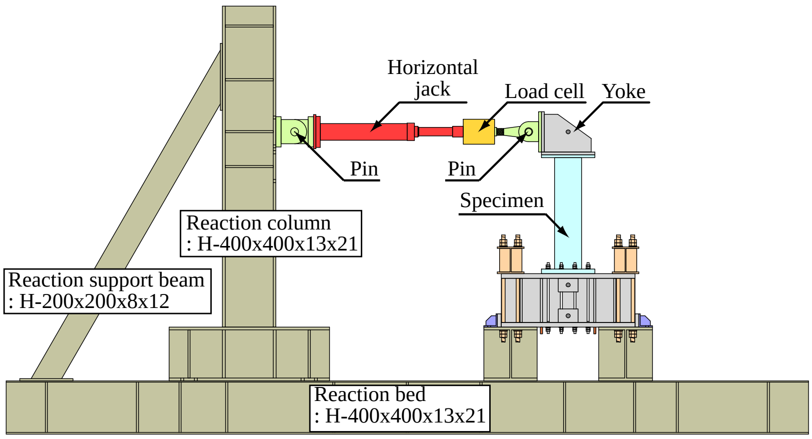
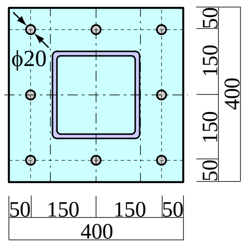
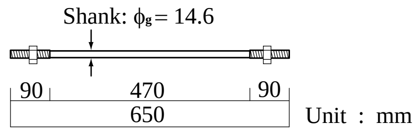


Figure 3 Apparatus

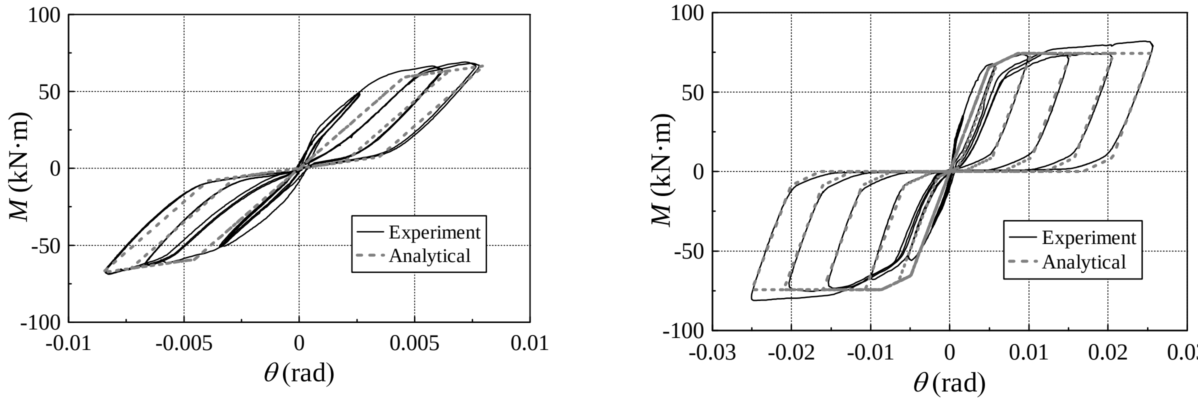


(a) Base plate



(b) anchor bolt

Figure 4 Specimen



(a) Results under the elastic limit of rotation (b) Results over the elastic limit of rotation

Figure 5 Bending moment v.s. Rotational angle relations

3. NON-COMPRESSION BRACES

3.1 FUNCTION OF NON-COMPRESSION BRACE

The non-compression brace proposed by the authors is shown in Figures 6 and 7. It consists of a slender rod with tensile-connected ends equipped with the wedge device. One end of the brace is pinned and the other with the wedge device is designed as a roller moving only in the compressive direction. The brace can only resist tensile force so there is no buckling caused by compressive force. The tensile force exceeds the axial yield force and the brace elongates plastically. During cyclic loadings, plastic elongation of a conventional brace causes slip-type restoring force characteristics, but the wedge of the non-compression brace under spring compression slides into the gap between the counter-wedge and the wedge-stand to prevent looseness of the brace. A pair of non-compression braces subjected to seismic loadings shows perfect elastic-plastic restoring force characteristics. The non-compression brace has the following advantages over conventional braces. 1) It shows no buckling and no looseness in the tensile direction. 2) A pair of them shows perfect elastic-plastic curves, so that an analytical model of cyclic behavior can be easily formulated. 3) The brace end connection can be simply designed as a tensile connection. 4) Sliding displacement of the wedge is the most significant measure for design of the non-compression brace. The plastic deformation capacity or the energy absorption capacity of the non-compression brace depends upon the movable length of the wedge. Therefore, the non-compression brace is suitable for performance-based design.

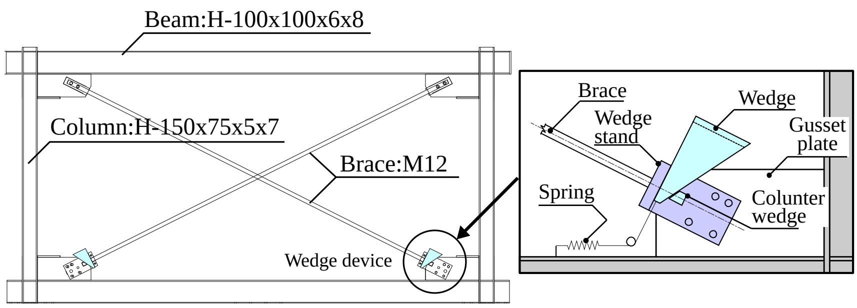
3.2 EXPERIMENT

A horizontal loading apparatus was used in the experimental studies. Figures 8 and 9 show the apparatus and a brace member, respectively. The specimen was a portal frame with non-compression braces. It was subjected to cyclic loadings and the braces were pre-tensioned to 50% of their axial yield force.

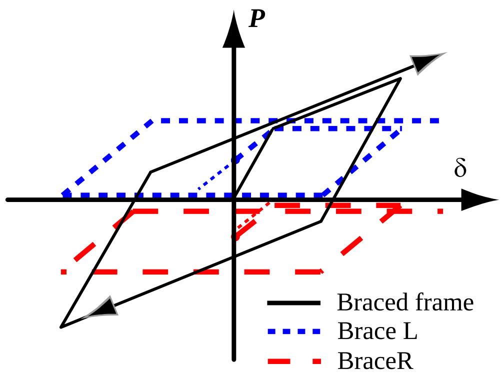
3.3 RESULTS AND DISCUSSIONS

The experimental results are shown in Figure 10. The relationships between the horizontal load P and the horizontal displacement δ of the frame with braces are shown as the restoring force characteristics. The dotted line in the figure shows the result given by the model of restoring force characteristics, and the solid line shows the result of the loading test.

In the cyclic loading tests, the braced frame showed spindle-type restoring force characteristics at each loading cycle, and constant elastic-stiffness curves.



(a) Arrangement of wedge-device on brace end



(b) Model under cyclic loadings

Figure 6 Restoring force characteristics

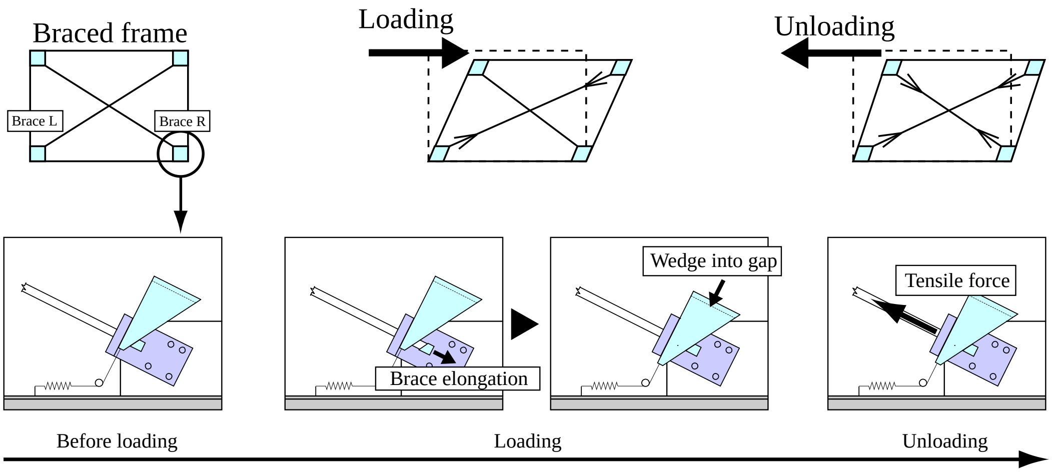


Figure 7 Function of non-compression brace

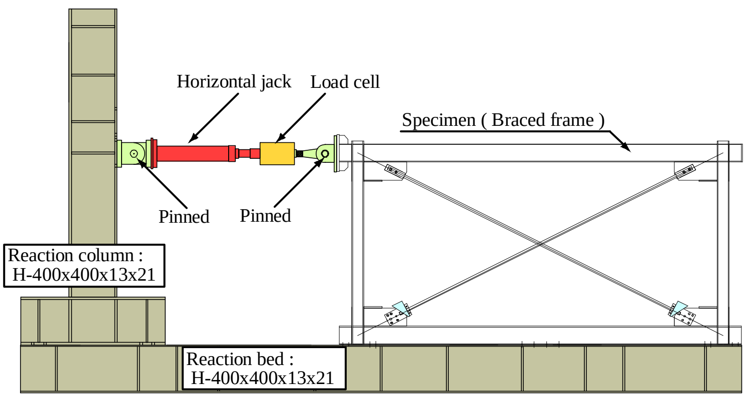


Figure 8 Apparatus

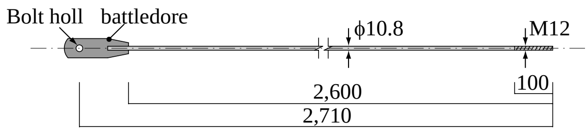


Figure 9 Brace member

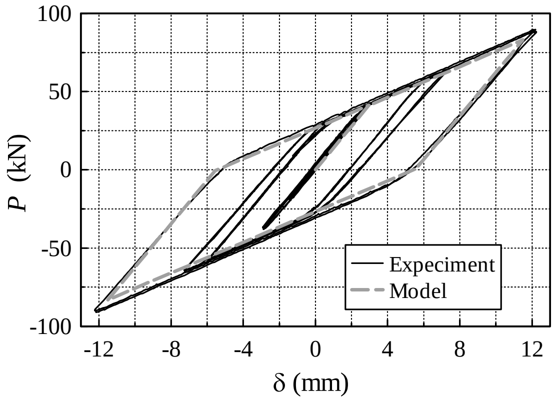


Figure 10 Horizontal load v.s. Horizontal displacement relations

4. SELF-CENTERING CONNECTION

4.1 FUNCTION OF SELF-CENTERING CONNECTION

The self-centering connection proposed by the authors is shown in Figures 11 and 12. It consists of an end-plate-type beam-to-column connection using normal-strength bolts with the wedge device, and the same resistant mechanism as the non-slip-type column base.

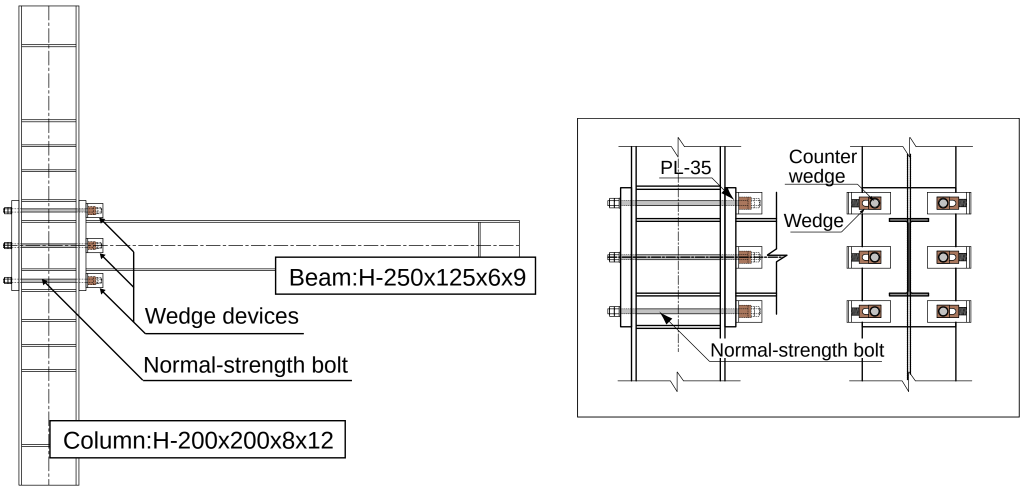
4.2 EXPERIMENT

A horizontal loading apparatus was used on the experimental studies. Figures 13 and 14 show the apparatus and a normal-strength bolt, respectively. The specimen was rotated 90 degrees and the top of the beam was subjected to cyclic vertical loadings by a horizontal jack. The specimen was a T-shaped beam-to-column connection with a wedge devices.

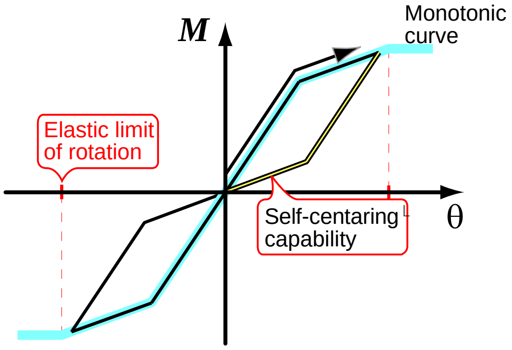
4.3 RESULTS AND DISCUSSIONS

The experimental results are shown in Figure 15. The relationships between the horizontal load P and the horizontal displacement δ of the frame with the self-centering connection are shown as the restoring force characteristics. The bold-solid line in the figure shows the result given by the model of restoring force characteristics, and the thin-solid line shows the result of the loading test.

In the cyclic loading test, the restoring force characteristics showed the same cyclic behavior as the non-slip-type exposed column base. The rotation of the connection did not exceed the elastic limit of rotation so that the connection sustained self-centering capability, returning to the origin after unloading. The experimental elastic stiffness was higher than the analytical stiffness owing to the pre-tension of the bolts. The cyclic behavior was in good agreement with the analytical curves. Members other than the bolts were in the elastic region.



(a) Arrangement of wedge device on end-plate
Figure 11 (a) Restoring force characteristics



(b) Model of restoring force characteristics
Figure 11 (b) Restoring force characteristics

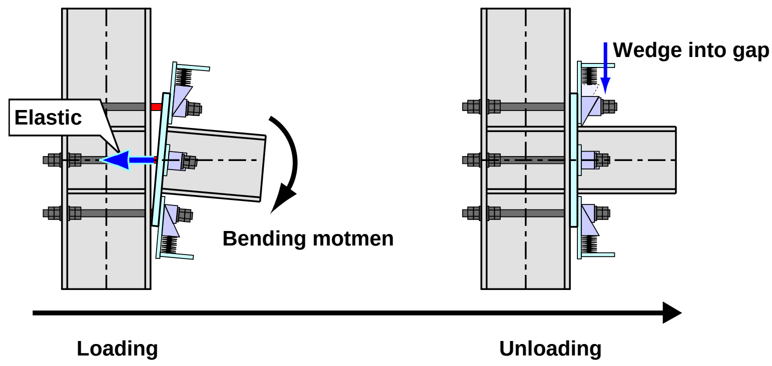


Figure 12 Function of self-centering connection

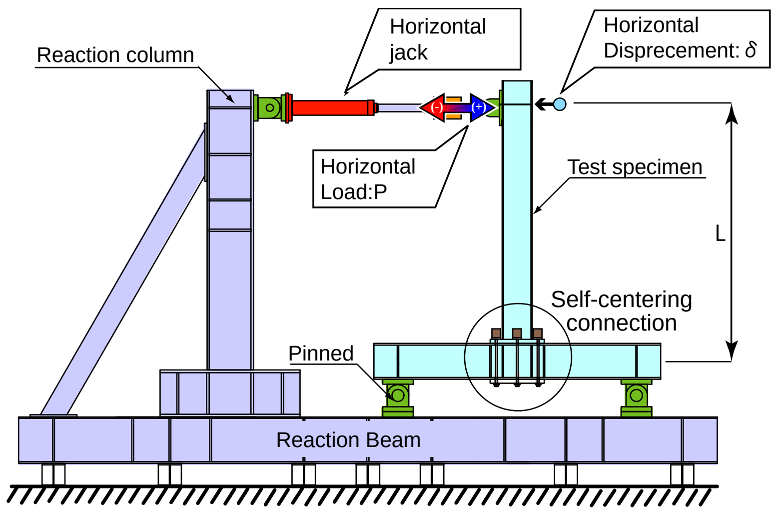


Figure 13 Apparatus

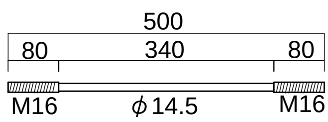


Figure 14 Normal-strength bolt

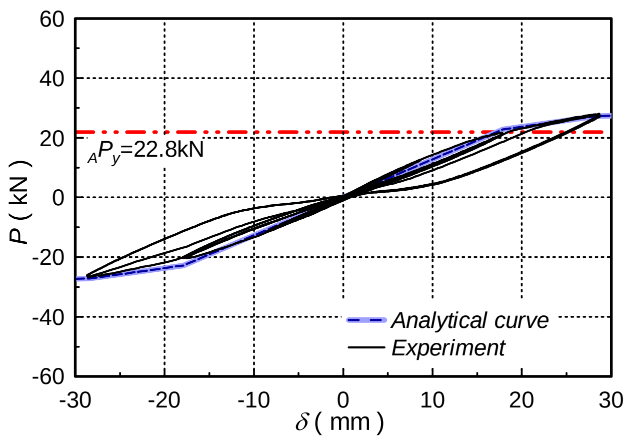


Figure 15 Horizontal load v.s. Horizontal displacement relations

5. NON-COMPRESSION KNEE-BRACE

5.1 FUNCTION OF NON-COMPRESSION KNEE-BRACE

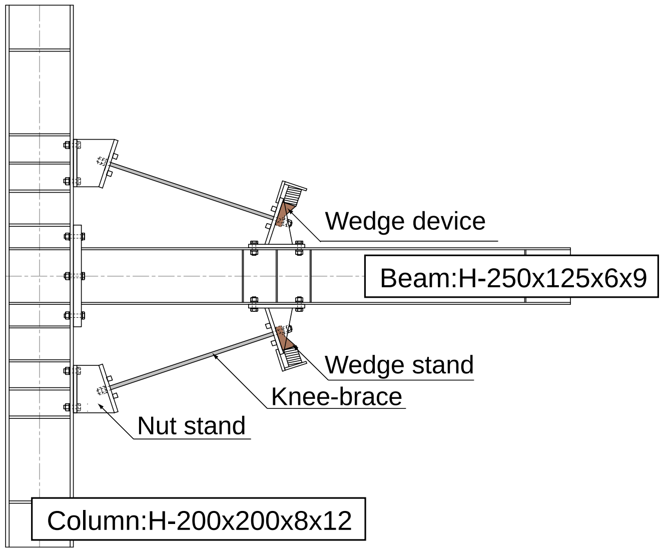
The non-compression knee-brace proposed by the authors is shown in Figures 16 and 17. The specimen consists of a rigid connection with non-compression knee-braces. The knee-brace has the same resistant mechanism as the non-compression brace.

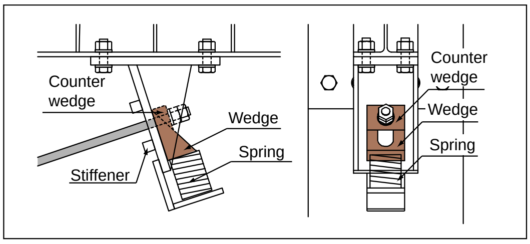
5.2 EXPERIMENT

A horizontal loading apparatus was used in the experimental studies. Figures 18 and 19 show the apparatus and a knee-brace member, respectively. The specimen was rotated 90 degrees and the top of the beam was subjected to cyclic vertical loadings by a horizontal jack. The specimen was a T-shaped beam-to-column connection a non-compression knee-brace.

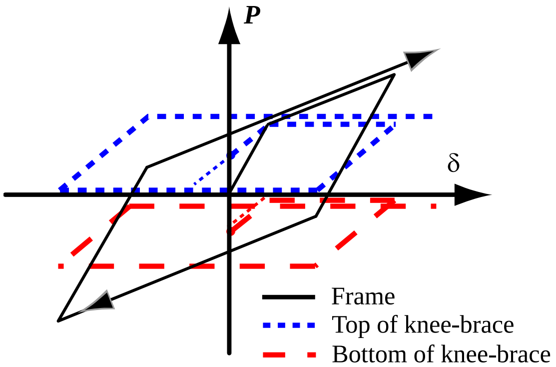
5.3 Results and Discussions

The experimental results are shown in Figure 15. The relationships between the horizontal load P and the horizontal displacement δ of the frame with non-compression knee-braces are shown as the restoring force characteristics. The bold-solid line in the figure shows the result given by the model of restoring force characteristics, and the thin-solid line shows the result of the loading test.
In the cyclic loading test, the restoring force characteristics became bi-linear curves. The elastic stiffness was in accordance with the analytical elastic stiffness of the rigid connection with the non-compression knee-braces. The second stiffness coincided with the analytical elastic stiffness of the frame. The yield load was equal to the yield load of the non-compression knee-brace. The members other than the knee-braces were in the elastic region.





(a) Arrangement of wedge device on knee-brace end



(b) Model of restoring force characteristics
Figure 16 Restoring force characteristics

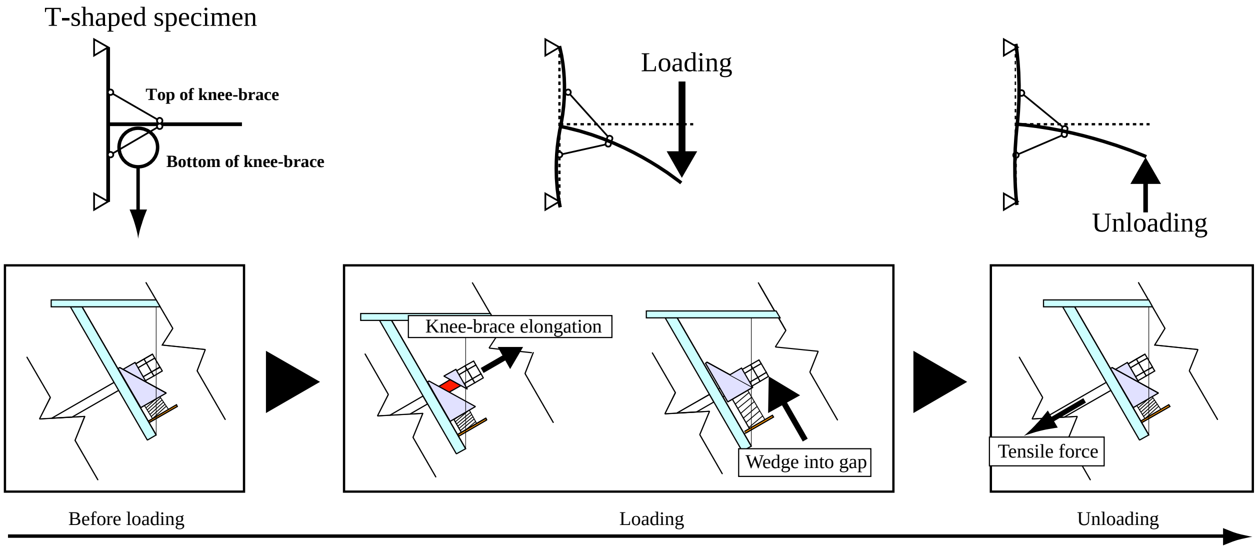


Figure 17 Function of non-compression knee-brace

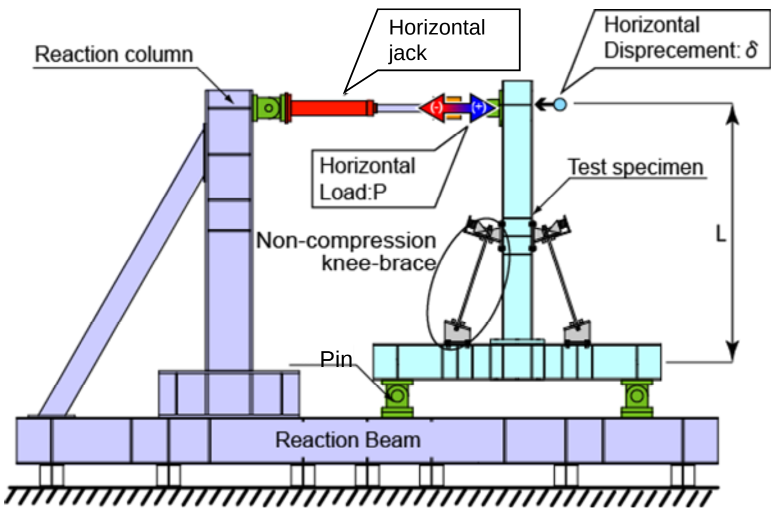


Figure 18 Apparatus

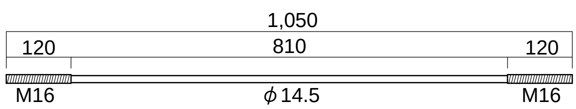


Figure 19 Knee-brace member

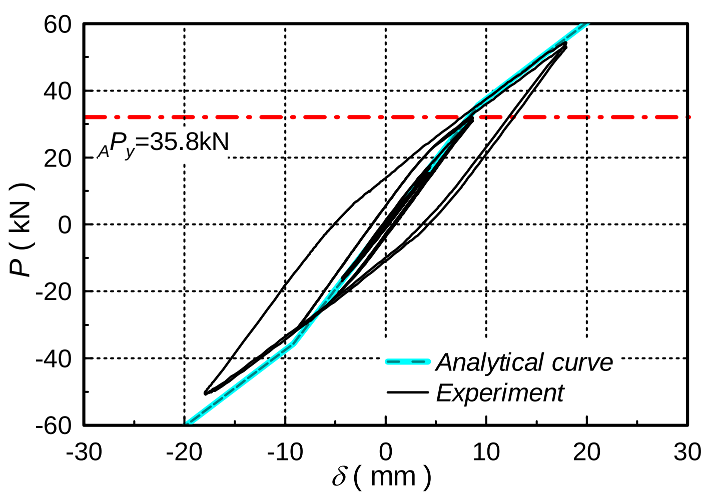


Figure 20 Horizontal load v.s. Horizontal displacement relations

6. CONCLUSIONS

An experimental study was performed on structural elements with a wedge device under cyclic loadings to investigate the restoring force characteristics. Based on the test results the following conclusions were drawn:

1) The non-slip-type column base and the self-centering beam-to-column connection showed non-slip-type behavior, linear from the origin, and had self-centering capability. Therefore, they are applicable to a sustainable structure with all elastic members except anchor-bolts and normal-strength bolts remaining elastic after a huge earthquake.
2) The non-compression braces and the non-compression knee-braces showed perfect elastic-plastic cyclic behavior without buckling or slipping. Therefore, they are excellent energy absorption dampers and are applicable to rehabilitation of moment-resisting framed structures because of their easy installation.

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