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ANALYSIS OF TIMBER COLUMN-GROUND SILL JOINTS REINFORCED WITH IMPROVED ARAMID FIBER SHEETS

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High-performance aramid fiber sheets are a new class of composite materials made up of weaved polyamide fibers. In this study, the seismic performance and failure behavior of timber column–ground sill joints reinforced with aramid fiber sheets were investigated. In a past study, we conducted bending tests under cyclic loading for three column–ground sill specimens. After reinforcing the specimens with aramid fiber sheets, the joint strength improved but was dependent on the method of attaching the sheet. It was found that the compression zone of the aramid fiber-reinforced plastic layer broke at the joint boundary. In this paper, we proposed an improvement in the method of attaching the fiber sheet to the joint. On the compression zone at the boundary of the joint, resin was not pasted onto the aramid fiber, the fiber was not cured, and the plastic layer was not formed. Therefore, we could solve some problems and control the failure of column-ground sill joints.

Keywords: New material, Cyclic loading, Restoring force, Destruction mechanism, Resin, Deformation performance, Maximum force.

1 INTRODUCTION

Many timber structures collapse during earthquakes because of joint damage. To prevent this, the Japanese Building Standard Law was revised in 2000 to include joint specifications for timber structures (MLIT 2016). However, the seismic resistance of timber frames with steel joints could be compromised by the partial loss of member sections such as bolt holes (Sawai 2012).

High-performance aramid fiber sheets are a new class of composite materials made up of weaved polyamide fibers. Recently, a method for reinforcing timber joints with aramid fiber sheets was proposed, wherein existing timber structures could be reinforced without large-scale demolition because aramid fiber sheets could be easily glued to the joints using an adhesive agent.

In our last study, we conducted bending tests under cyclic loading for three column–ground sill specimens with T-shaped joints (Yamaguchi *et al.* 2016) to evaluate the seismic performance and failure behavior of joints reinforced with aramid fiber sheets. However, we encountered the following problems: (a) joint strength of the specimens improved after reinforcement with aramid fiber sheets but was dependent on the method of attaching the sheet, (b) after fractures on the compression zone of the aramid fiber reinforced plastic layer at the joint boundary, failure occurred easily, and (c) failure occurred due to brittleness induced by the sheet peeling off.

In this paper, we conducted additional bending tests under cyclic loading to solve the problems discovered in the last study, and propose the new method for attachment of fiber sheets. Further, we elaborate on the destruction mechanism and restoring forces, and present out results.

2 CYCLIC LOADING TEST

2.1 Specimens

Two T-shaped column–ground sill specimens were designed (Figure 1(a)). The columns and the ground sills (105 mm × 105 mm) were made from cedar wood, and the joints were fastened using V-shaped steel members. The cyclic loading tests involved five steps:

1) Load was applied to the specimen.
2) V-shaped steel members were removed and reinforced with aramid fiber sheets using the existing attachment method.
3) Load was reapplied to the specimen. (The three steps mentioned before were part of the previously conducted study. The steps mentioned ahead were part of the study in consideration in this paper.)
4) The damaged sheets were removed and reinforced with aramid fiber sheets using the proposed attachment method.
5) Load was reapplied to the specimen.

The sheets were attached to both sides of the joints of the specimens by using two attachment forms—vertical form (specimen V-1, Figure 1(a)) and vertical form with an additional widened crossing sheet (specimen C-2, Figure 1(c)) on the first reinforcement. To avoid affecting the compression in the aramid fiber reinforced plastic layer, resin was not covered around the joint surface on the second reinforcement (specimen V-1n, C-2n, Figure 1(b), 1(d), respectively). The specifications of the materials used to fabricate the specimens are listed in Table 1.

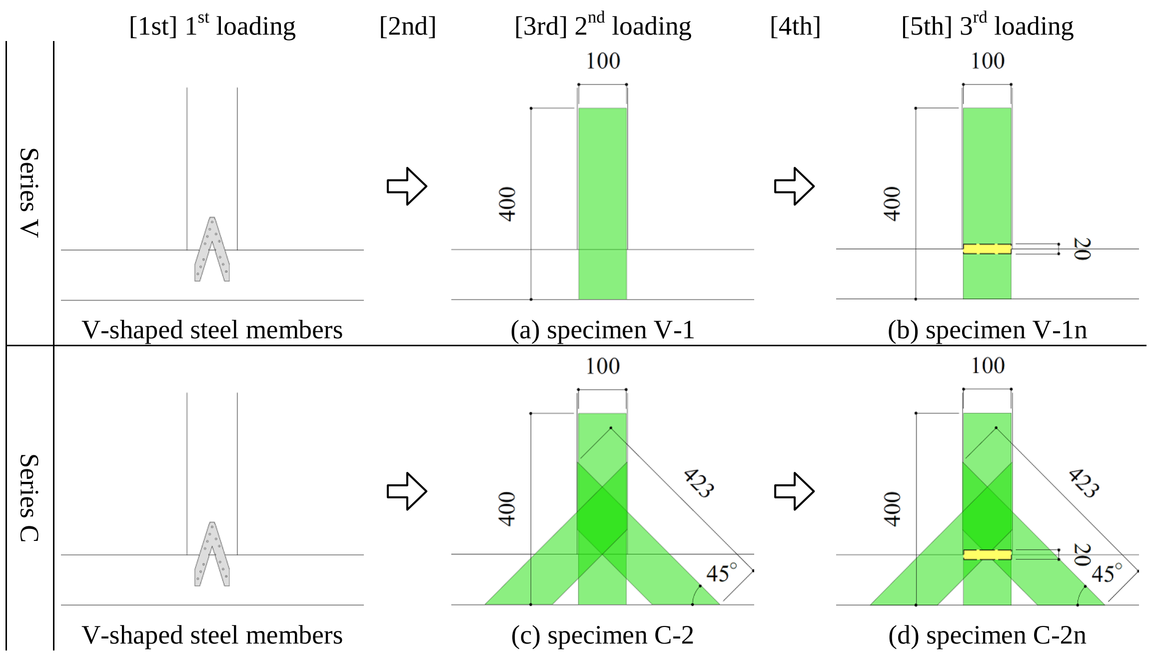


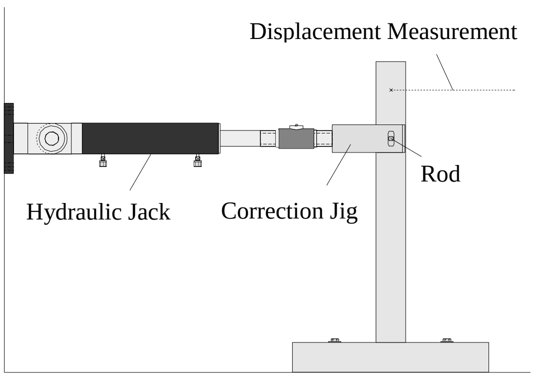
Figure 1. Specimens.

Table 1. Materials used to fabricate specimens used in the tests (Fibex 2016, Asahi Bond 2016).

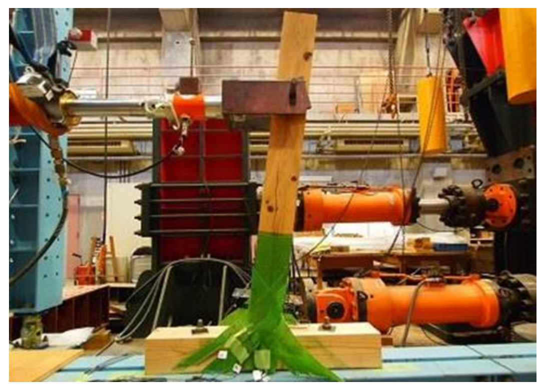
Material	Item	Notes	Item	Notes
Aramid Fiber Sheet	Description	FiBRA Sheet, AK-40	Manufacturer	Fibex Co., Ltd
	Tensile strength	2060 N/mm^2	Young's Modulus	118 kN/mm^2
	Design thickness	0.193 mm	Width	100 mm
Resin	Description	Asahi bond, 701	Manufacturer	Asahi Bond, Inc.
	Tensile strength	38.3 N/mm^2	Bending strength	66.0 N/mm^2

2.2 Loading System

The loading system is illustrated in Figure 2. The vertical displacement at the top of the column was measured using a displacement transducer, and the rotation angle *R* was determined trigonometrically from the measured vertical displacement and the known column length. Cyclic loading was applied to the specimen such that the amplitude of *R* increased gradually. Strain gauges were attached to both faces of the member. For the analysis, the left side of Figure 2 was assumed to be the positive direction; the front was designated as the S side and the back was designated as the N side.



(a) Schematic diagram



(b) Loading state

Figure 2. Loading system.

2.3 Damage and Restoring Force

The damaged specimens are shown in Figure 3, and the relationship between bending moment and *R* is presented in Figure 4, where black lines indicate the hysteresis loops of the non-reinforced specimens and red lines indicate the skeleton curves of the reinforced specimens.

For non-reinforced V-1, the restoring force reached a maximum value of 1.8 kN at +1/10 rad, and the ground sill split at the nail of the joint at +1/6 rad. For reinforced V-1, a linear fracture formed on the compression zone of the aramid fiber reinforced plastic layer at the boundary of the joint at +1/50 rad, as shown in Figure 3(a). The edge of the sheet began peeling off at +1/30 rad. On the N side, the sheet peeled off entirely, and the restoring force reached a maximum value of 1.0 kN at −1/30 rad, whereas on the S side, the linear fracture of the boundary broke at +1/20 rad, as shown in Figure 3(b). For reinforced V-1n, the edge of the sheet on the N side began peeling off at -1/100 rad. With increase in the rotation angle, the unimpregnated part started warping outward, as shown in Figure 3(c). The restoring force reached a maximum value of 0.6 kN at +1/30 rad. The sheet peeled off entirely at −1/30 rad on the S side, and at +1/15 rad on the N side.

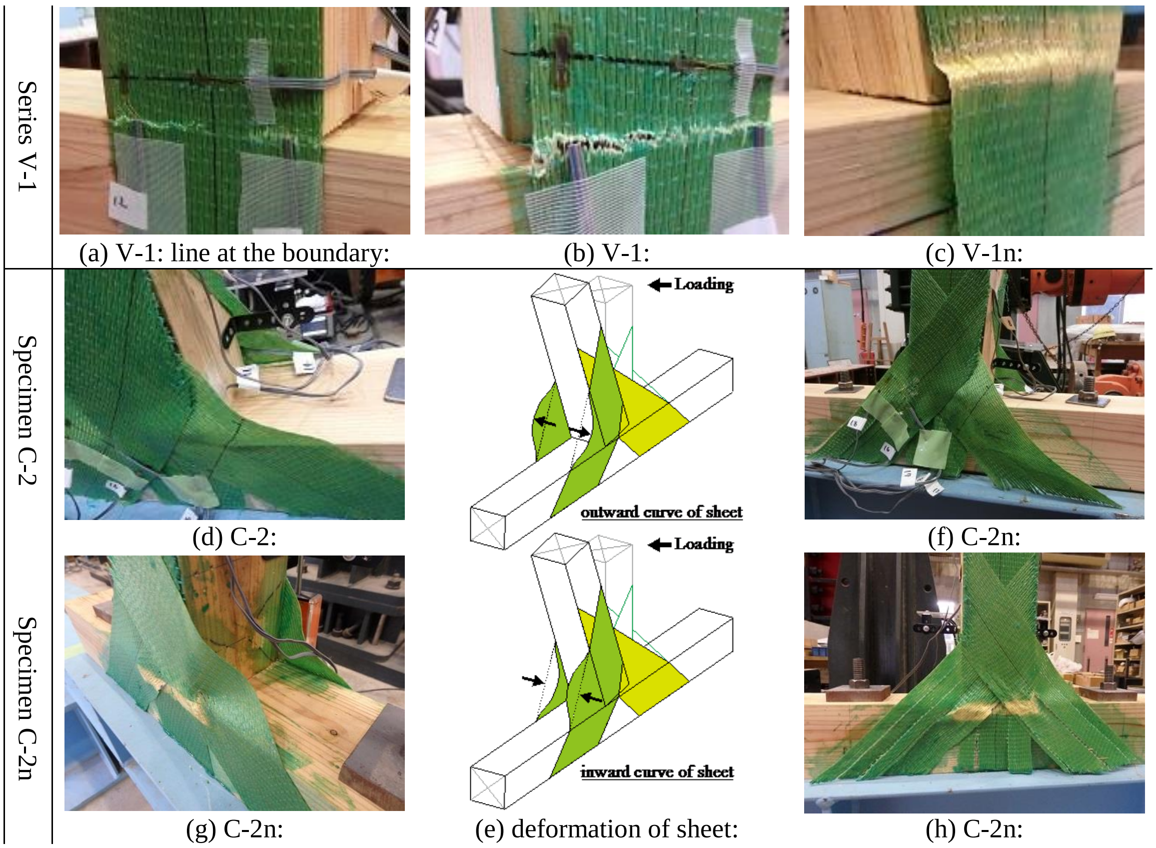
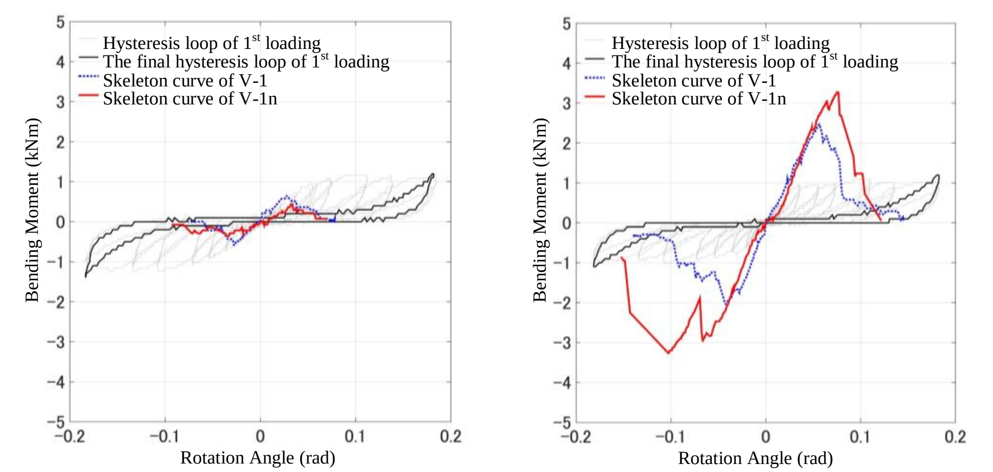


Figure 3. Damaged specimens.



(a) Vertical (V-1, V-1n). (b) Cross (C-1, C-1n).

Figure 4. Relationship between bending moment and rotation angle.

For non-reinforced C-2, the ground sill split at the nail of the joint at +1/15 rad and the restoring force reached a maximum value of 1.5 kN at +1/10 rad. After reinforcement, the unattached triangular sections of the crossing sheet curved outward, as shown in Figure 3(d) and upward, as shown in Figure 3(e). The crossing sheet attached to the ground sill began peeling off at +1/30 rad, and the restoring force reached a maximum value of 3.6 kN at +1/20 rad. The sheet peeled off entirely at +1/8 rad as shown in Figure 3(f). For reinforced C-2n, the unattached triangular sections of the crossing sheet curved inward as shown in Figure 3(g) and under, as shown in Figure 3(e). After the restoring force reached a maximum value of 4.5 kN at +1/10 rad, the sheet peeled off sequentially from the outermost edge, while divided in the fiber direction, as shown in Figure 3(h).

3 DISCUSSIONS

The major findings from this study are discussed in the following section:

(i) As shown by the results corresponding to reinforced V-1n, not covering resin around the joint surface prevented the aramid fiber sheet from breaking easily, since compression did not occur in the aramid fiber reinforced plastic layer.

(ii) As shown by the results corresponding to reinforced C-2 and C-2n, in cases where the unattached triangular sections of the crossing sheet curved outward, it was easy to peel off the sheet from timber members. In contrast, in cases where the triangular sections curved inward, it was difficult to peel off the sheet. Additionally, the maximum value of restoring force when the triangular section curved inward was 1.25 times as high as when it curved outward.

(iii) As shown by the results corresponding to reinforced C-2 and C-2n, the deformation performance of the restoring force was higher when the sheet peeled off sequentially from the outermost edge compared to when the entirety of it peeled off instantly.

4 CONCLUSIONS

In this paper, we proposed a new method for attachment of aramid fiber sheets to timber column-ground sill joints in order to solve the problems encountered in a previous study. As part of the study, we also conducted additional bending tests under cyclic loading. The major findings from this study are summarized in the following section:

(i) We recommended not covering resin around the joint surface. It was established that this prevented the aramid fiber sheets from breaking easily by inhibiting compression in the reinforced plastic layer, and that destruction mechanism caused the sheet to peel off from the ground sill.

(ii) The curvature of the unattached triangular sections of the crossing sheet determined the ease with which the sheet could be detached. When the triangular sections curved outward, it was easy to peel the sheet off from the timber members. In contrast, when the sections curved inward, peeling the sheet off was not easy. Additionally, the maximum value of restoring force was higher when the section curved inward compared to its value when the section curved outward.

(iii) The deformation performance of the restoring force was high when the sheet peeled off sequentially from the outermost edge, while divided in the fiber direction.

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References

Asahi Bond, *Asahi Bond, Inc.*, 2016. Retrieved from http://www.asahibond.co.jp/ on June 1, 2016 (in Japanese).

Fibex, *Fibex Co., Ltd*., 2016. Retrieved from http://www.fibex.co.jp/index.html on June 1, 2016 (in Japanese).

Ministry of Land, Infrastructure, Transport and Tourism (MLIT), 2016. Retrieved from http://www.mlit.go.jp/index.html on June 1, 2016.Sawai, S., *Timber Structure Seismic Construction Perfect Guide*, X-Knowledge Co., Ltd., Japan, 2012 (in Japanese).

Yamaguchi, A., Chen, X., and Takiyama, N., Performance Confirmation Test for Timber Column-Ground Sill Joints Reinforced with Aramid Fiber Sheets, *Proceeding of the ASEA-AEC-3*, Kuching, Sarawak, Malaysia, November 2016.