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PERFORMANCE CONFIRMATION TEST FOR TIMBER COLUMN–GROUND SILL JOINTS REINFORCED WITH ARAMID FIBER SHEETS

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High-performance aramid fiber sheets are a new class of composite materials composed of weaved polyamide fibers. This seismic performance and failure behavior of timber column–ground sill joints reinforced with aramid fiber sheets were investigated. We conducted bending tests under cyclic loading for three column–ground sill specimens. The maximum bending moments were estimated using a simple method and compared with the experimentally obtained moments. After reinforcement with aramid fiber sheets, joint strength improved but was dependent on the sheet-attaching form. Moreover, it is remarkable to break from peeling sheet. Further, the proposed sheet-attaching form (with widened crossing sheets) exhibited a higher restoring force than did the conventional form because of sheet is further away from the center of rotation.

Keywords: Restoring force, Damage, Resin, Bending test, Bending moment, Estimation.

1 INTRODUCTION

Many timber structures collapse during earthquakes because of joint damage. Therefore, the Building Standards Law in Japan was revised in 2000 to include joint specifications for timber structures (Ministry 2016). However, the seismic resistance of timber frames with steel joints can be compromised by the partial loss of member sections, such as bolt holes (Sawai 2012).

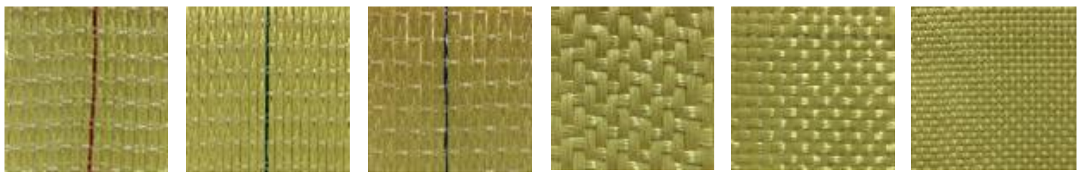
High-performance aramid fiber sheets are a new class of composite materials composed of weaved polyamide fibers. A method of reinforcing timber joints with aramid fiber sheets was recently proposed; through this method, existing timber structures can be reinforced without large-scale demolition because aramid fiber sheets can be easily glued to the joints by using an adhesive agent.

In this study, to evaluate the seismic performance and failure behavior of joints reinforced with aramid fiber sheets, we conducted bending tests under cyclic loading for three column–ground sill specimens with T-shaped joints. In addition, we proposed a new method to attach the sheets to the timber joints. In the tests, sheets were attached to the joints by using three methods: two conventional methods and the proposed method.

2 REINFORCEMENT OF TIMBER JOINTS WITH ARAMID FIBER SHEETS

The fibers in aramid fiber sheets may be woven in one or two directions, as depicted in Fig. 1. These sheets possess superior corrosion-, water-, and heat-resistance properties (Fibex 2016).

Using aramid fiber sheets in construction can improve structural strength and prevent structural degradation. Impregnating resin in aramid fiber sheets decreases their porosity and increases their plasticity; such sheets are light and soft and can be used to easily reinforce structural members without requiring additional expertise or large working spaces. These sheets have largely been used to reinforce RC structures but have recently been applied to traditional wooden structures as well.



(a) One-dimensional weave (b) Bidimensional weave

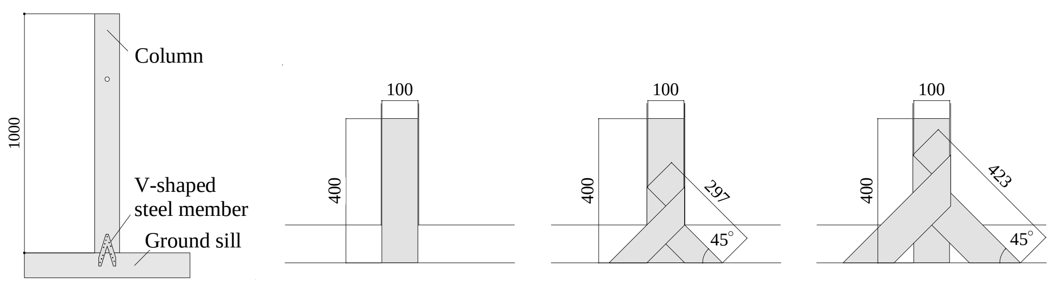
Figure 1. Aramid fiber sheets.

3 CYCLIC LOADING TESTS

3.1 Specimens

Three T-shaped column–ground sill specimens were designed (Fig. 2 (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 tests involved three steps: (1) apply the load on the specimen, (2) remove the damaged specimen and reinforce it with aramid fiber sheets, and (3) reapply the load on the specimen.

The sheets were attached to both sides of the joints of the specimens by using two conventional methods—vertical form (specimen V-1, Fig. 2 (b)) and vertical form with an added crossing sheet (specimen C-1; Fig. 2 (c)) (Tezuka 2003) —and a newly proposal form in which the crossing sheet was widened (specimen C-2, Fig. 2 (d)). The specifications of the materials used to fabricate the specimens are listed in Table 1.



(a) Specimen (b) Vertical (V-1) (c) Cross (C-1) (d) Cross (C-2)

Figure 2. Test specimens.

Table 1. Materials used in the tests (Fibex 2016, Asahibond 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

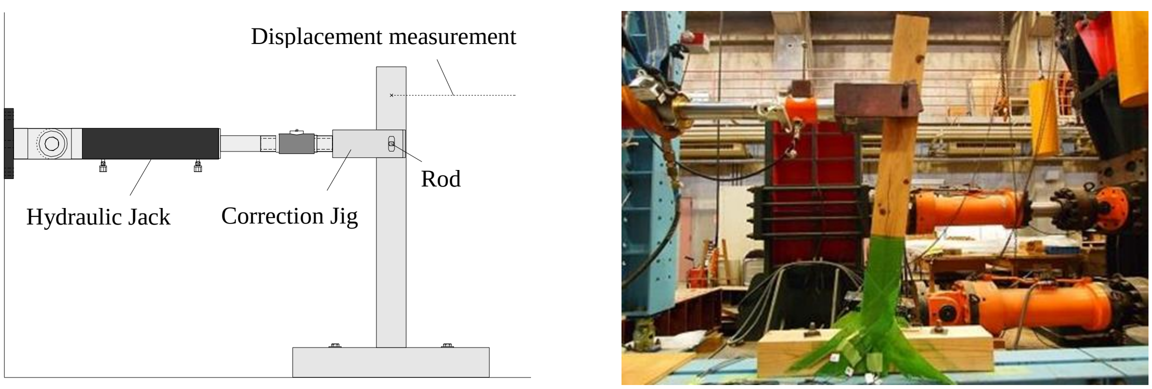
The First, the timber face is cleaned and the resin is pasted on joint (see Fig. 3 (a)). Next, the sheet is attached on resin (see Fig. 3 (b)). Then, the resin is impregnated in the sheet and repasted on the sheet (see Fig. 3 (c)). Finally, they are cured about one week.

(a) Cover the joint with resin (b) Place the sheet over the joint (c) Impregnate the sheet with resin

Figure 3. Method of attaching the aramid fiber sheet to the joints of the specimens.

3.2 Loading System

The loading system is illustrated in Fig. 4. 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 Fig. 4 is assumed to be the positive direction; the front is designated the S side and the back the N side.



(a) Schematic diagram (b) Loading state

Figure 4. Loading system.

3.3 Damage and Restoring Force

The damaged specimens are shown in Fig. 5, and the relationship between bending moment and rotation angle is presented in Fig. 6, where black lines indicate the hysteresis loop in the unreinforced specimens and red lines the skeleton curve in the reinforced specimens.

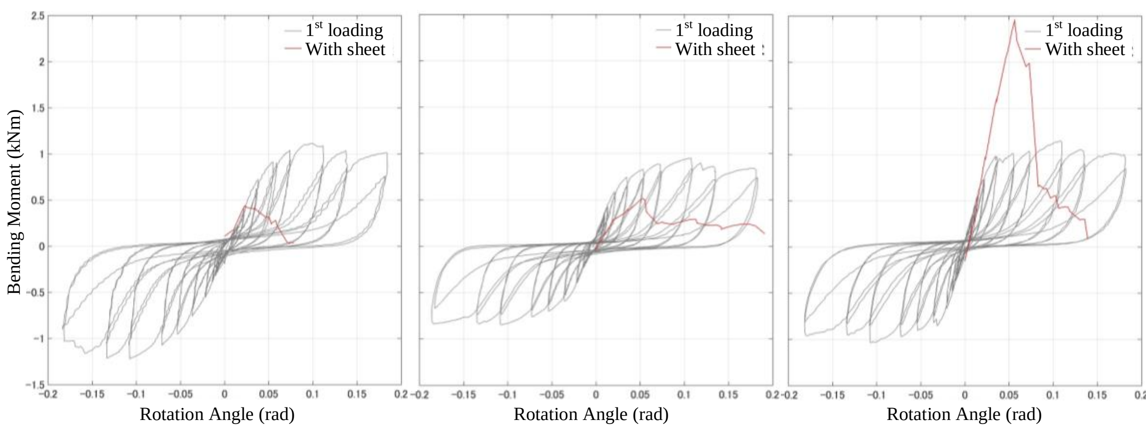
For unreinforced V-1, the restoring force reached a maximum of 1.8 kN at +1/10 rad, and the ground sill split at the nail of the joint at +1/6 rad. After reinforcement, line formed on the compression zone of the aramid fiber reinforced plastic layer at the boundary of the joint at +1/50 rad. The edge of the sheet began peeling off at +1/30 rad. In the N side, the sheet peeled off entirely, and the restoring force reached a maximum of 1.0 kN at −1/30 rad, whereas in the S side, the line of the boundary broke at +1/20 rad.

For unreinforced C-1, the restoring force reached a maximum of 1.6 kN at +1/10 rad. The ground sill split at the nail of the joint at +1/6 rad. After reinforcement, the edge of the vertical sheet began peeling off at +1/50 rad. In the N side, the crossing sheet of ground sill start to peel off and the restoring force reached a maximum of 1.3 kN at +1/20 rad. The crossing sheet of column peels off at +1/15 rad.

For specimen C-2 with hardware, the ground sill split at the nail of hardware at +1/15 rad. and the restoring force reached a maximum of 1.5 kN at +1/10 rad. After reinforcement, the crossing sheet attached to the ground sill began peeling off at +1/30 rad, and the restoring force reached a maximum of 3.6 kN at +1/20 rad; the sheet peeled off entirely at +1/8 rad.

(a) Joint hardware (b) Vertical (V-1) (c) Cross (C-1) (d) Cross (C-2)

Figure 5. Damaged specimens.



(a) Vertical (V-1) (b) Cross (C-1) (c) Cross (C-2)

Figure 6. Relationship between bending moment and rotation angle.

4 ESTIMATION OF BENDING MOMENT

The maximum bending moment after reinforcement was estimated using a simple model (Fig. 7) under the following assumptions (Architectural 2006):

(a) The center of rotation of the joint is on the edge of the column base.

(b) The reinforcing sheet is subjected to tension stress only.

(c) The sheet experiences triangular tension stress, as evidenced by the strain gauges.

(d) The maximum bending moment at a point is the sum total of the product of tension stress along the direction of the fiber and its distance from the center of rotation.

The estimated and experimentally obtained bending moments are compared in Fig. 8. The maximum bending moment of C-1 was overestimated.

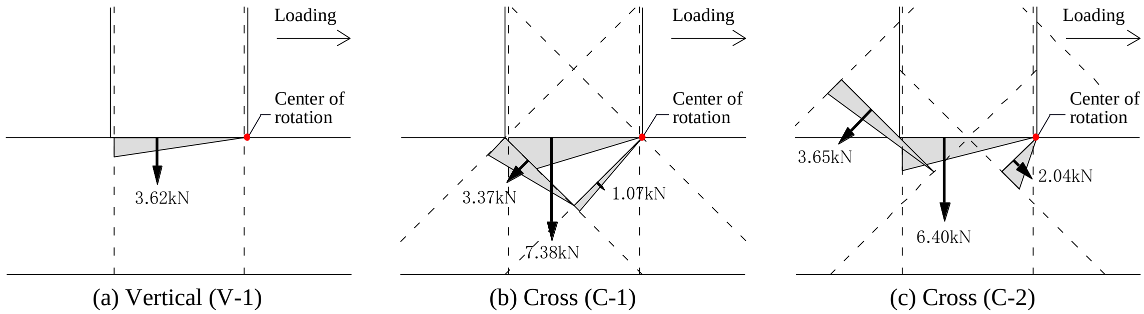


Figure 7. Simple model for estimating the maximum bending moment.

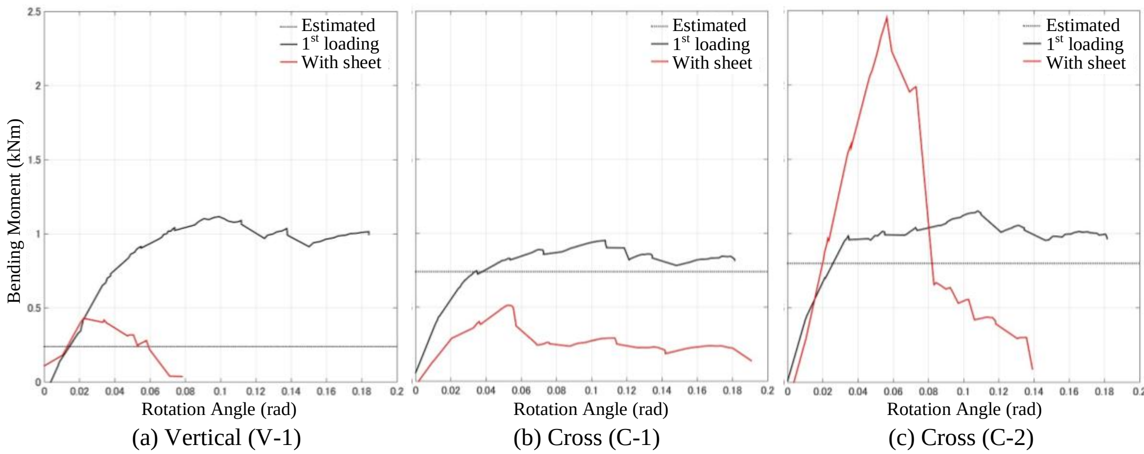


Figure 8. Estimated and experimentally obtained bending moments.

5 CONCLUSIONS

We conducted bending tests under cyclic loading for three column–ground sill specimens in order to investigate the seismic performance and failure behavior of joints reinforced with aramid fiber sheets. The maximum bending moments were estimated using a simple method and compared with the experimentally obtained moments. The major findings of this study can be summarized as follows:

(a) For joint fastened using V-shaped steel members, the ground sill split at the nail of the joint at a maximum restoring force. After reinforcement with aramid fiber sheets, joint strength improved but was dependent on the attaching form. However, the destruction occur brittleness.

(b) After reinforcement with aramid fiber sheets, it is remarkable to break from peeling sheet.

(c) The proposed sheet-attaching (with widened crossing sheets) exhibited a higher restoring force than did the conventional form because of sheet is further away from the center of rotation.

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References

Architectural Institute of Japan, *Standard for Structural Design of Timber Structures*, Maruzen Co., Ltd., Japan, 2006. (in Japanese)

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

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

Ministry of Land, Infrastructure, Transport and Tourism. 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)

Tezuka, J., Noguchi, T., Yamashita, J., and Taniguchi, H., Experiment of Joint of Timber Structure Reinforced with Aramid Fiber Sheet and Metal Fittings, *Summaries of Technical Papers of Annual Meeting*, Architectural Institute of Japan, C-1(III), 2003. (in Japanese)