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DEFORMATION PERFORMANCE IMPROVEMENT IN TIMBER COLUMN–GROUND SILL JOINT REINFORCED USING ARAMID FIBER SHEET

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We report the progress of an experimental study conducted to understand the seismic performance of a timber column–ground sill joint reinforced using an aramid fiber sheet, and to improve the deformation property of the reinforced joint. An aramid fiber sheet is a new material that weaves high-performance aramid fibers in one or two directions. In previous research, certain problems were found: (a) even when applying a similar reinforcement, the sheet did not necessarily demonstrate the same failure mode, and (b) when the sheet was peeled off in stretches, the joint is destroyed through brittleness. In this study, based on the preceding research, we proposed a new sheet-pasting method for an improvement in the deformation property, and conducted a bending test under cyclic loading for some column–ground sill joint specimens to verify the seismic performance and failure behavior. It was found that, by splitting the sheet, the problems of the preceding research are avoidable.

Keywords: New material, Cyclic loading, Restoring force, Failure mode, Deformation property, 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 (Ministry of Land, Infrastructure, Transport and Tourism 2016). However, the seismic resistance of timber frames with steel joints can be compromised through a partial loss of the member sections such as the bolt holes (Sawai 2012).

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

In a previous study, to evaluate the seismic performance and failure behavior of joints reinforced with aramid fiber sheets, we conducted bending tests under cyclic loading for some column–ground sill specimens with T-shaped joints (Yamaguchi *et al.* 2016, Yamaguchi *et al.* 2017), and found a few problems: (a) even when applying a similar reinforcement, the sheet did not necessarily demonstrate the same failure mode, and (b) when the sheet was peeled off in stretches, the joint is destroyed through brittleness.

In this study, we conducted additional bending tests under cyclic loading to solve the problems discovered in our previous research. We propose a new sheet-adhesive approach for an improvement in the deformation property, and conducted a bending test under cyclic loading for eight T-shaped column–ground sill joint specimens to verify the seismic performance and failure behavior. Herein, we attempted using a single sheet split into a certain number of parts before adhering them onto the timber.

2 IMPROVED METHOD AND COLUMN–GROUND SILL JOINT SPECIMENS

2.1 Results of the Previous Study

The major findings from our previous study are as follows:

(i) Not covering a resin around the joint surface prevented the aramid fiber sheet from easily breaking, as shown in Figure 1(a), because compression does not occur in the aramid fiber reinforced plastic layer, as indicated in Figure 1(c).

(ii) The deformation performance of the restoring force was higher when the sheet is peeled off sequentially from the outermost edge, as shown in Figure 1(c), as compared to when it is entirety peeled off instantly, as shown in Figure 1(b).

(a) Linear fracture of boundary (b) Sheet peeled off entirely (c) Split in the fiber direction

Figure 1. Main damage indicated in a previous study.

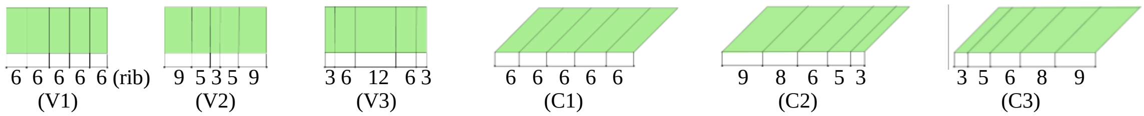
2.2 Improved Sheet Adhering Method and Test Specimens

For an improvement in the deformation performance of the bending property for a timber column–ground sill joint, we propose splitting the aramid fiber sheet into pieces by cutting the horizontal threads that connect the fiber ribs in advance. Thus, we can control the failure mode in which a splitting failure mode continuously occurs, as shown in Figure 1(c).

T-shaped column–ground sill specimens were designed. The columns and ground sills (105 mm × 105 mm) were made from cedar wood, and the joints were fastened using V-shaped steel members. After a load was applied to the specimen, V-shaped steel members were removed and reinforced with aramid fiber sheets, and the load was reapplied to the specimen.

The sheets were attached to both sides of the joints of the specimens using a vertical and crossing sheet. To study the effects of the improved method, we prepared some specimens with split sheets. The aramid fiber sheet used in this study has 30 ribs. Thus, we tried to split the sheet, as shown in Figure 2. For a vertical sheet, in the case of V1 shown in Figure 2(a), 30 ribs are divided into five groups of six ribs each. Then, V2 is divided into 9-5-3-5-9 ribs, and V3 is divided into 3-6-12-6-3 ribs. For the crossing sheet, C1 is divided into 6-6-6-6-6 ribs, C2 is divided into 9-8-6-5-3 ribs from the outside, and C3 is divided into 3-5-6-8-9 ribs, also from the outside.

The types of specimens are shown in Table 1. For the sheet-attachment method, vertical sheets V1–V3 and horizontal sheets C1–C3 are combined. Moreover, to avoid affecting the compression in the aramid fiber reinforced plastic layer, resin was not covered around the joint surface. The specifications of the materials used to fabricate the specimens are listed in Table 2.



(a) For vertical sheets (V1–V3) (b) For crossed sheets (C1–C3)

Figure 2. Number of rib partitions.

Table 1. Joint specimens and sheet adhering style.

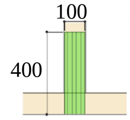
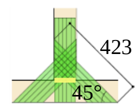
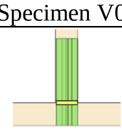
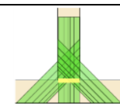
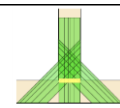
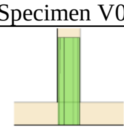
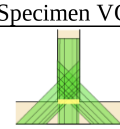
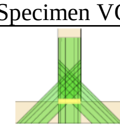
		Crossed Sheet			
		Non	(C1)	(C2)	(C3)
Vertical Sheet	(V1)	 Specimen V01	 Specimen VC4		
	(V2)	 Specimen V02		 Specimen VC5	 Specimen VC7
	(V3)	 Specimen V03		 Specimen VC6	 Specimen VC8

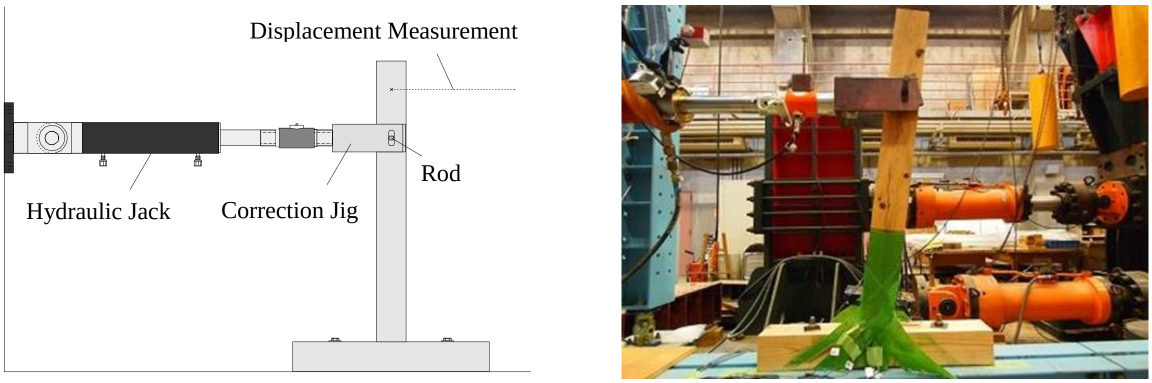
Table 2. Materials used to fabricate specimens applied during the tests (Fibex 2016, Asahi Bond 2016).

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

3 CYCLIC LOADING TEST

3.1 Loading System

The loading system is illustrated in Figure 3. 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 gradually increased. For the analysis, the left side of Figure 3 was assumed to be in the positive direction; here, the front was designated as the S side, and the back was designated as the N side.



(a) Schematic diagram (b) Loading state

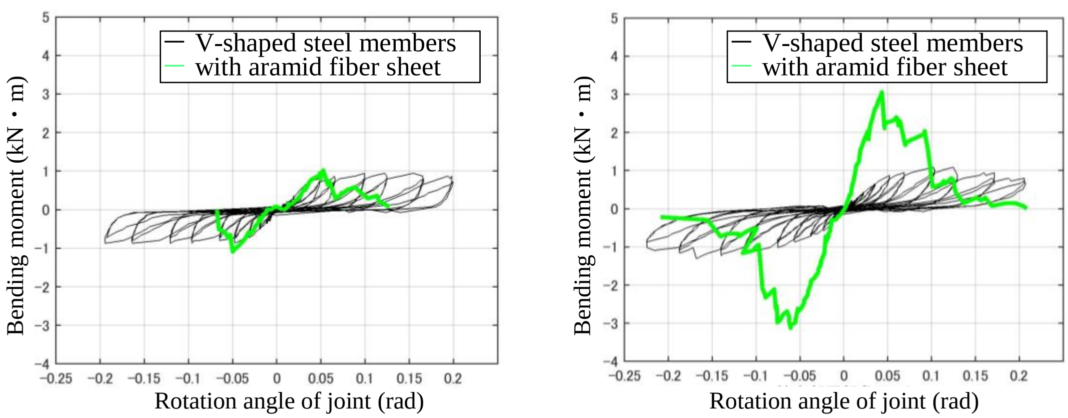
Figure 3. Loading system.

3.2 Failure Mode and Restoring Force

The main failure mode is shown in Figure 4, and representative restoring force of specimens V02 and VC7 are shown in Figure 5. The main values are indicated in Table 3, including the maximum horizontal force, rotation angle, and failure mode. A comparison of the restoring force of specimens V02 and VC7 with the previous results is provided in Figure 6.

(a) Linear fracture of boundary (failure mode I) (b) Fracture or peeling from the outside (failure mode II)

Figure 4. Main damage.



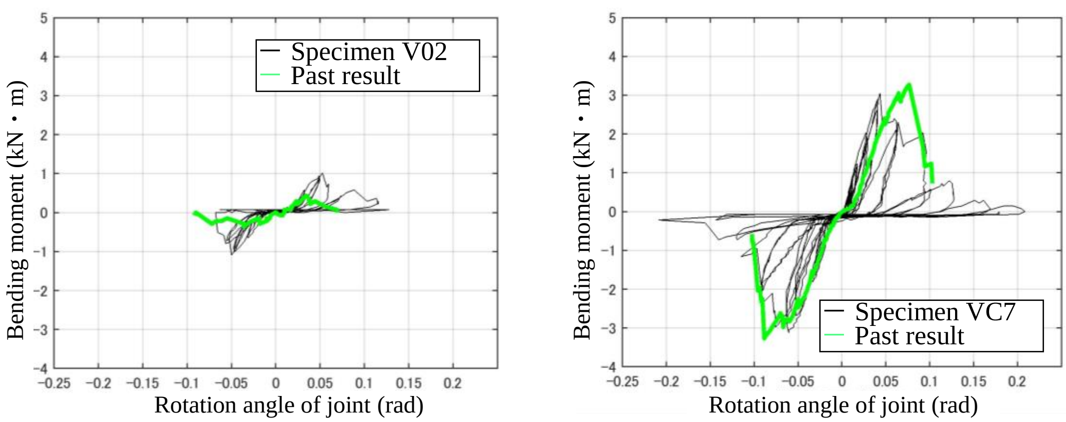
(a) Specimen V02 (b) Specimen VC7

Figure 5. Restoring force.

Failure mode I is a linear fracture of the boundary. This occurred in specimens V01 and V03, which do not have a no-resin area. Failure mode II is a fracture or peeling from the outside. This occurred on the other specimens, which have a no-resin area. The restoring force of the specimens with vertical and crossing aramid fiber sheets is higher than that with V-shaped steel members, as indicated in Figure 5(b), for example. The restoring force of the specimens reinforced using a split sheet achieves a higher deformation performance than when using the existing method, as indicated in Figure 6.

Table 3. Results of the bending test.

Specimen	Maximum horizontal force (kN)	Rotation angle when Max. (rad)	Failure mode
V01	0.5	1/30	I
V02	1.6	1/15	II
V03	0.8	1/30	I
VC4	4.3	1/15	II
VC5	5.2	1/15	II
VC6	5.2	1/10	II
VC7	4.3	1/15	II
VC8	3.8	1/15	II



(a) With vertical sheet (b) With vertical and crossing sheet

Figure 6. Comparison of restoring forces.

4 DISCUSSIONS

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

(i) For reinforcement using both a vertical sheet and a vertical and crossing sheet, a column–ground sill joint using a split sheet has a greater deformation property than one using an existing sheet under a bending load. A sudden drop in force from the maximum value does not occur, as indicated in the results from the improved sheet adhesion method.

(ii) The maximum force is not affected by the improved sheet adhesion method. The maximum force of a joint reinforced using a split sheet is as strong as that using an existing sheet.

5 CONCLUSIONS

In this paper, we proposed a new method for the attachment of aramid fiber sheets to timber column–ground sill joints in order to develop deformation performance. As a part of this study, we also conducted additional bending tests under cyclic loading.

The major findings from this study are summarized as follows:

(i) For an improvement in the deformation performance of the bending property for a timber column–ground sill joint, we proposed splitting an aramid fiber sheet in advance, allowing the splitting failure mode to continuously occur.

(ii) A joint reinforced by a split sheet has a higher deformation property than one reinforced by an existing sheet. However, as the results indicate, the maximum force is not affected by the improved sheet adhesion method.

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