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DIFFERENCE IN MECHANICAL PROPETIES DUE TO INHIBITION TECHNIQUES OF FRICTION APPLIED TO LATERAL TESTS OF TIMBER JOINTS

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ABSTRACT: Dowel-type connections are commonly used in modern timber buildings. Evaluation of the mechanical characteristics of timber joints is essential for building design. To accurately evaluate the lateral characteristics of dowel-type joints, the effect of friction between members on the evaluation results should be clarified. This study aims to reveal the differences in the mechanical properties owing to friction-inhibition techniques applied to lateral tests of dowel-type joints. In our previous study, we used only a perfect elasto-plastic model. This study uses three methods to elucidate the test results. Three types of dowel-type connections applied with various friction-inhibition methods are tested, and three methods for determining their characteristics are used. A significant difference in characteristics is observed in all the determination methods between the friction-inhibition conditions. This highlights the importance of friction-inhibition treatment when conducting lateral loading tests on dowel-type timber joints.

KEYWORDS: dowel-type joint, lateral test, mechanical properties, testing method, evaluation accuracy

1 – INTRODUCTION

Wood is a well-known ecofriendly material. Owing the increasing interest in reducing carbon-dioxide emissions, the promotion of timber buildings has become vital. The evaluation of timber joints is important for realizing timber buildings that are safe against earthquakes and typhoons. Dowel-type connections are typically used in timber buildings. Lateral loading is a major loading mode in buildings, and lateral loading tests on dowel-type joints have been conducted worldwide.

In most types of timber joints, strong contact occurs between the timber members. An example of this is shown in Figure 1. When the bolt was tightened, strong contact occurs, as indicated by the blue arrows. If a lateral load is exerted on the bolted joint, then frictional resistance occurs, thus affecting the results of lateral loading tests. To accurately evaluate the lateral properties of timber joints, friction inhibition in joint test specimens is necessary.

Researchers have attempted to inhibit friction in joint specimens using various methods. Ochiai et al. [1] applied silicon spray on a region where wood is in contact with a steel plate. Tanahashi et al. [2] inserted a Teflon sheet between the wooden members of a traditional wood-to-wood joint and reported the effect of friction on the rotational performance of the joint. Additionally, the authors inserted a Teflon sheet into nailed and screwed joints [3, 4].

The authors investigated the friction coefficient using various inhibition methods [5]. The combined use of a Teflon sheet and grease significantly affected friction inhibition. Using this method, the friction coefficient was

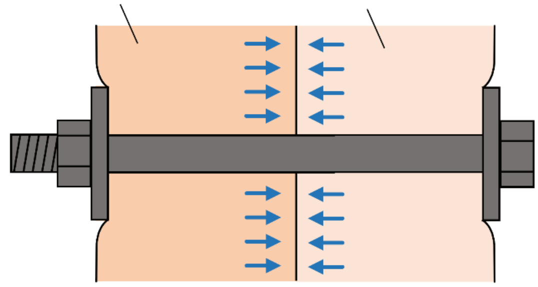

Figure 1. Strong contact between members due to bolt tightening

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approximately 0.1, which was much lower than that when the combined use was not implemented (i.e., 0.4).

The authors previously conducted lateral loading tests on bolted, screwed, and nailed joints [6]. The friction at the contact points between the main and side members was varied using different tightening methods for the fasteners. For example, the initial stiffness of the bolted joint was affected significantly by friction. When a Teflon sheet and grease were inserted between the members, the initial stiffness decreased by 48% compared with that of the control group.

In our previous studies [6], these characteristics were determined using a perfect elasto-plastic model [7, 8]. As reported by Watanabe et al. [9], the characteristics differed depending on the determination method used. To understand the effects of friction conditions on the evaluated results of dowel-type joints, evaluations using other well-established determination methods are necessary. However, we previously [6] used only a perfect elasto-plastic model. In the current study, the authors determined the characteristics using various methods.

2 – MATELIALS AND METHODS

2.1 JOINT SPECIMENS

Bolted (B), nailed (N), and screwed (S) joints were prepared, and lateral loading tests were performed on them. Although the joint specimens have been documented in our previous report [6], we provide the details below.

Japanese cedar (*Cryptomeria japonica* D. Don) was used for the bolted joint specimens. As shown in Figure 2(a), three members measuring 60 mm ×100 mm ×300 mm were connected using a bolt. The bolt had a diameter of 12 mm, whereas the washer had a diameter of 40 mm and 3.2 mm thick. As shown in the figure, the center member was mounted to create a space at the bottom of the joint specimen. The height of the space was set to 75 mm. Three types of friction conditions were specified in the test series, as shown in Figure 3. In series B1, no materials were inserted into the contact region, thus indicating that each wood surface was in contact. In this series, the bolt was hardly tightened such that the washer was sufficiently embedded in the wood member, as shown in Figure 3(c). In series B2, no material was inserted in the contact region. In this series, the bolt was laugh tightened based on the "finger tightness" specified in ASTM D5652-21[10]. In Series B3, grease and Teflon sheets were inserted into the contact region. In this series, the bolts were hardly tightened.

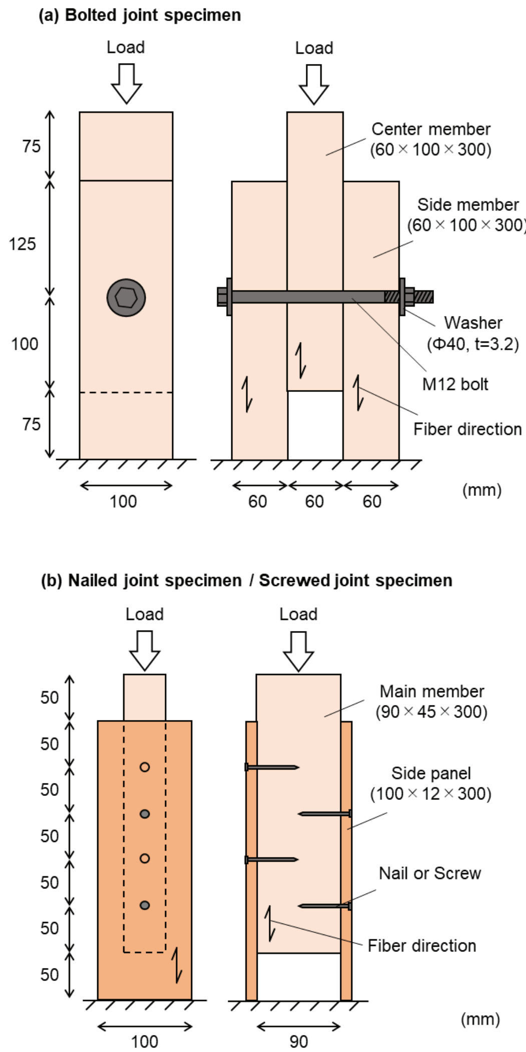

Figure 2. Experimental setups of joint specimens [6]

For the screwed and nailed joint specimens, Japanese cedar was used as the main member, whereas structural plywood made of Japanese cedar was used as the side member. Four screws and nails were used for each specimen. For the screwed joint specimens, screws for the shear walls (BX Kaneshin Co., Ltd., KS4041) measuring 41 mm long with a nominal diameter of 3.9–4.1 mm were used. For the nailed joint specimens, CN50 in JIS A 5508[11] measuring 50.8 mm long and 2.87 mm in diameter was used. In the N1, N2, and S1 series, no material was inserted into the contact region, as shown in Figure 3(a).

Grease and a Teflon sheet were inserted into the N3 and S3 series, as shown in Figure 3(b). When nailing was performed in series N1 and N3, the nail head was sufficiently hit such that the top surface of the nail head

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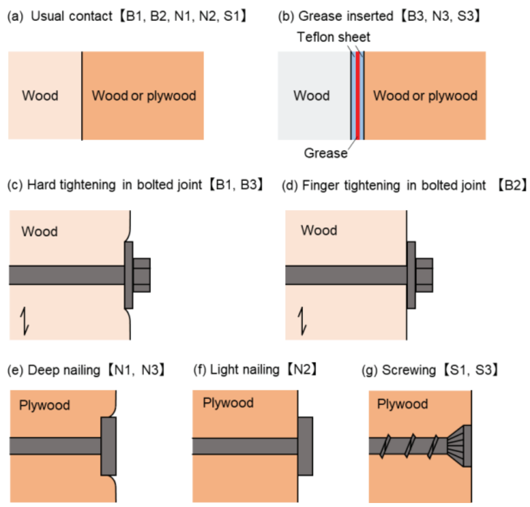

Figure 3. Conditions for friction control [6]

Table 1. Specifications of specimen series [6]

Series	Fastener	Friction	Tightening	Replicate
B1		Control	Hard	6
B2	Bolt	Control	Finger	6
B3		Inhibited	Hard	6
N1		Control	Deep	10
N2	Nail	Control	Light	10
N3		Inhibited	Deep	10
S1	Screw	Control	Usual	10
S3		Inhibited	Usual	10

(in Figure 3, right edge of the nail head) matched the wood surface. In series N2, light nailing was applied such that the bottom surface of the nail head matched the wood surface, as shown in Figure 3(f). In the series using screws, screwing was conducted such that the top surface of the head matched the wood surface, as shown in Figure 3(g).

Before creating the joint specimens, the densities of the wood members were measured. For the members used in the bolted (B) series, the average and standard deviation were 367.9 ± 19.3 kg/m^3. The values of the main members used in the nailed (N) and screwed (S) series were 373.7 ± 31.1 kg/m^3. To create the specimens, the members were divided into groups to achieve a low average density between the groups. The series of joint specimens is summarized in Table 1.

2.2 LOADING METHOD

A hydraulic testing machine (Maekawa Testing Machine MFG Co., Ltd., IPU-B43) with a series of bolts (B) was used for lateral testing. Monotonic downward loading was applied to the top surface of the center member. The loading speed was controlled at approximately 2.0 mm/min. The load was measured using a load cell (Tokyo Measuring Instruments Laboratory Co., Ltd., TCLM-100kNB) attached to the cross-head of the testing machine. To measure the relative displacement between the main and side members, two displacement transducers (Tokyo Measuring Instruments Laboratory Co., Ltd., SDP-100) were attached to both sides of the main member, and the targets were attached to the side member. The loading was maintained until the load decreased to 80% of the maximum load after reaching the maximum load or until the relative displacement reached 50 mm.

A universal testing machine (Shimadzu Co., Ltd., AG-I 250kN) was used for the nail (N) and screw (S) series. Monotonic downward loading was applied to the top surface of the main member. The loading speed was controlled at 2.0 mm/min. The load was measured using a load cell (Shimadzu Co., Ltd., SFL-50kNAG) attached to the cross-head of the testing machine. To measure the relative displacement between the center member and side panel, two displacement transducers (Tokyo Measuring Instruments Laboratory Co., Ltd., CDP-50) were attached to both sides of the center member, and the targets were attached to the side panel. The loading was maintained until the load value decreased to 80% of the maximum load or until the relative displacement reached 35 mm.

2.3 THREE METHODS FOR DETERMINING CHARACTERISTICS

This study compared the characteristics obtained from lateral tests to reveal the effect of friction inhibition. As reported by Watanabe et al. [9], the values differed depending on the determining method used. In this study, three authorized methods were selected and applied.

The first is the perfect elasto-plastic method [7,8], which is illustrated in Figure 4(a). In this study, only the yield load and stiffness were determined. First, direct lines I and II were drawn between 0.1 P_{max} and 0.4 P_{max}, and between 0.4 P_{max} and 0.9 P_{max}, respectively (where P_{max} denotes the maximum load). Line II shifts until it satisfies the load–displacement relationship, and the shifted line is named Line III. The value of the vertical axis at the intersection of Lines I and III represented the yield load.

Line IV was drawn between the origin and yield points, and the slope represented the stiffness.

The second method is described in EN 12512 [12]. As shown in Figure 4(b), direct Line I was drawn between 0.1 $P_{\max}$ and 0.4 $P_{\max}$. Next, Line II was drawn such that it satisfied the load–displacement relationship and its incline became 1/6 of the incline of Line I. The load at the intersection of Lines I and II represented the yield load.

The third method is described in ASTM D5652-21 [10]. To determine the yield load, a straight line was fitted to the initial linear portion of the load–displacement curve.

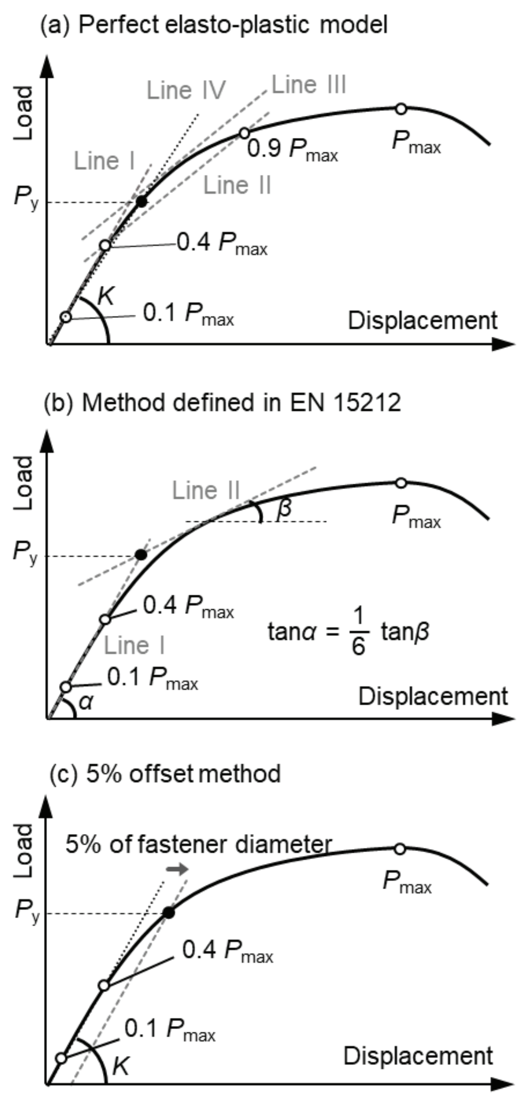

Figure 4. Methods of determining characteristics used in this study. P_{max}, P_y, and K denote maximum load, yield load, and stiffness, respectively

In the ASTM standard, no precise method is provided for drawing a straight line. In this study, the authors drew a line using the least-squares method for the data plots between 0.1 $P_{\max}$ and 0.4 $P_{\max}$, and the slope of this line represented the stiffness. The line was displaced by 5% of the nail diameter. The yield load was determined as the load at which the offset line intersected with the load–displacement curve, as shown in Figure 4(c).

3 – RESULTS AND DISCUSSIONS

3.1 LOAD-DISPLACEMENT RELATIONSHIP

The load–displacement relationships obtained from the tests are shown in Figure 5.

The results for the bolted-joint specimens are shown in Figure 5(a). Series B1 exhibited a higher load at the beginning of the test. A resistance of approximately 5 kN was indicated at a displacement of 0 mm, which appeared to result in static friction between the members. Considering that the maximum load of the B1 series was approximately 20 kN, static friction is not negligible when evaluating the lateral properties. In series B2 and B3, no static friction was observed. A comparison between B2 and B3 indicated a difference after yielding. B2 showed increased load after yielding, which is attributable to an increase in the frictional resistance with the bolt bending deformation. The maximum load of B2 was similar to that of B1. The maximum load of B3 was approximately 15 kN, thus indicating that no additional friction occurred even when the bolt was bent considerably.

As shown in Figure 5(b), static friction was observed in the nailed joint at the beginning of the test in series N1. Although the degree was lower than that of the bolted series, it was approximately 0.1 kN. Similar to series B2, series N2 exhibited a lower load at the beginning of the test. After yielding, the load continued to increase, and the maximum load was almost equal to that of N1 and significantly higher than that of N3. The friction resistance increased with the displacement. Evidently, friction was inhibited effectively only in the initial stage of the test, although the method used for B2 and N2 is known to inhibit friction in lateral tests of timber joints.

The friction-inhibition effect was similarly observed in the screwed joint, as shown in Figure 5(c). At the beginning of the test, the load difference was approximately 0.15 kN. Near the maximum load, the difference increased to 0.3–0.4 kN.

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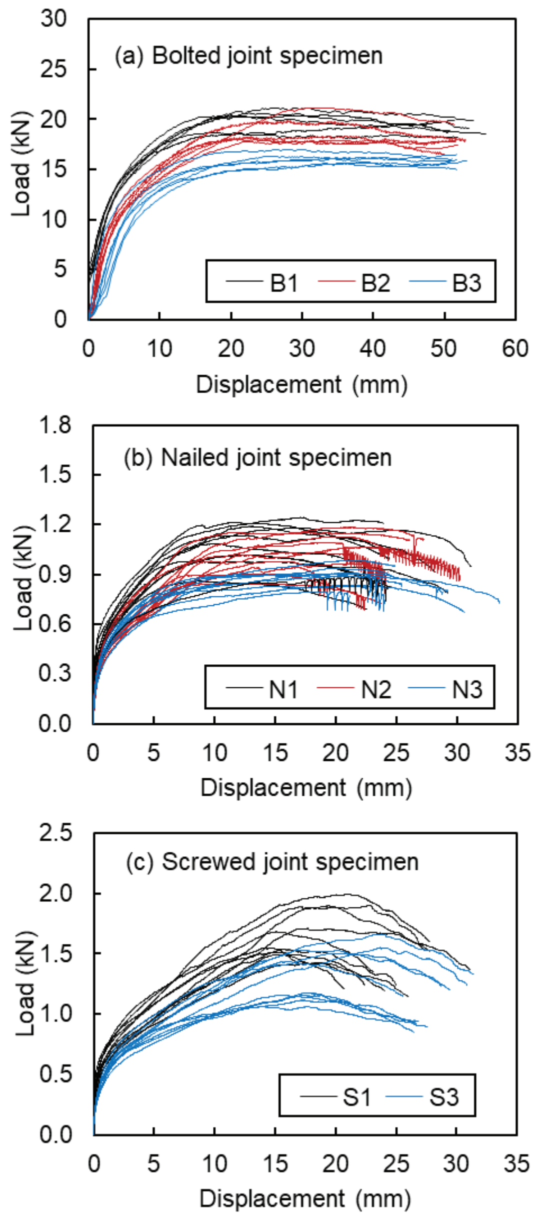

Figure 5. Load-displacement relationships

3.2 CHARACTERISTICS

The characteristics obtained using the three methods are summarized in Table 2. In all the joint types and determination methods, the values in the series with friction inhibition (B2, B3, N2, N3, and S3) were lower than those in the non-treated series, i.e., B1, N1, and S1. To provide an example that shows a significant difference, the yield load in the 5% offset method was selected as follows: The yield loads of B2 and B3 were 9.51 and 9.66 kN, respectively, which are approximately 20% lower than that of B1. In the nailed joint, a decrease in the yield load due to friction inhibition was observed. The yield loads of N2 and N3 were 0.42 and 0.39 kN, respectively, which were 10.4% and 18.2% lower than those of N1, respectively. The yield load of the screwed joint decreased by 17.7% owing to friction inhibition.

As a statistical approach, a t-test was conducted with the null hypothesis that the population average of the two samples are equal. The p-values are listed in Table 3. Values lower than 0.05, colored in gray, indicate a significant difference at the 5% significance level. As shown in the table, many pairs exhibited significant differences, which indicates the importance of friction-inhibition treatment when conducting lateral loading tests on dowel-type timber joints.

4 – CONCLUSIONS

The differences in the lateral properties of dowel-type joints due to friction inhibition were investigated. Bolted, nailed, and screwed joint specimens were prepared using various friction-inhibition techniques. Lateral loading test results revealed that friction inhibition significantly affected the characteristics of the abovementioned specimens. For example, the yield load of a bolted joint determined using the 5% offset method decreased by approximately 20% owing to friction inhibition. The differences in characteristics are not negligible, which implies the importance of friction-inhibition treatment when conducting lateral loading tests on dowel-type timber joints.

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Table 2 Average and standard deviaton of characteristcs obtained by the lateral loading tests

Series		Perfect elasto-plastic model*		EN 12512 method	5% offset method	
	Maximum load (kN)	Yield load (kN)	Stiffness (kN/mm)	Yield load (kN)	Yield load (kN)	Stiffness (kN/mm)
B1	20.20 ± 0.84	11.34 ± 0.43	4.07 ± 0.41	12.50 ± 0.87	11.97 ± 1.03	3.27 ± 0.75
B2	18.90 ± 1.33	9.96 ± 0.40	2.65 ± 0.21	11.43 ± 0.73	9.51 ± 0.34	3.34 ± 0.35
B3	16.23 ± 0.49	9.77 ± 0.52	2.12 ± 0.71	11.21 ± 0.78	9.66 ± 0.80	2.75 ± 1.07
N1	1.09 ± 0.12	0.54 ± 0.05	0.61 ± 0.16	0.50 ± 0.08	0.47 ± 0.04	0.79 ± 0.30
N2	1.03 ± 0.11	0.50 ± 0.08	0.36 ± 0.10	0.53 ± 0.12	0.42 ± 0.04	0.38 ± 0.12
N3	0.89 ± 0.06	0.51 ± 0.05	0.33 ± 0.08	0.44 ± 0.03	0.39 ± 0.02	0.51 ± 0.09
S1	1.67 ± 0.20	0.78 ± 0.10	0.45 ± 0.15	0.87 ± 0.29	0.69 ± 0.07	0.45 ± 0.21
S3	1.33 ± 0.22	0.67 ± 0.08	0.33 ± 0.07	0.69 ± 0.16	0.56 ± 0.07	0.37 ± 0.13

* This results were already shown in reference [6]

Table 3 p-value obtained by T-test

Compared series		Perfect elasto-plastic model		EN 12512 method	5% offset method	
	Maximum load	Yield load	Stiffness	Yield load	Yield load	Stiffness
B1 and B2	0.0208	0.0001	0.0010	0.0818	0.0032	0.8112
B1 and B3	0.0002	0.0057	0.0009	0.0357	0.0035	0.3281
B2 and B3	0.0078	0.5030	0.1545	0.7248	0.6863	0.3112
N1 and N2	0.3207	0.2284	0.0042	0.5741	0.0362	0.0049
N1 and N3	0.0005	0.1427	0.0006	0.0419	0.0002	0.0219
N2 and N3	0.0012	0.6129	0.6089	0.0274	0.0064	0.0124
S1 and S3	<0.0001	0.0024	0.0068	0.0061	0.0001	0.1165

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