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Evaluation of the Strength Properties of Glulam Connections with Inserted Steel Plates and Drift Pins[*1]

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ABSTRACT

It is well-known that the strength properties of wood connections depend on the density of the wood members, the diameter of the fasteners, the number of fasteners, and the arrangement of the fasteners, etc. In this study, the connection with inserted steel plates and drift pins was made in different configurations. The specimens were Larch and Sugi glulam connections. The specimens were loaded in tension, and the yield loads of the connections were obtained. The values obtained from the tests were compared with the predicted values. Good agreement between the yield loads obtained from the tension failure tests and the predicted yield loads were shown. It was shown that the density of the wood member barely affected the strength properties of the connections. The strength decreases of the Sugi glulam connections by the group effect were less than those of the Larch glulam connections.

Keywords : glulam connection, inserted steel plates, drift pins, yield load, density

1. INTRODUCTION

Large cross-section members and various fasteners were used in heavy timber framing systems. To connect the members to fasteners is the core technology of the heavy timber framing system. Connections are very weak parts where stresses are concentrated, and the failures of structures almost occur in the connections. Therefore, the evaluation of the strength properties of connections is quite necessary.

Recently, the configuration of the connections has changed in research and field construction. The configuration is being changed from connections with exposed steel plates to connections with inserted steel plates. The latter connections have advantages. Connections with inserted steel plates improve the external appearance of the structures and fire resistance. Also, the fasteners used in the connections are being changed from bolts to drift pins because drift pins are easier to manufacture and assemble than bolts.

In the case of the connections with drift pins, because the lead holes are drilled smaller than the actual drift pin diameter, the connections are

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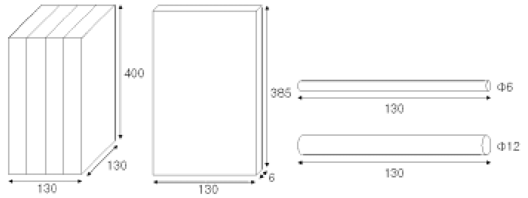


Fig. 1. Specifications of materials (mm).

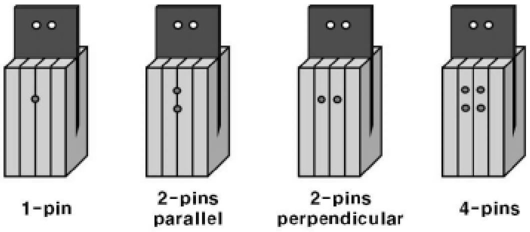


Fig. 2. Configuration of connections.

not affected by a gap between the lead hole and the drift pin. And it is well-known that a low-density member is easier than a high-density member in cutting, sawing and working.

Previous studies dealt with the connections with exposed steel plates and bolts. Recently, studies of the connections with inserted steel plates and drift pins have been conducted. The strength and stiffness of a single fastener connection depend on the physical and geometrical properties of the member and the fasteners. Member properties include the number and thickness of the members, wood species, moisture content, and direction of loading to the grain. Geometric properties include lead hole, fabrication tolerances, spacing, end distances, and edge distances (Soltis and Wilkinson, 1987).

The strength of multiple fastener connections does not equal the strength of a single fastener connection multiplied by the number of fasteners. Generally, the connection fails at a lower load because the timber splits and softening of the wood member, which can be explained by the complicated stress distribution around the fastener (Jorissen and Andre, 1999).

The purpose of this study was to evaluation of the strength properties and investigate the affect factors (density, fastener arrangement and number) on the structural performance of the glulam connection with inserted steel plates and drift pins. Connections were made in different configurations. Then, the yield loads of the connections were obtained using tension failure tests. The values obtained from the tests were compared with the predicted values.

2. MATERIALS and METHODS

2.1. Materials

The connections were composed of the glulam, steel plates, and drift pins. The glulam was made of Larch, which has a high density. To compare the strengths of connections with a low density, Sugi was used as the connections' lamination. The average moisture contents of laminations were 12% for Larch and Sugi. The average densities were 0.511 g/cm^3 and 0.395 g/cm^3. The dimension was 130 mm × 130 mm × 400 mm. The steel plate was kind of a part of the SS400 according to KS D 3503. The steel plate was 130 mm × 385 mm with 6 mm thickness. The drift pin was SS400, too. The diameters of the drift pins were 6 mm and 12 mm. The length of drift pins were 130 mm (Fig. 1).

2.2. Specimens

Sixteen specimen groups were made in different configurations. One inserted steel plate was used. The diameters of the drift pins were 6 mm and 12 mm, and the number of the drift pins used were 1, 2, and 4. The arrangements of the 2 drift pins were parallel and perpendicular to the grain direction (Fig. 2). The distances

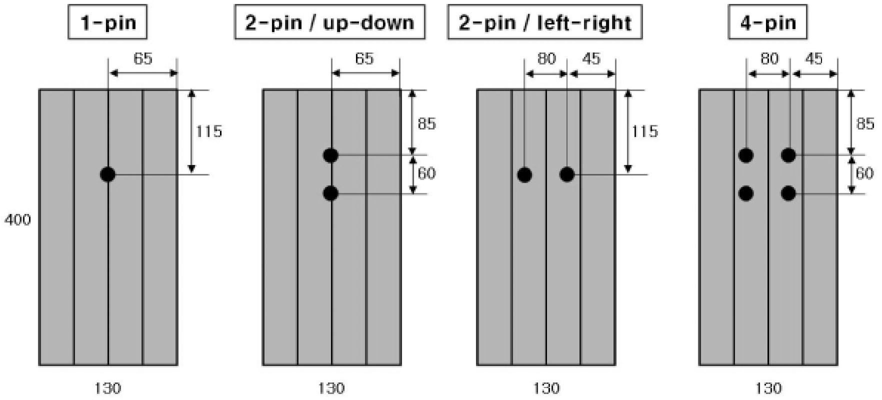


Fig. 3. Distances between drift pins and member (mm).

between the drift pins and the wood member were as recommended in NDS 2005 (Fig. 3). The specifications of the specimen groups were summarized in Table 1. Three replicates were tested for each group.

2.3. Methods

2.3.1. Dowel-bearing Strength Test

Dowel-bearing tests were performed to obtain the dowel-bearing strength of glulam with the drift pins. The tests were conducted in accordance with ASTM D 5764-97a half-hole test. The loading direction was parallel to the grain, and the rate of loading was 1.0 mm/min. After the tests were completed, the average dowel-bearing strength were obtained using equation (1). Ten specimens of each drift-pin diameter and species were tested.

$$f_h = \frac{P_y}{D \cdot t}(N/mm^2) \tag{1}$$

f_h : Dowel bearing strength (N/mm^2)
P_y : Yield load (N)
D : Dowel diameter (mm)
t : Specimen width (mm)

2.3.2. Dowel-bending Yield Strength Test

To determine the bending yield moment of the drift pin, dowel-bending tests were performed in accordance with ASTM D 1575-03. The bearing point spacing (s_{bp}) was 70 mm with the 6 mm drift pin and 140 mm with the 12 mm drift pin. The rate of loading was 1.5 mm/min. After the tests were completed, the average dowel bending yield strength was obtained using equation (2). Three drift pins of each diameter were tested.

$$F_{yb} = \frac{3P \cdot S_{bp}}{2d^3}(N/mm^2) \tag{2}$$

F_{yb} : Bending yield strength (N)
P : Yield load (N)
S_{bp} : Bearing point spacing (mm)
d : Diameter of drift pin (mm)

2.3.3. Failure Test

For each manufactured connection, failure tests were performed in accordance with ASTM D 5652. A universal strength tester was used in the tests, and the loading direction was loaded parallel to the grain. The rate of loading was

Table 1. Summary of specimens groups

Group	Species	N_{sp} [b]	d [c] (mm)	N_{dp} [d]	Arrangement	n_r [e]	e [f]	S_d [g]	S_r [h]
1	C [a]	1	6	1	-	1	115	-	-
2	C	1	6	2	perpendicular	1	85	60	-
3	C	1	6	2	parallel	2	115	-	80
4	C	1	6	4	-	2	85	60	80
5	C	1	12	1	-	1	115	-	-
6	C	1	12	2	perpendicular	1	85	60	-
7	C	1	12	2	parallel	2	115	-	80
8	C	1	12	4	-	2	85	60	80
9	L [a]	1	6	1	-	1	115	-	-
10	L	1	6	2	perpendicular	1	85	60	-
11	L	1	6	2	parallel	2	115	-	80
12	L	1	6	4	-	2	85	60	80
13	L	1	12	1	-	1	115	-	-
14	L	1	12	2	perpendicular	1	85	60	-
15	L	1	12	2	parallel	2	115	-	80
16	L	1	12	4	-	2	85	60	80

a) C : *Sugi*, L : *Larch*
b) N_{sp} : Number of steel plate
c) d : Diameter of drift pin (mm)
d) N_{dp} : Number of drift pin
e) n_r : Number of row
f) e : End distance (mm)
g) S_d : Spacing (mm)
h) S_r : Row spacing (mm)

1.0 mm/mim. To fix the connections, clamps were used. To measure the displacement of the inserted steel plates, LVDT (Linear Variable Displacement Transducer) sensors were equipped at the side of steel plates (Fig. 4). The configuration of the tests was shown in Fig. 5.

After the failure tests, load-displacement graphs were obtained. Based on the 5% offset method, the yield loads of the connections were obtained, and the failure modes were observed. The values obtained from the tests were compared with the predicted values. The prediction equation is based on the EYM (European Yield Model) (Johansen, 1949).

2.3.4. European Yield Model (EYM) Prediction

EYM is based on equilibrium equations resulting from the free-body diagram of a fastener in a wood member. The EYM provides several yield modes, which depend on member dimensions, strength, and fastener strength. The yield load is the smallest value of the all possible mode equations. The failure modes of the connections with the 1 inserted steel plate were

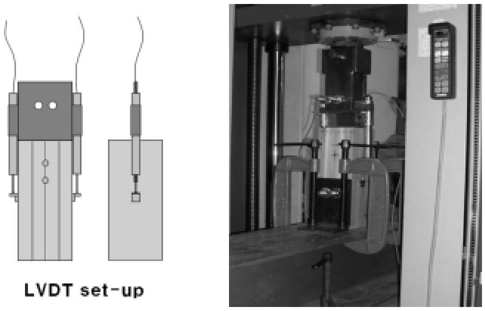


Fig. 4. Configuration of connection failure test.

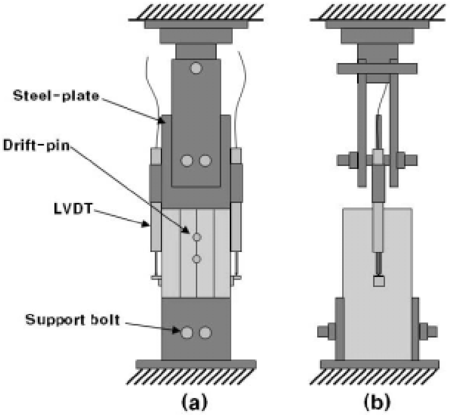


Fig. 5. Schematic diagram of connection failure test for parallel to the grain direction (a) front-view (b) side-view of the specimen with inserted 1 steel plate.

shown in Fig. 6. The yield loads in each type were given in equation (3), (4) and (5).

$$R = f_{h,1} t_1 d \qquad \text{Type I} \tag{3}$$

$$R = f_{h,1} t_1 d \sqrt{2 + \frac{4M_y}{f_{h,1} d t_1^2}} - 1 \qquad \text{Type II} \tag{4}$$

$$R = \sqrt{2}\sqrt{2M_y f_{h,1} d} \qquad \text{Type III} \tag{5}$$

R : Load carrying capacity per fastener per shear plane (N)

$f_{h,1}$: Embedding strength corresponding to t1 (N/mm^2)

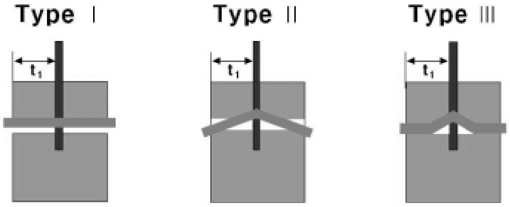


Fig. 6. Yield failure type of fastener connection with inserted 1 steel plate (a) Type I (b) Type II (c) Type III.

Table 2. Results of dowel bearing strength tests

Species	$D_{dp}$$^{a)}$ (mm)	Bearing strength (N/mm^2)	Standard deviation (N/mm^2)	COV$^{b)}$
Larix -leptolepis	6	30.43	3.58	0.12
	12	28.03	2.98	0.11
Cryptomeria -japonica	6	41.89	4.21	0.10
	12	38.16	3.88	0.10

a) D_{dp} : Diameter of drift pin (mm)
b) COV : Coefficient of Variation

t_1 : Timber thickness or fastener penetration of member 1 (mm)

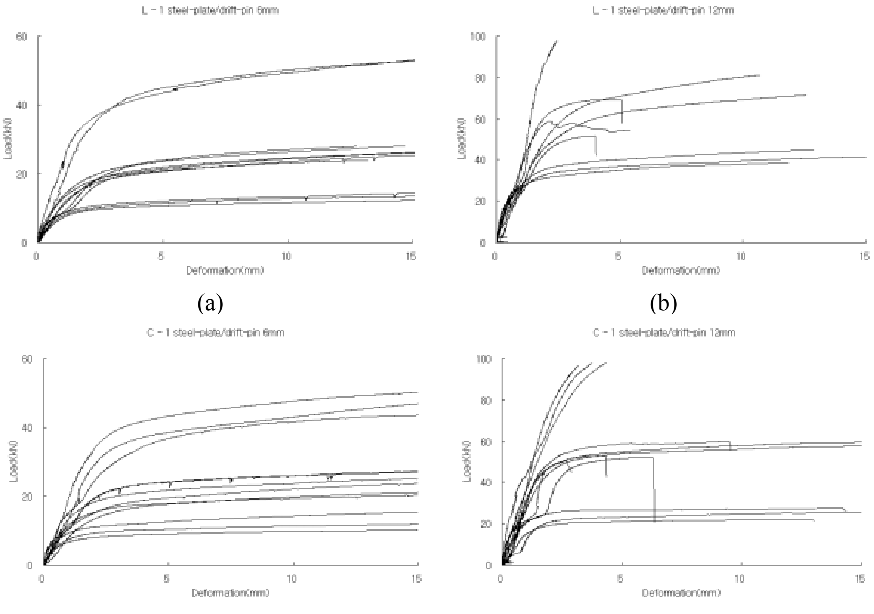
d : Fastener diameter (mm)

M_y : Fastener bending yield moment (N・mm)

3. RESULTS and DISCUSSIONS

For each drift pin with diameter 6 mm and 12 mm, the bearing strengths of glulam are listed in Table 2. These values were used in predicting the equations.

The results shows that the average yield loads of 6 mm and 12 mm drift pins are 1553.13 N and 5343.89 N, and bending yield strength were 754.99 N/mm^2 and 649.43 N/mm^2. The yield moments of the fasteners were calculated using equation (6). The calculated values were used in



(a) (b)

(c) (d)

Fig. 7. Results of connection failure tests (a) Larch (6 mm drift pin) (b) Larch (12 mm drift pin) (c) Sugi (6 mm drift pin) (d) Sugi (12 mm drift pin).

predicting equations.

$$M_y = \frac{\pi}{32} f_y d^3 \tag{6}$$

M_y : Fastener yield moment (N · mm)
f_y : Yield stress of fastener (N/mm^2)
d : Diameter of fastener (mm)

Fig. 7 and Table 3 show the results of the connections failure tests. In Table 3, the experimental and predicted values are good agreed.

3.1. Yield Failure Modes

The predicted yield failure modes of the connections with inserted 1 steel plate have three modes (Type Ⅰ, Type II, Type III). According to the EYM, in the case of connections with 1 inserted steel plate, the connections with 6 mm

Table 3. Results of connection failure tests

Group	P_y[a] (kN)	K[b] (kN/mm)	P_J[c] (kN)	P_y/P_J
1	9.09	13.10	6.84	1.33
2	18.68	14.09	13.68	1.37
3	13.95	10.32	13.68	1.02
4	33.24	17.18	27.35	1.22
5	25.82	22.35	21.97	1.19
6	50.66	32.68	43.94	1.17
7	49.47	33.85	43.94	1.14
8	93.63	34.36	87.88	1.08
9	9.92	10.97	7.78	1.24
10	19.81	9.87	15.56	1.23
11	17.44	11.97	15.56	1.09
12	35.76	20.16	31.13	1.11
13	30.83	41.21	27.02	1.15
14	57.44	36.57	54.05	1.07
15	58.06	44.37	54.05	1.09
16	98.57	72.16	108.10	0.92

a) P_y : Experimental yield load (kN)
b) K : Initial stiffness (kN/mm)
c) P_J : Johansen's equation prediction value (kN)

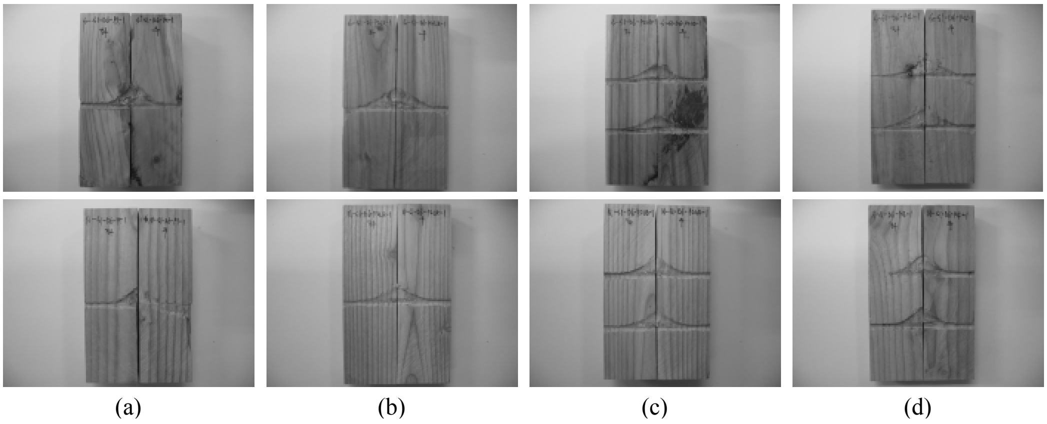

(a) (b) (c) (d)

Fig. 8. Failure modes of connections with 6 mm drift pins (sugi (above), larch (bottom)) (a) 1 drift pin (b) 2 drift pins (perpendicular to the grain arrangement) (c) 2 drift pins (parallel to the grain arragement) (d) 4 drift pins.

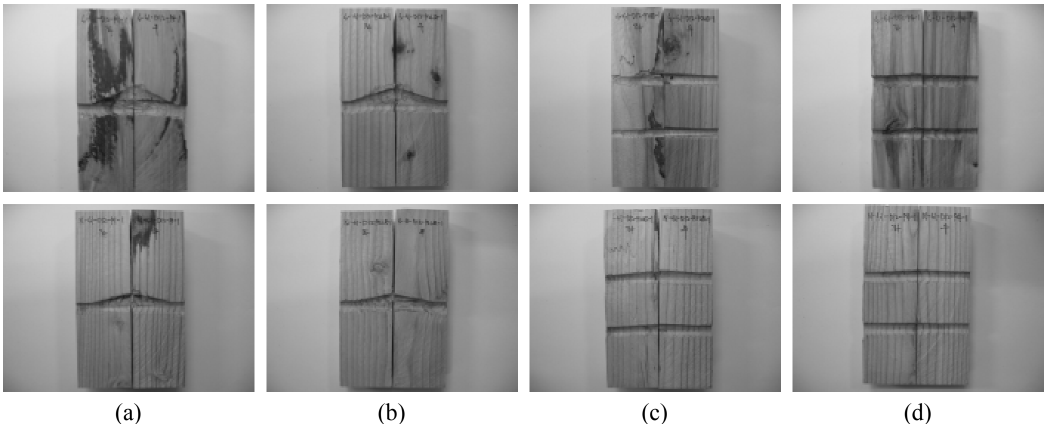
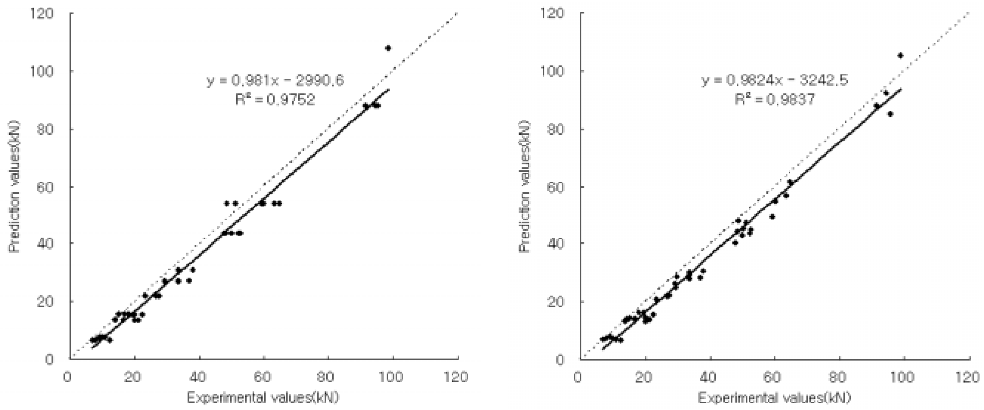

(a) (b) (c) (d)

Fig. 9. Failure modes of connections with 12 mm drift pins (sugi (above), larch (bottom)) (a) 1 drift pin (b) 2 drift pins (perpendicular to the grain arrangement) (c) 2 drift pins (parallel to the grain arragement) (d) 4 drift pins.

diameter drift pins showed a Type III mode that appeared as plastic hinges at the intersection of the steel plate and drift pin and in the wood member. The connections with 12 mm diameter drift pins showed a Type II mode that appeared as a plastic hinge only at the intersection of the steel plate and drift pin. Sections of the connections were shown in Fig. 8 and Fig. 9.

Generally, the densities of each lamination in glulam are different. And drift pins were joined at partial selected laminations in this study. The densities of the lamination were measured, and the bearing strength was obtained using equation (7) (Whale et al., 1989). Then, the predicted yield loads were obtained using the EYM equation and were compared with the obtained yield loads from the failure tests. As a result, more precise predicted values could be obtained



(a) (b)

Fig. 10. Comparison between experimental values and prediction values for different density of member (a) average density of all laminations (b) average density of laminations joined drift pins.

when the average density of laminations joined drift was used instead of average density of all laminations (Fig. 10).

$$f_h = 0.082(1-0.01d)\rho \qquad (7)$$

f_h : Dowel bearing strength (N/mm^2)
d : Diameter of fastener (mm)
ρ : Timber density (kg/m^3)

Fig. 10. Comparison of the dowel bearing strength between experimental values and prediction values for different member densities.

3.2. Effects of the Wood Member Density

It is well-known that the properties of connections are affected by the density of the wood member because the density of the wood member affects the bearing strength and the properties of connections depend on the bearing strength. However, in this study, the results showed that the density of the wood member had little effect on the yield loads of the connections. Though the density ratio of the Larch member to the Sugi member was about 1.3 (0.511 g/cm^3 and 0.395 g/cm^3), the ratio of the yield loads was only about 1.12. Also, as a result of the t-test at the 5% significance level, there was no significance between the density of the wood member and the yield load of the connections (Table 4).

Table 4. Comparison of yield load between Larch connections and Sugi connections

Group	P_c[a)] (kN)	Group	P_L[b)] (kN)	P_L/P_C
1	9.09	9	9.92	1.09
2	18.68	10	19.81	1.06
3	13.95	11	17.44	1.25
4	33.24	12	35.76	1.08
5	25.82	13	30.83	1.19
6	50.66	14	57.44	1.06
7	49.47	15	58.06	1.17
8	93.63	16	98.57	1.05
Average				1.12

a) P_c : Yield load of *Sugi* glulam connection (kN)
b) P_L : Yield load of *Larch* glulam connection (kN)

Table 5. Comparison of yield load between multiple fastener connection and single fastener connection

Ratio of P_m[a)] to P_s[b)]	C-6 mm	C-12 mm	L-6 mm	L-12 mm	Average
$P_{2parallel}$[d)]/P_1[c)]	2.05	2.00	1.96	1.86	1.97
$P_{2perpendicular}$[e)]/P_1	1.53	1.76	1.92	1.88	1.77
P_4[f)]/P_1	3.66	3.60	3.63	3.20	3.52

a) P_m : Yield load of connection with multiple fasteners
b) P_s : Yield load of connection with single fastener
c) P_1 : Yield load of connection with 1 drift pin
d) $P_{2parallel}$: Yield load of connection with 2 drift pin - parallel to the grain arrangement
e) $P_{2perpendicular}$: Yield load of connection with 2 drift pin - parallel to the grain arrangement
f) P_4 : Yield load of connection with 4 drift pin

3.3. Effects of the Drift-pins Number and Arrangement

Table 5 shows the ratios of the yield loads of the connections with 2 and 4 drift pins to the yield loads of the connections with 1 drift pin.

In the case of Sugi glulam connections, except for the connections that are arranged perpendicular to the grain direction, the increase of the yield loads was more higher than those of the Larch glulam connections as the number of drift pins increased. In other words, the applied load decrease on one drift pin in multiple fastener connection were less than those of the Larch glulam connections.

4. CONCLUSIONS

In this study, the strength properties of the glulam connections with inserted steel plates and drift pins were evaluated. Using tension failure tests, the yield loads of the connections were obtained and compared with the yield loads predicted by EYM. Then the following conclusions were attained.

1) As a result, good agreement between the yield loads obtained from the tension failure tests and the values predicted by EYM equations was shown. When the fasteners were joined at partial selected laminations, more precise prediction values could be obtained using the density of the lamination where the fasteners were joined.

2) It was shown that the strength properties of connections do not depend on the densities of wood members.

3) The yield loads of the connections with Sugi glulam increased more than those of the connections with Larch glulam as the number of drift pins increased. The result shows that the group action factor of multiply fasteners connection was performed differently according to the density of the member. Thus, when the multiply fastener connection is applied in wood construction, a low-density member like Sugi glulam could be utilized effectively.

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