



# HOKKAIDO UNIVERSITY

Title	Structural joints with glued-in hardwood dowels
Author(s)	Koizumi, Akio; Jensen, Jørgen L.; Sasaki, Takanobu
Relation	Joints in Timber Structures(International RILEM Symposium, proceedings pro022), ISBN:2-912143-28-4, pp. 403-412
Issue Date	2001
Doc URL	<a href="https://hdl.handle.net/2115/22104">https://hdl.handle.net/2115/22104</a>
Type	book part
File Information	RILEM.pdf



# STRUCTURAL JOINTS WITH GLUED-IN HARDWOOD DOWELS

Akio Koizumi<sup>1)</sup>, Jørgen L. Jensen<sup>2)</sup>, Takanobu Sasaki<sup>2)</sup>

<sup>1)</sup>Faculty of Agriculture, Hokkaido University, Japan

<sup>2)</sup>Institute of Wood Technology, Akita Prefectural University, Japan

## Abstract

Joints with axially loaded glued-in hardwood dowels were studied. A dowel whose length is ten times as long as diameter is glued into a loose-fit hole. The dowel-hole clearance is filled with flexible polyurethane adhesive to relieve shear-stress concentration along a bond line. A series of pull-out tests was conducted to reveal effects of a number of parameters. Consequently, withdrawal strength of proposed joint with single dowel of 12 mm in diameter was proved to be about 18 kN. Simple theoretical expressions based on Volkersen model for a lap joint fitted well for various conditions. End joint of beams, corner joint of frames and post-sill joint were designed as applications. Moduli of rupture for the moment-resisting joints observed in experiments were approximately 30 MPa, which corresponds to the strength of Japanese-cedar timber.

## 1. Introduction

Joints in timber construction are mostly connected with metal fasteners, such as steel plates and bolts or drift pins. However, high-strength performance of steel that consume much energy to produce and to process is not fully utilized in some cases. For example, joint efficiency is rather low in case of using dowel-type fasteners to bear lateral loads that cause splitting failure in wood members. In case of using metal fasteners with adhesives to bear withdrawal load, long-term performance might be suspicious because size changes in relation with moisture and temperature changes are quite different between wood and metal. Furthermore, it is not easy to cut wood members at joint section after use. Considering these factors, we developed a glued joint using axially loaded hardwood dowels with polyurethane adhesives.

## 2. Withdrawal properties of a dowel

### 2.1 Materials and test method

A series of withdrawal tests was conducted to determine shear strength and stiffness of a bond line and to reveal the effects of various parameters expected from the theory [1],[2],[3]. Dowels were made of hard maple (*Acer saccharum*) by dowel cutter into diameters of 8, 12 and 16 mm without any processing on surface. Dowels were glued into holes of wood members made of Japanese-cedar (*Cryptomeria japonica*) lumber or glulams with one-component polyurethane glue (Sunstar Engineering, #930 and Nihon Polyurethane, C3060). Dowel-hole clearance (DHC = hole diameter – dowel diameter) was 1 mm for standard conditions. Cure times after adhesion were 2 days or more. Numbers of test specimens were 5 for individual conditions. Approximate MOE values of dowels and wood members were 15 GPa and 8 GPa, respectively. Schematic diagrams for withdrawal tests parallel and perpendicular to wood grain are shown in Fig. 1.

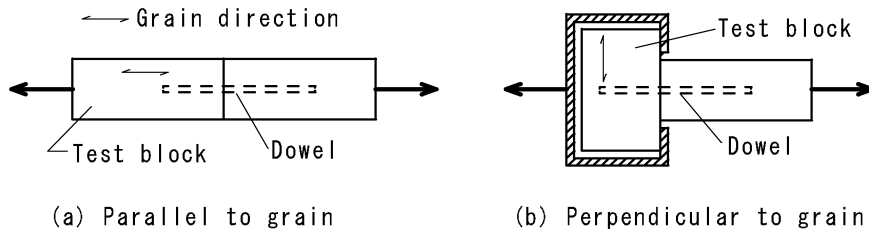


Fig. 1: Withdrawal test specimens.

### 2.2 Shear properties of bond lines

Shear stress in a bond line of wood-dowel joint does not distribute uniformly compared with glued-in bolt joint, because stiffness of a wood dowel is much lower than steel one. Therefore, withdrawal strength is not proportional to embedded dowel length and levels off for long dowels. Theoretical expressions were developed solving a differential equation derived from equilibrium conditions for a small section of a dowel joint based on Volkersen model for lap joints [4]. For usual practical joints with hardwood dowels where stiffness of a wood member ( $E_w A_w$ ) is much higher than that of a dowel ( $E_d A_d$ ), good approximations of withdrawal strength ( $Q_{\max}$ ) and slip modulus (ratio of load to slip,  $K_s$ ) are given by Eqs. (1) and (2) for both cases shown in Fig. 1

$$Q_{\max} = \xi \pi d l f_v \quad (1)$$

$$K_s = \xi \pi d l \Gamma \quad (2)$$

where  $\xi = \frac{\tanh \omega}{\omega}$ ,  $\omega = 2l \sqrt{\frac{\Gamma}{dE_d}}$ ,  $d$ : dowel diameter,  $l$ : embedded length,  $E_d$ : MOE of dowel,  $f_v$ : shear strength of bond line (MPa),  $\Gamma$ : shear stiffness of bond line (N/mm<sup>3</sup>).

Bond-line parameters: shear strength ( $f_v$ ) and stiffness ( $\Gamma$ ) were determined by curve-fitting the theoretical expressions on observed withdrawal strength of 8-mm dowels in diameter with various embedded lengths. Bond-line parameters obtained at various cure times are listed in Table 1. Approximate estimations of  $f_v$  and  $\Gamma$  are 10 MPa and 20 N/mm<sup>3</sup> for cure time of 7 days or more. No significant difference in  $f_v$  and  $\Gamma$  between two grain directions ( $a$  and  $b$  in Fig. 1) was observed, which makes it easy to apply the method to joints with various joint angles.

Table 1: Cure-time-related changes in bond-line properties and withdrawal strength.

Cure time (day)	$f_v$ (MPa)	$\Gamma$ (N/mm <sup>3</sup> )	$Q_{\max}$ (kN)
2	6.8	16.3	7.5
4	8.0	10.6	10.2
7	8.7	18.8	9.5
14	9.6	14.4	10.8
28	10.3	22.8	10.5
186	8.3	12.7	10.4
382	8.5	11.0	10.7

$Q_{\max}$ : average observed strength for  $d=8\text{mm}$ ,  
 $l=80\text{mm}$ .

Load direction: parallel to wood grain.

Bond-efficiency ratio ( $\xi$ ) takes value ranging from 0 to 1 and is affected by shear stiffness of bond line and length, diameter and MOE of dowels.

### 2.3 Effects of shear stiffness of bond line

Low stiffness of a bond line is desirable for long dowels because shear stress distributes uniformly and  $\xi$  approaches to 1 when shear stiffness ( $\Gamma$ ) approaches to zero as shown in Fig. 2. Fig. 3 shows withdrawal strength of tested three adhesives as a function of embedded length. As predicted from the theory, stiffer epoxy and resorcinol adhesives result in lower strength than flexible polyurethane adhesive for long dowels. Another way to lower  $\Gamma$  is to thicken bond line with gap-filling adhesives. Fig. 4 shows fitted curves on test results of various dowel-hole clearance (DHC).  $\Gamma$  is in inverse proportion to DHC for polyurethane adhesive. The result suggests that the shear layer nearly corresponds to glue line. At the same time,  $f_v$  tends to decrease as increase in DHC. Optimal clearance seems to be 1-2 mm

for polyurethane adhesive. In contrast to the results for polyurethane glue, no significant difference in bond-line parameters were observed among DHCs ranging from 1 to 3 mm for epoxy adhesive. The result suggests that the shear layer does not exist within stiff epoxy glue line but in wood or dowel member.

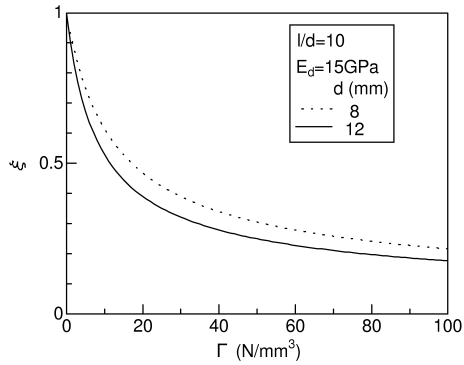


Fig. 2: Theoretical effects of shear stiffness of bond line on bond-efficiency ratio.

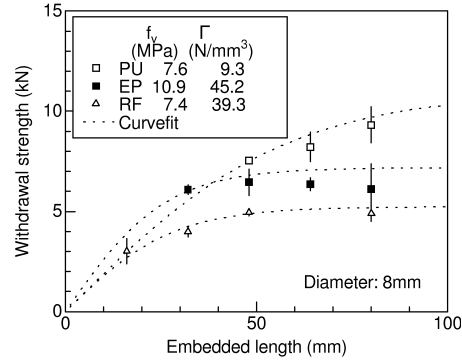


Fig. 3: Effects of bond-line parameters on withdrawal strength.

Note: PU: polyurethane, EP: epoxy, RF: resorcinol.

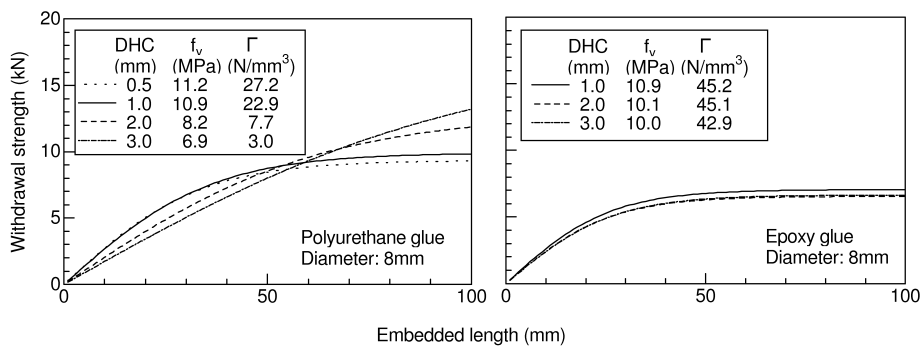


Fig. 4: Effects of dowel-hole clearance on withdrawal strength as a function of embedded length.

#### 2.4 Effects of embedded length and diameter of a dowel

Fig. 5 shows calculated bond-efficiency ratio ( $\xi$ ) as a function of embedded length for diameters of 8, 12 and 16 mm. Bond efficiency decreases as embedded length

and diameter increase. Although variations in 16 mm dowel was large, test results agreed well with theoretical predictions as seen from Fig. 6. Though smaller dowels in diameter show higher  $\xi$ , the maximum normal stress in dowels of small diameters may be critical against tensile strength of material.

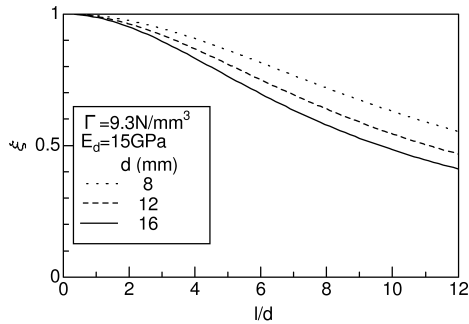


Fig. 5: Bond-efficiency ratio as a function of dowel length and diameter.

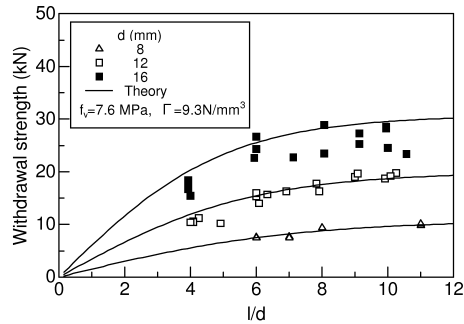


Fig. 6: Withdrawal strength parallel to the grain.

## 2.5 Effects of modulus of elasticity (MOE) of dowels

Fig. 7 shows theoretical effects of MOE of a dowel ( $E_d$ ) on  $\xi$ . Bond-efficiency increases rapidly as  $E_d$  increases to about 50 GPa and then levels off. That is, MOE much higher than 50 GPa, such as of steel, is not required for a dowel. Theoretical predictions agree with test results of aramid and steel dowels (Fig. 8).

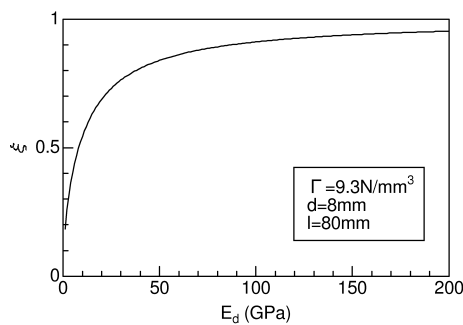


Fig. 7: Bond-efficiency ratio as a function of dowel MOE.

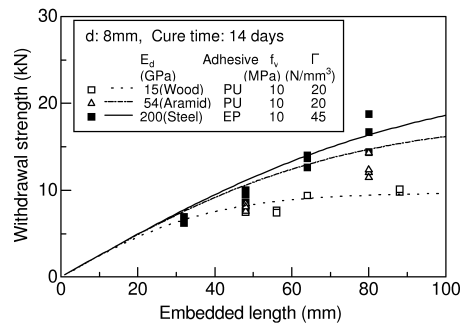


Fig. 8: Withdrawal strength of dowels made of various materials.

## 2.6 Withdrawal stiffness and maximum displacement

Stiffness is also important in designing structural joints. Typical withdrawal load-displacement curves are shown in Fig. 9. Proportional-limit loads are the halves

of the maximum loads, approximately. Slip modulus ( $K_s$ ) defined in Eq. (2) is considered to correspond to secant modulus from the origin to the maximum load of load-displacement curve, because  $K_s$  is calculated on  $F$  which is determined from maximum withdrawal load. Fig. 10 compares calculated  $K_s$  with experimental secant modulus as a function of embedded length. Though it is possible to predict  $K_s$  at  $l/d$  ratio of 10, observed  $K_s$  seems to take constant value over different embedded lengths. The reason may be due to maximum displacement increase in proportion to embedded length as seen from Fig. 9, contrary to the theory where ultimate displacement takes constant value.

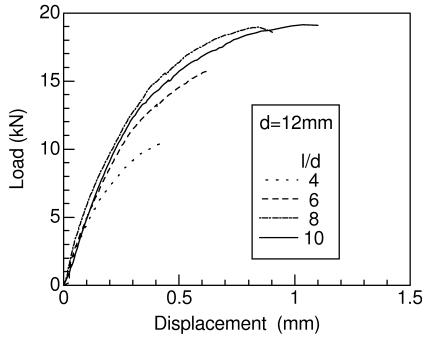


Fig. 9: Load-displacement curves observed for various  $l/d$  ratios.

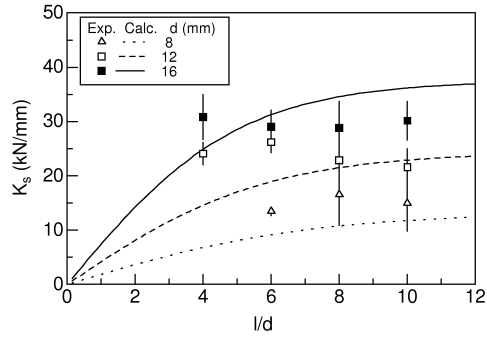


Fig. 10: Relationships between  $l/d$  ratios and  $K_s$ .

### 2.7 Dowel spacing and joint efficiency

Dowel spacing is determined as  $2d$  from a series of withdrawal test. Taking this spacing for unit area of single-dowel joint as shown in Fig. 11, withdrawal strength of a hardwood dowel (12 mm in diameter and 120 mm in length) per unit joint area is calculated to be about 30 MPa, which corresponds to the strength of Japanese-cedar timber (Table 2). In Japanese code, bending strengths of Japanese-cedar beams are specified 27 MPa for the first grade of visually graded timber and 29.4 MPa for E70 grade of stress graded timber. The results indicates a possibility to achieve high joint efficiency for timber joints.

## 3. Applications

### 3.1 End joint of glulam beams

One of the applications is moment-resisting beam joint as shown in Fig. 12 [5], [6],[7],[8]. Dowels are arranged in multiple layers for both tension and compression sides. Embedded lengths are 10 times of diameter at outermost layer and gradually decrease toward inner layers. These setbacks make it easy to assemble the joint and may relieve stress concentration at bottom ends of dowel holes. Dowels in

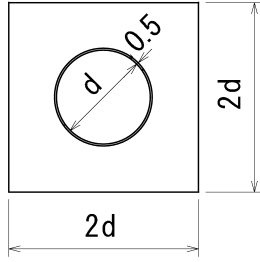


Fig. 11: Unit area for a dowel joint.

Table 2: Tensile strength ( $TS$ ) of a dowel joint.

$d$ (mm)	$Q_{\max}$ (kN)	$TS$ (MPa)
8	9.4	36.8
12	17.7	30.7
16	27.4	26.7
20	38.4	24.0

$$TS = Q_{\max}/4d^2,$$

$$f_v = 10 \text{ MPa},$$

$$\Gamma = 20 \text{ N/mm}^3,$$

$$E_d = 15 \text{ GPa}, l/d = 10.$$

compression side make that side stiffer and attribute to increase modulus of rupture (MOR) to some extent.

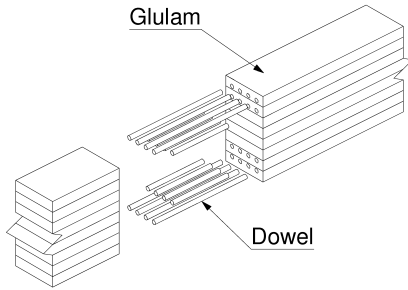


Fig. 12: End joint of glulam beam in  $100 \times 200 \text{ mm}^2$  cross section.

Table 3: Bending test results.

$b$ (mm)	$h$ (mm)	$m$	MOR (MPa)	
			exp.	cal.
100	200	2	29.8	30.1
120	420	3	25.7	26.1
120	420	5	30.0	30.3

$b$ : beam width,  $h$ : beam depth,  
 $m$ : number of dowel layers in tension side,  
 exp.: experimental, cal.: calculated.

Four-point-bending test results of glulam-beam joints with 12-mm dowels are summarized in Table 3. MOR values in the table are averages of three beams tested. MOR for two types reached 30 MPa to exceed the strength of Japanese-cedar timber. Actually, failure caused by knots in outermost lamina on tension side was observed in one of the test beams. Simple expressions for moment capacity and stiffness were derived modifying RC-beam assumptions. Calculated MOR agreed well with test results as seen from Table 3.

### 3.2 Corner joint of glulam frames

Moment-resisting corner joint has been developed as shown in Fig. 13 [9]. A plywood-corner member is inserted and is jointed to two glulam members with dowels of 12 mm in diameter. Preliminary tests revealed no significant difference

in withdrawal strength between plywood and lumber.

Moment test results are shown in Table 4. All specimens failed in withdrawal of dowels. MOR values are averages of three specimens tested. Calculation for maximum moment and stiffness was made in a similar way as for end joints. MOR for joints of  $100 \times 200 \text{ mm}^2$  cross section reached 30 MPa as expected from the theory, while those for  $120 \times 420 \text{ mm}^2$  cross section were around 22 MPa being lower than expected.

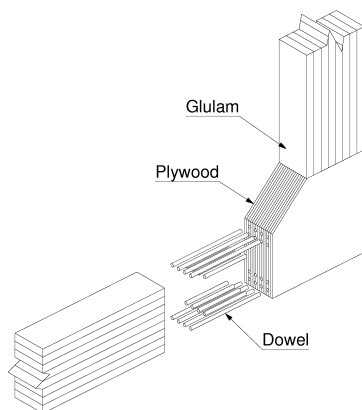


Fig. 13: Corner joint of glulam frame in  $100 \times 200 \text{ mm}^2$  cross section.

Table 4: Moment test results.

$b$ (mm)	$h$ (mm)	$m$	MOR (MPa)	
			$A$	$B$
100	200	2	30.5	29.8
120	420	5	22.1	23.8

$b$ : beam width,  $h$ : beam depth,  
 $m$ : number of dowel rows in each side.  
 $A$ : closing moment,  $B$ : opening moment.

### 3.3 Post-sill joints

We have applied the joint to post-sill joint in Japanese conventional post and beam constructions [3],[10]. Post-sill joints with short tenons in those constructions are designed to work as hinges and attached metal fasteners bear withdrawal forces. Dowel joint has high withdrawal resistance and are considered to be suitable for the post-sill joints. Proposed dowel joint shown in Fig. 14 has moment-resisting property to some extent. Average withdrawal strength and moment-resisting properties for 3 specimens for each type are shown in Table 5. All specimens failed in withdrawal of dowels. Withdrawal strength of three types are sufficient compared with metal fasteners used in conventional post-sill joint with a short tenon. Type B in Fig. 15 showed moment resistance which agreed well with theoretical predictions. Moment-resisting type joints could be used in the walls with openings. On the other hand, Type C showed large rotating capacity, accompanied with crushing of post into sill member at post edges.

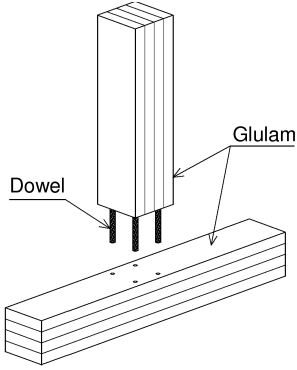


Fig. 14: Post-sill joint with glued-in hardwood dowels. (Type A in Fig. 15)

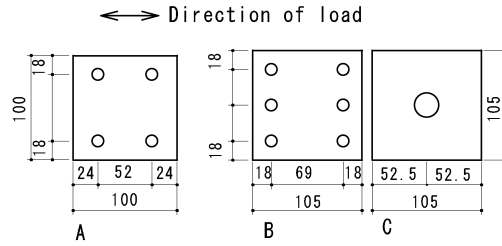


Fig. 15: Location of dowels in joint area. (Unit: mm)

Table 5: Test results for post-sill joint.

Type	$d$ (mm)	$n$	$l$ (mm)	$T_{\max}$ (kN)	$M_{\max}$ (kN m)	$\theta_{\max}$ ( $10^{-3}$ rad)
A	12	4	90	80.7 (68.4)	1.87 (1.96)	37.1 (45.2)
B	12	6	90	– (102.6)	3.49 (3.69)	38.6 (38.7)
C	24	1	90	29.8 (33.8)	1.15	94.9

Note: Types are shown in Fig. 15, Values in parentheses are calculated ones,

$d$ : diameter of dowels;  $n$ : number of dowels;  $l$ : embedded length;  $T_{\max}$ : withdrawal strength;  $M_{\max}$ : maximum moment;  $\theta_{\max}$ : rotation angle at maximum moment.

#### 4. Conclusion

As results of theoretical and experimental study, withdrawal strength of proposed joint of a hardwood dowel (12 mm in diameter and 120 mm in length) per unit joint area is proved to be about 30 MPa, which indicates a possibility to achieve high joint efficiency for timber joints.

Proposed joint method was applied to moment-resisting joints such as end joints and corner joints of glulam beams. Test results showed high strength properties and high joint efficiency. The moment capacity and stiffness can be predicted from theoretical expressions. Post-sill joints with dowels were also developed. It showed sufficient withdrawal strength compared with metal fasteners used in conventional post-sill joints with short tenon. Moment resisting properties could be added to some extent, by arranging dowels in the outer section of the joint area.

Glued-in hardwood dowel joints without ductile steel fasteners fail in brittle shear failure of adhesives or wood members. Some consideration might be necessary to supplement ductility in case of applying the dowel joints to structures where energy capacity is required.

#### 5. References

1. Koizumi, A., *et al.*, 'Withdrawal properties of hardwood dowels in end joints (1)', *Mokuzai Gakkaishi* **44**(1) (1998) 41-48.
2. Koizumi, A., *et al.*, 'Withdrawal properties of hardwood dowels in end joints (2)', *Mokuzai Gakkaishi* **44**(2) (1998) 109-115.
3. Koizumi, A., *et al.*, 'Withdrawal properties of hardwood dowels glued perpendicular to the grain', *Mokuzai Gakkaishi* **45**(3) (1999) 230-236.
4. Jensen, J.L., *et al.*, 'Axially loaded glued-in hardwood dowels', *Wood Science and Technology* **35**(1/2) (2001) 73-83.
5. Komatsu, K., *et al.*, 'Flexural behavior of GLT beams end-jointed by glued-in hardwood dowels', Proceedings of CIB-W18 30th Meeting, Vancouver, August, 1997 1-8.
6. Sasaki, T., *et al.*, 'End joint with glued-in hardwood dowels in timber construction (1)', *Mokuzai Gakkaishi* **45**(1) (1999) 17-24.
7. Jensen, J.L., Koizumi, A. and Sasaki, T., 'Timber joints with glued-in hardwood dowels', Proceedings of Pacific Timber Engineering Conference, Rotorua, March, 1999 100-107.
8. Sasaki, T., *et al.*, 'End joint with glued-in hardwood dowels in timber construction (2)', *Mokuzai Gakkaishi* (to be published)
9. Jensen, J.L., Sasaki, T. and Koizumi, A., 'Plywood frame corner joints with glued-in hardwood dowels', *Journal of Wood Science* (to be published)
10. Koizumi, A., *et al.*, 'Moment-resisting properties of post-to-sill joints connected with hardwood dowels', *Mokuzai Gakkaishi* **47**(1) (2001) 14-21.