

## **GLUED-IN HARDWOOD DOWELS AS AN ALTERNATIVE TIMBER END-JOINTING DEVICE**

## **EINGELEIMTE HARTHOLZDÜBEL ALS ALTERNATIVES VERBINDUNGSMITTEL FÜR HOLZTRÄGERSTÖSSE**

## **GOUJONS DE BOIS DUR COLLES COMME ASSEMBLAGE ALTERNATIF POUR POUTRES DE BOIS**

Kohei Komatsu

### **SUMMARY**

In this report, as a recent research topic in the field of Japanese timber engineering, a glued-in hardwood dowels joint was introduced. Tensile strength of glued-in dowel joints was found to be controlled by two parameters, one of which is the glue line shear strength  $f_{vs}$  and another is shear stiffness  $\Gamma$  which was defined as a proportional coefficient between glue line shear stress  $t$  and relative displacement between dowel and wood member.

From pull-out tests and push-out tests, glue line shear strength  $f_{vs}$  was estimated as 7.6 to 9.4 MPa for polyurethane adhesive and 10.9 to 12.9 MPa for epoxy adhesive in the case of Japanese maple dowel and Japanese cedar main member. Shear stiffness  $\Gamma$  evaluated from the two different test methods varied from 9.3 to 43.6 N/mm<sup>3</sup> for polyurethane adhesive and 45.2 to 73 N/mm<sup>3</sup> for epoxy resin adhesive. Flexural properties of glulam beams, which were end-jointed by glued-in hardwood dowels, were analysed theoretically and evaluated empirically using glued-in dowel jointed glulam beams of 100 mm x 200 mm cross section and 2700 mm total span length made of Japanese cedar. Good agreements were obtained between theoretical prediction and experimental observation.

## ZUSAMMENFASSUNG

In diesem Bericht wird als aktuelles Forschungsprojekt des japanischen Ingenieurholzbaus ein mittels eingeleimten Hartholzdübeln ausgebildeter Trägerstoß vorgestellt. Hierbei wurde festgestellt, daß die Zugfestigkeit dieser geklebten Hartholzdübelverbindung von zwei Parametern bestimmt wird. Zum einen ist dies die Schubfestigkeit  $f_{vs}$  der Klebefuge, zum anderen die Schubsteifigkeit  $\Gamma$ , die als proportionaler Koeffizient aus Schubspannung  $\tau$  der Klebefuge und relativer Verschiebung zwischen Dübel und umgebendem Holz definiert ist.

Aus Auszug- und -druckversuchen wurde die Schubfestigkeit  $f_{vs}$  der Klebefuge für Dübel aus japanischem Ahorn und Prüfkörper aus japanischer Zeder zu 7,6 - 9,4 MPa für Einkomponenten-Polyurethanklebstoff, und zu 10,9 - 12,9 MPa für Epoxydharzklebstoff bestimmt. Die Schubsteifigkeit  $\Gamma$ , die aus den Zug- und Druckversuchen bestimmt wurde, variierte im Bereich von 9,3 - 43,6 N/mm<sup>3</sup> für den Polyurethanklebstoff und von 45,2 - 73 N/mm<sup>3</sup> für den Epoxydharzklebstoff. Das Verformungsverhalten von Brettschichtholzträgern, die auf diese Weise mit Dübeln verbunden sind, wurde sowohl analytisch als auch experimentell an Prüfkörpern von 100 x 200 mm Querschnitt und 2700 mm Länge untersucht. Es wurde eine gute Übereinstimmung zwischen Rechnung und Versuch erzielt.

## RESUME

Dans ce rapport, un assemblage de poutres formée par moyen de goujons collés de bois dur est représenté comme projet de recherche actuel de la construction de bois japonais. Par ceci, on a reconnu que la résistance à la traction de ces assemblages collés de goujons bois dur est déterminée par deux paramètres. D'une côté, c'est la résistance cisaillement du joint de collage, de l'autre côté c'est la rigidité cisaillement qui est défini comme coefficient proportionnel de contrainte cisaillement du joint collé et décalage relative entre goujon et bois entourant.

Par des essais de traction et de pression, la résistance cisaillement du joint collé pour les goujons fait d'érable japonais et un échantillon fait de cèdre japonais de 7,6 à - 9,4 MPa pour la colle polyuréthane à 1 composante et de 10,9 à 12,9 MPa pour la colle epoxy avait été défini. La rigidité cisaillement, qui avait été défini par des essais de traction et de pression, variait entre 73 N/mm<sup>3</sup> pour la colle epoxy. La réaction de déformation des poutres de bois lamellé-collé qui sont liés de cette manière par des goujons, avait été examiné non seulement

analytiquement, mais encore expérimentalement aux échantillons d'un diamètre de 100 x 200 mm et d'une longueur de 2700 mm. Une bonne concordance entre facture et essaie avait été atteinte.

KEYWORDS: Timber joints, glued in hardwood dowels, glued in rods

## **1. INTRODUCTION**

Hardwood dowel might be a worth re-thinking material as an alternative jointing tool for engineered timber joints, because it can be harmonized with timber structural members more gently and naturally than such non-organic materials as steel or plastics and so on.

On the basis of above mentioned motivation, a research project team in the Institute of Wood Technology, Akita Prefectural College of Agriculture, Noshiro, Akita Prefecture, Japan has started a series of research projects in order to utilize hardwood dowels as an alternative device for end-jointing glulam beams on construction site.

In this report, as a visiting research associate of Otto-Graf-Institute, I would like to introduce some interesting research results to show how the hardwood dowel has an potential as an alternative on-site end-jointing device for glulam beams, which are now in many countries executed mainly by so-called glued-in steel bolts and/or bolted splice joints.

## **2. WITHDRAWAL PROPERTIES OF GLUED-IN HARDWOOD DOWEL JOINTS**

A series of pull-out tests were done by [KOIZUMI ET AL, 1998a,b] using the method shown in Fig. 1.

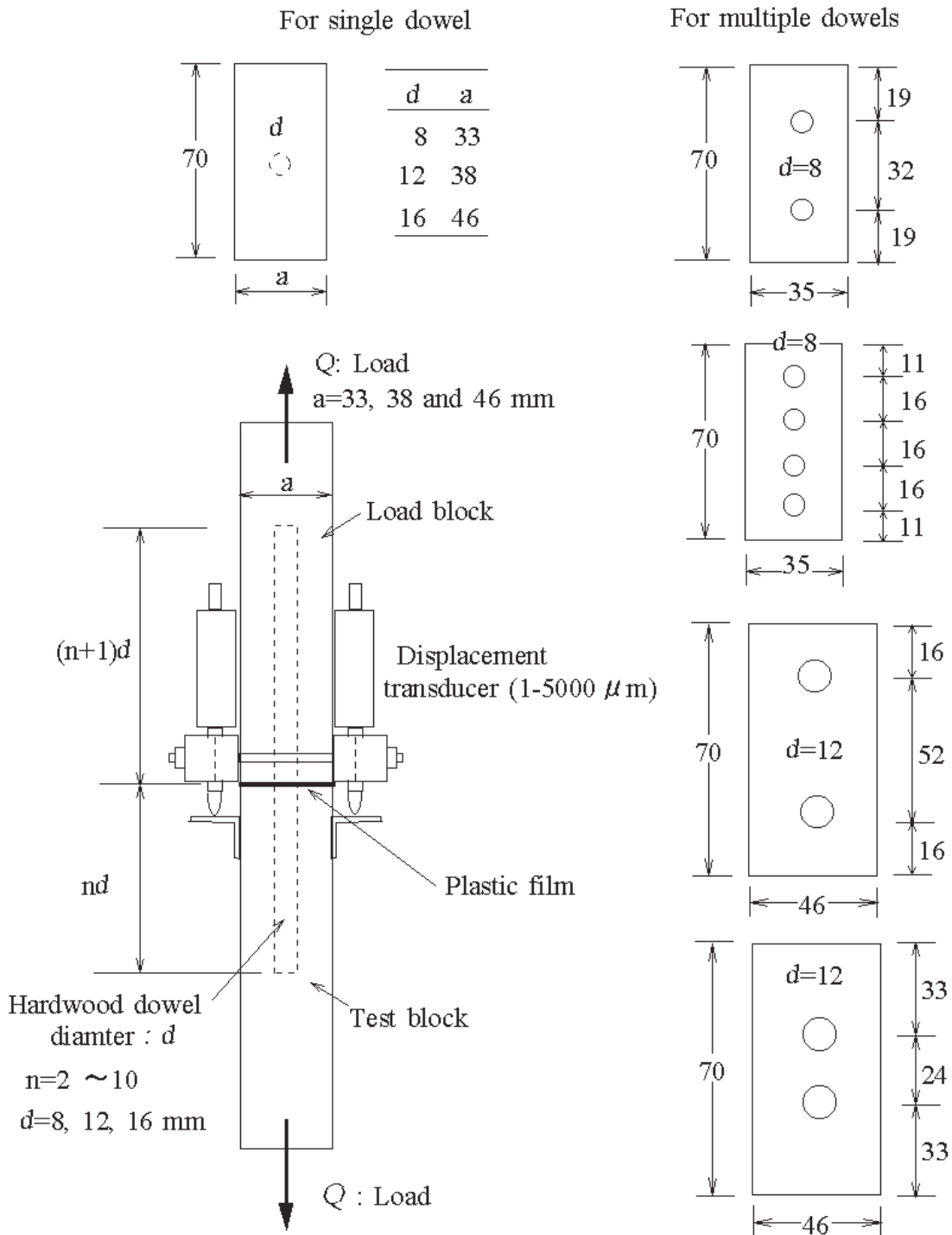


Fig. 1: Method of Pull-out test

In Table 1, some properties of the materials used in these tests are shown. For the main members, sawn timbers of Japanese cedar (*Cryptomeria Japonica*) having 33, 38 and 46mm x 70 and 90 mm cross section was used. For the dowels,

Japanese maple (*Acer mono*) having diameters of 8, 12 and 16mm were used. The diameter of leading hole for embedding dowels was always 1mm larger than the dowel diameters. The embedment length  $l$  of dowels were varied from  $2d$  to  $10d$ , where  $d$  was the diameter of the dowel. For the adhesive, one component polyurethane adhesive, epoxy resin adhesive and resorcinol-formaldehyde adhesive were used.

Item	n	Density		$E_f$		MC
		mean ( $\text{kg/m}^3$ )	CV (%)	mean (GPa)	CV (%)	
Dowel	4	713	0.7	15.1	2.3	9.7
Main member	24	377	6.2	8.5	3.4	10.5

n : Number of pieces of lumber

$E_f$  : Dynamic Young's moduli measured by longitudinal vibration method

MC : Moisture content

Table 1: Properties of materials used in withdrawal tests.

### 2.1 Summary of test results on single dowel joint

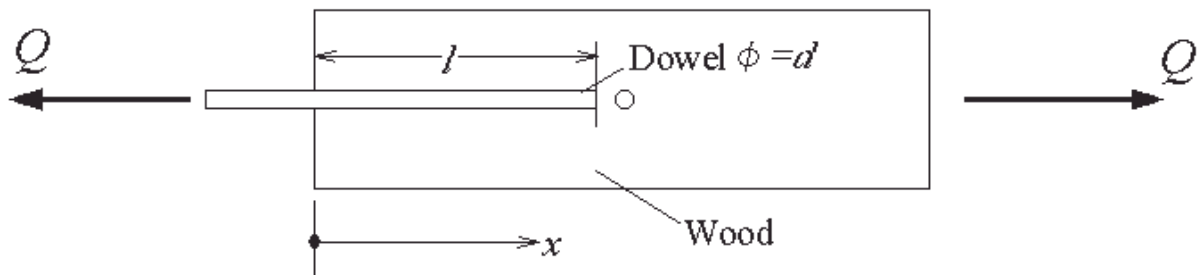


Fig. 2: Glued-in Hardwood dowel in wood member subjected to a tension force  $Q$ .

Maximum pull-out force  $Q_{\max}$  of glued-in hardwood dowel joint shown in Fig. 2 was expressed in eq. (1), which was originally derived by [JENSEN ET AL, in press] on the basis of Volkersen-type stress analysis, with including parameters of glue line shear strength  $f_{vs}$  and shear stiffness  $\Gamma$  governing the pull-out strength of the joint.

$$Q_{\max} = \frac{f_{vs} \pi d l (1 + \alpha) \sinh \omega}{\omega (1 + \alpha \cosh \omega)} \quad (1)$$

$$\omega = 21 \sqrt{\frac{(1 + \alpha)}{\alpha}} \frac{\Gamma}{d E_d}$$

$$\alpha = \frac{E_w A_w}{E_d A_d}$$

where

$E_w$  : Modulus of elasticity of wood member (see Table 1)

$E_d$  : Modulus of elasticity of hardwood dowel (see Table 1)

$A_w$  : Cross sectional area of wood member (see Fig.1)

$A_d$  : Cross sectional area of hardwood dowel(see Fig.1)

As it was difficult to define the pure shear rigidity of the glue line  $G$  in the case of the timber-glue joint, shear stiffness  $\Gamma$  was defined as shown in eq. (2) in which shear stress  $\tau$  in the glue line was assumed to be proportional to the relative displacement  $d$  between hardwood dowel and the surrounding wood member.

$$\tau = \Gamma \delta \quad (2)$$

Two unknown parameters, shear strength of glue line  $f_{vs}$  and shear stiffness  $\Gamma$ , could be estimated by applying a nonlinear least-squares method in eq. (1) with experimental data of maximum pull-out strength  $P_{\max}$

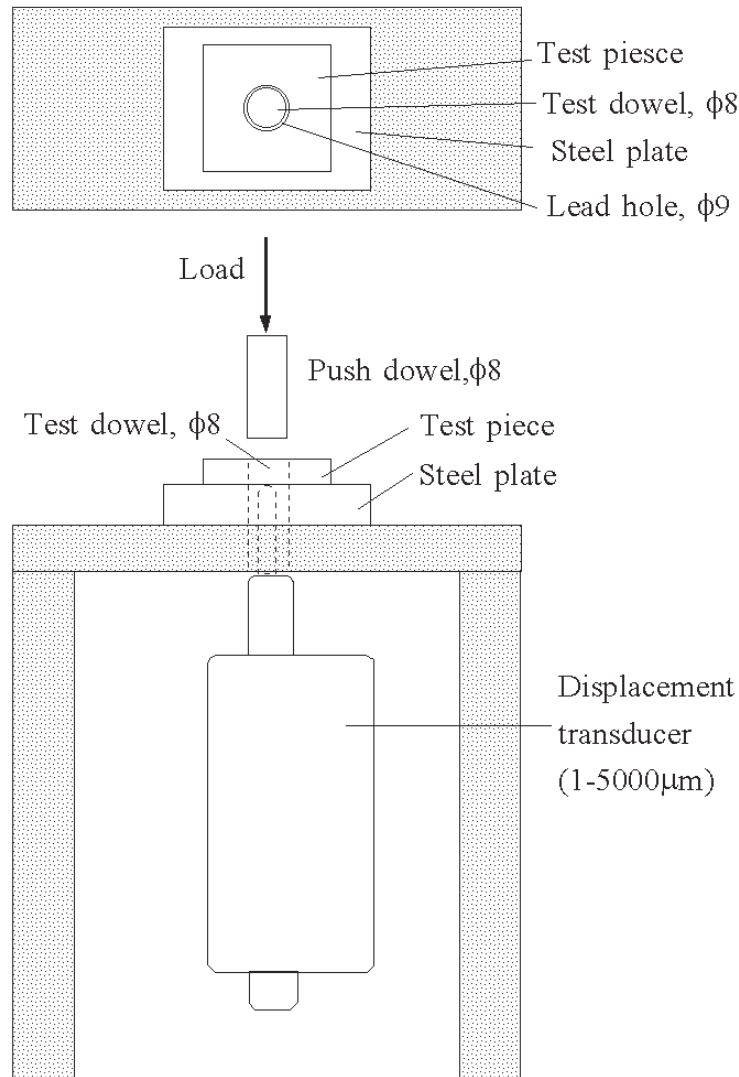


Fig. 3: *Set-up for push-out test.*

Shear strengths of glue line  $f_{vs}$  obtained directly from push-out tests shown in Fig. 3 were close to those estimated through pull-out test.

On the other hand, shear stiffness  $\Gamma$  observed in push-out tests was almost two times of those estimated through pull-out tests. This is because  $\Gamma$ 's through pull-out tests were estimated at the maximum load level while  $\Gamma$ 's through push-out test were defined as the initial stiffness.

Values of shear strength of glue line  $f_{vs}$  and shear stiffness  $G$  obtained from the two different test series are compared in Table 2.

Adhesives	$f_{vs}$ (MPa)			$\Gamma$ (N/mm <sup>3</sup> )		
	A	B	Ratio	A	B	Ratio
PU	7.6	9.4	1.23	9.3	43.6	4.69
EP	10.9	12.9	1.18	45.2	73.0	1.62

A : Pull-out test

B : Push-out test

Ratio=B/A

Table 2: Shear strength of glue line  $f_{vs}$  and shear stiffness  $\Gamma$  obtained from test methods A and B

Among the three adhesives tested, polyurethane adhesive joints showed the highest maximum pull-out strength values.

The optimum shear strength of the glue-line seemed to be about 10MPa by taking the tensile strength of dowel itself into account.

Optimum shear stiffness  $\Gamma$  seemed to be about 10N/mm<sup>3</sup> by taking the limit length and tensile strength of hardwood dowels into account.

## 2.2 Preliminary Comparisons with Glued-in Steel Rod Joints

At present, a series of pull-out tests on glued-in steel rod joints are being executed [AICHER ET AL] in the department of wood and timber engineering, Otto-Graf-Institute, as shown in Fig.4.



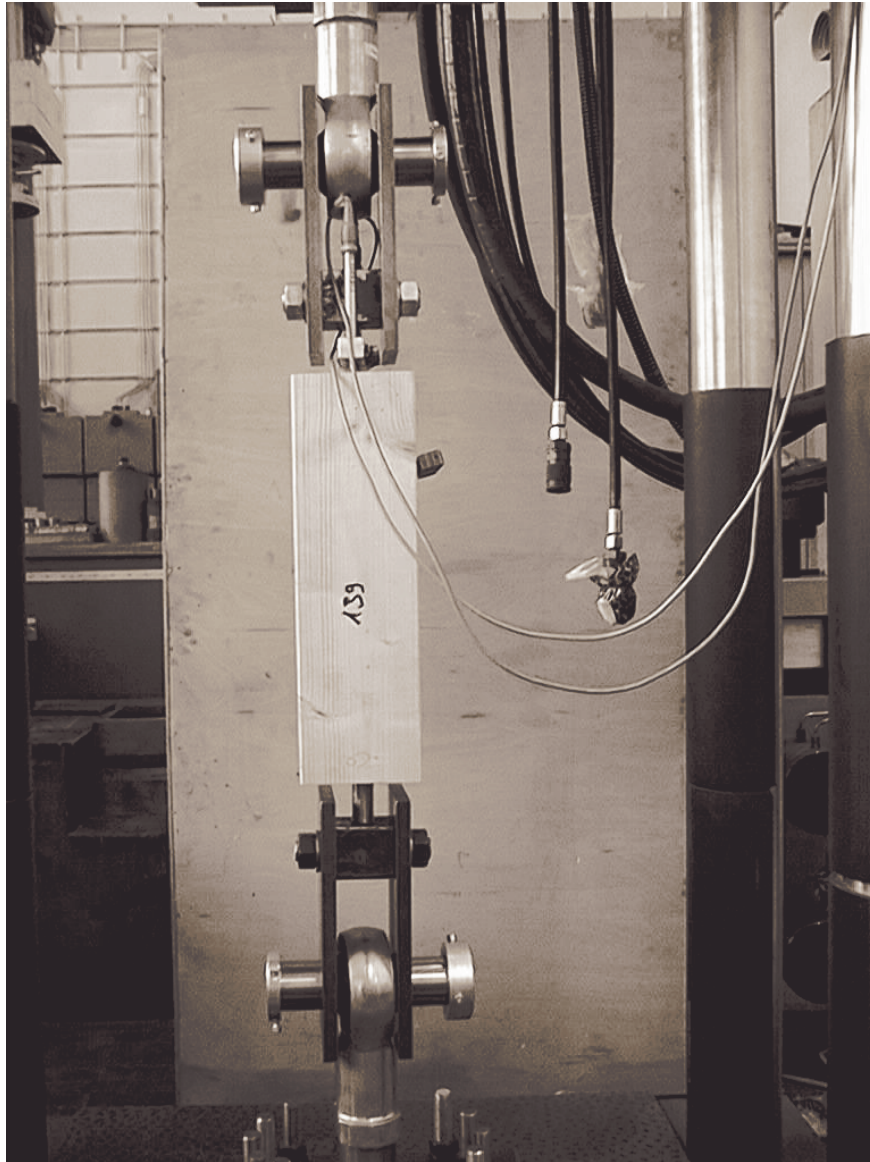


Fig.4: *Test set-up for glued-in threaded steel rod joint in the department of wood and timber engineering, Otto-Graf-Institute.*

It is interesting for the author to compare the strength properties of similar jointing methods. Unfortunately, however, the conditions between these two test series are too different to compare them rigorously, so very rough comparisons were attempted by defining the following "apparent average shear stress  $\tau_{ave}$ ";

$$\tau_{ave} = \frac{Q}{\pi dl}$$

Q: Applied tensile force on dowel

d: diameter of dowel

l: embedment depth of dowel

Fig. 5 shows comparisons between stress( $\tau_{ave}$ )-relative displacement ( $\delta$ ) relationships for glued-in hardwood dowel joints and glued-in steel rod joints. It is interesting to see that even if quite different materials are used for glued-in dowels or rods, almost same orders of stress-relative displacement relationships were obtained. This is probably because strength and stiffness of glued-in dowel type joints might be affected much more by the mechanical properties of the adhesive used and less by those of the dowel type material and/or surrounding wood member.

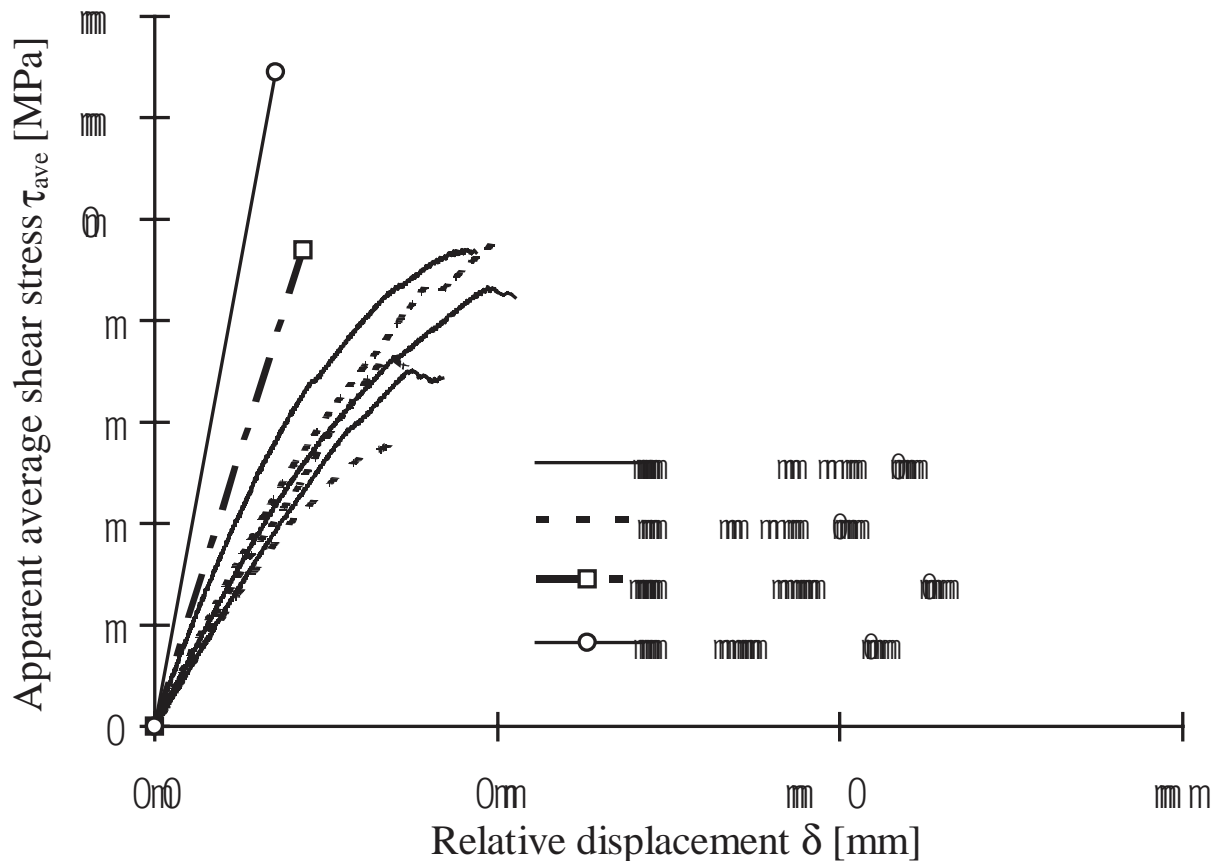


Fig.5: Comparisons of stress( $\tau_{ave}$ )-relative displacement( $\delta$ ) relationship. Wood members for glued-in steel dowel joint are European spruce glulam of 120 mm x 120 mm cross section.

### 2.3 Summary from multiple dowel joint tests

Withdrawal strength ought to be increased as the diameter of dowel increases, this prediction was coincident with experimental results from 8 to 12 mm dowels. In the case of 16 mm dowel, however, dowel failures were dominant.

The effect of MOE of the wood member surrounding the dowel(s) was less important in the range of experiments.

For dowel spacing, twice the dowel diameter seemed to be sufficient.

Withdrawal strength for multiple dowels joint was found to be about 80% of that for a single dowel joint.

### **3. BENDING STRENGTH AND STIFFNESS OF GLULAM BEAMS END-JOINTED WITH GLUED-IN DOWELS**

A glued-in hardwood dowel joint was first applied as an end-joint for glulam beams. At first, theoretical analysis for predicting bending strength and stiffness of end-jointed glulam beams were done by the author [KOMATSU, 1997] and also [SASAKI ET AL].

#### **3.1 Analytical Aspects**

The process for deriving the strength of the beam was essentially based on the concept for reinforced concrete beams (Fig.6), however, slip displacement between hardwood dowels and glulam member had to be considered in order to derive a more realistic behaviour typical to a glulam beam which was semi-rigidly jointed by an elastic adhesive.

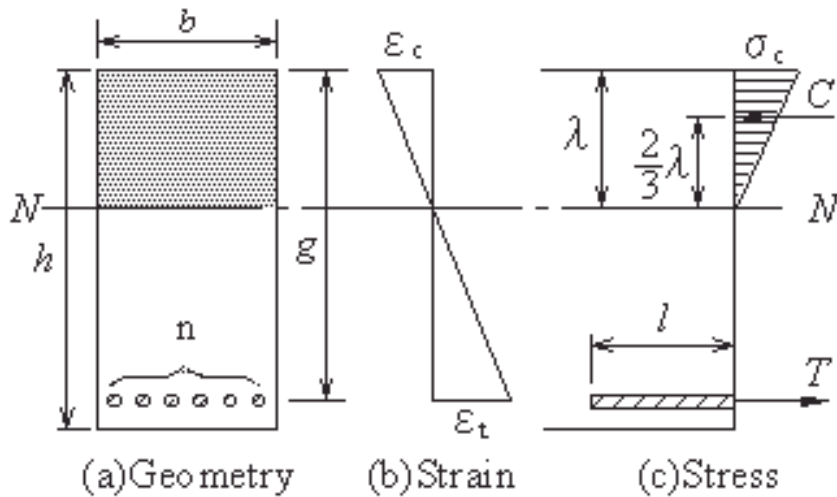


Fig.6: Geometry of cross section and assumption of strain and stress distributions.

For example, a maximum bending moment of glulam beams which were end-jointed with single row of glued-in hardwood dowels at the outer tensile side as shown in Fig. 6 might be predicted by eq.(3) [KOMATSU, 1997; SASAKI ET AL].

$$M_{\max} = nQ_{\max} \left( g - \frac{\lambda}{3} \right) \quad (3)$$

where  $Q_{\max}$  is the maximum tensile strength of a single dowel joint and could be expressed as follows by assuming  $\alpha$  (refer to section 2) to be infinite for a safety side approximation.

$$Q_{\max} = f_{vs} \pi dl \left( \frac{\tanh \omega}{\omega} \right)$$

or simply use experimental data

In eq.(3),  $l$  is the most important variable defined as a distance from the most outer compression side to the neutral axis, and is expressed in eq.(4) by solving equilibrium equation between resultant compression force  $C$  and resultant tensile force  $T$  as shown in Fig. 6

$$\lambda = \frac{1}{b E_w} \left\{ -n K_s l + \sqrt{(n K_s l)^2 + 2 b E_w (n K_s l) g} \right\} \quad (4)$$

where  $K_s$  is defined as „slip modulus“ between dowel and glulam and could be obtained also theoretically on the basis of Volkersen-type stress analysis [KOIZUMI ET AL, 1998A, B; SASAKI ET AL]

$$K_s = \Gamma \pi d l \left| \frac{\tan h \omega}{\omega} \right|.$$

Rotational rigidity  $R_J$  ( $= M/q$ ) of half part of the end-joint is expressed in eq.(5) by assuming rigid-body rotation due to slip  $S$  of dowel as well as the equilibrium of moment  $M$  and residual forces  $T$ ,  $C$  as illustrated in Fig. 7.

$$R_J = \left| g - \frac{\lambda}{3} \right| (g - \lambda) n K_s \quad (5)$$

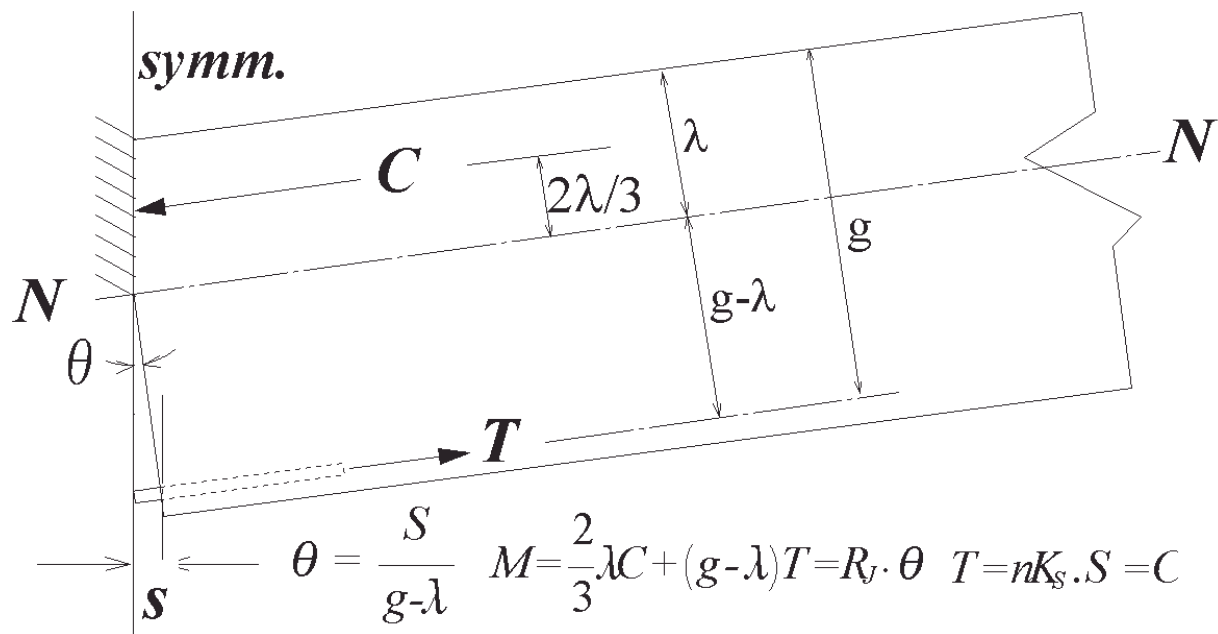


Fig.7: Rotation at the half part of end-joint.

Thus, a total mid-span deflection  $d_0$  of the end-jointed glulam beam subjected, for example, to four points bending loading as shown in Fig.8 was derived as eq.(6) by applying virtual work theory.

$$\begin{aligned} \delta_0 &= \delta_{\text{BENDING}} + \delta_{\text{SHEAR}} + \delta_{\text{JOINTS}} \\ &= \frac{P(3l_s L^2 - 4l_s^3)}{48 EI} + \frac{\kappa P l_s}{2 GA} + \frac{P l_s L}{4 R_J} \end{aligned} \quad (6)$$

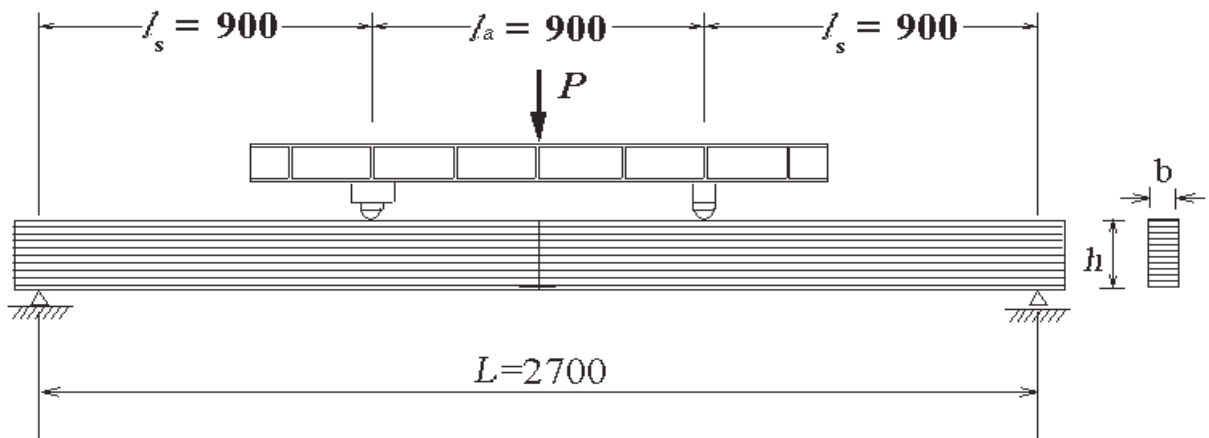


Fig.8: Four points bending test set-up.

### 3.2 Experimental Results

All experiments have been completed by a research group at Institute of Wood Technology, Akita Prefectural College of Agriculture by cooperating with Wood Research Institute, Kyoto University. In this article, a part of the test results is outlined. The rest of them is now being analysed and prepared for presenting to the Journal of Japan Wood Research Society.

Fig.9 shows a cross section of glulam beam with 6 hardwood dowels embedded in a row at most outer tensile side and also shows the test set-up.

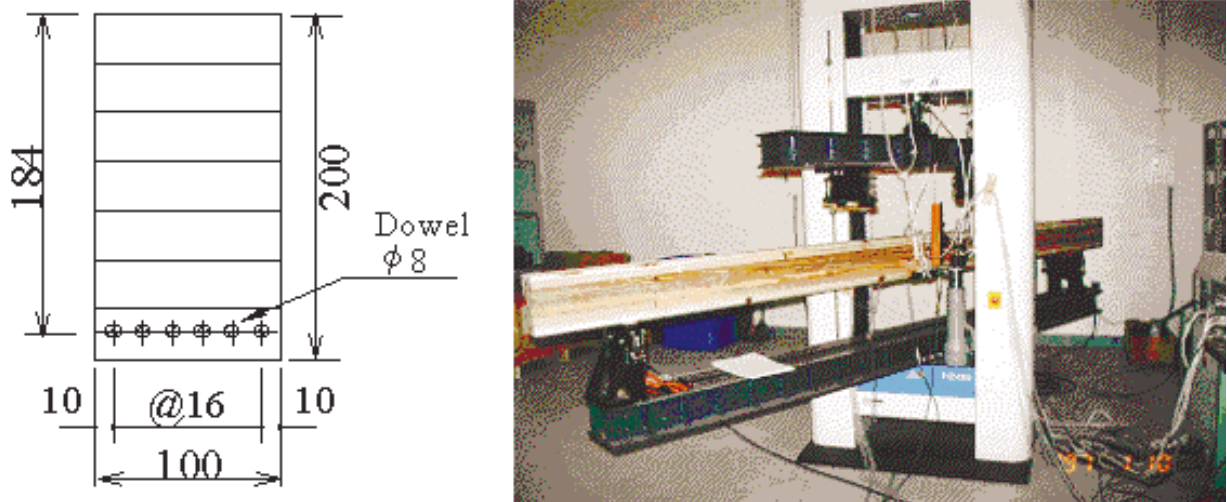


Fig.9: Cross section of tested beam and photo of test set-up.

Figure 10 shows comparisons between observed load ( $P$ ) - deflection ( $\delta_0$ ) relationship and calculated ones using eqs.(3)-(6).

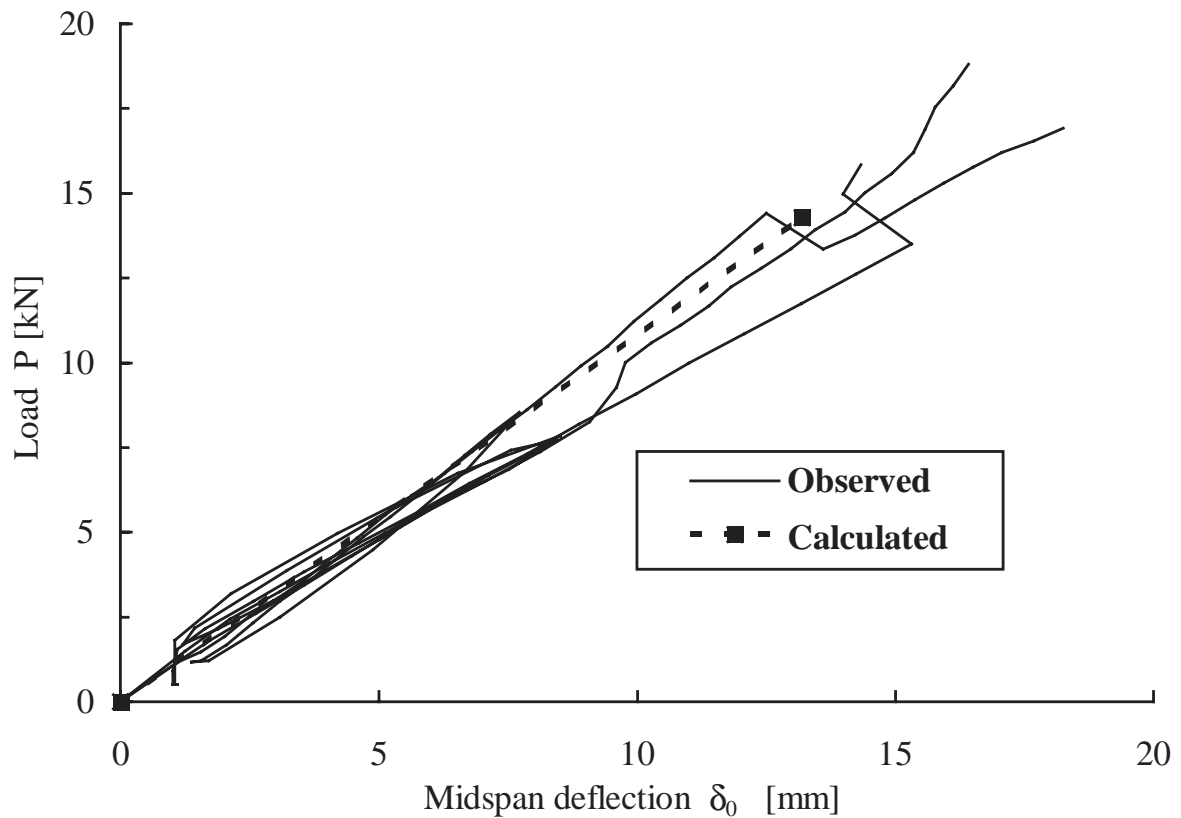


Fig.10 Comparisons between observed load ( $P$ ) - deflection ( $\delta_0$ ) relationship and calculated ones.

Table 3 supplies data used for calculation of maximum bending load and deflection of glulam beam, as well as some calculated results.

a)	$f_{vs}$ [Mpa]	$\Gamma$ [N/mm <sup>3</sup> ]	E [Gpa]	G [Gpa]	h [mm]	b [mm]	$l_s$ [mm]	L [mm]
	7.6	9.3 to 43.6 25 used	8.20	0.46	200	100	900	2700
b)	$\omega$	$\lambda$ [mm]	$Q_{max}$ [kN]	$R_J$ [kNmm/rad]	$M_{max}$ [kNmm]	$P_{max}$ [kN]	$\delta_0$ at P=15kN [mm]	
	2.31	56.45	6.49	2697660	6430	14.3	13.85	

Table 3a, 3b: *Data used for calculation (a) and calculation results (b).*

#### 4. CONCLUSIONS

In this report, as a recent research topic in the field of Japanese timber engineering, a glued-in hardwood dowels joint was introduced.

It is clear from this research mentioned above that the tensile strength of glued-in dowel joints is controlled by two parameters, one of which is the glue line shear strength  $f_{vs}$  and another is shear stiffness  $\Gamma$  which was defined as a proportional coefficient between glue line shear stress  $\tau$  and relative displacement between dowel and wood member.

From pull-out test and push-out test, glue line shear strength was estimated to be in the range of 7.6 to 9.4 MPa for polyurethane adhesive and 10.9 to 12.9 MPa for epoxy adhesive in the case of Japanese maple dowel and Japanese cedar main member. On the other hand, shear stiffness varied from 9.3 to 43.6 N/mm<sup>3</sup> for polyurethane adhesive and 45.2 to 73 N/mm<sup>3</sup> for epoxy resin adhesive.

On the basis of these experimental data, flexural properties of glulam beams which were end-jointed by glued-in hardwood dowels were analysed. For the test specimens jointed by only one row of dowels, good agreement was



obtained between theoretical prediction and experimental observation. For multiple rows of dowels, a new analysis is being executed at present and will be presented in near future.

A possibility of using hardwood dowels as jointing device of glulam beams could be shown by a series of investigation. It is, of course, impossible to apply this jointing method for any kind of timber joints, especially for the part where high stress is being sustained. This jointing method, however, will be usable for relatively small scale timber structures in which good appearance is especially demanded.

## 5. ACKNOWLEDGEMENTS

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