Dowel-bearing properties of glued laminated timber with a drift pin

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ABSTRACT

To investigate the accuracy of present design formulas for mechanical joints of glued laminated timbers (GLTs), dowel bearing tests with a drift pin were conducted in this study. GLTs with four moduli of elasticity (5.9, 7.9, 9.8, and 11.8 GPa) were prepared for the tests. These GLTs were composed of mechanically graded Japanese cedar and Japanese larch laminae with uniform modulus of elasticity. Specimens were largely divided into two types: "parallel type" in which load was applied parallel to the grain, and "perpendicular type" in which load was applied perpendicular to the grain. Five kinds of drift pin with the diameter of 4, 8, 12, 16 and 20 mm were embedded into the GLTs. Bearing stress was calculated by the ratio of bearing load to the diameter and the length of a drift pin.

We investigated the relation of the diameter of a drift pin to five percent offset values specified in ASTM-D5764, initial stiffness calculated by the ratio of bearing stress to unit bearing deformation, and effective elastic foundation depth (the ratio of modulus of elasticity of wood to the initial stiffness) based on the theory of a beam on an elastic foundation.

The following results were obtained:
(1) Five percent offset values were constant regardless of the diameter for the parallel type whereas they showed a declining tendency with increasing diameter for the perpendicular type.
(2) Initial stiffness decreased with increasing diameter for the perpendicular type, but this tendency was not clear for the parallel type.
(3) Effective elastic foundation depth increased with increasing diameter for both types. Hirai's formula commonly used to estimate the relationship between the depth and diameter of fasteners was applied to these results, however the correlation was low. This discrepancy resulted from the fact that the formula was derived from experiments in which fasteners of small diameters were used.

INTRODUCTION

Recently, glued laminated timber (GLT) has widely been used as engineered wood (EW), which is a building component with guaranteed strength. However, the present design equations of timber joints using GLTs are based on experimental results using timber and GLT produced before generalization of the concept of EW (for example, Whale et.al. 1986). In this study, bearing tests were carried out using GLTs as the first step for reexamining the suitability of current design equations for EW, and discussed the relationship between mechanical properties and connector diameter.

MATERIALS AND TEST METHOD

GLTs having graded moduli of elasticity of 5.9 GPa, 7.9 GPa and 9.8 Gpa, 11.8 GPa were used as test specimens. One grade (5.9 GPa) was a GLT of Japanese cedar (Cryptmeria japonica D. Don), and the other grades (7.9 GPa, 9.8 GPa, 11.8 GPa) were a GLT of Japanese larch (Larix leptolepis Gordon). The dimensions of GLTs were fixed for all specimens at 3600 mm length, 120 mm width, and 15 mm depth. Each GLT consisted of two surface layer laminae (15 mm thickness) and four inside and internal layer laminae (23 mm thickness). Eight GLTs were

Grade 〔GPa〕	Dynamic *MOE* 〔GPa〕	S.D. 〔GPa〕
5.9	7.4	0.490
7.8	9.9	0.422
9.8	12.4	0.379
11.8	14.4	0.546

Note.
MOE:Modulus of elasticity (Average)
S.D.:Standard deviation

Table 1 Dynamic modulus of elasticity of glued laminated timbers

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prepared for each grade.

The GLT was cut off at the length of 1720 mm (corresponding to 14 bearing test specimens), and the dynamic modulus of elasticity was measured by the longitudinal vibration method. The mean value of dynamic modulus of elasticity is shown in Table 1 for each grade. The grade given to the GLT was the lowest value of the lamina determined by the grading machine in the GLT factory. Therefore, grade values differed from the value of measured dynamic modulus of elasticity, and the measured value of dynamic modulus of elasticity varied by test specimen. However, in the following, the grade value was used as the modulus of elasticity of the test specimen, and is shown with "MOE".

A cube of 120 mm side was cut off from these GLTs, and the bearing test specimen shown in Figure 1 was processed. Actually, two specimens whose plane for the bearing was set face to face were pressed with a clamp, as shown in Figure 2, and in the center of the boundary line, a hole of size equal to the diameter of the drift pins used (hereafter, called "pin") was made. The four types of test specimen were to consider the relationship between bearing direction or axial direction of pin and the grain direction, as shown in Figure 1. In the following consideration, we define types A and B as parallel type, and types C and D perpendicular type in view of the relationship between the direction of loading and the grain of laminae. Diameters of pins were 4 mm, 8 mm, 12 mm, 16 mm, and 20 mm, and four specimens were made on each condition.

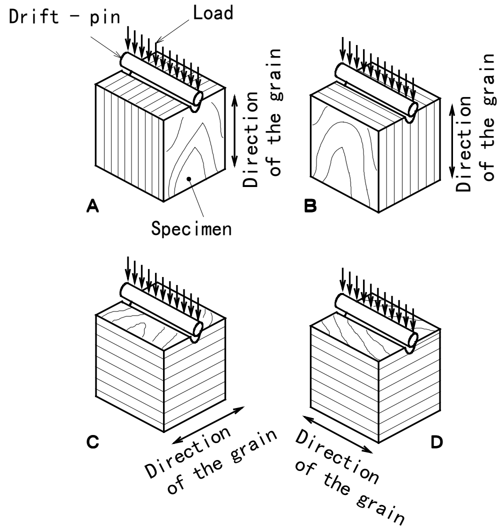
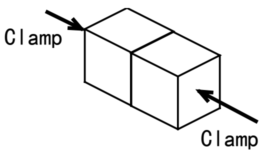
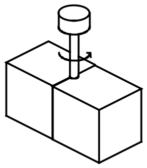


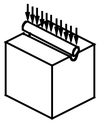
Figure 1 Schematic diagram of specimens



① Clamp the two pieces together with sufficient pressure to maintain contact between adjoinning faces



② Drill lead hole in seam of abutting pieces



③ Remove clamps and put a drift pin on a half-hole and load

Figure 2 Method of producing a specimen with semicircular groove

One problem was that the drill veered along the grain direction when holes of very small diameter were drilled, so the hole was opened from both sides of the test specimen to minimize this problem. In addition, a thin groove was cut into the test specimen using a circular saw, and the hole was drilled along this groove. After the semicircular groove had been inscribed by this method, the surface was repaired using sandpaper.

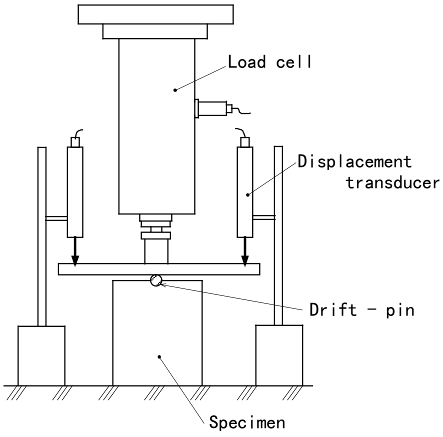


Figure 3. Loading apparatus

A schematic diagram of the bearing (loading) method is shown in Figure 3. With loading, the bearing load was measured with a load cell. The distance of movement of the loading plate was measured as bearing deformation with a displacement meter. Bearing stress (hereafter, called "stress") was defined as the value of load divided by bearing area (= product of length and diameter of the pin). Typical stress-deformation curves as a result of the

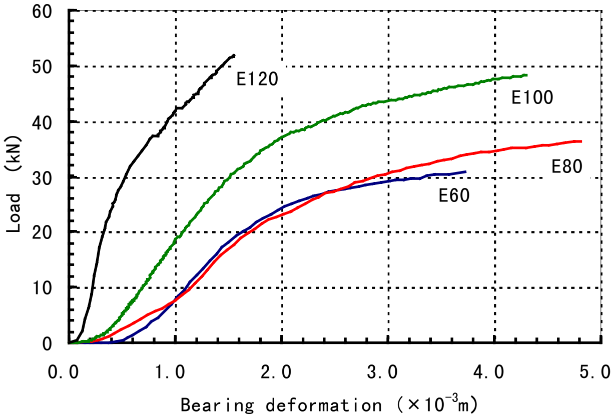


Figure 4. Typical load-deformation curve (Type A, *d* =20 mm)
Note : E60, E80, E100, E120: glued laminated timber graded as 5.9 GPa(60 tonf/cm^2), 7.8 GPa(80 tonf/cm^2), 9.8 GPa (100 tonf/cm^2), 11.8 GPa(120 tonf/cm^2)

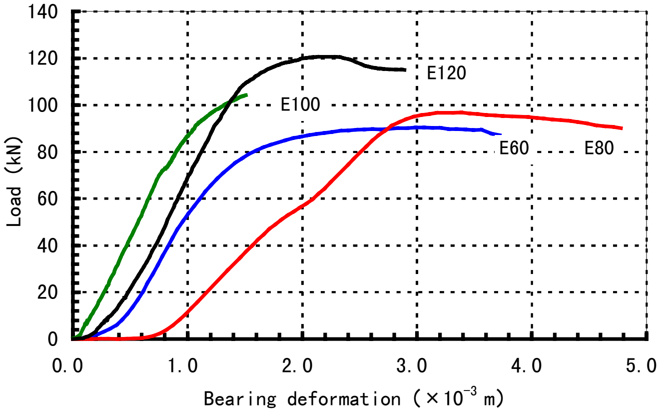


Figure 5. Typical load-deformation curve (Type C, *d* = 20mm).
Notations are same in Figure 4

measurement are shown in Figure 4 (for parallel type) and Figure 5 (for perpendicular type). In the perpendicular type, stress kept increasing with the deformation, so there were many cases in which there was no clear maximum stress (see Figure 5). Therefore, in this study, yield stresses were calculated from stress-deformation curves with the method of ASTM-D5764 (ASTM. 1997) (see Figure 6), and these values were used for evaluating the results. The yield stress is defined as the intersection point between the offset straight line, which is fitted to the initial linear section of the curve, by a deformation equal to 5% of the diameter of the pin and the curve. In the following, this stress is called "5% offset value ($\sigma_{0.05}$)".

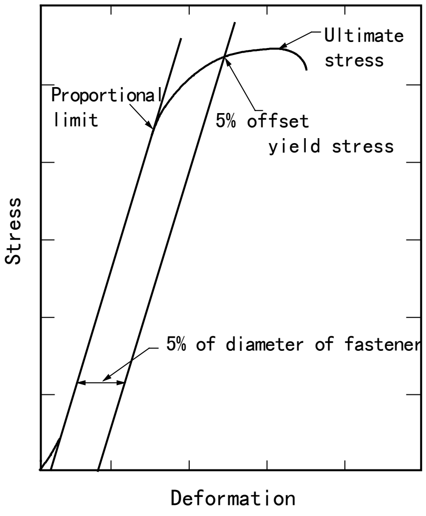


Figure 6. Method of evaluation of 5% off-set yield stress

RESULTS AND DISCUSSION

The 5% offset value ($\sigma_{0.05}$), 2% offset value ($\sigma_{0.02}$) (= stress when moving the straight line by 2% of the diameter of pin), stiffness k_e (= gradient of the elastic area) and effective elastic foundation depth α (see section 3.4) were determined from the stress-deformation curve as a characteristic value that expresses the bearing behavior, and the relationship between each characteristic value and the diameter of the pin (*d*) was discussed.

Relationship between $\sigma_{0.05}$ and *d*

Though there was no clear relationship between $\sigma_{0.05}$ and d for the parallel type, the stress showed the maximum value at *d*=8 mm for both type A and B. Regarding the coefficient of variation, the dispersion tended to generally decrease with the increase in *d*, however, when MOE was low (5.9 GPa), this tendency was not significant. For the perpendicular type (types C and D), the stress tended to decrease with the increase in *d*. An example in case of type C is shown in Figure 7. However, $\sigma_{0.05}$ was not significant for *d* as a result of ANOVA carried out for every group of each MOE. For all types A to D, the coefficient of variation was large at 11.8 Gpa (120

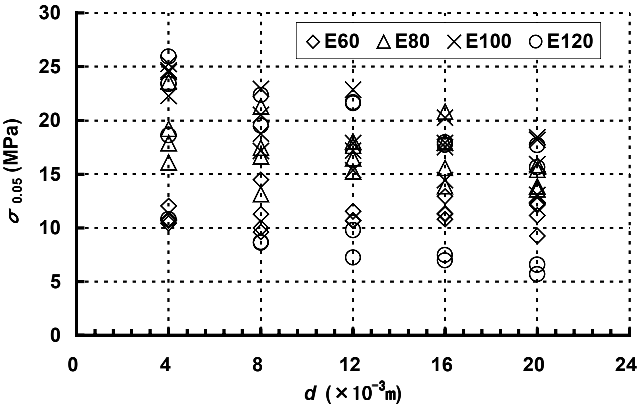


Figure 7. Relationship $\sigma_{0.05}$ and *d* (Type C).
Notations are same in Figure 4.

tonf/cm2) in MOE. There was no difference in comparison with the test specimens of other MOE in fracture morphology. It is necessary to investigate this matter further.

Relationship between $\sigma_{0.02}$ and *d*

The relation between $\sigma_{0.02}$ and d showed a similar tendency to that between $\sigma_{0.05}$ and d. The ratio of $\sigma_{0.05}$ to $\sigma_{0.02}$ was thus calculated, and the result is shown in Table 2. The offset value of the straight-line section for calculating the yield stress is a function of *d*. However regardless of connector diameter, MOE of test specimen or type of test specimen (loading direction), the ratio was a value from 1.00 to 1.20.

MOE 〔GPa〕	Diameter 〔mm〕	Type A	Type B	Type C	Type D
5.9	4	1.11	1.13	1.14	1.10
	8	1.11	1.12	1.12	1.10
	12	1.04	1.05	1.10	1.05
	16	1.04	1.07	1.12	1.05
	20	1.04	1.00	1.06	1.05
7.8	4	1.16	1.14	1.14	1.11
	8	1.09	1.08	1.15	1.11
	12	1.04	1.05	1.12	1.06
	16	1.01	1.01	1.10	1.04
	20	1.02	0.99	1.12	1.06
9.8	4	1.20	1.12	1.15	1.06
	8	1.12	1.08	1.17	1.09
	12	1.06	1.05	1.14	1.04
	16	1.04	1.02	1.12	1.11
	20	1.02	0.96	1.13	1.10
11.8	4	1.10	1.07	1.12	1.16
	8	1.09	1.05	1.10	1.13
	12	1.02	1.02	1.14	1.08
	16	1.04	1.05	1.06	1.09
	20	1.00	0.98	1.12	1.07

Table 2 Ratio of $\sigma_{0.05}$ to $\sigma_{0.02}$

Relationship between k_e and *d*

Generally, initial stiffness decreases with increasing diameter of the dowel, because of increasing bearing deformation (Hirai. 1989). This tendency was remarkable for the perpendicular type, but could not be clearly recognized for the parallel type, it. In the parallel type, the convex tendency at the bottom in which the value became a minimum at some diameters for either type was shown. In the type A, the value of *d* at which stiffness became a minimum varied by *MOE*, and the value decreased with increasing *MOE*. In type B, except for the case in which *MOE* was 5.9 Gpa (60 tonf/cm^2), the stiffness became a minimum when *d* was 12 mm. In the lateral compression type, there was a clear decline with the increase in *d* (see Figure 8). ANOVA showed a significant decline for all types at the 1% level of significance, except for the case in which *MOE* was 11.8 Gpa (120 tonf/cm^2) for type D.

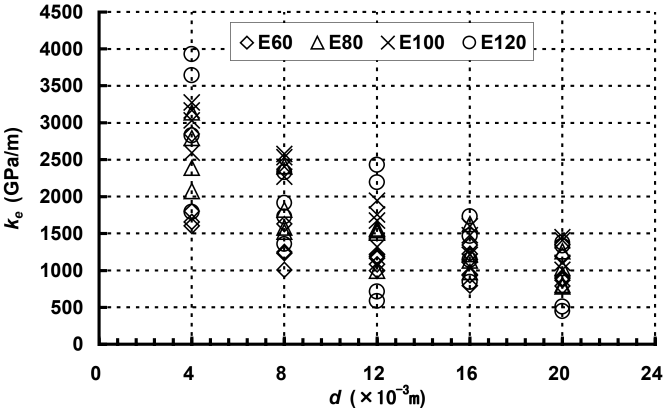


Figure 8. Relationship k_e and *d* (Type C). Notations are same in Figure 4.

The relationship between α and *d*

ssuming that the wood and connector at the bearing act like a beam on an elastic spring, the effective elastic foundation depth is defined by the length of the column replaced by the integrated value of bearing stress, which is distributed in a complex manner along a long column with cross section equal to bearing area. This value can be calculated as a ratio of *MOE* for k_e, if Hook's law is assumed to apply between bearing strain (ratio of the bearing deformation for *a*) and stress.

Hirai proposed the following equation for the relationship between α and *d* (Hirai et.al. 1982), and Komatsu proposed the compensated equation of Equation 1 for the bearing type in which loading direction is perpendicular to the grain (Komatsu et.al. 1989). These equations have also been adopted in the wood structural design standard (AIJ. 1995).

Figure 9a shows the relation between the measured value of type A and the design value (continuous line) derived from Equation 1, and Figure 9b shows that between the measured value of type C and the design value (continuous line) derived from Equation 2. The correlation of the design equation with the result of this study was not high especially for the parallel compression type. This is considered to be because Hirai used only the result of bearing tests using connectors of diameter 5 mm or less to derive Equation 1. Hirai stated that this was done to reduce the error caused by the reduction in contact area between connector and wood with the increase of connector diameter. Within the experiment in this study, this experimental condition applied only to the case in which the connector diameter was 4 mm, and therefore the suitability of Equation 1 was lower. On the other hand, Komatsu carried out bearing tests using Ezo-matsu (*Picea* *jezoensis* Carr.) and Todo-matsu (*Abies sachalinensis* Mast.), and confirmed the validity of Equation 1 over a wide range of connector diameter (3.3 mm, 12 mm, 18 mm) (Komatsu et.al. 1989). Further examination as to why the results of our experiment differ from this tendency is necessary.

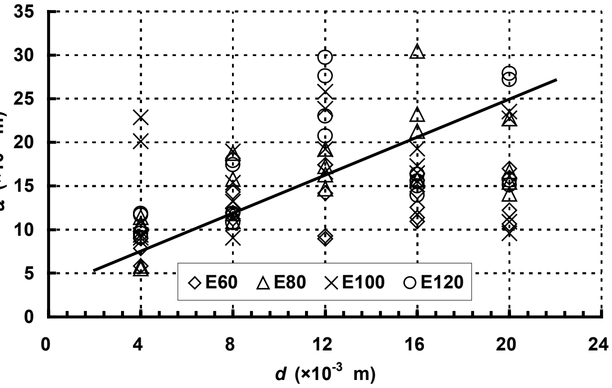


Figure 9a. Relationship between α and d (Type A)

(Note : Solid line: Hirai's formula, $\alpha = 3.16 + 10.9d$, other notations are same in Figure 4.)

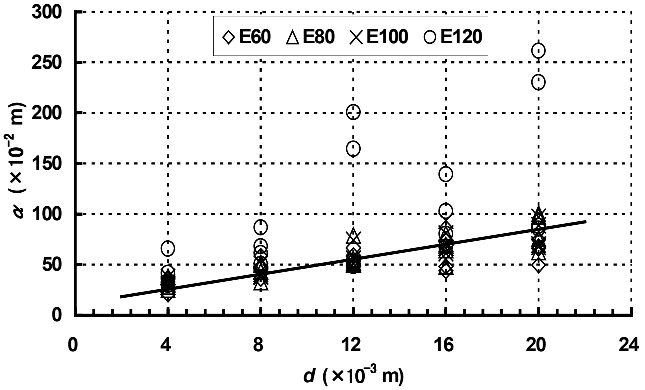


Figure 9b. Relationship between α and d (Type C)

(Note : Solid line: Komatsu's formula, $\alpha = 3.4\ (3.16 + 10.9d)$, other notations are same in Figure 4.)

CONCLUSIONS

The bearing test was carried out using GLTs in which *MOE* differed, and the relation between bearing characteristics and connector (drift pin) diameter was examined. The results are as follows.
(1) A clear relation could not be recognized between the 5% offset value and connector diameter.
(2) Regardless of connector diameter and material *MOE*, the ratio of 5% offset stress to 2% offset stress was 1.0 to 1.2.
(3) Bearing stiffness decreased with increasing diameter of drift pin.
(4) The relation between the axial direction of drift pin and lamination direction of GLT did not greatly affect the yield stress or relationship between stiffness and diameter.
(5) Regarding the relation between effective elastic property floor depth and diameter, the correlation of the present design equation of the wood structure with our experimental results varied according to the loading direction.

REFERENCES

1）AIJ (Architectural Institute of Japan). 1995. Standard for Structural Design of Timber Structures.

2）ASTM (American Society for Testing and Materials). 1997. Annual Book of ASTM Standards, 04.10, pp.608-611 of IUFRO Wood Engineering Group and CIB-Working Commission W18. 19-7-1.

3）Komatsu,K., Maeda,N., and Horie,K. Analysis of Glulam Frame-Structures Considering Nonlinear Characteristics of Fasteners II. 1989. Mokuzai Gakkaishi(in Japanese). pp.201-211.

4）Hirai,T. 1989. Basic Properties of Mechanical Wood-Joints. Research Bulletins of the College Experiment Forests, Faculty of Agriculture, Hokkaido University (in Japanese). pp.967-988.

5）Hirai,T., Sawada,M. 1982. Lateral Resistance of Bolted Wood-Joints with Steel Side Members Loaded Parallel to the Grain. Mokuzai Gakkaishi (in Japanese). pp.685-694.

6）For example, Whale L. R. J., Smith, I., Hilson, B. O. 1986. Behavior of nailed and bolted joints under short-term lateral load -Conclusion from some recent research-. Proceedings of Joint Meeting