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短　報（Note）

Comparison between compression strength perpendicular to the grain and shear strength parallel to the grain of Western hemlock lumber

IDO Hirofumi[1)*], NAGAO Hirofumi[1)] and KATO Hideo[1)]

Abstract

The amount of strength data on compression perpendicular to the grain and shear with ISO method has so far been limited because the testing method is different from the one commonly used in Japan. In the present study, tests of end-matched specimens of compression perpendicular to the grain and shear parallel to the grain of Western hemlock were carried out in accordance with ISO. As a result, characteristic strength values of both compression perpendicular to the grain and shear were more correlated with density than with Young's modulus by the longitudinal vibration method. Moreover, the regression lines between compression strength perpendicular to the grain and shear strength were significant at the 1% level of significance in end-matched specimens. Thus, it is possible to use density to estimate one strength from the other strength of a piece of timber. This result could help to fill the gaps in data on compression perpendicular to the grain and shear strength.

Key words : Western hemlock, compression strength perpendicular to the grain, shear strength, full-scale block shear test, ISO 13910

1.Introduction

International standard ISO 13910 (ISO, 2005) regulating strength testing methods for full-sized timber was established in 2005. However, the ISO methods for compression strength perpendicular to the grain and shear strength parallel to the grain of timber are somewhat different from the methods commonly used in Japan. Thus, the amount of the strength data in accordance with ISO method has been so far limited.

In this study, end-matched test specimens of compression perpendicular to the grain and shear were taken from Western hemlock lumber and then tested. Two characteristic strength values obtained by ISO 13910 methods were analyzed and compared with each other. Furthermore, a full-scale block shear test (Ido *et al*., 2004a) in which the scale of a JIS block shear test (Japanese Standards Association, 1994) was enlarged, was carried out on the specimen taken from the same lumber, because the ISO shear test method was not enough to make shear failure properly. The full-scale block shear strength values were compared with those by ISO method.

2. Experimental

2.1 Sampling method

As raw materials, 50 pieces of Western hemlock (*Tsuga heterophylla*) without a pith were prepared for the tests. Their dimensions were 105mm x 105mm in cross section, and 4000mm in length. As is usually takes place in non-graded Western hemlock lumber circulated in Japanese market, several pieces of fir lumber were involved in the raw materials. However, we did not eliminate them from the raw materials, because the actual condition of commercial lumber should be reflected to the test results. After measuring the density (ρ) and Young's modulus by longitudinal vibration method (E_{fr}) of each lumber, four kinds of test specimen were prepared (Fig.1).

The length of four kinds of specimens was 600mm for compression perpendicular to the grain by the ISO method, 700mm for the shear by ISO three-point bending method, 1200mm for the shear by ISO five-point bending method, and 150mm for the shear by the full-scale block method. Furthermore, a small test specimen for moisture content (MC) measurement by oven dry method was taken from the same sample. The MC, ρ and E_{fr} are shown in Table 1.

2.2 Tests of compression perpendicular to the grain

Tests of compression perpendicular to the grain were carried out according to ISO 13910. The ρ and E_{fr} of specimens were measured before the test. As shown in Fig. 2, these tests were carried out using a pair of 90mm-long steel-bearing plates with 3mm radius of rounding at the two corners which were arranged on the top and bottom at the middle position of the test specimen. Load was applied by a compression testing machine with

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* Department of Wood Engineering, Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato, Tsukuba, Ibaraki, 305-8687 Japan; e-mail: ido@ffpri.affrc.go.jp
1) Department of Wood Engineering, Forestry and Forest Products Research Institute (FFPRI)

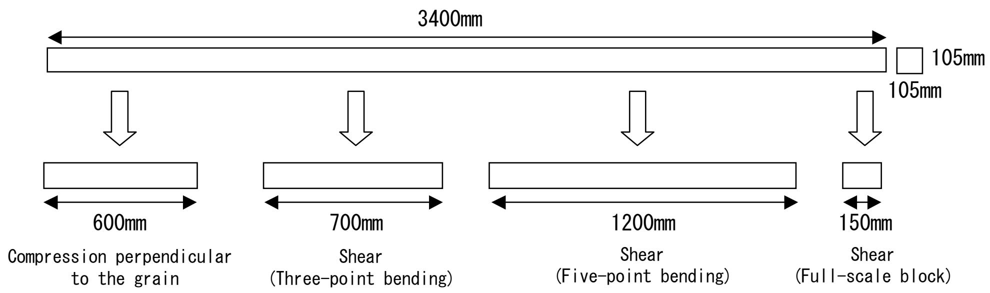

Fig. 1. Preparation of test specimens.

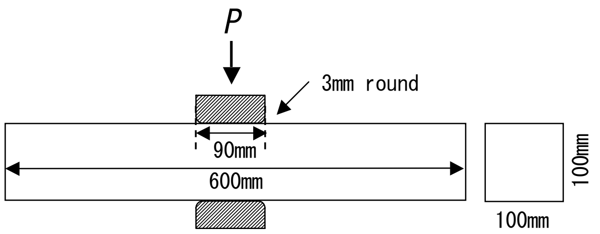

Fig. 2. Test scheme of the compression perpendicular to the grain.

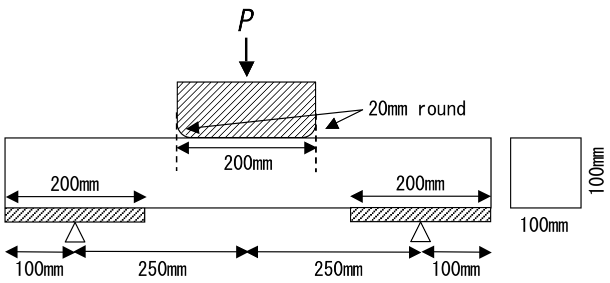

Fig. 3. Test scheme of the three-point bending method

a capacity of 3000kN (Maekawa Testing Machine Mfg Co., Ltd.) in which a loading head was fixed against rotation and testing time was targeted to five minutes.

Crosshead travel distance was measured by two displacement gauges (CDP-50, Tokyo Sokki Kenkyujo Co., Ltd.) arranged between two steel-bearing plates. The displacement of the test specimen was calculated with the mean value of the two displacement gauges. From the load-deflection curve obtained with a data logger, compression strength ($f_{c,90}$), yield strength ($f_{c,90,y}$) and compression perpendicular to the grain stiffness ($K_{c,90}$) were calculated according to ISO 13910.

In the ISO 13910, defects such as knots that might increase

Table 1. Moisture content (MC), density (ρ) and Young's modulus measured by longitudinal vibration method (E_{fr}) of raw materials.

	MC (%)	ρ(kg/m^3)	E_{fr} (kN/mm^2)
No.	50	50	50
Mean	18.9	494	11.5
Max.	23.6	601	18.3
Min.	14.8	374	6.31
CV(%)	11.3	10.2	18.5

strength, should not exist under the loaded position and in an area from each end of the bearing plate that is half of the specimen height. However it was difficult to select such clear specimens in this study. Therefore, in the case when a specimen contained a knot in one or more of these positions, the width and length of the knots were measured on each surface at these positions. After the test, a specimen for MC measurement was cut off near the failure position and MC was measured by the oven dry method.

2.3 Shear tests

The schematics of the three-point and five-point bending tests are shown in Fig. 3 and 4, respectively. A material testing machine with a capacity of 200kN (Tokyo Koki Co., Ltd.) was used for the loading and testing time was targeted to five minutes. In both bending methods, the shear span specified in ISO 13910 is three times as long as the depth of a specimen, but in this study, we adjusted it to two and a half times to increase the possibility of shear failure, referring to "Methods for testing the strength of structural timber" (AIJ, 2003).

After each testing, the failure load was measured and the shear strength (τ) was calculated. Failure modes (Shear: S;

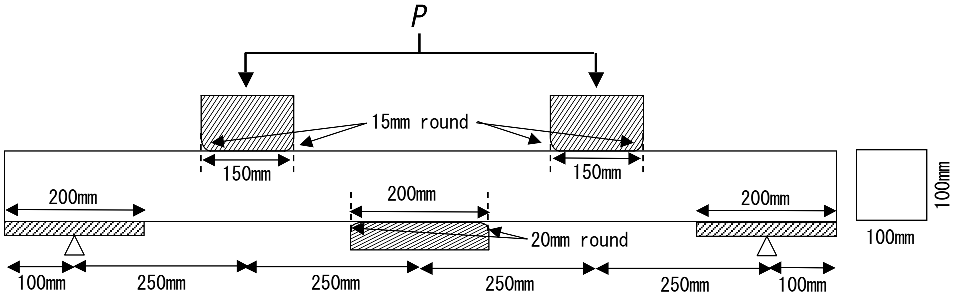

Fig. 4. Test scheme of the five-point bending method.

Bending: B; Combined shear and bending: S&B) were recorded. In the five-point bending method, initial shear failure was induced between the middle support and loading point; even after the initial shear failure, load did not decrease and eventually bending failure occurred. The load to induce initial shear failure was defined as the failure load in this test.

In the three-point and five-point bending methods, even if the specimen did not failed in shear, nominal shear strength was calculated from the failure load, because the ISO 13910 stipulated that "all test results shall be used to evaluate properties". The following equations were used for the calculation of shear strength in the three-point and five-point bending methods.

Three-point bending method: $$\tau = \frac{3P_{\mathrm{ult}}}{4A} \quad (1)$$

Five-point bending method: $$\tau = \frac{33P_{\mathrm{ult}}}{64A} \quad (2)$$

Where, P_{ult} is failure load and A is the cross section of a specimen.

In general, it is difficult to induce shear failure in all specimens by the three-point bending and five-point bending methods shown in ISO 13910 (Riyanto & Gupta, 1988; Nagao & Kato, 1988; HOWTEC, 1999; Ido *et al*., 2006). Thus, a full-scale block shear test using full-scale shear jigs (Ido *et al*., 2004a) was also carried out additionally.

Before the test, ρ and E_{fr} were measured in each shear method except for E_{fr} of the full-scale block specimens with a short length. After the test, specimen for a measurement of MC was taken near the failure position and MC was measured by the oven dry method.

3. Results and discussion

3.1 Test of compression perpendicular to the grain

The results of the test of compression strength perpendicular to the grain are shown in Table 2.

For the confirmation of the effects of knots on $f_{c,90}$, the knot area (π x radius of width x radius of length) was calculated from the measured width and length of the knots assumed to be elliptic. Then the relation between the sum of the area on four surfaces and the $f_{c,90}$ was examined. The coefficient of determination (R^2) was only 0.010, indicating that the knots had little effect on the compression strength.

3.2 Shear tests

The results of shear tests for the three-point bending, five-point bending and full-scale block tests are summarized in Table 3.

For the failure mode, the sum of the shear type (S) and combined type (S&B) was 23 pieces (46%) in the three-point bending, and nearly half of the specimens showed shear-related failure. On the other hand, the sum of types S and S&B was 34 pieces (68%) in the five-point bending test. This value was higher than that of three-point bending, but only a little over 30% of the specimens failed in bending.

For the shear strength, the mean value of five-point bending was the highest followed by full-scale block and three-point bending. It is noted in ISO 13910 that five-point bending tends to produce a higher bound to the shear strength than does three-point bending. The same tendency was found in this study. The mean value of shear strength of the full-scale block was between that of five-point and three-point bending. The shear strength increased as shear area decreased, but decreased with notching in block test specimens for stress concentration (Ido *et al*., 2006). These complex factors affected the full-scale block test.

Table 2. The results of the test of compression perpendicular to the grain.

	MC (%)	ρ (kg/m^3)	E_{fr} (kN/mm^2)	$f_{c,90}$ (N/mm^2)	$f_{c,90,y}$ (N/mm^2)	$K_{c,90}$ (N/mm^3)
No.	50	50	50	50	50	50
Mean	14.8	483	12.8	9.37	5.86	3.72
Max.	13.2	582	19.5	16.9	9.39	8.73
Min.	13.8	373	7.59	5.94	3.80	1.50
CV (%)	3.78	10.4	18.8	25.6	23.1	53.9

Symbols: MC: Moisture content; ρ: Density; E_{fr}; Young's modulus measured by longitudinal vibration method; $f_{c,90}$: Compression strength; $f_{c,90,y}$: Yield strength; and $K_{c,90}$: Compression perpendicular to the grain stiffness.

Table 3. The results of shear tests.

Three-point bending method.

	MC (%)	ρ (kg/m^3)	E_{fr} (kN/mm^2)	τ (N/mm^2)	Failure mode and number
No.	50	50	50	50	
Mean	13.9	489	12.2	6.25	B: 27 (54%)
Max.	15.0	587	18.4	9.75	S: 6 (12%)
Min.	12.6	387	7.21	3.76	S&B: 17 (34%)
CV (%)	3.70	10.3	17.7	18.0	

Five-point bending method.

	MC (%)	ρ (kg/m^3)	E_{fr} (kN/mm^2)	τ (N/mm^2)	Failure mode and number
No.	50	50	50	50	
Mean	15.2	489	12.4	8.22	B: 16 (32%)
Max.	16.4	588	20.2	10.3	S: 25 (50%)
Min.	14.2	363	6.68	6.09	S&B: 9 (18%)
CV (%)	3.27	10.1	19.4	12.2	

Full-scale block test method.

	MC (%)	ρ (kg/m^3)	τ (N/mm^2)
No.	50	50	50
Mean	13.5	477	7.49
Max.	14.9	595	11.1
Min.	11.8	370	5.00
CV (%)	4.91	10.9	15.3

Symbols: MC: Moisture content; ρ: Density; E_{fr}; Young's modulus measured by longitudinal vibration method; τ: Shear strength; B: Bending failure; S: Shear failure; S&B: Combined shear and bending failure.

3.3 Comparison between compression strength perpendicular to the grain and shear strength

It is well-known that compression strength perpendicular to the grain and shear strength are much more correlated with ρ than E_{fr} (Ido *et al*., 2004b; Ido *et al*., 2006; Morita *et al*., 2003). Therefore, by knowing the one strength, the other strength could be estimated through ρ, and that helps to fill the lack of strength data. The relationship between compression strength perpendicular to the grain ($f_{c,90}$) and shear strength (τ) with ρ and E_{fr} were shown in Fig. 5.

Both in $f_{c,90}$ and τ, R^2 with ρ was higher than with E_{fr} except for the three-point bending. In the three-point bending, more than half specimens failed in bending, and it probably caused higher correlation with E_{fr}. In the three kinds of shear tests, τ of the full-scale block showed the highest correlation with ρ , and it could be explained by the same reason because all specimens failed in shear for the shear block specimens naturally. These results reconfirmed that $f_{c,90}$ and τ were highly correlated with ρ. Therefore, by knowing ρ of specimens, it could estimate $f_{c,90}$ and τ to some extent.

Moreover, ρ of the specimens of the compression perpendicular to the grain and the shear were almost same because specimens were taken from the same lumber in this study, and $f_{c,90}$ and τ were compared in Fig. 6. Each regression lines were significant at the 1% level of significance, although R^2 was rather varied. Therefore, by knowing the one strength, the other strength could be estimated to some extent, and that helps to fill the lack of strength data of compression perpendicular to the grain or shear.

4. CONCLUSION

Tests of end-matched specimens of compression perpendicular to the grain and shear parallel to the grain of Western hemlock were carried out in accordance with ISO. As a result, characteristic strength values of both compression perpendicular to the grain and shear were more correlated with density than with Young's modulus by the longitudinal vibration method. Moreover, the regression lines between compression strength perpendicular to the grain and shear strength were significant at the 1% level of significance in end-matched specimens. Thus, it is possible to use density to estimate one strength from the other strength of a piece of timber. This result could help to fill the gaps in data on compression perpendicular to the grain and shear strength.

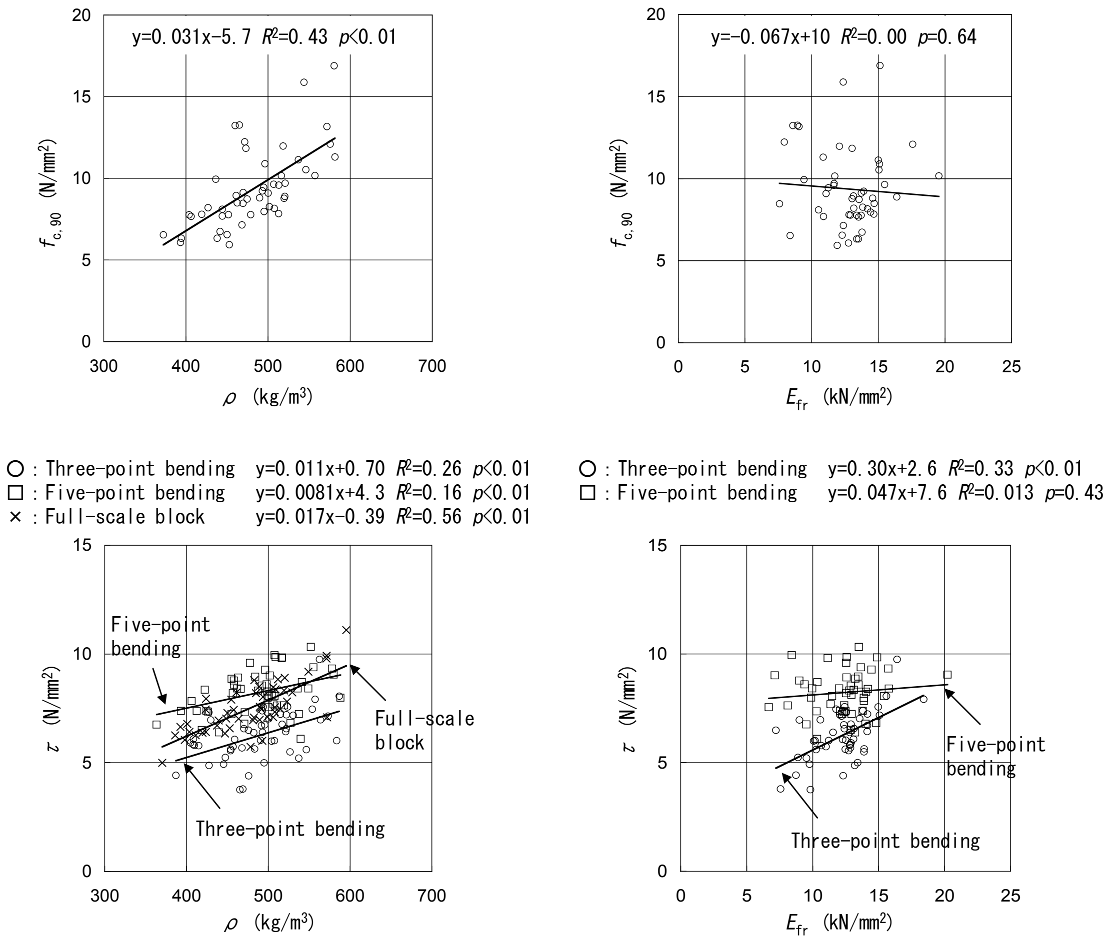

Fig. 5. Relationship between compression strength perpendicular to the grain($f_{c,90}$)and shear strength(τ) with ρ and E_{fr}.

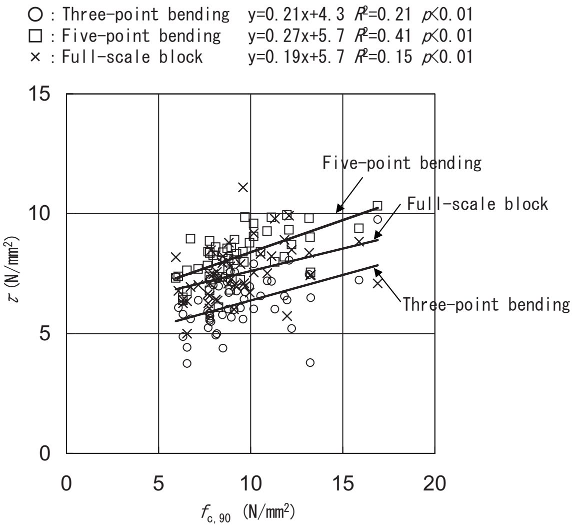

Fig. 6. Relationship between ($f_{c,90}$) and τ.

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ベイツガ製材品を用いためり込み・せん断強度の相対的比較

井道 裕史 [1)]、長尾 博文 [1)]、加藤 英雄 [1)]

要 旨

構造用製材の試験方法が、2005 年に国際規格 ISO 13910 として制定されるなど、実大材を対象とした強度試験方法が国際的に統一されつつある。しかしながら、実大材を用いためり込みおよびせん断強度データは、従来我が国で行われてきた試験方法と ISO 13910 とは異なるため、曲げ、縦圧縮、縦引張り強度に比べて非常に限られている。そこで、本研究では、ベイツガ製材品からエンドマッチでめり込み試験体とせん断試験体を採取して、新たに制定された ISO 13910 に従ってめり込みおよびせん断強度特性値を求めた。その結果、めり込みおよびせん断強度は縦振動法によるヤング係数よりも密度との相関が高いことを確認した。さらに、めり込み強度とせん断強度の間には有意水準 1%で相関があることがわかった。ゆえに、密度を用いることにより、一方の強度から他方の強度を推定できることがわかり、めり込みおよびせん断強度のデータ不足を埋める助けとなることを明らかにした。

キーワード：ベイツガ、めり込み強度、せん断強度、実大いす型せん断、ISO 13910

＊森林総合研究所構造利用研究領域 〒 305-8687 茨城県つくば市松の里 1 e-mail: ido@ffpri.affrc.go.jp
1) 森林総合研究所構造利用研究領域