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Effect of Test Zone Selection for Evaluating Bending Strength of Lumber*[1]

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ABSTRACT

This study investigated the effect of test zone selection for evaluating bending strength of visually graded lumber. This will contribute to the understanding of two different methods under different standards. In method Ⅰ, the major defect was randomly placed in the test specimen. In method Ⅱ, the major defect was randomly placed in the maximum moment zone (MMZ). The results showed that the method Ⅱ is more accurate for reflecting the effect of defects governing the grade of lumber. Unless the maximum strength-reducing defect (MSRD) is placed in MMZ, the evaluated value would be higher than that of MSRD. For evaluating the modulus of rupture (MOR) of visually graded lumber in test set-up of Method I, the Eq. (5) needs to be considered.

Keywords : modulus of rupture, bending strength, bending test, lumber, strength-reducing defect

1. INTRODUCTION

The exact structural strength of lumber must be known for it to be used efficiently in structural applications which directly affect life, safety, and protection of property. To determine these properties a representative sample has to be tested. As an international standard, ISO 13910 has been established for specifying sampling, full-size testing and evaluation procedures for assessing structural properties of sawn timber which must fit engineering design codes. However, different regions in the world have still different testing standards (Wang, *et al.*, 2005). To use lumber tested by different standards, the differences between testing procedures should be checked.

The maximum strength-reducing defect (MSRD) was located randomly in the maximum moment zone (MMZ) in In-grade testing program in North American (Evans *et al.,* 2001). ASTM D198 allows the test zone selection procedure to be varied depending on the purpose of test. Meanwhile, ISO 13910 and AS/NZS 4063 adopt a completely random selection approach and the test piece should be selected from random locations within a piece of timber.

The nonparametric tolerance limits, makes no

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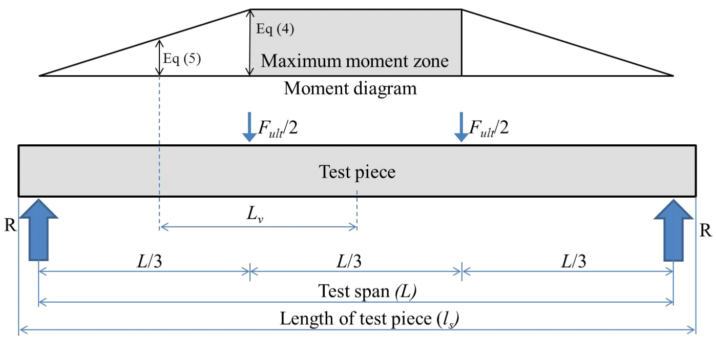


Fig. 1. Moment diagram with test set-up for measuring bending strength.

assumptions about the form of the underlying distribution, are based on the procedure by Wilks (1941) (Barrett *et al.,* 1994). ASTM D 2915 provides tables for determining associated order statistics as a function of sample size and significance level. In general, the 5th percentile nonparametric lower tolerance limit (the lower-5% NTL) with 75% confidence level was traditionally used for most wood and wood-based products (ASTM D2915). The North American In-grade testing program applied the lower-5% NTL with 75% confidence. AS/NZS 4063.2 provides 75% confidence level as well.

The objective of this study was to investigate and identify the more suitable test method for evaluating bending strength. Especially, this research was focused on the effect of test zone selection for determining the lower-5% NTL values.

2. MATERIALS and METHODS

2.1. Specimens

Two commercially important softwood species, Japanese larch (*Larix kaempferi* Carr.,), Korean pine (*Pinus koraiensis* Sieb. et Zucc.) in Gangwon Province were tested. After kiln drying, the surfaces were planed so that the final cross-sections were 38 × 140 mm, and the lengths were 3,000 mm. The moisture content of the specimens was approximately 15%.

2.2. Visual Grading and Test Zone Selection

Each specimen was visually graded by the KFRI notification 2009-01 and the grade of test pieces was determined by the maximum strength-reducing defect (MSRD). Thus, the MSRD was the major defect governing the grade of lumber. To investigate the effect of test zone selection, the MSRD was considered twice. At first, as the first test method (Method Ⅰ), a specimen was selected where the major defect governing the grade of lumber was randomly placed in the test piece. As the second test method (Method Ⅱ), the test specimen was visually graded again where the major defect governing the grade of lumber was randomly placed in the maximum moment zone (MMZ).

2.3. Experimental Procedures

Bending-strength measurements were done using a third-point bending test (Fig. 1) by a universal testing machine (Zwick GmbH & Co., Ltd., Ulm, Germany). The length of test piece (l_s) was 3,000 mm and the test span was 2,700 mm. The loading speed was 10 mm/min.

2.4. Lower 5th Percentile Strength

In accordance with ASTM D2915, the sample nonparametric 5th percentile point estimate (5% NPE) and the order statistic were used to estimate the 5th percentile nonparametric lower tolerance limit (the lower-5% NTL).

2.4.1. Nonparametric Point Estimate

The sample nonparametric 5th percentile point estimate (5% NPE) was interpolated from the samples. The test values were arranged in ascending order. Beginning with the lowest value, $i/(n+1)$ was calculated. The 5% NPE was interpolated by Eq. (1).

$$5\%\ \text{NPE} = \left[\frac{5}{100}(n+1) - (j-1)\right][x_j - x_{(j-1)}] + x_{(j-1)} \quad (1)$$

where,
n : total number of samples,
j : the lowest order of the test value when $i/(n+1) \geq 0.05$,
I : the order of the test value,
x_i : ith value

2.4.2. Nonparametric Lower Tolerance Limits

Nonparametric point estimates (NPE) of test samples are calculated to approximate true population percentiles. The estimate from a given sample should accurately represent the true population. In many situations, it is preferable to determine the interval within which one would expect to find the true value of the population. This interval is called an interval estimate. Tolerance limits are a kind of interval estimate, and when obtained using nonparametric procedures, they are called nonparametric lower tolerance limits (NTL) (Barrett *et al.*, 1994).

The 5th percentile nonparametric lower tolerance limit (the lower-5% NTL) was determined by m^{th} order statistic with the sample size at 75% confidence level. As the sample size increases, the tolerance limit is more likely to be close to the population value. Thus, it is desirable to select as large a sample size as possible after considering the cost of sampling and testing. For sample sizes that fall between the higher and lower sample sizes, interpolation was used to determine the lower-5% NTL by Eq. (2).

$$f_{0.05} = \left(\frac{\text{Sample size} - \text{Lower sample size}}{\text{Higher sample size} - \text{Lower sample size}}\right) \times (f_{above f_{0.05}} - f_{below f_{0.05}}) + f_{below f_{0.05}} \quad (2)$$

3. RESULTS and DISCUSSION

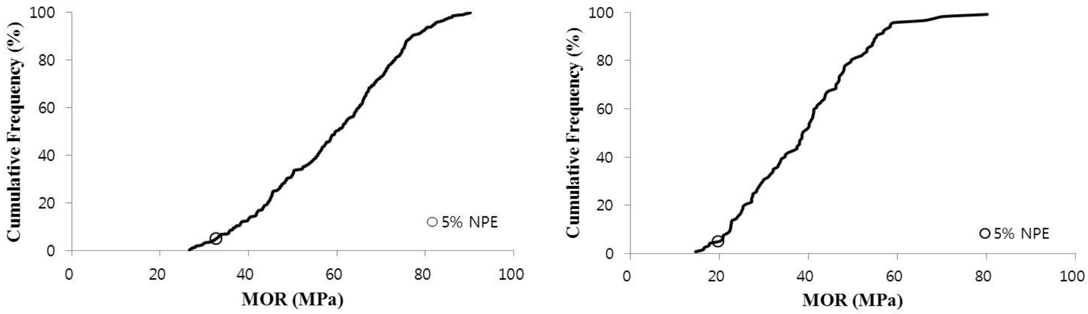
The sample sizes of No. 1 were the same from Method Ⅰ, the major defect governing the grade of lumber was randomly placed in the test piece, and Method Ⅱ, the major defect governing the grade of lumber was randomly placed in the maximum moment zone (MMZ) (Table 1), since the specimens which were No. 1 grade in test piece must be No. 1 grade in the MMZ (Fig. 1). In other words, if the maximum strength-reducing defect (MSRD) met the limits of No. 1 grade in test piece, other defects should meet the limits as well. Thus, the difference of the test zone selection was not investigated in No. 1 grade.

However, the sample sizes of No. 2 and No. 3 grades from Method Ⅱ were less than the sample sizes from Method Ⅰ. The different sample sizes were caused by the natural characteristics of lumber. It was difficult to place the MSRD in the middle of the lumber, because it was impossible to create artificially MSRD unlike artificial materials such as concrete and steel. Thus, the different sample sizes show that when the MSRD was placed in the test piece,

Table 1. Comparison of statistics by the different test zone selection

Species	Method Ⅰ					Method Ⅱ			
	Grade	Sample Size	MOR (MPa)			Sample Size	MOR (MPa)		
			Mean	5% NPE	5% NTL (75%)		Mean	5% NPE	5% NTL (75%)
Japanese larch	No.1	369	58.77	32.69	32.16	369	58.77	32.69	32.16
	No.2	279	46.67	22.65	22.05	111	44.03	20.12	19.26
	No.3	115	43.22	20.65	20.25	34	40.55	16.20	14.00
Korean pine	No.1	116	38.79	19.71	17.81	116	38.79	19.71	17.81
	No.2	230	28.29	13.76	13.31	104	24.19	11.49	10.24
	No.3	98	26.84	10.11	9.97	35	25.59	9.17	8.27

5% NPE = the nonparametric 5% point estimate
5% NTL (75%) = the 5^{th} percentile nonparametric lower tolerance limit with 75% confidence



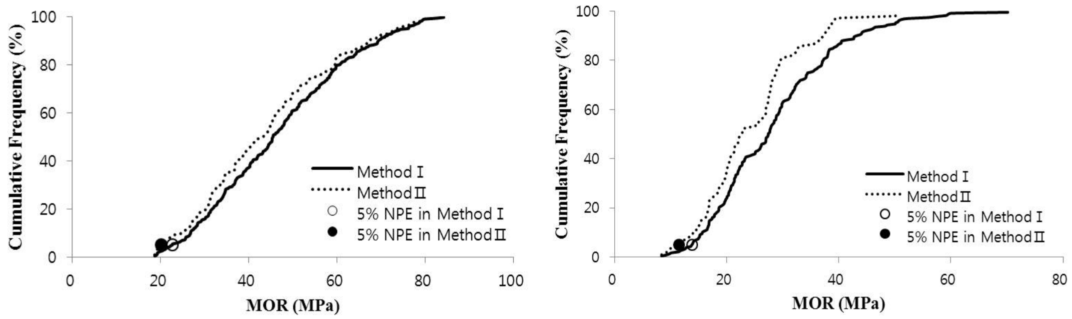
(a) Japanese larch (b) Korean pine

Fig. 2. Comparison of MOR cumulative probability distributions for No. 1 grade.

the sampling for the test set-up was much easier and economical than when the MSRD was within MMZ.

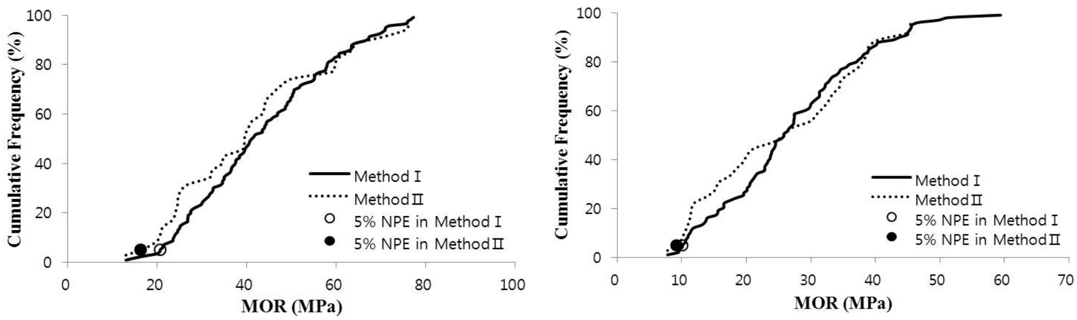
The MOR values were lower when the major defect governing the grade of lumber was placed in MMZ except for No. 1 grade. In the case of No. 1 grade, since the sample and sample sizes were same, the cumulative probability distributions (PDFs) of MOR overlapped (Fig. 2). In the case of No. 2 and No. 3 grades, however, the PDFs of MOR values from Method Ⅰ were located slightly to the right as shown in Figs. 3 and 4. In other words, MOR values were higher when the MSRD was randomly placed in the test piece.

The higher MOR values were caused by the failure that was occurred at not MSRD but another strength-reducing defect (SRD). When the MSRD placed out of MMZ and another SRD placed in MMZ, sometimes the failure was occurred in MMZ due to the SRD (Fig. 5). The different SRD has different strength ratio. Thus, when the MOR was determined by not MSRD but the smaller SRD, the tested specimens will



(a) Japanese larch (b) Korean pine

Fig. 3. Comparison of MOR cumulative probability distributions for No. 2 grade.



(a) Japanese larch (b) Korean pine

Fig. 4. Comparison of MOR cumulative probability distributions for No. 3 grade.

have higher MOR values than its own grade determined by MSRD.

Another reason, the differences of MOR by the test zone selections can be caused by the failure position and the calculation equation. The MOR values should be calculated with the maximum bending moment at the failure position from the following equations:

$$MOR = \frac{M_{\max} y}{I} = \frac{6M_{\max}}{bd^2} \quad (3)$$

$$M_{\max\ in\ MMZ} = \frac{F_{\max} L}{6} \quad (4)$$

$$M_{\max\ out\ of\ MMZ} = \frac{F_{\max}}{4}(L - 2L_v) \quad (5)$$

where,

M_{max}= maximum bending moment,

y = the distance from the neutral axis,

I = the moment of inertia of the cross section,

b = thickness of the test piece,

d = width of test piece,

F_{max}= the maximum load,

L = length of the test span,

L_v = the horizontal distance from the center of the test span to the point of failure ($Lv \geq$ L/6)

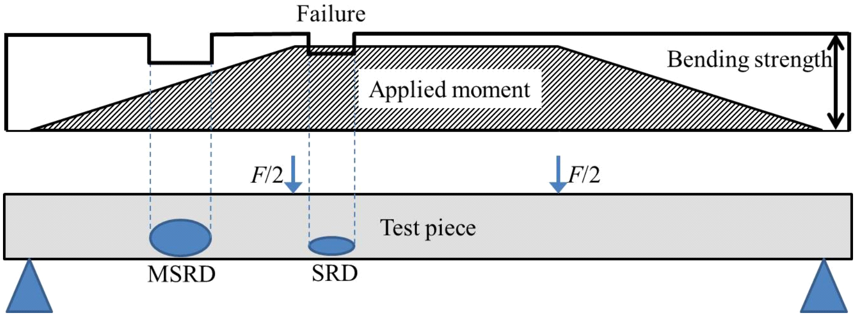


Fig. 5. An example for a failure at not MSRD but SRD.

Since wood is an inhomogeneous and anisotropic material, it is difficult to recognize the exact position of the failure in the tested piece the first time the failure occurred. Moreover, in the full-size bending test, sometimes the failure happened outside the maximum moment zone (MMZ). When the initial position of failure was not exactly investigated and failure was occurred outside the MMZ, it was difficult to calculate the exact MOR values. If the distance, L_v, was assumed with shorter length, the evaluated MOR value would be higher than that of MSRD.

In contrast, when the MSRD was placed in the MMZ, the failure occurred at MSRD in MMZ and the probability of being destroyed out of MMZ was reduced. In other words, more accurate MOR values were investigated with the initial position of failure. Thus, for calculating more accurate MOR reflecting the failure position, MSRD should be placed in MMZ.

For user convenience and to reduce calculation error, the standard needs to be described clearly. The accurate equations should be provided for users. In case of a homogeneous material or defect-free lumber, the failure will be occurred in the MMZ and the maximum bending moment for MOR shall be calculated from Eq. (4). However, lumber is inhomogeneous and the failure may happen outside the MMZ. In this case, since the failure position was not in MMZ, the maximum moment for MOR should be calculated from Eq. (5). If the failure is occurred at out of MMZ and the maximum moment is calculated with from Eq. (4), the calculated MOR value would be higher than that of MSRD. Except AS/NZS 4063.1, unfortunately, most of standards, KS F 2150, ASTM D198, ISO 13910, and EN 408 only provide one equation, Eq. (4), for calculating the bending moment, which calculates the exact MOR when the failure just occurred in MMZ. Thus, if the failure occurs at out of MMZ, the Eq. (5) needs to be considered.

4. CONCLUSIONS

In this study, the effect of test zone selection was investigated for evaluating bending strength of visually graded lumber. In method Ⅰ, the major defect was randomly placed in the test specimen. In method Ⅱ, the major defect was randomly placed in the maximum moment zone (MMZ). The results showed that the modulus of rupture (MOR) values by method Ⅰ were higher than by method Ⅱ. The reason is as follows:

1. In method Ⅰ, the failure of some specimens was occurred not at the maximum strength-reducing defect (MSRD) but at the smaller strength-reducing defect in the maximum mo-

ment zone (MMZ). It means that the bending strength of its own grade which had been determined by MSRD was not reflected. The evaluated value would be higher than that of MSRD.

2. In method Ⅰ, when the failure happened at MSRD which was out of MMZ, the MOR should be calculated by the Eq. (5). However, KS F 2150 only provide Eq. (4) for calculating the MOR. If the MOR is calculated by Eq. (4), when the failure occurred out of MMZ, the calculated MOR value would be higher than that of MSRD.

The method Ⅱ is more accurate for reflecting the effect of defects governing the grade of lumber. Unless the MSRD is placed in MMZ, the evaluated value would be higher than that of MSRD. For evaluating the MOR of visually graded lumber in test set-up of Method I, the Eq. (5) needs to be considered.

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