목재공학 21(4) : 55~59(原著)
Mokchae Konghak. 21(3) : 55~59. 1993

잣나무 間伐材의 機械的 性質에 對한 理論的 統計 分布 研究*1

車 在 卿*2

Study on Statistical Distributions for the Mechanical Properties of Thinning Crop-Trees from *Pinus koraiensis**1

Jae-Kyung Cha*2

要 約

한국의 중서부 지역에서 주로 벌채한 잣나무 간벌 제재목을 경기도 광주 소재 제재소에서 무작위로 추출하여 구입하였다. 본 연구는 휨강도 시험을 표준 시험 방법에 의하여 실시하였다. 각 무결점 시편으로 부터 측정한 영 계수와 휨 강도에 대하여 이론적 통계 분포인 정상 분포, Log-normal 분포, Weibull 분포를 계산하여 비교하였다. Weibull 분포가 휨영계수 및 휨강도 모두에 적합하였으며, Log-normal 분포는 영계수 분포에 대한 이용에 적합하였다. 휨강도 분포에서는 Normal 분포가 Log-normal 분포보다 적합하다.

Keywords : Normal distribution, Log-normal distribution, Weibull distribution, MOE, MOR, bending

1. INTRODUCTION

Effort is being directed towards economically efficient use of our supply with the increased demands on timber resources of the world. Several studies[1-3] has been conducted to find precise design procedures for residential home construction. If a design model can be derived for any species, grade, and any type of construction, much expensive full-scale testing can be eliminated. Recent design procedures for timber require only the characterization of near minimum properties. However, this information will not be sufficient for newer reliablity-based design procedures, which will require distributional data for the strength properties of wood.

Information on thinning crop-trees from Pinus Koraiensis used in this study was developed to furnish data need to implement the design method for residential home construction. Only small samples of bending strength data are available from several studies of *Pinus koraiensis*[4,5]. Although the data from those study was useful, it was inadequate to meet the present need for accurate characterization of bending strength distribution. Thus, it was important to collect and evaluate a large sample of clear specimen.

Accurate and reliable bending strength distributional characteristics for small clear specimens are also needed to provide a base-

*1 接受 1993年 9月 10日 Received September 10, 1993
*2 國民大學校 林業大學 College of Forestry, Kukmin University, Seoul 136-702, Korea

line for determining the acceptance of alternate products. Therefore, the purpose of this study was to evaluate bending strength distributional properties of the most important thinning crop-trees for Pinus Koraiensis from small clear pecimen.

2. MATERIALS & METHOD

Two hundred fifty of green, rough-sawn lumber(4.0 cm × 4.0 cm × 50 cm) for *Pinus koraiensis* were collected from Kwang-ju(Kyungki province) mill to allow for surfaching. Each piece was selected on its suitability to furnish an 3 cm × 3 cm × 48 cm. All samples were selected green and the kiln dried to about 12 % moisture content prior to test at the Korean forest product laboratory. After kiln drying, the lumber were surfaced four sides to 3 cm × 3 cm × 48 cm. To avoid degradation or collapse, a relatively mild schedule was followed. The samples were dried at the dry bulb temperature 20° and 3℃ depression.

All small clear specimens were tested in static bending by centerpoint loading. Forces were applied by Instron using the crosshead speed of 5 mm/min. until failure. The load-displacement was continuously recorded on the personal computer. The data were also used to compute modulus of elasticity(MOE) and bending strength(MOR) by personal computer. After the small clear samples were broken, specific gravity and moisture content coupon were cut from the end of each bending sample.

3. RESULTS & DISCUSSION

3. 1 Statistical analysis

The probability of density functions used in this study has the following forms :

$$f(x)=\frac{-1}{s\sqrt{2\pi}}\exp\left[\frac{1}{2}\left(\frac{x-\mu}{s}\right)^2\right]\cdots\cdots(1)$$

$$f(x)=\frac{1}{(x-\alpha)\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{\ln(x-\alpha)-\theta}{\sigma}\right)^2\right]\cdots(2)$$

$$f(x)=\frac{\gamma}{\beta}\left[\frac{(x-\alpha)}{\beta}\right]^{\gamma-1}\exp\left\{-\left[\frac{(x-\alpha)}{\beta}\right]^{\gamma}\right\}\cdots\cdots(3)$$

where α : location parameter
β : scale parameter
γ : shape parameter
x : random variable($x > \alpha$)
s : standard deviation of x
σ : standard deviation of $Ln(x-\alpha)$
μ : mean of x
θ : mean of $Ln(x-\alpha)$

Estimates on the normal distribution of Eg.(1), the parameter Lognormal distribution of Eg.(2), and the three parameter Weibull distribution of Eg.(3) were conducted. The computer program by Pearson[5] was used to obtain the estimates of the parameters and the observed and predicted frequencies in the intervals into which range of the observations was divided. Except for the normal distributions, two distributions were used the three lower bounds given in Table 1.

Lower bound α for Weibull distribution was assumed to be zero. The Weibull location parmeter α was also thought of as the smallest value in the population and thus should be between 0 and minimum obs- erved values. The location parameter was arbitrarily set equal to approximately one-half of the minimum observed value in this study. An alternative approach was also used, in which α was set to equal the smallest value of the productivity class that was one class lower than the one that contained the minimum value. The Log-normal location parameter α was also used as the same values of three Weibull location parameters, α.

The mean, variance, and minimum observed value were calculated from the raw productivity data. The mean and standard deviations of the observed values, and of the natural logarithms of the observed values minus location parameters, were the parameters for the normal and Lognormal distributions, respectively. Maximum likelihood estimates were obtained for the shape parameter γ of the Weibull distribution, and then of the scale parameter β using that estimate of γ. An iterative scheme solved a set of simultaneous non-linear equations with the aid of

Table 1. Three parameters of Log-normal and Weibull distributions for MOE and MOR data of small clear specimen from *Pinus koraiensis*.

Location parameter(α)	MOE(1000 kg/cm^2)			MOR(kg/cm^2)		
	0	28	40	0	200	400
		Weibull				
scale parameter(β)	84.264	56.021	43.089	703.739	501.649	295.692
shape parameter(γ)	9.626	6.402	4.980	8.772	6.163	3.418
		Log-normal				
mean of Ln(x−α)	4.379	3.941	3.668	6.492	6.124	5.510
standard deviation of Ln(x−α)	0.115	0.182	0.247	0.138	0.203	0.420

the IMSL subroutine ZSYSTEM[6] to obtain maximum likelihood estimates of the parameters. Table 1 shows the three parameters of Log-normal and Weibull distributions to calculate the probability of these density functions.

3. 2 Comparison of distributional characteristics for fitting mechanical properties

Average bending strength and MOE are given in Table 2 with standard deviations and the range of test values. MOE and bending strength(MOR) were 19 % and 14 % lower than those of former research[5], respectively. The former research was used the mature wood.

Table 2. Summary of small clear bending specimen properties of thinning crop-trees from *Pinus koraiensis*.

Property	Specific gravity	Modulus of elasticity (1000 kg/cm^2)	Modulus of rupture (kg/cm^2)
mean	0.443	80.29	665.70
standard deviation	0.040	8.99	88.31
maximum value	0.528	109.68	837.00
minimum value	0.360	52.86	437.00

The five test statistics are used to compare the goodness of fits of the three dis- tributions for MOE data. They are absolute deviation, chi-square, Kolmogorov-Smirnov, Cramer-Von Mises-Smirnov and log-likelihood statistics. The comparison of goodness of fits of distributions for fitting the data is given in Table 3 for MOE data. The smaller the value the better the fit. The rank of distributions is given in parenthesis. Except for log likelihood statistics, Log-normal and Weibull distributions are better than normal distribution for MOE data. The differences between Log normal and Weibull statistics were very small in this case. A similar goodness of fits was observed for the bending strength given in Table 4. Weibull distribution gave the best fit according to the five statistics of the three distributions. The Log-normal distribution did not fit any of the bending strength distributions well.

The effect of location parameters was also given at Tables 3 and 4 for MOE and MOR data, respectively. One class lower value than the one contained the minimum values(α=4,000 kg/cm^2) was best fit for Weibull distribution of MOE data. However, the one-half of the minimum observed(α=28,000 kg/cm^2) gave best fit for Lognormal distributions of MOE data. The one-half of the minimum observed values(α=200 kg/cm^2) shawed best fit for Weibull distribution of bending strength data. Log-normal distribution of bending strength was best fit at zero location parameter.

Figures 1 and 2 provide a visual comparison of the cumulative frequency distribution of MOE and MOR data with the cumulative frequency distributions of higher ranked theoretical distributions for Log-normal and Weibull distributions given in Tables 2 and 3. Figures 1 and 2 also shows that the Weibull distribution gave the best fit to the MOE and MOR data.

Table 3. Goodness of fits of distribution for modulus of elasticity. (unit : 1000 kg /cm²)

Location parameter(α)	Normal	Log-normal			Weibull		
		0	28	40	0	28	40
Absolute deviation	55.191	37.231	31.708	35.772	41.554	36.135	31.297
	(7)*	(5)	(2)	(3)	(6)	(4)	(1)
Chi-square	17.334	8.807	8.313	10.243	14.183	10.193	7.450
	(7)	(3)	(2)	(5)	(6)	(4)	(1)
Kolmogrov Smirnov	0.128	0.043	0.042	0.053	0.062	0.054	0.048
	(7)	(2)	(1)	(4)	(6)	(5)	(3)
Cramer-Von Mises-Smirnov	0.938	0.148	0.104	0.192	0.297	0.202	0.141
	(7)	(3)	(1)	(4)	(6)	(5)	(2)
log likelihood	−795.27	−799.17	−804.23	−811.72	−801.26	−797.93	−796.23
	(1)	(4)	(6)	(7)	(5)	(3)	(2)

* Rank of distribution

Table 4. Goodness of fits of distribution for bending strength. (unit : kg /cm²)

Location parameter(α)	Normal	Log-normal			Weibull		
		0	200	400	0	200	400
Absolute deviation	33.016	48.502	56.041	85.546	32.879	28.709	32.200
	(4)*	(5)	(6)	(7)	(3)	(1)	(2)
Chi-square	8.191	13.854	18.224	43.370	8.105	7.265	8.740
	(3)	(5)	(6)	(7)	(2)	(1)	(4)
Kolmogrov Smirnov	0.062	0.088	0.101	0.147	0.034	0.030	0.042
	(4)	(5)	(6)	(7)	(2)	(1)	(3)
Cramer-Von Mises-Smirnov	0.270	0.490	0.653	1.564	0.058	0.035	0.116
	(4)	(5)	(6)	(7)	(2)	(1)	(3)
log likelihood	−1297.94	−1304.11	−1308.56	−1333.57	−1295.38	−1294.45	−1296.70
	(4)	(5)	(6)	(7)	(2)	(1)	(3)

* Rank of distribution

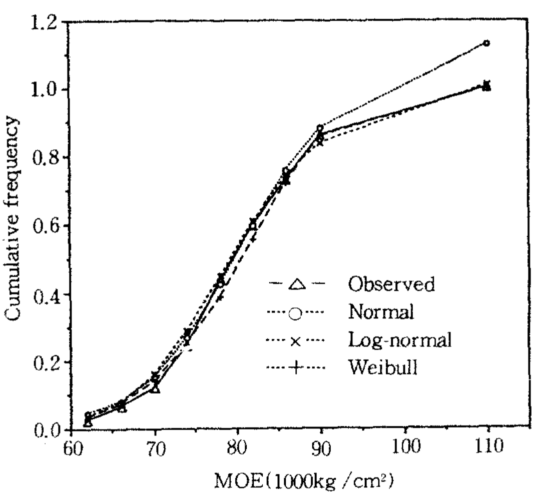

Fig. 1. Comparison of fits of cumulative distributions for MOE of 220 pieces of small clear bending specimen.(location parameter α : 28,000 kg /cm² for Log-normal and 40,000 kg /cm² for Weibull)

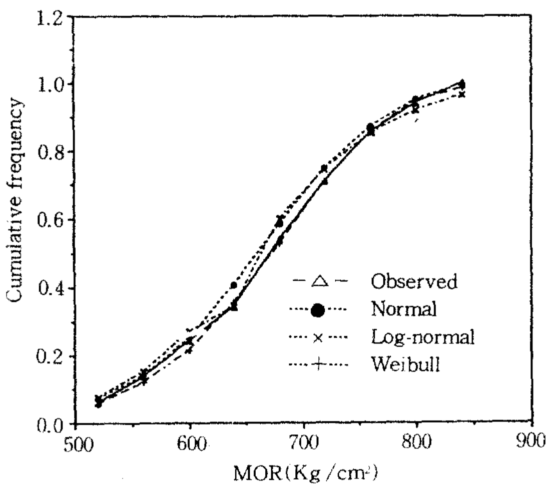

Fig. 2. Comparison of fits of cumulative distributions for MOE of 220 pieces of small clear bending specimen.(location parameter α : 0 kg /cm² for Log-normal and 200 kg /cm² for Weibull)

4. CONCLUSION

This study evaluates the statistical distributions on bending strength and modulus of elasticity. Three theoretical distributions were fitted to the abovementioned type of data for small clear specimens, but generally there was a statistically significant differences between the observed and theoretical distributions. However, the Weibull distribution for both data and the Log-normal distribution for MOE data fitted closely enough to be practical use.

REFERENCES

1. McLain, T. E. & F. E. Woeste. 1986. Rate of loading adjustment for proof testing of lumber in tension. *Forest Prod. J.* 36(9) : 51－54
2. O'Halloran, M. R. 1988. Considerations of reliability-based design for structural composite products. *Forest Prod. J.* 38(4) : 35－43
3. Thurmond, M. B. 1984. Roof loads for reliability analysis of lumber properties data *Forest Prod. J.* 16(2) : 278－297
4. 박문재, 이춘택. 1989. 낙엽송과 잣나무 간벌실대재의 구조 재료 평가. 임업연구원 연구보고 제39호 : 41－48
5. 심종섭, 조재명, 강선구, 안정모, 이찬호, 조남석, 정희석. 1975. 소나무속의 재질평가. 임업연구원 연구보고 제22호 : 71－84
6. Pearson, R. G. 1980. Potential of the Sb & Sbb distributions for describing mechanical properties of lumber. *Wood & Fiber Science* 12(4) : 244－254
7. Galligan, W. L & D. W. Green. 1980. Development of standardized concepts for assignment and assessment of the mechanical properties. *Forest Prod. J.* 30(9) : 39－46
8. Gerhards, C. C. & C. L. Link. 1987. A cumulative damage model to predict load duration characteristics of lumber. *Wood and Fiber Science* 19(2) : 147－164
9. Hawkins. K. E., J. E. Hotvedt, Q. C. Cao & B. D. Jackson. 1988. Using the Weibull distribution ot model harvesting machine productivity. *Forest Prod. J.* 38(4) : 59－65
10. Mark. C. M. & J. W. Evans. 1986. Tensile strenght of AITC 302－24 grade tension lamination. *Forest Prod. J.* 36(1) : 13－19
11. Mark. C. M. 1988. Tensile strength of laminating grades of lumber. *Forest Prod. J.* 38(7/8) : 6－14
12. Tang, Yifu & R. G. Pearson. 1992. Effect of Juvenile wood and choice of parametric property distributions on reliability-based beam design. *Wood and Fiber Science* 24(2) : 216－224
13. Taylor, S. E., Bender, D. A., D. E. Kline & Karen S. Kline. 1992. Comparing length effect models for lumber tensile strength. *Forest Prod. J.* 42(2) : 23－30