Transactions of the Materials Research Society of Japan 29[5] 2439-2442 (2004)

Preservation of Aged Wood Structures by the Determination of Strength Properties of In-Place Lumbers by a Non-Destructive Test Method

Grahme T. Williams and Jai B. Kim
Department of Civil & Environmental Engineering, Bucknell University, U.S.A

It is important to be able to determine the modulus of elasticity (MOE) and flexural strength or modulus of rupture (MOR) of in-place wooden members to predict the load carrying capacity of existing structures. This study was conducted to relate non-destructive stress wave results to the static MOE and MOR values of 2 in x 4 in x 8 ft long Spruce-Pine-Fir (SPF) No. 1 Grade lumbers. With the results from this study, it is expected that non-destructive tests conducted on existing structures of similar grade SPF lumber will yield the MOE and MOR values of the existing structural members for the determination of load carrying capacity.
Keywords: Aged wood Structures, In-Place Lumber Properties, Non-Destructive Test Method

1 INTRODUCTION:

The purpose of this project was to further the research for the correlation of nondestructive evaluation (NDE) techniques and physical properties of lumber. To achieve this, 160 visually graded, SPF No.1, 2 in x 4 in x 8 ft long specimens were first tested with a stress wave timer in the Bucknell University Structural Testing Laboratory. The initial 60 specimens were tested by a graduate student, with the other 100 specimens tested by two undergraduate students. The tests yielded a dynamic modulus of elasticity (MOE_d) based on the stress wave time measurements for each specimen. Destructive bending tests were then performed to determine the static modulus of elasticity (MOE) and rupture (MOR). It was the intent of this research to provide a relationship between MOE_d and the MOE and MOR values. All but five of these 160 specimens had moisture contents of 19% or less, with the lowest recorded value of 8.5%.

2 BACKGROUND:

The ability of determining the properties of in-situ structural members is paramount in the analysis of any existing structure. There are numerous wooden structures in existence with unknown ages and wood type that have experienced varying weathering and loading conditions throughout their lifecycle. Due to the impossibility of removing members and testing them in a laboratory environment, it is essential for a nondestructive testing technique to be developed that has the ability to predict the strength and stiffness properties of the existing structures.

Stress wave theories allow the determination of dynamic MOE_d. Equation 1 shows that the square of the velocity, v, of a stress wave propagating through a material multiplied by the density, □, of the material and then divided by the gravitational constant, g_c, will yield the dynamic MOE_d.

$$MOE_d = \frac{\rho \cdot v^2}{g_c} \qquad \text{Equation 1}$$

Several variables are known to affect the manner in which stress waves propagate through wooden members. Some of these include density of the material, orientation of stress wave propagation with respect to cell structure and grain alignment, grain characteristics dependent on species, flaws such as knots and checks, and moisture content.

In order to relate the dynamic MOE_d to the static MOE, destructive bending tests were performed in accordance with ASTM D 198 – 99 Standard Test Methods of Static Tests of Lumber in Structural Sizes.

Using ultimate bending load data it is possible to calculate the MOR of each test specimen.

3 TESTING;

3.1 NDE Tests using the Metriguard Model 239A Stress Wave Timer

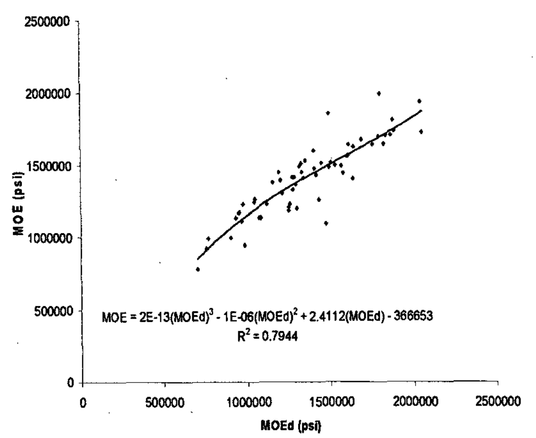

Figure 1: MOE vs MOE_d (Initial 60 specimens)

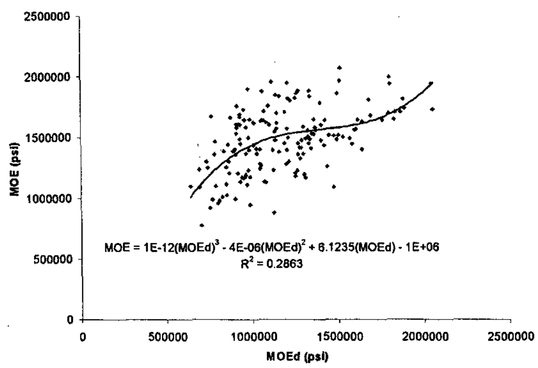

Figure 2: MOE vs MOE_d (Entire 160 specimens including initial 60)

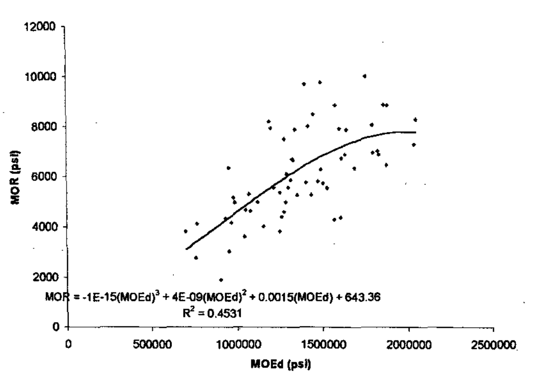

Figure 3: MOR vs MOEd (Initial 60 specimens)

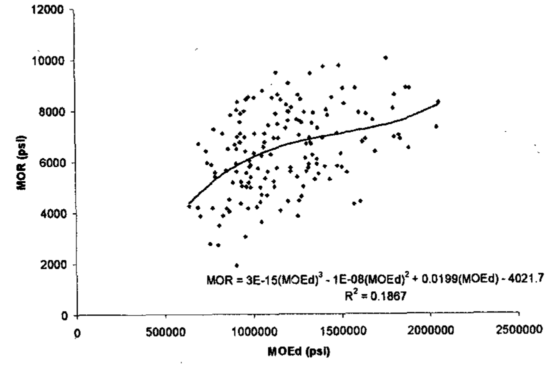

Figure 4: MOR vs MOEd (Entire 160 specimens – including initial 60)

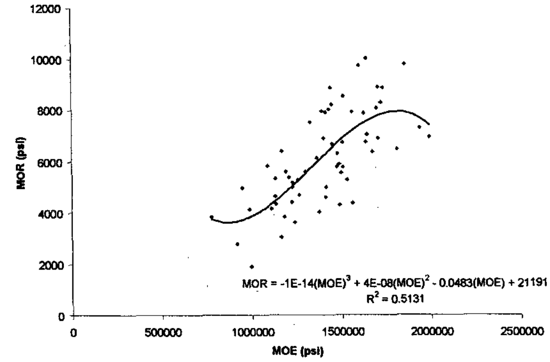

Figure 5: MOR vs MOE (Initial 60 specimens)

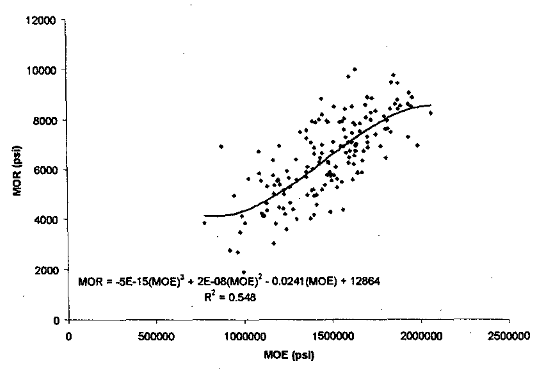

Figure 6: MOR vs MOE (Entire 160 specimens – including initial 60)

The SPF No. 1 grade 2 in x 4 in x 8 ft (test span of 84 in) dimensional lumber samples were evaluated using the stress wave timer initially. Both ends of each member were simply supported minimizing bearing resistance and keeping contact away from the faces surface waves would be traveling along. All four faces were tested as well as end to end and the wave times were averaged based on distance traveled to calculate an average time required for propagation.

3.2 STATIC BENDING TEST TO FAILURE:

Destructive bending tests were run on all 160 specimens using a test span length of 7 ft.

4 RESULTS:

To compare the stress wave results with those of the destructive bending tests, the following figures were created. These graphs show the relationship between the two sets of tests (initial 60 by a graduate student and 100 by two undergraduate students) and provide mathematical relationships between the two different modes of testing for the two sets of tests.

Figures 1 and 2 show the relationship between MOE and MOE_d, Figures 3 and 4 show the relationship between MOR and MOE_d, and Figures 5 and 6 relate MOR and MOE.

It is noted that correlation coefficients for two sets of tests, i.e. initial 60 specimens by a graduate student and 100 specimens by two undergraduate students, are different. Differences may be attributed to sources of lumber and also testing variations between the two groups.

Through the use of a statistical software, SPSS, data for the prediction of the modulus of rupture for the all 160 samples was analyzed. A histogram was also created to show what values were achieved and how often. The results of this analysis yield

Table 1

T-Test	N	Mean (psi)	Standard Deviation (psi)	5% Exclusion Value (psi)	95% Confidence Interval (psi)	
					Lower	Upper
MOR	160	6420.1	1615.7	3762.3	6167.8	6672.4

5 MOR vs MOEd with 5% Exclusion Limit

It is determined that data compiled by a graduate student for the initial 60 specimens (Figures 1, 3, and 5) are a better representation of the prediction of MOE vs MOE_d, MOR vs MOE_d, and MOR vs MOE relationships. The relationship between MOR_{MEAN} and $MOE_{d\,MEAN}$ is assumed to follow the MOR vs MOEd relationship shown in Figure 3.

$$MOR_{MEAN} = -1E^{-15}(MOE_{d\,MEAN})^3 + 4E^{-9}(MOE_{d\,MEAN})^2 + 0.0015(MOE_{d\,MEAN}) + 643.36 \quad \text{Equation 2}$$

Assuming the data for MOR fit a statistically normal distribution curve; a 5% exclusion value can be calculated using Equation 3. Using the equation for the best fit of the data comparing MOR to MOE_d for the 60 specimens and

the calculations using SPSS it is possible to calculate a 5% exclusion value using Equation 2 as follows:

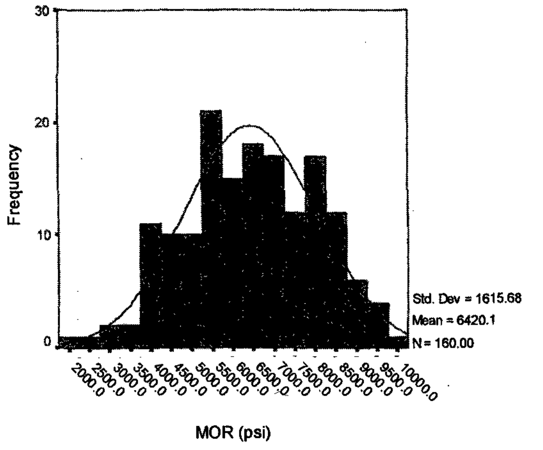

Figure 7 Histogram

$$MOR_{5\%\,EX} = MOR_{MEAN} - 1.645(\sigma) \quad \text{Equation 3}$$

$$MOR_{5\%\,EX} = -1E^{-15}(MOE_{d\,MEAN})^3 + 4E^{-9}(MOE_{d\,MEAN})^2 + 0.0015(MOE_{d\,MEAN}) + 643.36 - 1.645(1615.7)$$

$$MOR_{5\%\,EX} = -1E^{-15}(MOE_{d\,MEAN})^3 + 4E^{-9}(MOE_{d\,MEAN})^2 + 0.0015(MOE_{d\,MEAN}) - 2014$$

6 NUMERICAL EXAMPLE

Based on the stress wave measurements on a wooden member, $MOE_{d\,MEAN}$ is calculated and assumed to be 1,268,035. Substituting this $MOE_{d\,MEAN}$ value into Equation 3, the MOR at five percent exclusion limit, $MOR_{5\%\,EX}$, is:

$$MOR_{5\%\,EX} = -1E^{-15}(1{,}268{,}035)^3 + 4E^{-9}(1{,}268{,}035)^2 + 0.0015(1{,}268{,}035) - 2014$$

$$MOR_{5\%\,EX} = 4280.8 \text{ psi}$$

It is useful to determine similar base design values to the National Design Specifications (NDS) values for visually graded lumber based on the testing environment. NDS Base Design Bending Stress,

$$Fb = \frac{MOR_{5\%Ex}}{F.S. \cdot C_D \cdot C_F} \qquad \text{Equation 4}$$

Where: F.S. = factor of safety, 1.3, C_D = load duration factor, 1.7 for test duration time C_F = size factor, 1.5 based on dimensions of members

Substituting into Equation 4, the base design bending stress is determined:

$$Fb = \frac{4280.8\,psi}{(1.3)\cdot(1.7)\cdot(1.5)} = 1291 \text{ psi}$$

7 CONCLUSIONS:

It has been shown that non-destructive analysis methods can be used to predict design flexural strength values similar to those in the National Design Specifications published by American Forest & Paper Association and the American Wood Council.

Although this research was conducted on 2 in x 4 in x 8 ft Spruce Pine Fir Grade 1 dimensioned lumbers, similar research should be performed on various species, grades, and sizes in the future in order to create a database to predict design flexural strengths for other cases.

It is noted that mean flexural strengths (MOR_{MEAN}) from the 160 specimens were in the range of 6420 psi and these values must be reduced for base design flexural strengths, i.e. 1291 psi, considering test specific conditions such as moisture content, size, species, load duration time, and factor of safety.

ACKNOWLEDGEMENTS

The Authors acknowledge the assistance of the following individuals for this research:

Dr. Carmen Acuna, David W. Green, Jim Gutelius, Jr., Dr. Robert H. Kim, John Henning, Erika Reed, Robert Renn, and Bill & Katrina Williams

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(Received October 11, 2003; Accepted December 11, 2003)