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Relationship Between Stress Wave Transmission Time and Compressive Properties of Timbers Removed From Service

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Abstract

Stress wave nondestructive evaluation (NDE) techniques are used in the inspection of timber structures and frequently are included as a complement to visual inspection procedures. Inspectors use stress wave NDE techniques to locate internal voids and decayed or deteriorated areas in large timbers. Although these techniques have proven useful in inspections, little information exists concerning the relationship between stress wave parameters and important residual strength properties of large timbers. We examined the relationship between stress wave transmission time and the residual strength of large timbers obtained from two different structures. Stress wave transmission time, perpendicular to grain, was measured at several locations on each timber. Static compression tests, both parallel and perpendicular to grain, were then performed. A strong relationship was found between stress wave transmission time and residual strength in compression parallel and perpendicular to grain.

Keywords: nondestructive testing, column, compression, inspection

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Relationship Between Stress Wave Transmission Time and Compressive Properties of Timbers Removed From Service

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Introduction

The degradation of a wood load-bearing (in-service) member may be caused by any one of several organisms that derive their nourishment or shelter from the wood substrate in which they live. In addition, thermal degradation may weaken a member. Therefore, it is important to periodically examine wood structural components to determine the extent of degradation so that degraded members may be replaced or reinforced to avoid structural failure.

Stress wave nondestructive evaluation (NDE) techniques are used in such examinations, often as a complement to visual inspection procedures (Ross and Pellerin 1994). Stress wave NDE techniques are used to locate internal voids and decayed or deteriorated areas in large timbers. Although professional inspectors have found these techniques useful, little information exists on the relationship between stress wave parameters and important residual strength properties of large timbers.

In a study on the use of ultrasonic NDE technologies for inspection of timber pilings, Aggour (1989) found a useful working relationship between sound transmission times (perpendicular to grain) and compressive strength (parallel to grain) of piles. The most systematic investigation on the use of stress wave NDE techniques to estimate the residual strength of wood was conducted by Pellerin and others (1985). These researchers focused on speed of stress wave transmission and found a useful correlative relationship with the parallel-to-grain compressive strength of wood attacked by brown-rot fungi. A relationship between the longitudinal speed of stress wave transmission and compressive strength was not found in members attacked by termites. Termites attack earlywood but not latewood, which is still able to transmit a longitudinal stress wave.

A more recent study (Ross and others 1997) examined the relationship between stress wave speed and attenuation and parallel-to-grain compressive strength of biologically degraded wood. Speed of stress wave transmission and attenuation characteristics of clear wood specimens exposed to decay fungi and termites under field conditions were determined. These nondestructive parameters were then incorporated into a multivariable regression model and used to predict parallel-to-grain compressive strength of the specimens. Excellent agreement was found between predicted and actual compressive strength values.

Based on the encouraging results from these studies and the significant use of stress wave NDE for inspection of timbers, we designed a pilot study to examine the relationship between stress wave transmission times and residual compressive strength of timbers. Large timbers were examined instead of the small clear wood specimens used in laboratory investigations.

Materials and Methods

A schematic diagram of the study protocol is shown in Figure 1. Background information for the timbers, including species, size, and source, is summarized in Table 1. A commercially available stress wave timing unit was used to measure stress wave transmission time, perpendicular to grain, at various points along each specimen. The test setup is described in detail in Ross and others (1999). A stress wave was induced by striking a specimen with a hammer instrumented with an accelerometer that emits a start signal to a timer. A second accelerometer, which was held in contact with the opposite side of the specimen, sensed the leading edge of the propagating stress wave and sent a stop signal to the timer. The elapsed time for the stress wave to propagate between the accelerometers was displayed on the timer.

Static compression tests were conducted on the specimens. The Douglas-fir specimens, which were used as columns in service, were tested to failure in compression parallel to grain. Maximum load carrying capacity was compared to maximum (longest) stress wave transmission time. Load at failure was used because some specimens were deteriorated and because design values for timbers are frequently reported as loads rather than stresses. Maximum stress wave transmission time was used because we believe this corresponds to the weakest section of the member. The eastern white pine specimens were tested to failure in compression perpendicular to grain. Maximum stress in compression perpendicular to grain was compared to average stress wave transmission time.

Results and Discussion

Results of compression tests on Douglas-fir specimens are shown in Table 2 and Figure 2. In general, long transmission times were found in specimens with low load carrying capacity. Stress wave transmission times and corresponding strength (compression perpendicular to grain) values for eastern white pine specimens are shown in Table 3 and Figure 3. As for the Douglas-fir specimens, eastern white pine specimens with low strength values had long transmission times.

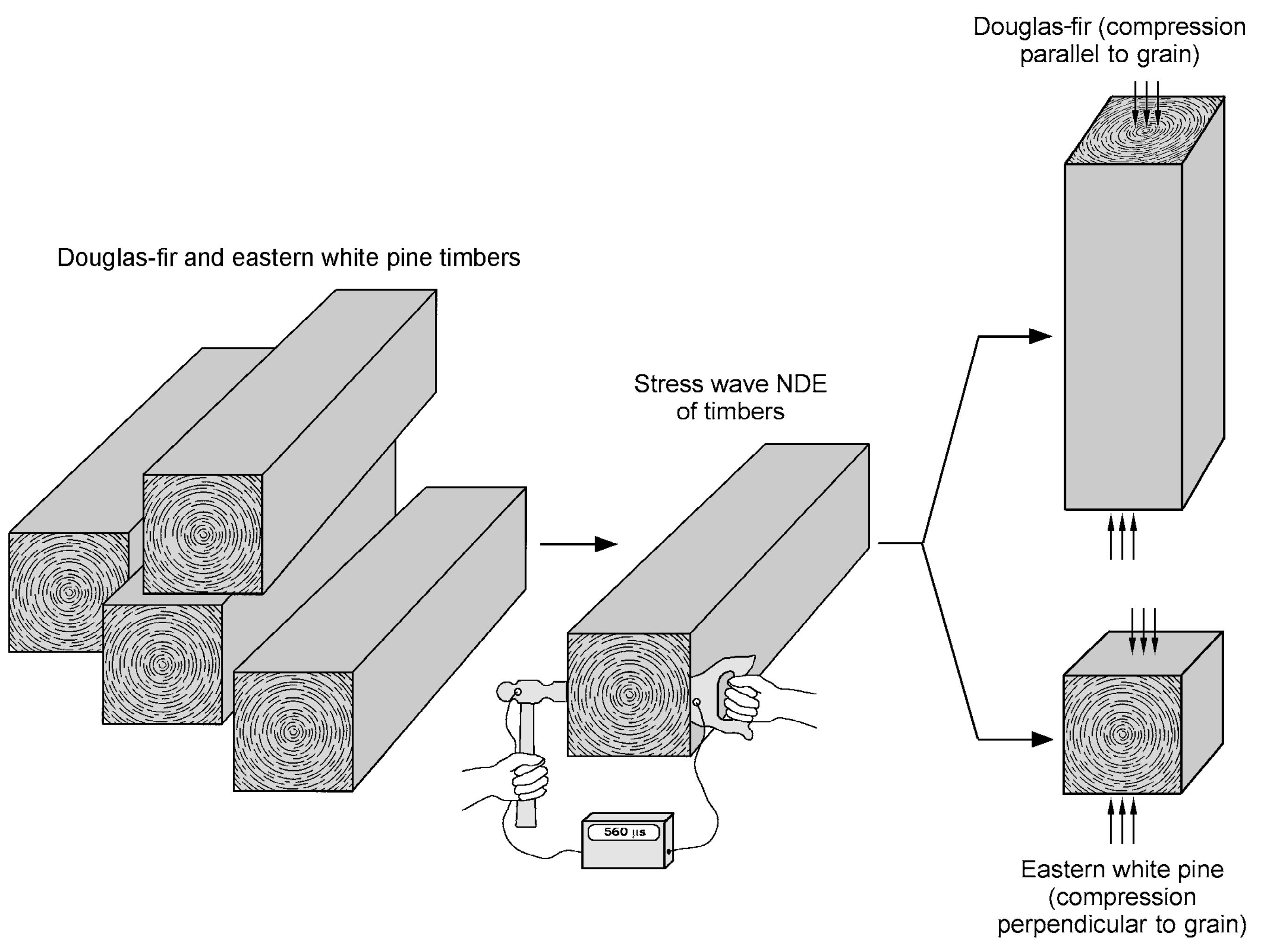

Figure 1—Schematic of study protocol.

Table 1—Description of study timbers

Species	Cross-sectional dimensions[a] (in.)	Preser-vative treatment	Previous use[b]	Location of structure	Previous load configuration
Eastern white pine	12 by 12	None	Blacksmith shop, bottom chord of truss	Northern Michigan	Compression perpendicular to grain
Douglas-fir	12 by 12	Creosote	Timber bridge, column	Eastern Oregon	Compression parallel to grain

[a]Nominal 12 by 12 in. is standard 286 by 286 mm.
[b]Type of structure and component.

Table 2—Stress wave transmission times and failure loads for Douglas-fir specimens

Specimen (no.)	Stress wave transmission time[a] (μs)	Load at failure[b] ($\times 10^3$ lb)
1	1,657	178
2	1,806	179
3	4,787	38
4	1,918	119
5	2,425	132
6	1,679	172

[a]Perpendicular to grain.
[b]Compression parallel to grain. 1 lbf = 4.448 N.

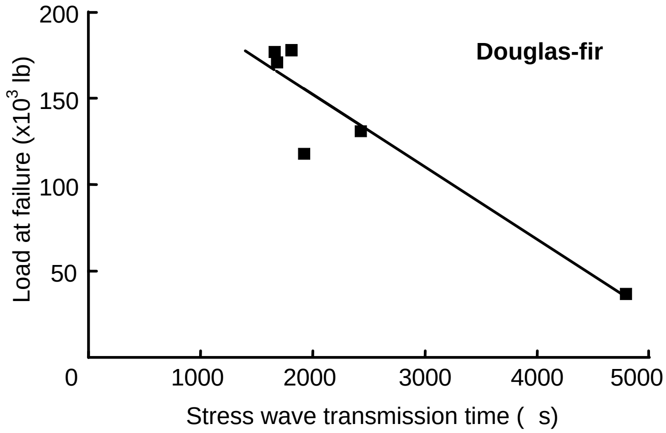

Figure 2—Relationship between stress wave transmission time and maximum parallel-to-grain load carrying capacity of Douglas-fir specimens. 1 lbf = 4.448 N.

Table 3—Stress wave transmission times and compressive properties for eastern white pine specimens

Specimen (no.)	Stress wave transmission time[a] (μs)	Compressive stress at proportional limit[a] (lb/in^2)	Maximum compressive stress[a] (lb/in^2)	Visual assessment of specimen condition
1	213	202	562	Sound
2	212	188	533	Sound
3	208	221	543	Sound
4	250	140	465	Sound
5	525	67	170	Center severely deteriorated
6	1,260	—	—	Severely deteriorated[b]
7	2,207	—	—	Severely deteriorated[b]
8	3,680	—	—	Severely deteriorated[b]

[a]Perpendicular to grain. 1 lb/in^2 = 6.89 kPa.
[b]Specimens fell apart during preparation for static testing.

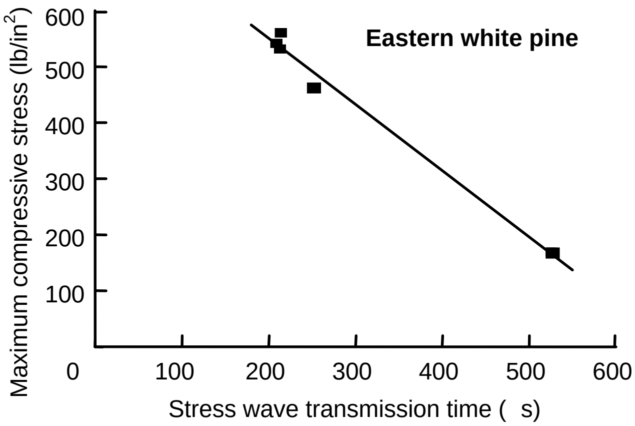

Figure 3—Relationship between stress wave transmission time and maximum perpendicular-to-grain compressive stress of eastern white pine specimens. 1 lb/in^2 = 6.89 kPa.

Conclusions and Recommendations

Based on the results of this study, we conclude the following:

1. There is a linear relationship between stress wave transmission time (perpendicular to grain) and residual strength (parallel and perpendicular to the grain) of timbers that have been in service.
2. In general, timbers with low strength values have long stress wave transmission times.

Because these results are encouraging, we recommend a larger study on the strength of the relationship between stress wave transmission time and residual capacity of in-service timbers. Such a study should include a much larger sample than that used in the study reported here as well as timbers from several species.

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