

Detection and Assessment of Wood Decay in Glulam Beams Using a Decay Rate Approach: A Review

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Abstract

A glulam beam is subjected to X-ray computer tomography and acousto-ultrasonic measurements to detect and assess wood decay. A glulam beam without visible indications of wood decay was taken from field use. A modified impulse-echo technique is employed as an inspection method requiring access to only one side of the beam. It is observed that decay-rate analysis of the collected signals allows detection and assessment of wood decay. The decay-rate approach leads to an overall rate of false calls of 7.2%. Considering the variability that exists in wood including the presence of splits, orientation and thickness of growth rings, etc., this relative low rate of false calls makes this approach very attractive. The results of the decay-rate analysis are found to be consistent with decay located using X-ray computer tomography. This paper is a review of findings first presented in (Senalik et al. 2010).

Keywords: Wood decay, structural lumber, glulam beams, X-ray computer tomography, impulse-echo

Introduction

While much has been done to preserve wood and wood composites, even the best preservative techniques available today have not been able to truly halt the natural decay process. The process of decay varies with species, but follows a sequential process of incipient, intermediate, and advanced decay. Incipient decay normally occurs with little visible change of the wood, although the dynamic strength properties are greatly reduced. The other extreme, i.e., advanced decay, is characterized by wood with no intrinsic strength.

Several nondestructive testing methods have been attempted to detect and evaluate incipient decay. The inherent variability of wood such as grain angle, density, moisture content variations, and presence of features such as knots, splits, and resin pockets mask the presence of incipient decay. An ultrasonic through-transmission approach was developed in (Senalik et al. 2008). It was shown that the frequency of maximum amplitude and ultrasonic velocities were sensitive to wood decay. However, often only one lateral side of the wooden beam is available for testing and evaluation. The ultrasonic pulse-echo configuration does not lend itself to this test, mainly because of the high levels of ultrasonic attenuation in wood and because of the growth ring channeling effects, (i.e., guiding wave effects). As a result, a modified impulse-echo decay rate approach was developed where the energy is delivered by dropping a steel sphere onto a steel plate previously coupled to the glulam beam. A good literature review of impulse-echo approaches is provided in (Sansalone 1997), (Reis and Habboub 2000), and (Senalik et al. 2009). This paper is a review of findings first presented in (Senalik et al. 2010).

Experimental description

One Douglas-Fir glulam beam with a cross-section of 7.5in by 5in (19.1cm by 12.7cm) was salvaged from a construction site. The glulam beam was made from five 5in by 1.5in (12.7cm by 3.8cm) laminas,

which were laminated to yield the final glulam beam. Visual inspection of the original beam did not show any indications of decay. A 45 inches (114 cm) long segment of this beam was then cut for this study. In this 45 in (114 cm) long segment, the only observed indication of decay was at the end of the beam in lamina 2 where an interior small hole was observed. However, the level of decay could not be assessed using visual inspection. In addition, a small (millimeter-wide) longitudinal crack, i.e., split, on the top surface was also observed. Before testing, the beam was marked with a one inch square (2.54mm square) grid for subsequent X-ray and ultrasonic measurements.

X-ray computer tomography was used to characterize the wood decay in the glulam beam. Tomographic views were made every centimeter along the beam length. The examined beam possessed decay at all severity levels ranging from sound wood to advanced decay. Based upon the cross-section tomographic views, a determination was made as to the severity of decay at each location within the beam. The third lamina of the beam possessed a transition region between sound wood and advanced decay, which provided a location to evaluate the ability of the decay-rate technique to identify incipient decay.

Data was collected using a modified impact-echo data acquisition system. The voltage signal from an accelerometer (Model PCB309M12 with a resonance frequency of 120 kHz) mounted near the point of impact was filtered using a Butterworth filter with a band pass of 500 Hz to 500 kHz. Each test data set consisted of 8192 data points collected at a sampling rate of 1 MHz. Data was recorded after the voltage exceeded the trigger voltage of 19 mV. A steel ball bearing of diameter 12.70 mm and mass of 8.33 grams was used as the impactor. The steel ball bearing was dropped from a height of 200 mm onto the center of a circular steel plate with a mass of 6.27 grams, a thickness of 6.35 mm, and a diameter of 12.71 mm. Using MatLab filtering tools, the recorded waveforms were further band filtered using a Butterworth filter between the frequencies of 500 Hz and 500 kHz.

The accelerometer was placed adjacent to the impact plate, and both were centered with respect to the width of each lamina. Care was taken to prevent contact between the impact plate and the accelerometer. Both the impact plate and the accelerometer were coupled to the lamina surface using Celvacene heavy, high vacuum grease. The presence of the plate prevented marring of the lamina top surface by the steel sphere and eliminated variability of the impact spectral power distribution caused by the presence of the growth rings on the top surface. The impact plate also increased the area across which the wave energy was distributed. The beam was fixed into a position such that a portion of the beam was cantilever to the test rig support. The location of testing was always within the cantilever portion of the beam in order to minimize signal loss due to leakage into surfaces abutting the beam.

Decay Rate Analysis

In this study, five measurements for each different location along each lamina were made. Five waveforms were collected using 8192 data points using a sampling rate of 1 MHz, and an average waveform was created. A window of 1024 points was moved across the waveform point by point and the corresponding FFTs were calculated. Using an FFT containing 1024 points, the frequency amplitudes ranging from 976 Hz to 19.53 kHz with increments of 976 Hz were calculated. A spectrogram of frequency magnitudes with respect to time was generated for each frequency. An exponential decay curve was fitted to the magnitude versus time curves for each frequency as shown in Figure 1a. The exponent is considered to be the attenuation rate of the magnitude with respect to time for each frequency. An average of the attenuation rates for the frequencies in a frequency band of 500Hz to 20 KHz (ranging from 976 Hz to 19.53 kHz with increments of 976 Hz) was then calculated. Figure 1a shows the decay of the amplitude corresponding to 12.72 kHz (solid line) and the dashed line represents the exponential fit ($r^2 = 0.87$) for data collected from lamina 3 at location 686 mm (27 in), which led to a decay rate value of

1.26 Nepers/ms. Figure 1b shows the decay rate of amplitudes of all the FFT frequencies at the same location.

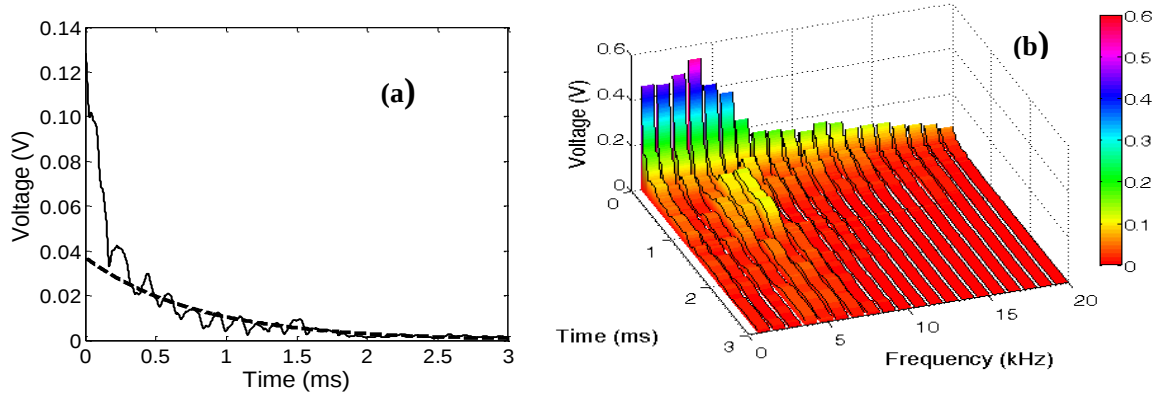


Figure 1 - Frequency voltage decay versus time at location 27 (686 mm) of Lamina 3. (a) The solid line represents the decay of one of the amplitudes (corresponding to 12.72 kHz) and the dashed line represents the corresponding exponential fit ($r^2 = 0.87$). The data was collected from Lamina 3 at location 686 mm (27 in). This frequency component has a decay rate value of 1.26 Nepers/ms; (b) Voltage amplitude versus time for frequencies 500 Hz to 20 kHz (FFT amplitudes) at the same location.

Figure 2 shows an histogram of the average exponential decay rate for sound and decayed wood showing the corresponding probability density functions, which are assumed to follow a normal distribution. The distribution corresponding to sound wood has a mean of 1.0 Nepers/ms and a standard deviation of 0.06 Nepers/ms while the distribution corresponding to decayed wood has a mean of 1.2 Nepers/ms and a standard deviation of 0.08 Nepers/ms.

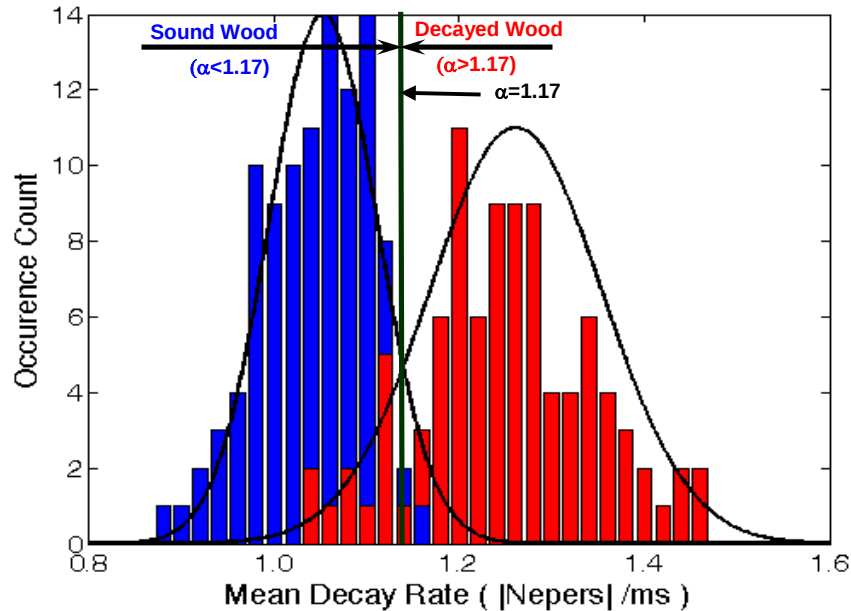


Figure 2 - Histogram of the mean exponential decay rate for sound and decayed wood showing corresponding probability density functions.

Figure 2 shows that the two normal distributions, intercept each other at the value of 1.17 Nepers/ms. Assuming that this average attenuation coefficient would be considered to serve as a decision criteria to differentiate between sound wood and decayed wood, the criteria would lead to 5.7% of false negative

calls (decayed wood considered to be sound wood) and to 3.5% false positive calls (sound wood considered to be decayed). This leads to an overall rate of false calls of 7.2%.

Conclusions

To detect and assess wood decay within a glulam beam, a modified impulse-echo technique is used in conjunction with a decay-rate analysis of the collected signals. The impulse-echo technique involves dropping a steel sphere onto a steel plate coupled to the surface of the beam. Wave data is collected using an accelerometer mounted near the point of impact. A spectrogram of the collected voltage signal is constructed. The voltage magnitude is fitted to an exponentially decreasing curve. An exponent magnitude greater than 1.17 Nepers/ms is a positive indicator of the presence of internal decay. The decay rate approach has an overall rate of false calls of 7.2%. Considering the variability that exists in wood including the presence of splits, orientation and thickness of growth rings, etc., this relative low rate of false calls makes this approach very attractive. The results provided by the modified impulse-echo decay-rate approach are consistent with indications of decay obtained using X-ray computer tomography. Furthermore, the modified impulse-echo results appear to indicate that the approach is sensitive to early stages of decay.

Acknowledgements

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References

- Reis, H., Habboub, A.K. 2000. Nondestructive Evaluation of Dimension Stone Using Impulse Generated Stress Waves: Part 1 – Theoretical Aspects and Experimental Prospects. ASTM 1394, K. R. Hoigard, Ed., American Society for Testing and Materials, West Conshohocken, PA, pp. 3-23.
- Reis, H., Habboub, A.K. 2000. Nondestructive Evaluation of Dimension Stone Using Impulse Generated Stress Waves: Part 2 – Estimation of Complex Moduli. ASTM 1394, K. R. Hoigard, Ed., American Society for Testing and Materials, West Conshohocken, PA, pp. 24-38.
- Reis, H., Habboub, A.K. 2000. Nondestructive Evaluation of Dimension Stone Using Impulse Generated Stress Waves: Part 3 -- Microstructure Characterization. ASTM 1394, K. R. Hoigard, Ed., American Society for Testing and Materials, West Conshohocken, PA, pp. 39-54.
- Sansalone, M. 1997. Impact-Echo: The Complete Story. American Concrete Institute-Structural Journal, Vol. 94, No. 6. pp.777-786.
- Senalik, C.A., Beall, F.C., O'Dell, K., and Reis, H. 2008. Detection and Assessment of Wood Decay in Glulam Beams Using a Through-Transmission Ultrasonic Approach. Proc. SPIE 6932.
- Senalik, C.A., McGovern, M.E., Beall, F.C. and Reis, H. 2009. Detection and Assessment of Wood Decay in Glulam Beams Using a Modified Impulse-Echo Approach. Proc. SPIE 7292, 72920Y.
- Senalik, C.A., Beall, F.C. and Reis, H. 2010. Detection and Assessment of Wood Decay in Glulam Beams Using a Decay Rate Approach. Insight-British Institute of Non-Destructive Testing, Vol. 52, No. 10. pp 553-560.



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