Calibration Of Stress Wave Timer for Amazonian Species

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Abstract

Non-destructive testing is increasingly being used on wooden structures. One of the preferred instruments for this task is the Stress Wave Timer, because it is portable and easy to use. This instrument needs to be calibrated to minimize possible reading errors. Tests were performed on samples of different sizes from four Amazonian timber tree species, with differing distances between the start/stop accelerometers and varying gain settings. The aim was to identify errors and find the best ratio between the Metricard SWT's start and stop accelerometers. The best ratio was observed with settings of 40 for stop and 1 for start. The calculation of the confidence interval for the mean of the stress wave velocities expresses a degree of uncertainty ranging from 2% to 8%, regardless of the species and according to the start/stop ratio. A more in-depth evaluation led to the conclusion that the greatest degree of uncertainty occurs with short pieces. This confirms the need to calibrate the equipment, especially when using the instrument with pieces approximately equal to or less than 70 cm in length. The value for offset time (intersection of the line with the axes) was determined by a simple regression analysis, and indicated that the data correction factor varied from 1.9 to 2.2 depending on the start/stop ratio, at least in the samples studied.

Keywords: stress wave timer, non-destructive testing, piezoelectricity, Amazonian timber

Introduction

Non-destructive methods are widely used to assess the mechanical quality of a given material. In general, these types of tests permit estimation of the rigidity of the material, which can be used to evaluate the quality of a structure and to classify the tested piece so as to define its use.

Researchers and professors in the State of Amazonas have used Stress Wave Timers (SWT) to conduct non-destructive testing of wood, without concern for the accuracy of the time readings. This factor can lead to incomplete readings and defects in the conclusions drawn from tests (AMINI, JALALPOUR and DELATTE, 2016).

In this specific study, a Stress Wave Timer manufactured by Metriguard was used to perform tests on pieces of Amazonian wood. This equipment uses the piezoelectric property of the wood to estimate the time required for the stress wave to travel through the wood from one side to the other.

The piezoelectric effect is a result of the linear electromechanical interaction between the mechanical and electrical state of crystalline materials that undergo electrical polarization when mechanical pressure is applied.

The speed at which the stress wave travels over a given distance is related to the density and elasticity of the test piece, according to the equation below:

$$V = \sqrt{\frac{E.g}{\rho}} \qquad \text{(Equation 1)}$$

Where:

E = dynamic elastic modulus

g = acceleration of gravity

ρ = wood density

The velocity is calculated by the following equation:

$$V = \frac{1000.L}{Tempo} \qquad \text{(Equation 2)}$$

L = Distance between the two accelerometers

Time = Travel time of a stress wave from one accelerometer to another

Note that the SWT gives the time reading in microseconds, therefore the unit of velocity is cm/microsecond.

In this instrument, the time reading of the stress waves caused by the impact of the pendulum on the wood depends on the Gain setting, as a minimum acceleration value is necessary to detect the impact time between the two accelerometers (Figure 01) (MATTHECK and BETHGE 1993).

Figure 01: Stress wave timer. A-Sample tested; B-Detail of the equipment

According to Wlodkowski, Deng and Kahn (2001), accelerometers are piezoelectric crystals that are firmly in contact with the timber at the extremes of the SWT connections. Upon receiving an impact, they generate an electrical signal and measure the time that the electrical signal takes to travel from one point (start) to the other (stop).

According to Arvind et al (2016), the stress waves decrease as they propagate through the material and may not be detected if their path of travel to the final accelerometer is too long. Sensitivity to the wave signals caused by the pendulum's impact can be improved by adjusting a time setting (start and stop button) on the instrument.

The variation in wave propagation time in relation to path length was studied by Hoyle and Rutherford (1987). Their study shows that there is a significant time error in the wave path for pieces of the same material with a length of less than 20" (50.8 cm). The error is due to the decrease in the stress wave's amplitude as it propagates through the material from the point of the pendulum's impact to the other extremity. As wood is a viscoelastic material it absorbs the energy transmitted by the pendulum, so that the stress wave decreases as it propagates through the tested piece.

Therefore, if the piece is small it can present a much greater stress than it would if it were long.

The purpose of calibration, according to Dietrich (2017), is to minimize the time reading error of the stress wave speed detected in a small piece, in order to correct it in the case of much larger pieces. "For example, if a piece is less than 20 inches in length, the stress speed per inch will be much lower than if the length of the same piece is greater than twenty inches. It is necessary to correct the error in order to provide similar values that offer conditions to determine the elastic moduli that are approximately equal both for short pieces or for long pieces".

In the present study, specific tests were performed to detect the gain settings (start versus stop) to be used when testing pieces with different lengths. Note that other variables such as moisture content, grain direction, fungi, and hollowness that alter the results obtained from the stress wave timer were considered, since the samples used were taken from the same piece under the same conditions.

The experiment aimed to answer the following questions: is there any variation in the velocity of the stress wave as a result of the gain settings and the length of the piece? if there is, which are the most appropriate start/stop settings to use with short pieces?

Methodology

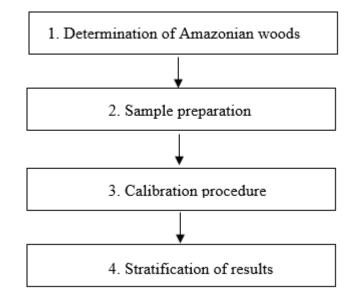The methodological procedure developed included the following steps, as shown in Figure 02:

Figure 02: Methodology used. Source: The authors (2018)

1. Determination of Amazonian timber species - The experiment was conducted with four Amazonian timber species: Cumaru (*Dipteryx odorata* (Aubl.) Willd.), Ipê (*Tabebuia serratifolia* (Vani) Nich), Jatobá (*Hymenaea courbaril* L.), and Tauari (*Couratari stellata* A. C. Smith).

2. Sample preparation - All samples were previously dried to a moisture content of approximately 12%, with an equal cross-section; the samples were then cut to dimensions of approximately equal sections, and lengths ranging from 23 cm to approximately 204 cm, with a thickness of 2.54 cm and width of 10.04 cm (Figure 03). There were five pieces per species and time information was determined three times in each assay.

The instrument used was the Metriguard stress wave timer model 238A, with an accelerometer clamp to attach to the ends of the piece of wood, and an impact pendulum.
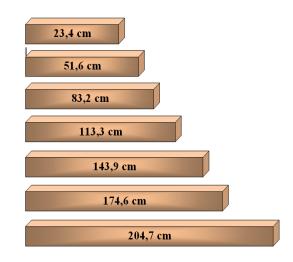
Figure 03: Length of samples used. Source: The authors (2018)

3. Calibration procedure - The maximum setting used for calibration was 40 for both start and stop, while the other extremity varied between 1, 2, 4, and 20; i.e., firstly the time that the stress wave took to travel through the wood in the longitudinal direction was determined for each species using the start/stop ratios of 1/40; 2/40; 10/40 and 20/40. Subsequently, new tests were performed on the same samples with start/stop setting ratios of 40/1, 40/2, 40/4, 40/10, 40/20 and 40/40. Therefore, the design of the experiment for statistical analysis contains the following information: 10 Start/stop x 4 species x 7 samples x 1 time = 280 points. This provides a considerable number of combinations where time (speed) is the dependent variable.

4. Stratification of the results – experimental statistics were used to consider the results obtained. The technique used was linear regression, which permitted inference of the relationship of the variables obtained in the calibration process with the independent variables specific to each species or sample.

Results and Discussion

The experiment involved submitting pieces of wood with different lengths, structural dimensions, and 12% moisture content to testing using a SWT. The information obtained enabled the following evaluations to be made:

1. The relationship between stress wave velocity, piece length, and the effect of the START/STOP gain settings.

The relationship between wave velocity and piece length was studied to evaluate whether the time information (velocity) obtained by the SWT can vary as a result of the gain settings and the distance between the accelerometers, as demonstrated in the graph generated by Figure 04.
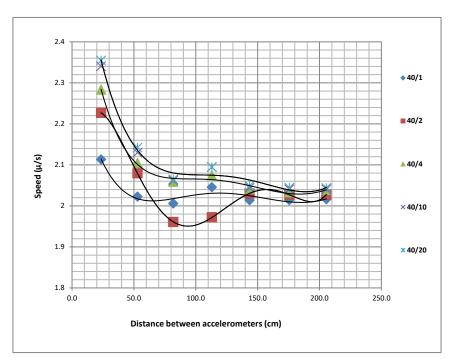
Figure 04: Relationship between wave speed (cm/µs) and sample length
(cm) for stop < 40 and start = 40

Observe that according to Figure 04 there is in fact a reduction in velocity in relation to the length of the sample. On the other hand, this variability decreases considerably for pieces less than 70 cm in length. It is therefore evident from the graph that using this instrument to determine the velocity in pieces that are less than 70 cm in length will produce a false result, since the velocity value is very high compared to the mean velocity obtained from the same piece of wood but with a length of more than 70 cm. Without proper correction this result could seriously compromise a diagnosis of the structural stability of a building.

The next step of the analysis involved increasing the start button setting while the stop button remained at 40 (Figure 05).
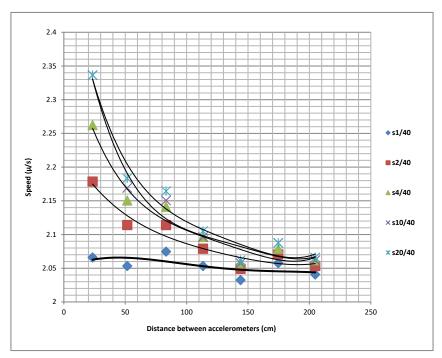
Figure 05: Relationship between wave speed (cm/μs) and sample length
(cm) for start < 40 and stop = 40

According to Figure 05, for pieces shorter than 150 cm there are differences in wave velocity in relation to the length of the pieces, regardless of the timber species.

The trend lines for the points of each start-stop ratio show that there is no difference in values as a result of gain settings for pieces of more than 150 cm in length. The figure also shows that the velocity appears to be approximately the same with the 1/40 start/stop ratio for both short and long pieces. Therefore, the most appropriate calibration, at least for the species studied, is with the start button positioned at 1 and the stop button at 40.

Taking advantage of the amount of information obtained during the test, some additional conclusions can be inferred.

1. The uncertainty of the experimental results obtained from the SWT tests:

The analysis of the degree of uncertainty of the average velocities for each species and each setting, with 95% confidence, showed that there are significant levels of uncertainties between the start and stop settings. The results confirmed the conclusions obtained graphically in Figure 06. The graph below shows that the average velocities with the lowest degrees of uncertainty were for pieces tested with a settings ratio of 1 for start and 40 for stop, regardless of the species.
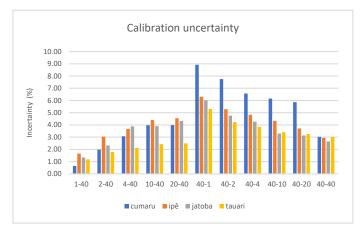
Figure 06: Uncertainty by calibration ratio and species

In order to understand what causes greater uncertainty in the results, the confidence intervals were calculated for the average velocity for each group of samples with the same length (Figure 07).
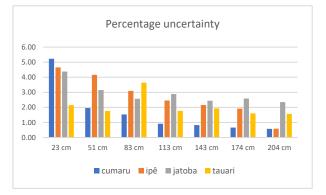

Figure 07:   Uncertainty in relation to piece length
(distance between start and stop accelerometers)

The calculation of the confidence interval for average stress wave velocity, grouped by distance between the accelerometers, clearly shows that a very high level of uncertainty is displayed in short pieces. This result only reinforces the previous analyzes and shows the need for calibration when SWT is used on pieces with a length approximately equal to or less than 70 cm.

1. The relationship between the time the stress wave takes to travel from one point to another, the density of the wood, and the distance between the accelerometers:

Multiple regression analysis was performed to understand the effect of the stress wave propagation time in relation to the density of the wood and the distance between the accelerometers. The equation found was:

$$Time = -1,7768 + 0,003286 * dens + 19,50794 * dist \quad \text{(Equation 3)}$$

According to the statistical analysis, there is a highly significant ($p < 0$) relationship between the time that the stress wave takes to travel from one point to another, the density (dens), and the distance between the sensors

(dist). Although this relationship can be explained with 99% (R - 0.995) confidence, given Equation 2 it is concluded that the density effect is reduced when compared to the distance for the different start/stop ratios.

1. The start/stop settings ratio that minimizes the time reading error, considering the reduction of the stress wave velocity with the increase in distance between the accelerometers.

The accuracy of the SWT reading depends on the gain setting of the accelerometers. Stress waves decrease in amplitude as they propagate through the material. These waves attenuate in such a way that they may not activate the timer; i.e., the stop accelerometer may not detect them. The sensitivity of the accelerometer to the stress wave can be adjusted via the instrument's gain calibration. Increasing the gain setting decreases the acceleration level that will start the SWT timer.

According to Hoyle and Rutherford (1987), the stress wave particle acceleration curve has a similar shape to that shown in Figure 08. The particle velocity at any point increases to a maximum and then drops away until it reaches a rate of zero velocity as the wave passes a certain point, and the slope of the curve is the acceleration of the particle.
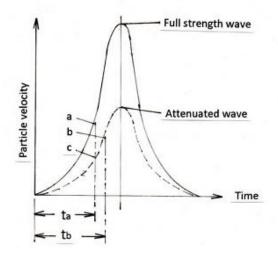

Figure 08 - Velocity curves of the stress wave particle at the start/end (full strength/attenuated wave) along the length of a piece. Source: Hoyle and Rutherford (1987)

They also point out that at points "a" and "b" the slopes of the curves are equal, but "a" occurs at time "ta" before passing through "b" near to the "stop" accelerometer. If the settings of the two accelerometers are the same, the travel time of the wave that will be measured will occur with an error at the highest point of tb-ta. By adjusting the start and stop buttons it is possible to reduce the error considerably. These corrections can be made through a regression analysis, considering that:

• The ratio of wave propagation time to distance between the two accelerometers is approximately linear;
• The definition of the gain with the least error is the straight line whose intersection with the axes passes close to the origin (time and length = 0).

Therefore, the next step in this analysis was to define the line that explains the variation of time with piece length for the different start/stop ratios. Thus, it was possible to identify the y-intercept in each start/stop ratio. The distance (Ty) between the point of interception of the line with the y-axis and the origin of the axes (x = 0; y = 0) should be corrected for the test values; i.e., the observed time (To) value obtained from the tests should be subtracted from the value of the y-intercept.

$$\text{Corrected time} = \text{To} - \text{Ty} \quad \text{(Equation 4)}$$

Thus, simple regression analyses were performed to find the relationship between the time for the stress wave to travel between the accelerometers and the distance between these accelerometers. It is clearly worth emphasizing that the equation obtained has the following model:

$$Y = a + bX \quad \text{(Equation 5)}$$

Where Y is the propagation time of the stress wave (microseconds) and X is the piece length or distance between the accelerometers (cm). In an ideal situation, where the measurement has no error, the value of the intersection of the line (a) would be zero. However, this rarely occurs due to the nature of the experiment, which can be affected in several ways (sample preparation, disturbances at the time of the experiment such as vibrations, etc.).

Thus, the value of the intersection is considered as the offset time to be used as a correction factor for the data obtained experimentally using the SWT. In this case, the experimentally obtained stress wave time value must be subtracted from the offset value.

According to ANOVA, it can be concluded that the linear relationship between wave propagation time and piece length is statistically significant with 95% confidence.

Also note that when observing Table 01, the accelerometer setting ratio with the smallest error is for START equal to 2 and STOP equal to 40, with the intersection value of 0.1936.

Tam vs Comprim.	Intercept	Slope	Correlation	R-squared	Standard error	Mean absolut error
40/1	1,91213	0,205102	0,998553	99, 7109	0,649464	0,522738
40/2	1,53061	0,203978	0,99862	99, 7255	0,629354	0,522614
40/4	2,19829	0,187506	0,991573	98,3216	1,67503	1,38229
40/10	1,97305	0,187545	0,991554	98,318	1,67725	1,36901
40/20	1,87971	0,187627	0,991652	98,3373	1,66816	1,35508
40/40	1,33518	0,1935	0,995574	99,1168	1,22662	0,821101
1/40	0,286782	0,197945	0,999399	99,8799	0,480129	0,368601
2/40	0,193609	0,198812	0,995037	99,0098	1,39058	0,637996
4/40	0,791982	0,197626	0,999395	99,879	0,481072	0,379323
10/40	0,837869	0,197799	0,999485	99,8971	0,444028	0,336356
20/40	0,877956	0,197856	0,999476	99,8951	0,448348	0,340662

Table 01: Table of accelerometer settings

Acknowledgements

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