Measurement Technique Development in Ultrasound Applied to Tropical Woods

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INTRODUCTION

The present work forms a part of a project "Use of Non Destructive Evaluation in Tropical woods Species” developed at the National Agrarian University La Molina Lima Peru

Using the wood species “tornillo" *Cedrelinga Cataeniformis Ducke* from plantation field. A Non destructive test with ultrasound wave were applied in wood slices cross section obtaining satisfactory results comparing the information obtained from 23kHz and 45kHz frequencies.

The C11, C 22 and C 33, coefficients of the stiffness tensor were obtained, they allowed us to know the features more about the wood growth response related with the trunk swelling and the buttress presence

Materials

Wood samples were extracted from the pilot area of Alexander Von Humboldt experimental center which is placed at the 86km of Federico Basadre freeway in Irazola District, Padre Abad Province in Ucayali western region of Peru (8º 22' to 9º 36' south latitude and from 74º 48' to 75º 35' of west longitude), and with the altitude between 200 and 340 m m.s.l.

The age of the tree plantation fluctuates between 20 to 23 years, the height fluctuates between 18,9 to 25,6 m and average dap between 32 to 38,9 cm.

Wave propagation in orthotropic medium

Theoretic bases.- The P is an ideal point of the wood sample, in cylindrical coordinates (z, θ, r) that is equivalent to the natural coordinates (L,T, R); where L is the longitudinal direction ., T is the tangential direction and R is the radial direction fig 1.

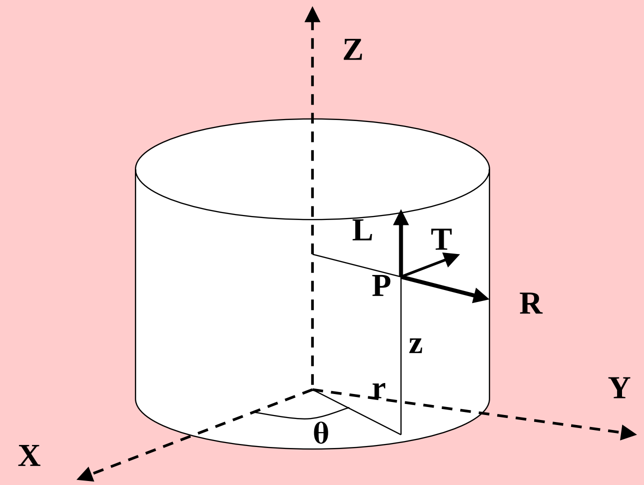

Fig1

Mechanic behavior.- The mechanic behavior of a solid, obeys the Hooke law equation (1) with 36 independent components in general. In wood case these components are reduced to a symmetric 9 independent components of the stiffness tensor as shows in equation 1 . Bucur (1984)

$$\sigma_{ij} = c_{ijkl}\varepsilon_{kl} \qquad (1)$$

Where: $\sigma_{i,j} =$ Stress tensor components,

$\varepsilon_{k,l} =$ strain tensor,

$c_{i,j,k,l} =$ Stiffness components tensor and i,j,k,l take 1,2 y 3 values respectively.

Wave propagation elastic in the main directions

The spread of an elastic wave in an infinite medium is given by the equation 2

$$c_{ijkl}u_{k,lj} = \rho u_{i,tt} \quad (2)$$

Where: u is the wave displacement; ρ is the sample density, lj are the derived directions from the displacement vector and tt is the double derived in time. Bucur (1984).

Applying to the previous equation the plane wave equation 3

$$u_k = A_k \exp\left[j\omega(t - \frac{p_i x_i}{v}) \right] \quad (3)$$

with the director cosine p_i in the propagation direction, or in general case one can write $A_k = A\,\mathbf{d}_k$, being d_k an unitary vector in the direction of the particle motion.

Appling the wave equation in equation and making:

$$\Gamma_{ik} = C_{ijkl}\, p_l\, p_j \quad (4)$$

we get the equation 5

Christoffel equation

$$\Gamma_{ik} - \rho v^2 \delta_{ik} = 0 \quad (5)$$

For slice cross sections samples with wave generated in the RT plane

Case I: Propagation direction 2 (tangential)
p2 =1, p1 = 0 and p 3 = 0 then the Christoffel equation becomes reduced to:

$c_{66} = \rho v^2$ for a transversal wave with polarization in the axis L, (6A)

$c_{22} = \rho v^2$ for a longitudinal wave with polarization in the axis T (6B)

$c_{44} = \rho v^2$ For a transversal wave with polarization in the axis R. (6C)

Case 2: propagation in the direction 3 (radial)
p3 =1, p1 =0 and p 2 =0 then the Christoffel equation becomes reduced

$c_{55} = \rho v^2$ for a transversal wave with polarization in the axis L, (6D)

$c_{44} = \rho v^2$ for a transversal wave with polarization in the axis T, (6E)

$c_{33} = \rho v^2$ for a longitudinal wave with polarization in the axis R. (6F)

Anisotropic between the radial and tangential velocity

Li et al (2007) when studying the anisotropic between the radial and tangential velocity defines the asymmetry factor:

$$F = \frac{(V_{RR} - V_{TT})}{V_{RR}} \quad (7)$$

Factor that for the species *E abliqua* and *Prunas Avium* take the value around 0,37 which is used to make corrections in acoustic tomography.

SAMPLES

Four complete slice cross sections from 4 trees which were properly identified in the anatomy wood laboratory of the forestry faculty of UNAML. Slice cross sections were conditioned in dry environment until they reached equilibrium moisture content. Samples were prepared in radial bands of 10 to 15 cm of width centered in wood pith trying to avoid areas of internal cracks is it is shown in figure 2.(INIA 1983)

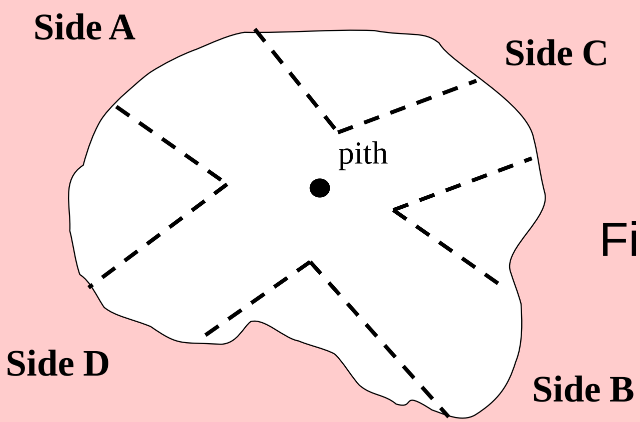

Fig 2

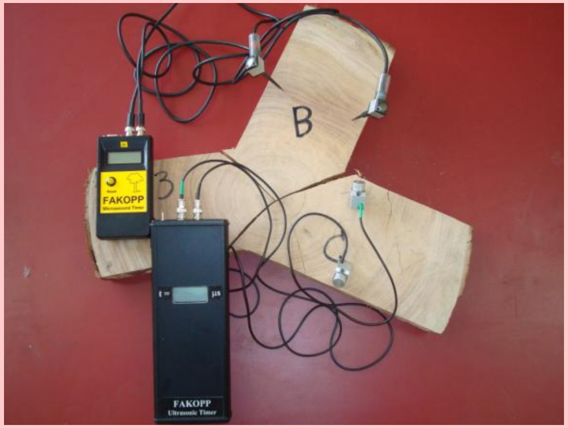

Fig 3

There were established two ways of measuring according to figures 4 and 5.

For the first way we get 2 modes, a radial mode which transductors were placed at points between 7-10 cm of distance until the edge of the sapwood, and the tangential mode at points along the edge of the sample fig 4

Second way, In order to analyze the angular variation of the velocity values between the radial and tangential direction points are located along the axis and tracing circles of 10cm radius, then placing points from the radial axis in the direction of the pith to the tangential direction with angles between 0 °, 30 °, 60 °, 90 °, 270 °, 300 ° and 330 °. Fig 5

First way: Localization of measuring points in radial and tangential orientation

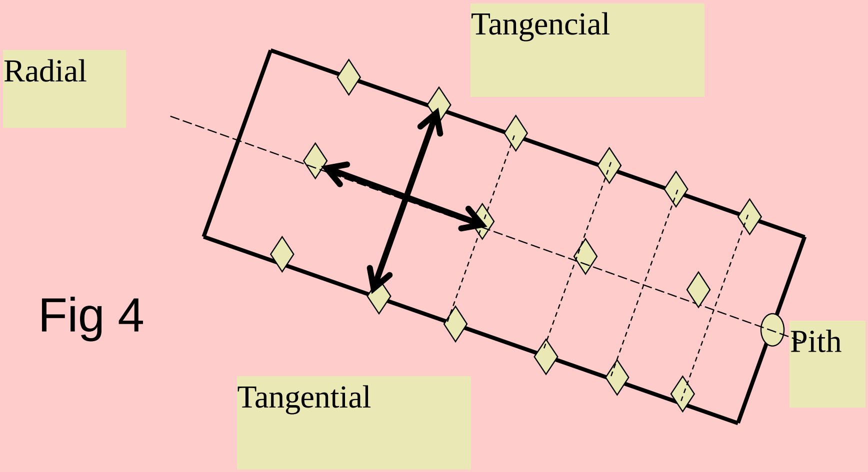

Fig 4

Second way: Localization of points for angular measurement

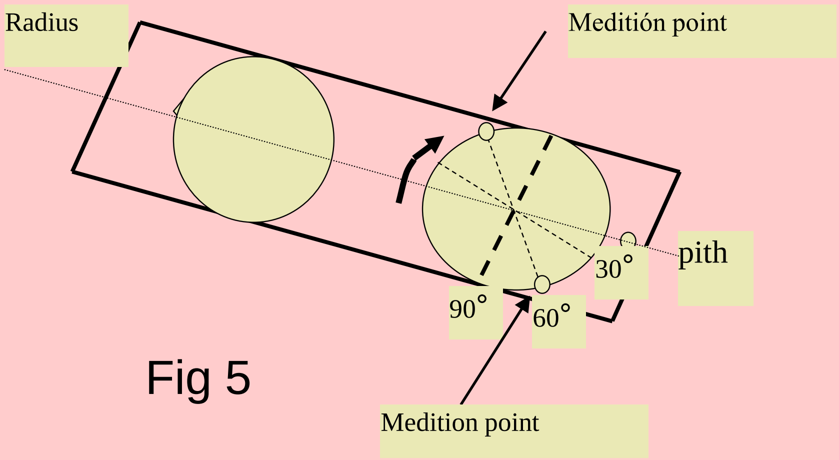

Fig 5

Measured radial and tangential velocities in the different slice cross sections

Velocities in both radial and tangential direction do not follow a similar pattern when comparing measurements made at 45 and 23 kHz, as shown in Figures 6,and 7 This different behavior between longitudinal waves of 45 to 23 kHz within the sample depends on the size of the obstacles encountered along the path followed by each type of wave, which in the case of 45kHz has almost half the length 23kHz wave.

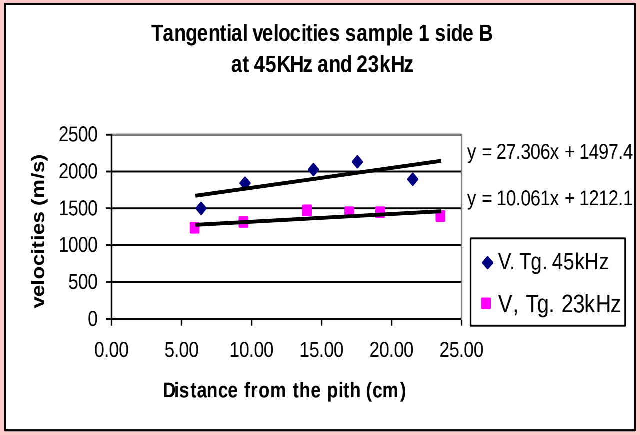

Fig 6

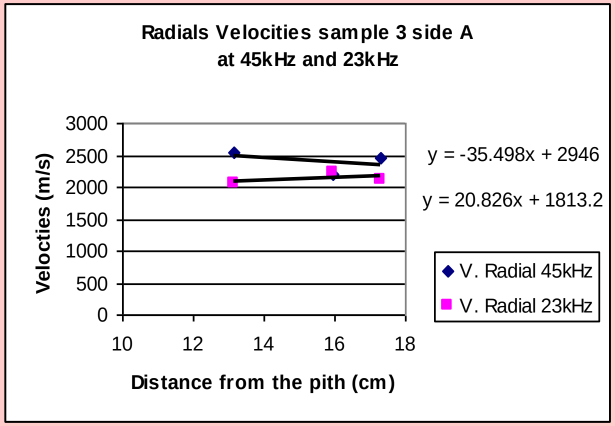

Fig 7

Figure 8 shows the velocity distribution from radial to tangential direction for the sample 1 side B-1 for 23 and 45 kHz

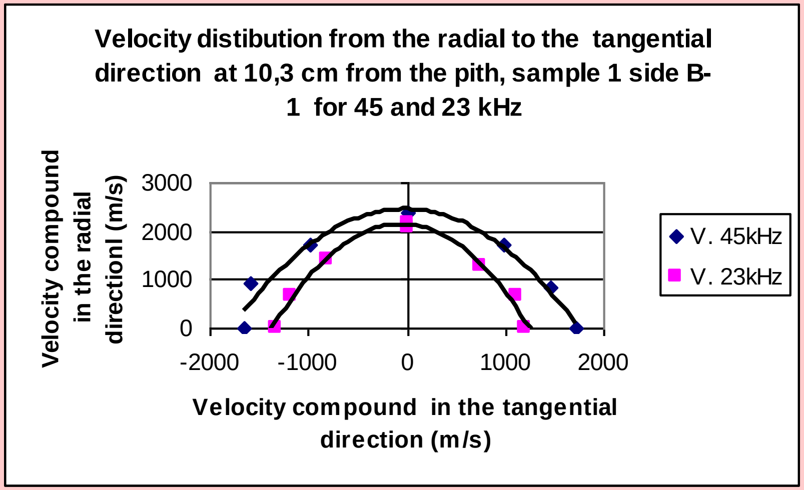

Fig 8

Figure 9 shows the velocity distribution from radial to tangential direction for the sample 2 side A-1 for 23 and 45 kHz

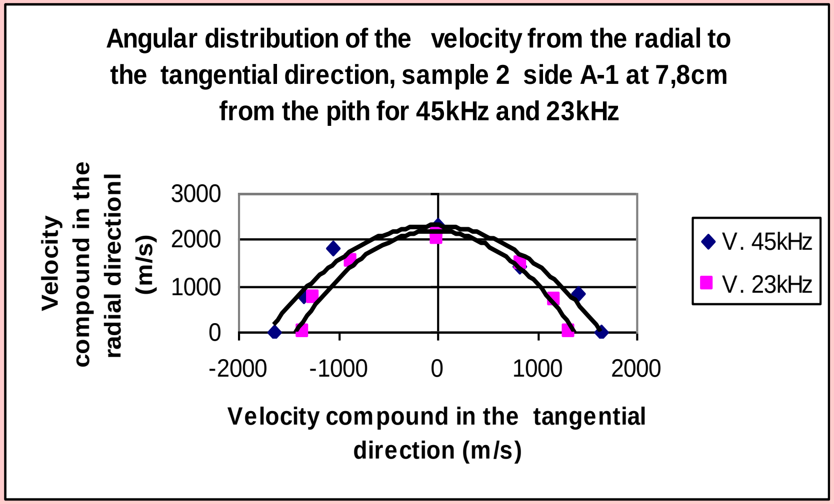

Fig 9

C11, C22 and C33 coefficients in *Cedrelinga Cataeniformis*

Previously determining the velocities and densities of samples, and using equations 6 was possible to calculate C22 and C23 coefficients of stiffness tensor for *Cedrelinga cataeniformis.* On the other side by using the study performed by Sucksmith (2007) , we could be determined the average longitudinal coefficient C11 of the total samples for the zone between the pith and the sapwood of each cross section, as it is shown in table2.

Coefficients C11, C22 y C33 of stiffness tensor for *Cedrelinga cataeniformis*

	C11(Longitudinal) (GP)	**C22 (Tangencial) (GP)**	**C33(Radial) (GP)**
45kHz	12,07*	1,73 ± 0,35	2,57 ± 0,45
23kHz	11,92*	0,82 ± 0,11	1,92 ± 0,21
Flexión dinámica	10,62*		
Flexión estática	10,22*		

CONCLUSIONS

•There are discrepancies between the measurements of 45 and 23 kHz as their modes of propagation depend on their wavelengths and the obstacles faced by each sample, such as internal cracks, knots, rings and other, becoming more noticeable when compared larger sample (15-20 cm or more).

•From the values found in table 5 we notice the importance of complete characterization study of the different woods because with only the coefficient C11 it can not be noticed the response of structural elements constructed to lateral forces and torque.

•The determination of C22 and C33 allow to know the way trees grow specially reaction wood since high values of those coefficients make the tree being less susceptible to torsion and avoid the crosslinked grain.

•In order to fully characterize *Cedrelinga cataeniformis* wood is recommended to conduct studies to fully characterize its stiffness tensor coefficients.

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