

# CHARACTERIZATION OF RAYLEIGH WAVE PROPAGATION IN CONCRETE USING LASER ULTRASONICS

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## INTRODUCTION

Ultrasonic nondestructive evaluation of non-traditional civil engineering materials such as aluminum are fairly well advanced. However the advancement of ultrasonic methodologies for the nondestructive evaluation of concrete lag behind primarily because of the lack of quantitative understanding of the propagation characteristics of ultrasonic waves in concrete due to the highly attenuating nature of concrete.

Concrete is a porous non-homogeneous material made up of both fine and coarse aggregates. The presence of this aggregate, in addition to voids and flaws, causes elastic wave scattering in concrete, which causes dispersion and attenuation. This phenomenon causes a variety of complications with the application of ultrasonic testing to concrete components. In order to effectively use ultrasonic waves to interrogate a concrete sample, the propagation characteristics of the individual constituents must be fully understood.

Reflection, transmission and attenuation of ultrasonic longitudinal and Rayleigh waves are used to develop non-destructive ultrasonic techniques to examine the size and location of flaws and to provide measurements of the internal structure of materials such as concrete. This paper presents the results of a study that uses laser generation and detection techniques to examine the propagation of Rayleigh surface waves on samples of aluminum, granite and mortar as part of a continuing effort to characterize Rayleigh waves in undamaged and damaged concrete.

Laser techniques are chosen for this investigation because of their numerous well published advantages over conventional systems. The advantages are fairly well known and will not be discussed in detail here, however, the high fidelity, large frequency bandwidth, and absolute, non-contact nature of laser ultrasonics makes this an ideal methodology to determine the propagation characteristics of ultrasonic waves in concrete.

## EXPERIMENTAL PROCEDURE

For this study, a 9 mJ Q-switched Nd:YAG laser, model LPS-1010 manufactured by Kigre with a pulse duration of 15 ns, operating in the infrared range with a wavelength of 1060 nm is used to generate the elastic waves. In this study, in order to increase the signal-to-noise ratio and to produce the maximum possible amplitude, the laser is employed in the ablation regime. The out-of-plane detection is accomplished by a heterodyne interferometer. For a complete description of the heterodyne interferometer used in this study the reader is referred to the paper by Bruttomesso, et al. [1].

For the experiments discussed here, the generation and the detection are on the same side of the specimens. The specimens are rectangular blocks measuring 200 x 100 x

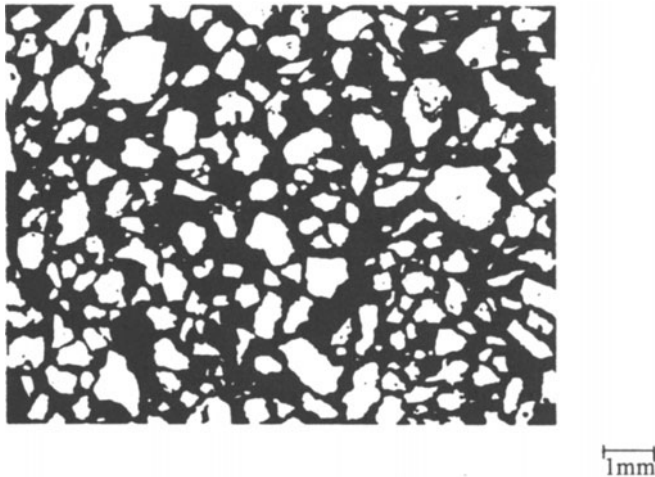


Figure 1 - Micrograph of mortar sample.

25 mm. ASTM Type I Portland cement (water/cement ratio of 0.55) is used in the mortar mix proportion. Figure 1 shows a micrograph of the mortar sample.

Several measurements are taken for each of the samples. Basically, the location of the detection point is moved and the peak-to-peak amplitude at each detection location recorded while keeping the generation point in the same location. The radial distance,  $r$ , from the generation point to the detection point is calculated by taking the arrival time of the Rayleigh wave and multiplying it by the phase velocity of the Rayleigh wave. The Rayleigh wave arrival times are measured to an accuracy of 10 nsec.

The Waveforms were recorded on a Tektronix TDS 420 digital oscilloscope and transferred to a personal computer via a GPIB interface for processing and storage. Waveform analysis is accomplished with the MATLAB software.

## EXPERIMENTAL RESULTS AND DISCUSSION

The Rayleigh wave velocities for the different samples are calculated as 2940 m/sec, 2240 m/sec and 3840 m/sec for the aluminum, mortar and granite respectively.

Figures 2, 3 and 4 show typical time-domain waveforms with their corresponding frequency-domain plots. The apparent signal (initial spike) in the time-domain plots, is

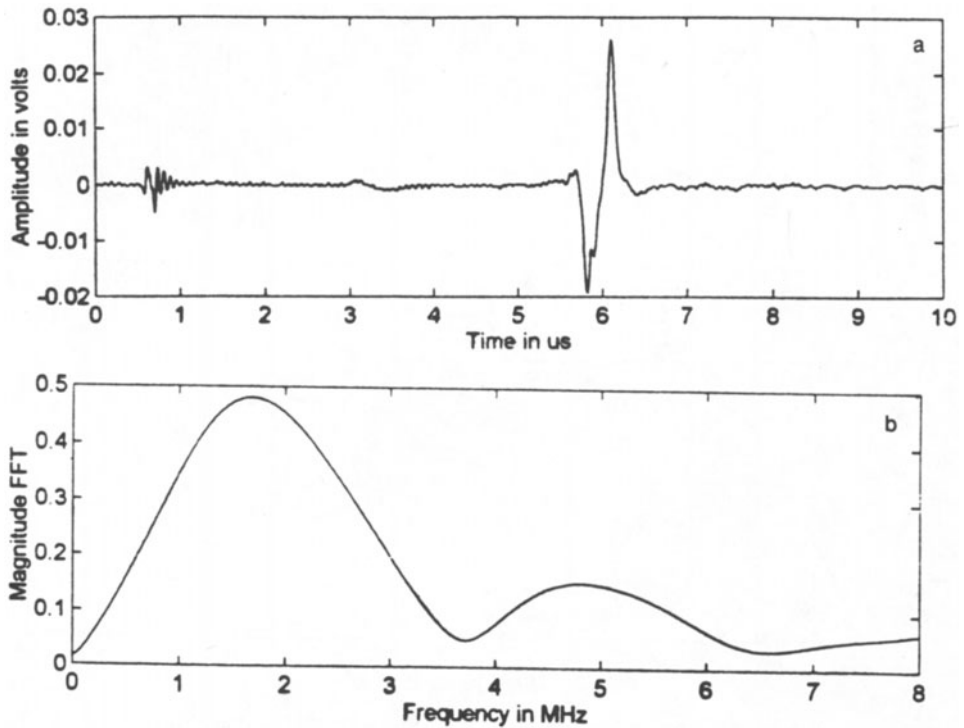


Figure 2 - (a) Time history of a Rayleigh for aluminum that propagates 26 mm  
(b) Frequency domain.

electromagnetic noise associated with the discharge of the capacitors in the generation laser power supply. A qualitative comparison of the three time history plots shows the absence of scattering and attenuation in aluminum, moderate scattering in granite and widespread scattering in the mortar sample. It is seen that for the mortar, the time-history waveforms are more spread out in time than the waveforms in aluminum or granite.

The frequency-domain plots are obtained by consistently windowing only the first 15  $\mu\text{sec}$  of the time-domain signal and using a Fast Fourier Transform technique. As can be seen in these plots (Figures 2,3 and 4), the higher frequency portion of the original signal is attenuated as the Rayleigh wave propagates along the surface of the mortar and granite while the same phenomenon is absent in the aluminum sample.

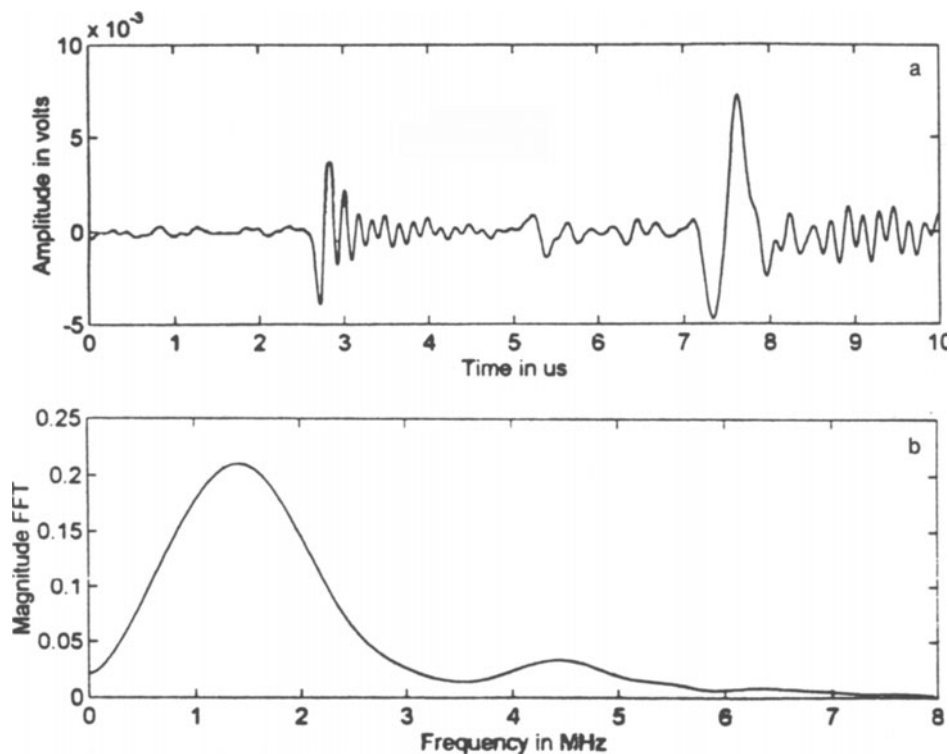


Figure 3 - (a) Time history of a Rayleigh for granite that propagates 18 mm  
(b) Frequency domain.

The corresponding peak frequency for the mortar, aluminum and granite occurs at 0.5 MHz, 1.75 MHz and 1.5 MHz respectively and the corresponding wavelengths are 4.4mm, 1.68mm and 2.56 mm. The cutoff frequency in case of the mortar sample is about 2 MHz while that for the aluminum and the granite is 4 MHz. For a Rayleigh wave speed of 2240 m/s, the wavelengths will vary linearly from 2.2 mm for 1 MHz to 1.1 mm for 2 MHz. From the results obtained in case of the mortar, it would seem that the grain size would be of the order of approximately 1 mm. This is confirmed by Figure 1.

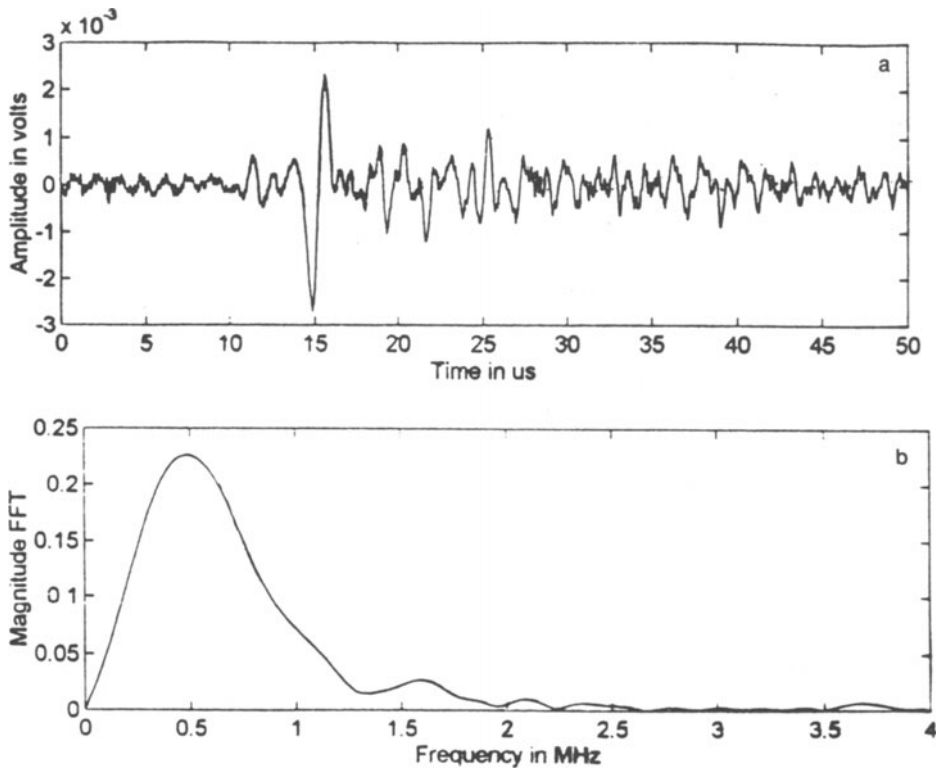


Figure 4 - (a) Time history of a Rayleigh for mortar that propagates 20 mm  
(b) Frequency domain.

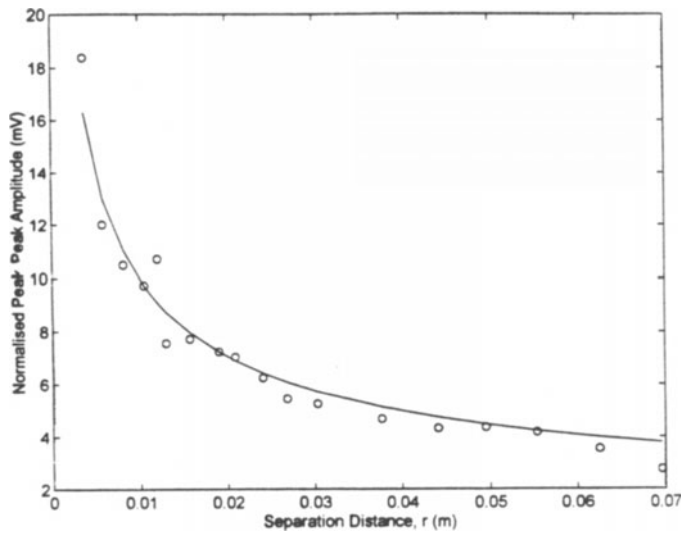


Figure 5 - Peak-to-peak amplitudes as a function of separation distance  $r$  for aluminum.

These results are also used to quantify the attenuation of Rayleigh waves in the aluminum and granite. The peak-to-peak amplitudes of the initial signal for each separation distance are plotted as discrete points in Figures 5 and 6. These curves also show the best fit of an inverse of the square root of the propagation distance,  $r$ , that fits the discrete peak-to-peak experimental amplitudes for aluminum and granite respectively. As expected, a qualitative comparison of the two waveforms shows the expected decrease in amplitude for increasing propagation distance.

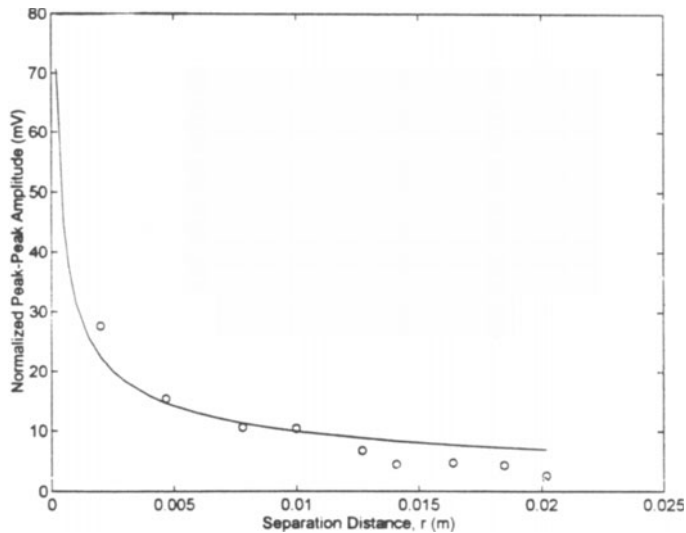


Figure 6 - Peak-to-peak amplitudes as a function of separation distance  $r$  for granite.

## CONCLUSIONS

This work demonstrates the potential of using laser ultrasonic techniques to experimentally characterize the propagation of ultrasonic waves in concrete. This work is a critical step in developing a technique to evaluate and characterize concrete components. Further work is needed to qualitatively model the attenuation of ultrasonic waves in concrete.

## REFERENCES

1. Bruttomesso, D. A., Jacobs, L. J., and Costley, R. D., "Development of an interferometer for the acoustic emission testing," *Journal of Engineering Mechanics*, Vol. 119, No. 11, pp.2303-2316(1993).