SITE CHARACTERIZATION USING SPATIAL AUTOCORRELATION METHOD IN LINEAR AND TRIANGULAR ARRAYS BY MEANS OF AMBIENT VIBRATION MEASUREMENTS

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ABSTRACT

The SPatial Auto-Correlation method (SPAC) method can be used to estimate the subsoil structure by using Ambient Vibration (AV) measurements. AV measurements were recorded at two different sites within the University of Puerto Rico at Mayagüez campus. Two different seismic arrays were used. The first design was a linear configuration, and the second one in an equaled spaced 120° triangular scheme at radial distances of up to 30-m. Time series of 30 minutes in length were recorded simultaneously at sampling frequency of 100 Hz. The SPAC method uses simultaneous records of ambient vibration measurements at several stations of a designated geometrical array of seismic instruments. In this study, the sub-soil shear wave velocity (Vs) model of two sites using the SPAC method was estimated. According to the local geological conditions of the area in which the experiments were conducted, the shear wave velocity profile with low Vs values agrees well with soft materials of Quaternary alluvial soil deposits (site A). The site with large Vs values agrees well with stiff materials of soil deposits derived from Cretaceous rocks (site B).

INTRODUCTION

The SPatial Auto-Correlation method (SPAC) is currently being used by the engineering community (near-surface geophysics, seismology, and geotechnical) for soil shear wave velocity (Vs) profiling as an in-situ technique for site characterization. The SPAC method was initially proposed by Aki (1957).The SPAC method estimates the correlation coefficients between pairs of measurements in an azimuthal array of ground motion sensors from which the dispersion curve of surface Rayleigh wave is estimated.

The aim of this study was to determine the Vs and the geometry of subsoil conditions using the SPAC method in a Linear and a Circular array at two selected sites.

SPATIAL AUTOCORRELATION METHOD (SPAC)

The essence of SPAC is that having AV records from an array of seismic stations along different azimuths, it is possible to estimate the phase velocity of the waves crossing the array. The phase velocity is determined as a function of frequency. The estimated function of the phase velocity is then inverted to estimate the Vs as a function of the depth, which will allow the estimation of the Vs profile of the site.

The Spatial Autocorrelation function $\Gamma_{0,j}(r,\theta,\omega)$ is calculated at two stations by computing the auto power spectrum and the cross power spectrum of the stations and between the pair of stations (center-location j), respectively.

$$\Gamma_{0,j} = \mathrm{Re}\left(\frac{A_{0j}(r,\omega,\theta)}{\sqrt{A_0(\omega)\cdot A_j(r,\theta,\omega)}}\right)$$

The spatial autocorrelation coefficient of signals recorded at two stations separates by a distance *r* can be written as:

$$\rho(r,\omega)=\frac{1}{2\pi\,\Gamma(r=0,\omega)}\int_0^{2\pi}\Gamma_{0,j}(r,\theta,\omega)\,d\theta = J_0\left(\frac{\omega r}{c(\omega)}\right)$$

J_0 The Bessel function of the first kind of zero order

$c(\omega)$ phase velocity at angular frequency ω for the Rayleigh waves

According to Chávez, et. al, (2006) consistent and similar results are obtained when using measurements of AV recorded along a line, which means it is not mandatory to use a circular array of sensors. The fact to consider is that larger time series are needed for the analysis.

The SPAC coefficients are obtained by averaging the normalized coherence functions with regard to site location θ, where the coherence functions are defined as the real part of cross spectrum and normalized by the power spectrum O(0,0) (Morikawa et al., 2004).

DATA ACQUISITION AND PROCESSING OF AMBIENT VIBRATIONS MEASUREMENTS

AV recordings were carried out at two experimental sites (site A, and B) in an open space inside the campus of the University of Puerto Rico at Mayagüez. The sites were selected taking in to consideration that they have significant differences on surface geological conditions, which are also expected at depth.

The measurements for the linear SPAC array (Site A) were taken using a linear, which consisted of stations placed at 2.5-, 5-, 10-, 15-, 20-, and 30-m, and the radial arrays (Site B) in which the sensors where placed at 5-, 10-, 20-, and 30-m all of them respect to the sensor located at the center. Figure 1, shows an schematic description of both arrays.

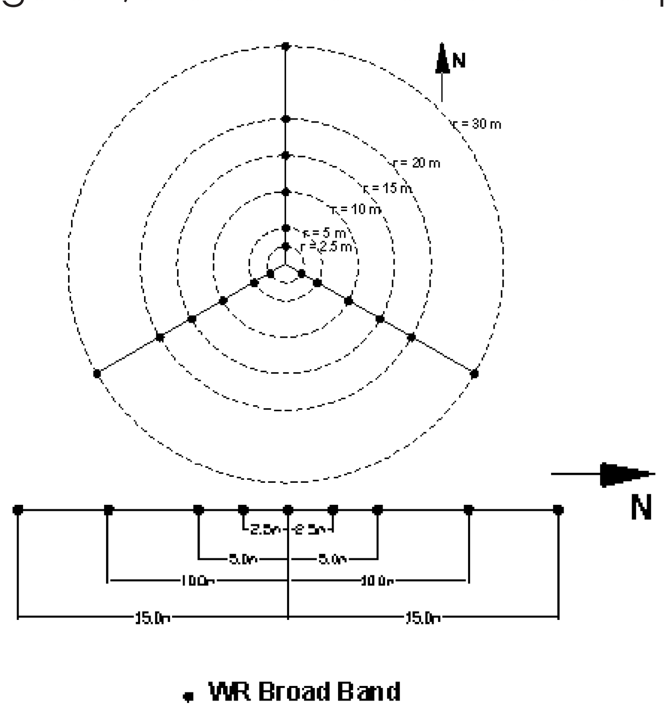

Fig. 1 Top: Geometry of the radial stations, bottom Geometry of the linear stations for ambient vibration detection

ANALYSIS OUTLINE

The SPAC method was used to determine the phase velocity of Rayleigh wave from ambient vibration measurements. Spatial Autocorrelation coefficients were calculated by averaging. Having the average autocorrelation coefficients function, the next step was to obtain the theoretical Bessel function of the first kind (zero order), which is also shown in Figure 2.

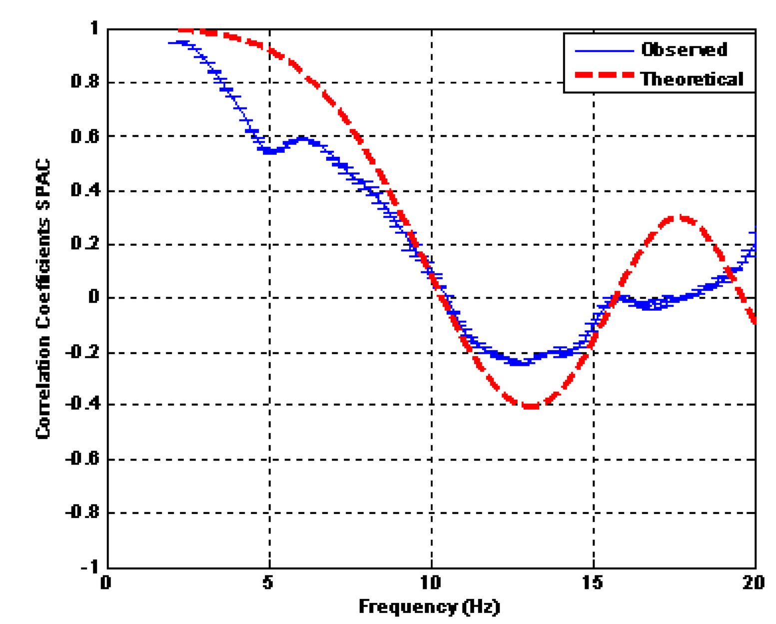

Fig. 2 Autocorrelation coefficients averaged observed and their fit to zero order Bessel function.

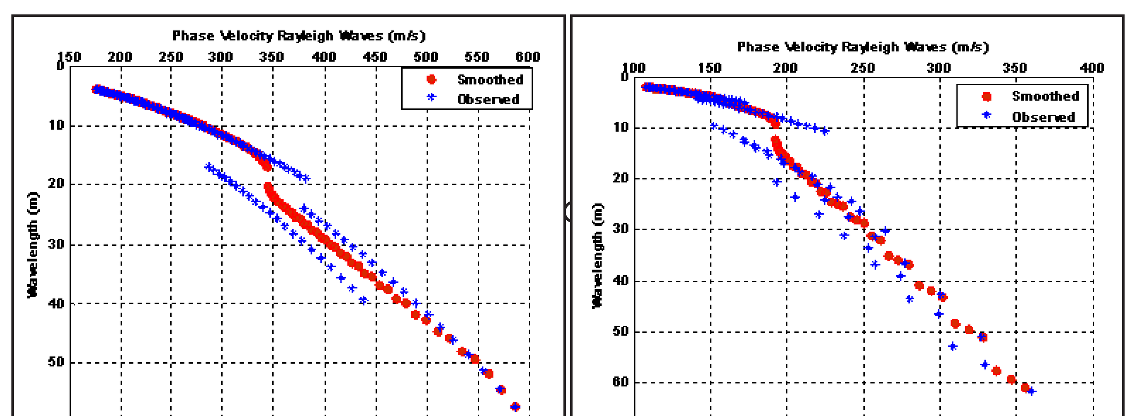

Fig. 3 Results from the inversion of the auto correlation function from which the phase velocity of Rayleigh waves was obtained

In the Circular SPAC case the parameterization of the subsoil model corresponded for a five layers soil model resting on the half space. Figure 4 shows the shear velocity model calculated for Linear and Circular Array (sites A and B).

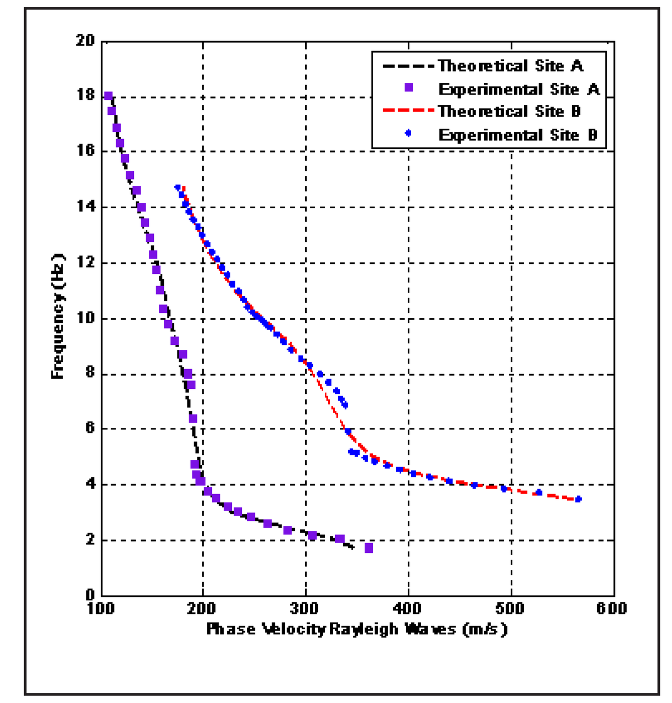

Fig. 4 Experimental (dots), and theoretical (dashed line) Phase velocity dispersion curves

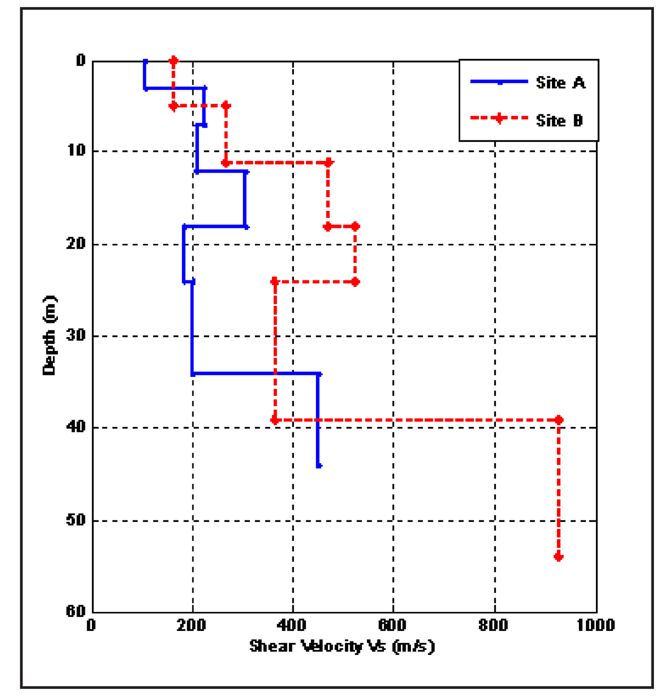

Fig. 5 Obtained shear wave velocity model profiles for sites A and B.

DISCUSSION AND CONCLUSIONS

The SPAC Linear array clearly shows a weak velocity inversion at the depth of 7- and 18-m. The velocity inversion at depth of 7-m of 15 m/s. probably results by the algorithm artifacts in the fitting process between the theoretical and the experimental curves. A real physical meaning of this velocity inversion, at this depth on the site is dubious. However the velocity inversion at the depth interval of 18- to 24-m is large enough that has non-dubious physical meaning of a change of the materials physical properties

The Circular SPAC clearly shows a velocity inversion at the depth of 24-m. in this case the inversion is slightly larger than 100 m/s.

Regarding to the frequency content and the wave type of AV measurements, the determination of dispersion curves indicate that surface waves are dominant. Moreover, it is assumed that a single mode is dominant and it may correspond to the fundamental vibration mode.

According to the local geological conditions of the area in which the experiments were conducted, the shear wave velocity profile with low Vs values agrees well with soft materials of Quaternary alluvial soil deposits (site A). The site with large Vs values agrees well with stiff materials of soil deposits derived from Cretaceous rocks (site B).

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