PROJECTIONS ANALYSIS OF SURFACE WAVES (PASW) - DESCRIPTION OF THE METHOD AND CASE STUDIES

Andrey Konkov, Institute of Applied Physics, Nizhny Novgorod, Russia
Andrey Lebedev, Institute of Applied Physics, Nizhny Novgorod, Russia
Sergey Manakov, Institute of Applied Physics, Nizhny Novgorod, Russia

Abstract

This study is intended to describe the PASW method and the results of its application. This technique is based on both the analysis of the dispersion and frequency dependence of the Rayleigh wave ellipticity. Unlike for SASW / MASW (Spectral / Multichannel Analysis of Surface Waves), during carrying out the PASW method there is no need for a priori information on the pressure wave velocity (or, in other words, on the Poisson's ratio) of the underlying layers. Thus, this technology allows one to reconstruct the velocity profiles of two body waves. By analogy with the names of SASW / MASW, the method is named PASW (Projections Analysis of Surface Waves). The study will describe the features of the technology, its advantages and disadvantages. The PASW method has been successfully used to solve various model engineering problems. The accent will be made on two cases: measuring the variations in soil characteristics under controlled saturation with water, and studying the effects of liquefaction.

Introduction

The SASW / MASW method has become popular for several reasons: (1) the ease of implementation, (2) characteristics of direct wave are analyzed, (3) when placing a seismic source on a surface, the Rayleigh wave has the highest energy among the other generated waves, what simplifies its extraction in the wave response of the medium. In the standard realization of the SASW / MASW method for medium's parameters reconstruction the Rayleigh wave dispersion chararacteristic is used solely, what allows determining only the shear wave velocity profile. Herewith, Poisson's ratio of the medium of study is assumed to be pre-specified. Such an approach eliminates the possibility of analyzing the variation with depth in the structure of the bonds in granular medium since lithological characteristics are largely associated with the value of Poisson's ratio.

It is known that in homogeneous half-space the ratio between amplitudes of horizontal displacement projection and vertical one (U_R/U_Z) is a function of Poisson's ratio and monotonically increases from 0.54 to 0.78 when decreasing the Poisson's ratio from 0.5 to 0 (Landau and Lifshitz, 1986). It was assumed and then clearly shown (Konkov et al., 2015a) that the dependence of this ratio on frequency provides sufficient knowledge about the distribution of Poisson's ratio in a vertically stratified medium, and the inverse problem solution in the case of considering variations of this parameter becomes more correct. Therefore we have modified the SASW / MASW method by taking into account the frequency dependence of the ratio of horizontal and vertical components of displacement in the Rayleigh wave along with the analysis of the dispersion characteristic and named it as projections analysis of surface waves (abbr.: PASW).

Projections Analysis of Surface Waves (PASW) Method

Let us start with illustrating the principles underlying the PASW method on a simple model example. Figure 1 shows the results of calculating the phase velocity and the ratio of the projections of the Rayleigh wave for a two-layer medium. The Poisson's ratios of the upper and lower layers are different, and the shear wave velocity in the lower layer is greater. The ratio of the thickness of the upper layer to the Rayleigh wavelength is plotted along the horizontal axis. The vertical axis represents the conventional units. Dashed lines correspond to values obtained for a homogeneous elastic half-space with parameters of the upper or lower layers.

It can be seen from Figure 1 that the Rayleigh wave phase velocity monotonely changes from the velocity corresponding to the lower layer to the velocity in the upper layer with a decrease in the wavelength. The projections ratio behaves in a more complex manner, but the trend remains the same in limiting cases. The behavior of the graphs in Figure 1 is explained by the fact that, depending on the wavelength, the number of layers involved in the oscillatory motion changes. This leads to a change in the "effective" or "averaged" characteristics of the Rayleigh wave. The ratio of displacement projections, like the phase velocity, is an excellent indicator of the elastic parameters of a layered medium.

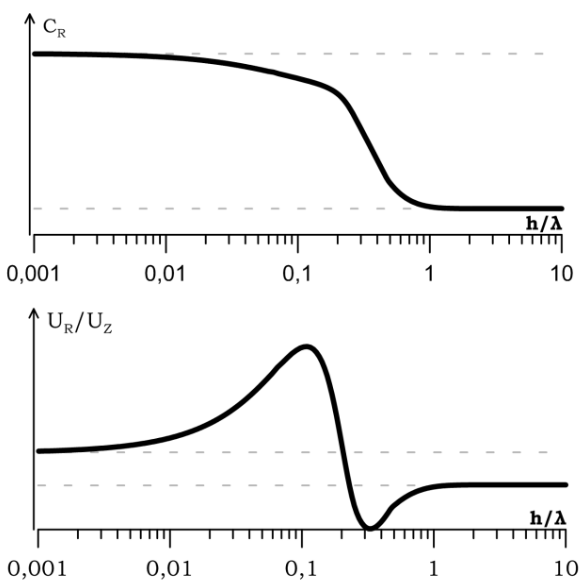

Figure 1: The phase velocity of the Rayleigh wave C_R and the ratio of the amplitudes of the horizontal and vertical displacement projections U_R/U_Z as a function of the normalized wavelength.

Experiment and Data Processing

In general, the procedure for obtaining field data and its processing consists of the following steps. At first, the measurements of full seismic response of the medium using a two-component geophone arrays (with vertical and horizontal polarization) are carried out. Two-component geophones can be replaced by two separate sensors with different orientations. A seismic source should be placed on the line connecting geophones. As a source, one can deploy either a shock (for example, a hammer) or a vibrator producing a vertical force. At the next step, the original data undergoes a double Fourier transform in order to change space-time coordinates to wavenumber-frequency ones. After this procedure, two so-called f-k spectrums for horizontal and vertical receivers are obtained. In the third step, the characteristics of the Rayleigh wave are derived from the f-k spectrums. The slope of characteristic on F-K spectrums corresponding to the Rayleigh wave determines its phase velocity, and the absolute values of the spectrum determine the projections ratio (Konkov et al., 2015a). At the last stage, the inverse problem is being solved, the parameters of which are the velocity profiles of the pressure and shear waves.

Earlier it was shown the possibility of using the proposed method for various tasks: monitoring of the liquid content in the soil (Averbakh et al., 2015; Averbakh et al., 2016), monitoring of the soil liquefaction (Konkov et al., 2015b), study of the "slow dynamics" effects in full-scale conditions (relaxation after pulse or vibrational exposure to the material).

Let us present a brief description of the results of applying the method for detecting the content of liquid in the soil and monitoring the soil liquefaction. Figure 2 depicts the velocity profiles reconstructed, depending on the water content in the ground. The amount of liquid in the soil changed artificially, through the loosened surface. Red color corresponds to the initial state of the soil, blue - to the state of the soil that corresponds to pouring out approximately 13 liters per square meter, black - to the end of the second day (35 liters per square meter). It is seen that pressure wave acts as a better indicator of the saturation of the soil, i.e. responds faster to changes in liquid content as compared with shear wave. At low degrees of saturation (second layer), the velocities of elastic waves, in general, decrease due to the disruption between grains. With more considerable increase in liquid content (what is typical for the upper layer), the pressure wave velocity increases since it is an integral magnitude of the stiffness of the skeleton and fluid in pores. The accuracy of determining the velocities in the third and fourth layers is low in reference to their variations during the experiment. So, the corresponding data are provided to demonstrate the general structure of the soil.

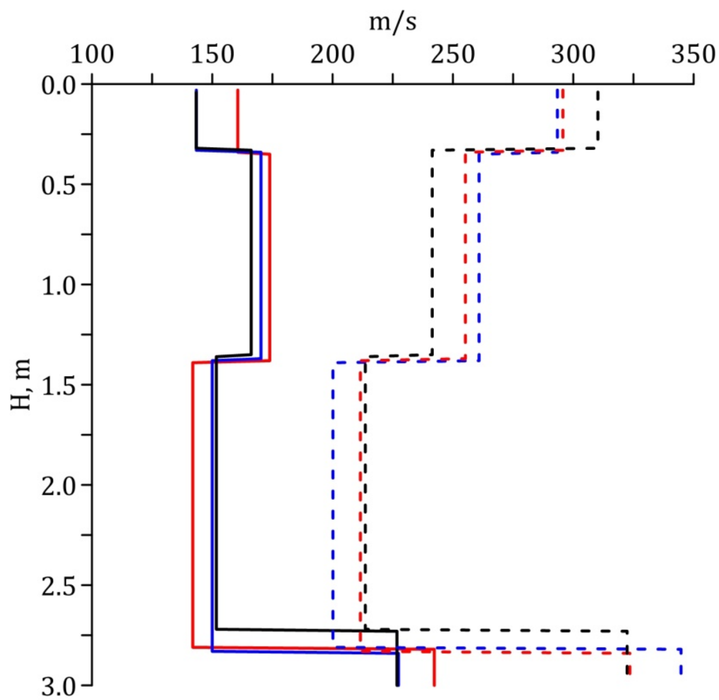

Figure 2: The reconstructed velocity profiles. Solid lines correspond to the shear wave, dotted ones – to the pressure wave.

In the second experiment, the phenomenon of soil liquefaction was investigated. Before its realization, a hose with holes was placed to the bottom of the artificially prepared ditch. Then the ditch was again covered with soil. During the experiment, water was supplied through the hose to the ground, until the soil became a liquefied state. Figure 3 shows in a brightness diagram a change in the phase velocity and the projections ratio in the Rayleigh wave. The main changes are observed in the high frequency domain, where the wavelength is comparable to the depth of the trench (40 cm). Relative variations for the projections ratio are higher than for the phase velocity. This is due to the fact that the velocity of the pressure wave for poorly consolidated soil increases with the addition of "hard" water. As a result of the pressure wave velocity change, the Poisson's ratio tends to 0.5. But as already outlined above, the projection ratio is sensitive to the Poisson's ratio. The decrease in the shear wave velocity is associated with the destruction of bonds between soil's particles upon saturation.

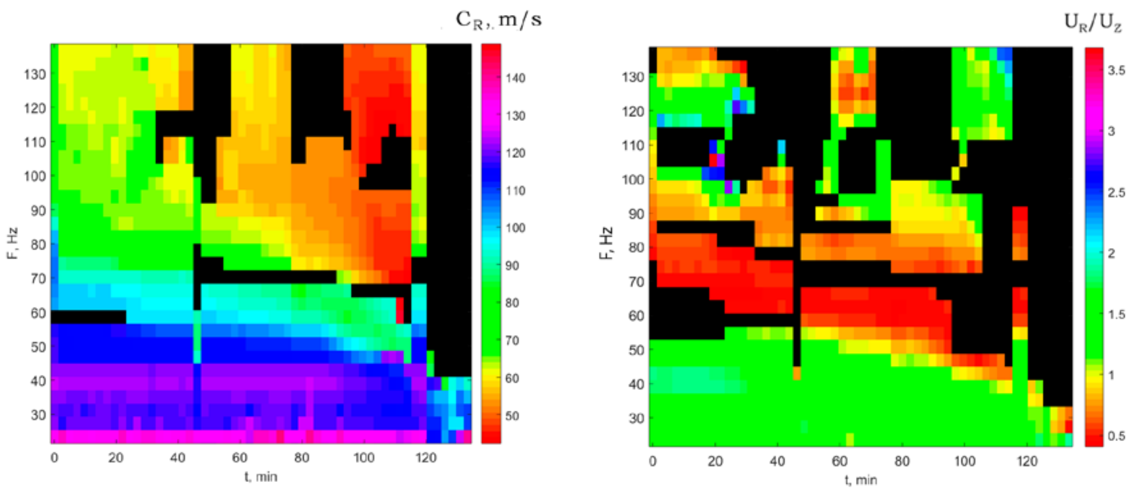

Figure 3: The change in the phase velocity C_R and the projections ratio U_R/U_Z in the Rayleigh wave in the experiment devoted to the soil liquefaction study. At frequencies above 60 Hz the relative change for the velocity is about 50%, and for the projections ratio – about 100%. The dark areas in the graphs are associated with an inability to correctly determine the characteristics of the Rayleigh wave there.

Conclusions

Let us sum up. The proposed development of the SASW / MASW method allows reconstructing not only the shear wave velocity profile but the profile of Poisson's ratio, which is associated with the nature of structure of bonds between grains in granular medium. The experiment conducted points to the possibility of practical realization of remote monitoring of the degree of saturation with fluid of the natural porous media.

The results of this study may be useful in conducting surveys for construction as well as in monitoring the environment when predicting undesirable geodynamic phenomena associated with the loss of stability (landslides, avalanches, etc.). The diagnostics of the degree of saturation is of obvious interest in location of pipeline leaks and in assessment of the degree of environmental contamination. Methods being employed in this study are universal and the results can be applied not only in geophysics but also in other technical applications where the surface waves are used, for example, in the analysis of quality of treatment of machinery parts.

References

Averbakh V.S., Gribov N.N., Konkov A.I., Lebedev A.V., Malekhanov A.I., Manakov S.A., Talanov V.I., 2016, New method of reconstruction of medium's inhomogeneities with use of Rayleigh wave: case studies, Bulletin of the Russian Academy of Sciences: Physics, Vol. 80, No. 10, 1314-1320.

Averbakh V.S., Konkov A.I., Lebedev A.V., Malekhanov A.I., Manakov S.A., Talanov V.I., 2015, Coherent seismoacoustic approach for engineering seismic surveys, Seismic Technologies, No. 2, 119–123.

Konkov A., Lebedev A., Manakov S., 2015a, Rayleigh Wave Dispersive Properties of a Vector Displacement as a Tool for P- and S-wave Velocities Near Surface Profiling, Springer Berlin Heidelberg, 2189–2206.

Konkov A.I., Lebedev A.V., Manakov S.A., 2015b, The acoustic study of soil liquefaction effects in-situ, The Journal of the Acoustical Society of America, Vol. 138, No. 3, Pt. 2 of 2, 1938-1939.

Landau L.D., Lifshitz E.M., 1986, Theory of elasticity, Butterworth Heinemann, 187 p.

Acknowledgments

The reported study was funded by RFBR according to the research project № 18-35-00653.