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GEOTECHNICAL PROPERTIES OF UPPER GEOLOGICAL LAYER BY MEANS OF EXPRESS MICROTREMOR STUDY

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The statistical evaluation of the *H*/*V* ratio of microseismic oscillations for determining the geotechnical properties of upper geological layer is proposed. Measurements have been carried out for different types of grounds and a good agreement of the results with its values of shear wave velocity is demonstrated. The proposed method is based on the usage of ultralow noise density 3-axis MEMS accelerometer, thus making the equipment very small and portable.

Key words: MEMS sensors, accelerometers, microtremor, seismicity, seismic microzonation, Nakamura method.

In the conditions of urbanized areas and in the presence of dense urban development, ordinary seismic observations must be carried out with greater details and depth. These problems stimulate the development of geophysical methods in recent decades for studying the geotechnical properties of a lower cost and higher productivity of measuring procedures. Among the available set of geophysical and, first of all, seismic methods, the Nakamura method (*H*/*V*) [1–2] is widely used in world practice, which allows using three-component registration of microseismic ground vibrations (microtremors) to obtain the amplitude-frequency characteristic of section and evaluate its geotechnical parameters, Fig. 1.

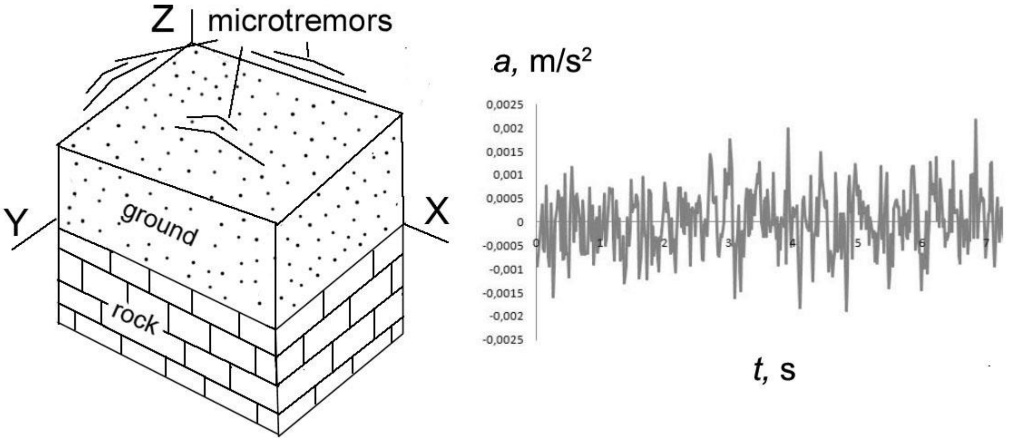

Fig. 1. Three-component registration of microtremors of the upper geological layers (left) and time fragment of the recording of acceleration component of ground vibrations (right)

The analysis of field measurements includes the acquisition of vibration spectra by means of Fourier transformation thus obtaining the ratio of horizontal to vertical microseismic components *H*/*V* depending on the frequency of oscillation. Nakamura's method allows modeling the 1-D vertical section of grounds in the format of shear wave velocities from the obtained *H*/*V* spectrum and further analysis of the geotechnical parameters of the stratified soil layer.

Nakamura, in his studies at many different sites, showed that in the soft soil the horizontal movement is greater than the vertical one. On the other hand, on firm ground, the horizontal and vertical movements are similar both in terms of maximum value and waveform. That is, the harder the soil, the smaller the value of *H/V* and closer to 1 (one). Very often, the determination of the peak value of the maximum value of *H/V* is sufficient for calculating the local seismicity of soils.

The *H*/*V* ratio at resonant frequencies of soil vibrations allows determining its mechanical properties. On the other hand, it is possible not to record and analyze the entire *H*/*V* spectrum, which takes a long time (about 2 hours), but to estimate the *H*/*V* ratio based on the static characteristics of the *H* and *V* signals in a much shorter period of time. The basis of our assumption is the calculation of the root square of deviations of each component of the microseismic signal, and not the analysis of the signal spectrum. The components of the standard deviation of the signal are defined by the following expressions:

$$\sigma_x = \sqrt{\frac{\sum (A_{xi} - M_x)^2}{N}}, \sigma_y = \sqrt{\frac{\sum (A_{yi} - M_y)^2}{N}}, \sigma_z = \sqrt{\frac{\sum (A_{zi} - M_z)^2}{N}},$$

where M_x, M_y, M_z – average values of three components of soil microoscillations; A_{xi}, A_{yi}, A_{zi} – values of three components of soil microoscillations. At the same time, even in the absence of microseismic fluctuations, the sigmas will not be zero, but will be determined by the temperature noise of the sensors and other technical reasons. Let's define “zero” fluctuations σ_{x0}, σ_{y0}, σ_{z0} which are obtained when ground is fully calm, i.e. when any vibration is absence.

If the sensor is affected by forces of a different nature, i.e., random forces determined by the sensor itself and the signals of microseismic vibrations, then the statistical dispersion will be the sum of the dispersions of the zero signal of the seismic sensor and the signal from microseismic vibrations. Therefore, the dispersion of microseismic signals $\Delta\sigma_x^2$, $\Delta\sigma_y^2$, $\Delta\sigma_z^2$ will be the difference between the total and “zero” records:

$$\Delta\sigma_x^2=\sigma_x^2-\sigma_{x0}^2,\ \Delta\sigma_y^2=\sigma_y^2-\sigma_{y0}^2,\ \Delta\sigma_z^2=\sigma_z^2-\sigma_{z0}^2.$$

Horizontal and vertical components of microseism is determined as follows:

$$\Delta\sigma_H=(\Delta\sigma_x^2+\Delta\sigma_y^2)^{1/2},\ \ \Delta\sigma_V=(\Delta\sigma_z^2)^{1/2}.$$

Thus, to obtain the values of root square of deviations of microseismic oscillations, it is sufficient to carry out a short-term (5–10 min) measurement of microseismic oscillation signals and a simultenous calculation of the statistical dispersions of these signals.

To test the proposed method of assessing the geotechnical properties of the grounds based on the $\Delta\sigma_H/\Delta\sigma_V$ ratio, we have used the method of recording microseisms with the ADXL355 MEMS sensor [3–5]. In recent years, significant progress has been made in the development of sensitive and compact acceleration sensors based on MEMS technology (micromechanical systems). Such sensors have already found their application in the operation of seismic stations and recording of microseisms. All these factors lead to the need to use advances in vibration recording technologies in microseismic research.

Areas with soils of known geotechnical characteristics were selected as observation polygons. These landfills are areas in the vicinity of the city of Lviv, which in the geological section in the upper part contain soils with known characteristics: peat, loam, marl, sandstone and limestone with a depth of 8–15 m. The areas with peat and loam are located in the vicinity of the city Dublyany, marl – in the quarry near Bohdanivska str., sandstones and limestones – within the educational geological training polygon of Medova Pechera, Fig. 2.

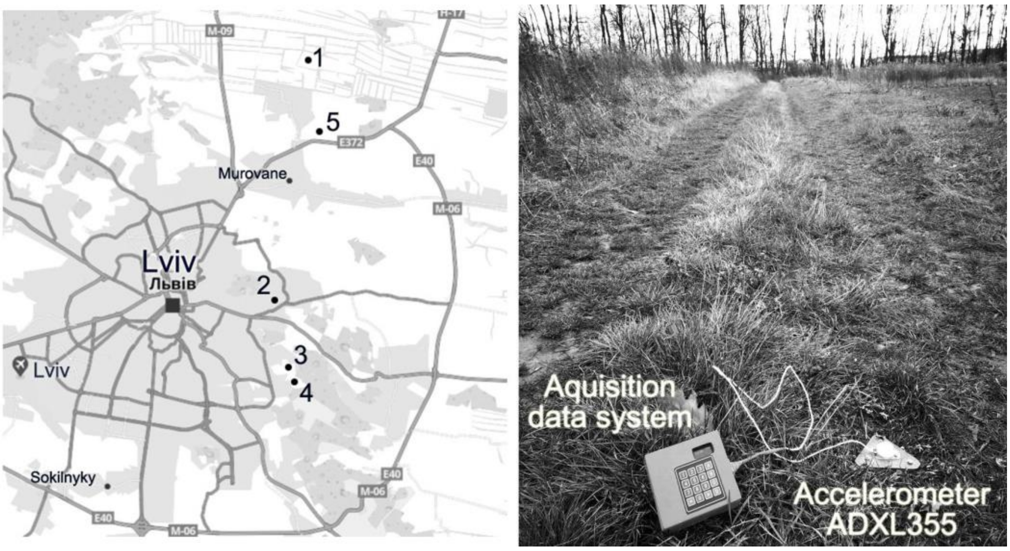

Fig. 2. The map with the marked points of express registration of microseismic vibrations (on the left); MEMS accelerometer ADXL355 and equipment for recording microseismic oscillations (right)

Each of the five recording points was observed for 10 min. A necessary condition for recording is the presence of sources of microseismic vibrations – highways, industrial plants. If there were no such sources of microseisms nearby, then vibrations were created by walking, stomping near the observation point in a radius of no closer than 5 m. Zero vibrations were recorded once at night on a concrete floor at the lomg distance from man-made vibrations.

Sediment type, observed values of $\Delta\sigma_H/\Delta\sigma_V$ and shear wave velocity

Point	Sediment type	$\Delta\sigma_H/\Delta\sigma_V$	V_s, m/s
1	Peat	3.1	90–120
2	Marl	1.2	800–1500
3	Sandstone	1.1	1200–1800
4	Limestone	1.5	1200–2000
5	Loam	1.7	200–300

Table shows the results of observations for 5 points. From the obtained results, a general regularity is observed – the harder the soil the smaller the value of $\Delta\sigma_H/\Delta\sigma_V$. For example, for peat this value is equal to 3.1, and for sandstone – 1.1. In general, these values agree well with Nakamura's method, in which the harder the soil, the lower the *H*/*V* ratio. In the *H*/*V* method, the ratio at resonant frequencies is taken. In our method the $\Delta\sigma_H/\Delta\sigma_V$ ratio is avareged for whole spectrum. Fig. 3 shows the dependence of the velocity of the shear seismic wave on the values of $\Delta\sigma_H/\Delta\sigma_V$. Dotted line indicates the area of possible values of velocity of mentioned types of grounds. This dotted area can be considered as correlation cloud of V_S vs $\Delta\sigma_H/\Delta\sigma_V$.

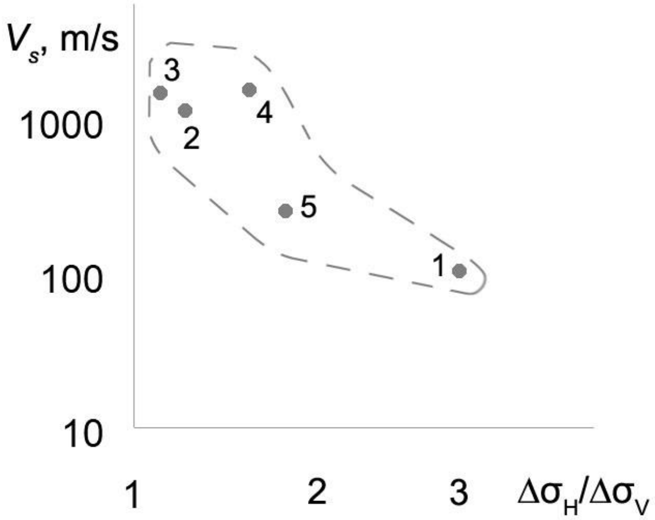

Fig. 3. Correlation between $\Delta\sigma_H/\Delta\sigma_V$ and the values of the velocities of shear seismic waves for grounds of different hardness. The range of possible velocities Vs is circled with a dotted line

Conclusions

Based on the results of the study of short-term (10 min) recordings of microseismic vibrations in areas with grounds of different mechanical properties using a three-component MEMS sensor, the following conclusions were made:

1. Calculation of the average deviation of signals of microseismic vibrations allows estimating the ratio $\Delta\sigma_H/\Delta\sigma_V$ as a simpler case of Nakamura's method (*H*/*V* method).
2. Express analysis of geotechnical properties of grounds and rocks is to calculate the ratio $\Delta\sigma_H/\Delta\sigma_V$, which serves as an approximate estimate of the mechanical properties of grounds and rocks.
3. Since shear seismic waves are characteristics of seismic properties of grounds, $\Delta\sigma_H/\Delta\sigma_V$ can be used to calculate the change in local seismicity of grounds.

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Геотехнічні властивості верхнього геологічного шару за даними коротких мікросейсмічних досліджень

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У статті запропоновано проводити статистичну оцінку співвідношення нетривалих мікросейсмічних коливань *H/V* для визначення геотехнічних властивостей ґрунтів. Проведено вимірювання для різних типів ґрунтів і вказано на добру узгодженість результатів з характеристикою ґрунтів за значенням швидкості поперечної сейсмічної хвилі. Запропонований метод базується на використанні MEMS акселерометра з ультранизьким рівнем шумів і високою чутливістю. Обладнання з сенсорами MEMS є легким і портативним.