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MSc. Krzysztof Fuławka
Supervisor: prof. dr hab. inż. Witold Pytel
Supportive supervisor: dr inż. Piotr Mertuszka

Abstract of doctoral thesis

Dominant frequency and rotational components of seismic wave in slope stability analyses

The correct evaluation of the slope stability subjected to additional dynamic loads is one of the key problems posed by geotechnical engineering. Despite the intensive development of methods for monitoring the stability of geotechnical objects and the continuous enrichment of numerical methods with more complex calculation algorithms, catastrophic failures of slopes have been observed in the last decade with a frequency of more than three events per year. Therefore, currently used methods of geotechnical risk evaluation should be examined in terms of their reliability to define if used assumptions allow to fully reflect the actual characteristics of e.g. a seismic load generated by earthquakes or mining tremors. When analyzing the current achievements in the field of geotechnical stability calculations, it can be observed that most of the analyses are performed under pseudo-static conditions, i.e. based solely on the maximum amplitude of acceleration / velocity / displacement of seismic vibrations, even though there are methods available to perform a detailed numerical analysis fitted to dynamic conditions, both in two and three dimensions. Moreover, all slope stability calculations performed not only in Poland but also around the world, are based solely on the translational components of the seismic wave. Seismic rotation is completely neglected in this type of analysis. Such a situation is related to the fact that the monitoring devices for direct measurements of rotational seismic motion are a novelty in seismological practice. As result, there are no extended databases on the characteristic of seismic rotation generated by both induced and natural seismicity.

In the first part of this study, the significance of the dominant frequency of seismic vibrations on the stresses and displacements changes within the slope has been analysed. The research has been performed for the near-field seismic records. Computations were carried out by applying dynamic calculations in the finite element method. Then, using the design of experiment (DOE) method and the statistical method of the response surface, the influence of each parameter defining the seismic load, i.e. amplitude, time and frequency, on the change of the factor of stability (FS) was determined.The dynamic change of the FS coefficient for each of the

analyzed systems was determined thanks to combining results obtained with the use of the Limit Equilibrium Method (LEM) and Finite Element Method (FEM). As a result, based on the outcomes of numerical and analytical calculations and statistical analysis, a procedure for determining the dynamic change of the safety factor was developed by using the hybrid LEM-FEM approach, which is in accordance with Polish and European legal regulations.

In the second part of this thesis, the possibility of implementing the rotational components of seismic vibrations into numerical calculations was analyzed. Information on the magnitude of the seismic rotation, the dominant frequency and the duration of the rotational movement induced by propagating seismic waves was determined based on the results of preliminary 11-month long, seismic measurements carried out in the Legnica-Głogów Copper Basin (LGCB) in 2019. In total, waveforms generated by 39 induced high-energy tremors were recorded at epicentral distances from 300 m to 10,000 m. On the basis of the collected data, Ground Motion Prediction Equations (GMPE) were developed, which were the basis for estimating the level of seismic rotation based on information on the energy and distance of the seismic event from the measurement stations. New GMPE made it possible to simulate the rotation of the object associated with a potential mining tremor not recorded during measurements. Then, using the Rayleigh wave equations, attempts were made to implement the rotational components of the seismic wave into numerical calculations. This was made with the finite element method using NEi Nastran numerical code. Due to software limitations, the seismic rotation was included in the calculations indirectly, i.e. based on the rotational notation, the maximum values of translational displacements resulting from the observed ground tilt were calculated and used in the calculation code. For all recorded high-energy tremors, the amplitude of displacements resulting from the rotational records and the size of displacements resulting from standard translational records were determined. Comparing these two values, a criterion that determines the significance of rotational components in the analysis of slope stability depending on the energy of the shock and the dominant frequency of seismic vibrations was developed. Finally, it has been proved that it is possible to indirectly take into account the rotational components of seismic vibrations in numerical calculation codes and that in the case of low-frequency, high-energy tremors with energy greater than E9 J, rotational components can play a key role in the analysis of slope stability, and should not be overlooked.

The methods and procedures presented in this paper were developed for the conditions of induced seismicity in LGCB conditions, however, the presented approach is a universal solution and can be successfully used for stability analyzes in other regions of natural or anthropogenic seismic activity.

Krzysztof Fuławka