

Seismic tremors, whether of natural origin or induced by human activity, are increasingly recognized as a real threat to large engineering structures. This is particularly relevant for geotechnical constructions such as slopes of geotechnical objects, embankments or tailings storage facilities, which are often located in close proximity to mining areas. In such regions, so-called induced seismicity occurs – ground vibrations caused by mining operations. This phenomenon may compromise the stability of these structures and, in extreme cases, lead to engineering failures.

Despite growing awareness of these threats, currently used methods for evaluating the stability of earth structures are still based on simplified assumptions. In most analyses, the limit equilibrium method (LEM) is applied, which – although proven under static conditions – fails to consider many key dynamic parameters. Specifically, it is based solely on peak ground acceleration and neglects critical factors such as the duration and frequency of ground shaking. Moreover, current computational approaches completely ignore the rotational components of ground motion and only account for translational seismic records. However, the latest studies show that in the so-called near field (i.e., in close proximity to the source of seismic vibrations), rotational ground motions can significantly influence stress distribution within the soil and, consequently, the mechanisms leading to slope failure.

The objective of the proposed project is to develop and test a new approach to the stability analysis of large geotechnical structures that accounts for the full spectrum of seismic motion – known as 6-DoF (six degrees of freedom), comprising three translational and three rotational components. The project is innovative in its integration of real seismic event data, containing not only information about the direction and strength of the vibrations, but also their duration and frequency characteristics.

A key part of the study will be the use of specialized electrochemical rotational sensors that enable precise measurement of the rotational components of ground motion. This technology is rarely used in engineering practice but holds significant potential for improving the quality of seismic risk analysis. Measurements will be conducted in areas with high levels of induced seismicity, including the vicinity of the "Żelazny Most" tailings storage facility – the largest in Europe and one of the largest in the world. Due to its size, complex geotechnical structure, and proximity to active mining operations, this facility is an ideal natural laboratory for field research.

The data collected from field measurements will be processed and used in a hybrid computational model combining the advantages of the classical limit equilibrium method (LEM) with the modern finite element method (FEM). This hybrid approach will allow for the simulation of not only stress and displacement distributions, but also the influence of spatially and temporally variable dynamic seismic loads, including rotational components. This will make it possible to assess the extent to which these previously neglected factors contribute to the weakening of earth structures and to develop more reliable safety factors.

Addressing this topic is a response to real needs in geotechnical engineering, especially in the context of climate change, increasingly intensive resource extraction, and growing safety requirements for critical infrastructure. The project will fill an important gap in the current approach to stability analysis and contribute to the development of design methods for structures resistant to dynamic seismic loads.

The expected outcomes of the project include:

- Development of a new, comprehensive method for assessing the stability of earth structures under dynamic conditions;
- Identification of the role and importance of rotational ground motion components in seismic engineering;
- Establishing a foundation for new design guidelines and technical standards;
- Providing knowledge applicable to hazard monitoring systems and risk analysis in the mining and energy sectors.