NUMERICAL ANALYSIS OF LIQUEFACTION POTENTIAL OF A TAILINGS DAM

PhD program in Civil and Environmental Engineering

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Abstract. Besides producing raw materials essential for contemporary societies, the mining industry also generates millions of tons of waste every year. Most of this waste is represented by tailings consisting of saturated fine non-plastic soils, generally arranged in structures called tailings dams located at a short distance from the mine. These structures contain the tailings through an embankment made with the coarser fraction of residual materials. The rate of failure for these structures is high and often results in the release of the materials in the downstream territories with catastrophic consequences for the population, the environment, and the local economy. In recent decades, the use of advanced numerical models to predict the mechanical behavior of these structures, subjected to different types of loading, initial and boundary conditions, has become increasingly widespread. Contrary to the more classical methods, such as the limit equilibrium, which only determines the safety factor for stability, these advanced tools can quantify stress distributions, deformations, accelerations and pore water pressures over time. In this PhD thesis, the liquefaction potential under seismic conditions of a tailings dam located in southern Tuscany was analyzed with a dynamic finite element model implemented in the OpenSees software. The constitutive models were calibrated based on the results of field tests and cyclic laboratory tests.

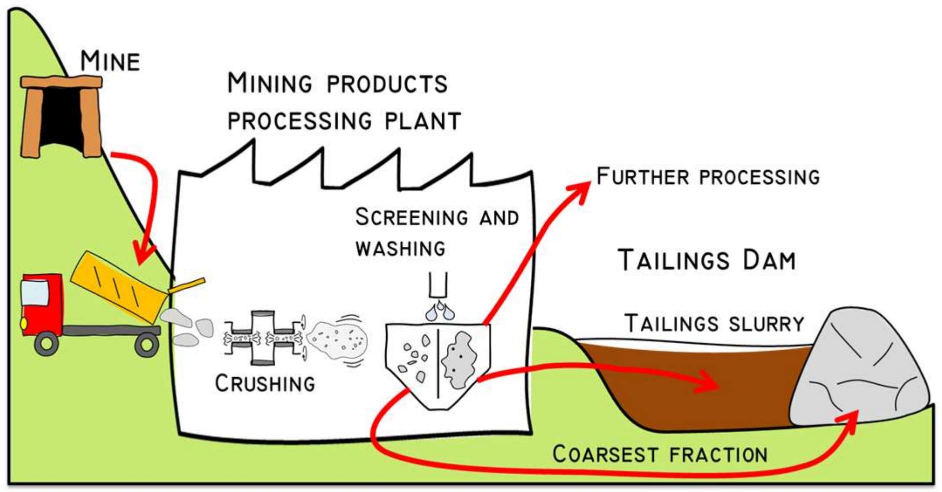
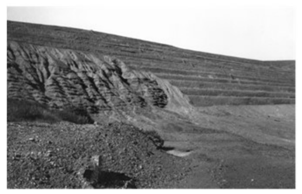


Fig 1. Tailings dams creation

Overview of the tailings storage facility. The analyzed tailings dam has a crest height of about 36.5 m above ground level and contains a volume of about 600.000 m3 of slurry. The dam built with the upstream method has the configuration shown, in which it is possible to identify three geotechnical units: settling tailings (U1), embankment material (U2) and clay foundation (U3).

Numerical model definition. A 2D finite element model of the structure was created with OpenSees software to examine its liquefaction potential under seismic conditions. The domain was discretized with a mesh incorporating 1147 quadrangular elements, each with the longest side of approximately 3 m. The dimensions of the elements were determined considering the shear wave velocity propagation in the material and the maximum frequency of the seismic signal. The water table was placed approximately at the level of the basin top to simulate fully saturated conditions. Different constitutive models were assigned to the three geotechnical units, to represent the diverse mechanical behavior of these materials. The SANISAND constitutive model was assigned to the U1 geotechnical unit, while PM4Sand was used for U2, and the Pressure Independent Multi Yield PIMY model was given to U3. The calibrated parameters for the SANISAND model were validated through the comparison of undrained cyclic triaxial tests results with numerical simulations of the same test. It was not possible to apply the same procedure to the U2 material, as it contains a large coarse fraction which prevents laboratory tests from being carried out. Therefore, the parameters attributed to the PM4Sand constitutive model were estimated by field surveys (CPT, SPT). Finally, for the PIMY model the parameters suggested by the authors in were used. The nodes at the base of the model were prevented from translating in the vertical direction and had the properties of a Lysmer-Kuhlemeyer (1969) dashpot. Elements close to the lateral boundaries of the domain were assigned a large thickness, to allow them to absorb the seismic waves and simulate free-field conditions. The seismic input obtained using SCALCONA 3.0 software, as suggested by the Tuscany Region guidelines for a 2475-year return period, was deconvoluted to bring the signal to the basis of the 2D model.



Results and conclusion. The performed analysis consisted of two steps. First, a gravitational load was applied to calculate the initial stress distribution. Later, a dynamic analysis was conducted in which the seismic load was applied to the nodes at the base of the model. The liquefaction potential was evaluated as

$$\zeta = -\frac{\sigma'_{ii}\left(t^{dyn}\right) - \sigma'_{ii}(t=0)}{\sigma'_{ii}(t=0)}$$

Where $\sigma'_{ii}\left(t^{dyn}\right)$ is the trace of the effective stress tensor at a precise moment of the earthquake and $\sigma'_{ii}(t=0)$ is the trace of the effective stress tensor before the earthquake. It is possible to observe (Fig. 2) that the maximum ζ , recorded at the end of the strong motion, reached is about 0.18 in some limited areas of the embankment.

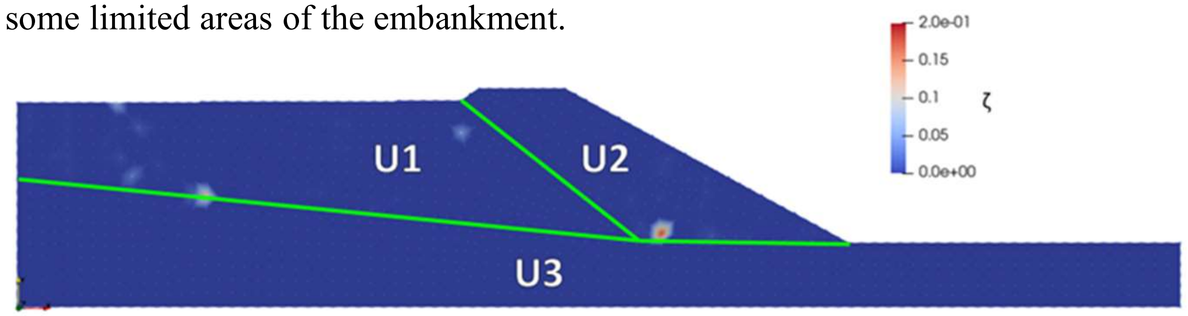


Fig 2. Liquefaction potential evaluation through effective stress ratio ζ.

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