**PROJECT TITLE: PRECURSORS OF FAILURE IN MINE TAILINGS DAMS**

**I. PROJECT STATEMENT**

The aim of the project is to obtain data for design of an early warning system to predict the conditions that could result in the onset of failure in a mine tailings storage facility called a tailings dam. This will be accomplished by

* quantifying, with laboratory-scale strength tests and geophysical methods such as seismic probing, mechanical indices of mine-tailings material before and after failure;
* correlating the seismic measurements to traditional indicators of performance such as soil strength affected by earth and water pressures; and
* validating *in situ* the utility of seismic and conventional monitoring of mine tailings.

The iron range area in northern Minnesota is home to numerous basins of mine tailings, which are essentially the remains of finely crushed rock after iron ore extraction. Currently there are six operating tailings storage facilities managed by their owners and under review by their engineering teams, while numerous (historical) tailings basins have been reclaimed or abandoned after use. The performance of tailings dams from a geoengineering perspective has been excellent, as no catastrophic events or failures have been recorded in the State of Minnesota. Unfortunately, this has not been the case in other locations. Although rare in the US, failure of containment systems for mine tailings can be deadly. A recent example is the January 25, 2019 collapse of Vale’s Brumadinho iron ore tailings dam in Brazil.

The mining and processing of low-grade metallic ores result in large quantities of material (finely crushed rock) in the form of a slurry – a mixture of water and clay-to-sand size particles. The slurry is retained in tailing storage facilities, where the solids settle with time, and the water is recycled to the processing plant or treated prior to discharge. Mining operations of 50,000 tons or more per day are common, with greater than 95% or more of the mined rock being non-ore material, which must be stored in tailings dams. Thus, the main function of a tailings dam is to store solids permanently and to manage process water temporarily. The length of time that water must be retained ranges from a few days to months, depending on gradation and mineralogy of the tailings. According to a 2006 joint report by the International Commission on Large Dams (ICOLD) and the United Nations Environment Program (UNEP), “… dams are prestigious structures used to … store water, whereas tailings dams are required for the storage of unwanted waste, desirably at minimum cost.”

A tailings dam is a “work in progress” since its size is dependent on how long a mine operates and at what rate the ore is processed. Continuous dam management is critical and conventional monitoring systems are often used. However, an early warning system for predicting the conditions that could result in the onset of failure in mine tailings has not been developed. To date, very little research has been performed on mine tailings specifically in regards to seismic and strength characteristics. Much of the published research contain only a few tailings-type materials in their database. This research aims to expand this body of knowledge.

**II. PROJECT ACTIVITIES AND OUTCOMES**

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| **Activity 1 Title: Laboratory testing of mine tailings combined with strength testing and seismic probing**  **Description:**A literature review of the current tailings dams within the State, active and non-active, will be completed. Triaxial compression tests with seismic probing on 12 specimens of reconstituted tailings material from one site, which is representative of the some of the materials found in northern Minnesota, will be performed. Specimens will be saturated and checked prior to testing. Consolidation under four different hydrostatic pressures will simulate field conditions. In essence, each compression test will involve seismic probing throughout the testing process and stress path, with 50 measurements of travel time recorded. The 12 specimens, each with 50 seismic records and corresponding displacement and loading conditions, will result in a wealth of data for a “machine learning” approach.  **ENRTF BUDGET: $108,000** | | |  |
| **Outcome** | **Completion Date** |
| *1. Literature review of tailings dams within the State of Minnesota* | *Mar 31, 2021* |
| *2. Triaxial compression tests with seismic probing of reconstituted tailings from one site* | *Jun 30, 2021* |
| *3. Database of displacement, stresses, pore pressures, and velocities* | *Jun 30, 2022* |
| **Activity 2 Title: Correlation between seismic and traditional indicators**  **Description:**Artificial intelligence and machine learning algorithms will be customized and applied to the obtained data sets. Despite its tremendous potential, this approach has not been applied to the mine tailings problem. The available measurements will be split into a training data set and a validation data set, designed to test the effectiveness of the proposed data interpretation methodology. The featured deformation, pore pressure, confining and axial stresses, and seismic velocities data will be interpreted both by the data learning approach and the construction of nomograms using traditional regression techniques.  **ENRTF BUDGET: $92,000** | |  | |
| **Outcome** | **Completion Date** |
| *1. Artificial intelligence and machine learning algorithms* | *Dec 31, 2021* |
| *2. Charts using traditional regression techniques* | *Mar 31, 2022* |
| **Activity 3 Title: Field testing of mine tailings cross-hole seismics and surface wave analysis**  **Description:**The most suitable form of a seismic survey such as the cross-hole testing or the spectral analysis of surface waves will be used to probe significant volumes of *in situ* mine tailings for seismic wave speeds at several frequencies of excitation. The obtained seismic measurements and their interpretation resulting from the analysis in activity 2 will be applied and correlated with the conclusions on stability using existing methods.  **ENRTF BUDGET: $98,000** | | |  |
| **Outcome** | **Completion Date** |
| *1. Cross-hole seismics at one site* | *Sep 30, 2022* |
| *2. Spectral analysis of surface waves* | *Mar 31, 2023* |

**III. PROJECT PARTNERS AND COLLABORATORS:** The UMN team will be led by Professors Joseph Labuz and Bojan Guzina, Department of Civil, Environmental, and Geo- Engineering. It will include one graduate and one undergraduate student. Labuz is an expert in lab testing and behavior of fluid-saturated materials; Guzina has extensive experience in seismic imaging and machine learning. Barr Engineering, industry leaders in mine tailings design and monitoring, will assist in specimen preparation and field testing at an available site.

**IV. LONG-TERM IMPLEMENTATION AND FUNDING:** The ultimate, long term goal of the project is to develop an early warning detection system for identifying failure of mine tailings. Stakeholders will have a tool to quantitatively assess a site-specific tailings dam. Further, this will be the first study in the State of Minnesota to investigate how seismic imaging and machine learning can provide relevant information on *in situ* behavior of mine tailings. Once the data are obtained from this study, the next step will be to design and implement the early warning detection system.

**V. SEE ADDITIONAL PROPOSAL COMPONENTS:**

**A. Proposal Budget Spreadsheet B. Visual Component or Map**

**F. Project Manager Qualifications and Organization Description**