Time-To-Failure Prediction of Fine-Grained Soil Slopes Subject to Weather-Driven Deterioration

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Introduction

Since the 1800s, long slopes have been constructed to support infrastructure such as railways, highways, and flood embankments. Unexpected failures of deteriorating, aged infrastructure can have severe societal and economic consequences and can, in the worst cases, lead to fatalities. Slope failures in earth infrastructure occur frequently, and globally, they cause approximately $4 billion in property damage and nearly 1000 human casualties every year.

Embankments remain a critical piece of infrastructure in transportation and flood defense. Embankments constructed from clays experience a suite of weather-driven deterioration processes that lead to a progressive loss of hydromechanical performance. This study aimed to forecast the time to failure of aging, deteriorating clay embankments supporting transportation infrastructure.

Study Methods

Since weather-driven deterioration mechanisms contribute significantly to the overall deterioration of earth infrastructure assets, a multi-phase numerical modeling approach was developed to simulate the long-term, weather-driven hydromechanical behavior of clay embankments. This approach modeled and simulated the behavior of a number of well-documented embankment failure case studies that had sufficient available data to derive the necessary soil properties and climate records. Numerical models were developed for a total of 34 case studies, and numerical simulations were performed to predict the time to failure of the embankments.

Specifically, FLAC (Fast Lagrangian Analysis of Continua) software v8.1 was used to create numerical models for the embankment failure case histories and conduct multi-phase hydromechanical numerical simulations. The code used an explicit finite difference method to perform numerical computations of grided models for geotechnical engineering applications. The software allowed the performance of coupled multi-phase hydromechanical analyses. This study utilized the user-defined subroutines that were developed and implemented by Morsy et al. to allow transient calculations of coupled hydromechanical behavior.

Long-term weather-driven deterioration of earthworks can be modeled and simulated numerically. Such models, once developed, can be used to produce practical predictions to aid in planning.

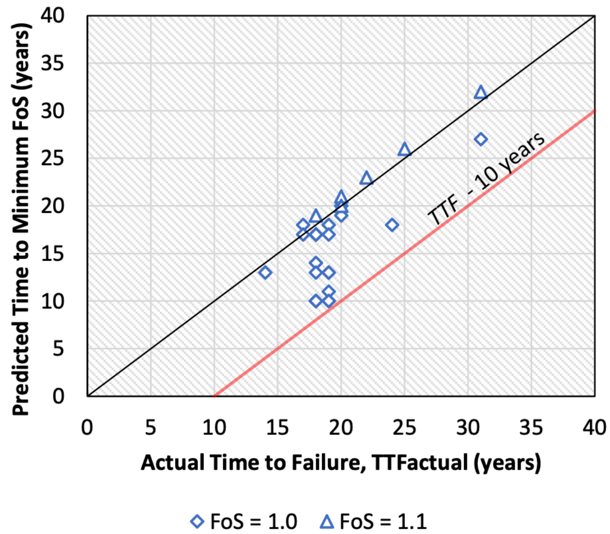
Findings

Predictions compared well with the actual times to failure reported for the simulated case studies. The modeling approach proved efficient in predicting the time to failure of embankments prone to weather-driven deterioration and produced data necessary for improving infrastructure asset management. The theoretical factor of safety calculation for infinite slopes was found to predict failure accurately.

Policy Recommendations

Based on the observations from the numerical results, it is recommended that a Factor of Safety (FoS) target against weather-driven shallow slides is introduced in evaluating the stability of existing embankment slopes and new embankment slopes. An FoS of 1.1 to 1.2 may be reasonable for existing embankments, considering the temporary nature of the conditions causing shallow slides. For new designs, an FoS of 1.3 may be recommended.

Overall, the numerical modeling approach proved efficient in producing data necessary to develop deterioration models. These models could improve infrastructure asset management, reducing the risk of catastrophic failures and improving safety.



Comparison between predicted time to minimum factor of safety (FoS) and actual time to failure (TTF_{actual})

About the Author

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Dr. Morsy is an Assistant Professor in the Department of Civil Engineering and Construction Engineering Management at California State University Long Beach. His research focuses on geotechnical infrastructure deterioration and asset management, climate change impacts on geotechnical and geoenvironmental infrastructure, geosynthetics applications in geotechnical engineering, and engineering solutions for sustainable built environment.

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