Numerical Modeling of Climate Change Impacts on Transportation Embankments

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Introduction

Embankments are key transportation infrastructure features providing essential support for long, linear stretches of transportation infrastructure. Clay embankments are susceptible to weather-related deterioration processes that can gradually compromise their stability and lead to unexpected failures. California's recent rainy season of 2017, following a five-year drought, has caused severe flooding, landslides, and coastal erosion, totalling over $1 billion in highway damages for Caltrans. Given that California plays a pivotal role as a major provider of goods and services to the broader United States, any disruption in its transportation system has the potential to cause calamitous repercussions for the entire nation, as per California's Fourth Climate Change Assessment.

In a survey on surficial embankment failures reported in NCHRP Synthesis 617, California is responsible for approximately 15,092 road miles, of which around 40% are estimated to be susceptible to surficial failures. Approximately 80% of embankment failures in California are considered surficial. Surficial embankment failures commonly occur following severe weather events or a sequence of events, a pattern that has also been observed in California. These types of failures typically occur in California embankments that are 20 to 40 years old, assuming they were designed and constructed appropriately.

Study Methods

Climate change, along with the associated shifts in weather patterns, is projected to adversely impact the weather-related deterioration processes leading to exacerbated failures and/or shorter service life. Additionally, climate change is projected to increase the frequency of extreme precipitation events, leading to an increase in embankment failure potential. This study evaluated (1) the effect of future climate scenarios on the long-term performance of clay embankments, and (2) the effect of extreme precipitation events brought about by future climate scenarios on the hydromechanical response of clay embankments to these extreme events. The study area examined was Central Los Angeles, CA. A multi-phase hydromechanical geotechnical model was developed for exemplary high plasticity and low plasticity clay embankments with varied side slope angles. Overall, it was concluded that climate change is generally projected to adversely affect the performance of clay embankments both in the long-term and during extreme events.

Findings

The following conclusions were drawn from the evaluation of the effect of future climate scenarios on the long-term performance of transportation clay embankments:

- Higher temperatures are expected to dry embankment slopes, while increased precipitation will make them wetter. High-plasticity clays will experience greater seasonal fluctuations in soil moisture. Extreme rainfall events may temporarily alter soil moisture but are unlikely to produce significant long-term effects.
- Higher temperatures are expected to lead to smaller outward slope displacements and an insignificant change in vertical displacements, while increased precipitation is expected to lead to larger outward slope displacements. High plasticity clay embankments are much more susceptible to slope deformation than low plasticity clay embankments. Extreme rainfall events may lead to larger long-term irrecoverable slope deformation, even when the annual average precipitation remains unchanged.

The following conclusions were drawn from the evaluation of the effect of extreme precipitation events induced by future climate scenarios on the response of clay embankments to these extreme events:

- Future extreme rainfall events are likely to lead to wetter slopes. High plasticity clay embankments are much more susceptible to damage from future extreme rainfall events than low plasticity clay embankments.
- Near-surface soil strength declines during extreme precipitation events. This decline increases with increasing duration of the event. Both high and low plasticity clay embankments are more sensitive to event duration than event intensity. High plasticity clay embankments are likely to experience irrecoverable deformation during 100-year extreme events that last for more than two days, whereas low plasticity clay embankments are much less susceptible to irrecoverable deformation.

Policy Recommendations

This study provided valuable insights into the effect of climate change on the long-term performance of clay embankments. Notably, the results of the study indicated that the rate of increase in irrecoverable vertical displacements reduced with time as soil swelling reaches its potential, whereas the increase in irrecoverable outward displacement persists with time. Swelling-induced shallow slides are likely triggered under these conditions. In the Los Angeles climate, this is likely to occur after 70-80 years in clay embankments with side slopes between 2:1 and 3:1 and after 20-40 years in clay embankments with side slopes between 1.5:1 and 2:1. Existing embankments constructed from high plasticity clays that are older than these limits and whose failure consequences are high may require risk mitigation strategies, such as monitoring of side slope displacement and near-surface soil moisture.

The study also provided insights into the effect of climate change on the response of clay embankments to extreme events. Notably, the results of the study indicated that high plasticity clay embankments are highly susceptible to the extreme precipitation events with a 100-year return period, especially those with durations larger than two days. Extreme precipitation events are much less likely to have detrimental impacts on low plasticity clay embankments than on high plasticity clay embankments.

The study shows how numerical models can be used to forecast the performance of geotechnical infrastructure. A simplified framework was presented to show how numerical predictions of long-term performance can integrate into geotechnical asset management.

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To Learn More

For more details about the study, download the full report at transweb.sjsu.edu/research/2457

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