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Evaluation of Long-Term Performance of Transportation Earthworks Prone to Weather-Driven Deterioration Under Changing Climate

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Introduction

Embankments are a key feature of the transportation network, supporting long, linear stretches of highways and railways in California and globally. Earthen embankments are susceptible to weather-related deterioration processes that can gradually compromise their stability and even lead to unexpected failures. California's 2017 rainy season, following a five-year drought, caused severe flooding, landslides, and erosion, totalling over $1 billion in highway damages. Given that California plays a pivotal role as a major provider of goods and services to the broader United States, any disruption in its system is likely to cause repercussions for the entire nation.

Weather-driven deterioration involves a variety of insidious processes, including seasonal changes in soil moisture and pore pressure. These processes make it difficult to identify the current condition of existing assets and predict their rate of deterioration; climate change is predicted to worsen weather-driven deterioration.

Study Methods

This study evaluated the impact of climate change on the rate of weather-driven deterioration of embankments in Los Angeles and Sacramento. A multi-phase hydromechanical geotechnical model was developed for an exemplar clay embankment to simulate the long-term performance of an embankment subject to a climate-controlled flux boundary. The model was used to perform numerical simulations of four future climate scenarios:

- Scenario (1) no average temperature or average precipitation changes.
- Scenario (2) +3°C average temperature change and −12.5% average precipitation change.
- Scenario (3) +3°C average temperature change and no average precipitation change.
- Scenario (4) +3°C average temperature change and +12.5% average precipitation change.

Findings

Performance indicators were obtained from the numerical simulations to compare the effect of climate change on embankment deterioration in Los Angeles and Sacramento. Overall, it was concluded that climate change is generally projected to adversely affect the long-term performance of clay embankments. The following insights can be drawn from the study:

- The increase in future temperature by +3°C without a change in future mean precipitation is likely to lead to drier slopes and higher matric suction. The increase in future mean precipitation is likely to lead to wetter slopes and lower matric suction.
- The increase in future temperature by +3°C without a change in future mean precipitation is likely to lead to smaller outward slope displacements and insignificant change in vertical slope displacements. The increase in future mean precipitation is likely to lead to larger outward and vertical slope displacements.
- The predicted trajectory of the slope surface over time showed an "oscillatory" displacement of the slope surface with seasonal cycles of wetting and drying. Slope displacements increase during the wet seasons and partially rebound during the dry seasons. The net cumulative displacements (irrecoverable displacements) are outwards and upwards, which increase over time as the slope experience more cycles of wetting and drying.

Policy Recommendations

This study provided a few insights into the effect of climate change on clay embankments. Notably, the results of this study indicated that rate of increase in irrecoverable vertical displacements reduced over time as soil swelling reaches its potential, whereas the increase in irrecoverable outward displacement persists over time. Swelling-induced shallow slides are likely triggered at this condition and are likely to occur in high plasticity clays after 70 years in Los Angeles climate and after 45 years in Sacramento climate. Existing embankments constructed from high plasticity clays that are older than these limits and whose failure consequences are high may require risk mitigation strategies (e.g., monitoring).

Numerical models that account for weather-related deterioration help predict failures, plan timely maintenance, and optimize budgets, extending the lifespan of transportation assets and reducing long-term costs.

Performance indicators were obtained from the numerical simulations to compare the effect of climate change in Los Angeles and Sacramento. Overall, climate change is generally projected to adversely affect the long-term performance of clay embankments. This effect varies significantly based on the climate zone.

This study's model could potentially be used to predict the long-term performance of other embankments in different climates through additional simulations. By adjusting the results based on local climate factors, like the balance between average annual potential evapotranspiration and average annual precipitation (PET/P), the model may be used to estimate risks and performance in various locations beyond the two CA regions in this study.

About the Authors

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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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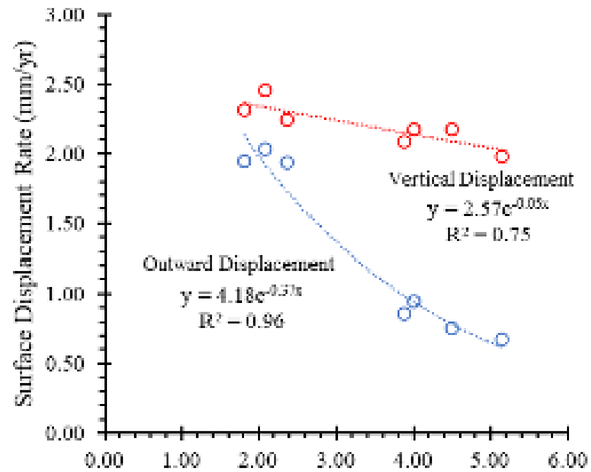
Emma Varela is a physics major in her junior year at California State University, Long Beach with a passion for the discipline and its interdisciplinary applications. Emma's academic and research experiences have allowed her to explore the intersection of physics with other fields, such as engineering and climatology, while developing technical expertise and problem-solving skills.



Correlation between the average surface displacement rate with the ratio of average potential evapotranspiration to average precipitation.

To Learn More

For more details about the study, download the full report at transweb.sjsu.edu/research/2438

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