Coupling Novel Soil Moisture-Suction Sensors and UAV Photogrammetry Technology to the Performance of Highway Embankments

Developing a predictive design and rehabilitation tool for highway embankments while addressing fundamental unsaturated and shear strength research questions

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Tran-SET
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$270,033

The majority of highway embankments across the United States, specifically in the South-Central region, are in marginal condition because the high-plasticity clays used during construction soften with time to significantly lower strengths. Also, infiltrating rainfall increases pore-water pressures and ultimately lead to slope instability. As a result, these failures have required periodic maintenance to ensure proper highway safety, which has been costly for the Louisiana and Texas DOTs.

This study will advance the understanding of how long-term wetting-drying cycles change the in-situ unsaturated and strength properties of high-plasticity clays. The project scope focuses on developing a predictive design and rehabilitation tool for highway embankments while addressing fundamental unsaturated and shear strength research questions. One highway embankment with prior history of shallow slides will be instrumented to collect undisturbed shear strength, in-situ soil moisture, and pore-water conditions. Specific objectives of the project include: (1) measure in-situ suction and moisture content using a novel suction-TOR sensor, (2) rapidly evaluate embankment geometry and slope movements using unmanned aerial vehicles (UAVs), and (3) develop a numerical tool that can predict fully softened shear strengths, slope failures for a rainfall event, and improvements in embankment to a repair.

Problem Statement

The movement of water plays a critical role in the mechanical performance and service life of transportation infrastructure, especially for pavement subgrades and highway embankments consisting of high-plasticity soils that saturate and ultimately lead to infrastructure distress. In the aftermath of heavy rains, pore-water pressures increase to a critical threshold such that a failure occurs. The implications of embankment failures range from repeated maintenance repairs to long-term road closures.

Prior research documented failures and rehabilitation methods in Louisiana, quantified the shear strength and unsaturated hydraulic properties of Texas and Louisiana soils, and conducted inverse slope stability analyses using climate data. Outcomes of that work include confirming Texas and Louisiana soils follow published fully softened shear strengths and incorporating soil water retention curves and climate boundary conditions in slope stability analyses. A Tran-SET ongoing research project is focusing on identifying the relationship explaining shear strength loss of high-plasticity clays with the number of wetting-drying cycles. However, knowledge gaps still remain and they include (1) in-situ soil suction and moisture content measurements, (2) rapid technique to evaluate embankment geometry and slope movements, and (3) a numerical tool that can predict shear strength loss, slope failures for a rainfall event, and improvements in embankment service life due to a repair.

The proposed project represents fundamental research in geotechnical engineering. However, no theory or design tool exists yet to unify (1) how long-term wetting- drying cycles change the in-situ unsaturated and strength properties of high-plasticity clays and (2) how heavy rains infiltrate into embankments and increase pore-water pressures. Furthermore, why do shallow slides occur in localized areas of an embankment? It is likely that the plasticity index may be relatively higher than the stable areas. In addition, applications of unmanned aerial vehicles (UAVs) are growing beyond only visualizing infrastructure to collecting data for numerical models. The proposed research uses novel sensors to address in-situ moisture and suction measurement in embankments. State DOTs spend significant effort to repair shallow slides on highway embankments. However, a comprehensive design and maintenance guideline that provides methods for estimating FSS, performing stability analyses, and rehabilitating slopes is not readily available. Such a manual will be developed for the state DOTs in this project and can be implemented upon completion of the research.

Objectives

The objective of this research project is to (1) measure in-situ suction and moisture content using a novel suction-TDR sensor, (2) rapidly evaluate embankment geometry and slope movements using unmanned aerial vehicles (UAVs), (3) develop a numerical tool that can predict fully softened shear strengths, slope failures for a rainfall event, and improvements in embankment service life due to a repair; and (4) implementation of research results along with workforce development and education.

Intended Implementation of Research

Workforce development: The outcome of this research is directly applicable to the workforce. A design and maintenance report will be produced for use by state and local district offices and industry professionals. The information will also be disseminated using short courses, webinars, technical publications, and conference presentations. Research team will present some of the research findings in Soil Mechanics committees of AFS00 of Transportation Research Board.

Outreach: Dr. Jafari has participated in outreach activities at Kenilworth Science & Technology and Lee High School in Baton Rouge, LA. Through this research, Dr. Jafari can develop a classroom demonstration that will allow students to envision the effect of soil type and weather (rain) on slope stability. He will also contribute to science fair projects that would like to test a hypothesis on different mixtures of soil, moisture, and strength.

Education: The results from this research will be incorporated into several courses at LSU (CE 4300 Geotechnical Engineering ll, CE 4780 Coastal Geotechnics, and CE 7300 Advanced Geotechnical Engineering) as well as several courses at UTA, including CE5370 Experimental Soil Mechanics and CE5374 Ground improvement classes. ln each course, a module will be developed that the professor can use to lecture on drained shear strength of fine-grained soils. For example, the undergraduate courses will obtain a basic understanding of the three types of drained shear strength (peak, fully softened, and residual), how to measure the strengths, and how to apply the strengths to simple stability problems. The graduate level course will delve deeper into the fundamentals of shear strength, testing methods, and development of empirical correlations. They will also investigate the development of pore-water pressures from rainfall, which will be integrated with case studies to serve as an application. lt is anticipated these modules can be provided to other Tran-SET universities.

Anticipated Impacts/Benefits of Implementation

The findings of this study are expected to promote more resilient geotechnical infrastructure and use emerging technologies to possibly extend the service life and repair earth embankments. In particular, novel sensors that combine soil moisture and suction will be used to evaluate in-situ unsaturated and saturated conditions of highway embankments. This is a major breakthrough because these sensors will provide in-situ unsaturated hydraulic properties and suction-water characteristics that has yet to be measured. Moreover, UAV technology will be leveraged with photogrammetry for data collection to force finite element models to predict highway embankment performance under climate extremes.

Web links

- TranSET's website (https://transet.lsu.edu/research-in-progress/)
- TRB's Research in Progress (RIP) database (https://rip.trb.org/View/1644229)

Tran-SET

Tran-SET is Region 6's University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 "to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes".

Learn More

For more information about Tran-SET, please visit our website, LinkedIn, Twitter, Facebook, and YouTube pages. Also, please feel free to contact Mr. Christopher Melson (Tran-SET Program Manager) directly at transet@lsu.edu.