Investigation of the Impact of Rainfall Patterns on Highway Slope Instability

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Evaluating the impact of rainfall patterns of highway slope stability

Highway embankments are one of the most crucial elements of the transportation infrastructure system in the United States. Therefore, keeping the integrity of the highway slopes is of utmost importance for economic sustainability of the country. However, because of the variation of the environmental condition and the presence of unsuitable soil that constitutes many of the highway embankments often pose serious threat to these infrastructures' stability and cause property damages and casualties. Highway embankments constructed with unsuitable soil, especially expansive clayey soil are susceptible to reduction in the shear strength properties, and eventually cause the failure. The southern Texas (greater Houston region) has been experiencing multiple natural disasters and subsequent deterioration of the transportation infrastructures (e.g., pavement distress, slope failure etc.). Among these, the variable rainfall pattern is one of the major causes of slope instability. Additionally, substantial heterogeneities of geological composition have been observed in this region. In the proposed study, we aim to study the rainfall characteristics of the southern part of Texas and develop the rainfall pattern for this region. The typical measurement of rainfall is executed by rain gauge network, which is straightforward to estimate the surface precipitation and has significant spatial variation. To achieve greater resolution in rainfall measurement, this proposed research will incorporate the weather radar networks. Furthermore, we aim to develop a geotechnical database containing information such as sub-soil characteristics (e.g., physical, hydraulic, strength), slope geometrical configuration, and other pertinent information of highway slopes for this region to synthesize the hydro-geotechnical analysis.

Problem Statement

Field-scale studies have been performed to investigate the effect of rainfall infiltration on the stability of slope. Rainfall infiltration in slopes constructed with clayey soil may create critical condition. Expansive soil with high plasticity indices often forms cracks and fissures at the upper soil layer due to the cyclic wetting-drying process. This crack rich expansive soil allows easy path for rainfall infiltration and consequent slope failure. Numerous studies have been performed to investigate the slope failure mechanism through field monitoring, laboratory testing, and numerical modeling. There are several slope failure initiation indicators, such as excessive lateral and vertical deformation, surface cracking, wetting front approaching. The rainfall that causes an abrupt change in the indicators is the critical rainfall. However, different types of soil behave differently at different rainfall events. Preceding rainfall events affect the stability of low hydraulic conductivity slopes more than the slopes with high hydraulic conductivity. The varied rainfall events significantly affect the water content and soil suction, consequently affecting the hydraulic and strength behavior of the slope soil. Therefore, rainfall patterns can significantly influence infiltration behavior and, subsequently, the stability of the slope.

Objectives

The overall goal of this study is to develop the rainfall patterns for south Texas (Houston) and numerically evaluate their impact on the slope performance. The following are the major objectives that constitute the overall goal:

(i) Examine the rainfall intensity and duration for the past 20 years in the Houston area

(ii) Develop rainfall patterns based on high-resolution radar data

(iii) Radar rainfall calibration with existing ground stations in Houston

(iv) Development of a geotechnical database of existing highway embankments for this region (the Greater Houston) such as subsoil properties, slope geometry, slope failure mode and type, repair practice, and any other pertinent information

(v) Conduct numerical analysis using FEM to evaluate highway slope stability under the analyzed rainfall patterns and develop a hydrometeorology-geotechnical insight of slopes for this region.

Intended Implementation of Research

The efforts undertaken by the DOTs in repairing slopes of highway embankments are enormous in Region 6, especially in Texas. The current COVID-19 pandemic has put an extra challenge to the DOTs to monitor the slopes and subsequent repairs. In addition, the varied rainfall pattern in this region could lead to a more disastrous condition. So, close monitoring of the critical climatic loading (rainfall) by emerging technology and its effect on slope instability by thorough analysis are required. The research results are expected to assist the TxDOT and Harris County for future planning, design, construction, and maintenance of the highway embankments. The researchers will bring the private sector partners into their respective classrooms and discuss the job opportunities and internships at those firms in the classroom. To complete the research activities, we anticipate recruiting one graduate student to work on this project. The graduate student will be required to complete a master's thesis and a peer-reviewed publication that would form the core intellectual outputs for the current proposal. Through the current project, we expect to improve the participation of African American and Hispanic students in research.

Anticipated Impacts/Benefits of Implementation

The proposed project would provide a comprehensive analysis of rainfall pattern, intensity, duration, and extreme events, and its effect on the highway embankment safety through detailed slope stability analysis for south Texas (Houston). The results from the proposed project would provide valuable insight to TxDOT for future highway embankment design and construction and enhance the resiliency of existing earthen slope infrastructures in this region. These results would be provided to stakeholders and community leaders in Texas to increase technical awareness and sustainable growth of Region 6's transportation.

Web links

- Tran-SET's website https://transet.lsu.edu/research-in-progress/

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 Dr. Momen Mousa (Tran-SET Program Manager) directly at transet@lsu.edu.