Prediction and Rehabilitation of Highway Embankment Slope Failures in a Changing Climate

Highlight | Feb. 2018

Project No. 17GTLSU04

PI: Dr. Navid Jafari (LSU), Dr. Anand Puppala (UTA)

POP: May 2017 – November 2018

Developing a framework to identify high-risk locations that may fail from slope stability issues and to prioritize maintenance/repair with cost-effective solutions

The resilience of transportation infrastructure, such as highway embankments, is critical to avoiding commuter delays and costly repairs.To predict the progression of lower shear strengths earthen embankments, this study aims to characterize and model the effect of wetting and drying cycles on high plasticity soils typical of highway embankments in Louisiana and Texas. The research will be accomplished through comprehensive inverse analyses of embankment failures in conjunction with laboratory shear strength and unsaturated hydraulic testing of Louisiana and Texas soils. The outcome of this research will be twofold: (1) a methodology to predict locations of high failure probability areas, and (2) cost-effective rehabilitation techniques for DOTD districts. The first outcome will permit DOTD to identify critical areas that will need maintenance prior to a failure occurring. This outcome will also result in a Louisiana and Texas validated correlation for fully softened shear strengths that can be used fort he design of highway embankments. The review of past failures and continuous field monitoring will be used to develop guidelines for rehabilitating failed slopes so that the likelihood for subsequent slides is significantly reduced.

Problem Statement

The majority of highway embankments across the United States, specifically in Region 6, are in marginal condition because the highplasticity clays used during construction will soften with time to significantly lower strengths. In addition to lower strengths, infiltrating rainfall will increase 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 (Figure 1).

Stability analyses for highway embankments consisting of fine-grained soils are traditionally conducted using peak strengths or some percentage of peak strength determined from standard laboratory shear strength tests on undisturbed or freshly compacted samples.Using these peak strengths and slope ratios in the range of 3H:1V (3 horizontal to 1 vertical) to 4H:1V with vertical heights of 15 to 25 feet typically results in calculated factors of safety (FOS) above 1.5. However, many of these slopes have subsequently failed, which implies the FOS is approximately unity (-1.0). This disparity indicates the peak strength from standard laboratory shear strength tests is not representative of the long-term soil strength in embankment slopes.

Figure 1. Slope failure in Grayson County, Texas.

Summary

After embankment slope failures are identified, usually by local DOTD maintenance crews, inspections are performed to determine the failure mechanism and failure surface, collect soil samples,and map the post-failure slope geometry. The most common observation is the formation of desiccation cracks (Figure 2), which form in the high plasticity clays after repetitive wetting and drying cycles. The cracks provide a network of paths through the embankment for water to permeate through, leading to reduced soil shear strength and in some cases failure.

Figure 2. Photo of desiccation cracks along Louisiana Highway 327.

Following field inspection, the failures are input into a database of previous failures in Louisiana, which was first updated in the early 1990s. Hand borings are used to obtain geological information and disturbed soils for testing. The geological information is a key component to constructing a computer model of the failed embankment. Climatic information is sourced from local weather stations and the Louisiana Agriclimatic Information System. The numerical models couple the effects of the climate, including precipitation, humidity, temperature, and solar radiation with the movement of water through the embankment.

In addition to numerical simulations of the embankments, samples are retrieved from slope failures to determine the geotechnical properties at failure. As the soil undergoes repetitive wetting and drying cycles, the shear strength degrades from a peak value at construction to the fully softened shear strength (FSS). Using a modified Bromhead Ring Shear device (shown in Figure 3), the FSS is determined for the failed slopes and compared with inverse stability analyses.

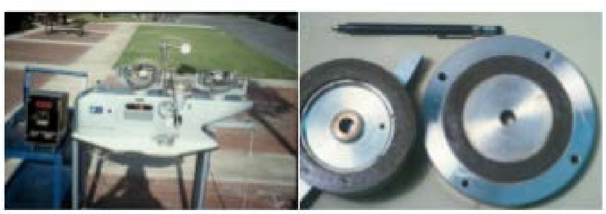

Figure 3. (a) Ring shear apparatus and (b) assembled specimen container with shear soil.

Findings

Compilation of embankment failures in Louisiana indicate that the majority of failures occur in high plasticity clays with a large percentage of smectite. Soil testing is in progress on several Louisiana case studies, primarily located in LA DOTD District 62, along with several failures which occurred after Hurricane Harvey in the northwestern corner of the state near Lake Vernon. Preliminary findings of the coupled soil-atmosphere modeling indicate that an embankment remains saturated with moderate precipitation over a range of typical soil values for compacted clays.

Impacts

The research conducted at Louisiana State University and the University of Texas at Arlington is expected to result in a predictive framework which can be used in the design of highway embankments in Louisiana and Texas. Once a database of fully softened shear strength properties of typical, high plasticity Louisiana soils is developed, they maybe used in a more economical and resilient design of highway embankments. Therefore, the research outcomes will permit state departments of transportation to identify critical areas that will need maintenance prior to failure. The review of past failures and continuous field monitoring will be used to develop guidelines for rehabilitating failed slopes to reduce the likelihood of subsequent slides significantly.

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.

Tran-SET