RESEARCH

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THE EFFECTS OF SOIL SUCTION ON SHALLOW SLOPE STABILITY

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PROJECT TITLE
THE EFFECTS OF SOIL SUCTION ON SHALLOW SLOPE STABILITY

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OVERVIEW Shallow slope failures in roadway cuts and embankments are frequent problems along Oklahoma highways and many other states. These failures represent a significant burden on maintenance budgets. Often, these failures are associated with clayey soils having relatively high plasticity. Generally, during construction these soils have high shear strength, a stiff consistency, and produce stable slopes. However, over time the soils experience cyclic wetting and drying resulting in a net increase in soil moisture content and corresponding decrease in shear strength due to softening and loss of suction. Eventually, the reduction in shear strength results in a slope failure, usually after a period of significant wetting. Exacerbating the problem are desiccation cracks that develop during extreme drying periods allowing water to penetrate the soil deeper and faster. Shallow slope failures in clayey soils are widespread and poorly understood and very little research has been conducted to provide guidance on how to address desiccation cracking in slope stability analyses.

Figure 1 Test Site

RESULTS This project improves the understanding of desiccation cracking and shallow slope failures in clayey slopes subjected to seasonal variations in weather. Research involved field and laboratory testing and computer modeling. Two test sites where shallow slope failures had occurred were instrumented with weather monitoring equipment and sensors (Figure 1) to measure variations in soil moisture. The purpose was to examine the variations in soil moisture, and hence shear strength, as a function of time and depth. A primary goal was to evaluate two commercially available computer programs with respect to their ability to predict soil moisture changes and suction. Results of the study indicated that reasonable predictions of soil moisture changes due to weather are possible with commercial software but considerable effort is needed for parameter determination, model calibration and validation. Unsaturated seepage analyses provided insight into pore water pressure development in the slopes considering the impact of desiccation cracking. The results suggest that desiccation cracks may increase the mass hydraulic conductivity of the near surface soils by one to two orders of magnitude. Further, results of seepage analyses suggest that upper layers of the slope soil profile may become nearly saturated in some areas with positive pore water pressure developing over a significant portion of the failure surface, as illustrated in Figure 2. Unsaturated slope stability analyses were conducted using the predicted pore pressure distributions from unsaturated seepage models and unsaturated strength parameters determined from suction-controlled direct shear tests on compacted soil.

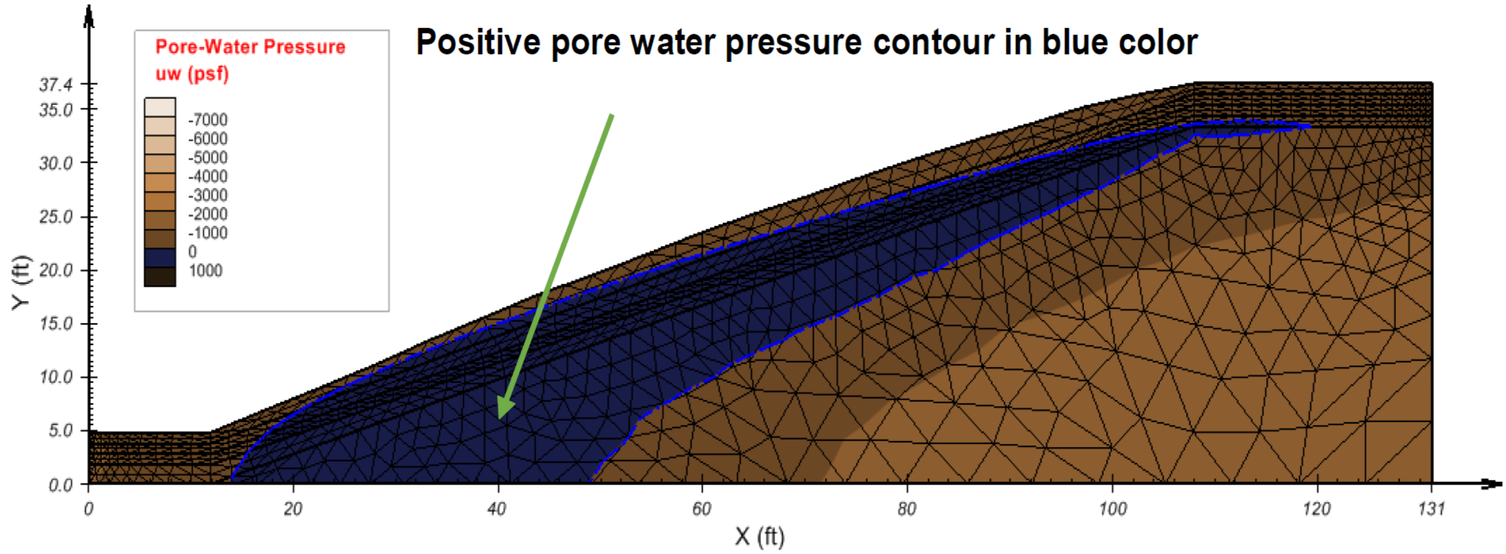

Figure 2 Pore Water Pressure Distribution at the Critical Situation from Unsaturated Seepage Modeling for K1=100K2= 5.7e-5 in/sec

In addition, traditional slope stability analyses were conducted using drained shear strength parameters and assumed positive pore pressures. Both methods provided reasonable predictions of the failure conditions (factor of safety of 1) for the two test sites; however, both have advantages and disadvantages relative to one another. A simple method of predicting the depth of desiccation cracks in compacted soil was developed based on linear elastic theory and shows promise relative to observations at one of the test sites. Tensile strengths used in crack depth predictions were based on measurements in a new apparatus developed and manufactured at the University of Oklahoma. Theoretical predictions of tensile strength based on a micro-structural effective stress model compared favorably to measured strengths (Figure 3).

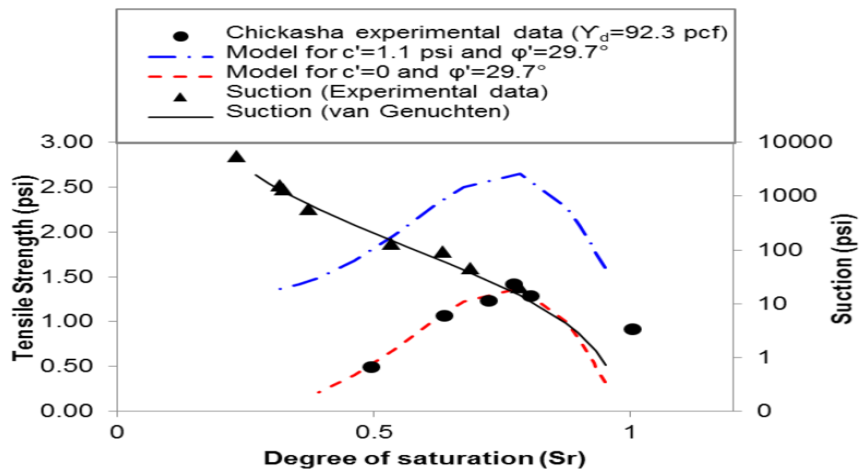

Figure 3 Comparison of Experimental Results with the Calculated Tensile Strength obtained from the Theoretical Model

Using weather data as input, unsaturated seepage modeling provides a fundamentally sound and systematic means of evaluating moisture profiles and pore water pressures, both positive and negative (matric suction), in slopes for use in unsaturated stability analyses. However, it requires considerable effort to learn the software and underlying concepts, determine the model parameters, format the input weather data, calibrate and run the numerical models. There is also much uncertainty associated with the influence of desiccation cracks and determination of several model parameters. Nevertheless, the analyses conducted in the study provided significant insight into the problem and provided realistic simulations of conditions leading to shallow slope failure. Therefore, whenever possible in the course of investigating shallow slope failures, it is recommended that unsaturated seepage modeling using historical weather data and unsaturated slope stability analyses be conducted. This should supplement traditional drained methods of limit equilibrium slope stability analyses performed using fully softened shear strengths.

POTENTIAL BENEFITS Conducting slope stability analyses per the recommendations should provide a reasonable approach to anticipate whether a given slope may fail at some point following construction due to drying and wetting cycles. This will aid Oklahoma Department of Transportation (ODOT) engineers in mitigating some of the significant burden on maintenance budgets by improving slope stability or reducing the impacts of desiccation cracking.