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Summary Report for Long-Term Strength of High-PI Clays

PROJECT SUMMARY REPORT

High-plasticity clays occur in many areas of Texas and often offer the most economical material for construction of highway embankments. When constructed with proper moisture and compaction control, embankments constructed of plastic clays can perform adequately with regard to overall stability. However, experience shows that the outer layers of these embankments can experience dramatic strength loss.

Softening of the surficial soils can begin soon after construction and continue for decades. The consequent sloughing and shallow slide failures represent a significant maintenance problem for the Texas Department of Transportation (TxDOT). The problem of strength loss in high-plasticity clay soils can impact other structures such as retaining walls, pavements, and riprap.

This report describes an approach for estimating soil strength loss as a function of time and space for typical slopes and earth structures used in TxDOT projects.

What We Did . . .

To pursue the objectives of the project, researchers performed the following tasks:

Literature Review. A literature review addressed topics regarding field and laboratory measurements and case histories.

Selection of Typical High-Plasticity Texas Soils for Testing. TxDOT provided samples of clay soils with a high plasticity index (PI) from a site near Waco, Texas, for laboratory testing.

Laboratory Tests. Apart from an initial series of index and classification tests, the

Slope failure like that shown here illustrates the need to investigate long-term strength of high-PI clays.

laboratory test program focused on determination of the moisture diffusion coefficient. This coefficient is a primary parameter controlling the time rate of strength loss in soils.

Evaluation of Ultimate (Lower Bound) Strength for Selected Soils. This evaluation developed an infinite slope model in which soil strength and slope stability are characterized in terms of soil suction. Applying this model to 34 case histories of slope failures in high-plasticity Texas clays identified in the literature review permitted estimates of soil suction at the time of failure.

Moisture Diffusion Model for Slopes. This part of the project developed a linearized model for moisture diffusion into slopes. The moisture diffusion coefficient controls the rate of moisture diffusion and strength loss. The crack patterns in the slope define the boundary conditions for the diffusion model. Empirical measurements of crack depth and spacing from published sources provided the basis for postulating crack patterns in slopes.

Evaluation and Calibration of Moisture Diffusion Model Based on Case Histories. The researchers developed predictions of times to failure for shallow slopes based on laboratory measurements of the moisture diffusion coefficient, postulated crack patterns, and the moisture diffusion model. These time estimates were then compared to actual failure times in published case histories.

Model for Moisture Diffusion beneath Structures. The moisture diffusion model for typical TxDOT earth-retaining structures is similar to that developed for slopes. Inputs into the model include the geometry of the earth-retaining structure, the moisture diffusion coefficient, the initial suction in the as-compacted soil, the suction in the wetted soil beneath the roadway pavement, and the equilibrium suction in the native soils.
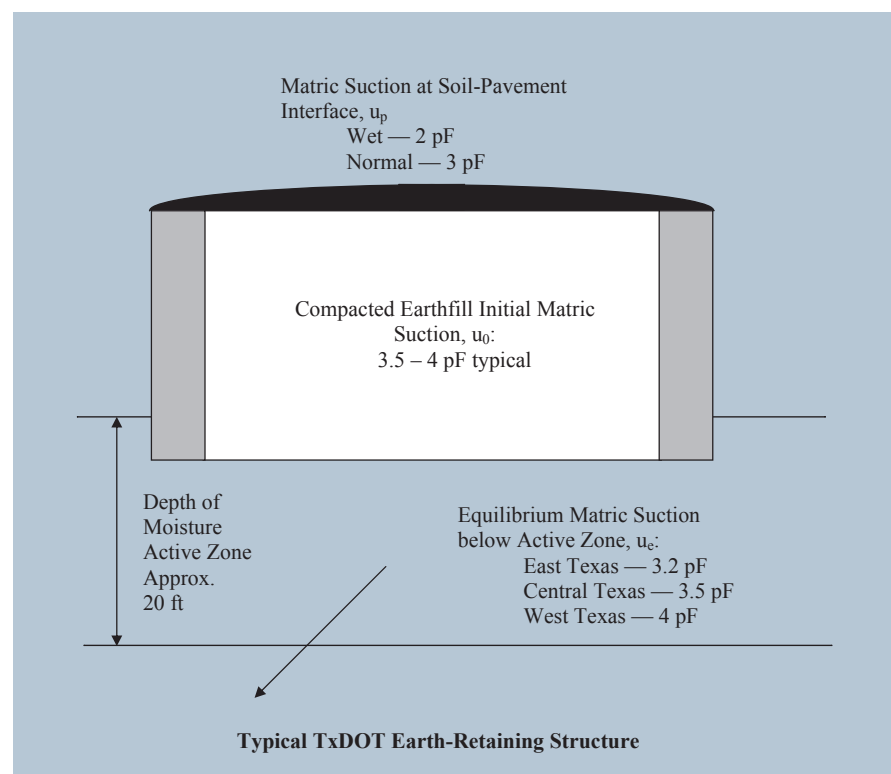
What We Found . . .

The previous formulation for moisture diffusion assumed that permeability variability varied with the inverse of the first power of suction. This research extended the formulation to accommodate situations in which permeability varies inversely with an arbitrary power of suction. The laboratory measurements indicated that the original formulation is sufficient in most cases.

The average moisture diffusion coefficient of the high-PI clays tested was 3.1×10^{-5} cm^2/sec with a standard deviation of 1.2×10^{-5} cm^2/sec. These values correspond to the clay in an intact state. Cracking can substantially increase the effective permeability of clay soils.

Analysis of pore water conditions in an unsaturated slope indicated that a constant suction in the soil on the surface of the slope — a very plausible condition — will lead to destabilizing hydraulic gradients in the slope. These hydraulic gradients provide the most plausible explanation as to why slope failures occur when the slope angle is less than the angle of internal friction of the clay.

Back-analysis of slope failures indicated that, upon wetting of the slope due to surface infiltration, the matric suction at the surface of a clay slope declines to a level

Matric Suction at Soil-Pavement Interface, u_p
Wet — 2 pF
Normal — 3 pF

Compacted Earthfill Initial Matric Suction, u_0:
3.5 – 4 pF typical

Depth of Moisture Active Zone Approx. 20 ft

Equilibrium Matric Suction below Active Zone, u_e:
East Texas — 3.2 pF
Central Texas — 3.5 pF
West Texas — 4 pF

Typical TxDOT Earth-Retaining Structure

of about 2pF. This suction level defines the lower limit to which the clay strength will degrade upon wetting.

This research postulated a crack pattern, supported by empirical evidence in the published literature, in which the crack depth equals the crack spacing. The crack depth is assumed to extend to the bottom of a potential slide mass in a clay slope. Moisture diffusion analyses based on this crack pattern tended to somewhat under-predict the time period to slope failure cited in the case histories. This discrepancy is attributed to the fact that crack development can take place over a substantial time period. Hence, a moisture diffusion model that assumes the cracks develop immediately after construction will tend to under-predict the time to failure.

The time rate of moisture diffusion into intact clays is much slower — about two orders of magnitude — than into cracked clay masses. Hence, design measures that inhibit the development of cracking can greatly increase the time to failure. A case in point is concrete "riprap" slope protection. Although the protection does not usually provide an effective moisture barrier — the soil beneath the concrete is typically very wet — it does inhibit the development of desiccation cracks by keeping the soil in a permanently moist state. Therefore, while the protection cannot guarantee that a slope failure will not occur due strength

degradation and suction loss, it is likely to substantially prolong the life of the slope.

This research produced a model for moisture diffusion into typical TxDOT earth-retaining structures with vertical retaining walls about 20 ft high, an aspect ratio ranging from 4H:1V to 8H:1V, drains behind the walls, and a pavement section covering the top of the earthwork. The design manual arising from this project, Report 2100-P1, presents numerical solutions for this model. The user may select the initial and boundary matric suction conditions for the moisture diffusion model based on site-specific conditions.

The Researchers Recommend . . .

Based on the research findings, we make the following recommendations:

- A moisture diffusion coefficient of 3×10^{-5} cm^2/sec is reasonable for calculations of moisture infiltration in intact high-plasticity clay soils. One may model cracked soil masses by assuming a crack pattern in which the crack depth equals the crack spacing.

- A matric suction of 2.0 pF appears to be a lower bound that will occur at the surface of high-PI clays subjected to wetting. Lower bound strength estimates should be made on this basis.

- Aside from the moisture diffusion coefficient, the critical site conditions influencing the rate of moisture infiltration into a soil mass are the availability of water and the depth of cracking. Therefore, adequate surface drainage is the most straightforward approach to reducing the potential for moisture infiltration and strength reduction.

- Measures that reduce the potential for desiccation cracks, such as riprap slope protection, can greatly reduce the rate at which moisture infiltrates into the soil mass. Although their expense precludes their usage on all slopes, in critical areas such protective measures can considerably prolong the life of a slope or earth structure.

In the absence of site-specific information, this research provides the following recommendations for initial and boundary matric suction for the moisture diffusion model:	
Initial suction in compacted clay:	3.5 – 4.0 pF
Suction beneath the pavement:	Wet conditions – 2.0 pF Average conditions – 3.0 pF
Equilibrium suction in native foundation soils:	East Texas – 3.2 pF Central Texas – 3.5 pF West Texas – 4.0 pF

For More Details . . .

The research is documented in the following reports:

2100-1, *Long-Term Strength of Compacted High-PI Clays*

2100-2, *Properties of High-Plasticity Clays*

2100-P1, *Estimating Strength versus Location and Time in High-Plasticity Clays*

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TxDOT Implementation Status
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The results from this research project cannot be confidently implemented at this time. Calibration and verification of the model need to be conducted with field data from existing embankments. TxDOT is considering additional research work to accomplish these tasks.

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