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Investigation of a shallow slope failure on expansive clay in Texas

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ABSTRACT

Highway slopes constructed with highly plastic clay soils undergo shrink-swell cycles during the wet-dry season, which usually soften the soil and may cause failure a few years following construction. There are two major wet-dry cycles in Texas, where summer to early fall is categorized as the dry period, and late fall to spring is categorized as the wet period. During this study, the failure of a highway slope located in Fort Worth, Texas was investigated, and the effect of rainfall on the slope failure was evaluated. The failure of the slope was investigated using soil test borings, geophysical testing, laboratory testing, slope stability analysis, and unsaturated flow analysis. The site investigation included sample collections from different depths of borings, determination of the soil index properties, and various shear strength testing to determine soil strength parameters. The obtained test results were further utilized in slope stability and flow analyses using the finite element method (FEM) in PLAXIS. The study indicated that both a fully-softened condition and rainfall were responsible for the slope failure. The fully-softened condition provided a factor of safety of 1.46, whereas the perched water condition after rainfall provided a nearly failing factor of safety of 1.05.

1. Introduction

Most highway fill slopes in the North Texas areas are constructed using in-situ high plasticity clay soil, which is highly expansive in nature. These fill slopes have recurring shallow failures a few years after construction, causing a significant maintenance problem for the Texas Department of Transportation (TxDOT). Shallow slope failures generally do not constitute a hazard to human life or cause major damage; however, they may constitute hazards to infrastructures by causing damage to guardrails, shoulders, road surfaces, drainage facilities, utility poles, or the slope landscaping (Day and Axten, 1989; Titi and Helwany, 2007). In some cases, shallow slope failures affect regular traffic flow if debris flows onto roadway pavements.

Clay minerals consist of two or three layers of gibbsite and silica sheets (Das, 2013). These are negatively charged aluminosilicate layers with the ability to absorb water between the layers (Hensen et al., 2002). Due to the presence of exchangeable ions on the surface of clay particles, dipolar water molecules are attracted towards clay minerals, resulting in a double layer of water. The plastic property of clay is attributed to the presence of this double layer.

The surface area of clay particles per unit mass is generally referred to as specific surface. The specific surfaces of kaolinite, illite, and montmorillonite are about 15, 90, and 800 m^2/g, respectively (Das, 2013). Clay minerals that have less surface area attract less water (such as illite and kaolinite) and are characterized as low plastic clay. On the other hand, montmorillonite has a significantly high surface area, which attracts a high volume of water, and is characterized as high plasticity clay. The thickness of the double layer water is highest for montmorillonite (Das, 2013). Due to the affinity of a high volume of water, high plastic clay exhibits expansive behavior: it swells when it absorbs water and shrinks when water is dissipated. Chabrillat et al. (2002) reported an abundance of montmorillonite in clays in the mid-zone of the United States. Previous studies indicated the presence of montmorillonite minerals in the Dallas-Fort Worth (DFW)-area clay (Punthutaecha et al., 2006; Puppala et al., 2013). Absorbance of water in the wet season results in volume expansion; the opposite is true in the dry season.

Rahardjo et al. (2001) presented a case study that described the effect of antecedent rainfall on slope stability in Singapore. The authors investigated several shallow slope failures on residual soil that occurred after a rainfall event of 95 mm (3.75 in.) within 12 h. The authors reported that the landslides were initiated by rainwater infiltration; that is, no changes in geometry or additional loading applied to the slopes could have initiated failure. In addition, both the daily rainfall and the antecedent rainfall were important triggering factors for the occurrence of the landslides.

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Rahimi et al. (2010) conducted a study on rainfall-induced slope failure due to antecedent rainfall for high and low conductivity residual soils of Singapore. The authors applied three antecedent rainfall patterns to soil slopes and conducted a transient seepage analysis to investigate the effect of rainfall on the stability of the slope. Results from the study indicated that antecedent rainfall affected the stability of both high-conductivity and low-conductivity soil slopes, with the stability of the low-conductivity soil slopes being more significantly affected. In addition, the stability of the slope was controlled by the amount of rainfall that infiltrated the unsaturated zone of the slope.

Highway slopes constructed on highly plastic clay soil are usually very strong immediately following construction. Skempton (1977) first reported that over time, the strength of slopes in the highly plastic London clay decreases, eventually reaching what Skempton termed a “fully-softened” strength. Skempton (1977) indicated that fully-softened strength is comparable to the shear strength of the soil in a normally consolidated state. A few years after construction, shrink-swell behavior can reduce the shear strength of the top few feet of a slope, which is susceptible to moisture variations. After the soil reaches the fully-softened shear strength, water that infiltrates the soil during intense and prolonged rainfall events may cause excess pore water pressure and compound the overall problem. As a result, the factor of safety of the slope may reduce to unity and approach failure (Wright, 2005). These types of failures occur within the upper 0.91 m–1.82 m (3 ft–6 ft) of the slope, and the failure surface is generally parallel to the slope face (Wright, 2005). The surficial failure may occur 3–7 years after construction. Surficial failure can even take decades to form, depending on the frequency of extreme weather conditions.

The shallow slope failure of a highway slope located in Fort Worth, Texas was investigated during this study. It was conducted using standard soil tests, geophysical testing, electrical resistivity tomography (ERT), extensive numerical modeling, and the finite element method (FEM). The strength parameters of the slope were determined using the direct shear (DS) and consolidated undrained (CU) triaxial tests.

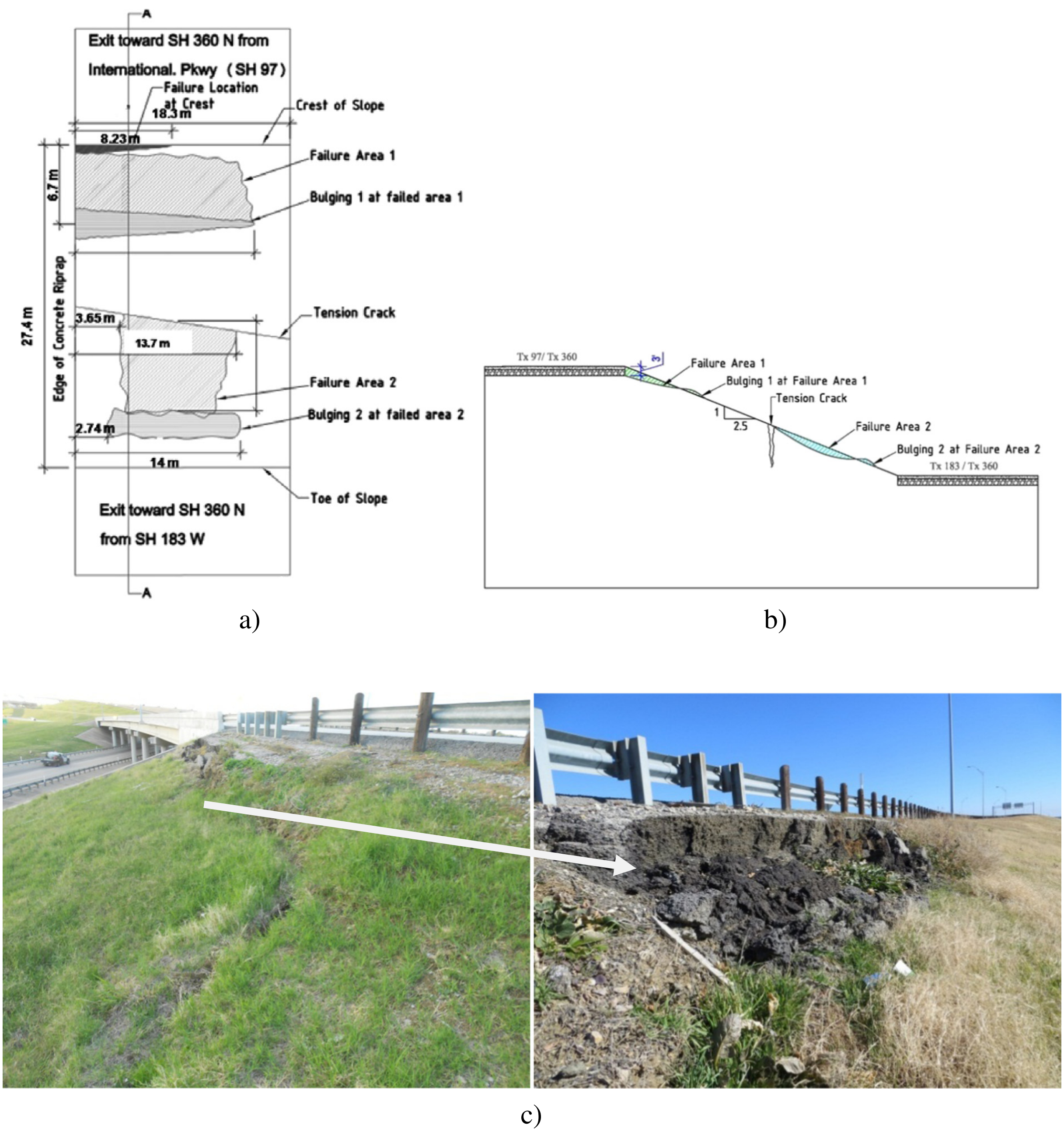

Fig. 1. (a) Failure Condition of SH 183 Slope (Plan View), (B) Section 1–1, (C) Failure near Crest.

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