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A case study of slope failure in central Trinidad due to water pipe leakage

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ABSTRACT

This study deals with a case study of slope failure in central Trinidad. Residents have been complaining about water pipe leaks in areas where there were no corrective actions to address the problem. To simulate the water pipe leakage in the road slope, numerical analyses were conducted in two ways: (1) unsaturated seepage analysis using SEEP/W software and (2) stability analysis during water leakage using SLOPE/W software. Results demonstrate that most important observations in the water flow and stability responses of unsaturated clayey soil slope under water pipe leakage condition can be reasonably well simulated using the proposed numerical procedure.

1. INTRODUCTION

Landslides are one of the major disasters in Trinidad and Tobago. During the period 2006~2019, 367 landslides were reported by the Ministry of Works and Transport. Of these, many landslides are suspected to have occurred due to water pipe leakage. Residents have been complaining about water pipe leaks in areas where there was no corrective action to fix the problem before slope failures.

Slope failures caused by water pipe leaks have been reported rarely in the world. Hui et al. (2005) reported over 206 landslide incidents involving buried pipes in the vicinity of slopes in Hong Kong between 1984 and 2004. Zhu et al. (2018a) conducted the stability analysis of a two-dimensional silty sandy slope subjected to pipe leakage. Zhu et al. (2018b) conducted the simulation of water infiltration in an unsaturated slope from a leaking pipe and the simulated results were compared with experimental data.

This paper deals with the stability analysis of a clayey slope subjected to water pipe leakage. Numerical analyses were conducted in two ways: (1) an unsaturated seepage analysis to obtain the porewater pressure distribution due to water pipe leakage using SEEP/W software (Geo-slope 2012a) and (2) a stability analysis to

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calculate the factor of safety using SLOPE/W software (Geo-slope 2012b).

2. STUDY SITE AND SLOPE MODEL

The slope failure case study is considered for a road slope located at Todd's Station Road. The road was built on highly plastic clay soils that are common in most central and southern Trinidad. The landslide occurred along Todd's Station Road. The area affected by the soil movement spans about 220 m along the Todd's Station Road, which damaged 12 private homes, two which were abandoned and demolished due to the landslide (EISL 2018).

A typical slope is selected in this study as shown in Fig. 1. An embankment slope in clayey soils with a buried water pipe has a breakage along its longitudinal direction. The slope is 7.6 m high and inclined at 33°. A water pipe, 150 mm in diameter, is embedded 2 m below the road.

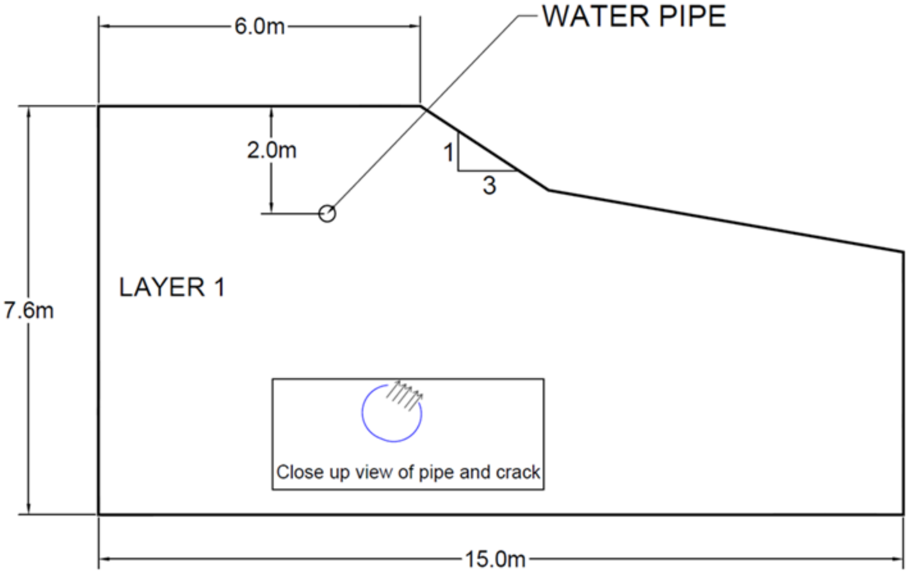

Fig. 1 Geometry of the slope and water pipe

3. METHODOLOGY

3.1 Material Properties

The basic soil properties of the soil are summarized in Table 1. The soil-water characteristic curve (SWCC) equation is obtained by a functional parameter regression model suggested by Perera et al. (2005) and Chai and Khaimook (2020), such as

$$a = 32.835 \times \ell n(wPI) + 32.438\,(kPa) \tag{1}$$

$$n = 1.421 \times wPI - 0.3185 \tag{2}$$

$$m = \left(-2.04 \times 10^{-4}\right) \times wPI + 2.22 \tag{3}$$

$$wPI = PI \times P_{200} / 100 \quad (4)$$

where a,n,m = curve-fitting parameters for Fredlund and Xing's (1994) SWCC equation, PI = plasticity index (%), and P_{200} = percent of soil passing US standard sieve # 200 (%). The SWCC used in this study is shown in Fig. 2. The shear strength properties of the soil are also shown in Table 2 and used for limit equilibrium analysis using SLOPE/W.

Table 1 Basic properties of the soil (EISL 2018)

Parameter	Value
USCS classification	CH
Gravel (%)	1.0
Sand (%)	3.3
Silt (%)	35.5
Clay (%)	60.2
Liquid limit (%)	76
Plasticity index (%)	54

Table 2 Soil properties used in this study

Parameter	Value
Unit weight (kN/m^3)	16
Effective cohesion (kPa)	5
Angle of internal friction (^{o})	25
Angle defining the increase in strength due to the negative pore water pressure	13

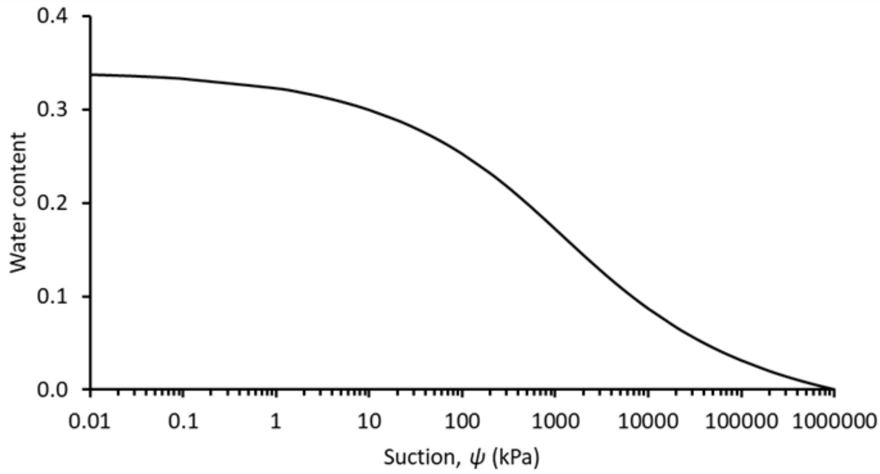

Fig. 2 SWCC used in this study

3.2 Seepage and Stability Analyses

To obtain the porewater pressure distribution, a transient seepage analysis is conducted using SEEP/W. Pipe leakage is modelled by applying a flow rate. The range of 1×10^{-10} ~ 1×10^{-6} m^3/s can be considered as a single undetected leak to a very large leak (Schwaller and van Zyl 2015). SLOPE/W is used to conduct the limit equilibrium stability analysis using the Morgenstern-Price method.

4. RESULTS AND DISCUSSION

Fig. 3 shows the variation of factor of safety with respect to time for different flow rates. The factor of safety for each flow rate at the start of the analysis is relatively high. This was due to the shear strength of the soil being greater than the active overburden stress. However, once the water leakage commenced, the factor of safety decreased steadily as the shear strength decreased with increased porewater pressure. The factor of safety fell below 1.0 for the larger leak rates (1×10^{-6} and 5×10^{-7} m^3/s) at 12 days and 50 days. However, the factor of safety is greater than 1.0 for the smaller leaks (1×10^{-7} and 2×10^{-7} m^3/s) during the 6-month period.

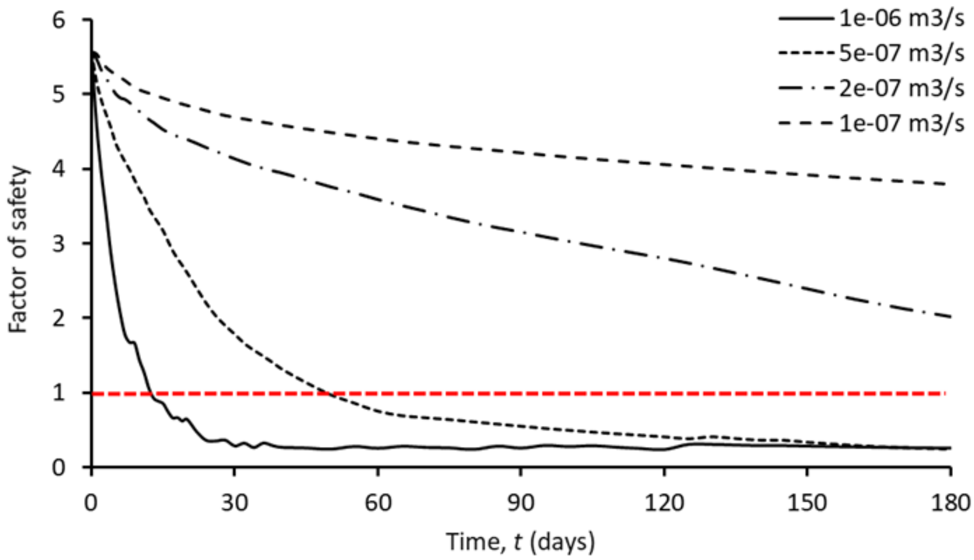

Fig. 3 Variation of FoS for different flow rates

Fig. 4 shows the porewater pressure distribution due to the water pipe leakage for the flow rate of 1×10^{-6} m^3/s at t=12 day. The porewater pressure around the pipe is the highest, around 260 kPa. Also, the increased pore water pressure is expanding to the entire slope. The results of Figs. 3 and 4 demonstrate that, as the pipe leak continues, a high porewater pressure occurs around the pipe, the increase of pore water pressure expands to the slope, an increase in the pore water pressure causes a decrease in shear strength, and eventually the slope failure occurs.

5. CONCLUSIONS

The numerical analyses were performed to investigate the stability of an unsaturated clayey slope subjected to water pipe leakage. For the study site, the factor of safety fell below 1.0 in about 12 and 50 days for the flow rates of $1{\times}10^{-6}$ and $5{\times}10^{-7}$ m^3/s, respectively. The factor of safety was greater than 1.0 until 6 months for lower flow rate of $2{\times}10^{-7}$ m^3/s. Results demonstrate that most important observations in water flow and stability responses of unsaturated clayey soil slope under water pipe leaking condition can be reasonably well simulated using the proposed numerical procedure.

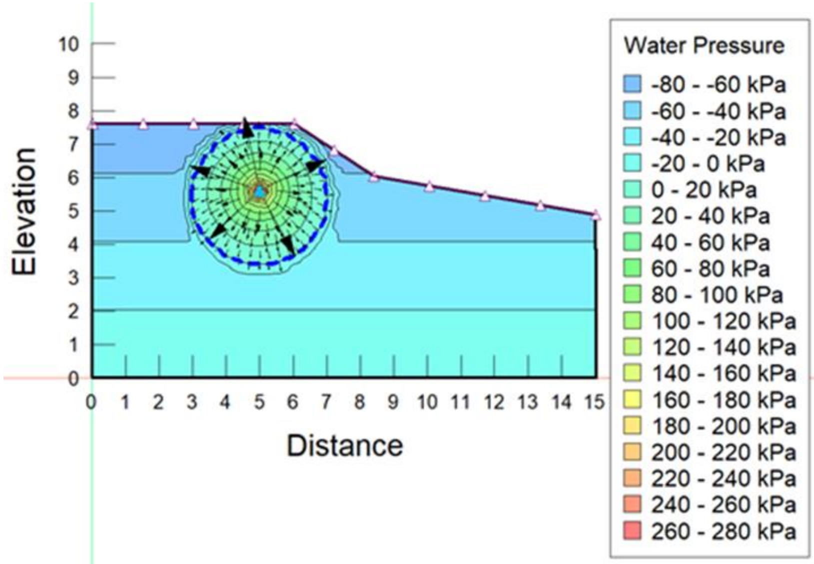

Fig. 4 Distribution of porewater pressure

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