Effect of Perched Water Table on Slope Stability in Unsaturated Soils

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Effects of perched water table on slope stability in unsaturated soils

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ABSTRACT: Instability is an extremely important consideration in the design and construction of man-made slopes and natural slopes. Slope failures and landslides are influenced by geologic topographic and climatic factors. In tropical region, most of the slope failure occurs during severe rainfall. Rain water infiltrates into the slope and reduce the soil matric suction and the strength of the soil. Perched water table may also develops depending on the permeability of the soil layers in the slope and the rate of infiltration. In the paper, effect of perched water table, which occurs after severe rainfall and underlying of impermeable layer were studied. The effects of perched water table on factor of safety of slope were analysed by varying the permeability ratio of soil layers, thickness of impermeable layer, position of impermeable layer, number of impermeable layer and orientation of impermeable layer.

1 INTRODUCTION

Tropical countries like Malaysia experiences warm and wet climatic conditions throughout the year. Most of the highlands are covered with tropically weathered residual soils. Significant infiltration into residual soils can cause slope instability. Many constructions of roads and highways are carried out especially on undulating terrain that mainly consist of residual soils.

Recently, slope stability problems had gained attention from both public and local authorities after a few cases of serious landslides occurred and caused losses in properties and even lives. A huge amount of money had to be spent on slope remedial works yearly and giving rises for the need of thorough and detail research on slope stability.

Most of the slope failures occurred during rainy seasons. Many researchers found that rainfall infiltration is the triggering factors of most landslides (Affendi, 1996; D.G. Fredlund 1993). The slope failure basically caused by the reduction of soil suction during prolong period of rainfall and reduced the shearing resistance.

Most of the sedimentary residual soils in Malaysia are not homogeneous. The non-homogeneity also caused by the weathering process. They usually overlaid by one or more layer of soils. Due to the different characteristic of the soil layers, ground water condition and seepage flow would be too and their influences to slope stability become unpredictable. Perched water table would probably built up when these non-homogeneous soil strata are exposed to prolong period of infiltration which is common for the climatic condition in this region.

2 METHODOLOGY

In this study, the water flux and seepage on slopes were simulated first by using a water seepage (SEEP/W) software (refer to Figure 1 for typical output). The output from SEEP/W was then exported to a slope analysis (SLOPE/W) software to find the safety factor of slope (refer to Figure 2 for typical output).

Before using SLOPE/W, the moisture condition for transient analysis from SEEP/W has to be clearly defined. The output at different interval of time was combined with SLOPE/W to make it possible to determine the factor of safety of each interval of time. For all cases, Bishop method of analysis were chosen for the stability check.

In the analyses, the strength parameters for soils has been defined as follow:

Unit weight (γ)	$= 18\ kN/m^3$
Angle of friction (phi)	$= 20^0$
Cohesion (C)	$= 20\ kN/m^2$

The strength parameters were used to study the effects of perched water(for both the permeable and impermeable strata).

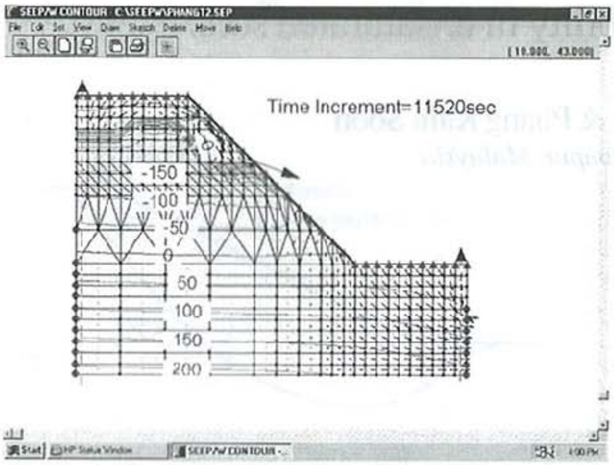

Figure 1. Typical output from SEEP/W

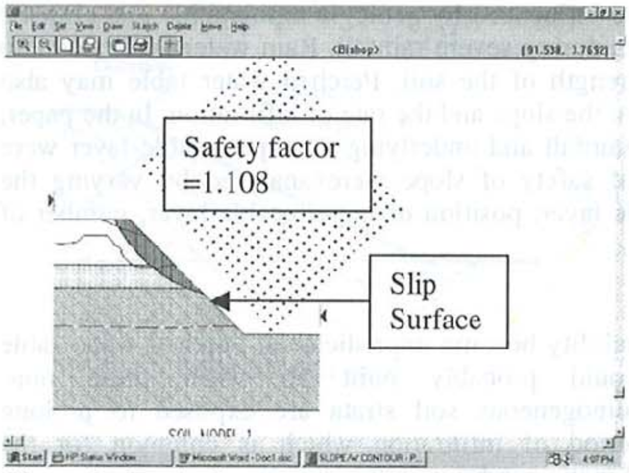

Figure 2. Typical output from SLOPE/W

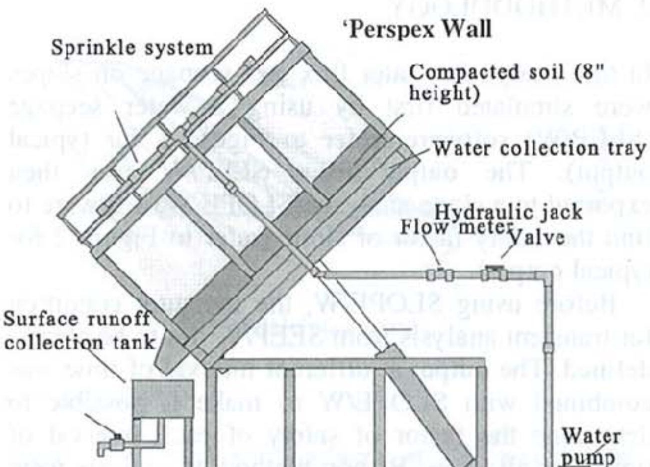

Figure 3 Laboratory Hydrological Model

Parametric Study

The pattern of rainfall chosen was constant rainfall with intensity 2.1 x 10^{-4} m/s for all cases. The duration of rainfall was 12000 sec (3.333 hrs). Under this type of rainfall intensity perched water table can be generated in most of the cases. Thus the effect of perched water table under these specified parameters can be studied carefully.

The effect of the permeability ratio (ratio of permeability of a permeable stratum to impermeable stratum) was also studied. The critical ratio that causes perched water table was determined.

The parameters chosen were as below:

i) 2.1 x 10^{-4} m/s and for sloping surfaces was 1.05 x 10^{-4} m/s.
ii) Thickness of impermeable layer was 2m and it was modelled at 4m below top surface.
iii) Height of slope was 8m.
iv) Permeability of impermeable layer had been selected as 1 x 10^{-8} m/s. The ratios were defined in the range of 30000 to 100000.

In the study few possible cases were considered: -

1) Effect of position of impermeable layer.
2) Effect of dipping of impermeable layer.
3) Effect of thickness of impermeable layer.
4) Effect of number of impermeable layer.
5) Effect of rainfall intensity

Verification of the SEEP/W program

Before the parametric study, verification of the suction values was carried out by comparing the measured suction values in the laboratory hydrological model (Figure 3) with the simulated suction values by the SEEP/W program. Figure 4 shows one of the typical variations of with time. The difference of the lowest simulated and measured suction is just 2 kPa. However, there is a time lag of about 100 minutes between the simulated and measured suction values. The rainfall pattern agrees well with the drop in suction. The trend in recovery of the suction values for the simulated and site values are also found to be almost the same.

The initial difference of the suction values might be due to the hysteresis effect of the soil water characteristics of the sample used.

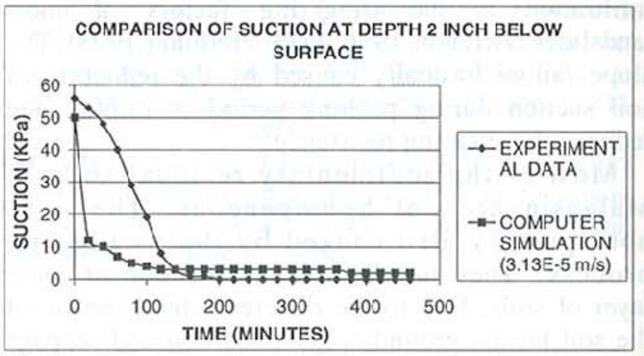

Figure 4 comparison of simulated and measured suction value.

3 DISCUSSION

Rainfall intensity for all the cases was specified for horizontal surface as well as dipping surface. The water flow into the slopes will be much more complicated as the interference of water flow from horizontal and dipping surface will happen. So, fluctuation is expected.

The conditions that cause slopes to become unstable and the factors that initiate the slip failure should be able to be identified. These factors are by the geological structure and hydro-geological conditions of the slope.

Generally in all cases the safety factor drops as the perched water table starts to build up. The drops are not very large i.e., not more than 20 %.

3.1 Effect of Permeability Ratio of Permeable Layer to Impermeable Layer

By varying the permeability ratio, it will affect the seepage and water content in the slope and hence the stability of the slope. From the results shown in Figure 5, it is clear that safety factors drop at certain interval of time when perched water table starts to build up. The perched water table starts to build up earlier for higher permeability ratio and this causes safety factor drop earlier. This is true because the higher ratio means the permeable layer with higher hydraulic conductivity, which allows water to infiltrate into the soil faster. Generally perched water table starts to build up from interval time 6000 sec to 8000 sec.

3.2 Effect of Position of Impermeable Layer

By varying the position of impermeable layer, the time to build up perched water table seepage infiltration and water content will be affected. From graph (Figure 6), the safety factor of slip surface starts to drop at time 6000 sec. This means perched water table starts to build up at this time. Generally the effect of position of the impermeable strata is not significant.

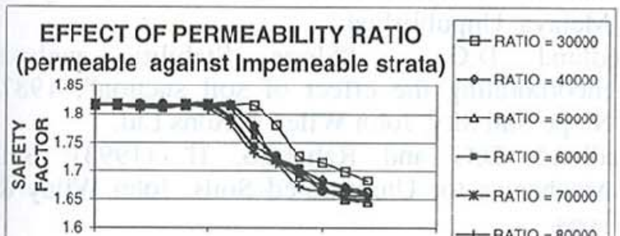

Figure 5. Effect of soil permeability ratio on slope safety factor (Permeability of 1x 10^{-8} m/s for impermeable stratum was used as datum)

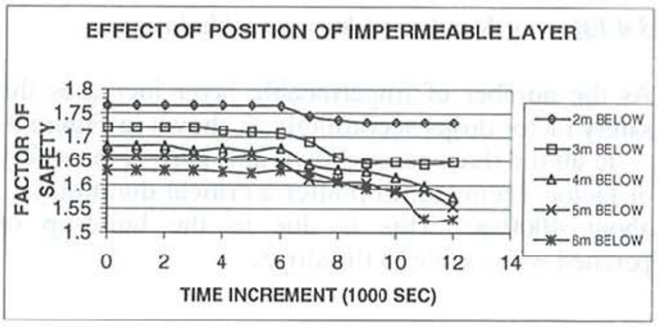

Figure 6. Effect of position of impermeable strata (distance referring to the top of the slope)

3.3 Effect of Dipping of Impermeable Layer

Cases with dipping layers generally have safety factor with sloping bed dipping backward (Figure 8). This is because the dipping backwards enables more water to accumulate above impermeable layer. The effect of perched water table is more significant as it is easier to form as safety factor drops earlier compare to model with dipping bed gradient same direction with dipping surface.

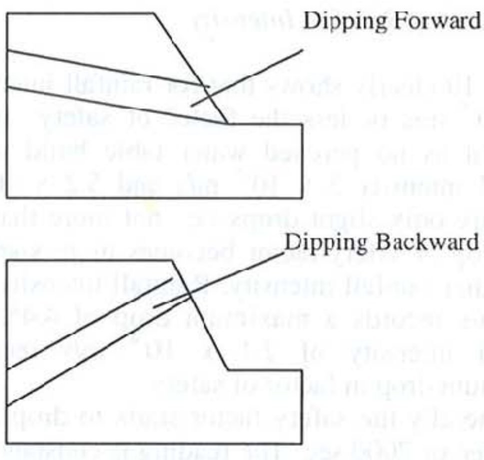

Figure 7 Typical profile showing the impermeable stratum

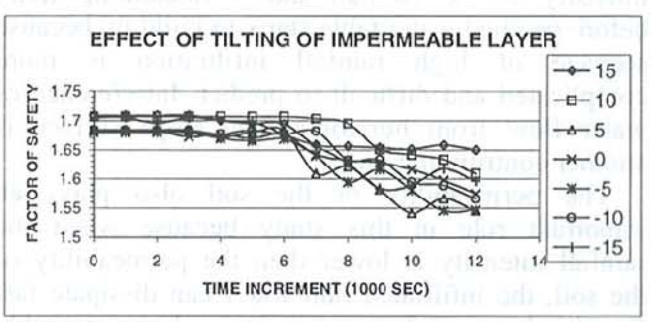

Figure 8. Effect of dipping of impermeable soil layer on slope safety factor. (negative in the figure indicates dipping backwards)

3.4 Effect of Number of Impermeable layer.

As the number of impermeable layer increases the safety factor drops accordingly as shown in Figure 9.

In all the three cases shown in Figure 7, the safety of factor seems to drop after a critical duration i.e., about 4000sec. This is due to the build-up of perched water table in the slope.

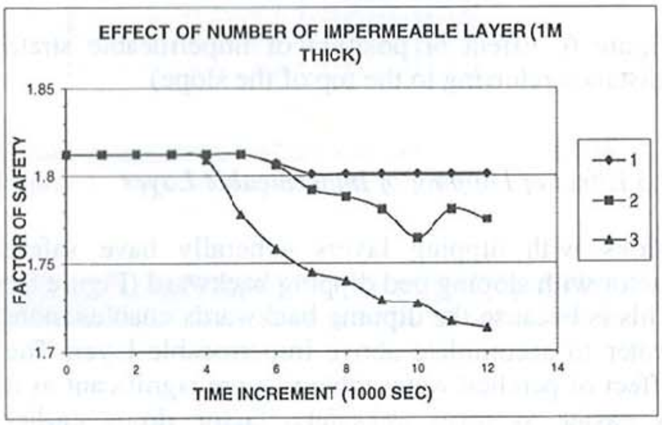

Figure 9. Effect of number of impermeable strata on slope safety factor.

3.5 Effect of Rainfall Intensity

Figure 10 clearly shows that for rainfall intensity of 1 x 10^{-5} m/s or less the factor of safety remains constant as no perched water table build up. For rainfall intensity 5 x 10^{-5} m/s and 5.2 x 10^{-5} m/s there are only slight drops i.e., not more than 2 %. The drop of safety factor becomes more significant for higher rainfall intensity. Rainfall intensity of 1 x 10^{-4} m/s records a maximum drop of 4.4% while rainfall intensity of 2.1 x 10^{-4} m/s records a maximum drop in factor of safety.

Generally the safety factor starts to drop at time 6000 sec or 7000 sec. The reading is constant for set of data with lower rainfall intensity, as for lower rainfall intensity the effect of perched water table is not significant. The safety factor for rainfall intensity 2.1 x 10^{-4}m/s shows fluctuating trend before perched water table starts to build up because seepage of high rainfall infiltration is more complicated and difficult to predict. Interference of water flow from horizontal and slope surface is another contributing factor.

The permeability of the soil also plays an important role in this study because when the rainfall intensity is lower then the permeability of the soil, the infiltrated rain water can dissipate fast into the slope and does not cause perched water table to build up. But, when the rainfall intensity equal to or more than the soil permeability value, perched water table will start to form.

In the analysis, the flux boundary condition needs to be considered carefully. If the rainfall intensity is more than the permeability of the soil, surface runoff needs to be specified.

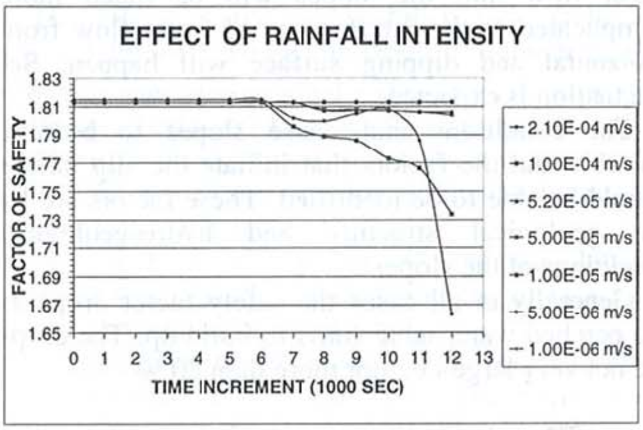

Figure 10 Effect of rainfall intensity on factor of safety

4 CONCLUSIONS

From the studies carried out, the following conclusion can be summarised:

i) Factor of safety will drop lower for slope with higher ratio of permeability.

ii) When perched water table is formed, it decreases the factor of safety. Further rainfall does not seem to lower the safety factor.

iii) Cases with impermeable stratum dipping backward generally gives lower safety factor compares to cases with impermeable stratum dipping forward.

iv) As the number of impermeable layer increases the safety factor will drop. The drop in safety factor is rapid after the critical duration.

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