SLOPE STABILITY ENHANCEMENT BY SUSTAINING MATRIX SUCTION DURING RAINFALL USING GEOSYNTHETIC

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1.0 ABSTRACT

Rainfall has always been the major cause of landslides all over the world. Many efforts were made by preventing or reducing slope saturation due to rainfall, such as introducing thick vegetation cover, surface guniting, subsoil drainage networks, horizontal drains, etc. With all the efforts made we still have slope failures due to rainfall. The primary mechanics of slope failure due to rainfall are the lost of soil matrix suction cause by rain water infiltration followed by increment in pore water pressure and soil weight beyond the shear strength capacity of the soil causing the slope to fail.

This paper address the mechanics of improving and enhance the stability of slope by maintaining or sustaining matrix suction during rainfall using geosynthetic.

1.1 INTRODUCTION

It is well documented and known to the fact that matrix suction is one of the key strength contribution element in slope stability. With many proven calculations, research works and publications made, the use of matrix suction in engineering practise remain undecided. Geotechnical engineers remain in the traditional slope design approach of not considering matrix suction in their design works. These approaches not only very conservative, it is also inflate the construction cost higher. Hence, with the experience of intensive research works carried out in the past and with the incoorporation of new geosynthetic technical advancement, this paper addresses various simple and practical approaches to sustain matrix suction within the slope mass during rainfall without compromising slope factors of safety.

2.0 UNSATURATED SOILS

The mechanism of suction induced failure of slope is due to rain water infiltration that causes reduction in matric suction within soil mass, due to saturation. This leads to decrease in effective stress of the soil strength to a point where equilibrium can no longer be sustained in the slope mass. The equation for unsaturated shear strength was written in terms of the stress strain variables with an extension for saturated soils. (Fredlund D.G. et al , 1978).

$\tau = c' + (\sigma - u_a) \tan \phi' + (u_a - u_w)\tan\phi^b$ ----------(1)

where:

c' = effective cohesion , σ = total stress ,

u_a = pore -air pressure, u_w = pore water pressure,

ϕ' = effective angle of internal friction ,

$(u_a - u_w)$ = matric suction,

ϕ^b = angle indicating the rate of increase in shear strength with respect to changes in $(u_a - u_w)$ when $(\sigma - u_a)$ is held constant.

The above equation assumes a planar failure envelope, the internal friction angle ϕ', remains constant under saturated and unsaturated condition. The angle ϕ^b , which quantifies the effect of suction is measured from the τ vs $(u_a - u_w)$ plot. The cohesion intercepts c_1, c_2 and c_3 due to the applied suction $(u_a - u_w)$ vary if the angle of internal friction ϕ' remains constant at different suction levels. Figure 1.0 shown the τ vs $(u_a - u_w)$ plot.

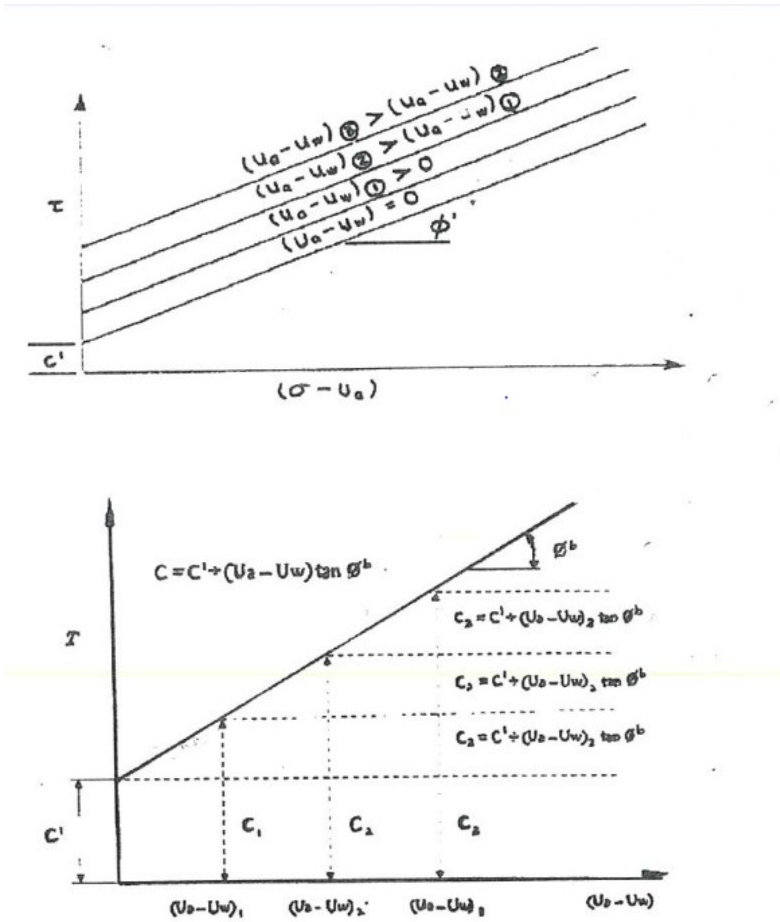


Figure 1.0: Matric Suction Drawn on a Failure Envelope

3.0 RATE OF DROP IN MATRIX SUCTION WITH RAINFALL

3.1 Field Record and Computer Simulation.

Rainfall simulation were performed at the field using artificial rainfall simulation sprinkler system.

a) Field test methology

An artificial rainfall simulation sprinkler system was setup at the field using steel frame parallel to the slope. The frame was sized at 15 feet by 15 feet with four rows of PVC host fitted with six sprinkler heads on each row. The schematic diagram of the frame and sprinkle head locations are shown in Figure 2.0. The required intensity of artificial rainfall was calculated based on the highest rainfall recorded in Malaysia. The inlet water supply was measured and monitored to be constant during the test using a flow meter. Whereby the surface run off water was collected using V-notch collecting drain and measured periodically.

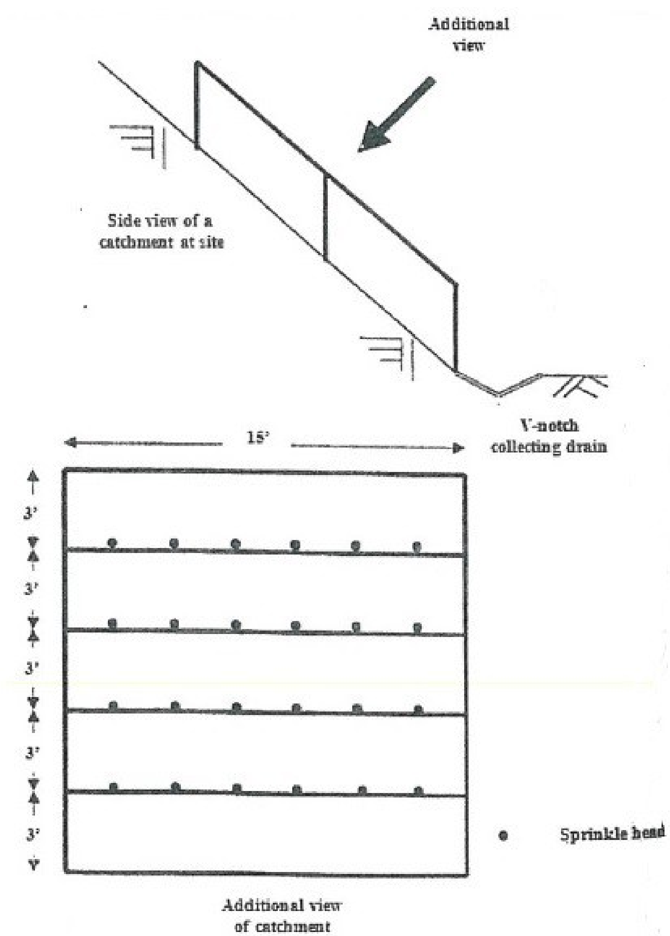


Figure 2.0: Illustrates The Sprinkling Frame and Sprinkler Locations

To monitor the suction changes 7 numbers of small tip tensiometer and 4 numbers of jet fill tensiometers were installed. The small tip tensiometers were installed at 10 inches depth perpendicular to the slope surface within the sprinkling frame. Wherelse jet fill tensiometers were installed at 0.5m, 1.0m, 2.0m and 3.0m near to the slope toe and perpendicular to the slope surface. The schematic layout of the installed tensiometer positions with respect to the sprinkling frame and slope is shown in Figure 3.0.

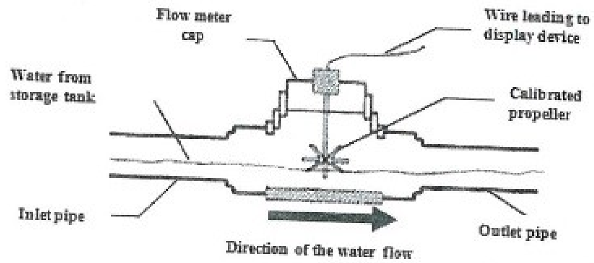


Figure 4.2: Working concept of flow water

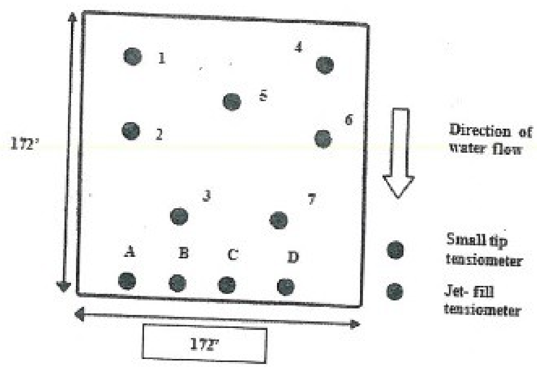


Figure 3.0 : Illustrates The Small Tip and Jet Fill Tensionmeter Layout Plan

The tests were performed at constant volume of water supply with artificial rainfall intensity of 3.4×10^{-5} m/s (122.4mm/hour). The soil suction and surface run off data were measured every 10 minutes intervals. The artificial rainfall was maintained for two and half-hours. And the subsequent time, the suction data were monitored till no further changes in reading.

b) Computer model

The computer simulations were performed using finite element model using seepage analysis software. The field experiment data are converted into input parameter of water Conductivity curve and combination of field and laboratory soil-water characteristic curve for berm 2 with respect to soil matric suction as shown in Figure 4.0 and 5.0 respectively. Figure 6.0 shows the developed computer model to simulate the site condition. Finer grids were given at the location where small tip and jet fill tensiometers were installed. Hence, relative comparison between field data and computed results can be analysed. The field recorded permeability rate of 2.31×10^{-6} m/s has also incorporated in the model. The analysis was executed using transient control mode with total run time of 2 hours 30 minutes.

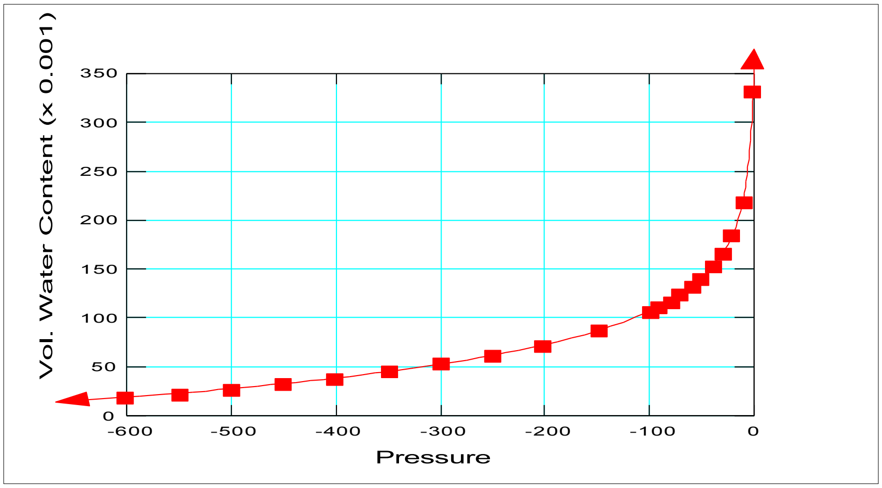


Figure 4.0 : Soil water characteristic curve for Berm 2 - Weathering grade IV

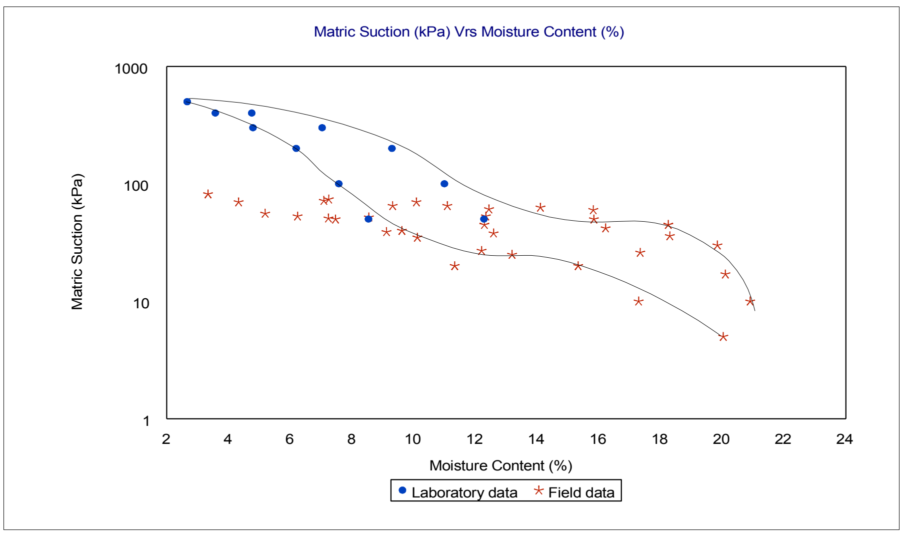


Figure 5.0 : Combination of Field and Laboratory Soil-Water Characteristic Curve Berm 2

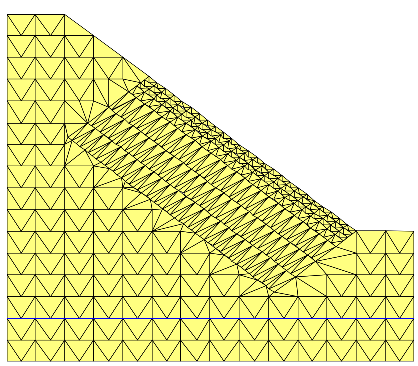


Figure 6.0 : Computer model of the site

C) Comparison between field and computed results

Relative comparison between field tensiometer data and the computed results were made by plotting the changes in matric suction with time. Figure 8.0 shows the plot of field and computed matric suctions with time for some selected points. Based on the plot, rate of suction changes with time after 30 minutes of rainfall is more the less same.

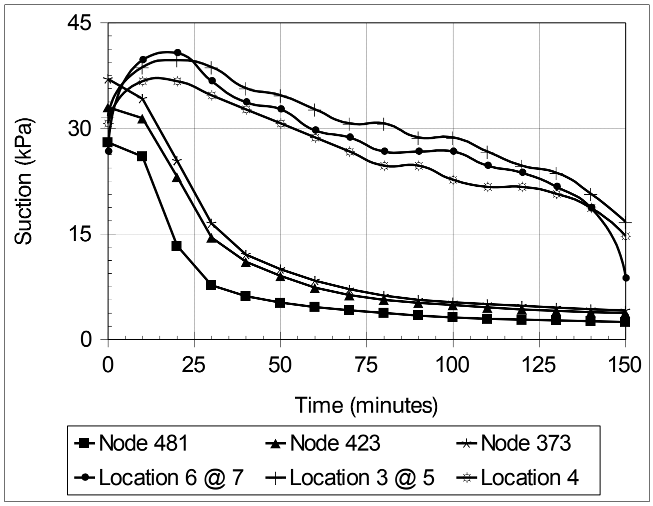


Figure 7.0 : Comparison plot between field and computed data

However a phenomena of sudden increase of matric suction in the first 20 minutes of rainfall is recorded in every tensiometers. The software did not compute this effect. Figure 8.0 shows the plot of continuos monitoring of suction after rainfall. The figure shows that when the rainfall is stopped at 150 minutes a sudden drop in matric suction takes place. In addition to the sudden drop in suction after 150 minutes, the rate of suction reduction is also recorded high for the next 30 minutes before stabilization take place and drying process begins. The sudden increase of matric suction in the beginning of rainfall, and sudden drop in matric suction after rainfall, believed to be caused by lamina flow of rainwater on slope surface. The flow creates lower pressure zone at the surface, which respectively increases matric suction. However a sudden drop of rainwater flow, releases the lower pressure zone at the surface, causing an increase in water infiltration rate into the slope. The sudden drop in suction after heavy rainfall is commonly not taken into consideration in a slope stability analysis. Hence, new mechanism or algorithm need to be developed considering the above mention phenomena in the slope stability analysis methodology.

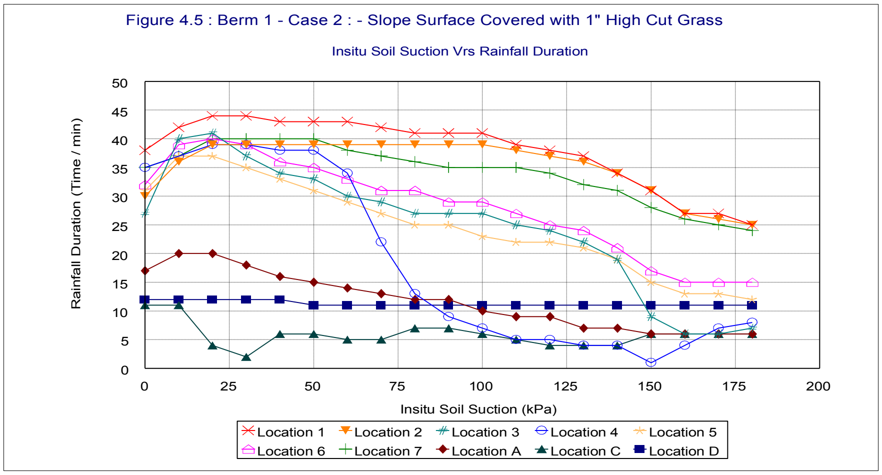


Figure 8.0 : Berm 1 – Case 2 : - Slope Surface Covered with 1" High Cut Grass

4.0 SUSTAINING MATRIX SUCTION DURING RAINFALL

Rainfall infiltration rate on slope with geosynthetic and bare slope surface can be observed by perform infiltration analysis. Figure 9.0 and 10.0 shows comparison in seepage analysis indicating the wetting front and the saturation condition of slope with built up ground water level

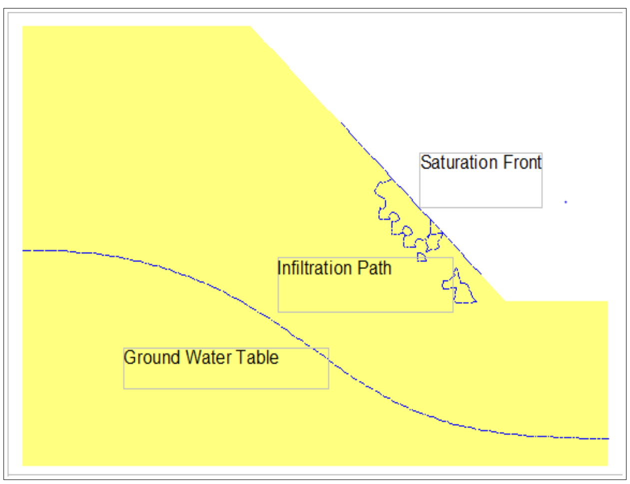


Figure 9.0 : Seep Analysis Model for Berm 3 (2 1/2 Hours Rainfall) Weathering Grade IV & III Slope Surface Covered with Natural Grass and Geosyntectic

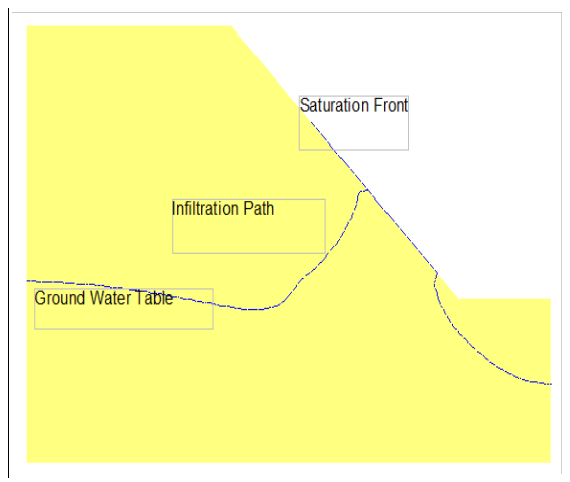
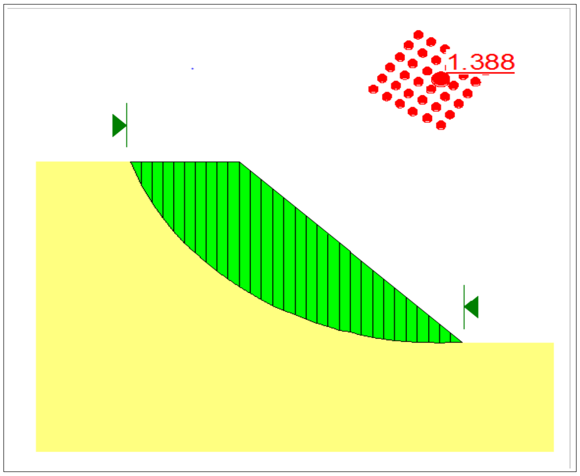


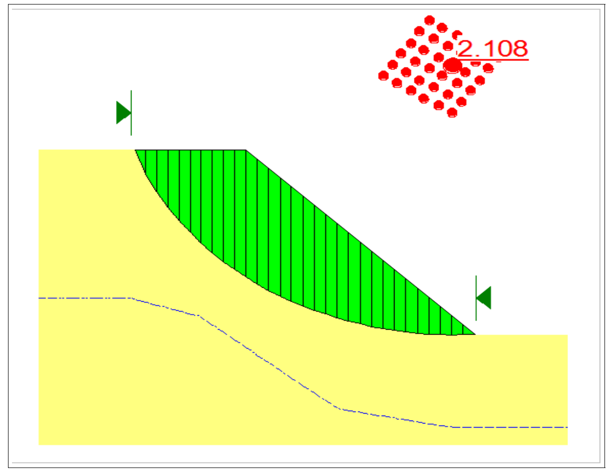
Figure 10.0 : Seep Analysis Model for Berm 3 (2 1/2 Hours Rainfall) Weathering Grade IV & III Bare Slope Surface

The changes in ground water profile will have direct effect to the slope factors of safety, comparison of slope factors of safety are shown in figure 12.0



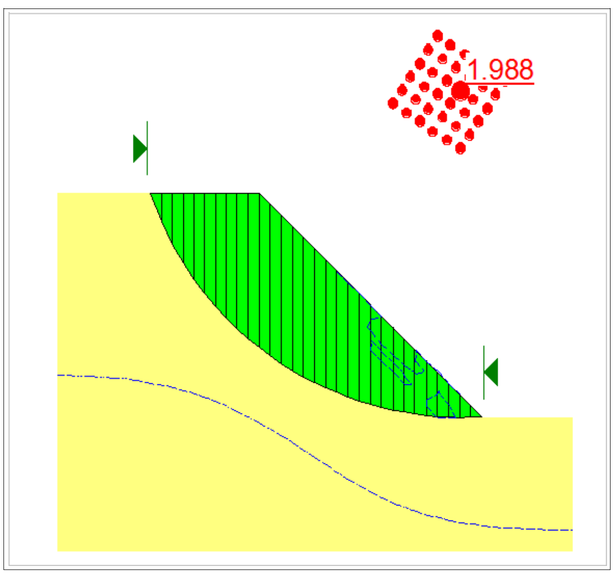
FOS = 1.38, Conventional slope analysis

Figure 11.0 : Slope Analysis for Berm 3 - Weathering Grade IV & III Conventional Analysis



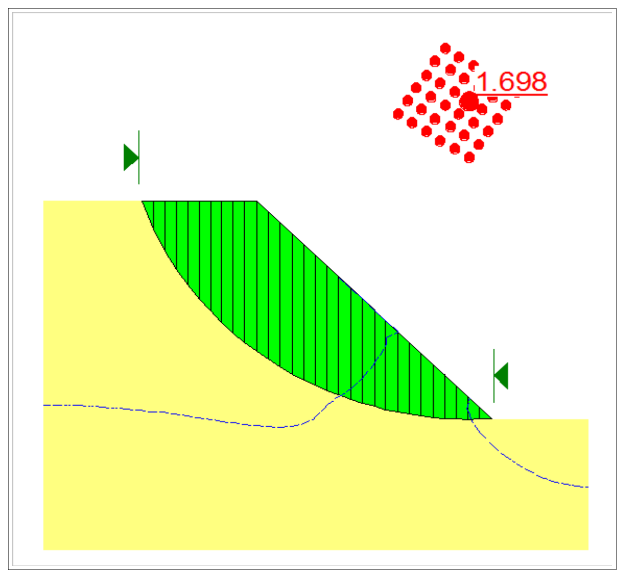
FOS = 2.108, Initial condition with matrix suction

Figure 12.0 : Slope Analysis for Berm 3 - Weathering Grade IV & III Initial Slope Condition with Matric Suction



FOS = 1.988, Slope surface covered with natural grass and geosynthetic.

Figure 13.0 : Slope Analysis for Berm 3 - (2 1/2 Hours Rainfall) Weathering Grade IV & III Slope Surface Covered with Natural Grass and Geosyntectic



FOS = 1.698, Bare slope surface

Figure 14.0 : Slope Analysis for Berm 3 - (2 1/2 Hours Rainfall) Weathering Grade IV & III Bare Slope Surface

The soil parameters used for analysis are as follows.

Bulk density, γ, kN/m³	= 18
Effective fiction angle, Ø'	= 31º
Effective cohesion, c', kN/m²	= 4
$Ø^b$	= 24º
Slope angle	= 45º (1V:1H)
Slope height	= 6m

Based on the analysis carried out the conventional slope stability analysis will be able to obtain FOS of 1.38 as compared to slope analyzed with matrix suction having FOS of 2.108, an increase in FOS of 52%. Under slope covered with geosynthetics the FOS dropped to 1.988 about 6%. Without the use of any surface cover the FOS dropped to 1.698 about 24.1%. Drop in 30% ~ 40% in FOS could be sufficient enough to cause shallow or facial failures.

In order to prevent such failures it is recommended to use geosynthetic in the form of erosion control mat couple with drainage net on the surface of slope as shown in Figure 15.0. Plate 1 and 2 shows a typical case study performed on poor ground condition with continous shallow failure. With the use of surface erosion control mat and drainage net, the failures were prevented.

Plate 1: Slope undergoing continous shallow facial failures.

Plate 2**:** Slope protected with erosion control mat and drainage net, managed to prevented failures.

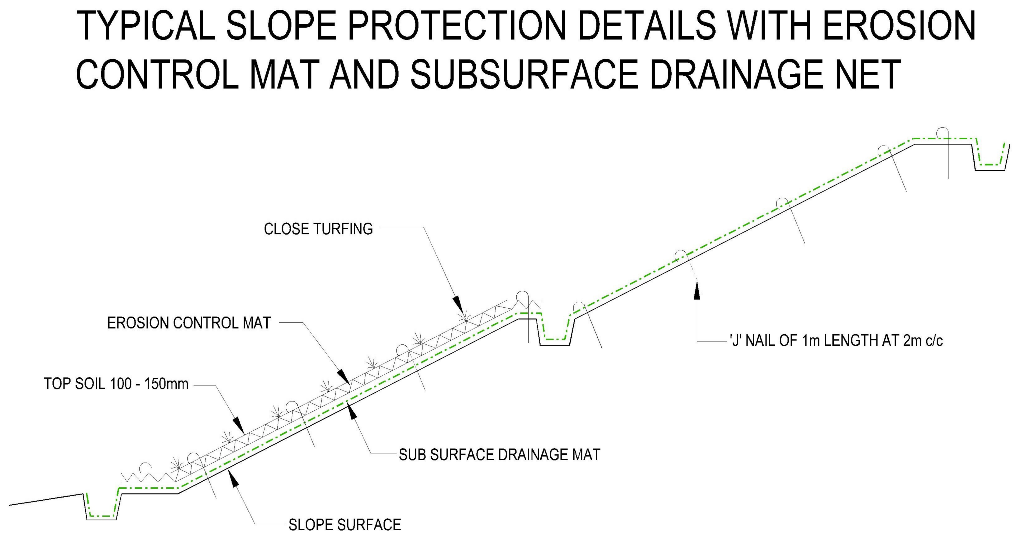


Figure 15: Typical Slope Protection Details with Erosion Control Mat and Subsrface Drainage net.

5.0 CONCLUSION

Matrix suction within slope mass contribute largely to sustaining stability. However, suctions are sensitive to the influence of groundwater fluctuation and surface/rain water infiltration. With the use of geosynthetics to prevent erosion and infiltration, matrix suction within soil mass can be sustaining, which in directly sustain adequate factors of safety and prevent slope failures. The arrangement of geosynthetics to enhance matrix suction are shown in Figure 13.0. Hence, engineers are encourage to adopt the use of matrix suctions in their analysis and design approach.