EFFECT OF RELICT JOINTS IN RAIN INDUCED SLOPE FAILURES IN RESIDUAL SOIL

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Abstract: Rain induced slope failures are a common geotechnical hazard in most parts of the world. Particularly in the tropical regions, which are covered with residual soil, the temporal frequency of rainfall induced slope failures is very high. These problems are encountered frequently in the construction of highway where very high cuts are made in the slopes. Residual soils are formed due to weathering of rocks and the joints remain as relict joint even after the weathering process. The residual soils are heterogeneous due to variable weathering of the jointed mass rock. Generally the ground water table is low during the dry season and these soils are in an unsaturated state with negative pore water pressure above the water table. As a result of infiltration of rain water, the matric suction will be destroyed and ground water table will rise. Relict joints present in the system will further complicate the pattern of infiltration. Changes in the pore pressure regime due to infiltration and its effect on safety was studied in a previous research. The objective of this research is to investigate the effects of different systems of relict joints in the infiltration and stability. This aspect was studied in this research using SEEPW, SLOPEW software.

Keywords: Slope stability, unsaturated soil, Matric Suction, Rainfall, Relict joint.

1. Introduction

Rainfall is one of the most significant triggering factors for a landslide. Most slope failures in residual soil are triggered by excessive infiltration. Residual soils are formed due to weathering of in situ rock and the joints in the parent rock remain as relict joints even after the weathering. The degree of weathering and the mineralogical composition of the weather product can vary in abrupt manner. The presence of relict discontinuities adds further complexity to the problem. These relict joints could be clean or could be filled with a weak/loose material that is of low shear strength and high permeability. Because of that the relict joint is a much weaker zone compared to the residual soil formed by the weathering of intact rock. If the relic joints are adversely oriented with respect to the topography of the cut slope, it would be highly vulnerable. The effect of the presence of layers of widely different permeability was studied in the early stages of this research program.

The variation of negative pore-water pressure in unsaturated soils is governed by the water flow, which can be affecting by many intrinsic and external factors. The intrinsic factors are mainly the hydraulic properties of the soils, including water retention characteristics and permeability. The external factors are mainly climatic conditions, such as rainfall intensity and duration, rainfall pattern, and evapotranspiration rate, vegetation covers .etc. The effects of these factors and technique to mitigate those failures will be investigated in this research.

2. Methodology

The analysis was performed under two different conditions. The case one was a slope made of uniform residual soil. In case two various arrangements of relict joints (slightly horizontal, slightly vertical and combined) were introduced to the uniform residual soils.

In this research, analysis was done using the commercial software SLOPE/W and SEEP/W. The finite element computer program SEEP/W was used to model the infiltration through the unsaturated soil slope. The pore water pressure distribution along different vertical sections of the slope due to prolonged rainfalls of different intensities was studied by the SEEP/W software. After the infiltration analysis the stability of the slope was studied by the SLOPE/W software which is based on the limit equilibrium approach. Two methods; Bishop's simplified method and Spencer's method was used for circular failure surfaces and non-circular failure surfaces respectively.

3. Saturated and Unsaturated Soil

All the voids in a soil below the ground water table are filled with water and the soil is in a saturated state. Above the water table some voids are filled with air and the soil is in an unsaturated state and three phase system exists with solids, water and air.

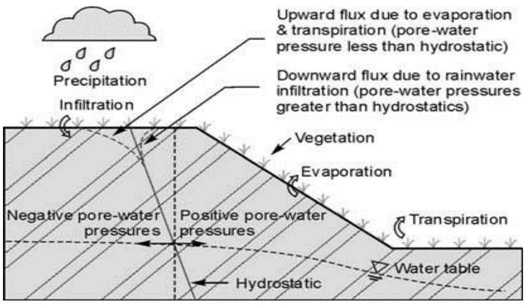


Figure 1 : pore water pressure profile near the ground surface

The pore water pressure above the water table is less than atmospheric (negative) as illustrated in Figure 1.

3.1 Relict Joints

Joints form as a result of expansion due to cooling, or relief of pressure as overlying rocks are removed by erosion. Joints form free space in rock by which water, loose fill, or plants can enter to reduce the cohesion of the rock.

The joints can get filled with weak material during the course of weathering. Results of laboratory shear strength testing show that the peak strength parameters along joint surfaces of could be of the order of; c' =0-6 kPa and ϕ'=20-30. The thickness of the exposed joint surfaces varies from several millimetres to more than 10cm.

Thus, the shear strength along relict joints is generally less than that of the weathered intact material. Relic joint material will also be of greater permeability. As such, relic joints will facilitate the infiltration and movement of water in the soil mass. If the relic joints are adversely oriented with respect to the topography of the slope, they will affect the formation of the critical failure mechanism.

3.2 Hydraulic properties of unsaturated soil

The soil water characteristics curve (SWCC) and the water coefficient of permeability are the most important hydraulic properties that influence the flow of water in an unsaturated mass of soils.

A typical curve for the water coefficient of permeability and a Soil Water Characteristic Curve are presented in Figure 3 and Figure 4 respectively.

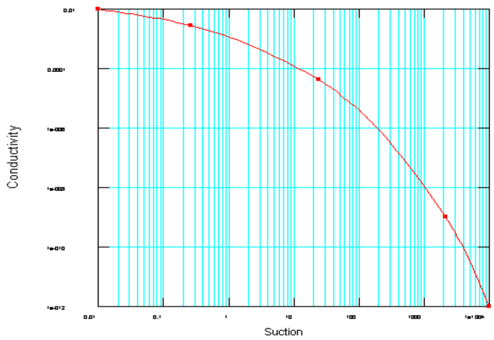


Figure 2: A Hydraulic conductivity function

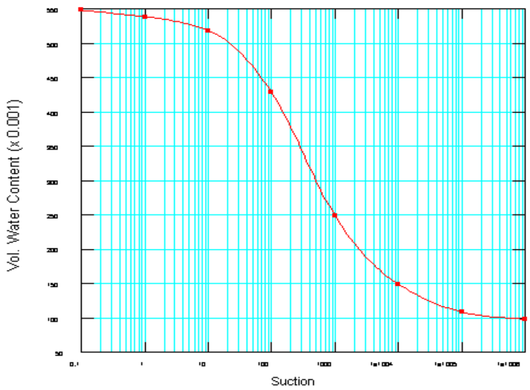
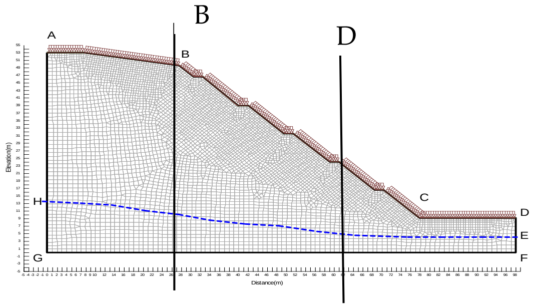


Figure 3: A Soil Water Characteristic Curve

3.3 Infiltration Modelling Using SEEP/W

The slope geometry with the gradient of 1:1 was used in this study. This analysis was carried out rain fall intensity of 5mm/hr, 20mm/hr. In the homogeneous soil (case 1) the entire slope was made of residual soil is shown in Figure 4 and the slopes with two different sets of relict joints are presented in Figure 5 and Figure 6 respectively.



Boundary conditions
AB, BC, CD= Ir (Rainfall intensity)
AH, DE, FG=Q=0m3/s (No flow Boundary)
EF, GH=ht (Total head at sides)

Figure 4: Finite element mesh and boundary conditions used in parametric study

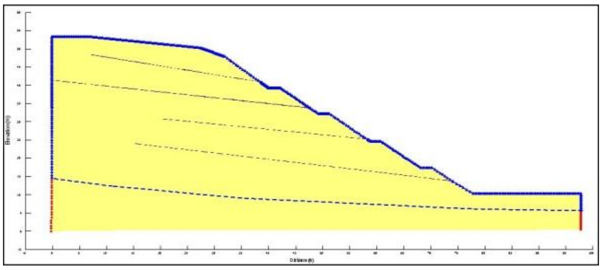


Figure 5: Geometry of 1:1 homogeneous slope with near horizontal relict joint s

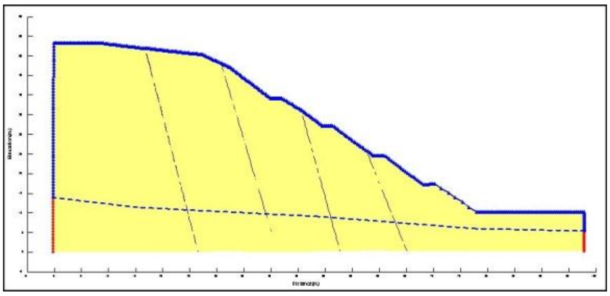
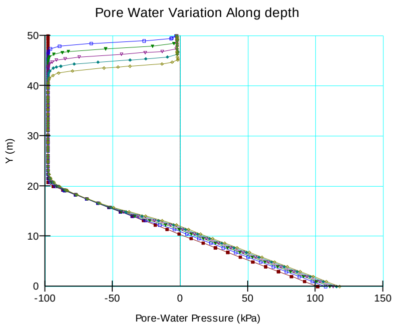


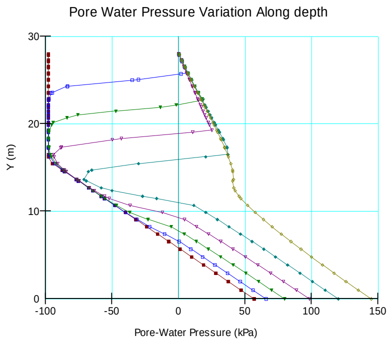
Figure 6: Geometry of 1:1 homogeneous slope with slightly near vertical relict joints

4. Results of Infiltration Studies

The changes in the matric suction-pore water pressure regime with the progression of the rainfall at section B and section D under different conditions such as uniform slope and slope with relict joints are presented in Figure 7, Figure 8, Figure 9 and Figure 10.

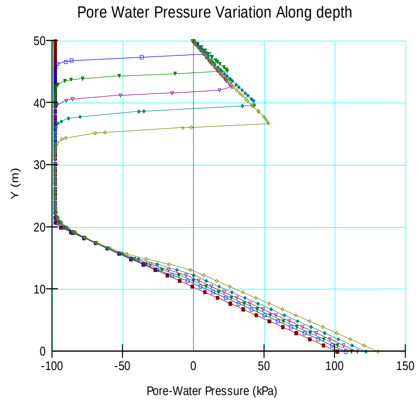


a) **Section B-B**

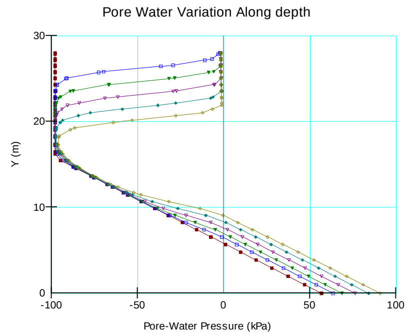


b) **Section D-D**

Figure 7: (5mm/hr Rainfall Slope (1:1with Homogeneous residual soil)

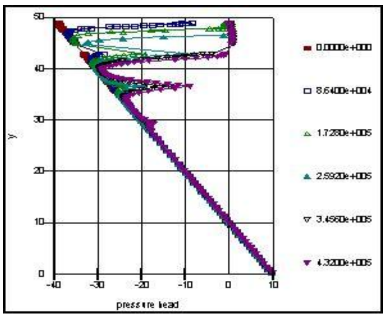


a) **Section B-B**

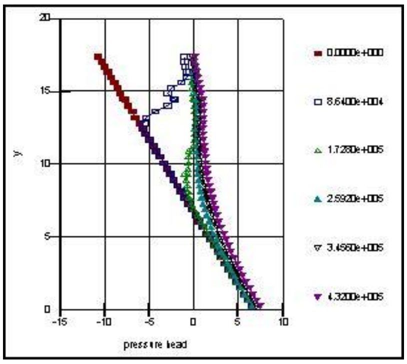


b) **Section D-D**

Figure 8: (20mm/hr Rainfall Slope (1:1with Homogeneous residual soil)

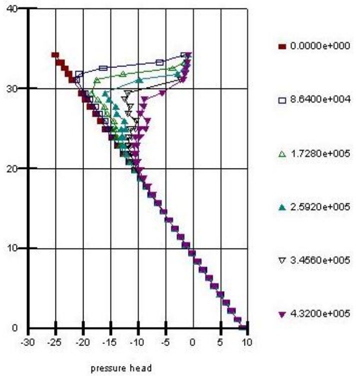


a) **Section B-B**

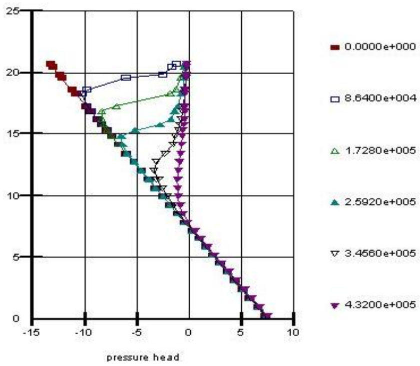


b) Section D-D

Figure 9: (5mm/hrRainfallSlope (1:1with Homogeneous residual soil with horizontal relict joint)



a) Section B-B



b) Section D-D

Figure 10: (5mm/hrRainfallSlope (1:1) with Homogeneous residual soil with vertical relict joint)

The analysis results clearly showed that the pore water pressure distribution change from negative to zero and the depth of influence increases as rainfall continues.

The comparison results show that the slope without relict joint as shown in Figure 7, 8 in section B-B, does not develop positive pore water pressures in intermediate section. Due to the presence of relict joint filled with loose material, the pore water pressure has become positive.

The plot compared with in section D-D, the positive pore water pressure developed in lower section could be larger in figure 8. The effect of 20mm/hr rainfall is much greater than effect of the 5mm/hr rainfall. Development of positive pore water pressure could be seen near the surface. When compared with the result in Figure 8 significant rise in water table could be observed to the lower end of the section. It is clearly visible that the effects more dominant to the lower part of the slope section.

5. Slope stability Analysis Using SLOPE/W

The slope stability analyses were performed to assess the safety margins of the slope as rainfall progressed. Analysis was done in a limit equilibrium framework with Bishop's simplified method and Spencer's method. Soil strength parameters used in the slope stability analysis are given in Table 1.

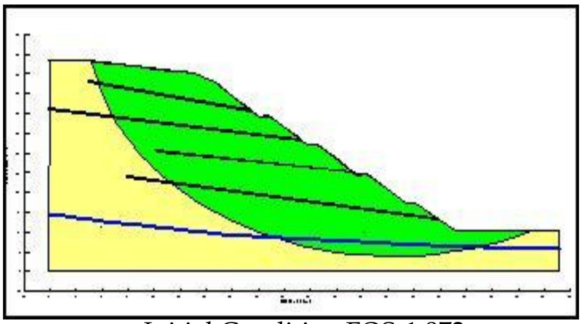
Table 1. Soil strength parameters used in the slope stability analysis

	Unit Weight	Friction Angle	Cohesion kN/m^2
Residual soil	19	34	10
Relict joint	12	25	3

Initially the positive pore water pressure are positive near the surfaces. Thus the matric suctions are high and apparent cohesion is high. Thus the failure surfaces would be quite deep.

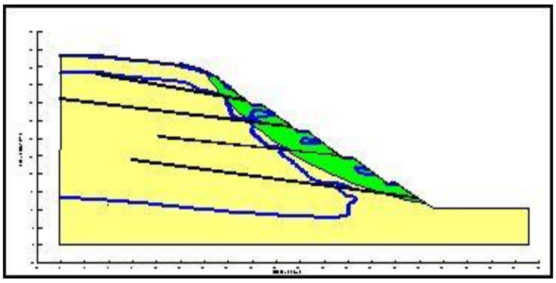
As the rain fall continuous, the water will start to wet the top layer of soil. The matric suction will first get destroyed near the slope surface. This loss of matric suction would reduce the apparent cohesion and the most critical failure surfaces will be at a shallow level.

This effect will be illustrated in Figure 11 and Figure 12, where critical failure surfaces are presented for the initial stage and after 5 days respectively.



Initial Condition FOS-1.972

Figure 11: (5mm/hr Rainfall Slope (1:1) Homogeneous residual soil with vertical relict joints)



Day 5 FOS-1.553

Figure 12: (5mm/hr Rainfall Slope (1:1) Homogeneous residual soil with vertical relict joints)

The variations of the factor of safety with the progression of the rainfall under different conditions are presented in Figure 13, Figure 14 and Figure 15 respectively.

The results presented in Figure 13 show that the reduction of factor of safety was more rapid for the rainfall of greater intensity.

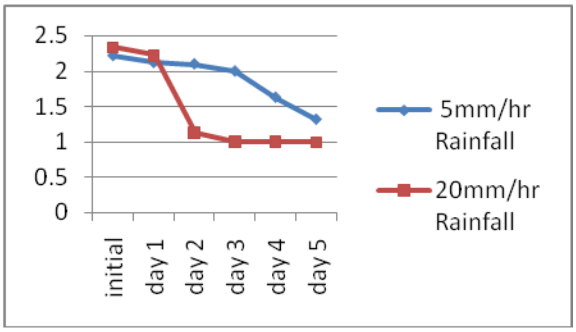


Figure 13: FOS values of Homogeneous residual soil slope (1:1) with combined Relict joint

The presence of relict joint will facilitate the infiltration. Thus in the slope with relict joints the factor of safety will reduce more rapidly than in the slope without relict joints as indicated by Figure 14..

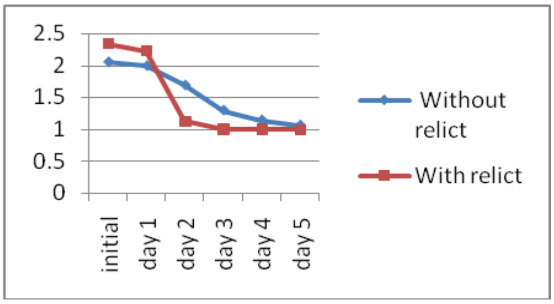


Figure 14: FOS values of Homogeneous residual soil slope (1:1) with combined Relict joint (20mm/hr Rainfall)

The variation of factor of safety with the various arrangement of relict joint is presented in Figure 15. When there is a system of two sets of relic joints, the infiltration is faster and the instability is reached at an earlier stage.

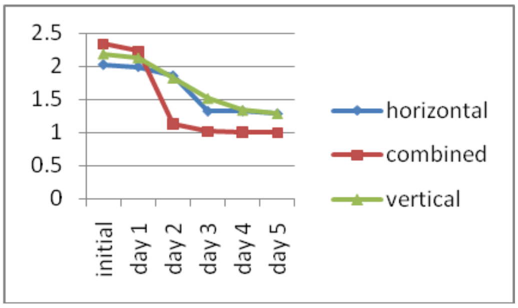


Figure 15: FOS values of Homogeneous residual soil slope (1:1) with relict joint (20mm/hr Rainfall)

6. Conclusions

Failures in slopes made of residual soil are often triggered by rainfall. Thus it is very important to understand clearly the mechanism of rainfall induced slope failures. This behaviour was analysed by modelling the infiltration with the SEEPW soft ware. The pore water pressure distributions along representative vertical sections were plotted.

It was found that the presence of relict joints in will facilitate the infiltration and the loss of matric suction and the development of positive pore water pressure is more dominant when there are relict joints.

The relict joint gets filled with weak material that has high hydraulic conductivity and less cohesion and friction. Thus they are weak planes and failure could occur through that when they are adversely oriented. This was quite evident in from the results of the stability analysis.

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