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Development A Simple Model for Preliminary Evaluation on Extreme Rainfall Induces Shallow Slope Failure

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ABSTRACT

A simple method is developed in this paper to evaluate rainfall induces slope instability. The method dealt with one dimensional infiltration on the shallow slope. The study was focused on the study of the effect of rainfall pattern, duration, soils type and slope angle on the stability of slope. Two soil types, those were low and high permeability, and slope angle were selected to examine the proposed model. The results of the study show that the proposed model was simple model and suitable to assess rainfall induced slope instability especially shallow landslides type. The proposed model enable to estimate the infiltration and slope stability during the rainfall as the FEM results was more conservative. Infiltration was strongly affected by rainfall pattern, inclination of slope and the hydraulic properties of soil.

Keywords: rainfall, infiltration, slope failure, seepage

1. INTRODUCTION

The climate change has been the worldwide issues including the extreme rainfall. This rainfall triggered many slopes and caused catastrophic disaster in many places in the world. Rainfall infiltration induced landslides are traditionally analyzed by using the two-dimensional limit equilibration numerical analysis. Attempts have been made to analyze the rainfall induces landslides by using coupling analysis of seepage and slope stability analysis. The common model to evaluate slope stability during rainfall was incorporated transient pore water pressure during the infiltration Modeling the infiltration and pore water pressure during rainfall was a complex analysis. Several investigators applied numerical modeling such as finite element method (FEM) to assess rainfall induces landslides [1-3]. However, the results of FEM were affected by several factors and much effort were required for performing calculation [5]. For practical purpose, a simple method is required as a rapid tool to assess the slope stability triggering by rainfall. Physically-based models coupling the infinite slope stability analysis with Green-Ampt infiltration modeling was developed in this research. Some investigators [6-8] have verified that the Green-Ampt equation could generate results, which were in good agreement with rigorous models such as Richard's equation. Hence, premier researches have been carried out on the shallow landslides analysis under steady and unsteady infiltration by applying the Green-Ampt equations [9-12]. In this paper, the effect of rainfall intensity and duration (rainfall pattern) on shallow landslides was investigated using the developed model. The study was focused on the study of the effect of rainfall pattern, soils type and slope angle on the stability of slope.

2. METHOD AND MODEL DEVELOPMENT

The method improved the previous model of Muntohar and Liao [11]. The improvement of analysis was made for calculation the pore water pressure (Part B) and slope stability analysis (Part C). The theoretical and derivation of the model has been clearly described in Muntohar and Liao [11,12]. The algorithm of the proposed model is presented in Figure 1. Principally the proposed model was based on the Green–Ampt infiltration model. The model was assumed one dimensional water flow through the slope. The slope stability analysis was modeled as infinite slope. In this study, the proposed model was then verified by using available numerical coupling model of SEEP/W and SLOPE/W [13-14]. The modeling of slope and boundary conditions are shown in Figure 2 for verification using two-dimensional finite element method. Three synthetic rainfall distributions including delayed, centralized, and advanced were selected to examine the effect rainfall pattern on the slope failure. The maximum rainfall intensity was 100 mm/h with total rainfall about 1250 mm. Two soil types, those were low and high permeability, and slope angle were selected to examine the proposed model. The soil properties are

presented in Table 1. The hydraulic conductivity and soil water characteristic curves of the soil were illustrated in Figure 3.

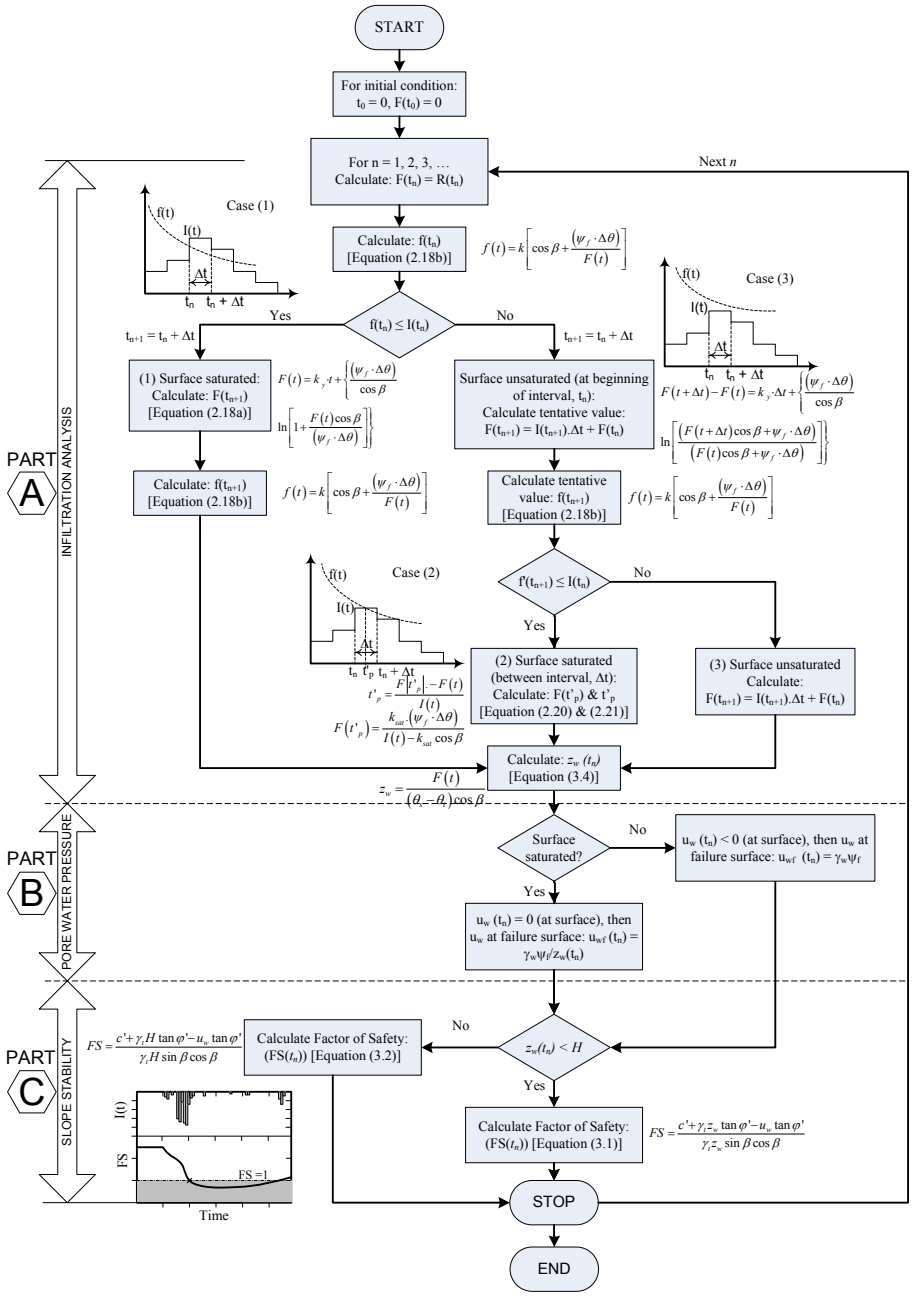


Figure 1 The algorithm for calculation the rainfall infiltration, water pressure, and slope stability

Table 1 Soil properties of the slope

Parameters	High Permeability Slope (K1)	Low Permeability Slope (K2)
Depth of bedrock, H (m)	5	5
Slope angle, β	20°, 40°	20°, 40°
Cohesion, c' (kPa)	0	5
Internal friction angle (ϕ')	30	30
Unit weight, γ_t (kN/m^3)	21.8	21.8
Saturated permeability, k_s (m/s)	1.0 x 10^{-4}	1.0 x 10^{-5}
Deficit volumetric water content, $\Delta\theta_w$	0.225	0.235
Suction head at wetting front, ψ_f (m)	0.5	1

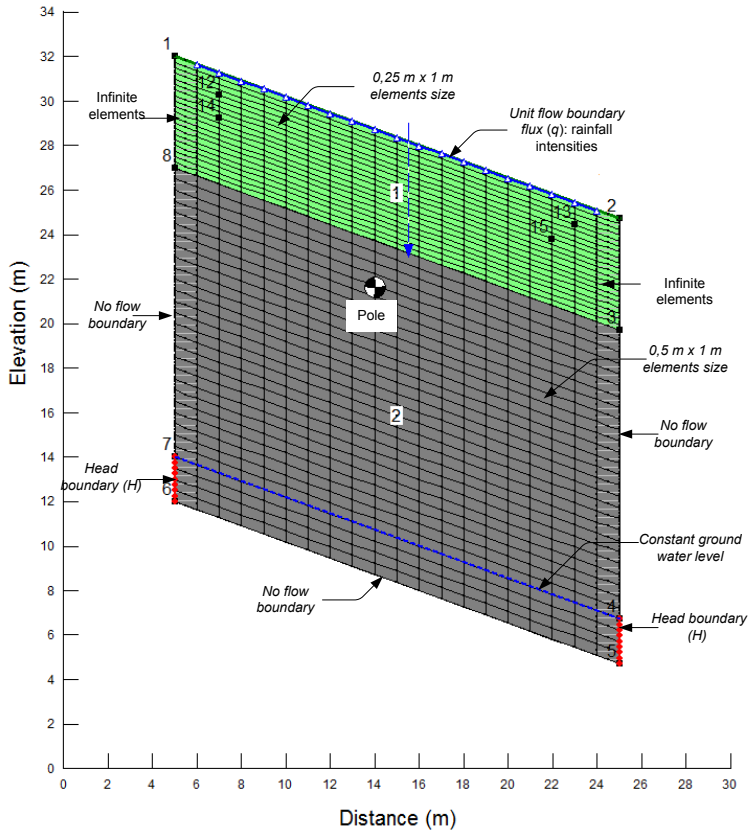
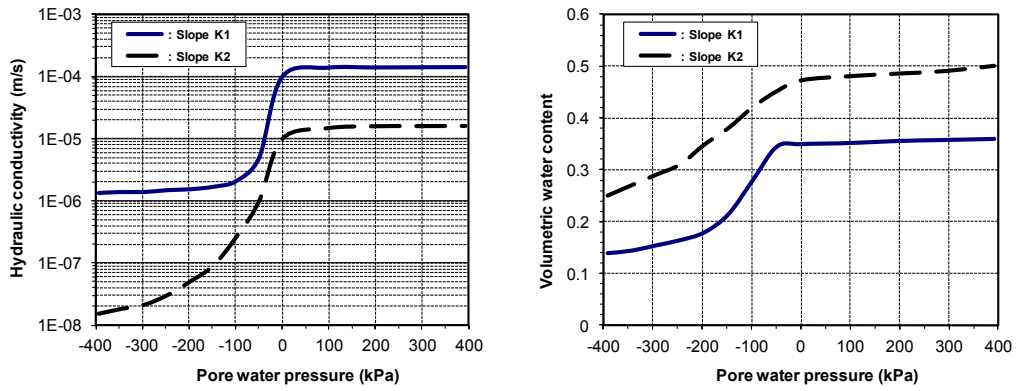


Figure 2 The modeling of slope and boundary condition for verification analysis



(A) (B)

Figure 3 The hydraulic properties of the soil (A) hydraulic conductivity curve, (B) soil-water content characteristics curve

3. RESULTS AND DISCUSSION

3.1 Infiltration Characteristics

Typical the result of analyses are illustrated in Figure 4. It was clearly observed that the infiltration in high permeability slope (K1) was the same with rainfall intensities. The infiltration pattern was the same with the rainfall pattern. In contrast with the low permeability slope (K2), the infiltration is affected by the rainfall pattern. Delayed and centralized rainfall pattern show a similar infiltration pattern as shown in Figure 4(A,D, C,F). The infiltration is the same with the rainfall intensity at the beginning of rainfall, then decrease gradually after certain elapsed time of rainfall.

It was observed clearly from the figure that for high permeability slope (K1), the infiltration of the Green–Ampt (GA) was in agreement with the FEM computation. It is because of the rainfall intensity (I_t) is lower than the saturated hydraulic conductivity of the soils (k_{sat}), $I_t < k_{sat}$. Simulation using FEM has shown that the slope

surface was unsaturated during the rainfall. Hence, all the rainwater infiltrate into the slope. For the case of low permeability slope (K2), the rainwater infiltration is controlled by the saturation at the slope surface. Saturation at slope surface will occur when the I_t is higer than the k_{sat} ($I_t > k_{sat}$). For this condition, the figures illustrated that the amount of rainwater infiltration from the proposed model was slightly difference with the FEM at the onset time of rainfall. The difference may be caused from initial suction head and volumetric water content at the initial state of the computation. In the GA infiltration model, the suction at slope surface and volumetric water content was assumed to be constant during the infiltration, while the FEM considered the change of suction, volumetric content and hydraulic conductivity during the calculation. But, after the slope surface saturated, the infiltration pattern for both model was the same. The deviation of infiltration from GA model and FEM was lesser for a slope with greater inclination as shown in Figure 4(D to F). The results indicated that the GA model is applicable for a sloping ground. The result is in agreement with Chen and Young [15]. It was observed in Figure 4(E) for K2 slope that the infiltration from GA model and FEM computation is relatively the same. The result indicated that the GA model is in good agreement when the slope surface is saturated at the beginning of rainfall.

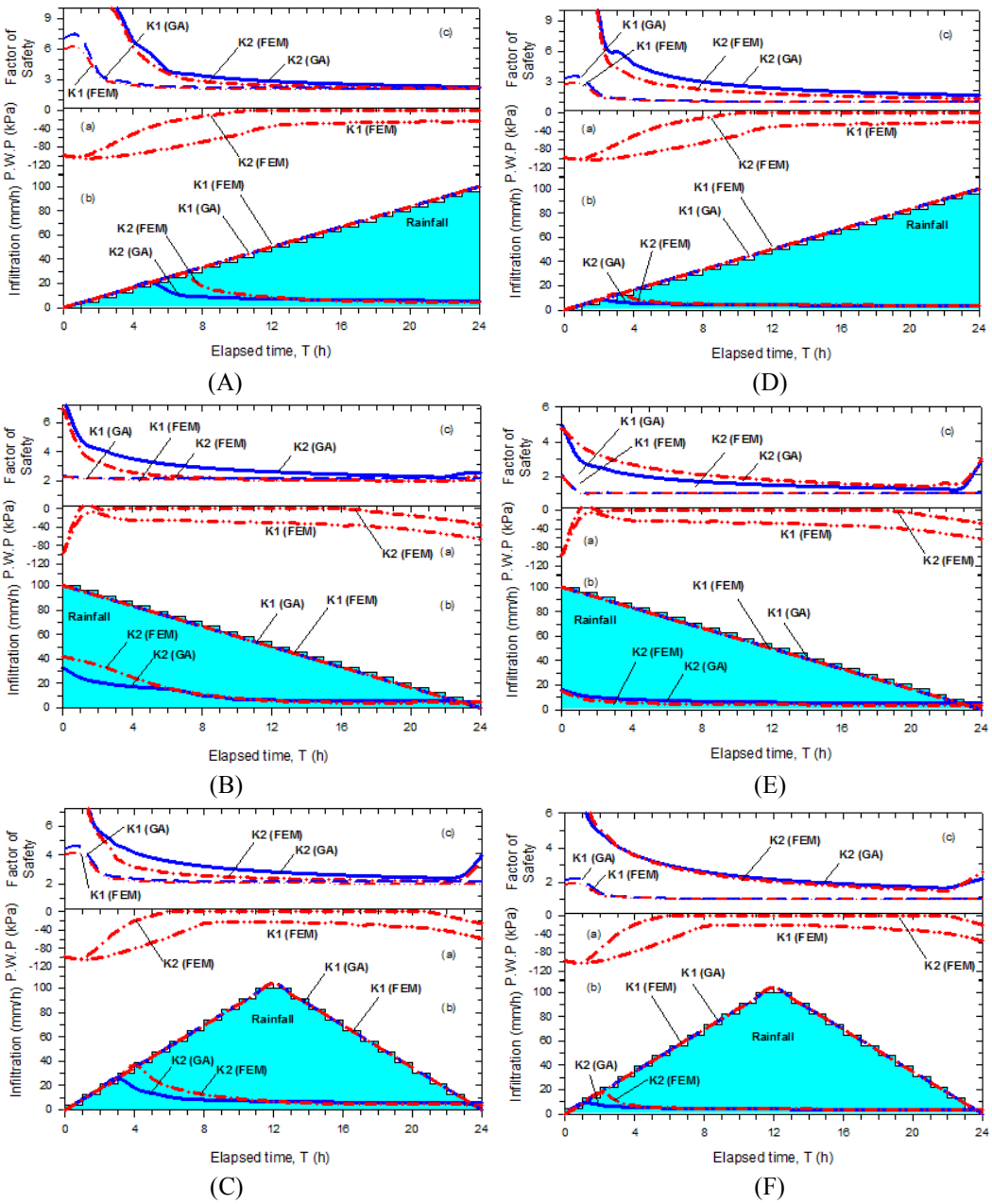


Figure 4 Typical of the result of the proposed model and two dimensional finite element analyses (A, D) delayed rainfall pattern, (B, E) advanced rainfall pattern, (C, F) central rainfall pattern.
Note: (A – C) for slope angle 20°, (D – F) for slope angle 40°.

3.2 Slope Stability

Slope stability is commonly represented by the factor of safety (FS). In the deterministic analysis, a slope will fail if the FS value is lower than one (FS < 1). The results illustrated in Figure 4 show that the advanced rainfall pattern resulted in the lowest minimum factor of safety for the given slope. Advanced rainfall generated rapid saturation on the slope surface at the beginning of rainfall, since the accumulated rainfall is greater than the saturated hydraulic conductivity of the slope. As the result, the pore water pressure increased drastically from 98.1 kPa to zero on the slope surface. Hence, the FS decreased significantly with the elapsed time of rainfall. It was observed for the delayed and centralized rainfall pattern, the factor of safety tend to increase at the end of rainfall. It was because of the decreasing of pore water pressure. The results indicated that rainfall pattern affected the slope instability. Slope failure rapidly occurred after the advanced rainfall pattern, while centralized and delayed rainfall pattern will generate a delayed slope failure. This finding is supported the research carried out by Tsai and Wang [16].

The effect of slope inclination was also observed from the relationship in Figure 4. For the slope inclination smaller than 20°, the estimated factor of safety from the FEM was more conservative than the results obtained from the proposed model for both K1 and K2 slopes. The analysis given in Figure 4 showed that the K1 slope was more prone to failure than the K1 slope subjected to the same rainfall intensities and duration. For the slope angle 40°, the factor of safety was observed to be dependent on the rainfall pattern. The factor of safety obtained from the proposed model was 5% lower than the results obtained from the FEM computation. In contrast with the K1 slope, the proposed model yield a lower factor of safety for K2 slope if compared to the FEM calculation. This result was completing the findings from the other research [1-3].

7. CONCLUSION

The proposed model has successfully estimated the infiltration and slope stability during the rainfall as wells as analysis of the FEM. Overall results were alluding to conclude that the proposed model was simple model and suitable to assess rainfall induced slope instability especially shallow landslides type. Infiltration was strongly affected by rainfall pattern, inclination of slope and the hydraulic properties of soil. For a high permeability slope which the saturated hydraulic conductivity of the soils (k_{sat}) is greater than the rainfall intensity (I_t), $k_{sat} > I_t$, infiltration was independent to the rainfall pattern. But for a low permeability slope, which the saturated hydraulic conductivity of the soils (k_{sat}) is lower than the rainfall intensity (I_t), $k_{sat} < I_t$, the rainwater infiltration is dependent to the rainfall pattern. The rainfall pattern controlled the saturation at the slope surface. For the slope angle smaller than 20°, the estimated factor of safety from the FEM was more conservative than the results obtained from the proposed model for both high and low permeability slopes. For the slope angle 40°, the factor of safety was observed to be dependent on the rainfall pattern. The factor of safety obtained from the proposed model was 5% lower than the results obtained from the FEM computation. In contrast with the high permeability slope, the proposed model yield a lower factor of safety for the low permeability slope if compared to the FEM calculation.

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