**SUSTAINABLE STRUCTURES AND MATERIALS,** *Vol. 6, No. 2, (2023) 12-16*

DOI: https://doi.org/10.26392/SSM.2023.06.02.017

# Numerical investigation of the slope stability under the rainfall infiltration of different intensities and duration using finite element code

**Abdul Qadeer Khan[1], Mehtab Alam[1*], Muhammad Shahkar[1], Asadullah[1], Muhammad Ahsan Aslam[5]**

[1]Ghulam Ishaq Khan institute of engineering sciences and technology:
* Corresponding author/ E-mail: Mehtab.alam@giki.edu.pk

*(Received April 18, 2023, Revised April 29, 2023, Accepted June 5, 2023)*

**ABSTRACT:** *This research presents a numerical analysis using the two-dimensional finite element code, PLAXIS 2D, to explore the impact of rainfall infiltration on slope stability through a fully coupled deformation flow analysis. In the numerical model, the soil is represented as an elastic-perfect plastic material, and its shear strength is modelled using the Mohr-Coulomb model. Using the 2D finite element method, the study explores the combined effects of varying rectilinear slope geometries, soil types, rainfall intensities, and durations on slope stability. Diverse slope configurations with significant variations in slope height and angle were considered. The results imply that the stability of the slope is significantly influenced by both the rainfall intensity and duration. Moreover, the influence of rainfall duration and intensity on slope stability is more pronounced for clayey soil and slopes with a steep angle. The findings of this study will provide guidelines to engineers in assessing the potential risk of slope failure under varying rainfall intensities and durations.*

**Keywords:** Numerical Method, Finite element analysis, Slope Stability, Rainfall infiltration.

## 1. INTRODUCTION

Rainfall-triggered landslides pose a significant threat to communities worldwide and are a widespread and serious disaster [1]. Natural slope instability has been increasing in recent years, particularly in the monsoon zone of South Asian countries, including Pakistan [1]. Although several factors, including geological activity, hydrological influence, and human intervention, can cause natural slope failure, rainfall is generally considered the primary factor [2], [3]. Rainwater infiltration or rising groundwater can induce a change in pore water pressure, which reduces matric suction and decreases the soil's shear strength in the unsaturated zone [2], [4]-[6].

Hydrogeologists, soil scientists, and geotechnical engineers have all conducted considerable research on the process of rainfall infiltrations into the ground and its seepage through soil layers, and they have published their findings in the literature [2], [3]. Additionally, existing literature has studied the influence of slope geometry and soil type on slope stability [2], [6]. However, there is a gap in research regarding the impact of rainfall intensity and duration on slopes with varying soil types and geometries, despite the widespread recognition that rainfall is a primary triggering factor for slope instability [3]. The current study's goal is to determine how different soil types and slope geometries are affected by rainfall intensity and duration. The study aims to determine how different soil types and slope geometries are affected by rainfall intensity and duration and is expected to provide important guidelines for designing slopes.

## 2. NUMERICAL MODEL

In this study, the behaviour of a slope subjected to rainfall was simulated using the fully coupled hydro-mechanical FE scheme in the PLAXIS 2D software. The fully coupled hydro-mechanical analysis is a simulation technique that considers the interactions between the mechanical properties of the soil and the flow of groundwater, by solving equations of fluid flow, deformation, and stress simultaneously, this approach is considered more accurate for the analysis of saturated or partially saturated soils and useful for geotechnical problems like slope stability[2], [3], [7].

### 2.1 Slope Geometry

The slope geometry is modeled as shown in figure 1 with the two varying parameters of slope angle α and height H (Table 1).

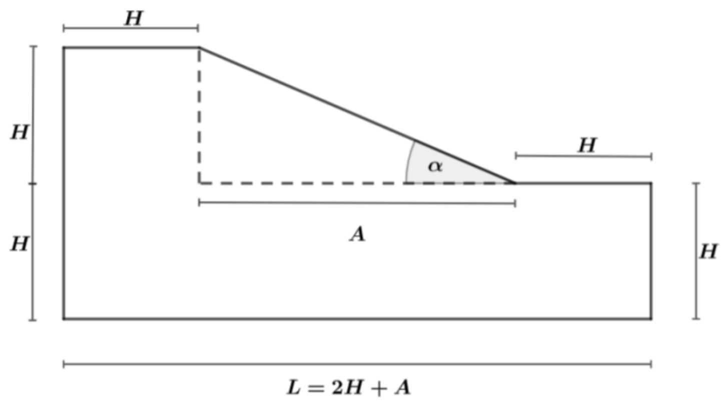


**Fig-1:** Model Geometry

The slope angle (α) and height (H) of the FE model for the simulation are given below in table 1 [8].

**Table-1:** Height and Slope angle of the model

| | | |
|---|---|---|
| Height of Model (m) | 10 | 15 |
| Slope Angle α | $11^0$ | $22^0$ |

### 2.2. Soil Types and their mechanical properties.

In this study, it is assumed that the mechanical behaviour of soil follows an elastoplastic nature with the Mohr-Coulomb failure criterion (Eq. 1) [1]. Two types of soil, clay, and sand are considered for simulations, and their corresponding mechanical properties are presented in Table 2 [2].

$$\tau = c + \sigma_n \tan(\phi) \tag{1}$$

### 2.3. Hydraulic Model for Soil.

The hydraulic model is defined by Genuchten model [3], the model expresses the water retention curve as a function of the soil's water content, and the water flow through the soil as a function of the soil's water potential. The hydraulic data for the Genuchten model is used as default values available in the Plaxis code. The rainfall intensities are assumed to be 6mm/hr and 10mm/hr for the duration of 2hr, 6hr, 12hr, and 24hr[2], [3].

**Table-2:** Soil Types and their mechanical Properties ([8])

| Mechanical properties | Soil Types | |
|---|---|---|
| | Sand | Clay |
| Dry density, $\lambda_d$ (kN/m$^3$) | 17 | 16 |
| Young modulus, E (kPa) | 13000 | 10000 |
| Poisson ratio, $v$ | 0.3 | 0.35 |
| Shear modulus, G (kPa) | 5000 | 3704 |
| Internal angle of friction, φ (deg) | 30 | 20 |
| Cohesion, c (kPa) | 0.001 | 2 |

## 2.4. Boundary Conditions

Two types of boundary conditions were specified for the model, the mechanical boundary condition, and the hydraulic boundary conditions.

### 2.4.1. Mechanical Boundary Conditions

Figure 2 shows the typical generated medium-size mesh and a coarseness factor of 0.2 for the surface boundary. The bottom boundary of the model will always be fully fixed, and no deformations or motion will have to occur, the vertical boundaries of the model were supposed to be deformable on y-axis and fixed x-axis, and the surface boundary is fully free to move.

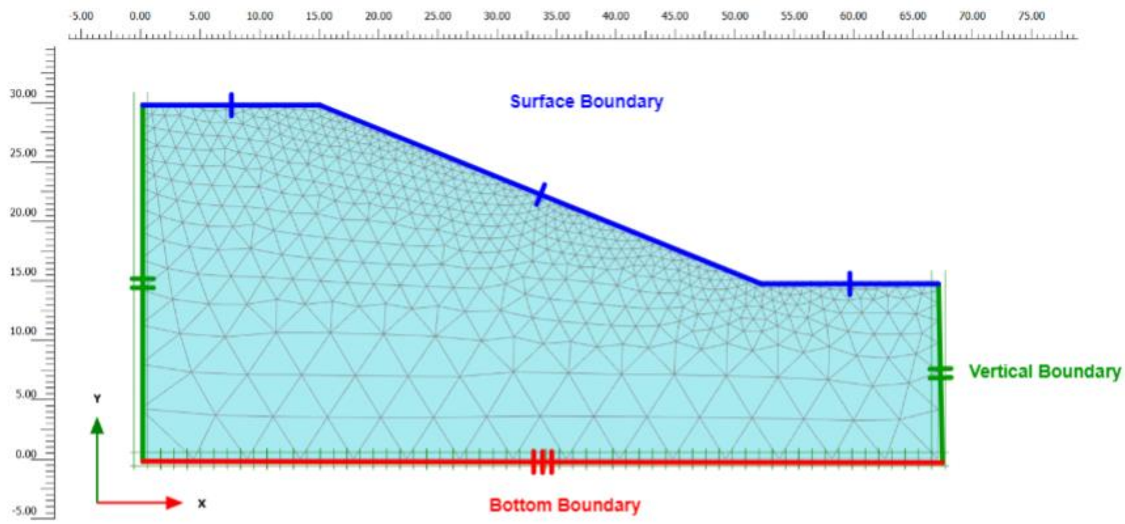


**Fig-2:** Typical Mesh of Medium Size of the Numerical Model

### 2.4.2. Hydraulic Boundary Conditions

For the ground flow water boundary conditions, the surface boundary is open for the rainfall infiltration, the vertical boundary conditions were assumed to be permeable in the x-direction and the bottom boundary was assumed to be impermeable.

## 3. RESULTS & DISCUSSION

The FOS of the slope was analysed for two types of soil under different rainfall intensities and duration.

### 3.1. The Influence of Rainfall Intensity and Duration on Matric Suction

In general, the results show that for all the investigated slope angles, as rainfall infiltrates into the unsaturated sandy soil slope, the pore water pressure increases with time and corresponding matric suction decreases because of the rise in moisture content (see Figure 3a) [1]. In comparison, the matric suction for clayey depends primarily on the total duration of the rainfall rather than its intensity. Many authors [9, 10] have reported their findings in the literature.

### 3.2. The Effect of Rainfall Duration and Intensity on FOS

For all the investigated soil type and slope geometry, the FOS initially increases for the first 2-5 hours of rainfall infiltration due to the generation of higher excess negative pore water pressure and matric suction in the unsaturated zone. As the rainfall duration increases, the FOS gradually decreases as the matric suction decreases with an increase in water content (figure 3c&e). [3], [9] also reported that a small duration of rainfall can increase FOS, while the increase in rainfall could ultimately decrease FOS due to the generation of positive PWP [9], [10].

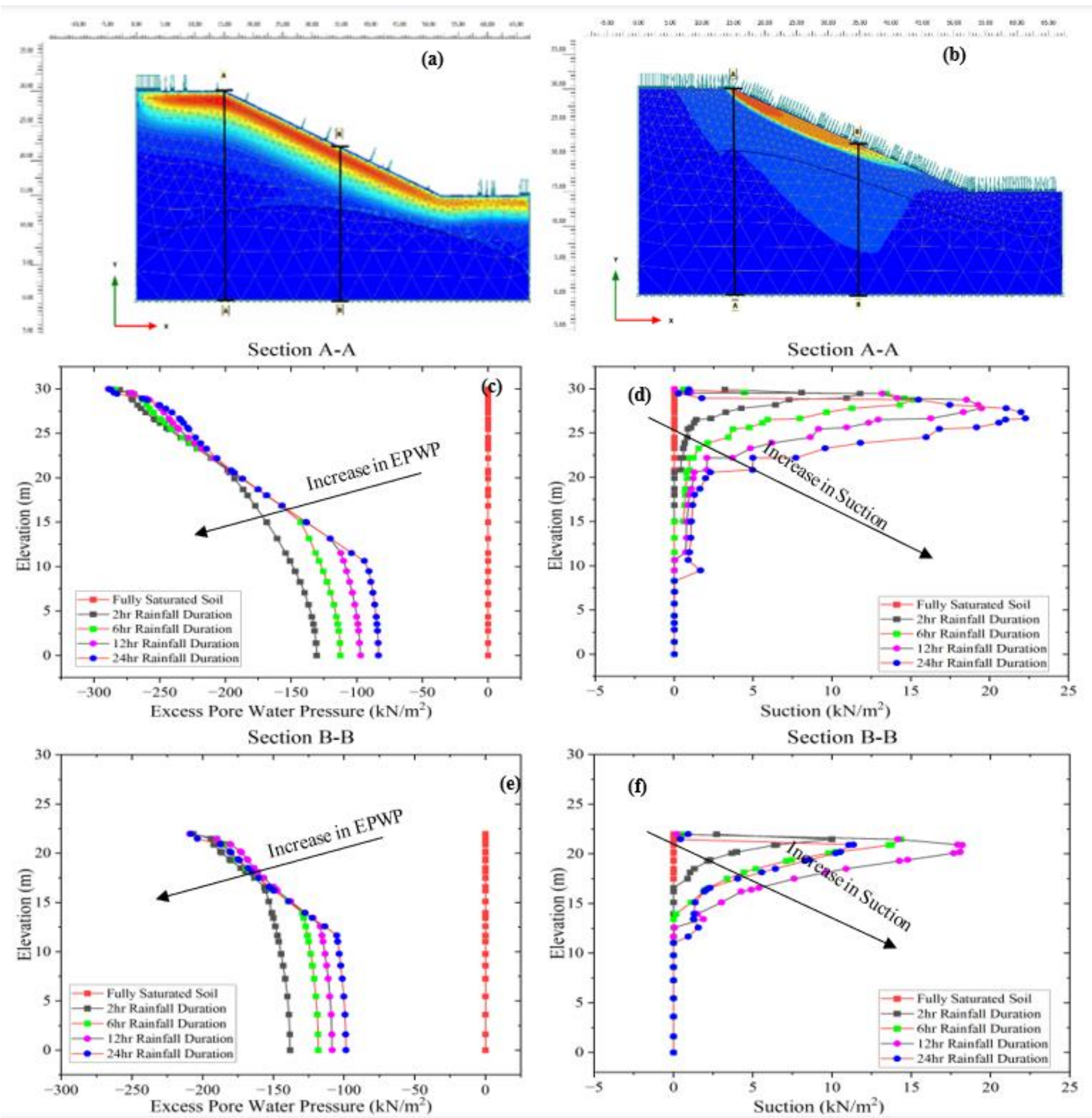


**Fig-3:** Effect of rainfall intensity and duration on the Excess pore water pressure and the suction of the unsaturated zone (a)Typical modelled slope with variation of suction and EPWP (b) Typical modelled slope showing failure surface (c&e) Variation of excess PWP with depth (d&f) variation of suction with depth.

Figure 4 shows the FOS initially increasing for the first 2–5 hours of rainfall infiltration due to the generation of higher excess negative pore water pressure and high matric suction in the unsaturated zone. As the rainfall duration increases, the FOS gradually decreases as the matric suction decreases with an increase in water content. [3], [9] also reported that a small duration of rainfall can increase FOS, while the increase in rainfall could ultimately decrease FOS due to the generation of positive PWP.

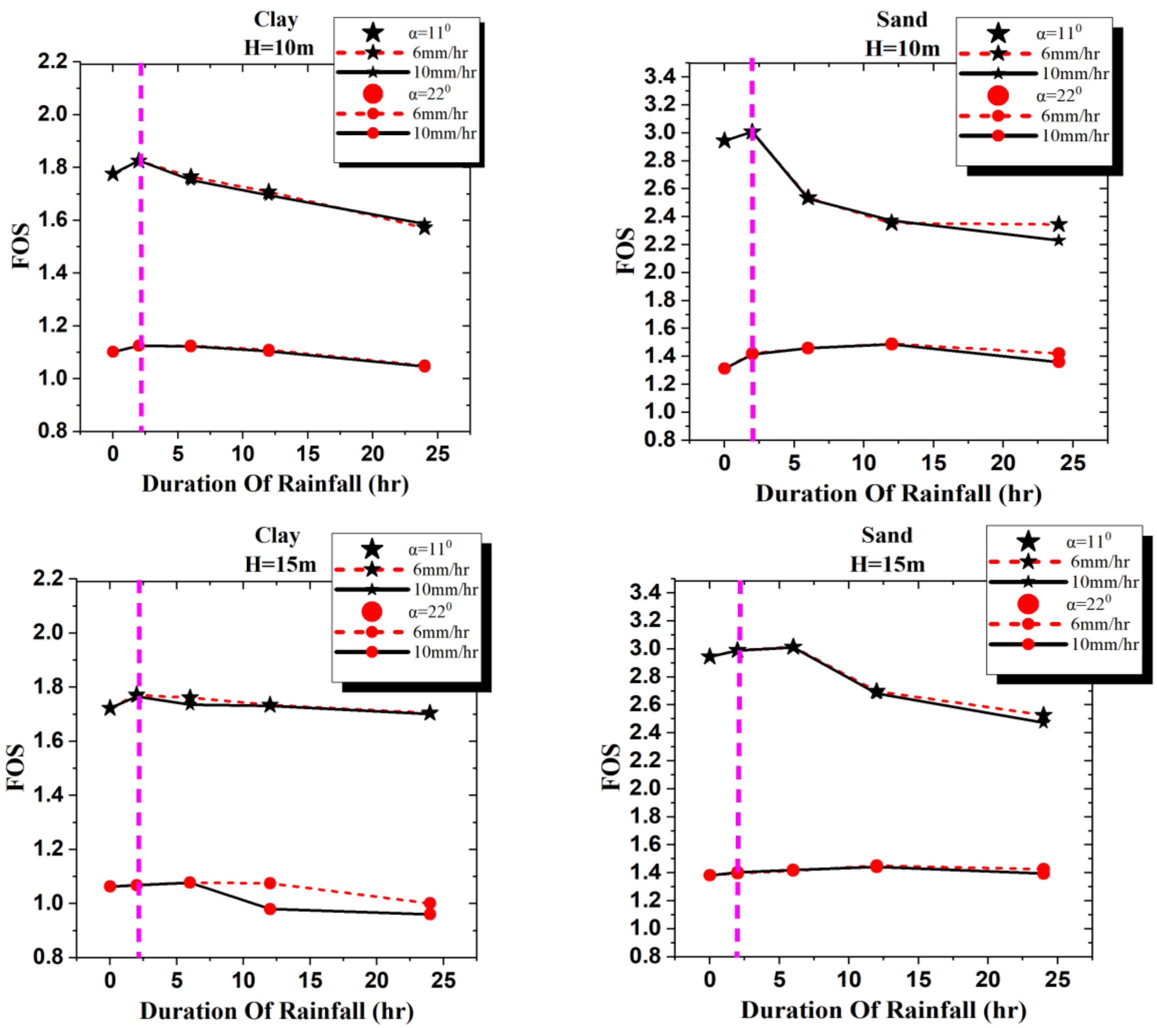


**Fig-4:** Effect of rainfall duration on stability of slope with different angle and slope height

## 4. CONCLUSIONS

The purpose of the current study was to investigate the impact of rainfall duration and intensity on a different slope's configuration and material types. A numerical analysis was performed using the finite element method to examine the slope. This involved conducting a coupled analysis of flow and deformation, which simultaneously evaluated seepage and deformation. The following conclusions were derived from the study:

- The stability of slopes is influenced not only by soil strength and slope geometry but also by the rainfall intensity and duration. The amount of infiltration that occurs is dependent on the soil's material type their hydraulic properties.

- The analysis of the relationship between the slope's FOS (FS) and related hydrological data (rainfall intensity, suction, and EPWP) revealed that the infiltration of rainfall into slopes reduces the matric suction, leading to a decrease in the shear strength of slopes and thus posing a significant challenge to their stability.

## REFERENCES

[1] S. M. H. Shah, Z. Mustaffa, F. Y. Teo, M. A. H. Imam, K. W. Yusof, and E. H. H. Al-Qadami, "A review of the flood hazard and risk management in the South Asian Region, particularly Pakistan," Sci Afr, vol. 10, Nov. 2020, doi: 10.1016/j.sciaf.2020.e00651.

[2] J. Josifovski and S. Lenart, "Some experience in numerical modelling of unsaturated slope instabilities", doi: 10.1051/08005.

[3] S. Naseer and R. Evans, "EFFECT OF RAINFALL INTENSITY AND DURATION ON STABILITY OF NATURAL SLOPES OF UNSATURATED FINE SOILS."

[4] J. W. Mburu, A.-J. Li, H.-D. Lin, and C.-W. Lu, "Investigations of Unsaturated Slopes Subjected to Rainfall Infiltration Using Numerical Approaches—A Parametric Study and Comparative Review," Sustainability, vol. 14, no. 21, p. 14465, Nov. 2022, doi: 10.3390/su142114465.

[5] H. Technology, H. Kong, ; Zhang, H. Kong, and C. W. W. Ng, "TRANSIENT SEEPAGE ANALYSIS OF RAINFALL INFILTRATION USING A NEW CONJUNCTIVE SURFACE-SUBSURFACE FLOW MODEL."

[6] D. H. Hsiao, C. S. Hsieh, L. C. Yeh, D. Y. Lin, and V. T. A. Phan, "A study on a instability slope in Taiwan subjected to rainfalls," in IOP Conference Series: Earth and Environmental Science, Apr. 2018, vol. 143, no. 1. doi: 10.1088/1755-1315/143/1/012018.

[7] J. W. Mburu, A.-J. Li, H.-D. Lin, and C.-W. Lu, "Investigations of Unsaturated Slopes Subjected to Rainfall Infiltration Using Numerical Approaches—A Parametric Study and Comparative Review," Sustainability, vol. 14, no. 21, p. 14465, Nov. 2022, doi: 10.3390/su142114465.

[8] N. K. Kokutse, A. G. T. Temgoua, and Z. Kavazović, "Slope stability and vegetation: Conceptual and numerical investigation of mechanical effects," Ecol Eng, vol. 86, pp. 146–153, Jan. 2016, doi: 10.1016/j.ecoleng.2015.11.005.

[9] J. W. Mburu, A.-J. Li, H.-D. Lin, and C.-W. Lu, "Investigations of Unsaturated Slopes Subjected to Rainfall Infiltration Using Numerical Approaches—A Parametric Study and Comparative Review," *Sustainability*, vol. 14, no. 21, p. 14465, Nov. 2022, doi: 10.3390/su142114465.

[10] S. Naseer and R. Evans, "EFFECT OF RAINFALL INTENSITY AND DURATION ON STABILITY OF NATURAL SLOPES OF UNSATURATED FINE SOILS."