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Investigation of the performance of horizontal drains in increasing slope stability in intense rainfall conditions by numerical simulation

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ABSTRACT: Every year heavy rainfalls cause many slope failures. In these rainfalls, the groundwater table increases that cause in increasing of pore water pressure and reduction of slope stability. Using of horizontal drains is an effective and economic method to control the slope stability in this condition. The purpose of this study is to investigate the performance of horizontal drains in increasing slope stability. For this purpose, the SEEP/W and SLOPE/W (subgroups of Geo-Studio software) were implemented. Results showed that increasing in the length, thickness, and number of horizontal drains causes increasing in slope stability during the heavy rainfalls and keep the slope more stable. In addition, installation of drains in the down part of slope is more effective than in the middle or top part of the slope. Relative drain length equal to 0.4 is proper for improving of slope stability. Increasing of drain thickness has more positive effect on slope stability than the drain length.

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1-Introduction

Due to the construction of many roads and residential houses on the slopes of the earth in different parts of the world, maintain the stability of these slopes is considered necessary. In regions of the world exposed to extreme rain fall, it is possible of the slopes failure and instability at the time of the occurrence of this rainfall. The intensity of rainfall usually changes during the rainfall, so the average rainfall intensity can be used. Several definitions and different values for rainfall intensity are presented. For example in a study, a 20-years period has been chosen a threshold above 125 mm per day as a heavy rainfall [1]. In another study of heavy rainfall in western of Iran, heavy rainfall in one day refers to a rainfall of at least 70% of that total month's rainfall. In another study, Massoudian has proposed a one-day threshold of over 100 mm for a single-day rainfall amount [2].

When the heavy rainfalls occur, the soil suction force and subsequently the shear strength will be reduced. This phenomenon reduces the stability of slope. Using horizontal drains in proper locations of the slope, is an effective way to quickly discharge rain water and maintain a slope stable. In this method, the water is removed from the soil by horizontal drains and consequently the stability of the slope is preserved. The design of horizontal drainage system is difficult and sensitive [3]. Martin et al. [4] suggested that using a small amount of drainage in appropriate sloped areas is better than using a large number of drains at equal intervals.

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A review of the past researchs has shown that the effects of rain with different intensities on the stability of slopes have been less studied. Therefore, the aim of this study is to investigate the stability of slopes under severity of various rainfall and the effect of drainage system construction on collecting infiltrated waters. The drain height from the slope base, the length of the drain and its thickness are among the design variables.

2-Methodology

In the present study, SEEP/W and SLOPE/W were used to study the effect of horizontal drain on maintaining the slope stability at the time of severe rainfall. For this purpose; rainfall is estimated at 2.88, 3.24, 3.6 and 3.96 mm/h. These values are based on the maximum 24-hours rainfalls in Tabriz city. That is, usually the intensities of the aforementioned rainfalls increase the saturation of the soil and causes increasing of the groundwater level. SEEP/W software is based on the finite element method and SLOPE/W software is based on the limit equilibrium method (LEM). Firstly, the desired geometric of the slope in the SEEP/W software is modeled. Then, by defining the existing materials (unsaturated soil condition) and boundary conditions in the SEEP/W software, the variation of pore pressure in the soil are investigated at the time of occurrence of rainfall. By implementation of horizontal drainage system, the effect of these drains on the reduction of pore water pressure is investigated. In the next step, the results were entered into the SLOPE/W software and the effect of applying horizontal drain on the maintenance of slope stability during occurrence of severe rainfall will be investigated. Table 1 presents the geotechnical characteristics of the modeling slope.

Table 1. Materials used in slope stability analysis

Parameters	Soil slope	horizontal drainage
Saturation Hydraulic Conductivity, k (m/s)	8×10^{-7}	8×10^{-4}
k_x/k_y	1	1
Saturated Water Content (m^3/m^3)	0.45	0.45
Residual Water Content (m^3/m^3)	0.05	0.05
Failure Criterion	Mohr-Coulomb	Mohr-Coulomb
Soil Unit Weight (kN/m^3)	18	19
Soil Friction Factor (ϕ)	26°	35°
Soil Cohesion (kPa)	5	2

In this research, the limit equilibrium method (LEM) has been used to evaluate the slope stability in according with the Morgenstern-Price method.

3. Results and Discussion

In Figure 1 contours of iso-pressure curves for a slope is presented. A zero pressure curve represents a ground water level that is subjected to a saturated state under 4 days precipitation. Figure 2 shows contours of iso-pressure curves for the cross-section of the slope with a drain of length 60 m and a thickness of 100 mm at a height of 20 m from the slope base. The change in iso-pressure contours due to the presence of drain is clearly seen. The groundwater level has fallen and the iso-pressure curves become more intense.

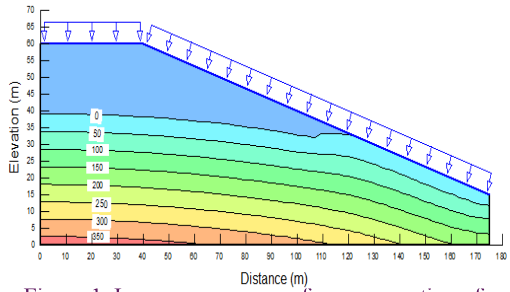

Figure 1. Iso-pressure curves for cross-section of the slope without drain (values in kPa)

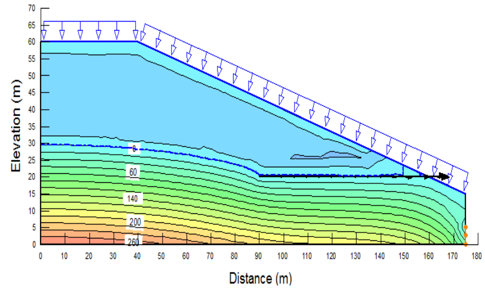

Figure 2. Iso-pressure curves for cross-section of the slope with a 60 m long drain and a thickness of 100 mm at a height of 20 m drain from slope base (values in kPa)

The effect of increasing the thickness of horizontal drains and their efficiency in maintaining the stability of the slope was investigated by numerical simulation of a 70-meter horizontal drain at an elevation of 20 meters, the drain with thicknesses of 25, 50, 100, 150 and 200 millimeters (Figure 3).

Table 2. Linear and nonlinear regression equations for determination factor of safety

Equations	R^2	RMSE
$\frac{F}{F_0} = 2.184*\left(\frac{D}{H}\right) + 0.005*\left(\frac{L}{H}\right) + 0.099\left(\frac{K}{I}\right)* + 1.462$	0.799	0.0012
$\frac{F}{F_0} = 1.153*\left(\frac{D}{H}\right)^{0.009} + 0.455*\left(\frac{L}{H}\right)^{0.031} + 0.024\left(\frac{K}{I}\right)^{81.031}$	0.929	0.0014

According to Figure 3, increasing the thickness of the horizontal drain, increases their positive effect on the factor of stability. It is also observed that curve for horizontal drain with 150 mm thickness coincide to horizontal drain curve with 200 mm thickness. In other words, the increase in drain thickness from 150 mm to 200 mm did not have a progressive effect on the efficiency of horizontal drains.

Also a sudden increase in the factor of stability has occurred when thickness of drain with 100 mm changes to 150 mm. Therefore, it would seem the best way to the design is to be 150 mm thickness for drain. Because, as already mentioned, the increase in the factor of stability is very small for a thickness of 200 millimeters in the drain.

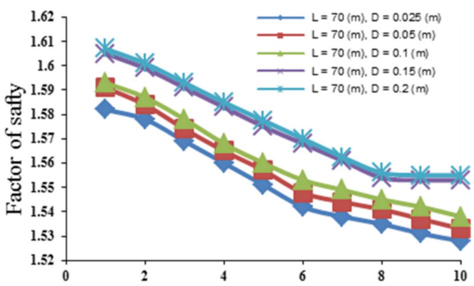

Figure 3. The effect of increasing the thickness of horizontal drains (70 m in length) on the increase of the factor of safety

The result of numerical simulations showed that the application of drain has a significant positive effect on increasing the slope stability.

Based on data generated from this study, SPSS software [5] was applied for regression equation. The proposed equation can determine the factor of safety based on L/H (ratio of drain length to its height from the slope floor), D/H (ratio of drain thickness to its height from the slope floor) and K/I (ratio of soil hydraulic conductivity to rainfall intensity). According to Table 2, the linear regression equation is less accurate than the nonlinear equation. For the nonlinear equation, the coefficient of determination was 0.929 and the root-mean-square error was equal to 0.0014.

4. Conclusion

Based on the results of this study, in all cases the installation of horizontal drains increases the reliability of the slope stability against landslides. The increasing in the length of horizontal drains up to 0.4 times the overall horizontal length of the free slope, increases the factor of safety of slope stability. But extension of the drain length greater than this value, does not positive effect on slope stability. The installation of horizontal drainage system at lower elevation of the slope, has greater effect on increasing the factor of safety of the slope than the installation of horizontal drain in heights of middle or upper part of the slope. By increasing the thickness of the horizontal drains, the effect of these drains on increasing the factor of safety of the slope is increased and according to the survey, the optimal ratio of drain length to drain thickness is 250 to 750. According to the results obtained from this study, increasing the thickness of horizontal drains has greater positive effect than the increasing the length of horizontal drains and the number of drains in increasing the safety factor of the slope stability. It seems the best way to design the drain is a thickness of 150 millimeters.

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