Effect of Concrete Piles on the Stability of Slope by LEM

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Abstract

Natural or man-made slopes are often required to stabilize for the construction of highways and railways. Since failure of such slopes may cost loss of lives and properties, it becomes a matter of concern to the design engineers. To make the slopes stable, the use of piles is one of the options to the engineers. In this paper, a numerical study is carried out to investigate the effect of concrete piles in stabilizing slopes. In this study, SLOPE/W is used to analyze the slope. The effects of the positions and inclination angles of concrete piles on the stability of slopes are investigated using the Limit Equilibrium Method. The study depicts that the position and inclination angles of concrete piles in slope have significant influence of the factor of safety of slope. Elevated values of factor of safety of slope are obtained when the pile is placed in the middle region of slope with a pile inclination angle of 60º to 90º.

Keywords: *Slope stability; Concrete piles; Factor of safety; LEM*

1. Introduction

Slope failure is a natural incident that occurs in all around the world. Preserving stability of slope is necessary because of the construction of residential buildings, roads, etc. on slope. To researchers and professionals, instability-related issues in man-made as well as natural slopes are common challenges. Due to changes in geometry, external forces and loss of shear strength, natural slopes that have been stable for many years may suddenly fail. Piles are using commonly to prevent the unstable situation of any slope. Piles are widely recognized as a common remedial option to transfer the loads of a heavy superstructure like high rise buildings and bridges to the lower layers of soil. Stabilization of a slope may depend on a number of factors such as geometry, surface and groundwater conditions, strength of materials and the reason for stabilization. A number of techniques have been developed to stabilize slopes considering the above mentioned conditions. Ito et al. (1979) used the limit equilibrium method (LEM) to deal with the problem of the stability of slopes containing piles. In this approach, the safety factor of the slope with piles was defined as the ratio of the resisting moment to the overturning moment acting on the potentially unstable soil mass. Two components are consisted of the resisting moment; the moment due to soil shearing resistance along the sliding surface and the moment provided by the reaction force from the piles. The driving moment and the resistance moment due to soil shearing resistance were obtained by

applying the ordinary method of slices. To calculate the resisting moment due to the piles, Ito et al. (1979) proposed the use of the theoretical equation due to the piles.

Considering both Limit Equilibrium Method (LEM) and Finite Element Method (FEM), numerous studies were also conducted. For example, Duncan (1996) described LEM and FEM in stability analysis of slopes. Cala and Flisiak (2003) investigated numerically the stability analysis of slopes in LEM. Sazzad and Haque (2014) presented the stability of slope having surcharge on the model. In a similar study, Sazzad and Moni (2014) investigated the effect of surcharge on the stability of slope by FEM and LEM and found that surcharge has significant impact on the stability of slope. In another study, Moni and Sazzad (2015) reported the influence of mesh size and shape on the stability of slope. They also reported that factor of safety of slope by LEM gives a bit smaller values than factor of safety calculated by using FEM. Recently, Sazzad and Alam (2021) studied the influence of cement grouting on the stability of slope by the finite element and limit equilibrium methods. The results depicted that the incorporation of cement grouting improves the stability of slopes.

This paper examines different conditions of the application of concrete piles to find the factor of safety of slope. Concrete is chosen for its availability, durability and economy. In real works, concrete piles can be applied vertically or inclined with various angles and in different positions. The foremost intention of the present paper is to calculate the factor of safety of slopes considering concrete piles in different inclination angles and positions. This paper also intends to show the most efficient position and inclination angle of pile to prevent the failure of slopes using concrete piles.

2. Geometric Model

In this analysis, SLOPE/W (2020), a sub-program of GeoStudio is used to carry out the analysis. In the numerical study, Morgenstern-Price (1995) method (LEM) is used. A 15.5 m height homogenous earth dam is considered and it is filled with soil. The geometric models with and without concrete piles are illustrated in Figure 1 to 4. The piles shown in Figure 4 only indicate their three different positions considered in this study and only one pile is used in the analysis for a particular position. For computing the stability of slope, concrete piles are applied in different positions and in different angles. The thickness and height of the concrete pile is 0.3 m and 7 m, respectively, and the slope angle is 30^0. The inclination angle of concrete pile is measured from the slope that varies from 45^o to 90^o with an increment of 15^o.

3. Material Properties

For the analysis, the basic properties of materials (soil and concrete) used such as unit weight, cohesion, angle of internal friction are given in Table 1.

Table 1: Properties of materials used in the analysis

Materials	Unit weight (kN/m^3)	Cohesion (kN/m^2)	Angle of internal friction (^{o})
Soil	15	5.00	10
Concrete	24	2323.53	20

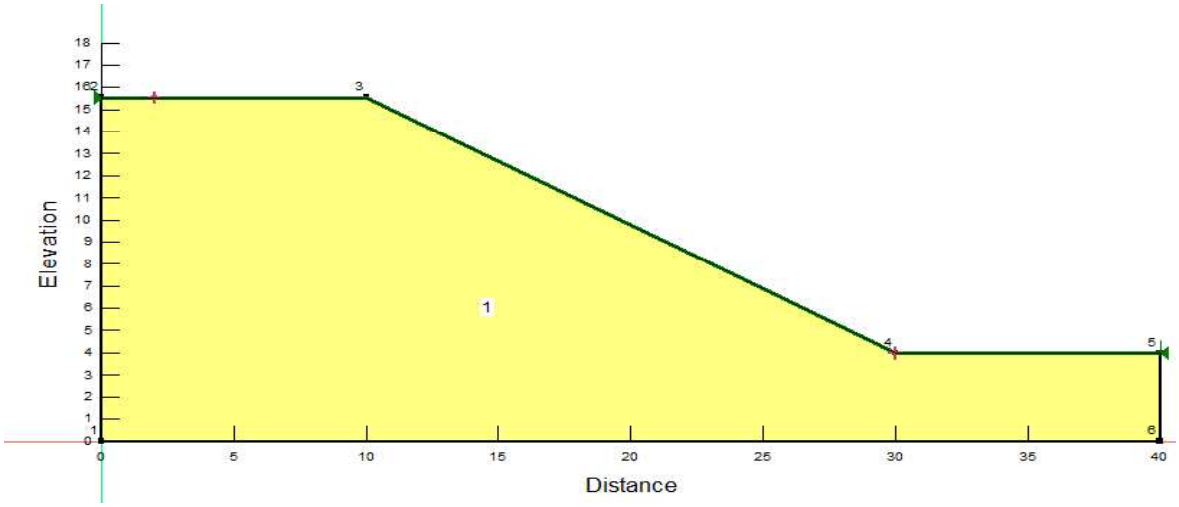

Figure 1: Geometric model of homogeneous earth dam without concrete pile

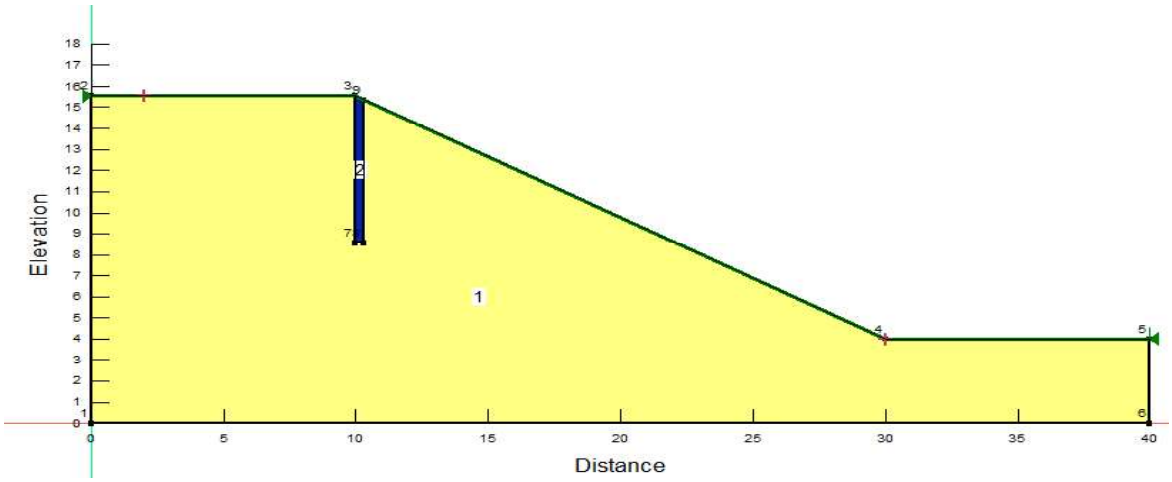

Figure 2: Geometric model of homogeneous earth dam with concrete pile

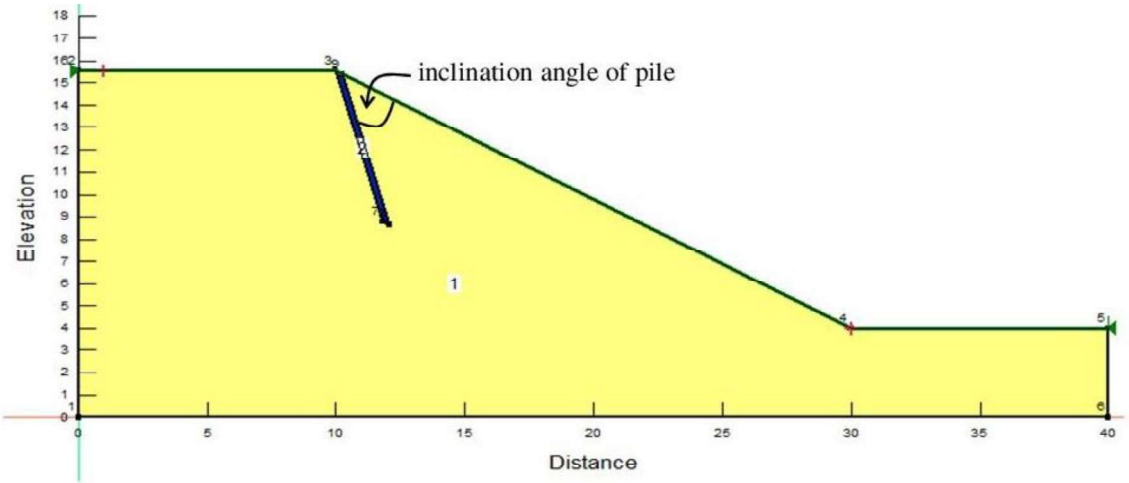

Figure 3: Geometric model of homogeneous earth dam with an inclined concrete pile

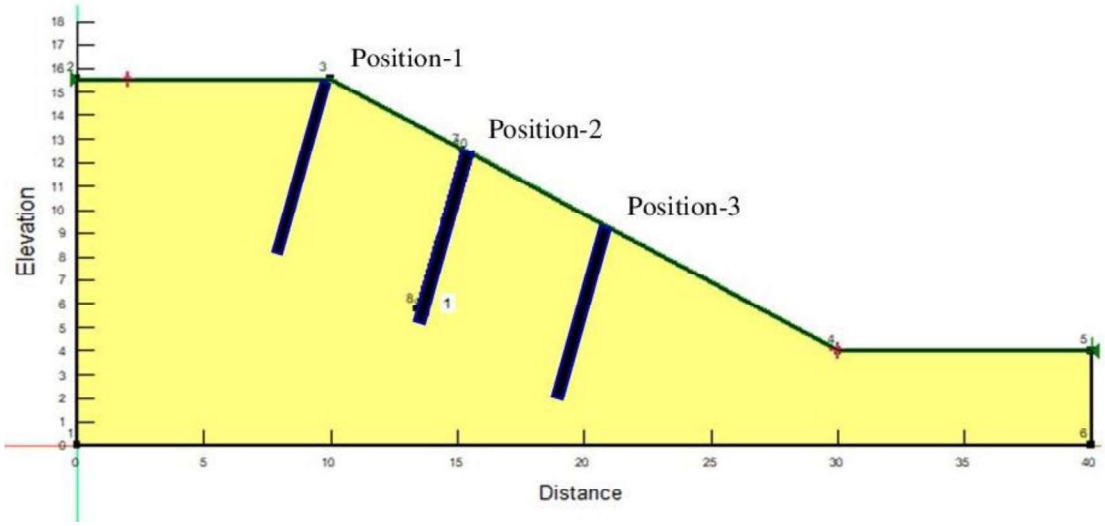

Figure 4: Geometric model of homogeneous earth dam with concrete pile for different positions. Ordinates are: Position 1 (10 m, 15.54 m), Position 2 (15.199 m, 12.54 m), Position 3 (20.398 m, 9.54 m)

4. Result and Discussion:

As stated earlier, the aim of this study is to investigate the influence of concrete piles on the stability of slope. For this, the position of the concrete piles along the slope is varied. Moreover, the inclination angle of pile is varied from 45º to 90º. Note that the inclination angle of pile is measure clockwise from the slope line. The slope angle is kept constant (30^0) for all the analysis. Note that the slip surface is same for all cases. The factor of safety of a slope without any concrete pile is computed first so that the value can be used to compare with other cases when concrete piles are used to stabilize the slope. When concrete pile is not used and all the parameters remain same, the factor of safety is 0.694 with a slope angle of 30º. This factor of safety of slope is used as reference value. The factor of safety of slope at this stage is below 1. This indicates that the slope is not stable without the use of concrete pile.

The effect of the position of concrete pile and its angle on the stability of slope is presented in Table. 2. From Table 2, it is observed that, in general, the factor of safety of slope increases due to the use of concrete pile. It should be noted that the position and angle of concrete pile has significant effect on the stability of slope. The concrete pile is placed in three positions and the position has already been depicted in Figure 4. When the pile angles are 45º and 60º, maximum factor of safety is obtained for position 2. However, when the pile angles are 75º and 90º, maximum factor of safety is obtained for position 3. However, the differences of the maximum factor of safety of slopes for position 2 and 3 are not so significant. So, the study depicts that the best positions for placing the concrete pile to stabilize a slope are position 2 or position 3 (middle region of slope) depending on the pile angle. Regarding the pile angle, it is noted that the elevated values of factor of safety of slope are observed for the pile inclination

angle of 60º to 90º. Note also that the maximum factor of safety of slope is obtained for a pile inclination angle of 60º.

Table 2: Effect of pile position and inclination angle on the factor of safety of slope

Slope Angle (º)	Pile Angle (º)	Pile Position	Factor of Safety	Remarks
30	45	1	0.692	Maximum at position 2
		2	1.428	
		3	1.384	
	60	1	1.976	Maximum at position 2
		2	1.986	
		3	1.947	
	75	1	1.867	Maximum at position 3
		2	1.908	
		3	1.940	
	90º	1	1.810	Maximum at position 3
		2	1.907	
		3	1.927	

4. Conclusions

In this study, the effect of concrete piles on the stability of slope is studied numerically. SLOPE|W is used for performing the numerical analysis and computing the factor of safety. The Limit Equilibrium method (LEM) is used to analyze the soil model and the analysis type is Morgenstern-Price (1995) to evaluate the factor of safety of slope with different pile inclination angles and positions. The numerical study indicates that the use of concrete pile has significant effect on the stability of slope. It is noted that the factor of safety increases for the application of concrete piles in the slopes. Elevated values of factor of safety of slope are found when the pile is located in the middle region of slope with a pile inclination angle of 60 toº 90º. However, the maximum factor of safety of slope is obtained for a pile inclination angle of 60º. The results presented in this study is valid for a slope angle of 30º. Further study is under consideration for other slope angles to reach a concrete conclusion for the position and inclination angles of concrete piles.

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