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Slope Stability Analysis by Shear Strength Reduction Method

Nima Farshidfar[1]*, Arash Nayeri[2]

[1]*Department of Civil Engineering, Bushehr Branch, Islamic Azad University Bushehr, Iran*
[2]*PhD of Geotechnical Engineering, Department of Civil Engineering, Arak branch, Islamic Azad University, Arak, Iran*

*Corresponding author's E-mail: farshidfar_nima@yahoo.com

ABSTRACT: This research uses the shear strength reduction method to study soil slopes stability. In this method shear strength is considered to be reduced as less as failure occurs. It uses Plaxis, which is capable of calculating deformations rates and safety factors by gaining geometry data of a problem and soil specifications and using the finite element method (FEM). The analysis is performed at both static and pseudo-static modes. The effects of different parameters on slopes stability are shown by performing several analyses. Finally, the analyses performed by this method are compared with the ones obtained by finite difference method (FDM).

Keywords: Finite Differential Method, Finite Element Method, Limit Equilibrium Method, Shear Strength Reduction, Soil slopes, Plaxis, Pseudo-Static.

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INTRODUCTION

One of the major issues in geotechnical engineering is to study slopes stability. Due to appropriate behavior of slopes at the time of an earthquake, their reasonable prices and simple implementation, their usages have been developed quickly during recent years. Therefore, various methods have been formulated to study slopes stability.

One of the very common methods to study stability of these structures is the limit equilibrium method with horizontal components (Lo and Xu, 1992), which are applied instead of vertical components. In this method, horizontal components, instead of vertical components, are used for investigating soil mass stability. One of the superiority of this method to vertical components method is that the mobilized forces do not appear on the inter-component borders.

Determination of critical failure surface is one of the fundamental challenges when using limit equilibrium methods. Many methods were used for determining critical failure surface (Chenget al., 2007; Cheng et al., 2008). Linear failure surface used to apply for investigating slopes stability through limit equilibrium method. Unacceptable results of linear failure surface made researchers propose other failure surface. Among proposed failure surface methods, log-spiral failure surface can be considered as one of the most accurate and applicable methods. Other disadvantages of investigating slopes stability through limit equilibrium method is lack of prediction of the deformations occurring over time (This method assumes that the soil behavior on failure surface is rigid and plastic).

In addition to limit equilibrium method, other methods including numerical methods such as FDM and FEM (Chen et al., 2003; Li, 2007 and Zheng et al., 2006), the method of stress characteristics (Keshavarz, 2006; Jahanandish and Keshavarz, 2005) and other useful methods (Bathurst et al., 2002) were used.

One of the problems of studying slopes stability is modeling method of the forces caused by an earthquake. Such simulation was carried out through pseudo-static method in most of the analyses performed earlier. That is, forces caused by an earthquake were supposed as fixed and static forces in horizontal and vertical modes and dynamic behavior of forces caused by an earthquake, time, and phase difference were not considered. Also, vertical forces caused by an earthquake has been neglected in most of the earlier studies. Choudhury and Nimbalkar studied rigid and vertical earth retaining wall under the influence of harmonic force and performed analysis using pseudo-dynamic method (Choudhury and Nimbalkar, 2006). 'Time' and 'phase difference' parameters are effective in this method. Finally, they compared the results with the ones of the pseudo-static method and achieved more accurate analysis.

In this study, the shear strength reduction method investigates slopes stability by applying finite element technique. Today, the use of the shear strength reduction method has been developed considerably than before. Superiority of this method to limit equilibrium method has developed this method and many engineering software.

Slopes stability was analysed at static mode and under seismic forces in this research. Seismic forces were modelled through pseudo-static method.

Modelling was performed by Plaxis in this paper. Safety factors were calculated in different modes and the effects of different parameters on slopes stability were evaluated. The results were then compared with the ones obtained from the modelling performed through FDM, which were executed by Dawsonet al. (1999) and Flac software.

MATERIAL AND METHODS

Generally, determination of safety factor for slopes is defined as proportion of soil shear strength to the minimum shear stress required for creating preliminary failure.

In shear strength reduction method, soil shear strength is gradually decreased by applying finite element and finite difference programs as long as the first indications of failure appear. Safety factor is defined as the ratio of real shear strength of soil to reduced shear strength.

The shear strength reduction method is superior to the other methods investigating slopes stability. One of the advantages is that there is no need to the primary guess at determination of critical failure surface. Due to the high-speed computer systems, this method is used increasingly today than before.

To examine slopes stability through shear strength reduction method, modeling is carried out using a set of safety factors as trial and error. In this method (RRS), slopes stability is defined using soil strength characteristics as follows:

$$C^{trial} = \frac{1}{F^{trial}} C \qquad (1)$$

$$\varphi^{trial} = \arctan\left(\frac{1}{F^{trial}} \tan\varphi\right) \qquad (2)$$

Where C^{trial} and φ^{trial} are soil reduced strength characteristics (adhesion and friction angle) in proportion to the real mode (C, φ).

As it is seen from Eq 1 and Eq 2, the increase in safety factor causes the reduction of soil strength parameters and such strength reduction makes the slope closer to instable behavior. Evidently, higher safety factor denotes much more tendency of a slope to be stable against driving and destructive forces.

RESULTS AND DISCUSSION

A cohesion less soil slope with 4-meter height was built on a bed of cohesive soils with 6 meter height (Figure 1). Table 1 shows characteristics of soils strengths. The backfill was built in two steps. Execution period was considered as 7 days for each step and there was a 100-day interval between the executions of the two steps. Construction of the soil slope was modeled by Plaxis software. Lattice work of the model is in course mode.

The analyzed backfill along horizontal direction was considered as fixed with zero displacement. The back fill's lower boundary along horizontal and vertical directions was also considered as fixed. Soils' behavior was modeled using elasto-plastic and Mohr–Coulomb model.

Table 2 shows the results obtained from investigation slope stability with friction angle of 30^o and adhesion of 2 KN/m^3 and 6-meter groundwater level from downstream for different values of backfill slope (β). The results showed that slope's safety factor lowers with the slope angle increasing and slope exposes to further risk of failure.

Table 3 shows the results obtained from studying slope stability with angle 1 to 3 and 6-meter groundwater level from downstream for different friction angles (φ). The results of Table 3 shows that the increase of friction angle leads to increasing safety factor and further stability of slopes. Table 4 studies the effects of groundwater level on slopes stability.

A slope with angle 1 to 3 and internal friction angle of 30° was considered in the calculations. Values of groundwater level are of downstream.

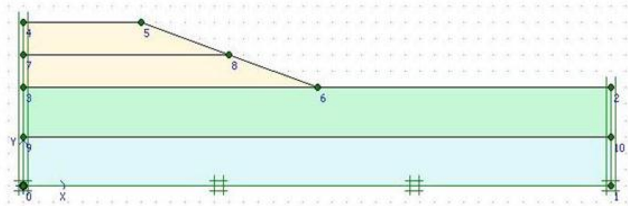

Figure 1. The scheme of constructed soil slope

Table 1: Characteristics of soils

Parameters	γ	γ_{sat}	E	ν	C	Characteristic
1-Sand	16	20	3000	0.3	1	Drained
2-Clay	15	18	1000	0.33	2	Un Drained
3-Peat	8	11	350	0.35	5	Un Drained

Table 2. Safety Factor vs. slope angle

β	15	30	45	60	75	90
F.S	1.557	1.262	1.020	0.702	0.500	0.259

Table 3. Safety Factor vs. slope friction angle

φ	10	20	30	40	45
F.S	0.969	1.305	1.384	1.463	1.505

Table 4. Safety Factor vs. slope level of water

Level of ground water	0	1.5	3	4.5	6
F.S	1.900	1.890	1.884	1.749	1.384

As per the results of Table 4, with the groundwater level increasing, the slope's safety factor lowers and the slope exposes to further risk of failure. The results achieved so far have been obtained from analyzing slopes under static mode and no seismic force was imposed to the slopes. However, as far as we know, most slopes destructions are caused by earthquakes and under the influence of seismic forces of an earthquake.

One of the problems of studying the slopes under seismic forces has always been how to model seismic forces. Different methods have been proposed for modeling seismic forces. One of the frequently used methods is pseudo-static method. Some assumptions are considered in pseudo-static method for simplifying calculations; some of them are: ignoring time, ignoring phase difference, and ignoring oscillatory nature of earthquake forces.

Despite the unreal assumptions of pseudo-static method in seismic analysis of slopes, it has had frequent applications, as it provides acceptable results during a short period. Here, seismic forces were modeled in a pseudo-static manner. Horizontal acceleration coefficient (K_h) and vertical acceleration coefficient (k_v) were considered equal to 0.2 and zero, respectively.

Calculations were made for a slope with angle 1 to 3 and internal friction angle of 30° and groundwater level of 6 meters. Figure 2 compares the results obtained for such a slope under the influence of seismic forces using pseudo-static method and the ones obtained from static analysis for the same slope without considering seismic forces.

As per the results of Figure 2, the slopes under the influence of seismic forces have safety factor lower than the static mode, which indicates lower stability of the slopes under seismic mode. Here, we study stability of a slope with height of 10 meters and angle of 45° using the FEM and Plaxis. Table 5 shows the results of this research and the results of the analysis of Dawson et.al (1999) performed by FDM and Flac.

It showed that the results obtained at lower angles of internal friction are almost similar; however, with the internal friction angle of soil increasing, FEM obtains bigger safety factor.

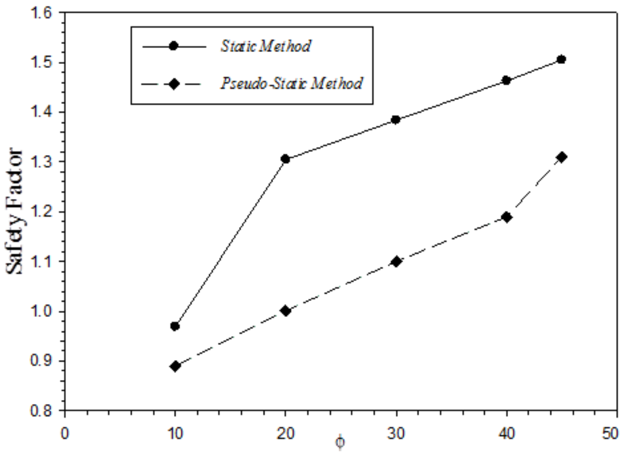

Figure 2. Comparison of Safety Factor obtained from Static & Pesudo-Static method by SSR technique

Table 5. Comparison of Safety Factor obtained from FEM&FDM method

φ	10	20	30	40
F.S (This Study)	0.898	1.071	1.357	1.699
F.S (Reff. 11)	1.019	1.026	1.031	1.080

CONCLUSION

The studies and calculations of the earlier sections show some facts on the slopes behavior, a summary of which is explained here:

- The use of shear strength reduction method of soils led to some simple analyses with acceptable results.
- With the slopes angle increasing, safety factors of slopes reduce and slopes expose to further destructions threshold.
- Increasing internal friction angle of a backfill leads to slopes stability.
- Rising groundwater level increases failure risk of slopes to some extent.
- The results of FEM and FDM at lower internal friction angles are similar.
- Soil shear strength reduction method predicts the deformations occurred over time.

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