

SLOPE STABILITY ANALYSIS OF SILICA SAND SLOPE MODEL SUBJECTED TO SURCHARGE LOAD

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ABSTRACT

Natural disasters such as landslides are frequent occurrences around the world. The loss of countless lives and valuable property continues to occur despite many studies on the behaviour of slopes have been conducted. In this study, GeoStudio software which is a popular and powerful Limit Equilibrium Method analysis tool was employed. The study was carried out using soil properties of silica sand under surcharge load conditions, which reveals that the surcharge load is the potential influencing factors on soil slope instability. SLOPE/W modelling was utilized to analyze slope stability using Mohr-coulomb criteria. The soil properties of silica sand such as saturated unit weight (γ_{sat}), angle of internal friction (ϕ) and soil cohesion (c) used in this study were determined in consolidated-drained triaxial tests. The result of FOS obtained from SLOPE/W modelling analysis is 0.969 with applied surcharge load of 6.4kN/m³. SLOPE/W result was then compared with results from another well-known geotechnical software using Finite Element Method (FEM), namely Plaxis 3D under the same loading conditions. The results from Plaxis 3D analysis showed a FOS of 9.931. The main difference in the analysis approach between LEM and FEM shows the difference between FOS values. Therefore, it is crucial to conduct a slope stability analysis to assure the stability and safety of the slope.

Keywords: Slope stability analysis, SLOPE/W, Plaxis 3D, Silica sand, Surcharge load

INTRODUCTION

The prevalence of slope failure worldwide has drawn a lot of interest from researchers, especially in the field of geotechnical engineering. Slope failure can be described as the movement of soil and rocks down a slope by the force of gravity on either natural or man-made slopes [1]. This occurrence is one of the well-known geological hazards that has led to many fatalities and economic losses due to their unpredictable nature [2,3].

Slope failure can occur for a number of reasons, including the complexity of slope-forming materials, geological and hydrological conditions, and human activities. According to Mizal-Azzmi N., Mohd-Noor N., and Jamaludin N. [4] and Paul and Kumar [5], among other considerations, surcharge loads have a significant impact on slope stability because the loads add gravitational force to the soil, which can result in slope failure. Jelani J., Baharudin S., Othman M., Mohd Daud M. N., Ahmad Ishak A. S., and Yahya M. A. [6] also mentioned that slope failure may occur when several civil structures are built near to the slope crest.

It is crucial to ascertain the stability of slopes with

surcharge load, in order to evaluate the slope's performance and minimize the occurrences of slope failure. The factor of safety (FOS) is frequently used to measure slope stability. The FOS can be defined as the ratio of the resisting forces to driving forces. The slope will be categorized as unstable if the value of FOS is less than 1.0. Therefore, geotechnical experts have given a high priority on slope stability studies.

There are several approaches for slope stability analysis, which can be further separated into conventional and numerical analysis [7-13]. Numerical analysis is commonly used due to technological advancements in computer computing power since it is a powerful tool that is frequently used in geotechnical engineering projects [14,15].

According to Salunkhe D. P., Bartakke R. N., Chvan G., and Kothvale P. R. [16], there are two fundamental types of slope stability analysis using numerical methods namely Limit Equilibrium Method (LEM) and Finite Element Method (FEM). The LEM has been the most popular approach for resolving geotechnical engineering problems due to its simplicity and precision. The FOS of slope model against slope instability may be determined by determining the proper slope geometry and soil

characteristics [17]. Furthermore, LEM only required a simple Mohr-coulomb soil model.

On the other hand, FEM is known as one of the most used numerical methods in practical applications. The FEM can simulate deformations and give a good prediction of the behaviour of soil-structure interaction problems as long as the different construction phases and material behaviour are correctly and precisely simulated in the analysis [18,19]. The FEM can be used to calculate the FOS that employs the strength reduction method and analyze the deformations of the slope model that subjected to surcharge load [20]. However, the FEM needs a comprehensive stress-strain model for the soil as opposed to LEM, that only required a simple Mohr-coulomb soil model. In addition, the main distinction between these two methods of analysis is that the LEM are based on the static of equilibrium whereas FEM utilize the stress-strain relationship or constitutive law [21].

In this study, slope stability analysis using soil properties of silica sand under surcharge load conditions was performed using two widely used geotechnical software programmes, GeoStudio, which is a LEM based software and Plaxis 3D, which is a FEM based software. Firstly, the slope stability under surcharge load conditions was determined using the SLOPE/W application in GeoStudio software using the Morgenstern-Price method [22], with the Mohr-coulomb criteria [23], to improve the computing of the FOS and the position and shape of the slip surface. In the meantime, Plaxis 3D software, with Mohr-coulomb model was used as recommended for analysing the deformations problems with various geotechnical structures [24-30].

RESEARCH SIGNIFICANCE

The aim of this study is to analysed the slope stability, that compared the FOS and the position of the critical slip surface for the proposed soil slope model based on two different geotechnical software, namely SLOPE/W analysis in GeoStudio software and Plaxis 3D software which are the LEM and FEM based software respectively. The properties of silica sand were used as the input parameters in the software and the analysis was performed under loading conditions.

METHODS

In this study, two different methods, LEM and FEM were used to analysed slope stability. The GeoStudio and Plaxis 3D employ the LEM and FEM respectively. Laboratory testing was conducted to determine the soil properties of silica sand. The parameters for both analyses were obtained from the standard proctor test and consolidated-drained (CD)

triaxial compression test as conducted by Ishak A. S. A., Jelani J., Wong S. Y., Suif Z., and Mazuki A. L. A. [31].

Laboratory Testing

Three parameters are needed for slope stability analysis in SLOPE/W software, which are dry unit weight (γ_d), angle of internal friction (ϕ) and the cohesion of soil (c). Meanwhile, the parameters needed for slope stability analysis in Plaxis 3D software includes the confining stress-dependent stiffness modulus (E_{50}^{ref}), effective friction angle (ϕ'), effective dilation angle (ψ'), saturated unit weight (γ_{sat}), dry unit weight (γ_d), cohesion of soil (c), and coefficient of earth pressure at rest (K_0). The values obtained from laboratory testing are shown in Table 1.

Table 1 The parameters of the silica sand

Parameter	Mohr-coulomb (SLOPE/W)	Mohr-coulomb (Plaxis 3D)
E_{50}^{ref} (kN/m ²)	-	36798
γ_{sat} (kN/m ³)	-	17.89
γ_d (kN/m ³)	15.33	15.33
ϕ (°)	30	30
ψ (°)	-	0.7
c (kN/m ²)	17.5	17.5
K_0	-	0.3572

Software Analysis

The concepts and principles of the SLOPE/W application for slope stability analysis are based on the LEM. According to Krahn [22], the programme calculates FOS for various shear surfaces, including circular, non-circular and defined surfaces. The Morgenstern-Price method was chosen to be utilised in the study of the LEM as its ability to satisfies the static equilibrium requirements [32]. In addition, the Mohr-coulomb input parameters, and a half-sine function for interslice forces were employed in this study. They are utilised to calculate the FOS based on the critical slipe surface that was identified using the entry and exit search option.

In the meantime, a programme called Plaxis 3D, is a specialized three-dimensional finite element analysis, that is capable for soil and rock analyses [33]. It can deal with complex geotechnical problems including soil deformation and stress [34,35]. Mohr-coulomb parameters were used as an input for slope stability analysis. The Plaxis's 3D slope stability analysis consists of four phases, namely the initial, excavation, surcharge, and safety phases. The soil materials of the slope model are activated in the initial phase. Additionally, the excavated soil volume was deactivated during the excavation phase, followed by

the surcharge phase where surcharge load was applied on top of the soil surface. The safety phase was finally activated to calculate the FOS of the soil slope model.

The proposed of the soil slope model for both analyses have a fixed dimension of 1.2m high, 0.5m wide and 3.5m long. A surcharge load of 6.4kN/m³ was applied on top of the soil model to analyse the FOS and the position of the slip surface as discussed further in the next section.

RESULTS AND DISCUSSION

Laboratory Testing

Figure 1 below shows the result from the standard proctor test. The obtained values for silica sand's maximum dry density, γ_d (kN/m³) and optimum moisture content, w (%) are 15.33kN/m³ and 16.7% respectively. Meanwhile, the value of saturated unit weight, γ_{sat} can be obtained using Eq. (1) which shows a result of 17.89.

$$\gamma_d = \gamma_{sat} / (1 + w) \quad (1)$$

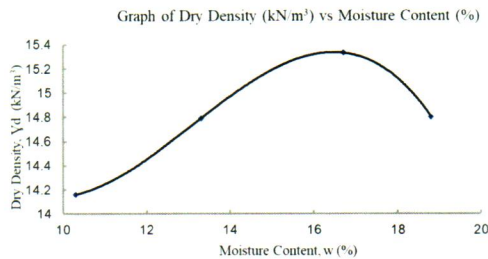


Fig.1 Graph of moisture content, w (%) against dry density, γ_d (kN/m³)

The values of soil cohesion, c and angle of soil friction, ϕ can be obtained from the graph of normal stress (kPa) against shear stress (kPa) as shown in Fig. 2. The values of normal stress and shear stress can be calculated from the major and minor principal stress obtained from CD triaxial compression tests as shown in Table 2 [31]. The values of c and ϕ obtained are 17.5 and 30° respectively.

Table 2 The parameters of the silica sand

Specimen	Minor principal stress, σ'_3 (kPa)	Major principal stress, σ'_1 (kPa)
A	50	260.43
B	100	491.13
C	200	839.68

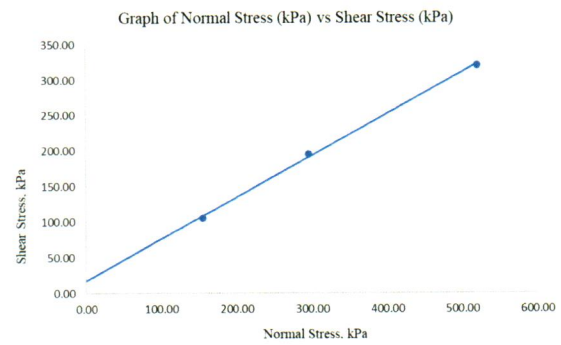


Fig.2 Graph of normal stress (kPa) against shear stress (kPa)

Figure 3 shows the determination of the dilatancy angle based on the graph of axial strain vs volumetric strain curve. The d value is chosen at a confining pressure of 50kPa because it has a smaller dilatancy than the others. The value of d obtained is 0.0236, which will be used in Eq. (2) to calculate the dilatancy angle, ψ [36], that shows a result of 0.7°.

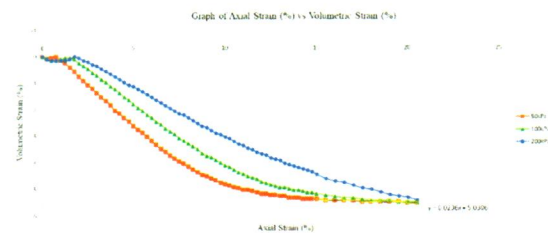


Fig.3 The determination of the dilatancy angle

$$\psi = -\sin^{-1} (d/2-d) \quad (2)$$

Software Analysis

The results of slope stability analysis based on SLOPE/W analysis are shown and Plaxis 3D software was utilised to compare the values of FOS against slope failure as well as the position and shape of the critical slip surface.

The geometry of the slope and the soil's shear strength are taken into consideration during the application of Morgenstern-Price method in the SLOPE/W analysis. In this analysis, the slip surfaces were generated using the entry and exit generation method under loading conditions. In order to determine the slip surface's position, as shown in Fig. 4, the starting and ending point from the entry and exit slip surface option were first identified.

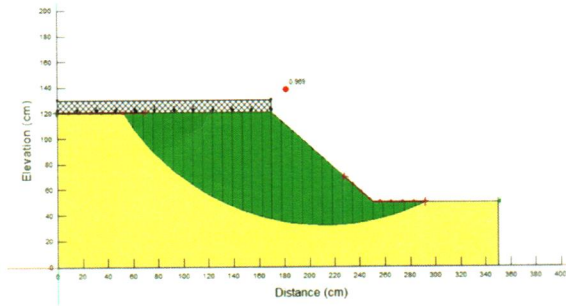


Fig.4 The results from SLOPE/W analysis

Figure 4 show the value of the FOS obtained from SLOPE/W analysis as 0.969, while Fig. 5 show the value of FOS acquired from Plaxis 3D analysis as 9.931. Compared to the Plaxis 3D analysis, the stability analysis from SLOPE/W has computed a lower value of FOS. Meanwhile, there is good agreement between the results of the SLOPE/W and Plaxis 3D analyses regarding the shape and position of the critical slip surface, which is closer to the slope inclination as shown in Figs. 4 and 5, have almost identical shading contours in both models.

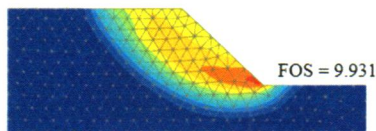


Fig.5 The results from Plaxis 3D analysis

The critical slip surface can be determined based on the shear strain rate contours from both SLOPE/W and Plaxis 3D analysis. The high shear strain rate contours indicate the potential for failure zone.

The difference between FOS values obtained from SLOPE/W and Plaxis 3D analysis are because the analysis for LEM is based on force and equilibrium, while the FEM apply the stress-strain relationships to simulating slope stability. Moreover, the basic assumption for LEM is that the FOS reflects an average of the assumed slip surface and is the same at all points along the slope surface, while for FEM analysis, the FOS is determined based on the shear strength reduction technique.

Furthermore, the sliding mass is divided into vertical slices in the LEM analysis to refine the slope stability analysis. The shear and interslice forces are calculated and appropriate force or moment equilibrium are met for static equilibrium conditions required to calculate the FOS and stress for each slice of the assumed slip surface. Meanwhile, the FEM analysis divides the soil model into several elements

of a mesh. The constitutive laws for materials used in the slope stability model are used to compute the stresses and strains. Failure happens to occur naturally in the zones where the soil's shear strength is unable to sustain the applied shear stresses.

The underlying difference between the basic principles of LEM and FEM analyses explains the difference between the computed findings of the FOS. The difference results of FOS based on LEM and FEM are mostly related to the normal stress distribution along the critical slip surface, which mainly occurs in the toe area of the slope model. The LEM analysis computes the FOS for each element along the critical failure surface, in contrast to FEM analysis, which computes a weighted average of FOS.

Based on the above description, both LEM and FEM for slope stability analysis have their own advantages and disadvantages in providing the results of FOS and slip surfaces. The application of LEM required a limited number of input parameters, which makes it simpler to use and speeds up the process of creating a slope model. On the other hand, FEM can handle stress-strain behaviour of soil and a more complex conditions and realistic stress distribution can be computed. However, FEM requires a slightly more input parameters than the LEM analysis. It is advised to adopt a suitable method according to the nature and purpose of slope stability based on the understanding of the different analysis approaches between LEM and FEM analyses.

CONCLUSIONS

This study was conducted to analyzed slope stability for silica sand under loading conditions based on two different commonly used geotechnical software programs, namely GeoStudio, which is based on LEM, and Plaxis 3D, which is based on FEM. Both SLOPE/W and Plaxis 3D analyses used Mohr-coulomb criteria for the input parameters. The FOS against slope failure and critical slip surface are two main behaviours observed in this study. The FOS obtained from SLOPE/W and Plaxis 3D analyses when the applied surcharge load is 6.4kN/m^3 were 0.969 and 9.931 respectively. The main difference between LEM and FEM's analytical approaches results in the difference between FOS values that were obtained. Both analyses have their own advantages and disadvantages that depend on the slope geometry and available input paramteres. Nonetheless, it is crucial to emphasize that the incidence of slope failure can be minimized when an appropriate measurement and analysis of slope stability are taken into consideration prior to any construction or development.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the National Defence University of Malaysia for funding and supporting this project under the grant with project code PS0056-UPNM/2022/GPPP/TK/24.

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