A Comparative Analysis of the Stability of Homogeneous and Non-Homogeneous Soil Slopes Subject to Various Surcharge Loading Conditions

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Abstract

Slope stability is a topic of great importance within the scope of civil engineering, this study investigates the differences between homogeneous and non-homogenous soil slopes when various surcharge loading conditions are applied. To analyse slope stability the finite element method is used, this method uses the shear strength reduction method. This method gradually reduces the cohesion and friction angle of the soil until failure occurs in the model. Typically, the limit equilibrium method is used by civil engineers, which splits the model into slices to identify the failure mechanisms and the factor of safety. However, as the software improves, and the accuracy of analysis increases, finite element analysis will become the more commonly used method [1, 2].

In this study 6 different models are used in the analysis, three homogenous soil slopes and three non-homogenous soil slopes to aid in the analysis, the soil properties were obtained from [3]. Each model was subject to surcharge loading, which was incrementally increased until failure occurred, recording the factor of safety at each point. The results gathered suggest that point loads caused failure in models to occur much quicker than surcharge loading from a uniformly distributed load, however, the failure area is much smaller.

The comparison of homogenous and non-homogenous soil slopes shows that stability is dependent on three key properties including cohesion, unit weight, and friction angle, with the properties of the soil slope influencing the maximum surcharge loading that can be applied to a model. The results indicate that homogenous soils can withstand higher surcharge loading conditions compared to that of non-homogenous soil slopes, except for homogenous models consisting of silty sand.

Keywords: *Homogenous; Non-homogenous; Finite element method; Soil slopes*

1. Introduction

The purpose of this study is to investigate and compare the stability of both homogenous and non-homogenous soil slopes subject to the effects of various surcharge loading conditions. It is important to highlight the differences in the stability of homogenous and non-homogenous soil slopes as this will determine if the soil on-site is sufficient or whether it must be replaced with a homogenous soil to improve the stability. The surcharge loading conditions applied in this study are used to simulate the effects that vehicles and buildings will have on the stability of soil slopes. This is achieved by using the software package Plaxis, which uses the finite element method to analyse slope stability in the form of deformation and the factor of safety. A recent paper by [3] investigated non-homogenous soil slope stability, this paper focused on the effects of rainfall conditions, the paper concluded that the factor of safety for non-homogenous soils is governed by the top layer, this is very important as results will be influenced by soils used in the non-homogenous models.

2. Problem description

To analyse the differences between homogenous and non-homogenous soil slopes, a 2D model was defined, the dimensions of this model remained the same throughout testing, this was done to produce a controlled set of results, focusing on soil properties rather than other factors such as slope height. Six models were analysed, three homogenous soil slopes and three, two-layered non-homogenous soil slopes. Each model was analysed with three surcharge loading conditions a UDL, point load, and trapezoidal UDL, this was done to simulate different loading conditions.

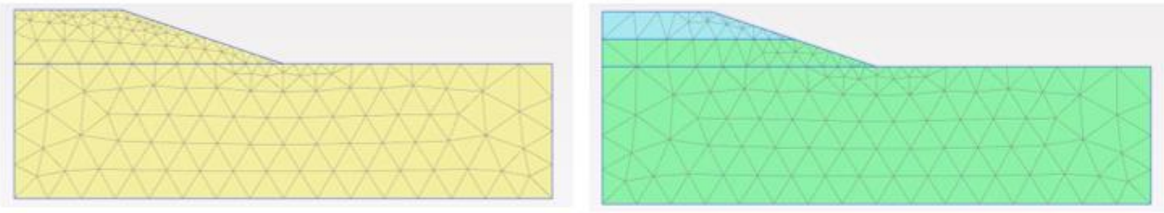

Figure 1 Plaxis Homogenous & Non-Homogenous Soil Slope Models

Figure 1 shows the 2D plain strain models created in Plaxis, one for homogenous soils and one for non-homogenous soils. The mesh generated for these models was a medium-mesh, as it was sufficient for slope stability analysis. The defining soil properties used in this analysis were, cohesion, friction angle, and unit weight. Table 1 shows the main soil properties used in this analysis.

Table 1 Soil Properties

	Cohesion (kPa)	**Friction Angle φ (◦)**	**Unit Weight γ (kN/m^3)**
Soil 1 – Silty Clay	10	30	17.6
Soil 2 – Silty Sand	0	36	16.8
Soil 3 – Silty Clay	25	18	19

3. Numerical results

Through the analysis of homogenous and non-homogenous soil slopes, several diagrams were produced to highlight the effects of surcharge loading. One example of this is a total displacement diagram which is shown below.

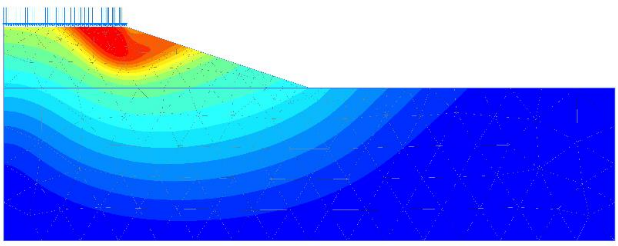

Figure 2 Total Displacement Model

Figure 2 is an output diagram produced in Plaxis when a UDL is applied, this diagram is taken from soil 3 at 160kN/m/m the point in the analysis at which failure occurred in the model. This model highlights where displacement has occurred in the model. From the diagram, it can be seen that the area with the most displacement is located beneath the crest of the slope.

The factor of safety was determined for each model and each load case for the UDL, point load, and trapezoidal UDL, this can be seen in table 2 which present two sets of results for the UDL load case.

Table 2 Results from Slope Stability Analysis

Soil 3 UDL		**Soil 3-2 UDL**	
Load (kN/m/m)	Factor of Safety	**Load (kN/m/m)**	Factor of Safety
20	2.755	**20**	2.145
40	2.247	**40**	2.072
60	1.871	**60**	1.770
80	1.594	**80**	1.474
100	1.342	**100**	1.247
120	1.163	**120**	1.074
140	1.032	**140**	0.955
160	0.931		

Table 2 shows results collected from Plaxis, in this case, it shows results for one homogenous and one non-homogenous soil slope. In this case, a UDL is applied along the crest of the model and the UDL is increased in increments of 20kN/m/m. As expected, under the initial load conditions, both models have a high factor of safety, this gradually decreases as the load applied is increased. The results show that the homogenous soil 3 performs better in this case as it has a higher factor of safety when the first UDL is applied, the factor of safety was 2.755 whereas soil 3-2 has an initial factor of safety of 2.145. At the point where both models fail with a factor of safety of less than 1, there is a 20kN/m/m difference. This shows that the homogenous soil was able to withstand a higher surcharge load on the soil slope before failure occurred.

Presented below is a scatter graph that represents the behaviour of both homogenous and non-homogenous soil slopes when a UDL is applied at the crest.

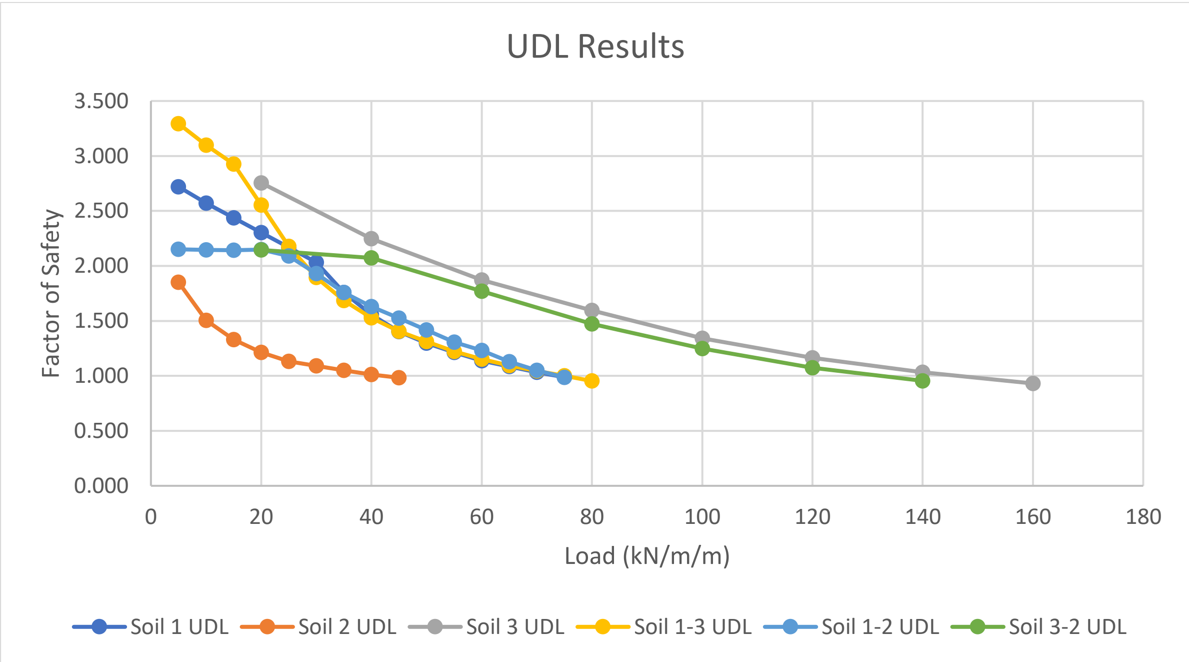

Figure 3 Plaxis UDL Graph for Homogenous & Non-Homogenous Soil Slopes

Figure 3 presents the results from each model analysed when a UDL was applied incrementally. The results show that soil 3 performed the best as it was able to take roughly an additional 80kN/m/m compared to soil 1, 1-2, and 1-3 this shows the importance of soil parameters, provided in table 1 as all other soils fail at roughly the same point within a 5kN/m/m range at 80kN/m/m. The exception to this is soil 2 which has the lowest starting factor of safety with a value of 1.852 and failure occurring at 45kN/m/m with a factor of safety of 0.983, This is because soil 2 was defined as silty sand with a cohesion value of 0 kPa, which is why failure occurs much sooner. The results from figure 3 show the importance of soil layers, as it is very clear that the top layer of soil directly influences the factor of safety. This can be observed from the results of soil 3-2, because soil 3 is used in the top layer of the non-homogenous model it produces results very similar to soil 3 with a difference of 20kN/m/m. This is also seen in soil 1 and soil 1-2 which fail at 75kN/m/m with a difference of 0.001 in the factor of safety. This shows that using silty sand as the base material does not affect the strength of the model.

4. Conclusions

This paper used the finite element method to analyse and compare the stability of homogenous and non-homogenous soil slopes using the software Plaxis. This investigation analysed slope stability when three types of surcharge loading were applied including a UDL along the top of the model, a point load at the crest of the slope, and a trapezoidal UDL, each type simulates a different load condition on the soil slope. The results show that the homogenous silty clays performed better than non-homogenous soils with soil 3 almost doubling the strength of other soils. However, the strength of the other soils was dependent upon the soil used in the top layer of the non-homogenous. Overall, the results show that a homogenous silty clay with good properties will outperform other soils, however, non-homogenous soils are still a viable option with a small amount of strength lost in the soil slope.

Acknowledgments

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