Effects of various surcharge loading conditions on the stability of soil slopes

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Abstract

The stability of soil slopes is a theme which has great significance within the field of civil engineering, this paper will focus on the analysis of soil slopes under varying surcharge loads. There are two main methods used in the analysis of soil slopes the first is the most commonly used method, the limit equilibrium method (LEM) and the second is a finite element method (FEM) which is becoming more commonly used due to three-dimensional analysis aspect. It is suggested by [1] that the factor of safety is greater for three-dimensional analysis compared to that of two-dimensional analysis. As the accuracy of software packages continues to improve (FEM) will be more commonly used by civil engineers.

In this study both analysis methods are used to analyse the effects on various surcharge loading conditions on the stability of soil slopes. By using two different approaches to the analysis of different surcharge conditions, two sets of data are produced both of which can be compared to validate the work. As this topic is widely studied previous papers with a similar research question where used as reference to compare results [2, 3]. The purpose of this study is to highlight the importance of understanding the effects of surcharge loading, it can be seen from previous studies that the focus is generally based on other factors such as the cohesion of the soil, the slope angle, the friction angle and the soil parameters. Whilst they are all individually important, the surcharge loading conditions are often neglected never investing the effects different loads would have on the stability of the soil slope. This shows a gap in the current field of study which this paper will investigate.

Key words: finite element method; limit equilibrium method; surcharge loading; factor of safety.

1.0 Introduction

The purpose of this paper is to investigate the effects of various surcharge charge loading conditions on the stability of soil slopes. This will be achieved by utilizing two different software packages; Plaxis and Slope/W. Each investigates a different method of analysing slope stability, Plaxis is a finite element software which analyses the deformation and stability of soil slopes. Slope/W uses limit equilibrium to determine the factor of safety for soil slopes by modelling a variety of slip surface geometries. A recent paper by [4] investigated a similar problem, focusing on the maximum surcharge loading possible on stable slopes and the impact of slope height on the stability. [4] concludes that the height and loading conditions have a large impact on the failure of soil slopes. Results obtained in this paper will be compared to studies with similar research questions as a method of verification.

2.0 Our Problem

This research paper aims to investigate the effects of various surcharge loading conditions on the stability of soil slopes. This was achieved by applying several different surcharge loads to a soil slope. This includes changing the type of load such as a point loads or a uniformly distributed load. The next loading condition investigated is the shape, this included two UDL's with different lengths and a trapezoidal shape. The last loading condition was intensity this condition was repeated throughout the study to examine the effects of increasing the loading on the soil slope. The soil material properties used in the analysis software were, unit weight γ (kN/m^3), cohesion c (kPa), friction angle φ (º).

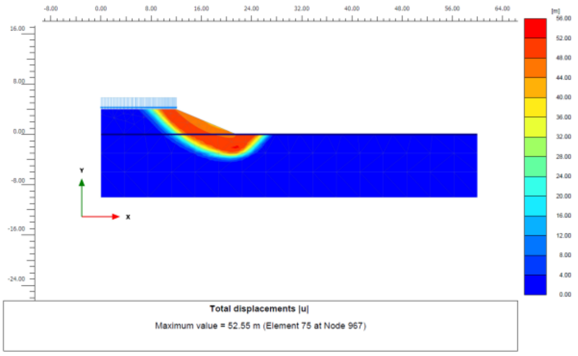
3.0 Numerical Results

To better understand the effects of surcharge loading conditions on soil slopes, several computer models were completed with different loading conditions, this included changing the shape, type and intensity of the surcharge load. This was achieved for FEM by constructing 2D models on Plaxis and simulating the different loading conditions on soil slopes to assess deformation in the soil due to loading, LEM evaluated stability using slip surfaces both circular and non-circular in the soil slope using Slope/W.

Table 1 Plaxis & Slope/W UDL Results

Plaxis 12m UDL			***Slope/W 12m UDL***		
Surcharge Load (kN/m/m)	Total Displacement |u| (m)	FoS	*Surcharge Load (kN/m³)*	Inter force factor (λ)	FoS
1	0.483	1.088			
2	0.490	1.080	*2*	0.244	1.269
3	0.544	1.076	*4*	0.261	1.246
4	0.559	1.071	*6*	0.276	1.225
5	0.671	1.065	*8*	0.289	1.204
6	1.214	1.059	*10*	0.313	1.185
7	2.270	1.052	*12*	0.325	1.167
8	3.253	1.047	*14*	0.333	1.130
9	21.144	1.038	*16*	0.342	1.108
10	27.762	1.033	*18*	0.349	1.087
11	30.813	1.024	*20*	0.356	1.067
12	41.605	1.018	*22*	0.363	1.049
13	33.161	1.012	*24*	0.369	1.032
14	40.455	1.006	*26*	0.375	1.016
15	48.000	1.001	*28*	0.379	1.002
16	47.495	0.996	*30*	0.385	0.998

Table 1 shows the results obtained from Plaxis, tabulating the most important information, this includes the loading applied in kN/m/m, the total displacement in meters and the factor of safety for each iteration of load increment. Table 2 shows results gathered from Slope/W this includes the load applied in kN/m^3, the factor of safety and the inter force factor (λ) which is the ratio of the interslice shear and the inter slice normal forces. Both tables show a clear trend which indicates that as the surcharge load is increased the factor of safety for the soil slope decreases. Until the soil slope reaches the minimum factor of safety of 1 at this point the soil slope is close to failure. There are several points in table 1 where the displacement decreases despite the increase in load, this is shown at 14kN/m/m where the displacement decreased from 41.605m to 33.1.61m this suggests a local failure occurred and the soil slope resettled as at the next increment the displacement increased again.



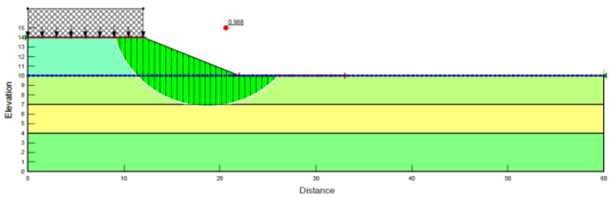


Figure 1 Total Displacement Model

Figure 2 Slope/W FoS Model

Figure 1 displays one of the total displacement models used in Plaxis the model is used to identify the areas within the soil slope model were displacement has taken place. This can be used to identify the failure surface and highlights areas that have larger displacement. Figure 2 is a model of the soil slope using the software Slope/W, there is a large difference compared to Plaxis in the output from Slope/W this is very different due to the methods used, figure two shows the area affected by the surcharge load which is the critical slip surface. Within this is the inter slice forces, this is calculated using the half-sine equation which focuses the inter slice forces towards the middle of the mass. In this output window the factor of safety is produced, this can be altered for many iterations or the critical slip surface may be used, this will be iteration with the lowest factor of safety.

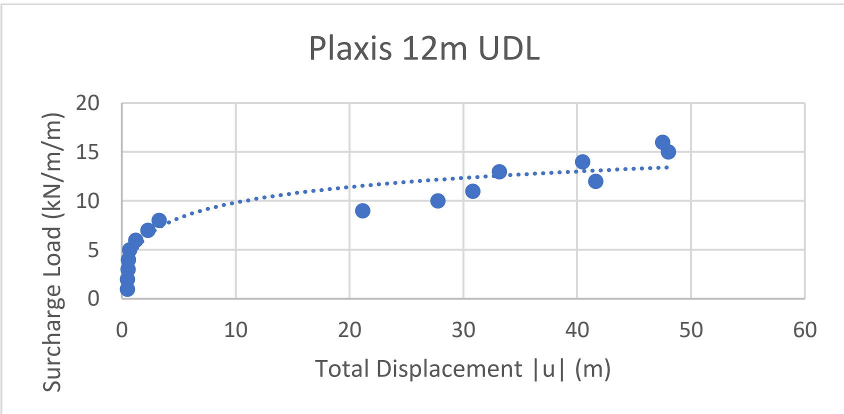


Figure 3 Plaxis 12m UDL Graph

Figure 1 shows a graph of surcharge load vs displacement. It is clear from the graph that as the surcharge loading applied is increases so too does the displacement in the soil slope. This figure also shows a local failure in the soil at this point the total displacement decreases until more loading is applied. The final point on the graph shows the point at which the general failure will occur in the soil this point indicates that the soil factor of safety is below 1 and will fail. Figures 3 and 4 have trendlines, the trendline for figure 3 show that at 8kN/m/m the graph does not follow the expected trend. The trend shows what would be produced using hand calculations and equations this is because they don't consider real life scenarios, which in this instance is a local failure in the soil slope. This is an advantage as software such as Plaxis can be used to predict all aspects of slope stability.

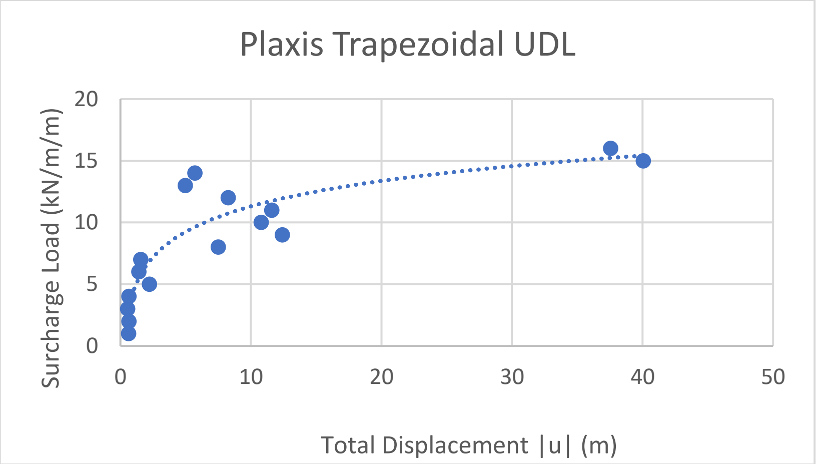


Figure 4 Plaxis Trapezoidal UDL

Figure 2 shows a similar load vs displacement graph to figure 1, however under a trapezoidal UDL the soil has several local failures in the soil slope before it has a general failure, when 15kN/m/m is applied there is a significant increase in the displacement as it drastically increases from 5.705m to 40.061m this point shows a large failure in the soil, however at this point the soil has a factor of safety of 1 which means it is on the verge of general failure.

4.0 Conclusions

In this paper the analysis of slope stability under various surcharge loads was examined using two different software packages, Plaxis for analysis using finite element analysis and Slope/W for the analysis using limit equilibrium. Different surcharge loading conditions were examined including, intensity, type and shape. Through the interpretation of the data gathered it can be seen that there is a clear relationship between the surcharge loading condition applied and the stability of soil slopes. Each loading condition effects the stability of the soil slopes differently due to the distribution of loading on the surface of the soil, this can be seen in the tables for Plaxis and Slope/W which highlight the decrease in the factor of safety as the surcharge load is increased. This study will help contribute to the field of geotechnics by improving the current understanding of slope stability under surcharge loading, this is an area of geotechnics that requires further investigation.

Acknowledgements

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