Generalized Three-dimensional Slope Stability Analysis of Soil Using PLAXIS-3D

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Abstract. Slope stability analysis requires sound geotechnical knowledge as well as sophisticated computer code for the design. The set of simplified design charts for analyzing the stability of soil slopes is developed by conducting a number of 3-Dimensional slope stability analysis using finite element code PLAXIS 3D. Three dimensional slope stability analysis was done for homogeneous clay under varying cohesion in different slope height. Also the variations factors of safety for dry and partially saturated condition were compared. It is observed that the factor of safety increases when cohesion increases and decreases with increase in slope height.

Keywords: Slope stability, Finite element analysis, PLAXIS 3D

1 Introduction

Slope stability analysis is found to gain more importance due to the huge constructions which are taking place on slopes. A slope stability problem essentially a 3-D problem and its analysis require sound geotechnical knowledge as well as an effective use of a sophisticated computing code for the design. Three-dimensional analysis methods consider the 3-D shapes of the slip surface. Three dimensional analysis becomes important in case where the geometry is complex that makes it difficult to select a typical two-dimensional section to analyze. The geometry of the slope and slip surface varies significantly in the lateral direction. The material properties are highly in homogeneous or anisotropic and the slope is locally surcharged. The slope with a complicated shear strength and/or pore-water pressure which requires combining the effect of slope geometry and shear strength to determine the direction of movement. It leads to a minimum factor of safety, or to back calculate the shear strength of the failed slope. In these situations, a 3D analysis may be necessary. The 3D slope stability analysis is found to give more reliable results than 2-D slope stability.

The factor of safety against slope instability is determined by gradually reducing the strength of the soil. As this is done, deformations occur, and at some value of the strength reduction factor, the deformation become very large, and the numerical process will no longer converge. This numerical instability is interpreted as physical instability, and the value of the strength reduction factor when this happens is the factor of safety – the factor by which the strength must be reduced to bring the slope to a rate of barely stable equilibrium.

2 Geometry of model for homogeneous soil

Firstly, a homogeneous soil with top width of 12m, slope angle = 30^0 and slope height = 6m and 8m respectively as presented in the below figure, was investigated in this study. Here the analysis was done for both dry and partially saturated condition. The fill and entire soil material were modeled as Mohr-coulomb. The below table states the summarize soil properties used in this PLAXIS-3D model.

Table 1. Geotechnical properties of soils

Parameters	Subsoil	Soil slope
Height (m)	10	6 and 8
Young's Modulus (kN/m^2)	15 x 10^4	50 x 10^3
Unit weight (kN/m^3)	16	18
Saturated unit weight (kN/m^3)	19	20
Cohesion (kN/m^2)	28	12 – 25
Friction angle (deg)	30	0

3 Method of analysis

The stability analysis of soil slope has been done by Finite Element method using PLAXIS-3D. The Mohr-Coulomb model was used as the analysis of the problem considered. Here different slope height and cohesion and the combination of both considered and both analysis was done in dry and middepth saturated condition where we get the displacement and factor of safety and the relation between these two important factors for all variable data set.

4 Soil slope stability analysis – without surcharge condition

Slope stability analysis for without surcharge condition was done in dry and middepth saturated condition. The construction of soil model and generation of mesh are shown in figure 1 and 2 respectively.

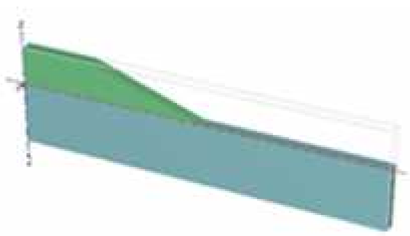

Fig. 1. Soil slope constructed above the subsoil

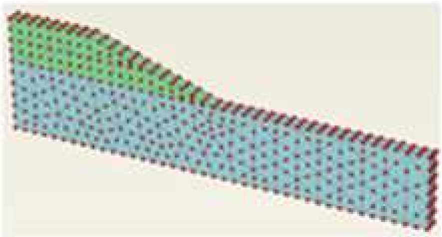

Fig. 2. Mesh generation

4.1 Without surcharge: At dry condition

The analysis was conducted in both 6m and 8m respectively under varying cohesion in homogeneous clay. The results obtained from the analysis shown in table 2 where the obtained factor of safety and incremental displacement were listed.

Table 2. Slope stability analysis of cohesive soil under dry condition

Height (m)	Cohesion (kN/m^2)	Incremental displacement (m)	Factor of safety
6	13	0.022	1.52
	15	0.016	1.80
	17	0.015	2.05
	19	0.014	2.29
	21	0.013	2.53
8	13	0.034	1.29
	15	0.031	1.49
	17	0.027	1.69
	19	0.025	1.88
	21	0.022	2.08

The variation of obtained factor of safety under cohesion is shown in figure 3. From the analysis it was clear that when factor of safety increases as cohesion increases and decreases when slope height increases.

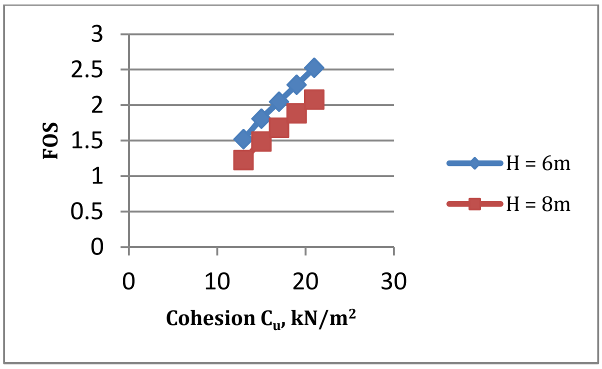

Fig. 3. Factor of safety v/s cohesion in dry condition

4.2 Without surcharge:At middepth saturated condition

In middepth saturated condition the obtained factor of safety value was lesser than in dry condition. Factor of safety obtained under varying cohesion of two different slope heights are shown in table 3 and here the incremental displacement was also listed.

Table 3. Slope stability analysis of cohesive soil under middepth saturated condition

Height (m)	Cohesion (kN/m^2)	Incremental dis-placement (m)	Factor of safety
	13	0.035	1.44
	15	0.033	1.66
6	17	0.031	1.88
	19	0.028	2.06
	21	0.026	2.32
	13	0.040	1.11
	15	0.037	1.28
8	17	0.035	1.46
	19	0.033	1.63
	21	0.030	1.80

Factor of safety v/s cohesion was plotted in figure 4 which shows the variation of increasing factor of safety under cohesion.

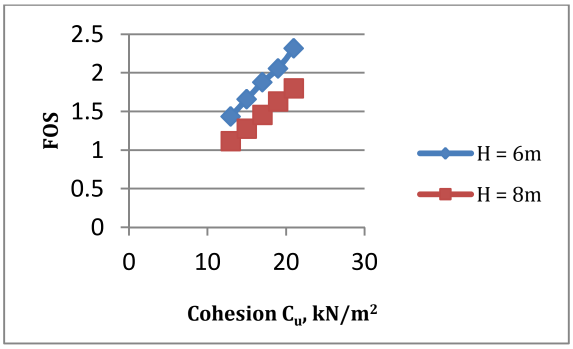

Fig. 4. Factor of safety v/s cohesion in middepth saturated condition

5 Soil slope stability analysis – with surcharge condition

Here the soil slope is designed as embankment for the construction of road. From IRC: 58-2002 the tyre pressure for the commercial highway vehicles was obtained as 800kN/m^2. For the road of commercial vehicle, the load safety factor may be taken as 1.1. So the stress acting on the embankment was obtained as 880kN/m^2.

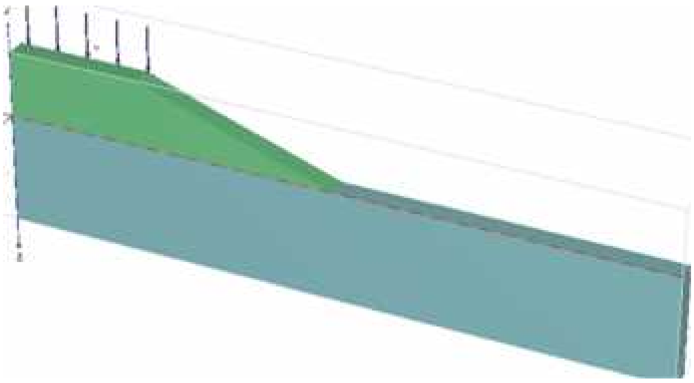

Fig. 5. Structure by loading condition

5.1 With surcharge: At dry condition

The factor of safety obtained in the analysis under varying cohesion was shown in table 4.

Table 4. Slope stability analysis of cohesive soil under dry condition

Height (m)	Cohesion (kN/m^2)	Icremental displace-ment (m)	Factor of safety
6	13	0.042	1.20
	15	0.034	1.39
	17	0.030	1.57
	19	0.026	1.72
	21	0.023	1.88
8	13	0.095	1.12
	15	0.076	1.30
	17	0.070	1.47
	19	0.047	1.63
	21	0.043	1.81

Figure 6 shows the variation of safety values under cohesion. And the analysis shows that factor of safety decreases when slope height increases.

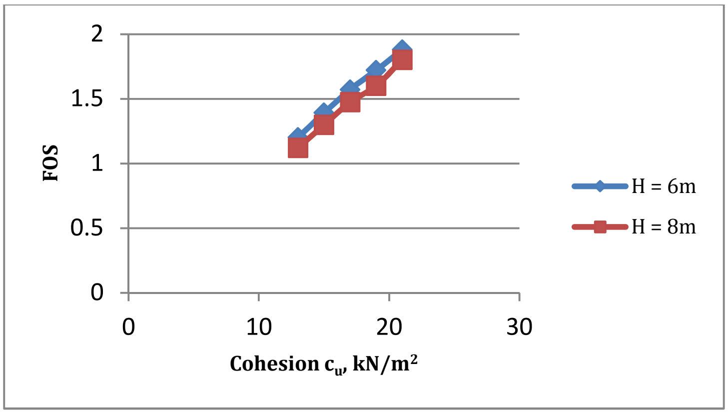

Fig. 6. Factor of safety v/s cohesion in dry condition

5.2 With surcharge: At middepth saturated condition

The lowest safety value was obtained in this analysis. Here the slope became unstable with a height of 8m under cohesion of 13kN/m^2. The obtained factor of safety and incremental displacement from the analysis was shown in table 5.

Table 5. Slope stability analysis of cohesive soil under middepth saturated condition

Height (m)	Cohesion (kN/m^2)	Incremental displacement (m)	Factor of safety
6	13	0.013	1.18
	15	0.129	1.32
	17	0.126	1.50
	19	0.119	1.69
	21	0.115	1.83
8	13	0.163	0.96
	15	0.158	1.05
	17	0.154	1.13
	19	0.152	1.34
	21	0.149	1.52

The variation of factor of safety was shown in figure 7. Here graph was plotted between safety value and cohesion. And the lowest safety value was obtained in slope height of 8m.

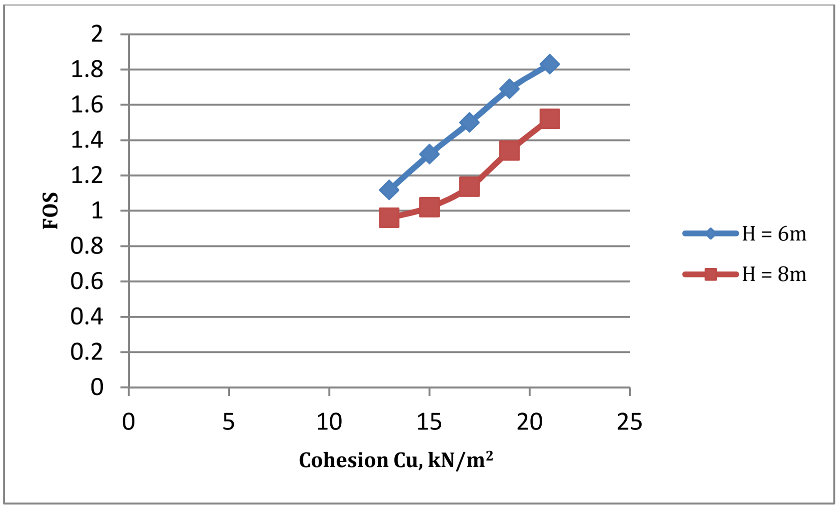

Fig. 7. Factor of safety v/s cohesion in middepth saturated condition

6 Discussion

Stability of soil slopes depends type of soil and soil height. And the soil became more stable in dry condition than saturated condition. From the analysis it was found that the lowest factor of safety was obtained as 0.96 in 8m slope height for the cohesion of 13kN/m^{2}under middepth saturated condition in loading case. And the higher safety value obtained in 6m slope height is 2.53 of cohesion 21kN/m^2 under dry condition in without loading case.

7 Conclusions

This study proposes a method of analysis for soft soil embankment. The use of PLAXIS software makes the analysis easier and practical. Factor of safety mainly depends on slope height, cohesion and soil condition. When slope height increases factor of safety decreases and it increases with increase in cohesion. The factor of safety varying from 1.2 to 1.88 and 1.18 to 1.83 for dry and saturated condition respectively under varying cohesion from 13kN/m^2 to 21kN/m^2 in 6m slope height. And the slope is safer in dry condition than saturated condition. Least factor of safety was obtained as 0.96 for saturated condition of 6m slope height.

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