EXPLORATION OF METHOD FOR SLOPE STABILIZATION INFLUENCE BY UNSATURATED SOIL

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ABSTRACT: *This study will lead to the analysis of unsaturated soil using Bishop's Simplified method which is one method to analyze slope stability in method of slices. Bishop's original formula of saturated soil was modified by adding the element of matric suction, $(\mu_a - \mu_w)$ together with unsaturated friction angle, ϕ^b which is applicable for the analysis of unsaturated soil. In this study, 40 kPa of matric suctions was applied in the analysis for both Bishop and Fellenius methods. From the analysis, the results indicate that the factor of safety (FOS) value of Bishop's Simplified method was 4.41 % higher than Fellenius's method for 40 kPa suction, as the soil is in unsaturated condition. The reason for the relative accuracy of Bishop's Simplified method is that in considering only the vertical equilibrium of any slice, there is no need to account for the horizontal components of the inter-slice forces.*

Keywords: Bishop, Unsaturated soils, Fellenius, matric suction, factor of safety (FOS)

1. INTRODUCTION

Nowadays, slope failure can be considered as one of the most frequent disaster that happened not only in Malaysia, but also in other countries. This is due to the increment and rising of development all over the world whether for developed or other countries which may lead to extensively cutting the existence slope during the development. According to [1] failure occur of man-made slope are caused by designs errors including geometric design i.e. slope inclination, slope height, and the inability to determine the load that may affect the slope together with the soil resistance.

Landslides or mass movement of soil, rocks, or a combination of both, is actually a natural phenomenon where a natural look for a new balance due to the disturbance or the factors that affect and cause reduction in shear strength as well as shear stress [2]. As suggested by [3], there are some factors that contribute to slope failure such as soil type, groundwater, seepage, soil stratification and also slope geometry. It is very important to conduct the analysis for slope stability. Generally, the analysis of slope stabilization was done by using method of slices which the potential failure surface was assumed to be circular or non-circular.

[4], there are some man-made slopes: cuts and fills for highways and railways, earth dams, dykes for containment of water, landscaping operations for industrial and other developments, banks of canals and other water conduits and temporary excavations. Slopes may also be naturally formed at hillsides or streambanks. [5] has suggested that, the slope stability play a very important role in geotechnical analysis and design of the earth structures particularly for construction of dam, road and other types of embankments.

This study aims to determine the factor of safety (FOS) of unsaturated soil slopes by using one method from method of slices which is Bishop's Simplified method [6]. The original formula of Bishop's Simplified method [6] for saturated soil will be modified in order to include the element of matric suction, $(\mu_a - \mu_w)$ together with unsaturated friction angle, ϕ^b. The FOS that been determined from the calculation using Bishop's Simplified method [6] will be analyzed and finally, a comparison of FOS between Bishop [6] with Fellenius [7] will be done in order to determine which method give higher and more accurate FOS for slope stabilization.

2. MATERIALS AND METHODS

In the current work, a reasonably simple framework has been sought that will permit the first assessment of the influence of soil suction changes on soil shear strength. For this purpose, the following relationship provided by [8] appears suitable:

$$\tau = c' + (\sigma_n - \mu_a)\tan\phi' + (\mu_a - \mu_w)\tan\phi^b \quad (1)$$

where $(\mu_a - \mu_w)$ represent the matric suction and ϕ^b is the angle indicating the rate of increase in shear strength relative to matric suction. $(\sigma_n - \mu_a)$ is the net normal stress, c' is the effective cohesion and ϕ' is angle of friction.

[9] show the relationship on how shear strength, matric suction together with net normal stress give a three dimensional failure surface, as shown in Figure 1. This figure show how a planar failure surface that has a slope angle ϕ^b with respect to matric suction axis.

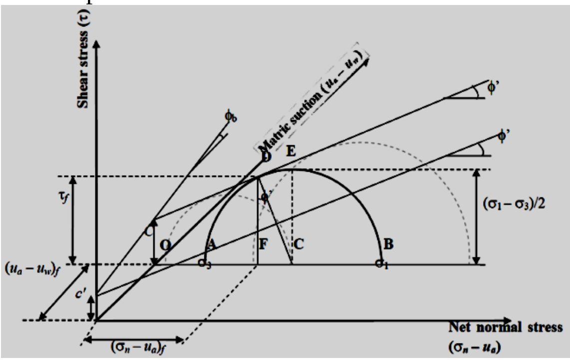


Figure (1) Extended Mohr-Coulomb failure envelope for unsaturated soils, modified after [9]

The FOS is defined as that factor by which the shear strength of the soil must be reduced in order to bring the mass of soil into a state of limiting equilibrium along a selected slip surface [10]. Calculations for the stability of a slope are performed by dividing he soil mass above the circular slip surface into vertical slices. Figure 2 shows the forces acting on a slice within the sliding soil mass.

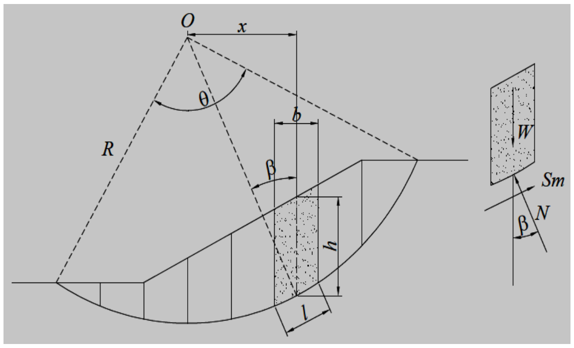


Figure (2) Forces acting on a slice through a sliding mass with a circular slip surface, modified after [9]

The variables in Figure 2 are defined as follows:

W = the total weight of a slice (*kN)*

N = the total normal force on the base of the slice (*kN)*

Sm = the shear force mobilized on the base of each slice (*kN)*

O = the centre of orientation

x = the horizontal distance from the centreline of each slice to the centre of orientation, *O (m)*

l = the length of the each slice (*m)*

b = the width of the each slice (*m)*

h = the vertical distance from the centre of the base of each slice to the uppermost line in the geometry (*m)*

R = the radius for a circular slip surface (*m)*

β = the angle between the tangent to the centre of the base of each slice and the horizontal (*degrees)*

θ = the angle between the slip surface and a centre about which it rotates (*degrees)*

A force equation which includes matric suction must be established in order to calculate the FOS in unsaturated soil slope. The mobilized shear force at the base of a slice can then be written as [11]:

$$S_m = \frac{\tau l}{F} \qquad (2)$$

where τ is shear strength of unsaturated soil as defined previously in equation (1). Combining equation (1) and (2), gives,

$$S= \frac{l\,(c'+(\sigma_n-\mu_a)\tan\phi'+(\mu_a-\mu_w)\tan\phi^b)}{F} \qquad (3)$$

By resolving Bishop vertically,

$$N\cos\alpha = W+\Delta X - S\sin\alpha$$

$$N= \frac{W+\Delta X - S\sin\alpha}{\cos\alpha}$$

$$S= \frac{(c'l+(N-\mu_a\, l)\tan\phi'+(\mu_a-\mu_w)\,l\tan\phi^b)}{F} \qquad (4)$$

Substitute for N;

$$S= \frac{(c'l\cos\alpha+(W+\Delta X - S\sin\alpha-\mu_a\, l\cos\alpha)\tan\phi'+(\mu_a-\mu_w)\,l\cos\alpha\tan\phi^b)}{F\cos\alpha} \quad (5)$$

As b = width of slice = $l\cos\alpha$ and substitute $(\mu_a-\mu_w)$ which is matric suction as M and also assuming the air pore pressure is constant (atmospheric) then $\mu_a = 0$;

$$S= \frac{1}{F}\left[\left(\frac{c'b+(W+\Delta X-\mu_a b)\tan\phi'+Mb\tan\phi^b}{\cos\alpha}\right)-S\tan\alpha\tan\phi'\right] \quad (6)$$

Substitute $\left(1+\frac{\tan\alpha\tan\phi'}{F}\right)=m_\alpha$;

$$S= \frac{1}{F}\left(\frac{c'b+(W+\Delta X-\mu_a b)\tan\phi'+Mb\tan\phi^b}{\cos\alpha}\right)\left(\frac{1}{m_a}\right) \quad (7)$$

Moment of equilibrium;

$$\sum W\sin\alpha = \sum S$$

$$F= \frac{\Sigma\left[\left(c'b+(W+\Delta X-\mu_a b)\tan\phi'+Mb\tan\phi^b\right)\left(\frac{\sec\alpha}{m_a}\right)\right]}{\Sigma W\sin\alpha} \quad (8)$$

After much consideration, the final formula is as stated in equation (8). The element of matric suction, $(\mu_a-\mu_w)$ together with unsaturated friction angle, ϕ^b was included in the original equation of Bishop's Simplified method [6] of saturated soil. When suction becomes zero, it means that the soil is saturated and the equation will turn to the original equation as done earlier by Bishop.

3. RESULTS AND DISCUSSION

[12] have pointed out that, the major difference between Bishop's Simplified method [6] with Fellenius's method [7] is that in considering the vertical equilibrium of any slices, there is no need to account for the horizontal components of the inter-slice forces. The resolution of forces takes place in vertical direction instead direction normal to the arc. Meaning that, with Bishop's Simplified method [6] of slices, the side forces E acting on the sides of the slices will not enter into the analysis. It is assumed that the shear side forces X may be neglected without introducing serious error into the analysis. Figure 3 show method of slices: division of sliding mass into slices and forces acting on a typical slice.

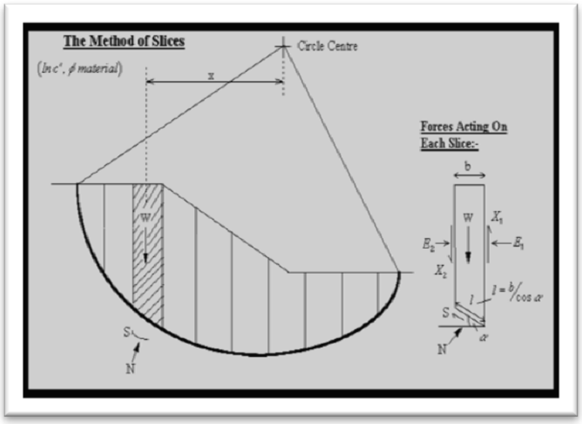
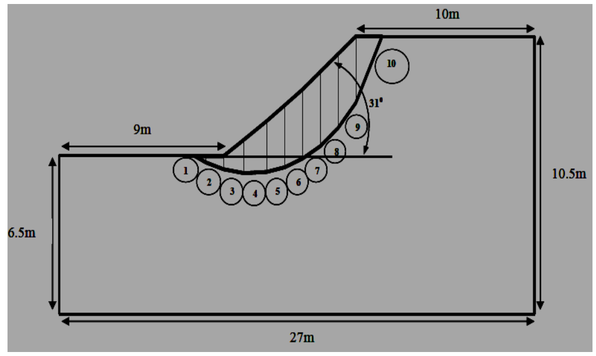


Figure (3) Method of slices: Division of sliding mass into slices and forces acting on a typical slice

Figure 4 shows the detail of slope geometry with slip surface and location of slices by [13]. [13] used this detail geometry in his research to calculate slope stabilization using Fellenius's method [7] equation for unsaturated soil which had been modified by [14].

The experimental values of shear strength with ϕ^b angle of tropical residual soil suggested by [13] is as shown in table 1.

Table 2 show the calculations of Bishop's Simplified method [6] with 40 kPa suction.



Figure(4) Detail slope geometry with slip surface and location of slices [13]

Table (1) Experimental values of shear strength with ϕ^b angle of tropical residual soil

Researcher	Location	c' (kPa)	ϕ' (°)	ϕ^b (°)
[13]	Faculty of Electrical Engineering, UTM	9	23	20

[13] suggested that the type of soil in faculty of electrical engineering, UTM was sandy silt with cohesion value, c is 9 kPa, friction angle, ϕ' is 23°, and saturated friction angle, ϕ^b is 20°.

Table (2) Calculations of Bishop's Simplified method with 40 kPa suction (values for *z*,*b*,*W*, and α are suggested from [13])

Slice	*z*	*b*	*W*	*α*	*sin α*	*c'b*	*Wtanϕ'*	*Ψbtanϕ^b*	*W sin α*	*assumed*	*assumed*
1	12.876	0.62481	1.5	-21.199	-0.362	5.62	0.637	9.096	-0.543	17.280	17.395
2	39.42	1	7.5	-15.04	-0.259	9	0.424	14.559	-1.943	25.670	25.782
3	92.1	1.18	20.6	-7.005	-0.122	10.62	8.734	17.179	-2.513	37.365	37.446
4	165.01	1.3	40.8	1.9909	0.035	11.7	17.299	18.926	1.428	47.753	47.733
5	218.51	1.01	41.9	10.4	0.181	9.09	17.766	14.704	7.584	41.334	41.228
6	253.06	1.01	48.6	17.944	0.308	9.09	20.606	14.704	14.969	44.906	44.666
7	276.34	1.0067	52.9	25.819	0.436	9.06	22.429	14.656	23.064	48.421	48.083
8	285.68	1.0067	54.6	34.259	0.563	9.06	23.15	14.656	30.740	52.378	51.881
9	272.04	1.0067	52	43.691	0.691	9.06	22.048	14.656	35.932	56.719	55.649
10	153.11	1.498	43.6	59.41	0.861	13.48	18.486	21.809	37.540	87.682	85.825
Total									146.258	459.508	455.688

$$\mathrm{FOS}_1 = \frac{459.508}{146.258} = 3.14$$

$$\mathrm{FOS}_1 = \frac{455.688}{146.258} = 3.12$$

Figure 5 indicates the graph of Bishop's Simplified method [6] with 40 kPa suction.

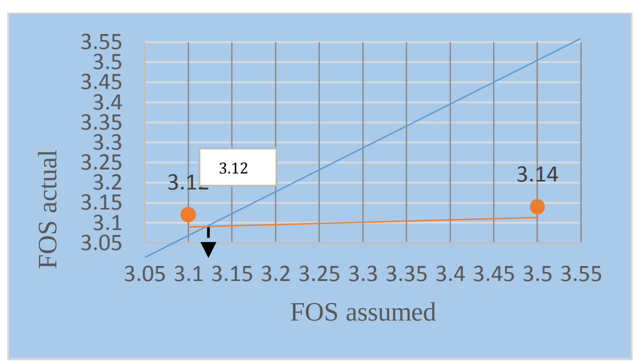


Figure (5) Graph of Bishop's Simplified method [6] with

40 kPa suction

The graph shows the actual FOS value for Bishop's method [6] with 40 kPa suction is 3.12. Since the FOS was greater than 1, therefore it was safe. Table 3 indicate the percentage differences of FOS between Bishop's Simplified method [6] with Fellenius's method [7] of 40 kPa suction.

Table (3) Differences of FOS value with 40 kPa suction

Type of Analysis	FOS	Percentage Difference (%)
Fellenius's method by [13]	2.9882	0
Bishop's Simplified method [6]	3.12	4.41

From the results, calculation by using Bishop's Simplified method [6] gave higher FOS value compare to ordinary Fellenius's method [7] by 4.41 % for 40 kPa suction. Clearly, this show that more accurate FOS value for slope stabilization can be obtained by calculating using Bishop's Simplified method [6] compare to Fellenius [7]. Also, as the FOS value was greater than 1, therefore, the slope was in safe condition.

4. CONCLUSION

It can be concluded that, Bishop's Simplified method gave higher and more accurate FOS value compare to Fellenius's method for slope stabilization. The analysis of Bishop's simplified method was carried out in term of stresses instead of forces which were used in Fellenius. The major difference between these two methods is that, in Bishop's method, the resolution of forces takes place in the vertical direction instead the direction normal to the arc. Bishop's method gives a better FOS compare to Fellenius's method which means a better slope with higher safety will be produce. This is very important for construction as safety for all living things must be the first priority before conducting development. Consequently, this may lead to low cost development will be produce due to a safe slope will need less money compare to slope that is less safe. This is because, a safe slope does not require frequent maintenance as a less safe slope which will result in low amount of money is needed if construction is develop on it.

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