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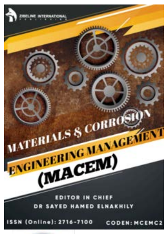

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RESEARCH ARTICLE

COMPARING THE VARIOUS SLOPE STABILITY METHODS TO FIND THE OPTIMUM METHOD FOR CALCULATING FACTOR OF SLOPE SAFETY

Muhammad Israr Khan*, Shuhong Wang

School of Resources and Civil Engineering, Northeastern University, China.
****Corresponding Author Email; 1727011@stu.neu.edu.cn***

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ABSTRACT

There are various slope stability analysis methods normally used to find the factor of safety of a slope. All the methods have different analysis techniques and formulation, due to which the results also varies in some cases. In this research article, all those methods are compared and the results are provided in graphical form to show the variation. The results can be used in any slope stability project to find the optimum value for factor of slope safety and hence can minimize the risk while designing any slope in hilly areas or in case of designing an earthen dam.

KEYWORDS

slope stability analysis, analysis techniques and formulation, slope stability project, earthen dam.

1. INTRODUCTION

Land siding is a very common issue all over the world especially in hilly areas and in case of earthen dams. This issue causes human and economy loss time to time. Therefore researchers are always working how to minimize and overcome this issue. There are various methods to design slopes and know about the factor of safety. There are various methods to analyse the slope stability which are summarized (Duncan, 1996).

The methods normally followed in analysing slope stability issues are:

- Bishop simplified
- Bishop modified
- Janbu simplified and corrected
- Spencer
- GLE – Morgenstern – Price

2. LITERATURE SURVEY

The influence of soil strength on the probability of failure of slopes using conventional limit equilibrium slip circle analysis has been explored (Li and Lump, 1987; Chowdhary and Xu, 1993; Low et al., 1998; Hong and Roh, 2008). A brief introduction to some of these methods is explained below.

2.1 Bishop Simplified

In this method, the slipping mass above the failure plane is divided into slices. On each slice, force equilibrium conditions are applied and equation for factor of safety is generated. Considering the mechanical equilibrium, the forces acting on each slice are obtained (Bishop, 1955). All slices are considered individually and the interactions of slices is neglected because the resultant forces are parallel to the base of each slice. Figure 1 shows all the assumed forces acting on the slice and equation 1 is the generated equation for calculating the factor of safety in this method.

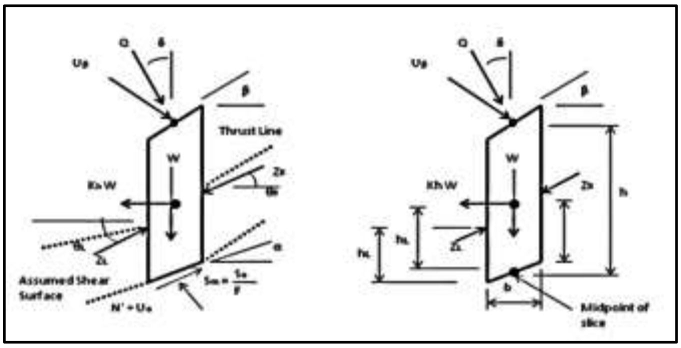

Figure 1: Assumed slice

Where; F = Factor of safety = C + N' tan ϕ
Sa = Available strength
Sm = Mobilized strength
$U\alpha$ = Pore water force
$U\beta$ = Surface water force
W = Weight of slice
N' = Effective normal force
Q = External surcharge
Kv = Vertical seismic coefficient
Kh = Vertical seismic coefficient
ZL = Left interslice force
ZR = Left interslice force
θL = Left interslice force angle
θR = Left interslice force angle
hL = ZL, Force height, left

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hR = ZL, Force height, right
α = Slice base inclination
β = Slice top inclination
σ = Surcharge inclination
b = width of slice
hc = Height of centroid of slice

$$F = \frac{\sum_{i=1}^{n}(C + N' \tan\phi)}{\sum_{i=1}^{n} A_5 - \sum_{i=1}^{n} A_6 - \sum_{i=1}^{n} A_7} \quad (1)$$

Where;

$$A5 = [W(1 - ku) + U\beta \cos\beta + Q\cos\sigma]\, R\sin\alpha \quad (2)$$

$$A6 = [U\beta \sin\beta + Q\sin\sigma]\, (\cos\alpha - \frac{h}{R}) \quad (3)$$

$$A7 = kh\, W\, (\cos\alpha - \frac{h}{R}) \quad (4)$$

2.2 Bishop modified

The difference between ordinary and modified Bishop method is that in modified method, an assumption is made that the normal interaction forces between nearby and adjacent slices are collinear and the final interslice shear force is considered as zero.

2.3 Janbu simplified and corrected

The Janbu's simplified method is applicable to non-circular slip surfaces as shown in figure 2 (Janbu et al., 1956). In this method, the interslice forces are assumed to be horizontal and thus the shear forces are zero.

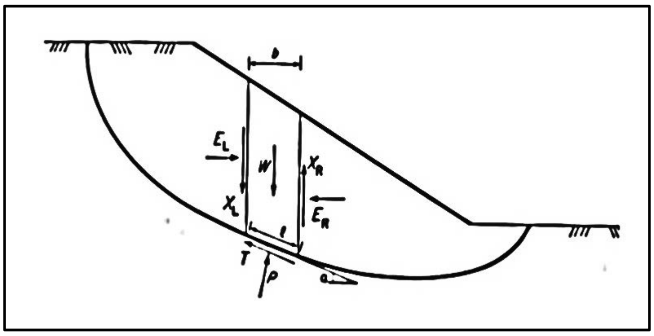

Figure 2: Janbu's simplified method (slice assumption)

The factor of safety equation in this case is:

$$F = f0.F0 \quad (5)$$

Where F0 is the factor of safety in simplified case and a correction factor f0 is applied to the same equation to take account of the interslice shear forces.

$$f0 = 1 + b1\, [\frac{d}{L} - 1.4\, (\frac{d}{L})^2] \quad (6)$$

$$F0 = \frac{\sum(c'l + (p - ul)\tan\phi')\sec\alpha}{\sum W \tan\alpha} \quad (7)$$

Figure 3 shows the Janbu correction factor.

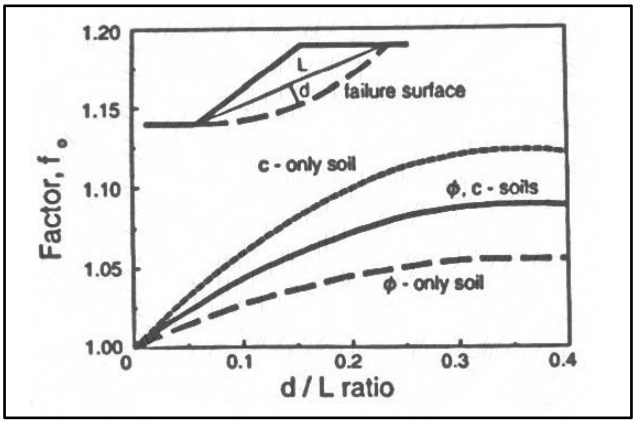

Figure 3: Janbu's correction factor (Abramson et al., 1996)

2.4 Spencer Method

Spencer's method was developed for analyzing circular slip surfaces but later on it was extended to non-circular slip surfaces by assuming a frictional center of rotation. This method is based on the assumption that the inter-slice forces are parallel to each other and they have the same inclination. Figure 4 shows Spencer's method diagram for the assumed slice.

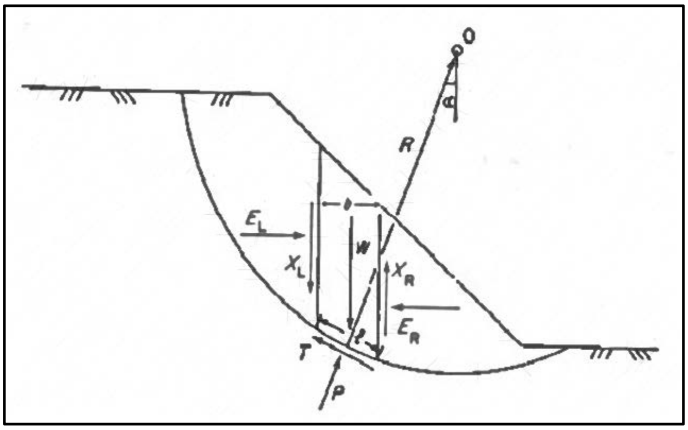

Figure 4: Spencer method slice diagram (Anderson, 1987)

The factor of safety equation in case of Spencer method is given below:

$$F = \frac{\sum(c'l + (P - ul)\tan\phi')\sec\alpha}{\sum(W - (X_R - X_L))\tan\alpha} \quad (8)$$

2.5 Morgenstern – Price Method

This method was introduced which considers both normal and tangential equilibrium along with the moment equilibrium for each slice in circular as well as non-circular slip surfaces (Morgenstern, 1965). The factor of safety equation in this case is:

$$F = \frac{\sum(c'l + P - ul)\tan\phi')\cos\alpha}{\sum P \sin\alpha} \quad (9)$$

Similarly, there are other methods of analysis such as:

- Ordinary / Fellenius
- Lowe – Karafiath
- Corps of Engineers #1
- Corps of Engineers #2

In Corps of Engineer method, resultant interslice force direction is;

The average slope from the beginning to the end of the slip surface or Parallel to the ground surface.

Figure 5 shows the classification chart for few slope stability methods (Wright, 2005).

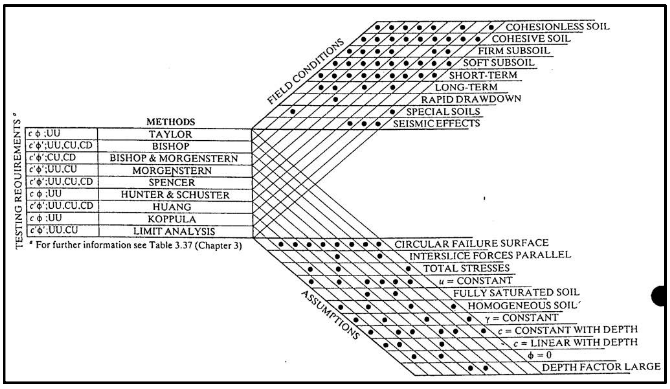

Figure 5: Slope stability methods, field conditions and assumptions

Summary of assumption, limitations and usage of some of these analysis methods is given in Table 1.

Table 1: Brief description of commonly used slope stability analysis methods (Wright, 2005)

Method	Equilibrium condition	Slip Surface	Assumptions	Unknowns
Logarithmic spiral method	Moment equilibrium about centre of spiral	Log spiral	The slip surface is logarithmic spiral	One, that is factor of safety
Friction circle method	Moment and force equilibrium	Circular	Resultant of the normal and frictional component of shear strength tangent to friction circle.	One, that is factor of safety
Ordinary method of slices	Moment equilibrium about centre of circle	Circular	Side forces of the slices are neglected and normal force equals Wcosα and the shear force Wsinα.	One, that is factor of safety
Simplified Bishop method	Vertical equilibrium and overall moment equilibrium	Circular	Zero interslice shear forces	n + 1
Janbu's Simplified Method	Force equilibrium (vertical and horizontal)	Any shape	The side forces are horizontal.	2n
Swedish circle (ϕ = 0) Method	Moment equilibrium about centre of circle	Circular	Circular slip surface and Zero Friction angle	One, that is factor of safety

3. METHODOLOGY

Three different material types are investigated in this analysis. All these three material types have different properties such as cohesion, friction, unit weight and angle of repose. Results for factor of safety were achieved using all the below methods:

- Bishop simplified
- Bishop modified
- Janbu simplified and corrected
- Spencer
- GLE – Morgenstern – Price
- Ordinary / Fellenius
- Lowe – Karafiath
- Corps of Engineers #1
- Corps of Engineers #2

A limit equilibrium software is used in this analysis namely slide. The variation of factor of safety is provided in graphical form out of which designer can select the optimum value.

4. RESULTS AND DISCUSSIONS

Figure 6 shows the slope model used in this analysis:

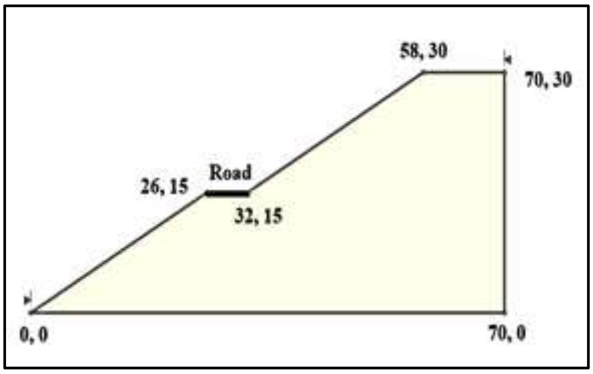

Figure 6: Slope model

Three types of material is used in this analysis. Table 2 shows the material properties details and factor of safety for all the analysis methods. Figure 7, 8 and 9 shows the variation of factor of safety for all the three material types.

Table 2: Material properties and analysis details

Material Number (M)	Cohesion (kN/m2)	Angle of Repose (AOR)	Unit Weight (kN/m3)	Friction angle(ϕ)	Material Type	Method	Factor of Safety (FS)
1	11	30	14	31	Clay	Bishop simplified	1.702
1	11	30	14	31	Clay	Ordinary / Fellenius	1.631
1	11	30	14	31	Clay	Janbu simplified	1.616
1	11	30	14	31	Clay	Janbu corrected	1.700
1	11	30	14	31	Clay	Spencer	1.697
1	11	30	14	31	Clay	Corps of Engineers # 1	1.704
1	11	30	14	31	Clay	Corps of Engineers # 2	1.705
1	11	30	14	31	Clay	Lowe-Karafiath	1.701
1	11	30	14	31	Clay	GLE / Morgenstern-Price	1.698
2	12	35	16	33	Clay	Bishop simplified	1.655
2	12	35	16	33	Clay	Ordinary / Fellenius	1.601
2	12	35	16	33	Clay	Janbu simplified	1.590
2	12	35	16	33	Clay	Janbu corrected	1.633
2	12	35	16	33	Clay	Spencer	1.654
2	12	35	16	33	Clay	Corps of Engineers # 1	1.658
2	12	35	16	33	Clay	Corps of Engineers # 2	1.669
2	12	35	16	33	Clay	Lowe-Karafiath	1.660
2	12	35	16	33	Clay	GLE / Morgenstern-Price	1.654
3	5	40	17	38	Clayey Sand	Bishop simplified	1.318
3	5	40	17	38	Clayey Sand	Ordinary / Fellenius	1.278
3	5	40	17	38	Clayey Sand	Janbu simplified	1.273
3	5	40	17	38	Clayey Sand	Janbu corrected	1.321
3	5	40	17	38	Clayey Sand	Spencer	1.313
3	5	40	17	38	Clayey Sand	Corps of Engineers # 1	1.316
3	5	40	17	38	Clayey Sand	Corps of Engineers # 2	1.320
3	5	40	17	38	Clayey Sand	Lowe-Karafiath	1.315
3	5	40	17	38	Clayey Sand	GLE / Morgenstern-Price	1.313

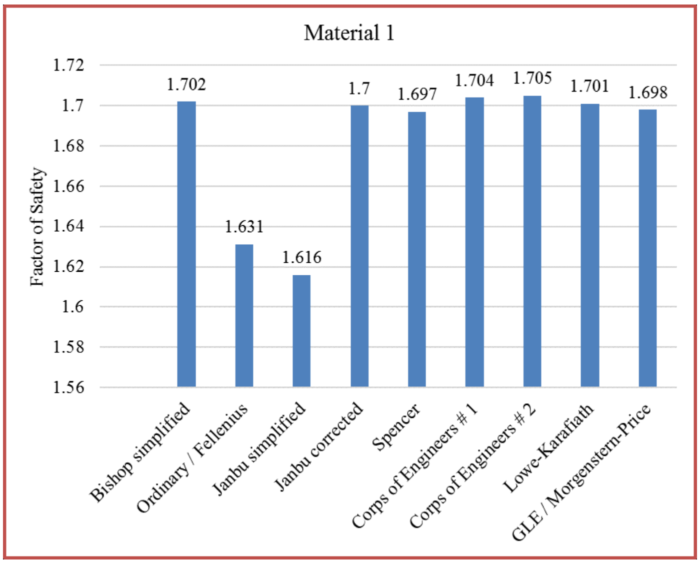

Figure 7: Bar graph showing factor of safety for Material 1

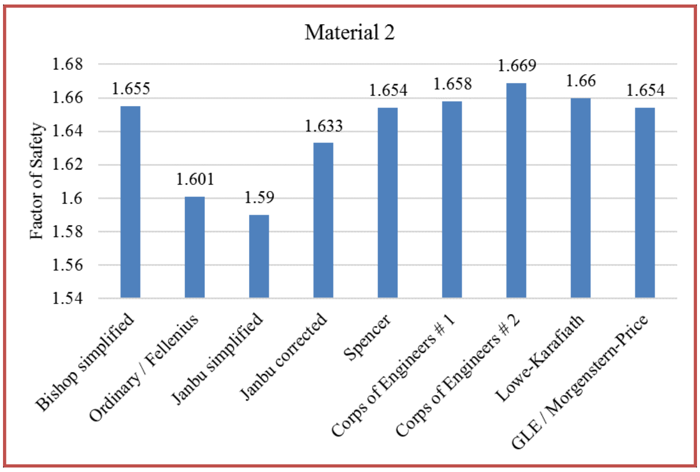

Figure 8: Bar graph showing factor of safety for Material 2

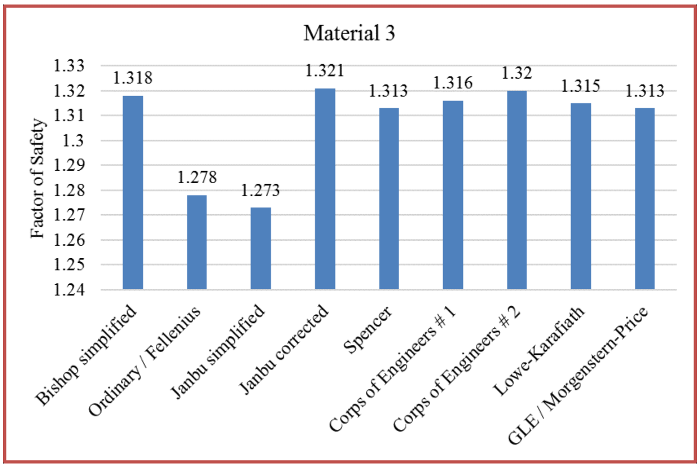

Figure 9: Bar graph showing factor of safety for Material 3

5. CONCLUSIONS

In case of material 1, the maximum value for factor of safety is 1.705 given by Corps of Engineer # 2 method while the minimum value for factor of safety is 1.616 given by Janbu simplified method. The overall average value for factor of safety by all the methods came out to be 1.684 which is very near to the value given by Spencer method that is 1.697.In case of material 2, the maximum value for factor of safety is 1.669 given by Corps of Engineer # 2 method while the minimum value for factor of safety is 1.59 given by Janbu simplified method. The overall average value for factor of safety by all the methods came out to be 1.642 which is very near to the value given by Janbu corrected that is 1.633. In case of material 3, the maximum value for factor of safety is 1.321 given by Janbu corrected method while the minimum value for factor of safety is 1.273 given by Janbu simplified method. The overall average value for factor of safety by all the methods came out to be 1.307 which is very near to the value given by Spencer that is 1.313. This analysis shows that Spencer method gives optimum value for factor of safety in homogenous slopes.

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REFERENCES

Abramson, L.W., Lee, T.S., Sharma, S., Boyce, G.M., 1996. Slope Stability and Stabilization Methods. John Wiley and Sons, N.Y.

Anderson, M.G.R., 1987. Slope Stability: Geotechnical Engineering and Geomorphology. John Wiley and Sons, N.Y.

Bishop, A.W., 1955. The use of the slip circle in the stability analysis of slopes. Geotechnique, 5 (1), Pp. 7-17.

Chowdhury, R.N., Xu, D.W., 1993. Rational polynomial technique in slope reliability analysis. Journal of Geotechnical Engineering, 119 (12), Pp. 1910-1928.

Duncan, J.M., 1996. State of the art: limit equilibrium and finiteelement analysis of slopes. J. Geotech. Eng., ASCE., 122 (7), Pp. 577-597.

Hong, H., Roh, G., 2008. Reliability evaluation of earth slopes. Journal of Geotechnical and Geoenvironmental Engineering, 134 (12), Pp. 1700-1705.

Janbu, N., Bjerrum, L., Kjaernsli, B., 1956. Soil mechanics applied to some engineering problems, Norwegian Geotechnical Institute, Publication, 16, Pp. 5-26.

Li, K.S., Lumb, P., 1987. Probabilistic design of slopes. Canadian Geotechnical Journal, 24 (4), Pp. 520-535.

Low, B.K., Gilbert, R.B., Wright, S.G., 1998. Slope reliability analysis using generalized method of slices. Journal of Geotechnical and Geoenvironmental Engineering, 124 (4), Pp. 350-362.

Morgenstern, N.R.A.V.E.P., 1965. The analysis of the stability of general slip surface. Geotechnique, 15 (4), Pp. 289-290.

Wright, D.J.M.A.S.G., 2005. Soil Strength and Slope Stability. John Wiley and Sons. NY.