International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 7, July-2018

COMPARATIVE STUDY OF EMBANKMENT SLOPE BY LEM AND SRM TECHNIQUES

[1] Amandeep Singh Chaudhary, [2] Vinod K. Sonthwal, [3] Sunil Kaswan

[1]*M.E. Student, Department of Civil Engineering, NITTTR Chandigarh, India,*
[2]*Associate Professor, Department of Civil Engineering, NITTTR Chandigarh*
[3]*M.E. Student, Department of Civil Engineering, NITTTR Chandigarh*

Abstract— ***This paper presents the comparison of slope stability analysis using limit equilibrium and strength reduction techniques. Variation in soil properties and complexity of soil geometry requires in depth understanding of different methods available and viability of best suitable procedure. The embankment slope of NH73 (new NH 344) is studied by altering soil properties obtained from study site under different conditions. With the advent of technology, various methods are available to find the most critical slip surface in stability analysis. This study uses software tool MIDAS GTS NX for 3D simulation and SOILWORKS for 2D simulation, to find the values of Factor of safety along the most critical slip surface.***

Keywords— Factor of Safety, Equilibrium, Shear strength, Comparison, Slope Stability.

I. INTRODUCTION

The complexity of slope and variation in soil properties requires in depth understanding to calculate the most critical slip surface. With the advent of technology, various methods are available to calculate the value of factor of safety. However, limit equilibrium method (LEM) is most preferred due to its simplicity less time consuming procedure. The slip surface in LEM is always assumed to be circular and soil mass is divided into number of slices. LEM satisfies equilibrium of these slices and due to numerous unknowns, the equation becomes indeterminate and to counter these various assumptions are made with respect to the forces. The strength reduction method does not divide soil mass into slices and Mohr – Coulomb strength parameters are altered with an increment in factor of safety. The embankment slope of NH 73 (new NH 344) is selected as the study site and soil properties are determined in the laboratory to simulate the real- time conditions. A simple geometry slope is used for the analysis as in case of complex geometries there always exist a point of local minima and the actual slip surface may not be same due to various assumptions. [1]

II. IMIT EQUILIBRIUM METHOD

The conventional method of slope stability analysis is still practiced because of its simplicity and less time consuming. LEM include two types of analysis – either by considering the total soil mass as a whole and satisfy its equilibrium or by dividing the surface into number of slices. In this method, slope surface is divided into number of slices and their individual equilibrium is satisfied due to which it requires some assumptions to make the equation determinate. The result output of LEM is the factor of safety obtained by decreasing the shear strength of slope so that a point of shear stress equilibrium can be approached.

The shear strength equilibrium is chosen because it has the maximum tendency to vary. In this study, two methods of LEM are used i.e. Fellenius or ordinary method of slices and Bishop method. The ordinary method of slices satisfies the equilibrium of the soil mass which is lying above each element I the slip surface. This method uses moment equilibrium whereas; in Bishop method vertical equilibrium is considered as well.[4]

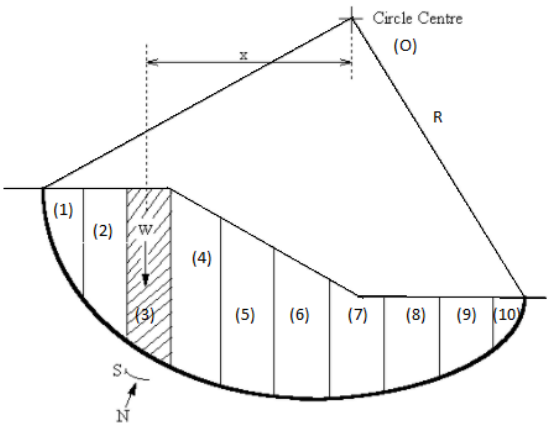

Figure 1 Method of Slices

FOS = τ_r / τ_m

τ_r is defined as the shear strength developed on the failure surface.

τ_m is the total mobilized magnitude of shear forces which is acting on per unit area of the defined plane.

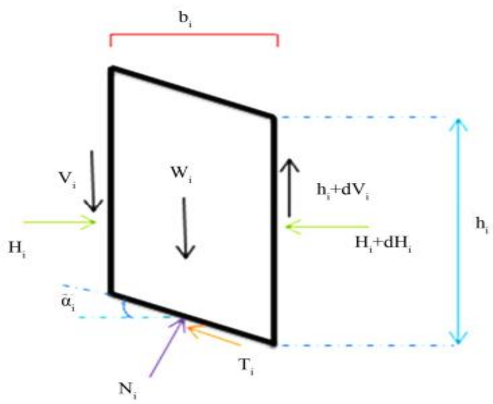

Figure 2 Forces on Single Slice

- W_i is per unit weight of i^{th} slice.
- N_i and T_i are resultant forces of the normal and tangential forces acting on the i^{th} slice.
- Length of base is l_i and inclination α with respect to the horizontal.
- dV_i and dH_i are vertical and horizontal interslice forces respectively.
- γi is the unit weight of i^{th} slice [3]

An implicit assumption in LEM method is that it assumes that the stress strain behavior of the soil is ductile and therefore, it does not provide any information about the information about the strain and variation of displacement in the soil mass. [2]

III. STRENGTH REDUCTION METHOD

The behavior law of the soil mass and its self weight should be known so that each element is subjected to the action of the nearby element, this type of modeling is known as finite element modeling (FEM). In this FEM is done using strength reduction method through simulation with MIDAS GTS NX. The Mohr-Coulomb failure criterion is the most commonly used one in soil mechanics. The Mohr-Coulomb equation for a failure plane can be written as:

The factored or reduced shear strength of a Mohr - Coulomb material is described by the equation:

$$\tau = \frac{C'}{F} + \frac{\sigma \tan\varphi'}{F}$$

Where,

- τ is the shear strength developed,
- c' is the force of effective cohesion
- σ is the effective stress
- ϕ' is the effective angle of friction.
- F is the reduction factor used by the simulating program.

The value of factor of safety does not give the actual behavior of soil failing criteria, but the other values obtained from the results are helpful in understanding the actual criteria. FEM modeling is further used for various calculations that help in illustrating the exact behavior.

1. The value of settlement can be calculated by using the actual displacement which is obtained by FEM which can be used to strengthen the slope by using various measures.
2. The exact shape of the failure surface.
3. The use of results from field samples tested can be further used for various tests.

IV. MODELING THE SLOPE ON MIDAS GTS NX AND SOILWORKS

The selection of correct geometry for the comparison of slope stability is necessary to avoid the uncertainties associated with the assumption in different method of analysis. The slope of soil is modeled using the following properties:

Section	**Landfill Layer**	**Weathered Soil**
Dry unit weight (kN/m^3)	19.60	18.30
Saturated unit weight (kN/m^3)	20.60	19.56
Cohesion (kN/m^2)	7.0	20.8
Internal friction angle [deg]	33.00	27.80
Modulus of elasticity (kN/m^2)	25050	5000
Poisson's ratio	0.3	0.36
Initial void ratio (e_o)	0.58	0.68

Rectangular mesh shape was selected in this stage as efficacy of the rectangular meshes is found to be more precise than triangular meshes. Higher Order Element meshing was done to optimize the meshing quality. Because when low order elements are used, the rigidity of the model is relatively higher. Mesh generation is not required in Limit Equilibrium Analysis as it does not require nodes to converge and failure surface is determined by using grid surface. This grid surface is a three - point definition and it should be projected to the corners of geometry so that it assumes the centre of rotation somewhere between the grids, about which the factor of safety is to be calculated.

V. RESULTS AND CALCULATION

Soil models are prepared by varying the value of angle of internal friction in landfill layer. As per the codal provisions of **IRC SP: 84-2014** - Manual of Specifications and standards for four laning of highways, Side slopes shall not be steeper than **2H: 1V** unless soil is retained by suitable soil retaining structures.

Two geometries are selected for the simulation -

- Simple slope (3H: 1V)
- Steep slope (2H: 1V)

For a simple slope 3H: 1V with low slope angle, the percentage deviation of factor of safety is represented by:

- FOS by LEM (Bishop/ Fellenius) = Fs2-D
- FOS by SRM = Fs3-D
- Percentage increase = (Fs2-D – Fs3-D) /Fs3-D

Case 1: Simple slope (3H: 1V)

Factor of safety obtained from different method is compared, and the correct answer to the analysis is the method which gives almost same results as SRM method.

Table 1 Factor of Safety (Slope 3H: 1V)

φ	Bishop	Fellenius	SRM
21^0	1.8108	1.6941	1.6518
25^0	2.1135	1.9715	2.0568
29^0	2.4216	2.2676	2.0072
33^0	2.7541	2.5876	2.5517

Table 2 Total Deviation (Slope 3H: 1V)

φ	Bishop –Fellenius	Bishop - SRM	Fellenius – SRM
21^0	6.888613	9.625863	2.5608427
25^0	7.202638	2.756709	-4.147219
29^0	6.791321	20.64568	12.973296
33^0	6.434534	7.931967	1.4069052
Avg.	6.829277	10.24005	3.1984563

For simple slope (3H: 1V), Fellenius or ordinary method of slices is closer to the SRM. Therefore, if the embankment slope is mild then Fellenius method is more accurate as compared to Bishop.

The percentage deviation of Fellenius and SRM in this case i.e. ΔFs/Fs 3-D monotonically increases with an increase in c', φ'. The variation in ΔFs/Fs3-D with various combinations of φ' values ranges from 1.4% to 12.97 %.

Case2: Steep slope (2H: 1V)

Steep slope is modeled using the same properties of soil.

Table 3 Factor of Safety (Slope 2H: 1V)

φ	Bishop	Fellenius	SRM
21^0	1.3032	1.2240	1.3095
25^0	1.5084	1.4116	1.4954
29^0	1.7274	1.6118	1.7276
33^0	1.9489	1.8282	1.9442

Table 4 Total Deviation (Slope 2H: 1V)

φ	Bishop –Fellenius	Bishop- SRM	Fellenius- SRM
21^0	6.470588	-0.4811	-6.52921
25^0	6.857467	0.869333	-5.603852
29^0	7.172106	-0.01158	-6.70294
33^0	6.602122	0.241745	-5.966464
Avg.	6.775571	0.1546	-6.200617

For steep slope (2H: 1V), Factor of safety results of Bishop method of slices are closer to the SRM. Therefore, if the embankment slope is steep then Bishop method is more accurate as compared to Fellenius.

The percentage deviation of Fellenius and SRM in this case i.e. ΔFs/Fs 3-D monotonically increases with an increase in c', φ'. In this case Fellenius method gives more conservative results for the same slip circle. The variation in ΔFs/Fs3-D with various combinations φ' values ranges from 0.01% to 0.86 %.

VI CONCLUSION

The analysis of slope stability requires an in depth understanding of failure mechanism and various geometrical parameters. This study focuses on comparing various techniques and finds the best suitable method depending on conditions.

Displacement variations which are lacking in limit equilibrium method (LEM) are very well integrated into strength reduction method (SRM). The results obtained in terms of factor of safety from LEM (2D) using bishop & Fellenius method is compared with strength reduction method and it was found that for mild slopes FOS results of SRM are much closer to the results obtained from Fellenius method. Whereas in case of steep slope or maximum value of limiting slope i.e. 2H: 1V, results for FOS from SRM method are much closer to Bishop Method of slices than Fellenius method.

Incas of steep slopes, almost same results are obtained from Bishop and SRM method. It can be concluded that this is because the critical slip surface is passing through the shallow plane which is parallel to the surface of slope.

Maximum deviation in value of factor of safety obtained from any method which satisfies the equilibrium condition cannot be greater than 12% [5].

The average deviation of factor of safety by Bishop and Fellenius method as compared to SRM method is 0.15 %, largest deviation is 10.24 %. This deviation could be smaller by refinement of the mesh.

REFERENCES

[1] Duncan, James M., S. G. Wright, and Kai S. Wong. "Slope stability during rapid drawdown." Proceedings of the H. Bolton seed memorial symposium. Vol. 2. 1990.

[2] Lowe, Donald R. "Grain flow and grain flow deposits." Journal of Sedimentary Research 46.1 (1976).

[3] W. X. Peng, J. J. Mo, and Y. J. Xie, “Comparison for the Results from 2D and 3D Analysis for Slope Stability,” Appl. Mech. Mater., vol. 90–93, pp. 255–259, 2011.[4] A. W. Bishop, “The use of the Slip Circle in the Stability Analysis of Slopes,” Géotechnique, vol. 5, no. 1, pp. 7–17, 1955.

[4] A. W. Bishop, “The use of the Slip Circle in the Stability Analysis of Slopes,” Géotechnique, vol. 5, no. 1, pp. 7–17, 1955.

[5] J. M. Duncan, “State of the Art: Limit Equilibrium and Finite-Element Analysis of Slopes,” J. Geotech. Eng., vol. 122, no. 7, pp. 577–596, 1996.

[6] T. H. Abderrahmane and B. Abdelmadjid, “Assessment of Slope Stability by Continuum and Discontinuum Methods,” vol. 10, no. 4, pp. 528–533, 2016.

[7] D. V. Griffiths and P. a. Lane, “Slope stability analysis by finite elements,” Geotechnique, vol. 49, no. 3, pp. 387–403, 1999.

[8] S. Saha, “Stability Analysis of Slopes By Discrete Finite Element Method,” 2010.

[9] K. Baba, L. Bahi, L. Ouadif, and A. Akhssas, “Slope Stability Evaluations by Limit Equilibrium and Finite Element Methods Applied to a Railway in the Moroccan Rif,” Open J. Civ. Eng., vol. 02, no. 01, pp. 27–32, 2012.

[10] Z. Rahman, “Slope stability analysis and road safety evaluation,” p. 111, 2012.

[11] H. H. Lu, L. M. Xu, M. D. Fredlund, and D. G. Fredlund, “Comparison of 3D Finite Element Slope Stability With 3D Limit Equilibrium Analysis,” pp. 3–6, 2013.

[12] A. Kainthola, D. Verma, R. Thareja, and T. N. Singh, “A Review on Numerical Slope Stability Analysis,” Int. J. Sci. Eng. Technol. Res., vol. 2, no. 6, pp. 1315–1320, 2013.

[13] C. Paper and T. Khar, “Slope stability analysis of slides at Sonapur using strength reduction method SLOPE STABILITY ANALYSIS OF SLIDES AT SONAPUR USING,” no. January 2017, pp. 15–18, 201