STABILITY ANALYSIS OF SLOPE USING DIVERSE PARAMETERS, TECHNIQUES AND SOFTWARES: A REVIEW

[1]Jeevan Kaushal, [2]Vinod Kumar Sonthwal
[1]M. E. - Scholar, [2]Associate Professor
[1]Civil Engineering Department
[1]National Institute of Technical Teachers Training and Research, Chandigarh, India.

Abstract: Landslide is a very prominent issue, which is becoming a major obstacle in infrastructural development. In recent times, the frequency of slope and embankment failures has been increased. Researchers have analysed a lot of slopes/ embankments to counter this issue. Meanwhile, a lot of landslide affected areas have been recovered and many landslide reactivations have been mitigated. This paper presents a succinct review of the various conditions, parameters calculated, techniques and software used to perform the stability analysis of slope which results in the future scope of the study for a certain slope. The location which has been fixed for the future study is Chakki Mod, Distt. Solan, Himachal Pradesh. MIDAS GTS NX software has been opted for the analysis, as this software has not been explored yet completely on the large scale.

Index Terms **– Slope stability analysis, FEM, SRM, Matric suction, Midas GTS NX.**

I. INTRODUCTION

Landslide is the devastating alteration in the existing landform under the effect of gravity by means of certain governing factors of either internal or external nature. As per the studies of CSIR – Central Roads Research Institute, India, The Himalayas and the Western Ghats stipulate high to extreme rate and high rate of landslide incidences in India, respectively (Chand, 2014). Slope failure is thus, a very prominent issue in the path of infrastructural development and environmental sustainability. In recent times, the frequency of slope failure has been increased. Meanwhile, the geotechnical investigation of already failed slopes in case of chances of reactivation and slopes which are under anticipation due to either recent excavation or any other natural agencies or calamity occurred in that area, is exigent.

Certain methods have been evolved by the researchers for performing the slope stability analysis. These methods can be adapted to carry out 2D and 3D analysis. But, the 2D analysis is a conservative approach, as it doesn't account the actual replica of the slope area which needs to be investigated. Also, considering the practical conditions, in the main, slope failures are of 3D in nature. Severe practical stress conditions, high scrutiny led the interest of the engineers to the 3D analysis. Contrariwise, 3D analysis is time consuming, economic, ensures much precision in the critical failure surface and accounts stress conditions in a better way. In this, the finite element method (FEM) is the most greeted by the engineers and researchers for the analysis.

Various researches have been done on three-dimensional stability analysis for different types of slopes and embankments with the help of certain software like ABACUS, Plaxis, Phase 2, Soil Vision, GeoSlope, MIDAS GTS NX software etc. In these researches, certain engineering parameters of the slope has been inputted in the software and the stability analysis will be investigated under the influence of some static or dynamic governing factor.

In this paper, we will review the various studies and investigation done on the respective slopes based on the three-dimensional slope analysis using Finite Element Method (FEM). The objective of this paper is to focus on the various parameters considered in the already done studies which include material properties, type of governing factor (static or dynamic), type of software used and then considering the results of those studies for future scope for the detailed slope stability analysis of some respective slope. In the end, investigation objectives including the parameters required and methodology will be suggested the detailed analysis of any particular slope. In this paper, the slope of a location named Chakki Mod, Distt. Solan, Himachal Pradesh, India has been considered, for future analysis where the landslide incidences have been encountered along the National Highway, for the last two years.

II. ADVANTAGEOUS FEM OVER LEM

This paper presented the finite element method (FEM) as an advantageous method over the Limit Equilibrium Method (LEM). In the study, the authors probed the slope failure by both LEM and FEM and found that FEM accoutered a strong, more precise, versatile approach, which required fewer assumptions as compared to the traditional LEM. The soil failure on FEM approach occurred naturally through the zones which were incapable of withstanding shear stress. No notions had been made regarding the shape and location of the failure, and slice side forces which were suggested by the authors as somewhat advantageous for FEM over LEM. Moreover, the authors suggested that FEM is capable of monitoring the progressive failure up to overall shear failure. FEM along with an elastic – perfectly plastic stress-strain method turned out to be a well-grounded and vigorous method for determining the factor of safety of slopes. Thus, the authors recommended that FEM must be used as a standard in geotechnical practice (Griffiths & Lane, 1999).

III. LEVERAGE OF SUING FEM-SSR TECHNIQUE

A 3-D model had been compared using the Finite Element Method and Limit Equilibrium Analysis. SVSLOPE 3D and SVSOLID 3D Software had been used for the comparison of LEA and FEM, respectively. It had been concluded that an actual slope fails along the critical sliding direction, which is often unknown in general 3D slopes. In FEM-SSR technique, the main advantage is, no such requirement is there, to specify the sliding direction in advance. However, it could not give the exact value of the sliding

direction angle either. Though, SVSLOPE 3D catered an optimization technique which can find the critical sliding direction including the factor of safety (Lu et al, 2013).

IV. Effect of matric suction and air entry value on the unsaturated soil

The modelling of the unsaturated soil zone had been done and the repercussion of matric suction on it has been analysed for the stability of the slope. Earlier, the linear equation had been used in Mohr-Coulomb theory, to define the shear strength of the soil with respect to a linear increase in matric suction. This linear increase in shear strength used to designate with an angle ϕ^b which signified a character of friction angle. In case, the value of ϕ^b was not known, a ϕ^b value equal to 15° had been used sometimes, to assess the influence of the matric suction on the stability of the slope. However, in many cases, the repercussion of matric suction had been ignored by taking the value of ϕ^b as zero. Previous researches showed that the relationship amongst the shear strength of the unsaturated soil and the matric suction is non-linear and certain semi-empirical formula/equations had been proposed for estimating the relation between the unsaturated soil and the matric suction. In this paper, three examples have been illustrated and certain recommendations have been made based on the outcomes of the examples. The assumption of neglecting the repercussion of matric suction on the shear strength had not been applicable for all types of soils. It had been concluded that, when the air entry value (AEV) of soil is less than 1kPa, the matric suction shows a trivial effect on the slope stability in which ϕ^b value can be taken as zero. When AEV of soil is in between 1kPa to 10 kPa, the nonlinear estimation equations for the unsaturated shear strength should be considered and ϕ^b value of 15° can be generally considered for the shear strength of unsaturated soil when AEV of soil is in between 10 kPa to 200 kPa. For soils having AEV greater than 200 kPa, ϕ^b value can be considered ϕ'. There were also certain limitations which comprise of slope failures for unsaturated soils. The water infiltration changed unsaturated soil stability. Also, in this study, the suctions conditions in the soil slopes had been considered hydrostatic. The effect of various suction profiles during rainfall infiltration needs to be analysed in further (Zhang et al, 2014).

V. Numerical limit analysis (NLA) for various conditions of the soil slope

A numerical limit analysis (NLA) using the second-order cone programming has been performed on a 3-D slope for stability analysis. Three examples had been presented for the affirmation of this method. The first one evaluated the slope stability with a heterogeneous weak layer subjected to plane strain conditions. The second example included a 3-D geometry with boundary conditions which focused on the efficiency of using NLA to evaluate the stability of the slope. The third example aimed to validate the situations which considered the pore pressure of steady-state for changing the soil strength due to saturation (Camargo et al, 2016).

VI. Midas GTS NX software for slope stability analysis

The static and dynamic stability of slope had been analysed which is located at Sonapur, in Meghalaya state by applying SRM technique in MIDAS GTS NX software. The slope of the region was inaccessible due to undulated terrain and thick vegetation. Thus, neither in-situ tests were possible nor the collection of undisturbed samples was possible. Hence, the disturbed samples had been collected and used for determining the strength parameters. The analysis had been done considering plane strain conditions for three slope heights and five possible slope angles. The slope heights were 5m, 10m, 20 m and the slope angles were taken 30°, 40°, 50°, 60° and 70°. In the analysis, the safety factor had been found to be decreasing as long as horizontal deformation was incrementing with increment in both slope height and inclination. On that basis, the limiting inclination criteria were suggested for the region. The stress variation in the slope and the shear stress at the toe had also been studied. SRM found to be advantageous primarily for providing additional information about stress, strain and displacements developed in the slope. The slope of height 20 m was extremely vulnerable even during the dry static condition. The factor of safety reduced with increment in the degree of saturation. Under the effect of dynamic load, the slope was found to be unsafe, for both dry and wet analysis (Saikia & Dey, 2016).

VII. Software analysis promotes FEM based technique

A review in which LEM and FEM had been compared by performing software-based slope stability analysis. In this, the introduction of various software like SLIDE, PLAXIS, SLOPE/W, GSLOPE, STABLE WV, FLAC SLOPE, CRISP 2D, HYDRUS and GEOFEM had been mentioned along with the advantages of FEM over LEM. In the end, it was concluded that FEM is a more effective, robust and reliable method for calculating the safety factor. Although, the difference in the results for the safety factor was small for FEM and LEM. The prime advantageous finding of FEM in this paper was FEM turned out as a great tool to model in which stress-strain behaviour was non-linear, and also it easily understood the stability deformations. However, there was no such concept of slices in the FE technique and no assumptions were required to be conceived in advance about the model shape or the failure surface (Vinod et al, 2017).

VIII. Determination of strength reduction factor (SRF) for varied slope sections

The 2D-FEM technique had been used to evaluate the potential surface instability in Kharsali Village, Yamuna Valley, in Northwest Himalaya. In this, three different slope sections had been analysed using shear strength reduction (SSR) analysis in the Phase^2 software. The shear strain and displacement patterns had been determined along the slopes which results in the critical stress reduction factor (SRF) of 1.5 for section (S-1), 1.08 for section (S-2) and 2.76 for section (S-3). It was also noted that the section (S-1) had produced relatively shear strain as compared to section (S-2). Although, the total displacement in the section (S-1) was found to be progressive, with a distinct failure surface and thus found more vulnerable to the slope failure (Jamir et al, 2017).

IX. Comparison of the factor of safety (FOS) of strengthening measures using Midas GTS NX software

This paper aimed to the study of the strength parameters of a slope of 15 m height in Morni Region in Shivalik Mountain Range for the slope stability analysis using the SRM technique of FEM in MIDAS GTS NX software. During the simulation, only the dry period of the soil slope was considered for analysis. The soil classification had been found of Clayey Sand group. After the simulation, the strengthing of the soil had been done by using Shotcrete and soil nail anchoring, and then the factor of safety using both the strengthening measures had been calculated and compared, which was 2.13 for shortcreting and 1.64 for soil nailing.

Hence, the author proposed shortcreting as the better strengthing measure for the stabilization of slope on the basis of the factor of safety (Goel & Sonthwal, 2017).

X. COMPARISON OF THE FACTOR OF SAFETY (FOS) FOR PRE AND POST-FAILURE CONDITIONS

The stability analysis of a soil slope along NH-5, Himachal Pradesh, had been done which was facing repetitive failures. The analysis performed was based on 2D- LEM technique to visualize and examine the pre and post-failure stability of the slope. The slope failure was found be to of semi-circular and shallow in nature, which is still vulnerable. SEM/EDS tests had been performed which affirmed the inter-granular pores with intra-granular pores spaces in the silty soil sediments, which inflate the water retaining capacity of the soil. The rainfall threshold had also been taken into account to check the effect on the soil which was the main reason for the saturation of the soil. The cumulative rainfall data analysis showed greater than 91 mm rainfall threshold for 30 days, which may reactivate the soil slope. Also, the existing geometry of slope made it vulnerable due to its steep slope. Hence, the authors recommended the soil nailing reinforcement to stabilize the soil slope (Singh et al, 2018).

XI. ANALYSIS OF SLOPE USING SHEAR STRENGTH REDUCTION METHOD USING DUAL-FACTOR STRATEGY

An analysis using the shear strength reduction method had been performed, rooted with a dual factoring strategy in which 'c' and 'ϕ' was reduced by a different factor. A series of numerical tests were conducted to develop the slope into varied states of critical equilibrium, which had been used to evaluate the factor of safety and the strength reduction path of some preceding studies. This strategy was found to be more conservative than the traditional shear strength reduction method. It had been concluded that the LEM based technique should be adopted while using the dual factoring strategy (DFS), to describe the effects of the normal stress and most probable strength reduction path must be used to simplify the computational process. In this study, the FOS value based on LEM first decreased and then increased with an increase in cohesion reduction factor, such that the failure mode transformed gradually from a deep-seated rotational failure to surface slumping. Hence, LEM-based FOS turned out to be of minimum value for DFS, which was lower than the calculated value of FOS by the traditional SRM (Wu et al, 2018).

XII. EVALUATION OF THE FACTOR OF SAFETY (FOS) FOR THREE DIFFERENT CONDITIONS OF THE SLOPE

The authors exhibited the strength reduction method for the slope stability analysis. In this, the key parameters which affect the stability analysis of soil slope were discussed for LEM and SRM. The simulation of the soil stress-strain behaviour had been done on the basis of the elastoplastic Mohr-Coulomb failure criterion. An iterative search method was proposed for the safety factor evaluation in which both design and precision parameters were taken into account. Three case studies were evaluated using this method: (a) A homogeneous dry slope, (b) A dry slope with a weak layer, and (c) A partially-wet slope with a weak layer. The soil parameters were assumed to be constant in all these cases. In the simulation, the advantages of this method were related to real-world problems. Along with this, the method became more beneficial in terms of reduction of computational efforts, consistency in the estimation of safety factors (Kolbadi et al, 2019).

XIII. SLOPE STABILITY ANALYSIS FOR SATURATED AND UNSATURATED CONDITIONS OF SLOPE

A geological investigation and slope stability analysis had been exhibited on Kotrupi Landslide occurred in 2017. The analysis performed using FEM in Phase^2 software for numerical simulation. The findings of the paper included the comparison of strength reduction factor (SRF) of pre and post-failure conditions under saturated and unsaturated conditions. The X-diffraction was used to determine the mineral content in the soil along with the strength parameters of the soil. The critical SRF determined through the Phase^2 simulation was found to be 0.77 and 0.81 respectively, for the saturated and unsaturated conditions during the pre-failure stage, whereas it was found to be 0.54 and 0.57 respectively, for the saturated and unsaturated conditions. In the end, the authors concluded that the low safety factor of the present condition of the slope may spawn another landslide if the proper mitigation measures will not be taken soon (Pradhan et al, 2019).

XIV. FUTURE SCOPE

The future research objectives for the analysis of landslide affected area Chakki Mod, Distt. Solan, Himachal Pradesh, India, for the study by the researchers are as under:

1. Analysis of the stability of slope using the FEM method, as it is advantageous over LEM.
2. Using MIDAS GTS NX software for the analysis, as this software has not been explored yet by the researchers.
3. Analyse the slope of considering 3-D model using strength reduction technique in FEM.
4. Model the real-time 3-D slope using surveyed contour co-ordinates and GIS tools and their comparison for the further slope stability analysis.
5. Analysis of stability of the heterogeneous and homogenous slope and its comparison.
6. Determination of factor of safety (FOS) and critical sliding direction using.
7. Analyse the effect of matric suction and air entry value in the unsaturated soil.
8. Evaluation of the variation in the suction profiles in the soil slopes due to rainfall infiltration.
9. Analyse the FOS of the stability of the slope for pre and post-failure stability of the slope.
10. Analysis of the stability of the slope under the effect of static and dynamic load conditions.
11. Analysis of the stability of the slope under saturated and unsaturated conditions.
12. Analysis of the stability of the slope under seismic conditions.
13. Determination of cohesion and angle of internal friction strength parameters by Triaxial Shear Test.
14. Comparison of the stability of the slope under dry, wet and dynamic infiltration conditions.
15. Comparison of the slope stability analysis using the strength parameters of disturbed sample and undisturbed samples of the same slope.
16. Optimization of the best strengthening measure for the slope considering the FOS.
17. Optimization of the best strengthening measure for the slope considering the factors of strength, serviceability and economy.

XV. CONCLUSION

The prime objective of reviewing these existing researches is to present the future research parameters for the analysis of landslide affected area Chakki Mod, Distt. Solan, Himachal Pradesh, India. The slope stability analysis plays a pivotal role while considering the real-time issues, which can be proven very devastating without proper attention. Hence, it is recommended that every point which has been mentioned in the future must be studied in detail, to tackle real-time landslide issues.

REFERENCES

[1] J. Chand, "Mechanism of Landslides of National Highway-22 in Himachal Pradesh," *International Referred Online Research Journal*, no. XX, pp. 8-19, 2014.

[2] 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," *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris 2013*, pp. 759-761, 2013.

[3] Zhang, L. L., Zhang, J., Zhang, L. M., & Tang, W. H. (2013). Stability analysis of rainfall-induced slope failure: a review. *Proceedings of the Institution of Civil Engineers - Geotechnical Engineering, 164*(5), 299-316.

[4] J. Camargo, R. Q. Velloso and E. A. Vargas Jr., "Numerical limit analysis of three-dimensional slope stability problems in catchment areas," *Acta Geotechnica*, vol. 11, no. 6, pp. 1369-1383, 2016.

[5] R. Saikia and A. K. Dey, "SLOPE STABILITY ANALYSIS OF SLIDES AT SONAPUR USING STRENGTH REDUCTION METHOD," *Proceedings of Indian Geotechnical Conference IGC*, pp. 15-17, 2016.

[6] B. R. Vinod, P. Shivananda, R. Swathivarma and M. B. Bhaskar, "Some of Limit Equilibrium Method and Finite Element Method based Software are used in Slope Stability Analysis," *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*, vol. 6, no. 9, pp. 6-10, 2017.

[7] I. Jamir, V. Gupta, V. Kumar and G. T. Thong, "Evaluation of potential surface instability using finite element method in Kharsali Village, Yamuna Valley, Northwest Himalaya," *Journal of Mountain Science*, vol. 14, no. 8, pp. 1666-1676, 2017.

[8] T. Goel and V. K. Sonthwal, "Slope Stability Analysis of a 15m Slope in Morni Region of Shivalik Himalaya," *IJSRD - International Journal for Scientific Research & Development*, vol. 5, no. 06, pp. 2112-2114, 2017.

[9] A. K. Singh, J. Kundu and K. Sarkar, "Stability analysis of a recurring soil slope failure along NH-5, Himachal Himalaya, India," *Natural Hazards*, vol. 90, no. 2, pp. 863-885, 2018.

[10] S. Wu, L. Xiong and S. Zhang, "Strength Reduction Method for Slope Stability Analysis Based on a Dual Factoring Strategy," *International Journal of Geomechanics*, vol. 18, no. 10, p. 04018123, 2018.

[11] S. Seyed-Kolbadi, J. Sadoghi-Yazdi and M. Hariri-Ardebili, "An Improved Strength Reduction-Based Slope Stability Analysis," *Geosciences*, vol. 9, no. 1, p. 11, 2019.

[12] S. P. Pradhan, S. D. Panda, A. R. Roul and M. Thakur, "Insights into the recent Kotropi landslide of August 2017, India: a geological investigation and slope stability analysis," *Landslides*, vol. 16, p. 1529–1537, 2019.