SLOPE STABILITY BASED ON SEISMIC LOADIN

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ABSTRACT

One of the main issues that geotechnical engineers in practice around the world are concerned with is slope stability issues. Due to the change in pore water pressure caused by the existence of a water table, soil behavior becomes more complex. For the purpose of resolving any slope stability issue, the consideration of the rise in pore pressure caused by the cyclic nature of seismic forces has not been taken into account in prior studies. The current study takes into account Janbu's method of slices for the analysis and Skempton's equation for determining the excess pore pressure to examine the impact of pore water pressure on the factor of safety of both unreinforced and reinforced slopes. The quantity of nails needed to increase the safety factor to the appropriate level.

Keywords: Stability, Pore Pressure, Earthquake, Nailed Slope, Factor of Safety.

1. Introduction

The stability of slope is one of the most challenging task of geotechnical engineers for both economic and safe design of the natural and man-made slopes (Ameen, 2018; Ansari et al. 2021). he limit equilibrium methods (LEM) have been used in such analyses, which was originally developed and refined for reinforced (Prater, 1979; Spencer, 1967) due to development in software methods using finite element and finite difference techniques, finite element method/ analysis (FEM/FEA) are extensively used in recent years. Due to the availability to predict stresses, strains and displacements within the body., the finite element analysis/difference (FEA/FD) technique score over the conventional approach of LEM (Ansari et al. 2021). In the starting phases of research, the use of ordinary method of slices (OMS) suggested for slope stability computations due to its simplicity and adaptability, which further refined by (Ansari, 2017; Prater, 1979; Spencer, 1967) assuming circular slip surface.

A generalized method for the optimum design of nailed soil slopes is carried out based on limit equilibrium method of analysis satisfying both internal and as well as external equilibrium (Janbu, 1973). A simple design method suggested to analyze the reinforced soil structure subjected to seismic forces for the internal and external stability (Basha &Basudhar, 2010; Prater, 1979). From the parametric study it is found that the design parameters like horizontal and vertical seismic acceleration, number of reinforcement layers, total length of reinforcement, angle of shearing resistance, uniformly distributed surcharge load have significant effect on the internal and external seismic stability of the wall. The influence of vertical seismic acceleration (Kv) on the factor of safety is insignificant for L≤H and is significant for L/H greater than 1 (Patra &Basudhar, 2005).Here, in this study an attempt has been made to estimate the minimum factor of safety required and corresponding critical slip surface considering the increase in pore pressure due to earthquake loading. Furthermore, a generalized optimum design of nailed slope has been given to find the optimum location, length, diameter, and orientation of the nails in order to achieve the desired factor of safety.

2. Generalized Formulation

The generalized assumptions and design constraints for both unreinforced and reinforced slopes are mentioned here.

2.1 Analysis of the Unreinforced Slopes

The assumptions, design variables, the target function and therefore the design constraints are for unreinforced slope presented below.

- The factor of safety is constant along the whole shear surface and plane strain conditions apply.
- The total resultant ΔN is assumed to act where the road of action of ΔW intersect the bottom of the slice.
- The position of the road of thrust for the entire side force E is assumed to be known.

2.2 Analysis of the Reinforced Slopes

The assumptions, design variables, the objective function and the design constraints are for reinforced slope presented below.

- Factor of safety remains same along the whole slip surface and the plane strain conditions are valid.
- The resultant of the normal force at the base of the slice is assumed to act where the resultant of weight intersects the base of the slice.
- For the no tension to develop within the slope, the position of line of thrust is assumed to act at one third of the height of the slice from the interslice base.
- At failure, the locus of maximum tension and maximum shear force in nails coincides with the failure surface developed in the soil (Juran,1993).
- The pull-out capacity of the length of the nails beyond the failure surfaces can be estimated by the relation given by Powell and Watkins (1990).

3. Unreinforced Slope under Seismic Condition

Based on the formulation a computer code in MATLAB has been developed. In the present chapter, the current formulation and code for the unreinforced slope has been validated using some standard problem available in the literature. Also, the effect of earthquake forces and increase in pore pressure due to earthquake on the slip surface and on the factor of safety has been studied.The computer code is validated by comparing the results of some standard problem given in the literature. Also, the effect of earthquake force and increase in pore water pressure due to the cyclic nature of the earthquake force has been studied.

A homogenous slope of height 16 m having slope as 1 vertical to 2 horizontal is to be analyzed. The effective shear strength parameters ϕ' and c' are 22^0 and 19.5 kN/m2, pore pressure coefficient (ru) is 0.2. The unit weight (γ) of the soil is 17.6 kN/m3.

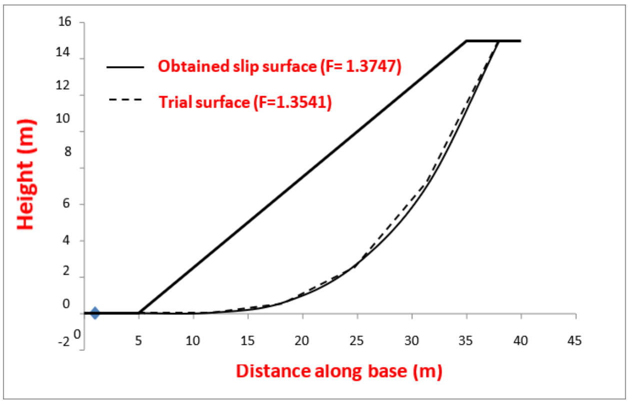


Figure 1. Assumed initial and obtained critical slip surface

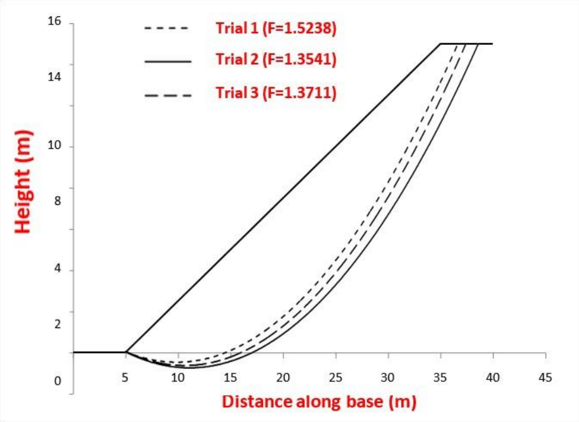


Figure 2. Obtained critical slip surface starting from different initial guess values

Figure 1 shows the critical slip surface obtained from the current analysis, minimum factor of safety obtained from the current analysis is found to be 1.3747 which is very close to factor of safety value that is obtained using Bishop and Morgenstern charts (1.37). It has been found that the critical slip surface and minimum factor of safety shows a strong dependence on the initial guess value.

4. Reinforced Slope under Seismic Condition

The formulation and code for the reinforced slope has been validated using some standard problem available in the literature. In addition, the effect of the initial values of the various parameters on the optimum design and seismic forces and the increase in pore pressure due to the earthquake on the slip surface and on safety factor has been studied.

The slope used to study the effect of different parameters on the slip surface and volume of reinforcement required to increase the factor of safety [6]. The minimum factor of safety of the unreinforced slope has been reported as 1.14. The nails are most effective when placed horizontally having using 4 layers of reinforcement of 28 mm diameter with horizontal and vertical of 0.5m [6]. Using the same location, orientation and diameter of the nail as shown in Fig. 3, the factor of safety of slope obtained is 1.4113 and the total length of nail obtained by present method is 7.121 m which is 4.21 % less as compared to 7.41 m computed by [6] and 2.13% more compared to 6.9 m computed by [2].

In order to study the effect of initial value of diameter on the optimal design four set of diameters 23 mm, 26 mm, 29 mm and 32 mm have been considered. Following Table 1 shows the effect on optimal volume of nails, location, resistive length and total length of nails on varying the initial diameter. From the table it is seen that there is not much difference in optimal volume of nails (4.63 %), maximum difference in the optimum length of the nails is found to be 7.95%. however, it is observed that the choice of initial diameter influences the optimum orientation of nails and position of nails at the upper part of the slope.

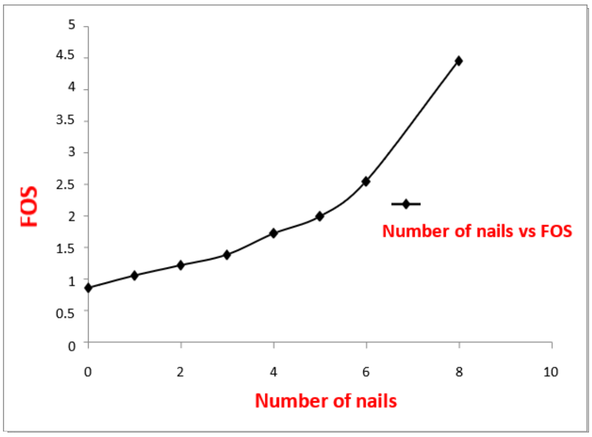


Figure 3. Variation of factor of safety with number of nails

Table 1. Optimal value of parameters for different earthquake coefficients (F_d =1.4).

K_h	K_v	Optimum dia (m)	Position of nails from top (m)	Resistive length of nails (m)	Volume of nails required (m^3)
0.1	0.00	0.0232	1.7010 2.5012 3.3012 4.1014	2.2275 2.3239 1.9874 1.4178	0.0049
0.2	0.12	0.0233	1.4120 2.2120 3.0122 3.8122	2.1531 2.3047 2.1800 1.6087	0.0432

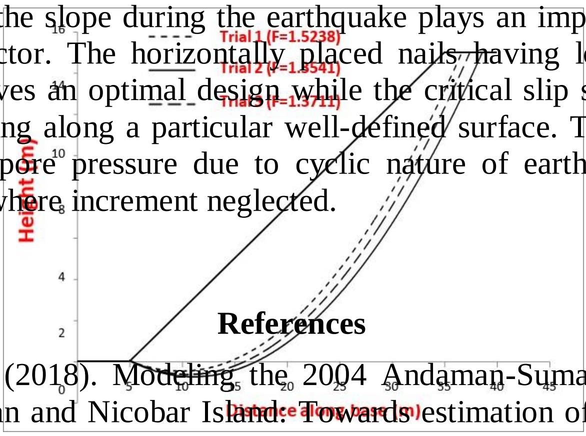
The initial orientation of the nails ranges from 0^0 to 25^0 , with an increase of 120. It has been found that the optimum volume of nails needed to achieve the optimal safety factor is highly influenced by the initial orientation of the nails, with a maximum volume difference of up to 55%. The overall difference in nail length is found to be 52%.

To research the influence of the inclination of the nails on the different parameters, the position and orientation of the nails remains constant. The nails are found to be more efficient when positioned horizontally, the volume and optimum diameter of the nails increases as the angle of inclination increases. Due to the increase in inclination from 0^0 to 25^0 , the total volume of nails may increase up to 51.32% while the optimum diameter may increase up to 34% and 37%.

The safety factor has been found to increase considerably as the number of nails increases. Earthquake forces are considered, in the present analysis, to increase the pore pressure due to the cyclic nature of the earthquake forces. Maximum increase in optimum nail diameter is found to be 30.59% when the vertical earthquake coefficient is increased from 0 to 0.2 and when the Kh value is increased from 0.1 to 0.2 and Kv = 0 is maintained, an increase in diameter is observed to increase by 13.62%. In this analysis, the increase in pore pressure due to the cyclic nature of the earthquake forces is considered.

5. Conclusion

The accuracy of the developed MATLAB computer code has been established by taking several examples of problems and comparing the results obtained. The value of the safety factor from this analysis is found to be close to that obtained by the use of other methods. The excess pore pressure generated on the slope during the earthquake plays an important role in reducing the value of the safety factor. The horizontally placed nails having longer length in the upper portion of the slope gives an optimal design while the critical slip surface is found to lie in a zone instead of occurring along a particular well-defined surface. The location of slip surface when the increase in pore pressure due to cyclic nature of earthquake forces is not same compared to the case, where increment neglected.



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