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SEISMIC STABILITY OF THE NAILED SLOPES

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ABSTRACT

The study undertaken in this project pertains to the determination of ultimate bearing capacity of nailed slopes. In this soil is modeled as composed of homogeneous layers of soils. Analysis has been carried out to obtain an upper bound solution of the problem. A two dimensional collapse mechanism has been assumed to ascertain the bearing capacity with the velocity discontinuities radiating from the applied strip load and satisfying the compatibility of the displacements. The mechanism is defined by relevant angles or lengths. Each velocity vector makes an angle of ϕ' with the direction of discontinuity. For ϕ_u =0 there is no jump in the normal velocity and the velocity vector is parallel to the direction of the discontinuity. Foe-Mohr coulomb material the ϕ' angle assumed between the velocity vector and the discontinuity facilitates the flow rule condition. Assuming that one of these velocities is equal to a specified value, the values of the velocities of the blocs are estimated such that compatibility of the displacements is satisfied. Work done by the external loading includes the boundary loading and the weight of each block. The algebraic sum of the work done is equal to magnitude of the force multiplied by the velocity in the direction of the force. The dissipated work is solely due to the cohesion. The internal work dissipated along the velocity discontinuity of length l is computed from the expression, $\int_0^l c'v\cos\phi' dl$. By equating the work done by the external forces and the dissipated work, the upper bound solution of the bearing capacity is obtained. Above approach initially developed for unreinforced layered slopes has been modified to include the effect of reinforcement on the bearing capacity. The reinforcements are put in a regular fashion with equal vertical spacing. The tension developed due to the friction is estimated and work done by the same is estimated and added with the work done equations. Pseudo static analysis is carried out for considering the effect of earthquakes on the bearing capacity. At the centre of gravity of each block inertial force equal to the earthquake coefficient times the weight of the block is applied and the work done by each of these are estimated and added to the external work done for computational purpose.

The correctness of the developed computer code is first established by checking the calculations with manually computed values. Thereafter, the effect of the depth of reinforcement (in case of single layer of reinforcement)/ depth of the placement of the first reinforcement (in case there are more than one layer of reinforcement and the spacing of reinforcement, earth quake force, values of cohesion and angle of friction on the bearing capacity has been studied. All these parameters are found to have significant influence on the bearing capacity of such nailed slopes.

INTRODUCTION

Rapid growth of population and industrialization has put a heavy demand for urbanization and infrastructure development. This has put heavy pressure on land. Therefore, cost of good land has escalated phenomenally and has become exorbitant. In addition, good land for construction purpose has become scarce and people are forced to construct on filled up soil or reclaimed soil. Some of these have very weak or soft deposits lying underneath with a very low bearing capacity. Therefore, these soils needs special attention and engineering before these can be used. There many options for engineering of grounds. Out of those, reinforcement of ground with geosynthetic inclusions is very common.

Geosynthetics for improvement of ground, are available in various forms e.g. geotextiles, geomats, geogrids, geocells etc. Geosynthetics have a very high tensile strength and some of these (geogrids, geomats, geocells) possess bending resistance. Their inclusion in the medium increases the bearing capacity of soils significantly. This aspect has been researched significantly over the years. Several effects like confinement effect, string effect, shear resistance and bending resistance etc due to the inclusion of geosynthetics imparts the increased strength. Geosynthetics acts as separators, filters and load bearers. However, in this study we would explore the increase in the bearing capacity of ground with geosynthetic inclusion under seismic condition.

In such construction, a geosynthetic reinforcement layer is first put over the weak ground after laying a sand layer of small thickness. Then a cushion of sand layer is placed above it. Thus, this layer also acts as a separator. If required successive layers of reinforcement are placed in the same manner before finally putting the structure in place.

In analyzing such foundations, the procedures that are generally applied for unreinforced soils are modified to take into account the effect of reinforcement on such reinforced beds. Most of the analyses are based on the limit equilibrium approach. Finite element based solutions are also available. Finite element solutions have edge over limit equilibrium based solutions as deformation can also be predicted from such analysis contrary to that of limit equilibrium solutions. However, literatures on the upper bound solution of such problems are very scanty.

Therefore, in this project an attempt has been made to predict the upper bound to the bearing capacity of reinforced foundation beds.

However, in the pseudo-static analysis, the dynamic loading induced by earthquake is considered as time independent, which ultimately assumes that the magnitude and phase of acceleration is uniform throughout the soil layer. Apart from this, the pseudo-static analysis does not consider the amplification of vibration which generally takes place towards the ground surface and depends on various soil properties such as damping, elastic and shear modulus.

The details of the analysis procedure, results and discussions are presented in the following discussion.

PROBLEM FORMULATION

Mechanism is first started with simple case and then it finally proceeds with various complexities. General formulation of problem is given under various headings as follows:

Soil-geotextile interaction mechanism

'Confining Effect' is responsible for the increase in bearing capacity of the reinforced soil. This confining effect depends on the properties of the soil and the reinforcement besides depending on the soil-reinforcement interaction. 'Confining Effect' may be explained as follows:

Due to superimposed loads, soil grains surrounding the reinforcement tend to move downward and outward. It induces tensile stress on the reinforcement and side by side compressive force is also developed in the soil. This results in increasing the bearing capacity of the reinforced soil.

Failure mechanism to some extent is affected by the reinforcement but characteristic features of the failure mechanism resembles to unreinforced soil failure mechanism to great extent.

Reinforcement helps in increasing the bearing capacity till the reinforcement is within the collapse mechanism. If the reinforcement is below the range of collapse mechanism then also it helps in increasing the bearing capacity of the soil by preventing the spread of the collapse mechanism down.

'String Effect' is also responsible for its contribution in increasing the bearing capacity of the reinforced soil by reducing the vertical stresses in the soil and the settlement.

Statement of the problem

Fig. 1 shows the strip load of width *b* acting on the reinforced mechanism. It is one sided mechanism; one side of which is being acted by the uniform load of intensity *q*. Reinforcing layer is placed at a depth d from the free surface. Successive reinforcements (if any) are placed at equal spacing of *s* from the first reinforcement. Different conditions have been considered as follows:

- Depth of the top reinforcement from the free surface is varied.
- Number of reinforcements is varied
- Successive difference between the reinforcements is varied
- Coefficient of horizontal and vertical component of earthquake force is varied.
- Properties of the soil are varied and results are obtained for different types of the soil.

Method of analysis

Analysis is carried out using upper bound limit solution. Rate of work done due to reinforcement is calculated using numerical analysis. Solutions are obtained for the optimized surface. Optimized surface for given number of blocks is one which gives least value of the bearing capacity for given properties of the soil. Optimization is also done using numerical analysis. Kinematic theorem of limit analysis state that a slope will collapse if the rate of work done by external loads and body forces exceeds the energy dissipation rate for any assumed kinematically admissible failure mechanism. Applicability of the theorem requires that soil will be deformed plastically according to the normality rule associated with the Coulomb yield condition.

Following the pseudo-static approach, the effect of earth earthquake on a potential failure soil mass is represented by force acting horizontally at the centre of gravity, which is calculated as the product of a seismic intensity coefficient and the weight of the potential sliding mass. An appropriate value of the seismic coefficient should be selected to account for possible acceleration amplification that is not implicitly considered in the analysis. The effects of pore pressure build-up and change of soil strength due to earthquake shaking are ignored. The analysis concerns slopes of homogeneous cohesionless soils, where the reinforcement layers are finite in number and have the same length. The reinforcement provides forces acting in the horizontal direction that are given by the tensile strength or pull-out resistance of the layers. As is usually assumed in the case of geosynthetics, resistance to shear, bending and compression is ignored. Under these assumptions, the rate of external work is due to soil weight and inertia force induced by earthquake and the only contribution to energy dissipation is that provided by the reinforcement.

Assumptions made are listed below.

<u>Assumptions</u>

- Kinematic approach of limit analysis is selected, based on kinetic theorem of limit analysis
- The rate of internal work is not smaller than the rate of work of external forces in any kinematically admissible mechanism.
- Reinforcement is assumed to be strong enough to withstand the stresses developed and it does not rupture.
- Reinforcement does not slide with respect to the adjacent soil.
- Only mode of collapse is due to the collapse of the mechanism.
- Blocks are assumed to be rigid perfectly plastic.
- Effective length of the reinforcement is one which is within the limits of the collapse mechanism. Reinforcement outside the mechanism is not considered.

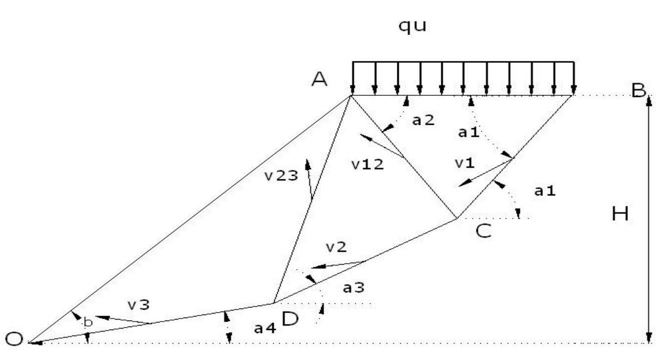

Fig. 1. Mechanism (without reinforcement)

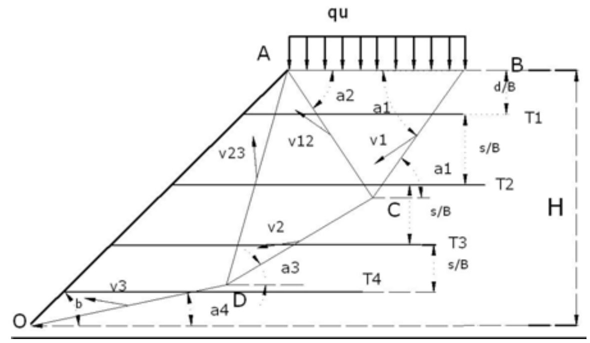

Fig. 2. Mechanism (with reinforcement)

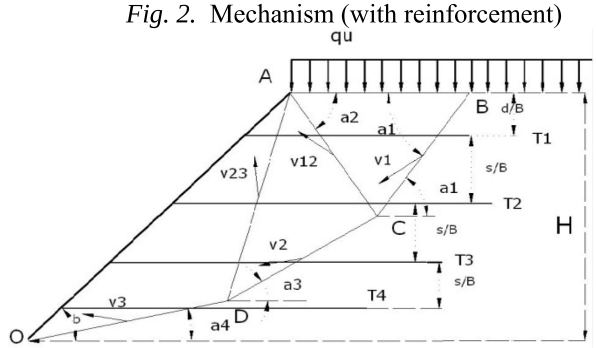

Fig. 3a. Mechanism when load is acting till infinity from the edge of the slope

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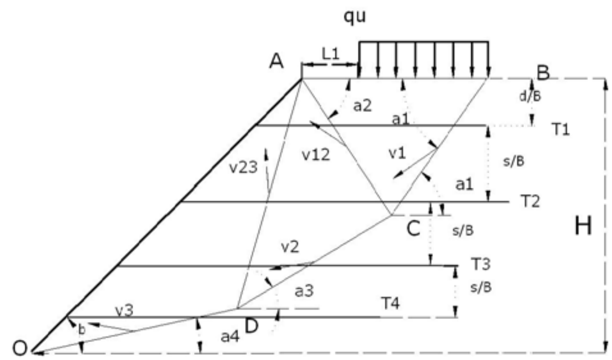

Fig. 3.b. Mechanism when load is acting from a fixed distance from the edge of the slope.

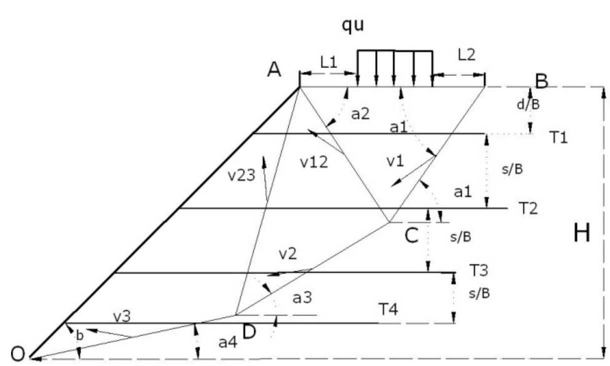

Fig. 3.c. Mechanism when load is acting at fixed distances from both the edges of mechanism wedge

EQUATIONS

The loose slope is modeled by the Mohr–Coulomb (M–C) plasticity model with a non-associated flow rule.

The upper-bound limit analysis for slopes can be described as: for a rigid plasticity soil slope, the rate of work done by external loads is equal to the energy dissipation rate in any kinematically admissible failure mechanism, and the relative slope height will be the upper-bound limit height.

Shear strength of soil is given as:
$\tau_f = c' + (\sigma - u)\tan\varphi'$
Factor of safety, $F = \frac{\tau_f}{\tau}$
External work done due to weight of each block is given as:
$Ex_{,i} = W_i * V_i * \sin\varphi''$

Internal work done due to weight of each block is given as:
$Ei_{,i} = L_i * V_i * \cos\varphi$

$Ei = \sum Ei,i$
$Ex = \sum Ex,i$

And due to reinforcement
Due to reinforcement:
$T = \frac{\mu * (c + (\sigma + \gamma * h)\tan\varphi) L_{reinfo}}{F}$
Here,
V_i is the velocity of the wedge, $_i$
W_i is the weight of the wedge$_{,i}$
φ'' is the angle that the velocity vector of the wedge makes with the gravity$_{,i}$
γ is unit weight of the soil
φ is the corresponding friction coefficient
σ is stress
μ is Poisson's Ratio
h is depth of the reinforcement
L_{reinfo} is length of the reinforcement in the contact with the soil
σ is calculated using first principle of integration.
σ is $\frac{q}{\pi}$ (α+(sinα)*cos(2*β))
α is the angle that envelope to strip load make at the point
β is the angle with the vertical line connecting midpoint of the strip load and the point on which load is to be calculated.

Assessment of permanent displacement

The calculations carried out using the pseudo-static approach indicate that both force and length of the reinforcement increase considerably with an increase in the seismic force. Consequently, for large values of the seismic coefficient, the design of a reinforced soil structure could prove very expensive or even impracticable. In these circumstances, it is more reasonable to reduce the amount of the reinforcement and consequently accept that the structure is affected by permanent displacements during earthquakes. Due to the transient nature of ground motion, the slope could in fact experience only a finite displacement rather than a complete failure.

The calculations for permanent displacement are usually conducted using the sliding block. According to this method, the potential failure soil mass is treated as a rigid block on an inclined plane, which moves in the downhill direction whenever ground acceleration exceeds yield acceleration of the slope. Given a design accelerogram, the earthquake-induced displacement can be obtained by integrating twice the equation of motion,

Results and discussion

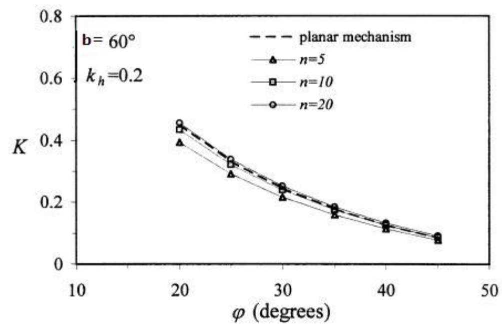

Fig. 4.a. Effect of n on K

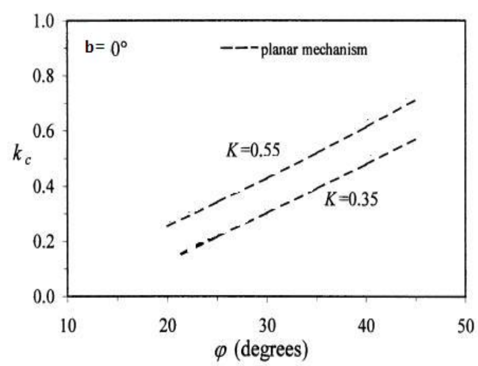

Fig. 4.b. Critical acceleration factor versus ø at different seismic coefficients

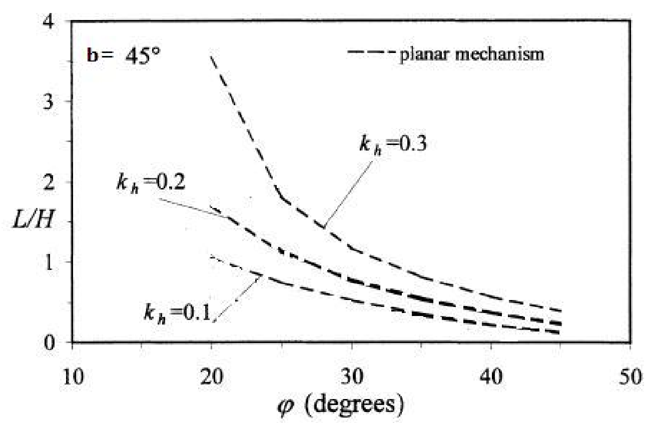

Fig. 4.b. L/H versus ø at different seismic coefficients

It is quite expected that the soil properties such as damping, elastic and shear modulus do not remain constant throughout the depth of the soil layer rather they go on changing from the surface to the greater However, the influence of the distribution of those soil properties is not explored in this paper. As the waves approach the ground surface, the vibration in the cohesionless soil also gets amplified. The nature of amplification depends on many factors such as stiffness and damping of the soil mass, the depth of soil layer, geometry and rigidity of adjacent structures.

By considering the pseudo-dynamic approach, the effect of soil friction angle, embedment ratio, horizontal and vertical seismic accelerations on reinforced slope was examined. The analysis was carried out by using the upper bound limit analysis. The values obtained from the present analysis were compared with the available results reported by pseudo-static method of analysis. In presence of horizontal and vertical earthquake acceleration, the present values were found to be the highest.

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