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PSEUDOSTATIC SLOPE STABILITY ANALYSIS

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ABSTRACT

Earth embankments are required for railways, roadways, earth dams, leeves and river training works. Stability of these embankments or slopes needs to be thoroughly analysed. Their failure occurs in every conceivable manner, slowly or suddenly and with or without any apparent provocation leading to loss of life as well as colossal economic loss. Failure of slope takes place due to action of gravitational forces and seepage forces within the soil. In this paper, it has been proposed to analyze stability of slope considering static and dynamic forces. However to reduce the complexity in dynamic analysis, seismic forces are converted into their equivalent static forces called as Pseudo static forces. Hence the analysis is called Pseudo static slope stability analysis. An attempt is made to study behavior of slope considering various parametric and material property variations for static as well as Pseudo static forces. A computer program was developed to validate manual calculations and facilitate calculation work. Variation of Factor of safety with respect to static forces and pseudo static forces has been studied considering various parameters. Conclusion has been drawn based on results obtained

KEYWORDS: stability analysis,pseudo static forces, parametric study,failure of slopes.

I. INTRODUCTION

Slopes are inclined, unsupported surface of soil mass.When a mass of soil located beneath a slope fails,it is termed as a 'slide'.Slope failure involves a downward and outward movement of soil so that the soil mass comes to a level surface. Slopes generally fail due to a) action of gravitational forces and b) action of seepage forces within soil mass. Slopes failures having impressionable magnitudes result in loss of life and property.Therefore study and analysis of slope failures is being carried out everywhere today.Slope stability analysis includes determination of most severly stressed internal surface, magnitude of shearing stress to which it is subjected and role of shear strength along the failure surface. Shearing stresses depend on unit weight of soil,geometry of slope,surcharge loads and seepage pressure.Shearing strength depends on character of soil,density of soil,drainage conditions and nature of loading(static or cyclic).

Beginning in the 1920's,the seismic stability of earth structures has been analysed by a pseudostatic approach in which the effects of an earthquake are represented by constant horizontal and vertical accelerations.The first explicit application of the pseudostatic approach to the analysis of seismic slope stability has been attributed to Terzaghi(1950).

II. STABILITY ANALYSIS

A. STABILITY OF FINITE SLOPES

In present study, it is considered that slope is made up of homogenous and isotropic soil having cohesive(c) and frictional (φ) properties.It is a finite slope and fails along a surface which is circular (Peterson 1916) in geometry.Field investigations by Swedish Geotechnical Commission justifies circular arc as close approximation of actual slip surface.Slope is said to bestable if its factor of safety (FOS) is unity.

B. METHOD OF ANALYSIS

The stability of finite slopes can be investigated by a number of methods as follows.

1. The Swedish slip circle method.
2. Friction circle method.
3. Bishop's simplified Method.

In present study, Swedish slip Circle Method is used for static and pseudostatic analysis. An effort is made to represent FOS considering variation in slope parameters which are slope angle (i =25º - 35º), frictional angle (φ =15º-35º), cohesion (c=5kPa-20kPa), unit weight of soil (γ=15 kPa -25 kPa) and height (H=5m - 20m) of slope. FOS is calculated for static and pseudo static condition using equation (1) and (2) as below

$$\text{FOS} = \frac{\text{resisting moment (MR)}}{\text{static driving moment (MD)}} \qquad (1)$$

$$\text{FOS} = \frac{\text{resisting moment (MR)}}{\text{static + pseudo static driving moment}} \qquad (2)$$

C. VALIDATION OF ANALYSIS

A computer programme in C-language was developed to validate results obtained during manual calculations. The results obtained from programme are presented in form of charts.Conclusions are drwan based on these results.

III. PSEUDO STATIC ANALYSIS

A. PSEUDOSTATIC FORCES AND ITS EFFECT ON STABILITY

Pseudostatic analysis represents the effect of earthquake shaking by pseudostatic accelerations that produce inertial forces.Fh and Fv acting through centroid of failure mass is shown in the following diagram.

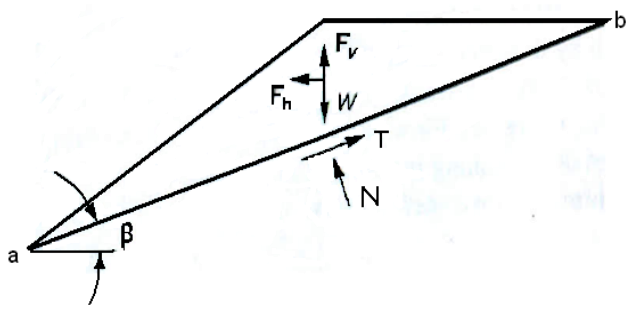

Fig.1 Forces acting on triangular wedge of soil above planar failure surface in pseudostatic slope stability analysis.

The magnitudes of the pseudostatic forces are:

$$Fh = \frac{a_h.W}{g} = k_h.W \qquad (3)$$

$$Fv = \frac{a_v.W}{g} = k_v.W \qquad (4)$$

Where ah and av; are horizontal and vertical pseudostatic accelerations. kh and kv; are dimensionless horizontal and vertical pseudostatic coefficients and W is the weight of the failure mass. The magnitudes of the pseudostatic accelerations should be related to the severity of the anticipated ground motion.Selection of pseudostatic accelerations for design is not a simple matter. Resolving the forces on the potential failure mass in a direction parallel to the failure surface,

$$FOS = \frac{\text{resisting moment (MR)}}{\text{static + pseudo static driving moment}}$$

$$= \frac{c.L + [(W-Fv)\cos\beta - Fh\sin\beta]\tan\varphi}{(W-Fv)\sin\beta + Fh\cos\beta} \qquad (5)$$

Where c and φ are the Mohr-Coulomb strength parameters that describe the shear strength on the failure plane and L is the length of the failure plane. The horizontal pseudostatic force clearly decreases the factor of safety. It reduces the resisting force (for φ > 0) and increases the driving force. The vertical pseudostatic force typically has less influence on the factor of safety since it reduces (or increases, depending on its direction) both the driving force and the resisting force.As a result, the effects of vertical accelerations are frequently neglected in pseudostatic analyses. The pseudostatic approach can be used to evaluate pseudostatic factors of safety for planar, circular, and noncircular failure surfaces. Many commercially available computer programs for limit equilibrium slope stability analysis have the option of performing pseudo static analyses.

B. SELECTION OF PSEUDOSTATIC COEFFICIENT

The results of pseudostatic analyses are critically dependent on the value of the seismic coefficient k_h .Selection of an appropriate pseudo static coefficient is the most important, and most difficult, aspect of a pseudo static stability analysis.

The seismic coefficient controls the pseudo static force on the failure mass, so its value should be related to some measure of the amplitude of the inertial force induced in the potentially unstable material. If the slope material was rigid, the inertial force induced on a potential slide would be equal to the product of the actual horizontal acceleration and the mass of the unstable material. This inertial force would reach its maximum value when the horizontal acceleration reached its maximum value In recognition of the fact that actual slopes are not rigid and that the peak acceleration exists for only a very short time, the pseudo static coefficients used in practice generally correspond to acceleration values well below amax. Terzaghi (1950) originally suggested the use of k_h = 0.1 for "severe" earthquakes (Rossi-Forel IX), k_h = 0.2 for "violent, destructive" earthquakes (Rossi-Forel X), and k_h = 0.5 for "catastrophic" earthquakes.

Seed (1979) listed pseudostatic design criteria for 14 dams in 10 seismically active countries; 12 required minimum factors of safety of 1.0 to 1.5 with pseudostatic coefficients of 0.10 to 0.12. Marcuson (1981) suggested that appropriate pseudostatic coefficients for darns should correspond to one-third to one-half of the maximum acceleration, including amplification or deamplification effects, to which the dam is subjected. Using shear beam models, Seed and Martin (1966) and Dakoulas and Gazetas (1986) showed that the inertial force on a potentially unstable slope in an earth dam depends on the response of the dam and that the average seismic coefficient for a deep failure surface is substantially smaller than that of a failure surface that does not extend far below the crest. Seed (1979) also indicated that deformations of earth dams constructed of ductile soils (defined as those that do not generate high pore pressures or show more than 15% strength loss upon cyclic loading) with crest accelerations less than 0.75g would be acceptably small for pseudostatic FOS of atleast 1.15 with kh = 0.10 (M = 6.5) to kh = 0.15 (M = 8.25). These criteria would allow the use of pseudostatic accelerations as small as 13 to 20% of the peak crest acceleration. Hynes-Griffin and Franklin (1984) applied the Newmark sliding block analysis described that earth dams with pseudostatic FOS greater than 1.0 using kh = 0.5amax/g would not develop "dangerously large" deformations.

As the preceding discussion indicates, there are no hard and fast rules for selection of a pseudostatic coefficient for design. It seems clear, however, that the pseudostatic coefficient should be based on the actual anticipated level of acceleration in the failure mass (including any amplification or deamplification effects) and that it should correspond to some fraction of the anticipated peak acceleration. Although engineering judgment is required for all cases, the criteria of Hynes-Griffin and Franklin (1984) should be appropriate for most slopes.

C. LIMITATIONS OF THE PSEUDOSTATIC APPROACH:

Representation of the complex, transient, dynamic effects of earthquake shaking by a single constant unidirectional pseudo static acceleration is obviously quite crude. Even in its infancy, the limitations of the pseudostatic approach were clearly recognized. Terzaghi (1950) stated that "the concept it conveys of earthquake effects on slopes is very inaccurate, to say the least," and that a slope could be unstable even if the computed pseudostatic factor of safety was greater than 1. Detailed analyses of historical and recent earthquake-induced landslides (e.g Seed et al. 1969, 1975: Marcuson et al., 1979) have illustrated significant shortcomings of the pseudostatic approach. Experience has clearly shown that pseudostatic analyses can be unreliable for soils that build up large pore pressures or show more than about 15% degradation of strength due to earthquake shaking as illustrated in Table given below:

TABLE I: Results of Pseudostatic Analyses of Earth Dams That Failed during Earthquakes

DAM	kh	FOS
Sheffield Dam	0.10	1.2
Lower San Fernando Dam	0.15	1.3
Upper San Fernando Dam	0.15	-2 to 2.5
Tailings dam (Japan)	0.20	-1.3

Source: After Seed (1979).

Pseudostatic analyses produces FOS well above 1 for a number of dams that later failed during earthquakes. These cases illustrate the inability of the pseudostatic method to reliably evaluate the stability of slopes susceptible to weakening instability. Nevertheless, the pseudostatic approach can provide at least a crude index of relative, if not absolute, stability.

IV.RESULTS AND CONCLUSION

Using equations (1), (2), (3), (4) and (5); FOS were calculated for different parameters mentioned below and charts were prepared to interprete the results.

A.VARIATION IN FRICTION ANGLE(φ)

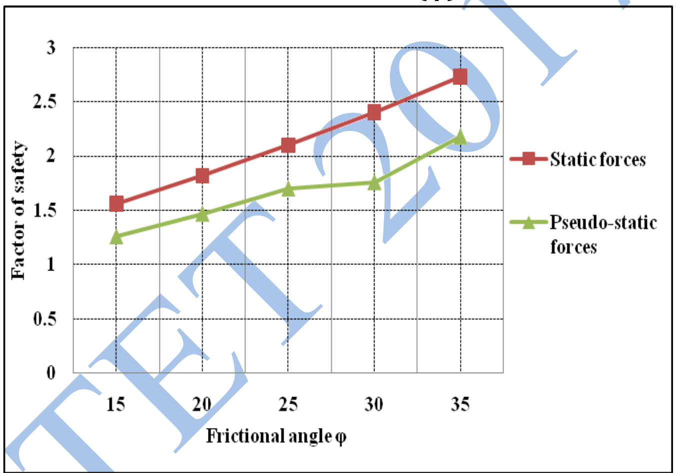

Fig.2 Variation of factor of safety (FOS) with respect to Frictional angle (φ)

From fig.2, it can be concluded that FOS increases with friction angle.FOS decreases when pseudo static forces are considered.The percentage difference is around 25% which is almost constant for all values of frictional angle.

B.VARIATION IN SLOPE ANGLE(i)

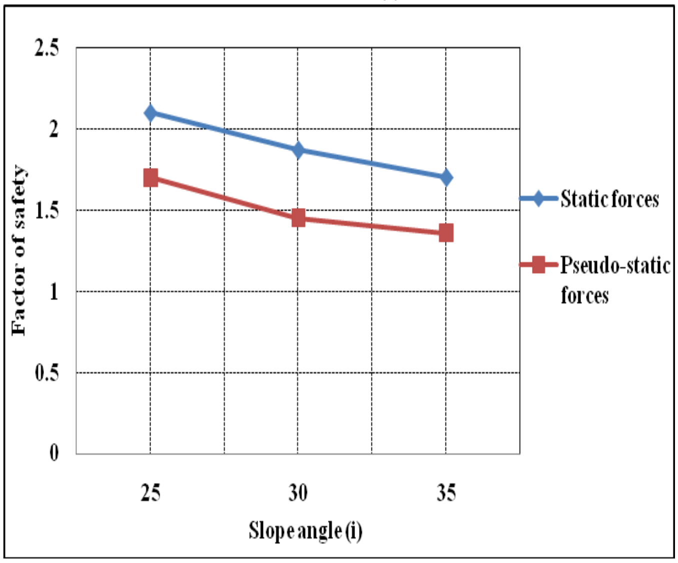

Fig.3 Variation of factor of safety (FOS) with respect to slope angle (i)

From fig.3, it can be concluded that FOS decreases with increase in slope angle. FOS reduces by 20% when pseudo static forces are considered yet the percentage difference is constant which about 20%.

C.VARIATION IN HEIGHT OF SLOPE(H)

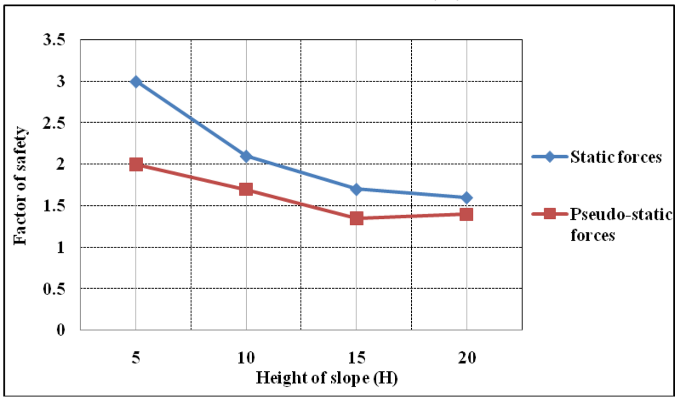

Fig.4 Variation of factor of safety (FOS) with respect to height of slope (H)

From fig.4, it can be concluded that FOS decreases with increase in height of slope but rate of decrease of FOS is higher in static condition as compared to pseudo static condition.Difference in FOS for static and pseudostatic case is more for small height.As the height increases percentage difference in FOS decreases.

D. VARIATION IN UNIT WEIGHT OF SOIL (γ)

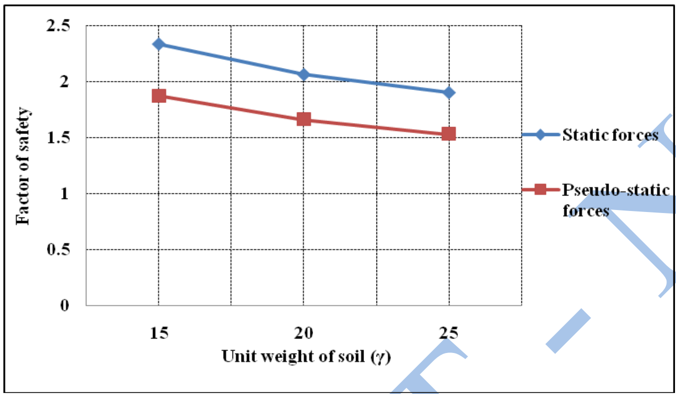

Fig.5 Variation of factor of safety with respect to unit Weight of soil (γ)

From fig. 5, it can be concluded that FOS decreases with increase in unit weight of soil.The percentage difference in FOS is in the range of 20%-25% when pseudo static forces are considered.

E.VARIATION IN COHESION(c)

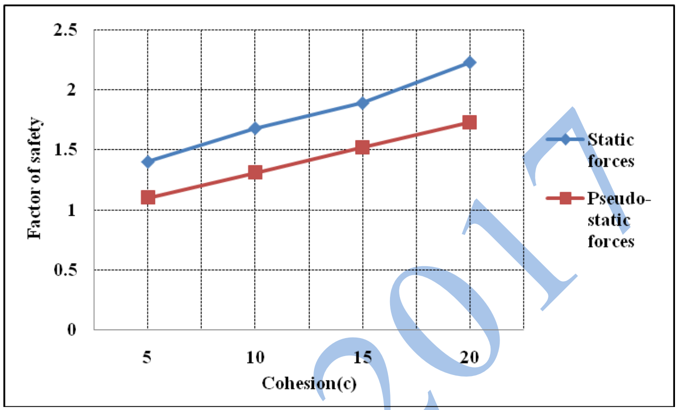

Fig.6 Variation of factor of safety (FOS) with respect to cohesion (c)

From fig.6, it can be concluded that FOS increases with cohesion .Again the percentage difference in FOS is about (20-25) %.

V. FUTURE SCOPE

Future study can be done by considering interslice forces and using analysis methods which also account for pore pressure generation for different types of soil.

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