The Effect of the Depth Factor on Stability of the Straight Slopes

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ABSTRACT

Based on the study, the analysis method and stability of the slope is investigated based on the combination of the finite element method and the lower bound theory, and under three-dimensional situations and modeled finite element method and the situation of the lower bound including equilibrium equations, tensions' separation conditions, bound situations and surrendering condition are introduced as problem adverbs, and the tension field is searched to obtain the most lower bound of the safety coefficient, the most reduced slope angle, the effect of the depth factor is more in the strength of the slope. The result is in the form of a set of vague dimensional diagrams that could be used in engineering applications.

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INTRODUCTION

The main problems of the soil mechanics are investigated in differentiated situations because of the way of development of solid materials physics and also their simple application, and thus are divided to two separated groups including strength (in final bound mode) and the variations of the shapes (exploitation). In problems of the strength, the soil condition is analyzed in the moment of separation that includes defining the removing force of the supporting walls, load capability of the bases and investigation of gables. In these problems of the soil behavior is considered as rigid-plastic, and the evaluation of the varying shapes is not considered. The analysis methods based on this assumption of soil behavior are considered as bound methods that are introduced based on 2 upper and lower bound methods. In second group, the tensions' situation and variation of the soil mass are defined in exploitation situations. Defining the reducing the bases is one the most important problems of this group. The use of the bound methods to analyzing the strength of the gables is too common. In these methods, first an assumed separation mechanism is considered, and its analogous coefficients are calculated, then by the error and trial method the mot weak friction surface with the minimum coefficient is obtained.

The unstable soil gables and the earthquakes are the disasters that follow with many problems in different countries. So, the evaluation of the coefficient of the gables is always considered by researchers.

The above problems are not so accurate because of three-dimensional analyses and the lack of suitable software, and often are done as two-dimensional analysis.

Defining the limits of separation load:

The bound analysis method is one of the most suitable methods to analyze the unstable bound modes and solving the limits of separation load. Usually, if all the equilibrium equations, behavioral equations and ... are satisfied at the same time, the uniqueness of the answer can be certified. In the bound analysis, the behavioral analysis is considered in an ideal shape. This idealization is the base of the bound hypothesis. These hypotheses make it possible to define the upper and lower bounds of the separation.

The assumptions used in the analysis part are:

A - Materials behavior mode, so the dough is complete materials.

B - Limit state equation $F'(\sigma_y) = 0$ called with a convex function of the yield function (Yield Function).

C - Plastic behavior of materials is function associated flow rule. In other words:
\[
\dot{\epsilon}_{ij}^p = \dot{\lambda} \frac{\partial F(\sigma_{ij})}{\partial \sigma_{ij}} \quad \dot{\lambda} \geq 0
\]  

(1)

In the above relationship, \(\dot{\epsilon}_{ij}^p\) tensor is the relative deformation rate and \(\sigma_{ij}\) is the stress tensor and \(\dot{\lambda}\) is the scalar function and plasticity and non-negative.

Based on the lower bound theorem, under the assumed stress field which satisfies the necessary conditions, the release dough flow would not have occurred. In other words, the external load analogous to stress field shall not exceed the actual failure load. The lower bound method, strain rate of compatibility equations (kinematic condition) is not considered.

On the other hand, in upper case, issues regarding the kinematic conditions are resolved. In this case, considering a hypothetical velocity field and put into the development of domestic and foreign forces, the failure load is calculated.

By selecting the appropriate field and stress responses of two ways to approach the speed, the range of the actual failure load is placed on it, be smaller.

In the issues that the answer is the same for both methods, the real answer is obtained. Thus, this method is determined by the position of the answer to the real answer that is a clear supernumerary or defects approximate. The main advantage of the method is somewhat the same thing.

For example, the Figure 1 the state in which the external load has two components, Q1 and Q2 are independent, is shown. If so actual loads locus pairs in the coordinate space, Q2, Q1 Curve A will be a lower boundary point for each answer obtained in the method or on the curve. Thus, to obtain a set of closest points to curves A, impairment approximate curve is obtained.

![Fig. 1: approximation of limit loads locus pair (Q2 and Q1) at the lower boundary method.](image1)

![Fig. 2: approximation of limit loads locus pair (Q2 and Q1) in the upper approach](image2)

Other hand, the method is considered upper borderline as No. 2 in the solutions obtained are outside of the curve and get A set of these points, curves A are made the extra approximation. Although the theory of limit analysis method is very simple and useful for analyzing geotechnical formations, this analysis resulted in a three-dimensional theoretical issues rarely has been analyzed, and more 3 dimensional researches that used the theory of analysis are based on upper bound method.
Of such research, we can mention Chen et al. (2003, 2001), Doland (1997), F. and Askari (2003), Debuhan (1998), Michalowski (2002, 1989) and Viratjondr (2006). Due to the problems manually is acceptable to create a stress field, limit analysis method in most previous research had focused on using the upper limit of that. In spite of that the answer can be a great guess of problems; however, bottom line is used because of the confidence in the use of administrative issues.

Based on the lower bound solution satisfying the boundary conditions and is subject to the stress discontinuities and also equilibrium equations and the yield condition and all of these models are applied as a set of constraints on stress points. This method was first solved by Lyamin and Sloan (2012) presented in 2011 by Tootoonchi and Askari (Wei, W.B., et al., 2009) were developed.

In 2002, Lyamin and Sloan began to provide a new method of applying the lower bound and finite element theory. The theoretical lower bound limit analysis is based on the acceptable stress fields. According to the researchers’ methods for each of the stress field, it can be found a lower bound that the best of them is the highest. In order to obtain the best lower bound method for three-dimensional models by the nonlinear programming is optimized. In a study using linear finite element method and non-linear optimization is considered to obtain the maximum value of the lower bound of acceptable stress field by taking the yield criterion. To create an acceptable stress field of linear finite element program combination will be used which the above mentioned conditions are applied as a constraint on the elements. In 2011, Tootoonchi and Askari by applying the solution of Lyamin and Sloan to resolve the shortcomings in promotion optimization, and presenting a new mesh were able to investigate the three-dimensional flat and curved gables. (Wei, W.B., et al., 2009)

Application of basic concepts in the restrict analysis:

Balance equations, behavioral and adjustment solution in elastoplastic materials including steps to begin loading (elastic behavior), creating the plastic zones enclosed in elastic regions and creating the plastic flow was free and often to find some stability issues with the three stages is very difficult to the three mentioned stages. Therefore, in addition to the complete solution of boundary value problems in mechanics of solids will need to solve simultaneous equations, approximation methods are needed to be available for estimating limit loads on these issues.

Yield criterion in the bound analysis:

Chart of the stress - relative deformation of soil in a uniaxial loading is often like Figure 4 (Farzaneh, O., and F. Askari, 1994). It is observed that soil materials usually after achieving the maximum strength (Peak) have softening behavior and their resistance reduces to the extent that the residual resistance (Residual) is known.

In bound analysis the softening part of this curve is ignored, and the bound resistance of the soil between the maximum resistance value and the cysts will be considered (Chart Chinese line in Figure 4).

**Fig. 4**: Schematic diagram of stress - relative deformation of soil in a uniaxial loading (Farzaneh, O., and F. Askari, 1994)

Plastic flow rule limiting analysis (Flow Rule):

The material that their behavior is considered in extreme cases as complete plastic, the plasticity deformation after reaching the stress state can be followed indefinitely to the yield surface. And thus regarding
not considered the time-dependent properties (such as viscosity), the absolute amounts of these materials and the plastic strain rate plastic deformation can be determined by the relative amount of cheating.

Experimental observations indicate that the main objects of the same strain rate tensor and the stress tensor are superimposed on each other dough. Consequently axes used in the stress space, the yield surface is used for display can be used to represent the speed of the plastic strain.

**Convexity of the yield surface and the normality:**

The acceptance of the principle of maximum plastic work, convexity of the yield surface and perpendicular implied to the velocity vector relative plastic deformation on the yield. The latter result is known as the principle of normality.

**Fig. 5:** The convexity of the yield surface and the normality

One of the results if the normality principle, the zero is the result of \( \sigma_{ij} \varepsilon_{ij}^p \) in time of deformations. This result is obtained due to the tangent vector of the vector perpendicular to the surface and the yield surface.

**Associated flow rule:**

Vector \( \varepsilon_{ij}^p \) perpendicular to the surface of normality to surrender or principle can be stated as follows:

\[
\varepsilon_{ij}^p = \lambda \frac{\partial f}{\partial \sigma_{ij}} \]

The correlation coefficient \( \lambda \) is a positive scalar factor of proportionality. The relationship is known to depend on the law.

By definition, the relative plastic deformation on the surface of all the vectors are perpendicular to the surface potential is called plasticity. Thus, if the flow is dependent manner, the yield surface and plastic potential are superimposed on each other. If do not have the compliance levels, the flow rule is as follows:

\[
\varepsilon_{ij}^p = \lambda \frac{\partial g}{\partial \sigma_{ij}} \]

The relationship is called the law of non-dependent stream.

**Stress and velocity fields acceptable:**

As previously stated, finding the exact answer boundary value problems requires the simultaneous solution of the balance equations, behavioral equations and equations is consistent. In most cases, this process is very difficult, but it can be answered using a static stress field acceptable or unacceptable estimated a kinematic velocity field.

Acceptable static stress field stress is a field that equilibrium equations and boundary conditions satisfy investigated environment and tension and the stress state at any point does not exceed the yield surface. Velocity field is acceptable for kinematic compatibility equations and boundary conditions to satisfy rapidly (Farzaneh, O., and F. Askari, 1994).

In general, the above mentioned fields in static or kinematic boundary value problems are infinite. Its uniqueness is achieved correctly when the relationship between stress and velocity fields is based on behavioral equations. The answer is often very difficult to find. In some analysis, using static fields and limit theorems acceptable limits shall be determined by answering the question.
The principle of virtual power:

The method of limit analysis, limit theorems are proven using the principle of virtual power. This principle can be stated using the following equation (Farzaneh, O., and F. Askari, 1994).

\[ \int_A T_i u_i dA + \int_V F_i u_i dV = \int_V \sigma_{ij} \varepsilon_{ij} dV \]

where \( T_i \) and \( V_i \) are the study area and circumference surface and volume forces acting on it. \( \sigma_{ij} \) is Stress tensor that is in balance with \( T_i \) and \( V_i \) are the volume and surface forces. In other words, the elements of a static stress field are accepted.

On the other hand, in the above equation represents the rate of deformation and deformation rate, tensor is relatively consistent with that. Thus, the elements of a kinematic velocity field are acceptable. If parts of the boundary are, respectively, the boundary conditions of stress and deformation in the area, specified in part are zero. It can be assumed that the effect of surface forces on the section is equal. Hypothetical distribution of surface forces and is a constant scalar. Thus, the above equation becomes as follows:

\[ \mu \int_A T_i^0 u_i dA + \int_V F_i u_i dV = \int_V \sigma_{ij} \varepsilon_{ij}^0 dV \]

It should be noted that the above stress and velocity fields are independent of each other and cannot have any relationship with each other. Moreover, each of these two fields and the actual field survey may be permitted. If the relationship is the principle of virtual power.

If the behavior of rigid materials - plasticity is considered, the elastic part of the strain rate is zero and the above equation becomes as follows:

\[ \mu \int_A T_i^0 u_i dA + \int_V F_i u_i dV = \int_V \sigma_{ij} \varepsilon_{ij}^0 dV \]

Upper case law in the interests of the independent:

If the material or the associated flow rule normality does not hold, proving theorems is somewhat difficult. In other words, the boundaries of these loads, so materials cannot be achieved using some cases. However, the following theorem can be used to determine the upper limit loads of materials which are not established in their associated flow rule were used:

Theorem: Two types of materials with the same yield criterion are considered. If the flows rule material-dependent type I and type II materials are as unrelated, the first time the extent material, the upper time limit will be two types of materials.

In this case resulted when the type of material the stress field during failure of a static stress field is acceptable because the same yield criterion in both materials, the static stress field of the first kind of materials would be acceptable. Due to the lower bound theorem, this agreement or under external load corresponding to the load limits on the type of material first. In other words, once enough material type, material type, the upper time limit will be assumed to depend on materials establishing the rule of law do not follow the upper limit time gives.

Comparison of Three-Dimensional Analysis:

In Figure (6 a) Three-dimensional analyzes of Ugai (1985), Leshinsk (Gens, A., et al., 1988) or, Farzaneh and Askari (2003) respectively in 1985, 1986 and 2003 are presented in the present analysis are compared. As can be seen the results are satisfactory FELAB program. The results of the analysis are obtained using models with 72 elements. Comparing Bishop Techniques and methods, we can see that the lower \( L / H \) despite lower boundary responses in the present method, the results over the next Bishop responses are presented in two ways. Figure (6 b) Comparison between the results is given.
Fig. 6(a): Comparison of two-dimensional to three-dimensional reliability analysis Yoga, Leshinsky, F - Askari (as above) the present research, (b). Comparing the results of the present method and the method of Bishop (Tootoonchi 2012)

Stability of slopes, flat bed with increasing depth:

One of the graphs presented so far has not been considered by this study to evaluate the effect of bed depth factor (D) is the stability of slopes. Figure 5-23 and 5-24, respectively, and the modeling of this type of model examples show that sort of thing.

Fig. 5-23: Stability of slopes under the influence of bed depth factor
As was noted in the preceding sections of this chapter, in the absence of external loads, the reliability of the two-dimensional, three-dimensional is larger than the width of the reduction mechanism is added to the index. Also, for a specified amount of reduction increases. Thus, the slope stability analysis, three-dimensional effects in granular soils, cohesive soils are much more important. This is due to the reduction of the depth of the sliding surface adhesion is reduced. Figure 5-25 - A demonstrates this.

**Fig. 5-24: Models of deep seabed slope influence factor**

**Fig. 5-25-a: Effect of bed depth on the estimated factor Ns (3D) \ Ns (2D)**

**Fig. 5-25 – b: A comparison between the upper and lower bound results in order to evaluate the effect of bed depth**
Fig. 5-25-b: a comparison between the results of our method in static mode (lower bound) and the results Askari (upper bound) is shown. Modeling that has been done in this area, bistro area by the German depth the Cutting (Chapter III) have been extended.

Fig. 5-26: POSITION Cutting elements on flat slopes, factors influencing bed depth

In the diagram of Figure (6-24 to 6-26) Effect of bed depth factor in the stability of three-dimensional flat slopes in static conditions (Kh = 0) has been studied. The safety factor of three-dimensional graphs with the
changes in the lower bound L / H and inclination angle are presented. Figure (27 - b) is seen to be much less steep angle, impact factor is higher bed depth on slope stability. Similarly, Figure (28 - a) can be seen that with increasing L / H, as expected, the safety factor is reduced.

**Conclusion:**
1. How much inclination angle is less, the effect of bed depth factor in slope stability is higher.
2. With increasing L / H, as expected, the safety factor is reduced.
3. It seems that for values of 1 < D / H stays and higher safety factor, this parameter does not affect the stability problem.
4. The amount of \( F_{10} \), the reduction and slope angle decreases, increases. One of the disadvantages is presented in the graph are just for \( \lambda = 2 \) are provided. It is recommended to complete the diagram of \( \lambda \) also be used for other values.
5. If moves towards infinity, to a certain value, the minimum value seems to increase stability and reduce the number of. This represents a reduction factor of safety is increased.

**REFERENCES**


