Cost/Benefit Analysis in Slope Stability Design

Analyse Coût/Gain dans l'Etude de la Stabilité des Pentes

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SYNOPSIS The decision as to whether a slope should be classified as a potential slide area or not is often based on a calculated factor of safety. If the reliability of the factor of safety is low, a high number for the factor of safety is required.

When large areas are to be investigated it is necessary to make a critical assessment of the way the resources should be used in order to optimize the result.

In this article an attempt is made to define five different levels for slope stability analysis. If such a scheme is used in slope stability engineering together with empirical knowledge of the soil conditions in the area and a flexible computer program it is the authors' opinion that the money spent on investigations will be much more efficiently used than in a traditional slope stability analysis.

INTRODUCTION

Stability calculations are made within a large number of disciplines on the basis of most varying basic knowledge. The results of the calculations, often a number for the factor of safety, are to be the basis for the decision of a suitable design or change in the proposed or existing design. A traditional decision process is often followed, and very rarely is a critical assessment made of how the available resources should be used in order to optimize the result. This fact is believed to be true especially in slope stability engineering.

FACTOR OF SAFETY

The factor of safety commonly used in slope stability engineering is no unique number. It depends to a high degree, among other things, on the choice of shear strength parameters and pore pressure distribution and on the numerical method used. Therefore, the variation of the value of the factor of safety can be expected to be fairly large.

WORKING SCHEME FOR SLOPE STABILITY ANALYSIS

No doubt, the soil engineer makes sound judgements all along in his daily work, judgements where benefits from different methods are compared with the cost. In slope stability engineering there are a number of different methods available, from very crude to highly sophisticated ones.

Below is an attempt to define five different levels of slope stability analysis, each level used at a different stage in the analysis.

1. a) Mapping of large areas using geological soil maps, marking areas with clay deposits where the inclination of the surface is larger than an established percentage, e.g. 2 or 5%.
   b) Mapping and classification of landslide conditions using aerial photography (Viberg, 1979).
2. Simplified calculations using slope stability charts (Janbu, 1954)
3. Calculations based on available data for the soil in the neighbourhood or on data from general investigations.
4. Calculations based on a detailed site investigation.
5. A research-oriented analysis, making use of elaborate laboratory tests.

Generally, it is true that the more we know about the soil conditions at the site, the higher the reliability of the factor of safety, and thus the lower a factor of safety can be justified, or the less we know about the soil, the more conservative should our choice of shear strength parameters be. This is schematically illustrated in Fig. 1 where the increase in reliability in the factor of safety is given as a function of increasing cost of investigation.

FUTURE POSSIBLE IMPROVEMENTS

New numerical methods for slope stability analysis will probably be developed in the future. However, the analysis can be greatly improved, or give satisfying results to a much lesser cost without further numerical sophistication, if:

A. empirical knowledge about soil parameters are more systematically investigated and used in the surveyed analysis;

B. data of pore pressure variation with time (time of year, wet year or dry year, etc.) is analysed for different type of geological terrain;

C. flexible computer programs for classical slope stability methods are developed and used.

A. Empirical knowledge about soil parameters

A soil engineer naturally uses, his experience and general knowledge of the soil conditions in the area at

hand. However, this should be done more systematically and the engineer should force himself to make safe and sound estimates of the shear strength parameters, drained as well as undrained, at an early stage of the investigation. If these data are used in simplified calculations good indications will be obtained of where in the area the stability is low, and thus where further site investigations should be concentrated. Other types of empirical knowledge that the local people, contractors and farmers have should also be collected and considered. Moreover, the local contractors should be informed about areas where the stability may be unsatisfactory.

B. Diagrams for pore pressure variation

Just as important as the strength parameters is knowledge of the pore pressure variation. Pore pressure measurements are usually only taken during a short period of time, and from these observations a dimensioning pore pressure must be chosen which may be very dificult as the pore pressure varies with the time of the year and from year to year, depending on total rainfall.

Long series of pore pressure observations should be collected, grouped and classified in such a manner that the engineer can from his short observation period be helped to choose the dimensioning pore pressure. Diagrams like the one presented in Fig. 2 (Svensson & Sällfors, 1980) should be worked out for different geological terrains and surrounding topography. Rules for classifying the rainfall data into wet, normal and dry years is also necessary. Diagrams like the one given in Fig. 2 may be hard to establish and may not be very accurate but will, undoubtedly, be of great help to many soil engineers.

C. Flexible computer program

Most slope stability calculations are very time consuming and, therefore, computer programs are quite frequently used, programs that, for a given set of data, calculate the factor of safety for the most dangerous slip surface. If some data are changed, the program usually must be run again.

At Chalmers University of Technology an extremely flexible program has been developed (Sällfors & Tägnfors, 1980) where data can be changed very easily, and where the analysis is done on a computer-aided design basis. The program has been found to be very useful indeed.

COST/BENEFIT ANALYSIS

A regular cost/benefit analysis is hard to apply to a slope stability problem as the benefit or increase in reliability of the factor of safety for a specific investment is hard to estimate.

As part of a research program at Chalmers University of Technology a few areas have been investigated according to the scheme described above over the course of the last year, and it is the authors' opinion that an analysis at level 3 (above) has great advantages and can be very useful if empirical knowledge of soil parameters and pore pressure variations are used in combination with a flexible computer program. This type of analysis, of course, does not replace the traditional analysis, but it sorts out areas with a factor of safety well above one, at a very low cost. Areas with factors of safety just above one are still a difficult problem, but the computer program makes it possible to calculate the factor of safety for a variety of data at a fairly low cost.

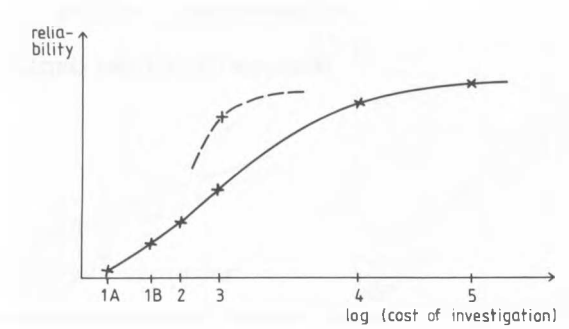

Fig. 1 Change in reliability of the factor of safety with increasing cost of investigation.

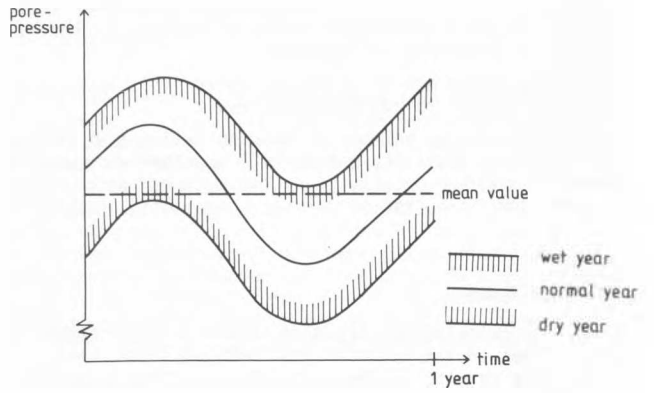

Fig. 2 Variation of pore-water pressure with time.

CONCLUSIONS

Traditional slope stability analysis is discussed and five different levels of analysis are defined. An attempt to make a cost/benefit analysis indicates that if empirical knowledge of soil parameters is combined with a minor site investigation and a flexible computer program is used, a very cheap and in many cases satisfactory analysis is obtained.

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