Slope Stability with Nonlinear Strength Failure Criterion

XIAORU DAI, BARBARA SCHNEIDER-MUNTAU, WOLFGANG FELLIN

Organisation(en):

Institute of Geotechnical Engineering, University of Innsbruck, Austria

Xiaoru.Dai@uibk.ac.at, Barbara.Schneider-Muntau@uibk.ac.at, Wolfgang.Fellin@uibk.ac.at

Abstract

Based on appropriate failure criteria for geotechnical materials, slope stability analyses are performed, which are of great significance to disaster research. The present work shows a comparison of linear and nonlinear failure criteria including the effect of tension cut-off. It demonstrates the necessity of considering the effects of tension cut-off and nonlinear shear strength, especially for soils with high cohesion. As a result, the use of nonlinear failure criterion in slope analyses is recommended for both limit equilibrium and finite element methods.

Introduction

As one of the classical geotechnical problems, slope stability attracts a lot of attention because of its high possibility of occurrence and difficult predictability. It is significant for disaster research due to possible hazards following a slope failure. There are several methods to perform slope stability analyses: analytical methods (such as limit equilibrium methods and limit analysis methods, including upper and lower bound analysis) and finite element methods (such as strength reduction methods). In geotechnical engineering, it's important to select an appropriate failure criterion to describe the strength of the soil. The linear Mohr-Coulomb failure criterion is a simple description of the relationship between normal stress and the maximum shear stress, and is widely used in geotechnical computations. However, it is proven by experiments that the shear strength of geotechnical materials can only be roughly approximated with a linear expression. Mohr-Coulomb can therefore be unconservative in certain cases especially when tensile stresses play an important role. Then a nonlinear strength failure envelope is to be preferred to the linear Mohr-Coulomb envelope.

Methods

Although the limit equilibrium method has been widely used in analyses of slope stability, e.g. Atkinson (2007), the idea of putting a nonlinear strength failure criterion into limit equilibrium method is rarely discussed, and a nonlinear failure criterion can't be employed in most software products. The limit equilibrium method with the simplified bishop method is one of the most often used limit equilibrium methods, which mostly employs the Mohr-Coulomb failure criterion. In this contribution, the simplified bishop method is used including a nonlinear strength failure criterion.

The three cases below are analyzed, as shown in Fig. 1:

- Linear shear strength:

  $\tau_f = c_0 + \sigma_n \tan\varphi$ (1)

- Linear envelope considering tension cut-off:

  $\tau_f = c_0 + \sigma_n \tan\varphi$

  and $\tau_f = 0$ if $\sigma_n \leq 0$

- Nonlinear shear strength:

$$\tau_f = \begin{cases} c + a(\sigma_n + d)^b, \sigma_n \leq \sigma_e \\ \sigma_n \tan\varphi_c, \sigma_n > \sigma_e \end{cases} \quad (2)$$

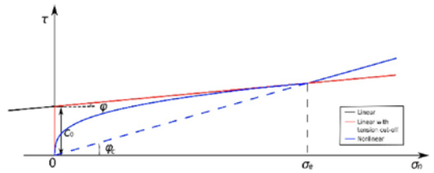

Figure 1: Three cases analyzed by limit equilibrium method

Results

The limit equilibrium method applied to the slope with H=10 m, β=75°, c_0=40 kPa, φ=5°, φ_c=15°, γ=20 kN/m³ in Fig. 2 computed, yields the results listed in Tab. 1, which shows a lower factor of safety η for Mohr-Coulomb when considering tension cut-off and for the nonlinear strength envelope.
The parameters for nonlinear envelope used are: a=10, b=0.33, c=0, d=0. This shear strength is plotted in Fig. 1.

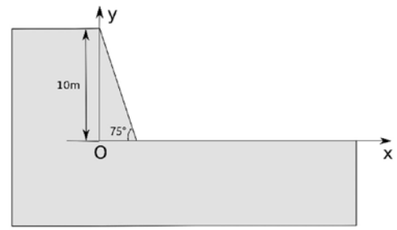

Figure 2: The geometry of the slope

Table 1: Comparison of calculation results by limit equilibrium method

Failure criteria	η
Linear envelope	1.019
Linear envelope considering tension cut-off	0.856
Nonlinear envelope	0.867

Conclusion

The results show that the effect of tension cut-off or nonlinear shear strength is relevant for soils with high cohesion. The investigated steep slope would be considered as stable with the simple linear Mohr-Coulomb criterion. Tension cut-off and nonlinear shear strength predict failure.

References

Atkinson, J. (2007): The mechanics of soils and foundations, CRC Press