ASEC 2025 Conference

The 6th International Electronic Conference on Applied Sciences

09–11 December 2025 | Online

A study on slope stability at earthquake limit state using the analytical and numerical methods

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INTRODUCTION & AIMS

INTRODUCTION

Phenomena of damaged ecosystems and environments have caught the widespread attention of scientists and engineers. Earthquake events are good examples, severely damaging slopes and houses. Figure 1 and 2 show the slope, relevant houses and trees and the damaged phenomena.

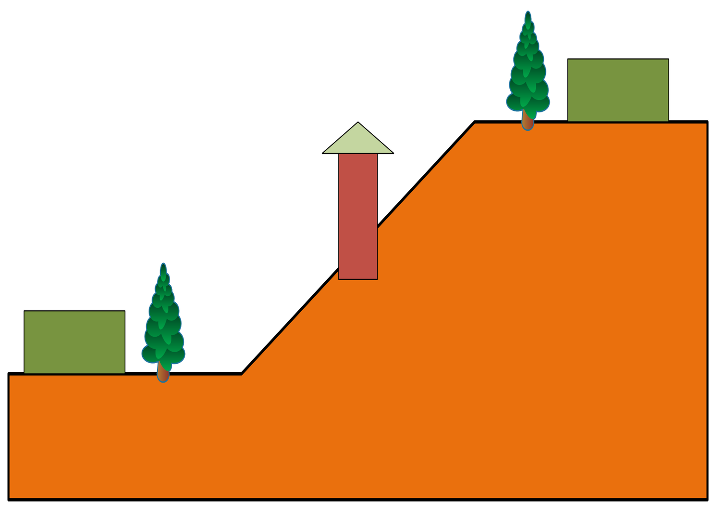

Figure 1. The slope and relevant houses and trees.

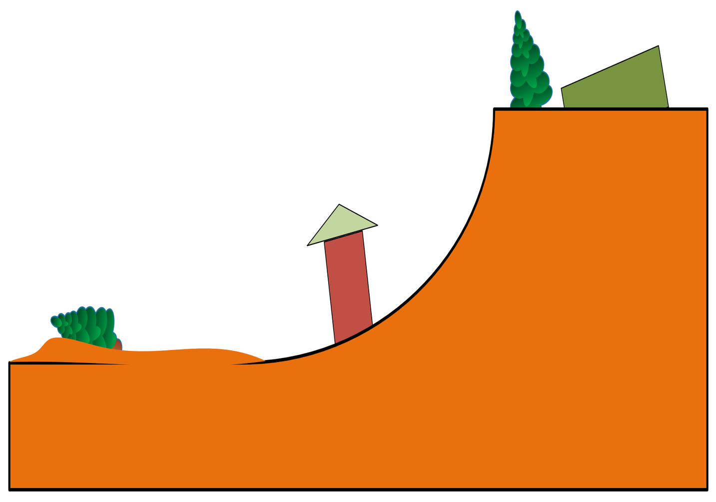

Figure 2. The damaged slope and relevant houses and trees after an earthquake event.

AIMS

A study is conducted on slope stability at earthquake limit state so that slopes and relevant houses can be safeguarded.

METHODS

The novel analytical and numerical methods are applied to the study on slope stability at earthquake limit state. The analytical method consults moment equilibrium equations of slopes and a limit equilibrium theory. The factor of safety of slopes through the analytical method is given by

$$k[G\sin\theta + F\cos\theta]=(G\cos\theta - F\sin\theta)\tan\phi + cL \quad (1)$$

where k means the factor of safety of slopes, G and F meaning separately the gravity and earthquake effect of a sliding body, and θ and ϕ mean separately the angle of the sliding surface and equivalent friction angle, c and L meaning separately the cohesion, and the length of the sliding surface.

The numerical method uses the coupled finite elements and strength reduction approach at the earthquake limit state. The virtual work principle can be expressed as follows

$$\int \sigma_{ij}\delta\varepsilon_{ij}dV = \int (G_i + F_i)\delta u_i dV \quad (2)$$

where σ means the stress, $\delta\varepsilon$ and δu meaning separately the virtual strain and displacement, and V means the volume. $i, j = 1, 2, 3$.

When the strength reduction is finished, the factor of safety of slopes can be obtained through the numerical method. Based on Mohr-Coulomb criteria, the factor of safety of slopes can be expressed as follows

$$k = \tan\phi / \tan\phi' \quad (3)$$

$$k = c/c' \quad (4)$$

where ϕ' means the equivalent friction angle after the strength reduction, c' meaning the cohesion after the strength reduction.

In addition, earthquake effect for the analytical and numerical methods is considered as a horizontal static force through the pseudo-static method. Its analytical expression is given by

$$F = GA_{max}/g \quad (5)$$

where A_{max} means the horizontal peak ground acceleration, and g means the gravitational acceleration.

RESULTS & DISCUSSION

RESULTS

The validation of the analytical and numerical methods is verified through a comparison between their calculation results. The factor of safety approaches to 2.2 using the analytical and numerical methods for a slope with the height H=15m at the natural state. Figure 3 shows characters of the slope geometry and material. The equivalent friction angle is 36 degrees and the cohesion is 20Kpa. Figure 4 shows the plastic strain paradigm of the slope.

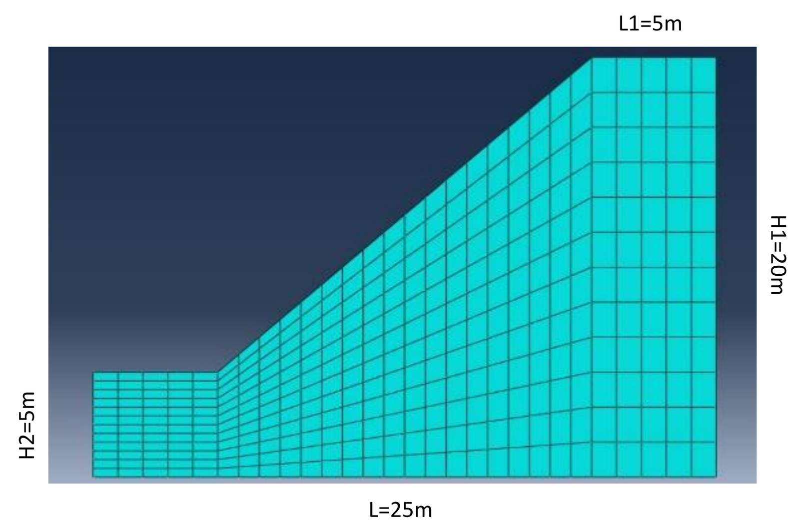

Figure 3. The slope model with Mohr-Coulomb criteria, the angle of the slope $\varphi = 45°$, and the density ρ=1800 kg/m^2, the elasticity modulus E=500Mpa, and Poisson's ratio υ=0.25.

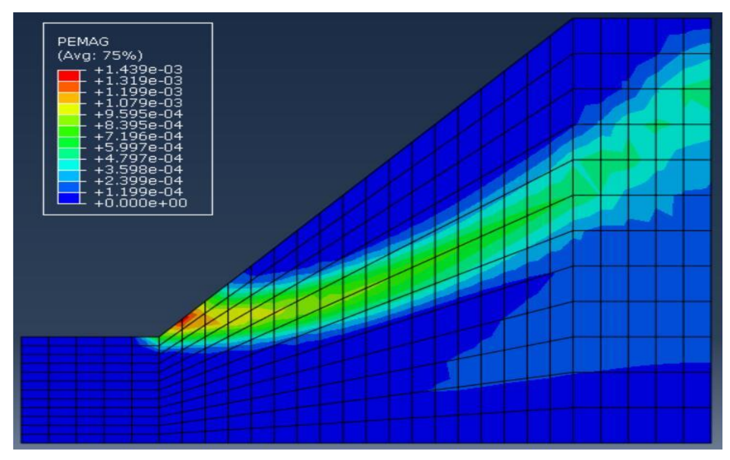

Figure 4. The plastic strain paradigm of the slope.

In engineering examples at the earthquake limit state, factors of safety of slopes are shown versus various strength factors of slopes and earthquake intensities. Figure 5 shows factors of safety of slopes versus the equivalent friction angle and cohesion. Figure 6 shows factors of safety of slopes versus the earthquake intensity.

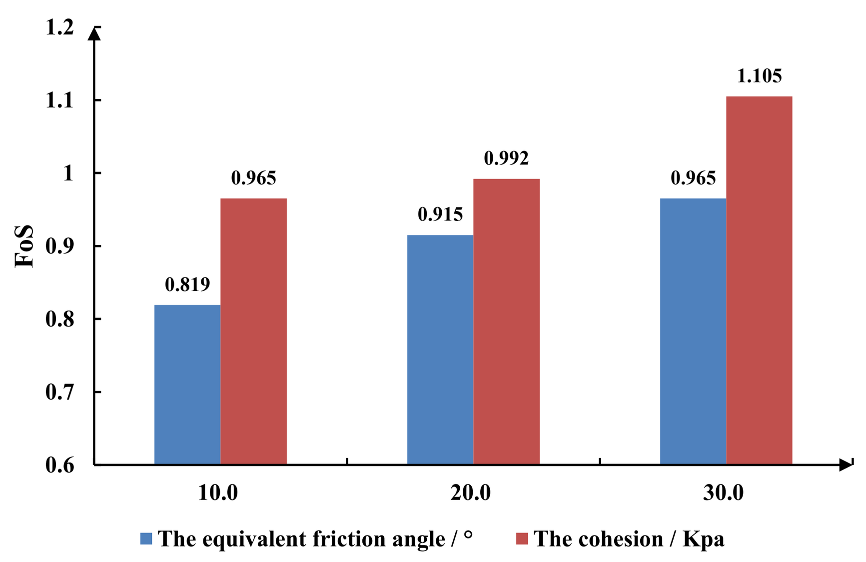

Figure 5. The factors of safety versus the equivalent friction angles for the cohesion c=10Kpa, and the factors of safety versus the cohesion for the equivalent friction angle $\phi = 30°$. $A_{max} = 65$gal in these engineering examples.

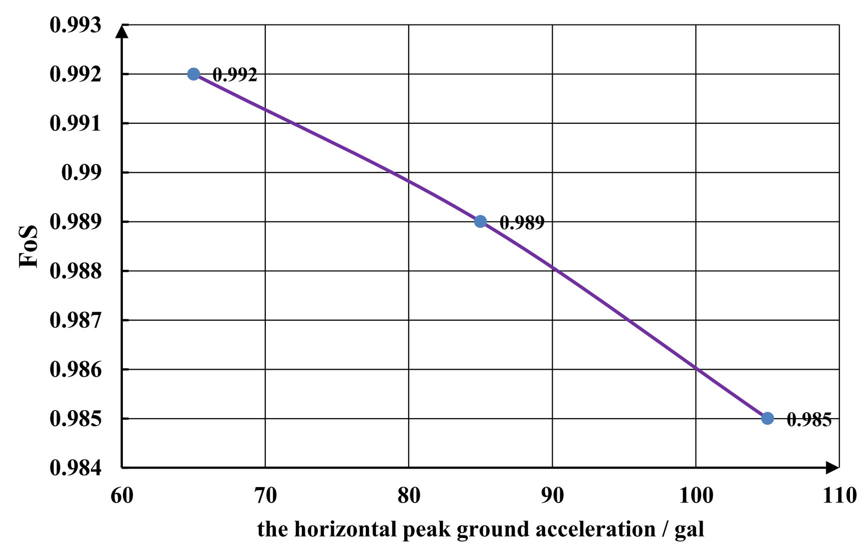

Figure 6. The factors of safety versus the horizontal peak ground accelerations for the equivalent friction angle $\phi = 30°$ and the cohesion c=20Kpa.

DISCUSSION

Factors of safety of slopes increase with the increase in strength factors of slopes, including equivalent friction angles and cohesive strength. However, factors of safety of slopes decrease with the increase in earthquake intensities.

CONCLUSIONS

They imply slopes may be safer with strong strength factors and low earthquake intensities. These would provide references for the protection of ecosystems and environments.

FUTURE WORK

- The consistence and precision could be further verified for the novel analytical and numerical methods proposed in the future.
- The newer results and discussion could be given, considering more engineering examples and using the novel analytical and numerical methods proposed in the future.