NRC Research Press

DISCUSSION

Reply to the discussion by Huang on "Probabilistic seismic slope stability analysis and design"[1]

Gordon A. Fenton, Jesse Burgess, and D.V. Griffiths

The development of design methods that account for the randomness of nature is essential if we are to properly balance the cost of our engineered systems against their probability of failure. Clearly, if the probability of lifetime failure is to be reduced (e.g., for lifeline structures), the cost of the original system (and its maintenance) must increase. As budgets are necessarily limited, it is important to be able to assess the failure probability of each possible design alternative to choose the design having the lowest overall risk, i.e., the lowest initial and maintenance costs plus the cost of failure multiplied by the probability of failure.

To aid in risk-based design, the goal of both the authors' paper (Burgess et al. 2019) and the Discussion (Huang 2020) is the estimation of the failure probability of various slope designs. To this end, both the paper and the Discussion provide practical means to estimate the failure probability of slopes under seismic loading via simplified equations, rather than through more rigorous Monte Carlo simulations. The discusser makes use of a first-order second-moment (FOSM) approximation to a deterministic factor-of-safety equation developed in Huang's (2018) thesis to similarly estimate failure probabilities. In contrast, the simplified equations presented in the paper are regressions that are fit to the Monte Carlo simulation results. The authors calibrated their simplified equations using the random finite element method (RFEM) Monte Carlo simulations, which include spatial variability and model the ground using the finite element method. The RFEM method is not limited by a first-order approximation, only by the number of realizations that can be performed in a reasonable timeframe.

While both approaches make use of pseudo-dynamic approximations, the authors believe that the finite element modeling of the ground via Monte Carlo simulation will provide better estimates of the failure probability of slopes because actual failure paths (especially through spatially variable soils) are determined for each realization. That being said, it is encouraging that the discusser's semi-analytical results are in very good agreement with most of the authors' results. The main discrepancies seem to be in the estimation of the failure probability, where for low failure probabilities, the discusser's failure probabilities seem to be significantly higher (i.e., very much more conservative) than those found by the authors. See, for example, the comparison made by the discusser in their Fig. D2.

The authors are uncertain why there is such a large discrepancy between estimated failure probabilities. Certainly the first-order approximation used by the discusser is a strong candidate for the discrepancies, given that both methods are using pseudo-dynamic approximations. The factor-of-safety equation developed by the discusser (Huang 2018; eq. (6.4)) shows good agreement with the results of Michalowski (2002), but it is not clear to the authors where the discusser's eq. (6.4) actually came from. For the assumed lognormal distribution, the FOSM first-order mean estimate might be significantly in error, depending on the overall coefficient of variation. Also, because the variance estimate used in the discusser's first-order approximation is highly dependent on the derivative of eq. (6.4), it is important to know how that equation is derived and how sensitive the first-order variance approximation is to the form of that equation.

In summary, while the authors applaud the discusser's work (Huang 2020), the authors think that unless significant conservatism is acceptable, additional effort needs to go into validating the probabilistic results before the discusser's method can be adopted in general practice as a replacement for RFEM-based results. The authors note also that the RFEM approach (and the derived simplified equations) are applicable not just for the single random variable case considered by the discusser (infinite correlation length), but also for more realistic correlation lengths.

References

Burgess, J., Fenton, G.A., and Griffiths, D.V. 2019. Probabilistic seismic slope stability analysis and design. Canadian Geotechnical Journal, **56**(12): 1979–1998. doi:10.1139/cgj-2017-0544.

Huang, W. 2018. Stability of unsaturated soil slopes under rainfall and seismic loading. PhD. thesis, Nanyang Technological University, Singapore.

Huang, W. 2020. Discussion of "Probabilistic seismic slope stability analysis and design". Canadian Geotechnical Journal, **57**. [In this issue.] doi:10.1139/cgj-2019-0486.

Michalowski, R.L. 2002. Stability charts for uniform slopes. Journal of Geotechnical and Geoenvironmental Engineering, **124**(4): 351–355. doi:10.1061/(ASCE)1090-0241(2002)128:4(351).

Received 24 August 2019. Accepted 26 August 2019.

G.A. Fenton and J. Burgess. Engineering Mathematics Department, Dalhousie University, Halifax, NS B3J 2X4, Canada.
D.V. Griffiths. Division of Engineering, Colorado School of Mines, Golden, CO 80401-1887, USA; Australian Research Council Centre of Excellence for Geotechnical Science and Engineering, University of Newcastle, Callaghan, NSW, Australia.
Corresponding author: Gordon A. Fenton (email: Gordon.Fenton@dal.ca).

[1]Appears in the Canadian Geotechnical Journal, **57**(7): 1099–1101 (2020) [dx.doi.org/10.1139/cgj-2019-0486].

Published at www.nrcresearchpress.com/cgj on 24 April 2020.