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3D FINITE ELEMENT MODELLING OF SLOPE RELIABILITY

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ABSTRACT

The paper considers the influence of spatial variability of undrained shear strength c_u on the stability of a long, 5 m high, 45° slope cut in clay. It investigates the suitability of boundary conditions adopted in 3D finite element simulations, and the feasibility of linking complex stochastic (Monte Carlo) analysis with basic probability theory for predicting the influence of slope length in reliability assessments.

The methodology is the same as in previous 2D [1] and 3D [2] investigations. The clay is modelled using a linear elastic, perfectly plastic Tresca soil model, and the slope is modelled using 20-node brick, 3D finite elements. Local average subdivision is used to generate 3D random fields of c_u; based on a normal distribution of c_u and a depth-independent mean (μ) and coefficient of variation (V = 0.3), and on vertical and horizontal scales of fluctuation, θ_v = 1.0 m and θ_h = 6.0 m, respectively. For each realisation, the random field of c_u is mapped onto the finite element mesh at the Gauss point level and the in-situ stresses in the slope are generated by applying gravity loading. By considering the slope for different values of μ, the relationship between reliability (R) and global factor of safety (F) is found: i.e. for a given value of F (based on μ), $R = 1 - (N_f/N)$, in which N is the total number of realisations and N_f is the number of realisations in which slope failure occurs.

Figure 1 shows details for a typical slope [2]. The elements are 0.5 m deep and 1.0 m × 1.0 m in plan, while the boundary conditions include a fixed base and rollers along the back face preventing displacement in the x direction. The two ends of the mesh have rollers allowing only vertical (z) displacement. It was decided to restrain movement in the x direction along these boundaries, as initial analyses suggested slope failure was attracted to the mesh ends when only the y direction was restrained—note that weaker zones near the mesh ends take on greater significance when the x direction is free, due to the implied symmetry of material properties about the boundary.

Reference [2] demonstrated that, for a slope of height H and length L, three failure modes are possible: for $H < \theta_h < L/2$, discrete failures occur through semi-continuous weaker zones and R depends on slope length (i.e. R is lower for longer slopes, due to the increased chance of encountering a zone weak enough to trigger failure).

Figure 2 shows the R versus F response for various slope lengths. The computed results are in close agreement with the response estimated by extrapolating the computed

results for L = 50 m. Specifically, the best estimate of reliability was found by using the relationship $R(L_A) = R(L_B)^{A/B}$, in which $R(L_A)$ is the estimated reliability for a slope of length L_A, based on $R(L_B)$, the computed reliability for a slope of length L_B = 50 m. In this equation, simple probability theory has $A = L_A$ and $B = L_B$. However, the results in Figure 2 have been obtained using $A = L_A - 2H$ and $B = L_B - 2H$ to account for mesh end effects. The figure shows that approximations in the mesh boundary conditions can be accounted for in reliability assessments, and that simple probability theory can be linked with 3D finite elements to provide efficient predictions for larger problems.

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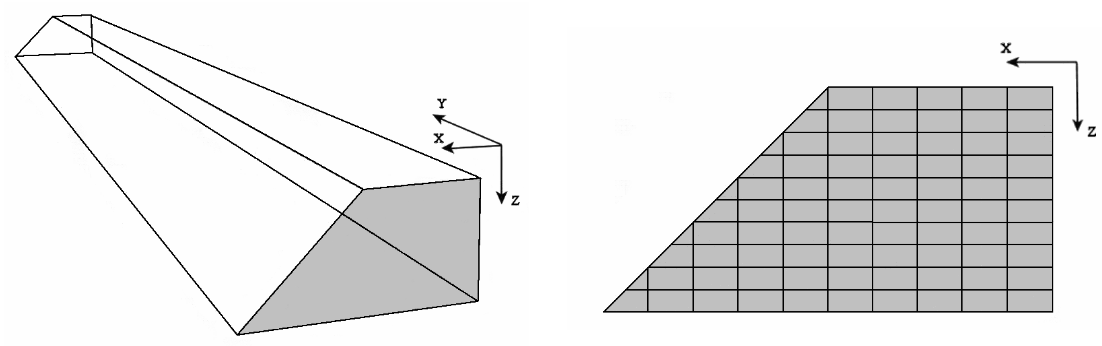

Figure 1. Problem geometry and mesh details for 100 m long slope [2]

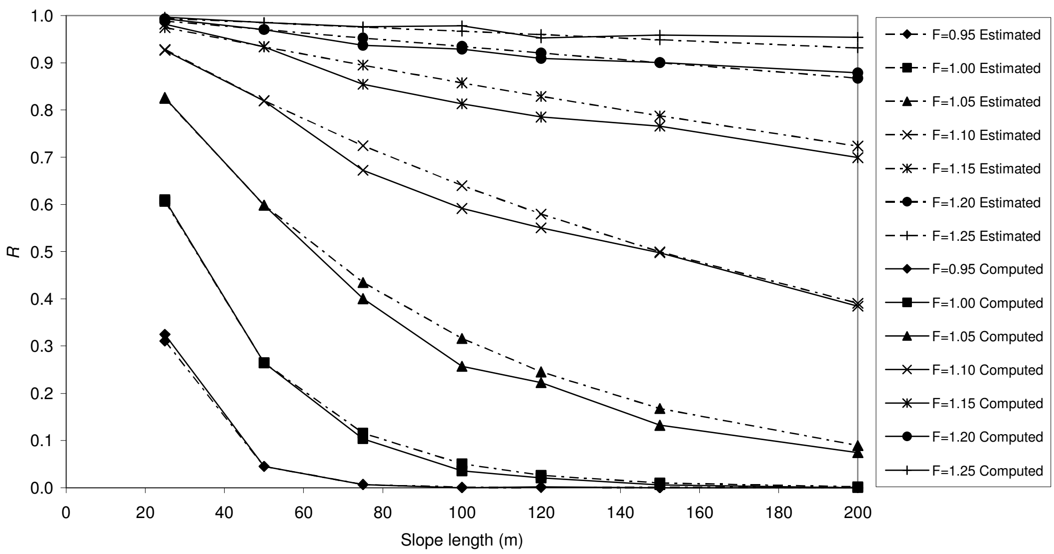

Figure 2. Influence of slope length on reliability versus factor of safety