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On the incorporation of transient groundwater conditions resulting from variable flood wave shapes in probabilistic slope stability assessments of dikes

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Slope instability of river dikes during floods is often driven by the evolution of groundwater pressures. Despite the temporal nature of high river water levels, pressure heads during floods are often assumed to reflect steady-state seepage conditions, leading to conservative estimates of dike slope safety. Here, we investigate the influence of transient groundwater conditions that result from variable flood wave shapes on probabilistic safety estimates of slope stability. We have sampled a large number of flood waves, aiming to maximize the variability in the flood wave shapes, and used them in a modeling chain consisting of a hydrological model (MODFLOW) and a probabilistic dike slope safety assessment (FORM). We compared the resulting time-dependent probabilistic dike safety for inner (landward) slope and outer (riverward) slope stability with the current flood safety assessment in the Netherlands. This comparison showed that current methods based on steady-state and analytical solutions seem to underestimate dike safety. Other methods, based on a design discharge wave, are more consistent with the multi-flood wave dike reliability, but their error increases at extreme water levels. In line with the temporal component of variable flood water levels, the failure probability also has a strong temporal component. Our results indicate that the highest failure probability always occurs after the river water level peak, with a delay of up to 15 days for both inner slope and outer slope stability. In addition, the uncertainty in the shape of the flood wave can be as important as the uncertainty in the geomechanical material properties for explaining the variation in dike failure probabilities. Therefore, this research strongly suggests that transient-groundwater conditions as a function of variable flood wave shapes should be incorporated in dike safety assessment. As a first step, we recommend further research on the occurrence probability of the most influential waveform characteristics, being the total flood wave volume (for the inner slope) and the total water level decrease after the peak (for the outer slope).