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# ULTIMATE LIMIT STATE ASSESSMENT OF DYKE RELIABILITY USING THE RANDOM MATERIAL POINT METHOD

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## 1. Introduction

This paper investigates embankment reliability based on the ultimate limit state (ULS). The ULS is generally not clearly defined and, especially for flood defences, the ULS is currently under discussion. According to Dutch law [1], flooding which leads to either casualties or substantial financial damage is considered as the ultimate limit state of a flood defence structure. However, initial slope instability is regarded as flood defence failure according to guidelines for the assessment of macro-instability of dykes [2]. Allowing initial failure, but preventing a dyke breach, is not prohibited by the current Dutch regulations and can lead to more efficient design. Analysis of both large deformations as well as the influence of spatial variability of soil properties is important to assess the reliability of a dyke against breaching. This paper uses a new technique called the random material point method (RMPM) [3], which combines MPM [4] for modelling large deformations, with random fields [5] for modelling soil variability, in a Monte Carlo simulation.

## 2. Problem description

The influence of soil heterogeneity on slope stability has been evaluated for an idealised boundary value problem. A 5 m high clay dyke, see Figure 1, is modelled with 8850 material points (i.e. four per 4-node element), using implicit RMPM with a time step of 0.01 s. The clay has been modelled using a cohesion-softening constitutive model and the soil parameters given in Table 1. Random fields of peak and residual undrained shear strength have been generated using the mean values of  $c_p$  and  $c_r$  given in Table 1, a coefficient of variation of 0.2 and a vertical scale of fluctuation ( $\theta_v$ ) of 1 m, and then mapped onto the material points. A parametric study has been performed to investigate the influence of the horizontal scale of fluctuation ( $\theta_h$ ).

## 3. Influence of anisotropy of the heterogeneity on the reliability against a dyke breach

Six Monte Carlo simulations, each comprising over 200 realizations, have been performed, with each simulation using a different horizontal scale of fluctuation. Each realization is loaded under gravity to generate the in-situ stresses, with most slopes being unstable under their own weight. In Figure 2, the reliability against failure has been plotted against time. Initial slope failure generally occurs within a couple of seconds. The results correspond to the findings of Hicks and Samy [5], who showed that a larger degree of anisotropy results in a higher reliability against initial failure for a slope with a factor of safety, based on the mean property value, below one.

Figure 2b depicts the reliability against dyke breach, which has been defined as the height of the dyke falling below the external free water level, which is defined to be at 4.5 m. A clear increase

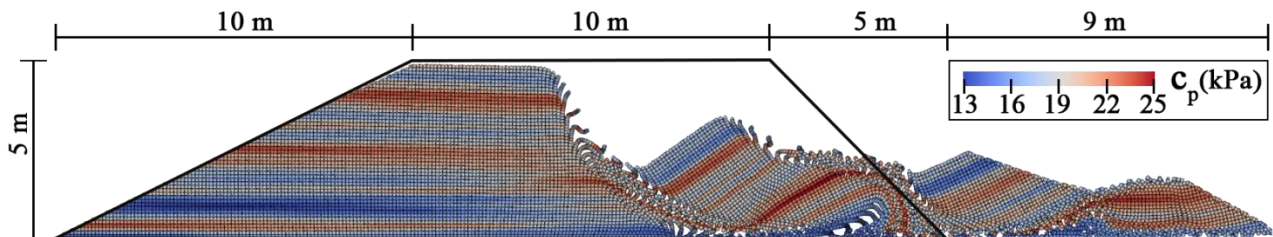


Figure 1. An example of a retrogressive failure mechanism for one realization of the spatial variability ( $\theta_v = 1$  m,  $\theta_h = 48$  m). Initial problem geometry shown in black.

Young's modulus $E$ (kPa)	Poisson's ratio $\nu$ (-)	Mean peak cohesion $c_p$ (kPa)	Mean residual cohesion $c_r$ (kPa)	Softening modulus (kPa)	Unit weight $\gamma$ (kN/m <sup>3</sup> )
1000	0.45	18	4	-50	17

Table 1. Soil properties.

in reliability between initial failure and a dyke breach, from 0-20% up to 55-85%, is observed. Counter-intuitively, the reliability against a dyke breach decreases with a larger degree of anisotropy of the heterogeneity. As shown by Wang et al. [3], a larger degree of anisotropy increases the standard deviation of the sliding distance, which reduces the reliability.

#### 4. Conclusions

As expected, the consideration of ULS failure results in a gain in reliability, and thereby to a more efficient design. The reliability gain decreases with an increase in the degree of anisotropy. Further investigation is necessary on the effect of 3D failure surfaces and pore pressures.

#### 5. Acknowledgements

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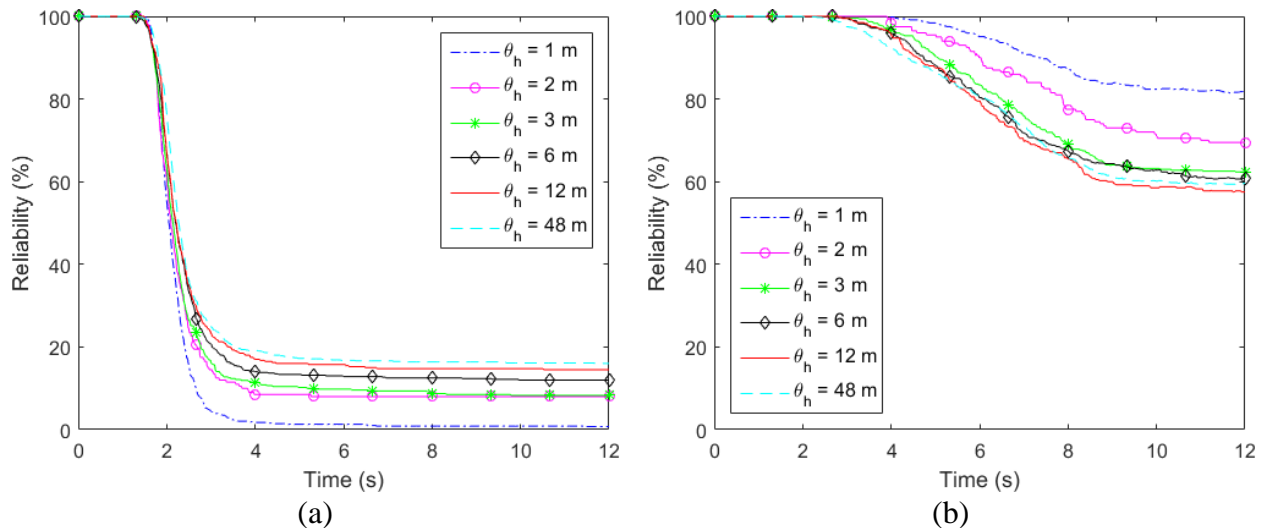


Figure 2. Reliability of Monte Carlo simulations with varying anisotropy. (a) Reliability against initial failure. (b) Reliability against a dyke breach.

#### 6. References

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