What is the effect of dike cover damages on the failure probability of wave overtopping?

Vera M. van Bergeijk[a*], Jord J. Warmink[a], Suzanne J.M.H. Hulscher[a]
[a] *University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands*

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Introduction

Climate change increases the vulnerability of grass-covered river dikes due to increasing river discharges in the winter and weaking of the dike cover during droughts in the summer. Wave overtopping is one of the main failure mechanisms of grass-covered dikes. Large waves during a storm overtop the dike, flow over the crest and flow down along the landward slopes. The high flow velocities in combination with turbulence result in erosion of the grass cover (Figure 1).

According to the WBI, the dike fails when an erosion depth of 20 cm is reached. Damages in the dike cover as the result of animal borrowings are weak spots that are vulnerable for wave overtopping erosion. In this study, we calculate the effect of these damages on the failure probability of wave overtopping to determine the vulnerability of these damages.

Figure 1: Erosion of the grass cover by overtopping waves results in the formation of a small cliff (Peeters et al., 2012).

Dike cover damages

Damages in the dike cover are more vulnerable for wave overtopping erosion due to (1) an increase in the hydraulic load and (2) the weaking of the dike cover. Firstly, a damage of the dike results in the formation of a vertical cliff (Figures 1 and 2). When the water flows over this cliff, a jet forms that impacts in the jet impact zone leasing to an increase in the hydraulic load. Secondly, the grass cover is often damaged resulting is a decrease in the cover strength.

In this study, we investigate the vulnerability of small damages resulting in a maximum cliff height of 20 cm. These damages can be the result of animal burrowing, small slope instabilities and erosion holes as the result of wave overtopping.

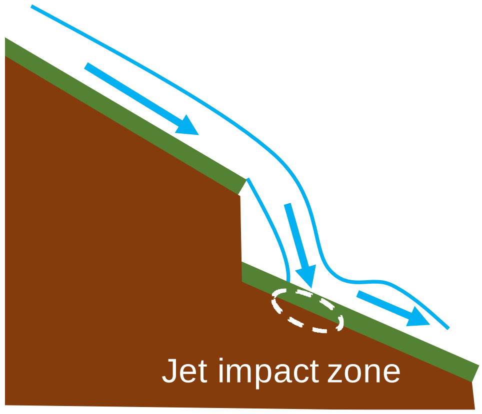

Figure 2: Flow over a vertical cliff at a damage results in the formation of a jet that impacts in the jet impact zone (white dashed circle).

Method

The failure probability is calculated using the framework of Van Bergeijk et al. (2021) using the water level, wind speed and critical velocity as stochastic variables. The erosion depth along the dike profile is computed using the analytical grass-erosion model (Warmink et al., 2020) where the cover strength is modelled using the critical velocity and the hydraulic load is simulated using the flow velocity and the turbulence parameter ω. The failure probabilities are calculated for a grass-covered river dike near Millingen a/d Rijn (Van Bergeijk et al., 2021).

Firstly, the failure probability of a regular dike profile with a good grass cover is calculated. A regular grass-covered dike profile is most likely to fail at the landward toe where the flow velocity is high and the slope change results in an increase in the load on the dike cover. The increase in the hydraulic load is modelled using a turbulence parameter ω_{toe} = 2.75 (Warmink et al., 2020).

Next, the failure probability for a damage $P_{f,damage}$ on the landward slope is computed. The failure probability depends on the location of the damage - because the flow velocity increases along the slope - and

* Corresponding author
Email address: v.m.vanbergeijk@utwente.nl (V.M. van Bergeijk)
URL: people.utwente.nl/v.m.vanbergeijk (V.M. van Bergeijk)

the type of cover at the damaged location. The $P_{f,damage}$ is calculated along the landward slope for four cover types with different critical velocities U_C (Table 1). The additional load due to jet impact is simulated using the relation found by Van Bergeijk et al. (2021)

$$\omega_{damage} = 0.074\, U_C + 2.1 \qquad (1)$$

where the turbulence parameter ω_{damage} depends on the cover quality.

Table 1: The critical velocity for four cover types (Verheij et al. 1995).

Cover type	Critical velocity [m/s]
Good grass	6.5
Poor grass	2.5
Good clay	1.0
Poor clay	0.4

Results

The failure probability at the inner toe $P_{f,toe}$ of a regular dike profile is $4.8 \cdot 10^{-5}$. The failure probability for a damage $P_{f,damage}$ increases along the landward slope (Figure 3) related to the increase in flow velocity along the slope. In case of a good grass cover at the damage, the failure probability at the inner toe is larger compared to the failure probability of the damage. This is because the additional load due to the slope change at the inner toe ω_{toe} is larger than the additional load near the damage ω_{damage}. For the other three qualities, the damage has a higher failure probability. A damage is 12, 60 and 120 times more likely to fail compared to the inner toe for a poor grass, good clay and poor clay cover, respectively.

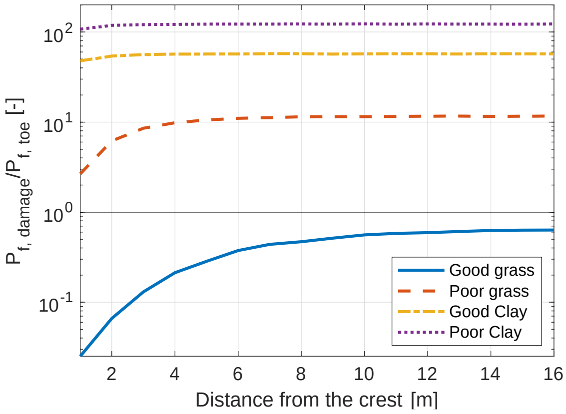

Figure 3: The ratio between the failure probability of a damage on the landward slope $P_{f,damage}$ and the inner toe $P_{f,toe}$ for four cover types.

Application

According to the current failure definition, a grass-covered dike fails once the erosion depth exceeds 20 cm. However, river dikes often consist of a clay core with a cover that is able to resist overtopping flows. The residual dike strength of the cover and core is not considered in the current failure definition. Design and assessment methods will become more cost-effective when the residual dike strength is taken into account.

The results of this study can be used as a first step for methods that include the residual dike strength. For example, the relation for the additional load near a cliff can be used in case the failure definition is extended to larger erosion depths where cliffs of 20 cm can form at multiple locations. The results are also applicable to small slope instabilities. A small slope instability does not lead to flooding but makes the dike more vulnerable for wave overtopping. Therefore, it is important to consider the interaction between macro-stability and wave overtopping in studies on progressive slope instabilities.

Conclusions

Damages in grass-covered slopes affect the failure probability by increasing the hydraulic load on the dike cover due to wave impact and decreasing the cover strength. When the grass cover is damaged, the damaged location is between 12 and 120 times more likely to fail compared to a regular dike profile depending on the cover quality. Damages on the upper slope are less vulnerable compared to damages on the lower slope due to the high flow velocity at the end of the slope. The results of this study can be used for methods that aim at taking the residual dike strength into account and thus improve dike assessment methods in general.

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