WAVE OVERTOPPING ON DIKES

THE EFFECT OF TRANSITIONS ON THE FLOW AND DIKE COVER EROSION

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More than 60% of the Netherlands is identified as flood prone area. Most of the flood prone areas are densely populated, so flood defence systems with low flooding probability are extremely important in the Netherlands. Currently, the major part of the Dutch flood defence system consists of dikes, with often a cover made of grass. One of the main failure mechanisms of dikes is wave overtopping (Figure 1). Waves run-up on the waterside slope, overtop the dike crest and run down on the landward slope. The overtopping flow causes erosion of the dike cover on the dike crest and the landward side of the dike. Once the dike cover is eroded, erosion of the core material of the dike starts resulting in weakening of the dike and finally in a dike breach (Oumeraci et al., 2005).

Dikes are nowadays not only used for flood safety, but play an equally important role in recreation, transportation and nature (Deltaprogramma, 2010). This leads to an increase in the amount of transitions in dike cover and dike geometry. Often, a road is located on top of the dike crest for transportation purposes resulting in transitions in cover type. Materials such as concrete blocks, asphalt and grass are often applied as revetments on the seaward slope of dikes to withstand the forces of the waves and currents (Figure 2). Changes in slope angle are also classified as transitions, for example changes in slope angle along the seaward slope and the transition from the dike crest to the landward slope. Height differences are also classified as transitions. Wave overtopping experiments identified transitions as weak spots in the dike cover (Steendam et al., 2014). However, the effect of transitions on the wave overtopping discharge and wave overtopping flow is uncertain. Also, the effects of transitions on the location and evolution of the dike cover erosion is unknown.

RESEARCH PLAN

Researchers in the Water and Engineering Management department aim to increase the knowledge of the overtopping process. Recently, 2 PhD's started on the challenge of quantifying the effect of transitions in grass covered dikes on the overtopping flow and the resulting dike cover erosion. This research is part of the All-Risk research program: Implementation of the new risk-based standards in the Dutch Flood Protection Program (HWBP). The program is a collaboration of 18 researchers located at 6 Dutch Universities and the goal of the program is to investigate flood risk and the reduction of flood risk by innovative measures. By increasing the knowledge of the overtopping process, we can investigate to what extend innovative technical measures and maintenance strategies are able to increase the stability of the dike cover: locally around transitions, and for the dike as a whole.

The first PhD, Weiqiu Chen, studies impact of transitions on wave overtopping characteristics using field and flume experiments. She investigates the effect of transitions, such as variati-

FIG. 1 Wave overtopping on a dike with a road on top of the dike crest resulting in roughness transitions.

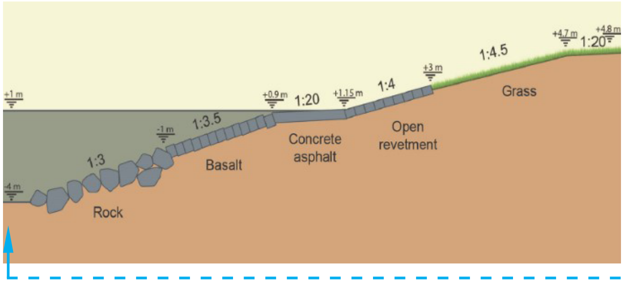


FIG. 2 Transitions in cover type due to different roughness elements on the slope and transitions in slope angle due to the berm and the different elements (EurOtop Manual, 2016).

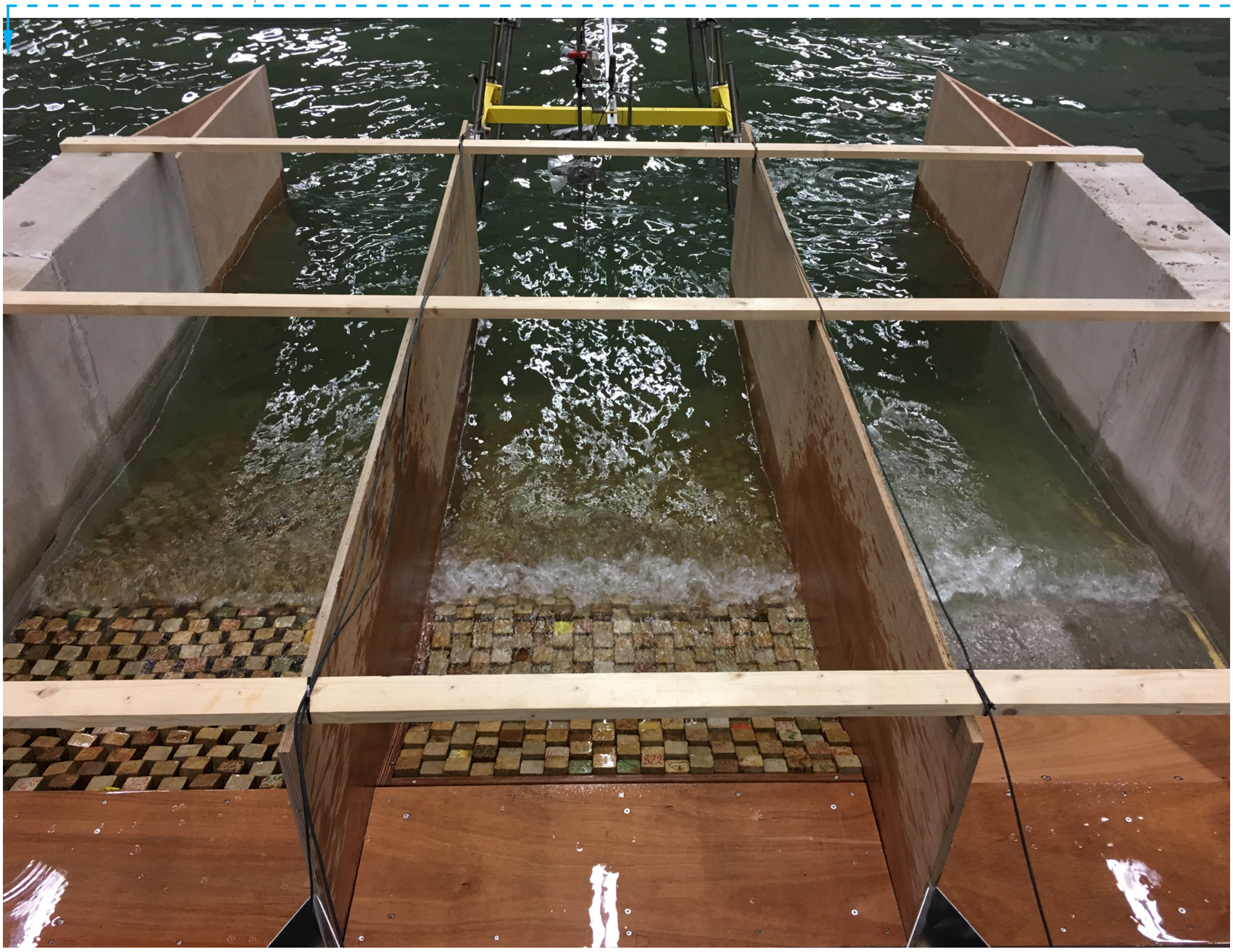
ons in roughness and permeability of the dike cover, on the rate of overtopping and overtopping flow characteristics. The goal is to find the optimal use of roughness elements that can reduce the required crest elevation. Also, she will study how the vegetation quality and transitions affect the scour of the dike cover in flume and/or field experiments.

The second PhD, Vera van Bergeijk, focusses on the numerical modelling of the overtopping flow and dike cover erosion. We want to know how well a numerical model can predict the dike cover erosion for a range of grass cover states and transitions configurations. This numerical model will be used to compare the use of berm with changes in slope angle and roughness transitions to find which measure is more cost effective in the reduction of erosion.

EXPERIMENTAL STUDY

Reliable estimation of wave overtopping discharge is necessary for the design and safety assessment of dikes. Existing overtopping discharge estimators normally take one single type of revetment into consideration (EurOtop Manual; Van der Meer et al, 2016). However, in practical engineering, different elements are often combined as an armor of the slope (Figure 2). Besides, it becomes complicated when a berm is introduced to reduce the wave run-up and therefore reducing the overtopping. It still remains unclear how the combined roughness factor affects the overtopping over the dike with a berm. Hence, an experimental study is performed to determine the influence of the berm and roughness on the wave overtopping discharge. Physical model tests (Figure 3) have been conducted in the Pacific Basin at Deltares. Four types of slope protection are considered in the tests, i.e. blocks with protrusion, blocks with open space, rocks and smooth slopes representing asphalt or grass. Preliminary result ▶

FIG. 3 The types of armour in the physical models tests at Deltares. From left to right: blocks with open spaces, blocks with protrusion and a reference case of smooth slopes.



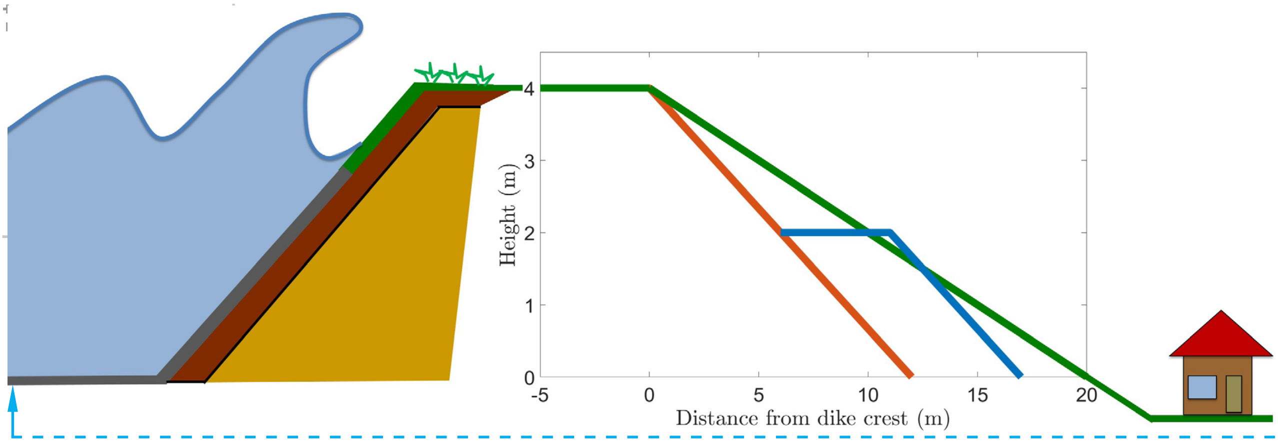


FIG. 4 The model domain of idealised wave model starts on top of the dike crest and can be adapted for different slope angles and a berm.

showed that the overtopping formula in the TAW (2002) may underestimate the effect of the berm on average overtopping discharge for smooth slope which is regarded as the reference structure. There is an intriguing finding that the average overtopping discharge of one structure with permeable blocks on the berm and down slope is even larger than that of the smooth and impermeable slope. The berm factor is firstly modified and an improved overtopping equation is developed for smooth slope, based on which the roughness factor for each test can be obtained by comparing the overtopping discharge of the reference section to that of the structure with roughness elements. Furthermore, the relationships between the roughness coefficient and overtopping discharge, wave steepness as well as the berm level will be investigated. Finally, an improved overtopping formula for berm dikes with different elements applied on the seaward slope will be developed.

IDEALISED MODEL

The discharge overtopping the dike causes erosion on the landward side of the dike. The overtopping flow and the dike cover erosion are affected by transitions on the dike crest and landward slope. As a first step, an idealised model is used to investigate the effect of several transitions types on the overtopping flow. Since the idealised model is computationally fast, it is a useful tool to investigate a wide range of dike geometries and transitions to get an idea about the order of magnitude of velocity changes and dike cover erosion. The model domain includes (part of) the dike crest and the landward slope (Figure 4). In this case, we determined the changes in the flow velocity along the slope and the effect of two measures: (1) decrease in slope angle and (2) addition of a berm. The flow velocity of the reference case is shown in orange in Figure 5 together with the velocity of measures 1 and 2 in green and blue respectively.

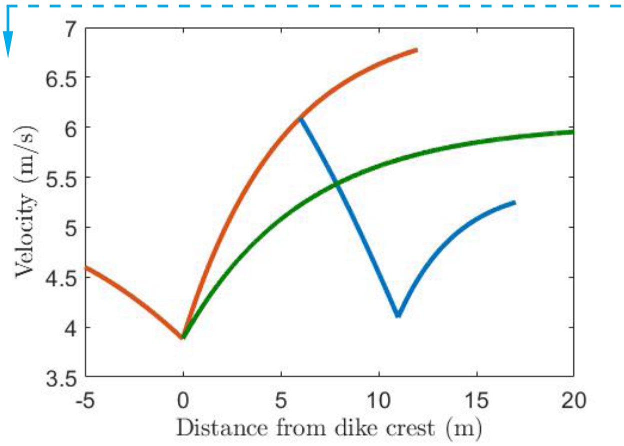
Decreasing the slope steepness from 1:3 (reference case, orange) to a steepness of 1:5 (green) results in a decrease in maximum flow velocity of 10 % (Figure 5). Placing a berm with a width of 5 m decreases the flow velocity at the toe of the dike by 20%. However, the maximum flow velocity (around 5 m from the dike crest) in case of a berm is larger than the maximum flow velocity for a steepness of 1:5. In the future, the model is extended with an erosion model to determine the erosional effects of the transitions and compare the erosion reduction of several measures.

DETAILED NUMERICAL MODEL

Dike cover erosion due to wave overtopping is mainly caused by the variations in flow velocity, especially turbulence. For this reason, we need detailed numerical model to solve the variations in time and depth necessary to model dike cover erosion. Aguilar-Lopez (2016) developed a detailed numerical model to simulate the overtopping flow and dike cover erosion. The model was validated for an experiment near the village of Millingen aan de Rijn in the Netherlands with the Wave Overtopping Simulator (WOS) for a dike section with a road on the crest.

Figure 6 shows as snapshot of the flow velocity 1.7 seconds after releasing the wave volume from the overtopping simulator (left of Figure 6). The road starts at x=-1 m, where changes in slope angle are observed between the grass layer (left of x = -1 m) and the asphalt road (right of x = 1 m). High turbulence was observed at the transitions in slope angle, e.g. on the sides of the road. The flow velocity shows a rough surface, which

FIG. 5 The flow velocity along the cross-dike profile for the reference case (orange, slope 1:3), decrease in slope angle (green, slope 1:5) and the addition of a berm (blue).



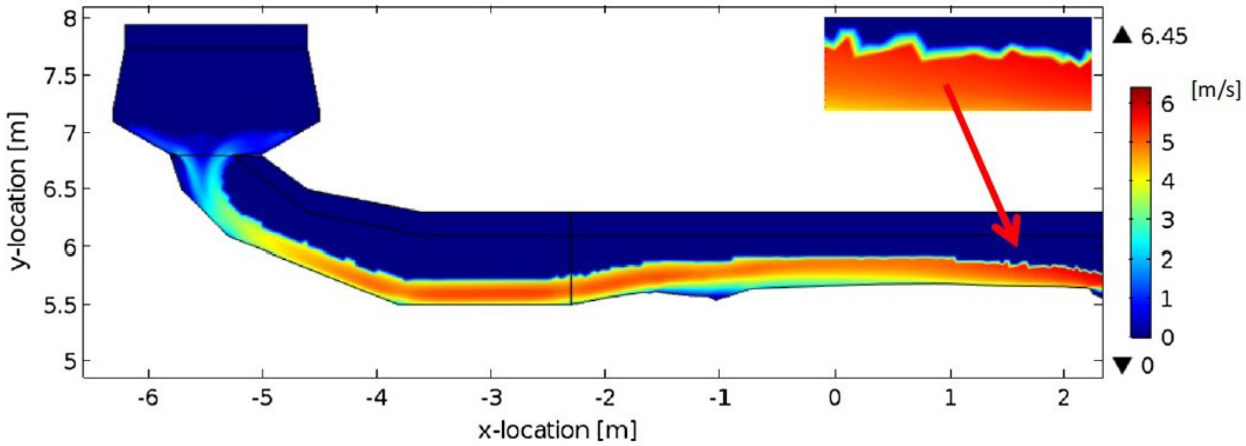


FIG. 6 Flow velocity [m/s] of the overtopping flow from the wave overtopping simulator over a dike crest with a road on top of the dike (from x=-1 m to x=2.5 m) at t=1.7s after release of the wave (Bomers et al. 2018).

is the results of high turbulence and air entrapment in the flow (Bomers et al, 2018). Due to bottom friction, the flow velocity is lower at the bed than at the surface.

The detailed hydrodynamic model is coupled to an erosion module to simulate the dike cover erosion. The coupled hydrodynamic-erosion model was able to simulate the location and order of magnitude of the erosion along the dike crest and the landward slope with reasonable accuracy. Most erosion was simulated and observed directly downstream of the road due to the high turbulence at this transition. The model results were only validated for on case and need to be tested for other types of transitions and dike configurations.

CONCLUSIONS

The wave overtopping process is highly variable in time and is affected by the transitions occurring on the dike, which makes it a complex process to describe. Flume experiments are used to determine the effect of a berm and roughness elements on the wave overtopping discharge. The results will be used for improvement of the formulas of the wave overtopping discharge in the EurOtop Manual and the improvement of dike design using an optimal combination of roughness elements. The discharge overtopping the dike causes erosion on the landward slope. Two types of numerical models are used to study the effect of erosion at several types of transitions, e.g. slope changes, height differences and roughness differences, to improve dike design and to find measures leading to the most effective erosion reduction. In future work, the developed erosion models can be applied for developing maintenance guidelines or tools for probabilistic dike safety assessments.

Probabilistic assessment requires a translation from wave conditions to wave run-up and wave overtopping, which are boundary conditions for assessing erosion resistance and stability of dike covers. Furthermore, fundamental understanding of dike cover erosion is essential to reliably assess and maintain the safety of dikes with other vegetation types (e.g. flower-rich vegetation) and transitions and objects in dike cover.

ACKNOWLEDGEMENTS

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