

Wave overtopping resistance of grassed slopes in Viet Nam

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Abstract

The Simulator was applied to test the resistance against wave overtopping of grass covered dike slopes in Viet Nam. Observation and measurement during destructive tests were performed to investigate the development process of damage induced by overtopping flow. Damages were likely to be initiated at transition of either geometry or materials, at eroded holes and around objects existing on the slope. Grass cover could withstand a certain overtopping rate that varies widely and in order of 10 l/s per m.

Keywords: wave overtopping, grass slope, damage, erosion, transition, grass root.

1 Introduction

Before 2009, the real quality of more than 800 km sea dikes in the north of Viet Nam could be only tested during storm season from May to September every year. It was almost impossible to estimate the resistance against wave overtopping and investigate the damage process of grass covered slope due to difficulties in performing observation or measurement in storm condition. Therefore in the present guidelines value of tolerable overtopping rate cannot be found. A series of destructive tests *in situ* using the Simulator has gradually revealed the potential capacity of the grass covered dike slope to withstand wave overtopping. Applied discharge causing failure of the grass slope was enormously different from section to section but not less than 10 l/s per m. It was specification of material and geometry that governed the failure mechanism of the grass slope.

2 Wave overtopping simulator

Already for many years that phenomenon of wave overtopping on sea dike has been studied on small to large scale physical models in wave flumes and formulae of overtopping volume, discharge and probability were established. However, the erosion and stability of dike crest and landward grass slope under attack of wave overtopping have been investigated intensively recently. The main reason is that these effects cannot be studied in a small wave flume as it is hardly possible to scale down properties of either soil or grass (root). Building up a section of real dike in a large wave flume is time consuming, very costly and grass needs about one or two years to get its mature condition, ready for testing. The Wave Overtopping Simulator was developed to simulate the overtopping waves on dike crest and then on landward dike slope and to study the behaviour of the stability of crest and landward slope in the Netherlands (Van der Meer et al., 2006). In 2008, the second simulator was designed and made for Viet Nam. The maximum volume is 5.5 m³ per 1 m wide (22 m³ for the simulator of 4 m in width). When working, the simulator is continuously filled by pump(s) with a constant discharge and is emptied at desired moments through two butterfly valves at the bottom in a way that simulates the overtopping tongues on dike crest and then on landward slope. The principle of the simulator is presented in van der Meer et al. (2006, 2007 and 2008) or Le et al. (2010).

3 Test set-up

Since 2006, a large number of destructive tests has been performed on different grass covered slopes in the Netherlands, Belgium and very recently in USA including river dikes, sea dikes

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and artificial dike sections. In two years, 2009 and 2010, seven slope sections were tested with the simulator on three sea dike stretches in the north of Viet Nam.

3.1 Test sections

Destructive tests were performed on slope sections that were selected according to a set of criteria of operation and testing (Le et al., 2010). The pilot test was conducted in Do Son, Hai Phong where dike was reinforced with concrete on three sides: seaward slope, dike crest, upper part of landward slope and berm. The lower part of the landward slope was sandy soil covered with Vetiver grass (*Vetiveria Zizanioides*). Slope section DS_01 with inclination of 1:2 was tested and the Vetiver covered part was 5 m long, next to the dike toe was a water canal, Fig 1.

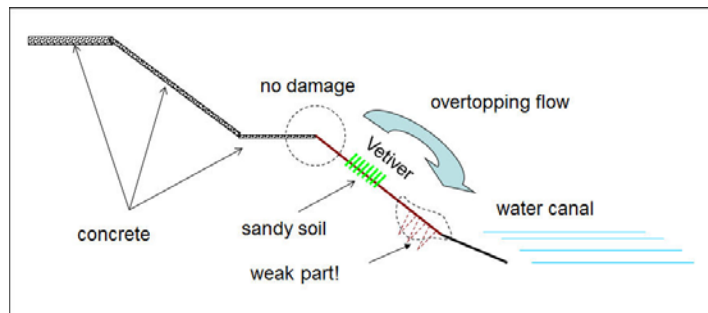


Figure 1: Do Son sea dike in Hai Phong, 2-year-old Vetiver grass on the low landward slope.

In Nam Dinh, Thinh Long sea dike with an inclination of 1:3 was tested and the slope was covered with Bermuda grass (*Cynodon Dactylon*) and sometimes Casuarina trees as well. The dike body was constructed by a sand core and a layer of clay with moderate quality, see Fig 2. The thickness of the clay layer was found to vary from 80 to 100 cm at 3 sections. On horizontal dike toe, it was Ray grass (*Hemarthria compressa*) that covered evenly toward a brackish water canal. Section TL_01: grass covered slope of 10 m long, relatively regular slope, no hole was found. TL_02: irregular slope, poorly covered with three different grass species (mainly Bermuda), 5 eroded holes and 7 Casuarina trees (amongst those, one with a trunk of 7 cm) were recognised. TL_03: relatively regular, covered with Bermuda grass and Crabgrass (*Eleusine indica*), 5 small Casuarina trees with diameter of 1 cm.

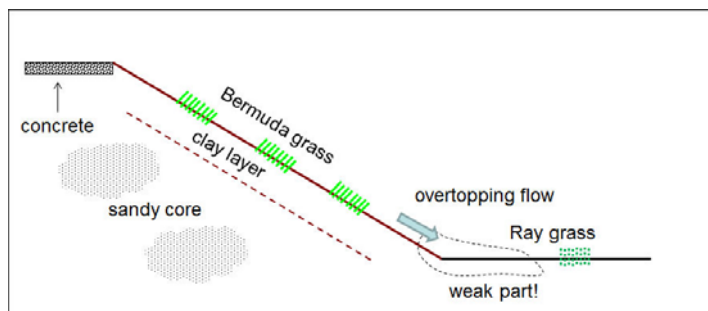


Figure 2: Thinh Long sea dike in Nam Dinh, 4-year-old Bermuda grass slope.

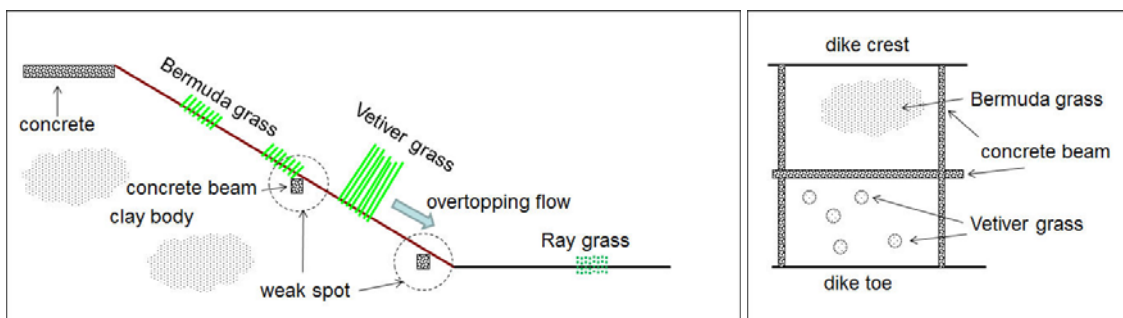


Figure 3: Thai Thuy sea dike in Thai Binh, a mixture of Bermuda and Vetiver grass on clay slope.

Within 50 m of the Thai Thuy dike stretch, 3 sections were tested. The slope inclination was 1:3. The dike body was constructed by good clay, a mixture of Vetiver and Bermuda grass was planted within concrete frames, see Fig 3. The horizontal berm was protected with a dense sward of Ray grass. Vetiver and Bermuda grass covered evenly section TT_01 and horizontal concrete beam was at the middle of the slope. TT_02: number of Vetiver clumps was few while Bermuda grass was dominant however with low density, concrete beams divided the slope section into 4 parts. TT_03: concrete beams divided the section into 4 parts, in which one was mainly covered with Vetiver while at the others both Vetiver and Bermuda grass could be found.

Local grass species like Bermuda grass, Crabgrass and Ray grass grow to knit a mat covering soil surface while Vetiver grass always grows in separate clumps, soil surface amongst these clumps are often bare or covered by mat grass.

3.2 Grass root quality

The resistance against erosion induced by wave overtopping of a grass covered slope is solely determined by the quality of grass turf. According to the Dutch guidelines for safety assessments of dikes (VTV 2006), quality of a grass cover can be estimated by the amount of roots in depth. 8 samples of 4 different grass species taken on Thai Thuy dike were analysed to derive the number of roots. In general, the quality of the tested grass slopes were far beyond “good” criterion of VTV, Fig 4. It should be noted that the growing condition of grass in Viet Nam and the Netherlands are obviously different and grass species are themselves different.

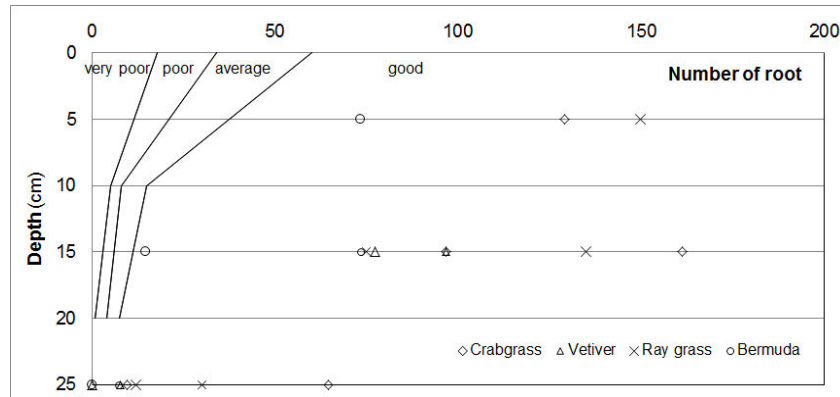


Figure 4: Classification of grass according to the Dutch guidelines VTV 2006.

3.3 Test set-up

The Simulator was always placed on dike crest that released water could flow over a short distance on the crest and then the grass covered slope. Two water pumps, capacity of 22 and 55 kW respectively, supplied a input discharge of more than 1000 m³/h to the Simulator. A 250 kVA diesel generator was applied to run all machines including the Simulator, water pumps, oil pump and other equipments on site. The two butterfly valves were operated manually according to control tables that were computed beforehand and dependent on the real input discharge and tested overtopping rate.

As wide as the out-put gate of the Simulator, each tested slope section was 4 m wide. On both sides of the section, a 50-cm-wall was erected to guide the water released from the Simulator. During destructive tests, grass slopes were captured with a digital camera in order to examine the development of damages induced by overtopping flows. Besides, dike slope profiles were also measured from crest to toe with a density of 1 point/ (0.5 – 1.0)m in either flow direction or transversely. In all tests, natural brackish or salt water was used.

The erosional resistance of grass covered slopes were tested with mean overtopping rate increasing from small to large: 10; 20; 40; 70; 80; 100 and 120 l/s per m. Each rate represented a real storm that was simulated (generated) by the Simulator lasting for 4 hours, a typical duration of storm attacking the north of Viet Nam. Each test condition is a distribution of overtopping volumes (see EurOtop, 2007) that is dependent on seaside wave boundary such as a wave height, wave period and a water depth. A significant wave height of 1.5 m and a peak

period of 6 s were applied to compute control tables in all tests. At some test sections, hydraulic measurements were carried out in order to determine the flow parameters on grass slope including flow depth, flow front velocity and flow duration.

4 Damages on grass slopes

Damage on a grass covered slope is defined as one or some aggregate(s) of soil including sward and root is (are) torn out of the slope surface and then moved away by overtopping flow. In other words, damage is initiated when at any point the grass cover is eroded, even within small area of some cm². Damage on a grass covered slope can be described by a limit state function of strength and load as follows:

$$Z = \text{Strength} - \text{Load} \quad (1)$$

In which, *Strength* is determined by the quality of grass cover that dependent on the combination of soil structure and root system. *Load* is mainly the effect of overtopping flow. Small overtopping discharge giving small overtopping volumes seemed to have little or no erosional effect (e.g. van der Meer et al., 2010 and Steendam et al., 2010). Depending on the specification of grass slope, there would be a certain rate of wave overtopping producing volumes that sufficiently energetic to initiate damage on the slope and later on enlarge it.

Damages were likely to be initiated at transition of either geometry or material. On slope, soil (bare or covered by mat grass, e.g. Bermuda grass) amongst Vetiver clumps was vulnerable spot which was often eroded first. Besides, damage could be also initiated around object like a big Casuarina tree and at an eroded hole existing on the slope. At dike toe, transition between steep part and horizontal part (berm in case of Thai Thuy) damage was found to take place as well but with relatively small probability. In general, at these position of transition or existing object, *Strength* was eliminated due to the discontinuity of grass cover. It was this discontinuity that caused flow blockage or/ and flow concentration, *Load* was hence enhanced.

4.1 Geometry transition

Section TL_01, slope surface was regular and covered with Bermuda grass, horizontal toe was covered with Ray grass. Around the transition between these two parts, grass cover was rather poor that clay was exposed directly to overtopping flow. Besides, at the transition acting force seemed larger than on the slope due to the rough guidance of overtopping flow, see left panel of Fig 5. Damages were therefore caused to take place at the dike toe, a geometry transition, right panel of Fig 5.



Figure 5: Rough guidance of overtopping flow (left) and damages (right) at dike toe, TL_01.

Section DS_01, bare soil was first eroded and subsequently Vetiver clumps were swept away at the transition between the low part of the slope and the canal bank as can be seen in Fig 6 right panel. It could be explained by the water flow with high energy flying into the air from the end of the concrete berm to attack the dike toe more or less vertically, Fig 6 left panel. Interestingly, the first row of Vetiver clumps next to the concrete berm was first hit by overtopping flow however these clumps remained intact till the end of the test, they were only forced to lie down.

Due to the long and straight root system, when Vetiver clumps were eroded and swept away hole with very steep wall was formed. The eroded hole was enlarged in upward direction under attack of overtopping flow. This is similar to the head-cut mechanism that is the last stage of an erosion process described by Valk (2009) consisting of: initial situation, scour hole due to surface erosion, transition and head-cut erosion. Scour hole due to surface erosion can be compared to the formation of trenches amongst separate Vetiver clumps and transition of surface erosion to head-cut erosion is like when these trenches get sufficient depth to split Vetiver clumps from the slope.



Figure 6: Overtopping flow flying from the berm attacks the dike toe.

Fig 7 left panel gives an impression of a damage at dike toe that expose the horizontal concrete beam, section TT_03. When the top layer of grass sod (about 10 cm) was eroded, a thin layer of mortar was found, Fig 7 right panel. The mortar layer prevented grass roots from penetrating deeply dike body underneath. As a result, the connection either between the top soil layer and the mortar layer or between the mortar layer and the soil body were weak. Therefore, either the top grass sod or the mortar layer were easily eroded to expose the underneath body of soil. The damage at geometry transition was facilitated by the transition of material.

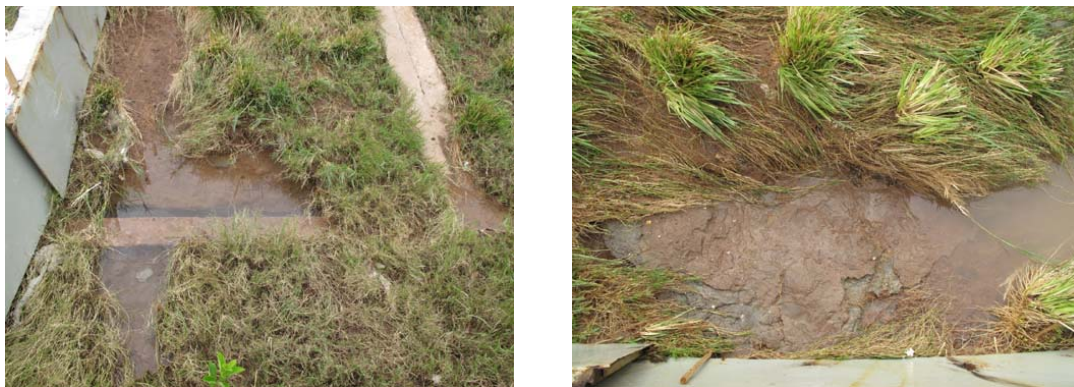


Figure 7: Left: concrete beam was exposed. Right: mortar layer under a top grass sod.

Assuming parallel seepage condition, full saturation of fissured cover layer and soil cohesion is not taken into account, Young (2005) argued that a grass turf may slide at the turf base to create a large erosion on the slope surface. This turf sliding is partly comparable to the shallow slip of the grass turf lying on the mortar layer observed at section TT_03, the mechanism however is different. At two test sections at Boonweg, Friesland in the Netherlands, it was observed that spots of grass cover (0.5 and 1.0 m²) were lifted up 0.1 to 0.2 m and then washed away by large waves (Steendam et al., 2008). Location of these spots were below potential weak spots existing on the grass slope.

4.2 Material transition

On a slope that covered by a mixture of mat grass (e.g. Bermuda) and Vetiver grass in Thai Thuy, the development of these species were not proportional. It was observed that in April 2010, Bermuda grass was evenly covering the dike slope while Vetiver grass was short and

sparse. Bermuda grass predominantly protected the dike slope. More Vetiver clumps were planted on the riverside slope in May 2010, beginning of the rainy season and about 6 months before testing. In November, when destructive tests were carried out, Vetiver clumps were growing well and about 1 m high. As can be seen in Fig 8, left panel, Vetiver sward was cut off to expose the thin cover of Bermuda grass. It was Vetiver grass that overwhelmed the mat grass. Due to the high shape of Vetiver clumps, flow tended to concentrate amongst close clumps, as a result, trenches were formed. The more soil was eroded the deeper the trenches became. Sufficiently deep trenches split Vetiver clumps from the slope, the slope was therefore damaged. As described above, at section DS_01 damages were also first initiated amongst separate Vetiver clumps where soil directly exposed to overtopping flow. The existence of more than one species of grass caused discontinuity of the dike slope, weak spots were often found at these transitions of different grass species.



Figure 8: Left: damages amongst Vetiver clumps. Right: poor cover of Bermuda grass and settlement of soil around concrete beams,

Transition between grassed soil and concrete beam could be potential vulnerable spot where grass cover was often poor and soil surface was settled down, Fig 8 right panel. Poor cover of grass might be due to a low root density in top soil layer and uneven surface around the beam would introduce flow concentration. Combination of these two features caused higher chance of erosion around the concrete frames as illustrated in Fig 9 left panel.

Another example of using different materials on a grass covered slope was demonstrated at the Vecht dike, the Netherlands, where concrete blocks (40 x 40 x 12 cm) allowing grass to grow through were applied on the riverside berm. A deep track was presented above the berm to result in an initial damage at overtopping rate of 1 l/s per m. Blocks were moved away from original position at 50 l/s per m, see more Steendam et al. (2010).

4.3 Objects and existing damages

Casuarina trees and eroded holes that existing on a grass slope presented interruption to the continuity of the grass sod. These positions became weaker and more vulnerable under attack of overtopping flow. Therefore, damages were likely to be initiated around the Casuarina trees and at the existing eroded holes.

At section TL_02, damage was first started from an existing hole. Later on, it was rapidly extended to reach the Casuarina tree. Overtopping flow eroded and carried away soil aggregates hold by the root system that the connection between the Casuarina tree and the dike slope became increasingly weak. The anchoring forces were reduced smaller and no longer sufficient to retain the tree anymore, the Casuarina fell down. Due to the large trunk of about 7 cm wide, the Casuarina tree also caused flow blockage, force intensity was hence increased. Situation of the Casuarina tree before its collapse is shown in Fig 9, right panel.

Steendam et al. (2010) described a test at Vecht dike, in which there was a tree (trunk of 0.8 m wide) on the berm. Grass cover around the tree was already eroded under a discharge of 5 l/s per m, damage developed rapidly resulting a slope failure after about 5 hours of 50 l/s per m. Another similar example is a section at Afsluitdijk, where erosion easily started at both sides of a staircase on the grass covered slope with a discharge of 10 l/s per m.



Figure 9: Left: damage around concrete frames. Right: damage extension to the Casuarina tree.

4.4 Distribution of damages

Damage could be generated at weak spots due to the discontinuity of grass cover and flow concentration. The initial damage was likely to determine the final situation of the dike slope after testing with the Simulator. In Do Son, damage was first initiated at the transition between the dike slope and the canal bank and then extended upward. In Think Long and Thai Thuy, damages were always generated on the dike slopes, there was only one case in which erosion took place at the dike toe at the end of the test. It meant that if damage was initiated on the steep part, the toe would be hardly eroded later on, probability of 1/6. There were 2 tests (TT_02 and TT_03) where damages were found at the transition between steep part and horizontal berm, probability of 2/6. It is solely specification of the grass cover that determines position of the initial damage on the tested dike slope. The damage that is caused by the overtopping flow influences the hydraulic behaviour of the flow. The development process of damage is governed by the overtopping flow and the quality of the grass turf.

5 Maximum wave overtopping discharge on grass slopes

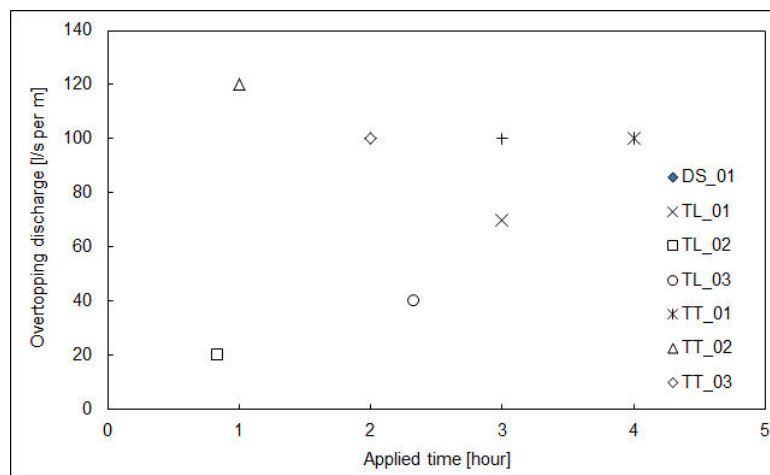


Figure 9: Maximum overtopping rate vs. applied time at 7 tested sections in Viet Nam.

A small number of destructive tests performed in Do Son, Think Long and Thai Thuy has given an impression of the resistance of different grass covered slopes against wave overtopping. At section DS_01, the low slope covered with 2-year-old Vetiver grass was severely damaged after 3 hours of 100 l/s per m. Test replications on a short dike stretch in Think Long, about 50 m long, revealed that strength of grass slope could vary considerably. At TL_01, the maximum applied discharge was up to 70 l/s per m lasting for 3 hours. TL_02 could withstand a overtopping rate of 20 l/s per m. Slope section TL_03 failed after more than 2 hours applying 40 l/s per m. Three tests performed within a 50 m dike stretch in Thai Thuy showed that the maximum applied discharge was likely to be consistent and not less than 100 l/s per m.

If the effect of smaller discharges that were applied before the maximum rate is not taken into account, the maximum rate and its applied time (time to failure) at each tested section are plotted in Fig 10. It can be seen that overtopping resistance of grass slope varies enormously from 20 to even more than 100 l/s per m. This high variability is due to the difference in geometry and soil/ grass characteristics of the tested sections and the length effect.

6 On-going research

By testing with the Simulator, the resistance against wave overtopping of several grass covered slopes were determined quantitatively. The formation and development of damages induced by wave overtopping flow were studied. Interacting relation between overtopping flow (*Load*) and resistance of grass cover (*Strength*) are under investigation.

7 Acknowledgements

The project “Technical Assistance for Sea Dike Research” financed by the Government of the Netherlands is acknowledged for funding to build the Wave Overtopping Simulator and to perform all the destructive tests in Viet Nam. Tests were performed by the Faculty of Marine and Coastal Engineering, Water Resources University, Ha Noi, Viet Nam.

8 References

- Eurotop, 2007. Wave Overtopping of Sea Defences and Related Structures: Assessment Manual. EA Environment Agency, UK; ENW Expertise Netwerk Waterkeren, NL; KFKI Karatorium für Forschung im Küsteningenieurwesen, DE.
- Le, H.T., van der Meer, J.W., Schiereck, G.J., Vu, M.C., van der Meer, G., 2010. Wave Overtopping Simulator tests in Viet Nam. ASCE, proc. ICCE 2010, Shanghai, China.
- Steendam, G.J., de Vries, W., van der Meer, J.W., van Hoven, A., de Raat, G., Frissel, J.Y., 2008. Influence of management and maintenance on erosive impact of wave overtopping on grass covered slopes of dikes; Tests. Proc. FloodRisk, Oxford, UK.
- Steendam, G.J., van der Meer, J.W., Hardeman, B. and van Hoven, A., 2010. Destructive wave overtopping tests on grass covered landward slopes of dikes and transitions to berms. ASCE, proc. ICCE 2010, Shanghai, China.
- Valk, A., 2009. Wave overtopping – Impact of water jets on grassed inner slope transitions. Master thesis, Delft University of Technology, Delft, the Netherlands.
- Van der Meer, J.W., Bernardini, P., Snijders, W. and Regeling, E., 2006. The Wave Overtopping Simulator. ASCE, proc. ICCE 2006, San Diego, US.
- Van der Meer, J.W., Bernardini, P., Steendam, G.J., Akkerman, G.J. and Hoffmans, G.J.C.M., 2007. The wave overtopping simulator in action. Proc. Coastal Structures, Venice, Italy.
- Van der Meer, J.W., Steendam, G.J., de Raat, G. and Bernardini, P., 2008. Further developments of the wave overtopping simulator. ASCE, proc. ICCE 2008, Hamburg, Germany.
- Van der Meer, J.W., Schrijver, R., Hardeman, B., van Hoven, A., Verheij, H. and Steendam, G.J., 2009. Guidance on erosion resistance of inner slopes of dikes from three years of testing with the Wave Overtopping Simulator. Proc. ICE, Coasts, Marine Structures and Breakwaters, Edinburgh, UK.
- VTV, 2006. Voorschrift Toetsen of Veiligheid Primaire Waterkeringen (in Dutch). Ministry of Transport, Public Works and Water Management. ISBN 978-90-369-5762-5.
- Young, M.J., 2005. Wave overtopping and grass cover layer failure on the inner slope of dikes. Master thesis, UNESCO – IHE Institute for Water Education, Delft, the Netherlands.