Sandy Dike

ComCoast – WP3: innovative concept of an overtopping resistant dike

Interreg North Sea Region

SANDY DIKE

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CUR

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Contents

CHAPTER 1 Introduction

1.1 INTRODUCTION

The CUR in Gouda has assigned ARCADIS – Alkyon to further elaborate on their proposal within the European ComCoast project of an innovative concept aiming to improve the overtopping-resistance of sea dikes called ‘Sandy Dike’.

ComCoast is an acronym for “COMbined functions in COASTal Defence Zones”, an innovative concept awarded with the European assignment within the Interreg IIIb programme. Sea defence in the ComCoast concept consists of three elements: an overtoppable sea defence at the seaside, a multifunctional defence zone and a secondary defence line at some distance from the primary defence line. Work Package 3 (WP3) is one of the six work packages within ComCoast and deals with all civil engineering matters.

An important element in the ComCoast concept is the overtoppable sea defence (often a dike). In a traditional design, the height of the dike is determined on the basis of maximum allowable overtopping rates (for instance 1 l/m/s). In the ComCoast concept the landward (inner) slope of the dike is adjusted in such a way that it can withstand higher overtopping rates.

Within this program, the combination ARCADIS – Alkyon developed the innovative concept ‘Sandy Dike’ to improve the overtopping resistance of a sea dike. It was one of three “winning” concepts to get the chance to elaborate the innovative concept in a short theoretical study. A final draft of this theoretical study report was presented at the fourth meeting of the ComCoast Users Group and WP3 team international on the 20th of October. The comments on the final draft and the presentation are taken into account in this theoretical study. The next step is a test case in which the theoretical concept is tested.

1.2 OBJECTIVE

The objective of this study is to elaborate the feasibility of the innovative concept ‘Sandy Dike’ to improve the overtopping resistance of sea dikes by means of a short theoretical study.

1.3 CONTENTS

The focus of the ‘Sandy Dike’ concept and the relation with its environment will be described in Chapter 2. In Chapter 3 the Sandy Dike concept has been further developed in a theoretical study. Chapter 4 gives a provisional design of the concept. Other technical aspects are described in Chapter 5. A short overview of aspects, which should be investigated in a test case, is given in chapter 6.

CHAPTER 2

Sandy Dike

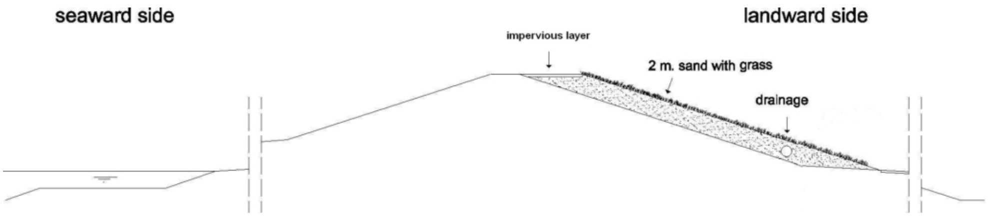
2.1 DESCRIPTION AND SKETCH

The main principle of the Sandy Dike concept is the placing of a sand layer on top of the inner slope to improve the overtopping resistance of a sea dike. The sand layer is a sacrifice layer in case of overtopping. The sand will be washed away during extreme overtopping events, but this will not threaten the stability of the dike if the thickness of the sand layer is sufficient. This is an important decisive factor for the design of this innovative concept. The sand layer is a flexible and dynamic solution, which compares well with the regular maintenance of for instance the Dutch coastline. In this case, however, extreme overtopping will be rare, so that maintenance of the Sand Cover is expected to be minimal. The main design parameter is the thickness of the Sand Cover, which mainly depends on the overtopping rate ($m^3/m/s$) and the total overtopping volume ($m^3/m/storm$).

The overtopping discharge will run over the surface of the Sand Cover, whether it is vegetated or not. Sand will be eroded and be washed downwards. To avoid a situation where the overtopping discharge enters the sand body (in stead of running over the surface), the portion of the Sand Cover at the top of the dike may be paved with clay and /or open tiles ("grasbetonkeien").

Figure 2.1

Sketch 'Sandy Dike'



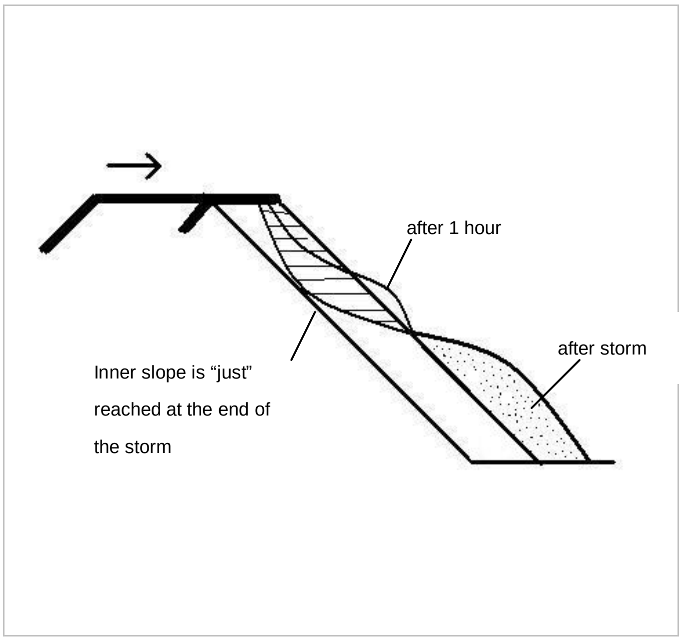
NB. A drainage pipe is optional. It is only necessary if build up tension occurs after heavy rain or overtopping (see section 4.1.3).

Figure 2.2 shows how the sand layer acts in case of a storm. It is rather easy to accommodate for higher overtopping rates. Just make the layer of sand a little thicker. It is just a matter of further design for specific conditions. In principle there is no maximum in overtopping rates as long as the sand layer is sufficiently thick. From a spatial point of view, this concept is especially interesting for Dutch dikes with rare overtopping, because a relatively small sacrifice layer is needed. The concept is less interesting for example for Belgian dikes, where the safety standards are much lower and where overtopping will occur more heavily. A bigger sacrifice layer is needed, which demands more space. More maintenance is needed as well.

An important strength of the concept is its sandy and natural features, especially when vegetated. It creates a more or less natural environment instead. Therefore, it's preferable that the Sandy Dike concept will be used in case a sea dike is situated in a more or less sandy and natural environment. Otherwise the sandy dike will conflict with the surrounding area.

Figure 2.2

Erosion of sand layer



2.2 ITS RELATION WITH THE ENVIRONMENT

The Sandy Dike concept is elaborated for the Westkapelle dike and the Hondbossche zeewering. The relation of the concept with the environment in both cases is described in this paragraph.

Landscape and Cultural History

Regional level

Both the Westkapelle dike and the Hondsbossche – Pettemer zeewering are artificial constructions and characteristic line-elements that break the surrounding landscape. Both dikes have the specific spatial quality of strengthening the contrast between the open wide sea on one side and the small villages (Camperduin, Petten and Westkapelle) and the polder landscape on the other. From a historic and geographic point of view both coastal defence structures are important regional elements in showing the history in coastal defence in Zeeland and Noord-Holland. Although the Sandy Dike looks more like a natural dune, the characteristic line and contrast features and the specific historic quality of both dikes will remain intact.

Figure 2.3 (left)

Hondbossche – Pettemer zeewering

Figure 2.4 (right)

Westkapelse zeedijk

Local level

The construction of a sand cover causes the toe of the dike to move landwards. In case the Hondsbossche Zeeweg/Westerduinweg needs to be moved a little further landwards, any harmful effects on the "De Putten" (historic clay puts) need to be prevented. Probably there is enough space. The interface between the dike and the adjacent polder will change, but if carefully landscaped, it won't harm the typical allotment pattern of the Hazepolder en Vereenigde Harger- en Pettemerpolder. The sandy dike could become a connection between Camperduin in the south and the Pettemerduinen in the north.

At the Westkapelle dike, the provincial road N287 is in some parts closely situated to the dike. Just north of Westkapelle the N287 might need to be moved a little further landwards, which is costly, but won't harm the landscape structure or any cultural historic elements. A sandy dike won't change the sharp interface between the dike and the Walcheren Polder as well.

The concept of the Sandy Dike could contribute to the recreational value of both dikes. A more dune-atmosphere gives a greater comfort for recreation forms like walking and cycling and enjoying the landscape. Although a very robust structure fascinates people as well.

Nature

The free development of vegetation is excellent for this type of reinforcement measures. The Sand Cover concept offers a unique opportunity to increase the ecological quality of the area. By connecting adjacent ecological zones it could function as an ecological bypass for certain species with important ecological value like the "Rugstreeppad, Zandhagedis, Heivlindertje or Blauwe Zeedistel". Especially a wet – dry transition between the Polder and the Sandy Dike contributes to the ecological quality of the area. But also the choice of vegetation could increase the ecological quality. If 'Duindoorns' or ''Duneroses' are planted, they will attract protected birds like the 'Zangertje'. The best opportunity to strengthen the ecological quality is at the Hondsbossche – Pettemer zeewering. The last decade there has been a lot of ecological development in the polder close to the dike. If this area is connected to the sandy dike it could become a wet – dry transition zone with great ecological quality. The sandy dike could also connect the Camperduin in the south and the Pettemerduinen in the north.

Figure 2.5

Example of a wet-dry transition between de polder and the dike.

European and Dutch environmental protection laws protect certain species. In the present situation on both dikes protected species might occur. To make sure no species will be harmed during construction activities an ecological quickscan or research needs to take place. If protected species occur, the construction activities need to be executed with the utmost precision. Eventually, this will result in an increase of the ecological quality.

Figure 2.6 (left)

Zandhagedis

Figure 2.7 (right)

Blauwe zeedistel

Another major benefit of vegetating the sand cover is, that it keeps the sand layer in shape and therefore its safety function. Less maintenance is necessary if the sand cover is vegetated as well. The vegetation also decreases the possible nuisance of sand spray on the adjacent roads and in the surrounding urbanized areas of Westkapelle, Petten and Camperduin.

FLAAUWE WERK

> Another great example for application of the Sandy Dike concept is the “Flaauwe Werk” sea dike on the northwestern coast of “Goeree” (the Netherlands). A layer of sand was placed some years ago on both the inner and the outer slope of the dike. The objective of this sand cover however was not structural, but architectural (landscaping). With the sand cover (which was afterwards vegetated) the dike fitted much better in the environment. It connects the dune areas on the eastern en western side of the dike and functions as an ecological zone between these protected ecological areas and the hinterland. We do believe however, that this sand cover may also prevent the inner slope from being exposed during extreme overtopping events. If that is true, structural improvements of the dike, which are foreseen for the near future may well be postponed. At present, the height of this dike is not sufficient to keep the overtopping rate below 1 l/m/s under design storm conditions (i.e. storm surge with annual probability of 1/4000).

Figure 2.8

Inner slope of Flaauwe Werk

Other environmental aspects

The type of sand that is needed to construct the sand cover has to be chosen carefully and adjust to the type of sand of the environment. Especially if the sand cover has an ecological function. For example, certain species are sensitive for the amount of chalk in the sand.

No important negative effects on the nearby water system are expected. Even positive effects might occur while sand reduces run off compared to clay dikes.

CHAPTER 3 Theoretical study

3.1 PROCEDURE

The concept of a sandy cover along the inner slope of a dike is a known concept (it is for example applied along the Flaauwe Werk in Zeeland), but design rules are not yet available. In order to determine whether a sandy cover will be feasible, the relevant erosion mechanism of the sandy cover has been studied by means of an inventory of the relevant physical processes (see Section 3.2). The study was focussed on only one erosion mechanism: Erosion of the sandy cover due to passing water. Besides this mechanism, there are other erosion mechanisms imaginable that are more related to geotechnical instabilities (sliding of large volumes, pressure build-up inside the sand layer). These aspects should also be dealt with when designing a sandy cover.

Based on the findings from the inventory, a parametric model has been made in Microsoft Excel. Within the model, the relevant processes are implemented and the user is authorised to use different parameter settings and different configurations of the dike (and its sandy cover). See Section 3.3 for a description of the model. Please note that the model has not been calibrated in any way, which means that the model cannot be used for design purposes. The model is only meant for creating understanding of the physical processes.

In Section 3.4 some results of the model tool are given. Model computations have been performed for two locations along the Dutch coast: The Hondsbossche Zeewering and the dike at Westkapelle. The behaviour of the model is tested by means of a sensitivity analysis for the Hondsbossche Zeewering.

3.2 INVENTORY OF RELEVANT PHYSICAL PROCESSES

A literature study has been performed in order to identify the most important physical phenomena, which should be taken into account when designing an overtopping resistant inner dike slope. In this section an overview is given of the findings. The erosion process of the inner (sandy) slope due to overtopping waves has been schematised as shown in the figure below:

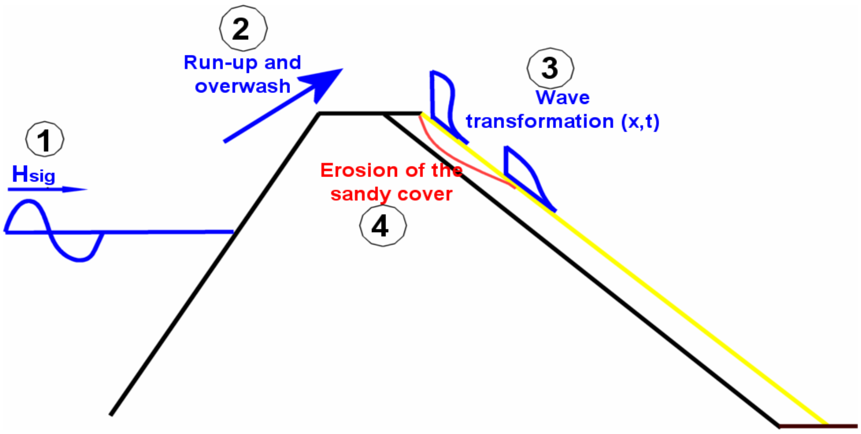


Figure 3.1

Sketch of the erosion process of the sandy layer

1. A single wave approaches the dike;
2. The wave runs against the slope of the dike and when the crest level is lower than the run-up, overtopping occurs;
3. The wave runs down along the inner slope of the dike. During this process, the shape of the wave changes;
4. Due to the passing wave, erosion of the sandy cover occurs.

In the next sections, the process as described above is described in more detail by means of (empirical) formulae.

3.2.1 WAVE RUN-UP AND OVERTOPPING

The wave run-up and overtopping depends on the dimensions of the dike in combination with the hydraulic conditions. This process has been investigated and written in many empirical formulas. It is however found that there is a high variation in the outcome of these formulas. The overtopping volume following the model PC-Overslag [TAW, 2002][1] is given in many reports (and also in the defined test-cases in the proposal request). Within this desk study, the given overtopping volumes from the proposal request were used as input for the model.

3.2.2 OVERTOPPING OF INDIVIDUAL WAVES

Usually, the wave at the toe of the dike is given in the form of a significant wave height. In reality however, the incoming wave field consists of many waves with different heights. In order to take into account the spectral wave height variety, either the probability distribution of the wave height or the probability distribution of the related overtopping should be taken into account. Since waves are depth-limited in the vicinity of the toe of the dike, the wave height distribution is difficult to predict without sophisticated modelling tools. It is therefore decided to apply a probability distribution on the overtopping. For this, a relation from [TAW, 2002] is used:

$P_v = P(V \square \underline{V}) = 1\text{-}\exp(-(V/a)^{0.75})$,
with $a = 0.84 * Tm * q / P_{ov}$

Where: P_v = Probability of an overtopping volume , which is larger than V (-);
V = Overtopping volume (m3/m)
T_m = Mean wave period (s);
q = Average overtopping volume (m3/m/s);

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[1] TAW, 2002, Technisch Rapport, Golfoploop en Golfoverslag bij Dijken, mei 2002

P_{ov} = Nov/N = Probability of overtopping (-);
N_{ov} = Number of overtopping waves (-);
N = Total number of waves during the storm (-)

3.2.3 SHAPE OF THE OVERTOPPING WAVE

An overtopping wave will reshape when it passes the crest and the landward slope of the dike. At the crest of the dike the overtopping water volume is relatively high and narrow. Due to the narrow base, sediment can be picked up over only a small surface. Along the inner dike slope, the overtopping water volume will transform into a more wide and less high volume, which means that sediment is picked up over a much larger surface. This means that most sediment is expected to be picked up along the inner dike slope and not along the crest (if the crest would be made of erodable material).

Since the shape of the overtopping water volume is important with respect to the erosion process of the inner slope, the shape of the overtopping water should be modelled properly as a function of both time and place.

The shape of the wave has been modelled following method II as described in [Steetzel, 1987][2]. This method is based on the following assumptions:

- the overtopping wave has the shape of half a “clock”;
- along the slope of the dike, the shape of this “clock” will change due to velocity differences: The base of the “clock” will increase and the height of the clock will decrease;
- when the “clock” reshapes, the volume (the overtopping volume per wave) will remain the same.

The shape of the wave is given by the following formula:

$$d(x,t)=2A_0/\square[4\square Dt]\ \exp[-(x)^2/(4Dt)]$$

Where: $d(x,t)$: Shape of the clock as a function of time and distance (m);
A_0 : Overtopping volume (m3/m/s);
D : Diffusion coefficient (m2/s);
t : Time (s);
x : Distance (m).

3.2.4 SEDIMENT TRANSPORT MECHANISM

When the overtopped wave is passing an erodable surface (in this case the sandy slope at the back of the dike), sediment will be picked up gradually along the slope. The erosion capacity (in terms of $kg/m^2/s$) of the passing wave is restricted and eventually, the sediment in suspension will reach a maximum value. Within the model, the erosion of the slope has been implemented in a pragmatic way:

$$S(x,t) = (1-Cs/Cs_{inf})*MaxCap$$

Where $S(x,t)$: Sediment transport ($kg/m^2/s$);
Cs_{inf} : The actual sediment content (kg/m^3);

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[2] Steetzel, 1987, Breedte-hoogteverhouding lage grensprofielen, Oriënterend onderzoek naar de relatieve veiligheid van lage, brede grensprofielen, Delft Hydraulics, report H298, part VI (in Dutch)

Cs_{inf} : The maximum sediment content (kg/m^3);

MaxCap : The erosion capacity ($kg/m^2/s$), which depends on (amongst others) the sediment characteristics.

3.2.5 FORMATION OF TRENCHES

In an ideal situation:

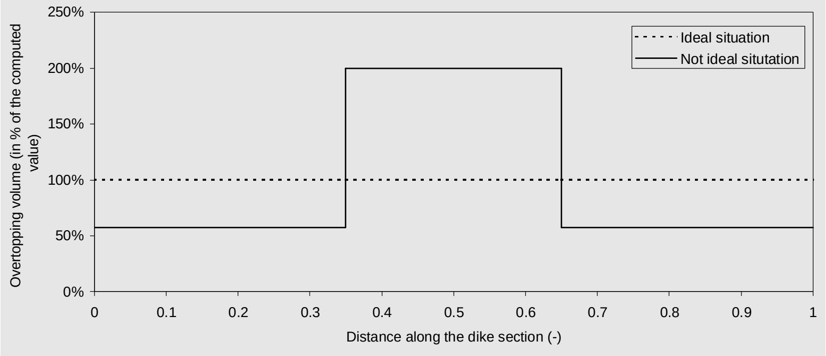
- the dike is perfectly straight;
- the overtopping volume is constant along the crest of the dike;
- the sand layer along the inner slope of the dike is perfectly flat and homogeneous.

In a situation that is not ideal, the layout of the dike and irregularities in the sand layer may cause a concentration of overtopped water at a specific location along the dike. At such a location a trench may occur and the erosion process takes place more rapidly.

In literature nothing is found on the formation of such trenches. However, the impact of a concentration of overtopped water on the erosion process can be schematised as follows. In an ideal situation the overtopping volume is 100% of the computed overtopping volume (the dotted line in the figure below). In a not ideal situation, the overtopping water volume is locally higher than the computed value over a specific portion of the dike section. Along the remainder of the dike section, the overtopping volume will then be lower than the computed value (conservation of water). As an example, this is schematically shown in the figure below. In this example it is assumed that, over a distance of 30% of the total width, twice as much water is overtopped as it would in an ideal situation. Consequently, only 57% of the average overtopping rate will be flow along the remaining 70% of the inner slope.

Figure 3.1

Water redistribution due to trenches



By simulating the erosion process for both the section in which there is a concentration of the overtopping volume and the section where there is a lower overtopping volume, a judgement can be made about the depth of possible trenches.

3.3 DESCRIPTION OF THE MODEL

3.3.1 GENERAL

Based on the processes as described above, a parametric model has been developed. This new model describes the erosion process along the inner slope of a dike. In this section a brief overview is given of the required input data and the outcome of the model. In Section 3.4 the model is applied for two locations (Hondsbossche Zeewering and Westkapelle).

3.3.2 COMPUTATIONAL METHOD

In this section, a short overview is given of the method, which is used to implement the given formulas in an Excel-application.

Based on the input parameters, the wave transformation along the crest and landward slope is computed. Based on the formula as given in Section 3.2.3, the shape of the wave (as a function of x) can be given for every available time. For computing the shape of the wave, arbitrarily 100 grid points are defined along the inner dike slope. The wave transformation is then computed for 100 time steps.

Based on the shape of the wave and the given parameters with respect to the erodability, the sediment concentration in the overtopped water volume is computed. Based on this, the erosion of the sand cover is determined.

The method, as described above, is applied for a specified probability distribution for the overtopping volume (see also Section 3.2.1).

The erosion after a specific time is computed by multiplying the erosion per wave by a user-defined time interval (in hours).

3.3.3 INPUT PARAMETERS

The model requires the following data with respect to the shape of the dike:

- the slope of the seaward side of the dike for computing the wave run-up;
- the height of the crest for computing the overtopping rate;
- the width of the crest;
- the slope of the landward side of the dike;
- the bed level at the landside of the dike;
- the layer thickness of the sand.

With respect to the environmental conditions, the following data is needed:

- the water level;
- the local significant wave height at the toe of the dike;
- the wave peak period at the toe of the dike.

The following parameters should be set:

- the diffusion coefficient, which determines the reshaping (flattening) of the overtopping wave along the crest and landward slope;
- the resistance factor, which determines the velocity of the overtopping wave;
- the maximum concentration of sediment in the overtopping water volume;
- the maximum erosion rate of the passing water (when passing an erodable surface). This parameters depends strongly on the sediment characteristics (grain size, cohesiveness,.....) and the present vegetation;
- contraction of the overtopped water volume with respect to trench formation (see Section 3.2.5).

3.3.4 MODEL OUTPUT

The output of the model consists of the following parameters:

- the shape of the passing waves for 10 different time steps;
- the shape of the sand cover after a time interval, which is specified by the user;
- the remaining thickness of the sand cover after a time interval, which is specified by the user.

3.4 MODEL RESULTS

3.4.1 GENERAL

The model, as described in the previous section, has been applied for two test cases: The Hondsbossche Zeewering and the dike at Westkapelle. The hydraulic conditions and the dimensions of these two dikes were already given in the Request for Proposal (dated April 5th 2005) . The results of the modelling effort are described in the next two sections. These are based on the following parameter settings:

- the diffusion coefficient: 15 m^2/s;
- the resistance factor: 1 s at the crest and 10 s along the sand cover;
- the maximum sediment concentration: 15%, which equals a concentration of approximately 400 kg/m^3;
- the maximum erosion rate: 0 $kg/m^2/s$ at the crest (since it is impervious) and 10 $kg/m^2/s$ along the sand cover;
- contraction of the overtopped water volume with respect to trench formation: 300% of the average overtopping over 10% of the width (see also Section 3.2.5).

The values as given above are probably quite conservative and are based on engineering experience. Physical modelling will be required in the next stage of the project to obtain more reliable estimates.

3.4.2 HONDSBOSSCHE ZEEWERING

The following hydraulic conditions were used for modelling the erosion of the sand cover at the landward slope of the Hondsbossche Zeewering:

- a design water level of NAP +5.49 m;
- a significant wave height of 3.6 m at the toe of the dike ([DWW-2003-040];
- an average overtopping volume of 10 l/m/s (based on the average sea level rise scenario in 2100);
- a crest height of NAP +11,87m and a crest width of 3 m;
- the layer thickness of the sand cover is 2 meters;
- it is assumed that the peak of the storm lasts for 3 hours.

In Figure 3.2 to 3.4 (in the back of this report) the results of the simulation are shown. A duration of 3 hours is considered, which can be seen as the peak of the storm. Figure 3.2 shows the computed profile along a section where there is no trench forming. As it can be seen, the erosion is concentrated at the most upper section of the slope. Along this section most sediment can be eroded since the sediment concentration has not reached the maximum of 15%. Further down, hardly any erosion can be seen. Along this section of the slope, the sediment concentration has reached the maximum value and no more sediment is picked up. Based on the simulation it is concluded that a layer thickness of 1 meter would be sufficient under the mentioned assumptions.

Figure 3.3 shows the computed profile for a section where trenches occur. More erosion takes place along this section because (in comparison to the section without trenches) more water flows along this section. From the simulation it is concluded that a layer thickness of 2 meters would almost be sufficient. Figure 3.4 shows the layer thickness for both sections (with and without trenches). The difference of both lines gives the trench depth in relation to the section without trenches. The trench depth is approximately 0.6 meters.

3.4.3 WESTKAPELLE

The following hydraulic conditions were used for modelling the erosion of the sand cover at the landward slope of the Westkapelle dike:

- a design water level of NAP +5.85 m;
- a significant wave height of 4.2 m at the toe of the dike (conform [DWW-2003-040]);
- an average overtopping volume of 8 l/m/s (conform the average sea level rise scenario in 2100);
- a crest height of NAP +12 m and a crest width of 3 m (estimate);
- a seaward and landward slope of 1 in 5 (estimate);
- the layer thickness of the sand cover is 2 meters;
- it is assumed that the peak of the storm lasts for 3 hours.

In Figure 3.5 to 3.7 (in the back of this report) the results of the simulation are shown. The same type of figures as shown for the Hondsbossche Zeewering are shown here. From the figures it can be seen that a layer thickness of 2 meters would be sufficient in this case. The trench depth is approximately 0.4 meters.

3.4.4 SENSITIVITY ANALYSIS

In the previous two sections the model results were given for two existing dike profiles along the Dutch coast. The parameter settings as used for the simulations were determined mainly on basis of engineering experience. In order to determine the impact of the parameters on the model results, a sensitivity analysis was conducted. This was done for the Hondsbossche Zeewering. The following parameters were varied:

- the overtopping rate (in l/m/s) during the peak of the storm (default value = 10 l/m/s);
- the contraction of the overtopping volume (in %) due to trenching or due to the configuration of the dike (default value = 300 % over 10% of the crest length);
- the maximum sediment content of the overtopping water volume (in %) (default value = 15 %);
- the maximum erosion capacity (in kg/m^2/s) of the overtopping water (default value = 10 kg/m^2/s);
- the diffusion coefficient (in m^2/s), which is related to the shape of the overtopping water volume (default value = 15 m^2/s).

In Figure 3.8 to 3.12 (in the back of this report) the computed layer thickness after a storm peak duration of 3 hours is presented for different parameter settings. A discussion of the results is presented below.

In the figures the remaining layer thickness of the sand cover is presented for different parameter settings. In black, the default parameter setting (see also Section 3.3.3) is given. In red, blue or green, the remaining layer thickness is given for a different setting.

Generally speaking it can be concluded that the parametric model provides results conform the expectations:
- when the overtopping rate increases, also the erosion of the sand cover increases (see Figure 3.8);
- more contraction of the overtopping water volume lead to more erosion in the trench and less erosion besides the trench (see Figure 3.9);
- a higher maximum sediment content results in more erosion of the sand cover (see Figure 3.10);
- a higher erosion capacity leads to more erosion of the sand cover (see Figure 3.11);
- a higher diffusion coefficient leads to a more spread erosion pattern along the sand cover (see Figure 3.12).

With respect to the quantitative results of the sensitivity analysis it is concluded that a contraction of the overtopping water volume does result in a significant increase in the trench depth after the storm. This aspect is not well predictable, which means that the results should be used with care. The diffusion coefficient does not have a great impact on the model results.

The other parameters (overtopping rate, maximum sediment content and the erosion capacity) have a large impact on the erosion of the sand cover. More research is recommended in order to be more certain about these values.

3.5 CONCLUSIONS

Based on a schematisation of relevant physical processes, as obtained from various sources, a practical model has been made for simulating the erosion process of a sand cover along the inner slope of a dike. The model simulates the initial erosion capacity of an overtopping water volume. By multiplying the erosion capacity by a specific time frame, the total erosion during a storm can be estimated.

From the first series of model simulations is can be concluded that it is indeed possible to protect the inner slope of a dike against erosion (and failure) by means of a sand cover.

The erosion of the sandy cover is however mainly described by empirical formulas. Within these formulas, parameters are applied, which cannot be measured or computed easily (such as diffusion coefficients and erosion capacity). Especially these parameters should be studied in more detail in order to obtain more certainty. This could be done by either (very) sophisticated numerical modelling or physical modelling. In Chapter 6 an indication is given of the required tests in order to obtain more knowledge and understanding on the relevant physical processes.

CHAPTER 4 Provisional design

4.1 TRANSITION BETWEEN THE CREST AND THE SAND COVER

The sand cover at the landward slope of the dike is meant for protecting the existing slope against erosion (and resulting failure). For a correct functioning of the sand cover, the upper part of the sand cover (near the crest of the dike) should be protected against local scour. This requires a smooth transition between the crest of the dike and the sand cover.

It is proposed to construct a clay layer on the crest of the dike, on top of the sand with a cloth underneath to make it impervious. Open tiles or grass can be put on top of the clay layer if needed. The construction prevents the starting of the erosion process to take place on top of the dike. In this way, the transition will remain, even when the sand cover along the landward slope has eroded.

A structural design of the transition construction is not given. However some aspects with respect to the functional design can be given. The transition should be able to withstand the following loads:

- During the storm, overtopping rates of several cubic meters area expected to occur. The transition construction should be able to withstand such load;
- The transition should be designed in such way, that a smooth transition occurs with the sandy cover (in order to prevent high erosion rates at the edge of the transition);
- Underneath the transition construction, some erosion of the sediment may occur. This means that the transition should also be stable as a stand-alone construction.

4.2 TRANSITION AT THE TOE OF THE DIKE

Initially, one of the demands was that the slope protection should not extent further landward than the toe of the dike. During the kick-off meeting of the study (dated 27-6-2005), it was however mentioned that this is not a very strict rule. It is therefore decided that the sheet pile (which was originally in the design will not be applied. Instead, the sand cover will be extended up to the hinterland landward of the dike. For this, a stretch of approximately 5 meters needs to be reserved.

4.3 DRAINAGE OF THE SAND COVER

The sand cover may be filled with water during heavy rain and during wave overtopping. This could lead to high pressure and could eventually lead to sliding of the sand cover (especially in case of steep slopes). Sand is however very permeable, which means that build-up of tension is not likely to occur. This should however be checked by a geotechnical expert. If tension build-up is likely to occur, drainage (by means of drainage pipes) of the sand cover can easily solve the problem. Otherwise more regular maintenance might be needed.

4.4 MAINTENANCE OF THE SAND COVER

The Sandy Dike concept doesn’t need much maintenance and is not vulnerable of vandalism. It can be compared with maintenance of ordinary sand dunes. The sand cover may erode gradually due to wind or heavy rain. In order to reduce losses of sand to a minimum, it is advised to stimulate vegetation or construct a flight of stairs underneath the sand cover or drainage pipes to reduce the chance of sliding and the need of regular maintenance. Prohibiting or at least minimize the allowance of human activities to take place on the sandy slope of the dike also contributes to a reduction of regular maintenance. The roads close by at both dikes might need more maintenance. In case of stormy weather, sand spray might drop on the road, which needs to be wiped.

CHAPTER 5 Other technical aspects

5.1 TECHNICAL LIFETIME OF THE MATERIALS AND THE CONSTRUCTION

The lifetime of the sand layer as material is virtually infinite. The lifetime of the pavement on top of the dike can also be 50 years if desired.
The sand is not vulnerable for molest. Even if holes are dug, this will not negatively impact the stability (as during extreme overtopping events, these holes will soon be washed out). The only matter of concern is that the sand may not be removed from the inner slope, but this must be easy to prevent.

5.2 COSTS

Estimated costs for construction per meter dike (with a width of at least 100 m) are between € 600,- and € 900, -. Given for a minimum and a maximum alternative. The maximum alternative concerns the Hondsbossche Zeewering, see also Annex 1.

	Minimum	Maximum
Height	6 m	10 m
Slope	1:3	1:3
Thickness sandlayer	2 m	2 m
Clay layer on crest	1 m	1 m
Cloth	5 m2	5 m2
Tiles (grasbetonkeien) on crest	3 m2	3 m2
Grass on crest	3 m2	3 m2
Vegetation	18 m	30 m

The costs include an admission of 50% other costs and include 19% BTW. The 50% admission consists of 10% incidentals, 15% preparation and execution control, 20% general costs, profit, risks en 5% detail drawings.

The cost for maintenance is approximately € 5-10 per meter dike. It only includes a periodical inspection and minor repairs. After a severe storm, the sandy cover may be fully or partially be damaged. After the storm, the sandy cover should therefore be reconstructed. The reconstruction of the sandy cover cannot taken into account in the figure for the maintenance costs. Severe damage (or even total loss) of the sandy cover will only occur during storm conditions (which occur less than say 1/1,000 per year), which is much longer than the lifetime of any man-made construction.

5.3 PERMITS

The following permits are needed in case of Dutch legislation. No legislative risks are foreseen, although it depends on the specific situation:

- Vergunning i.k.v. Wet op de Waterkering;
- Ontheffing i.k.v. Keur;
- Ontheffing i.k.v. Flora en Fauna Wet;
- Vergunning i.k.v. Wet Milieubeheer (Wm).

CHAPTER 6 Test case

6.1 GENERAL

In Chapter 3 a description is given of a parametric model for simulating the erosion of a sand cover along the landward slope of a dike. This parametric model is based on very limited literature on this subject. In order to calibrate and to improve the model properly, testing of the sand cover principle will be required.

In this chapter a short overview is given of the aspects which should be investigated by means of scale modelling or prototype modelling.

Basically there are three processes, which are of importance and which should be tested properly:
1. The shape of the water volume, which flows along the sand cover;
2. The erosion of the sand cover as a function of time;
3. The formation of trenches.

In the next section a short description is given of the possible testing method.

6.2 POSSIBLE TESTING METHODS

6.2.1 SHAPE OF THE OVERTOPPING WATER VOLUME

The shape of the water volume could be tested by, either:
- a more detailed literature study on this subject;
- sophisticated numerical modelling;
- a scale model test.

In this stage, physical modelling for determining the shape of the way would probably not be appropriate (too expensive in comparison the probable value of the results). It is recommended to conduct a more extensive literature study on this subject and to find out whether there are numerical models available for modelling the wave shape in a more sophisticated way.

6.2.2 EROSION OF THE SAND COVER

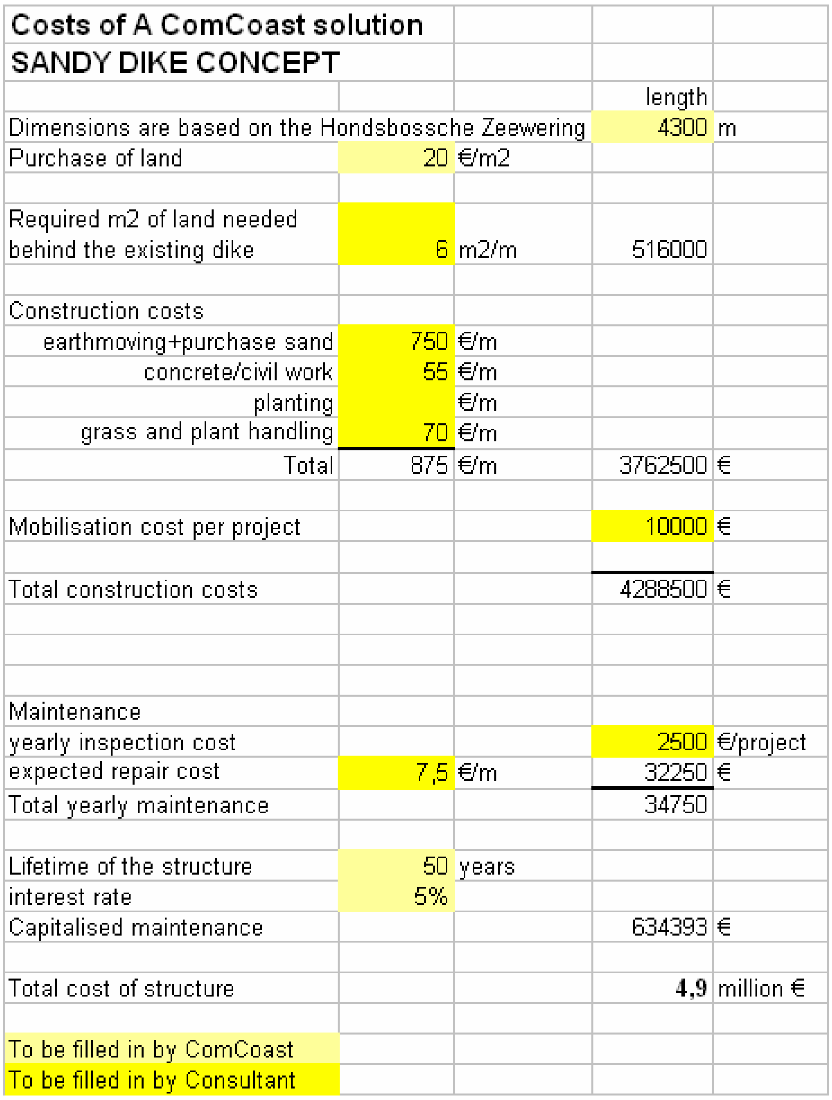
The erosion of the sand cover could be tested by, either a scale model or a prototype model. In a controlled situation the erosion of the sand cover can be investigated without having to deal with 3-dimensional effects such as trench forming and a not-uniform shape of the dike profile. Scale modelling could be conducted in a flume (such as the Delta Flume of Delft Hydraulics). Prototype modelling should be done by placing a construction on the crest of a dike, which is capable of discharging large volumes of water in a short time.

6.2.3 FORMATION OF TRENCHES

The formation of trenches along sand cover is a 3-dimensional process, which depends on various aspects such as the shape of the dike and turbulence in the overtopping water. The formation of trenches should therefore be tested in a 3-dimensional situation. This could either be a scale model or a prototype test.

The advantage of 3-dimensional scale modelling is that the costs will be relatively low in comparison with prototype testing. Another advantage is that every desired situation (with respect the shape of the dike and the overtopping volume can be applied.

ANNE 1 Costs Sandy Dike



Costs of A ComCoast solution				
SANDY DIKE CONCEPT				
			length	
Dimensions are based on the Hondsbossche Zeewering			4300	m
Purchase of land	20	€/m2		
Required m2 of land needed behind the existing dike	6	m2/m	516000	
Construction costs				
earthmoving+purchase sand	750	€/m		
concrete/civil work	55	€/m		
planting		€/m		
grass and plant handling	70	€/m		
Total	875	€/m	3762500	€
Mobilisation cost per project			10000	€
Total construction costs			4288500	€
Maintenance				
yearly inspection cost			2500	€/project
expected repair cost	7,5	€/m	32250	€
Total yearly maintenance			34750	
Lifetime of the structure	50	years		
interest rate	5%			
Capitalised maintenance			634393	€
Total cost of structure			**4,9**	million €
To be filled in by ComCoast				
To be filled in by Consultant				

ANNE 2 Figures

COLOPHON

SANDY DIKE

CLIENT:

CUR

STATUS:

Draft report

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