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Bachelor thesis

February 2017- April 2017

Simulate the erosion process of a dike made of cohesive material in the GWK with XBeach

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Content

Preface

For this thesis I stayed 10 weeks in Hannover at the Forschungszentrum Küste. During the stay in Hannover I did some research on the difference between erosion seen in the flume and erosion modelled with a numerical model. The experiments were conducted by Fugro. The work done for this thesis has been done under the supervision of Stefan Schimmels and Kathelijne Wijnberg. I would like to thank them for their support during the research. Also I want to thank Stefan for giving me the opportunity to do my thesis at Forschungszentrum Küste and for having the opportunity to be present during the experiments in the flume. Also I want to thank all the other people who are working at the Forszentrum Küste for their support and the pleasant time they gave me during my stay. Also I want to thank Clara Spoorenberg and Carolin Briele from Fugro for giving me the opportunity to work with their experiments and giving me some background information on the test.

Summary

At the Forschungszentrum Küste six experiments are conducted on dike erosion with six different cohesive materials. A new dike design should be evaluated with the experiments done in the flume. The goal for this thesis is to get to know if it would be possible to model erosion in a numerical model XBeach.

First there has been looked at the erosion process of the dikes built in the flume. Only three of the tested materials did erode. The erosion process of a dike could simply be divided in two stages. In the first stage the toe of the dike is eroding due to the breaking of the wave steep slope. This slope will be hit directly by the wave, which will dig a hole underneath the material. When the hole has become big enough the material of the dike will collapse. By the force of the waves the material will dissolve in the water. The way of eroding is for all the materials similar, but there is one big difference, which is the eroding rate of the different materials.

A very important part of the erosion process is the run-up and run-down of waves. In order to see whether XBeach is a good simulation for this process the model will be validated with measurements done in many flumes around Europe. The outcome of this validation is that XBeach isn’t very good in modelling the run-up on a slope.

Furthermore there has been looked into the erosion module of XBeach and done a small sensitivity analysis. The erosion module of XBeach consists of two main branches: the sediment transport and the bottom updating/avalanching. For the sediment transport there has been looked in to the two main parameters, the maximum allowed sediment concentration and the time material needs to be absorbed by the water. For both values the change in the erosion isn’t very big, therefore it would be recommended to use the default value in the final simulation of the dike in XBeach. The second part of the erosion module of XBeach is the avalanching. Avalanching is the module of XBeach which accounts for the suddenly collapse of material. There are three important parameters: the maximum slope for both dry and wet material and the maximum amount of falling material per second (D_{max}). Especially the value which is chosen for both the maximum dry and wet slope has a large effect on the erosion process in XBeach. Compared to the experiments in the flume the maximum slope for dry material is not steep enough to simulate the process. It seems that the default value for D_{max} is nearly large enough to let erode all the material. Therefore it would be recommended to use the default setting for the D_{max}.

In the present version of XBeach it isn’t possible to simulate cohesive material. There are many differences between the way of eroding in the flume and the way XBeach is simulating the erosion process. XBeach is only capable of roughly giving an indication of the first 1 to 1.5 hour of the experiments. After this the slope is too steep to work with for XBeach.

At first sight the physical process in XBeach looks completely different from the process in the flume. But in the numerical process of XBeach there are parts which have the opportunity to be used for different processes. The greatest challenge will be to make the model work with materials which are cohesive. This of course will affect all the other processes which are happing in the model.

1 Introduction

In the past only the best clay has been used to protect a dike, but this has become harder to find which, makes it an expensive material to use. In the experiments six different kinds of materials, which can be found near the project in Limburg, will be tested. The thesis will be based on experiments which are done for Fugro in the large wave flume at Forschungszentrum Küste (FZK). These experiments were done to evaluate the strength of a new dike design which is going to be built in Limburg alongside the banks of the river Maas. In figure 1 there is a drawing of the design of the dike. The main difference between this design and another dike designs is that the natural layer will naturally erode over time. This means that the outside of the dike isn't covered with grass or any other protection, therefore there should be a layer which can erode before the dike breaks. This erosion layer should be big enough to protect the dike during high discharge in combination with a storm. The first part of the erosion layer is more of a design layer (natural layer), this layer will erode due to weather influences and won't be considered as protected layer. After the natural layer there will be the erosion layer. This layer is there to protect the normal dike form a design storm. For this kind of design there are no regulations or methods available to calculate the dike. Therefore, there are done some experiments in the flume. The purpose of these experiments is to get an idea of the way in which different materials are eroding under the influence of waves.

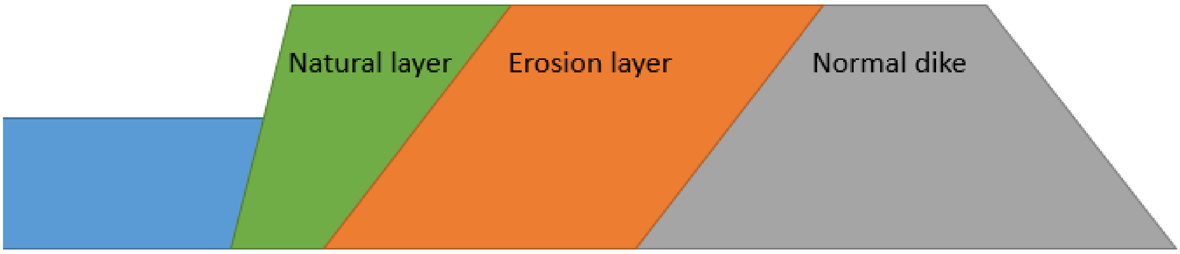

Figure 1 new dike design

In order to use the outcome of different materials used during the experiments, done in the Großen Wellenkanal(GWK), in the future it would be nice to have a model which can simulate the erosion of the different material. In order to simulate the erosion process an already existing model named XBeach will be used. The choice for this model is made because there is a lot of information about it and there are people at the FZK working with XBeach. For example there is made use of the manual of XBeach and a lot of papers on different research done with XBeach.

1.1 Problem definition

XBeach is a numerical process based model. It has been used a lot for different cases to simulate the erosion process of coastal dunes. The problem with using XBeach is that it is built for simulations with sand, which is a non-cohesive material. The experiments, which are done in the flume, are done with cohesive material. this causes a problem because XBeach isn't capable with simulating the material used in the experiment. Not only is the material cohesive, but also the input for sediments for XBeach is different than the model normal to handles. Furthermore the circumstances are different than in the normal world. The waves in the flume are only in one direction and the walls create another boundary than in the real world.

1.2 Research aim

The overall goal of this study is: "**To *which extent can XBeach be used to simulate the erosion of a dike made of cohesive material in the GWK***?" To answer this question there will be made use of four sub questions.

To get an idea whether XBeach is a good model to simulate erosion of cohesive material it is necessary to get an idea about how the erosions process of a dike is occurring in reality. In order to stay in the scope of the main question this sub question will only be about the erosion process in the GWK. The question gathered from this is:

"How is the erosion of a dike (made of cohesive material) occurring in the GWK?"

To simulate the process in the flume, with XBeach, there are a lot of model parameters needed. These will be different from the normal value of a simulation in XBeach, because there are some simplification and other circumstances in the GWK than in the real world. therefore it is a good idea to have a look in to the hydrodynamic behaviour of XBeach compared to the hydrodynamics of the flume. The question gathered from this is:

" To *which extent can XBeach simulate the hydrodynamics in the GWK?"*

For this question there will be looked in to the run up because this is an important factor in the erosion process. This is because the run-up and run-down

In order to get an idea about how well the simulation of XBeach is, in simulating the circumstances in the flume, it is necessary to have an idea about the sensitivity of the simulation of XBeach. The question gathered from this is:

"How sensitive is XBeach in the sub module of dune erosion to parameter changes?"

For this question there will be looked into the parameters which have control over the erosion process. There are two main process which control the simulation of the erosion in XBeach, which are the parameter for the sediment equations and the parameters which have influence on the avalanching (slumping material).

XBeach is a model which is made for a sand dune which is a non-cohesive material. In order to let it work with cohesive material it would be necessary to make some changes to XBeach.

In order to get an idea how good the simulation of XBeach is, it will be compared with the measured erosion, occurred in the GWK during the experiments. The question gathered form this is:

"How well can XBeach simulate the sediment dynamics from a dike made of cohesive material in the GWK?"

For this question there will be done a simulation with settings which are found appropriate. And the result of the simulation will be compared with the measured erosion in the flume.

2 Method and materials

In this chapter there will be talked about the model setup used and the date which is necessary to answer the research questions

2.1 Model set up

For all the runs of XBeach, except the one used in chapter 7, there has been made of the grid as can be seen in Figure 2. The distance between each point is 0,25 meter and the height of the slope is 5,5 meter. This model is used, because the slope is long enough to simulate the whole run-up and run-down.

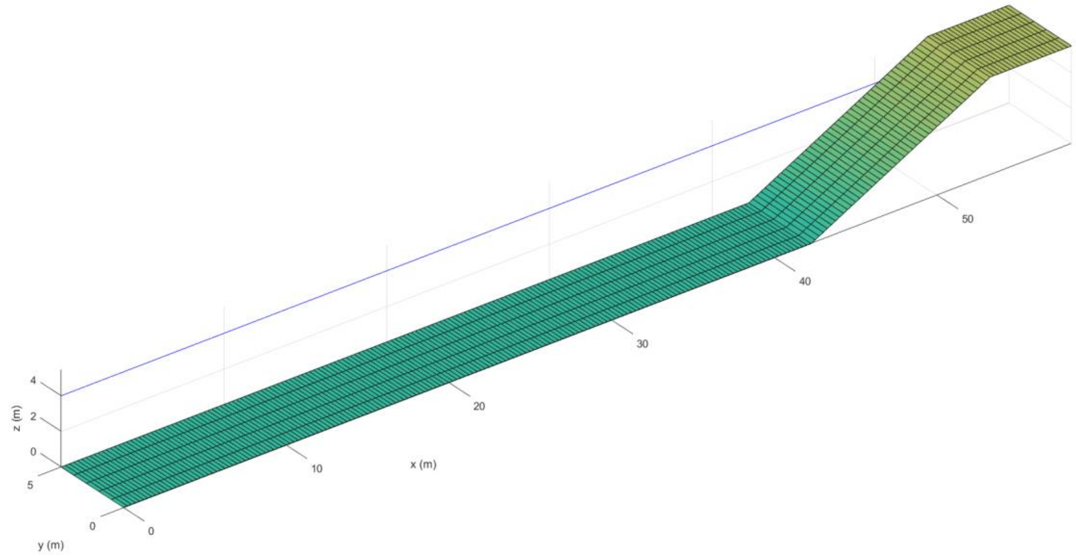

Figure 2: used grid for model (only used in 2D)

Al the simulations are conducted with the settings as can be found in Tabel 1.

Tabel 1: parameters used for the XBeach runs

Parameter	Value
Simulation time	3600 (s)
morfac	6 (-)
D90	0.0001 (m)
Hm0	0.4 (m)
Fp	0.3 (s^{-1})
Dry slope	1 (-)
Wet slope	0.3 (-)
maximum speed avalanching	0.05 (m/s/m)
Maximum sediment concentration	0.1 (m^3/m^3)

2.2 Data set

The data of the measured erosion are gathered after every 1,5 hour of testing with the 3D scanner. This data are processed to a x, y and z-grid with a spatial resolution (in both x and y direction) of 10 centimetres, as can be seen in Figure 5. These data are processed in MATLAB in order to get three 2D profiles out of it. The three profiles consist of one in the middle of the dike, one 50 centimetres right of it and the other one 50 centimetres left of the middle (as can be seen in Figure 3). The profiles are chosen because the erosion varices along the slope, because the reinforcement with the good clay cause a disturbance in the waves. Therefore there will be focused on the middle of the slope.

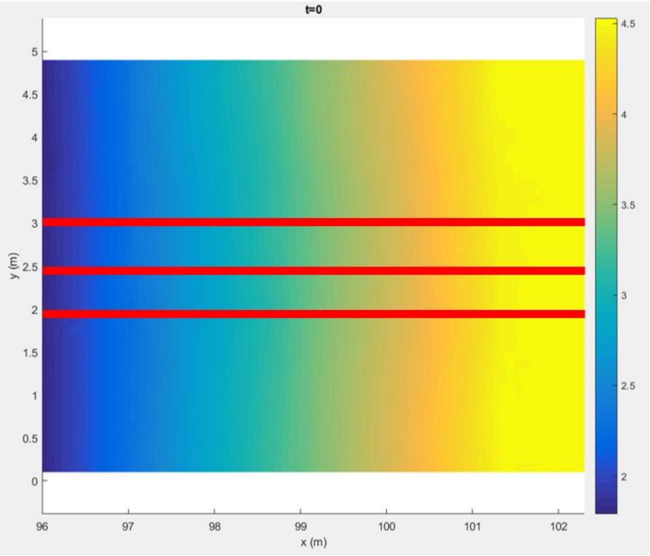

Figure 3: Top view of the dike with the places were the profiles are taken

The outcome of XBeach can be in two different formats. The first one is very hard to process, because all the variables are in different files. Therefore the netcdf output has been used. With this output type all the variables for every second will be written to one file. This file can then be further processed with the use of MATLAB.

2.3 Experiments

In the flume there are done six experiments with different materials (see Table 2). Only three of them had some significant erosion so the focus will be on those three.

2.3.1 Experiments set up

In the GWK the dike was built on the same scale as it going to be built in the field. The slope of the dike is 1:2 and built with material collected at the site in Limburg in the Netherlands. Because all the material has to travel a long distance not the whole dike in the flume was made of clay and sand.

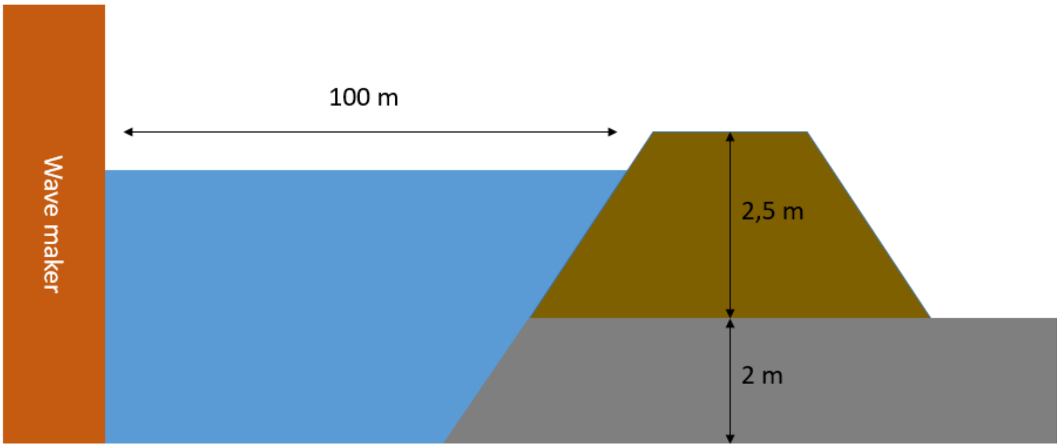

Figure 4: experiment set up

On the bottom there were laid a few concrete blocks to decrease the amount of material necessary to build the dike (as can be seen in Figure 4). Also in Figure 4 the setup of the dike in the flume can be seen, the slope of the dike is 1:2. In Figure 5 an image of the 3d scan made at the start of one of the experiments.

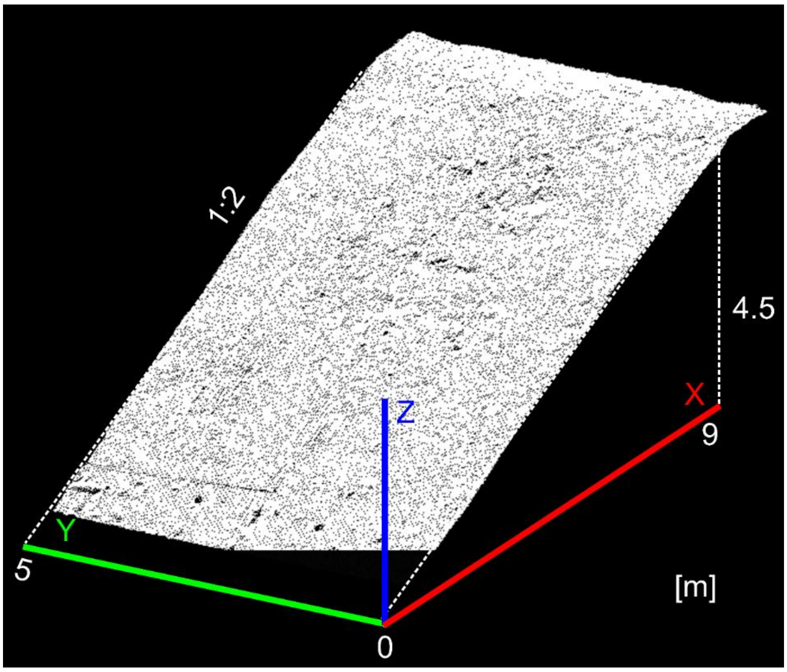

Figure 5: 3D picture of the slope made with a 3D scan (with axes of used in the flume and model)

All of the six experiments are done in the same way. The dike was exposed to 4 cycles of waves with a duration of 1,5 hour. During the first experiment there were constantly made 2D laser scans of the profile of the dike and the waves. Because a lot of erosion happened underneath the water level this didn’t have an added value to the experiments so this wasn’t done for all the experiments. After the 1.5 hour the flume was drained so the erosion underneath the water table was visible and could be measured with the laser scan and a mechanical profiler. The mechanical profiler was also not used for all of the experiments because by running the wheel of the mechanical profiler over the slope it pressed the material together which had an effect on the erosions at those places. In the second experiment there was a problem, because the material wasn’t cohesive enough to stick to the side of the flume, which caused a lot of erosion on the edge of the dike, as can be seen in Figure 6. In order to prevent these boundary effects along the sides of the flume. The dike edges were reinforced with material A (see Table 2) on either side of the dike (±0.5 m).

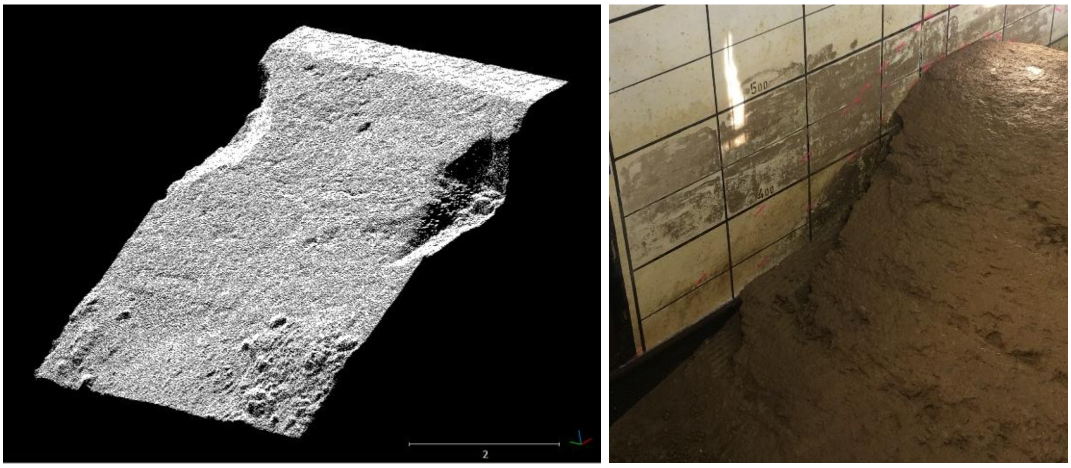

Figure 6: 3D scan and picture of the erosion on the sides

The waves were generated with four similar JONSWAP spectra. As said in 3.2.2 if the parameters of the spectra are the same, the waves that are formed are different every time. For the spectra the following parameters were used: a significant wave height of 0.4 meter and a wave period of 3.0 seconds.

2.3.2 Material

In the table below the different materials which were used for the test could be found.

Table 2 materials used for the six experiments

Material	clay%	silt%	sand%	classification
A	24.3	70.2	5.5	Silty clay
B	18.8	42.5	41.3	Silty clay
C	14-16	42-44	41.7	Silty clay
D	28.2	65.5	6.3	Sandy loam
Waterboard I	14.3	82.9	2.8	Sandy loam
Waterboard II	16.7	80.3	3	Sandy loam

During the six experiments different materials are used. These materials could be divided into two groups, silty clay and sandy loam. This classification is based on the NEN 5104 norm.

The silty clay was so cohesive that there was nearly no erosion during the experiments so this will be excluded from the research. So the focus will be on material D, Waterboard I and Waterboard II.

3 Theoretical frame work

In this chapter there will be described which background materials will be used during this thesis.

3.1 Erosion process

A large part of this thesis is about understanding the erosion process of a dike due to waves. In general, there are two processes involved in the erosion process. The first one is the erosion of individual particles, this kind of erosion is called surface erosion. Another kind of erosion, which is called mass erosion, is the erosion of large lumps of material. According to De Vroeg (2002) in compacted cohesive soil, as used in a dike, it is unlikely that there is a lot of surface erosion. Therefore, for cohesive material, mass erosion is the main erosion to focus on. Compaction will affect the erosion resistance, if a soil is more compacted it will be less vulnerable to erosion.

One of the important erosion mechanisms during a wave attack is caused by the force of the breaking of the waves. As said before, for cohesive material, the main erosion due to wave attacks is the knocking loose of chunks of material. These chunks of material could be loosened by different mechanisms. The erosion mechanism is caused by the pressure due to the waves on the slope, the forces caused by the breaking of the waves on the slope and the water which flows over the slope. Due to the interaction of the different mechanisms the erosion process will evolve progressively.

3.2 XBeach

XBeach is a numerical model developed by Deltares. The model is being used to calculate the hydrodynamics and the sediment dynamics of a dune close to the shore during a storm. This model could be used to simulate the erosion of dunes or the impact of hard structures on the sediment transport. The model is process based on physical mathematical principles. The model is made for modelling a sandy coast of a few kilometres, in the time scale of the duration of a storm. But it has been applied in many other applications (Deltares , 2017).

XBeach has two modes: a hydrostatic and a non-hydrostatic mode. In the hydrostatic mode, the short wave amplitude variation is solved separately from the long waves, currents and morphological change. This saves considerable calculation time, but the fact that short waves are not simulated is a simplification. A more complete model is the non-hydrostatic model which solves all processes completely, including the short wave motions, but it demands more calculation time.

In the figure below the flow chart of the model can be seen. This is a basic scheme of the way in which XBeach solves the different parts of the numericalization of the physical process.

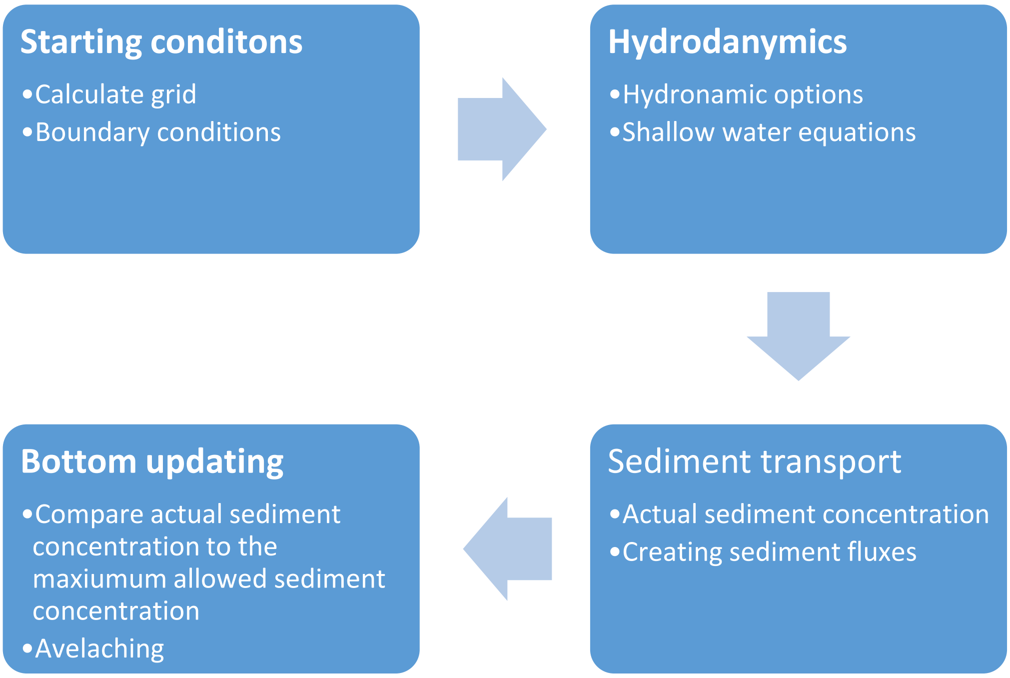

Figure 7: basic scheme of XBeach Model

3.2.1 Grid

In order for XBeach to work it is necessary to have a grid of the area. The input to make a grid is the x coordinate with the responding y and z coordinate. In this case the y value is the width of the flume and the z value is the coordinate of the bottom. With these coordinates XBeach is capable to calculate a grid form the bathymetry (bathymetry is the underwater equivalent of topography).

The grid at the start is the starting point for the simulation, in which the water levels and bed levels are defined in the centre of the grid cell. The velocities and sediment fluxes are defined in points at the outside of a cell as. Because there will be worked with a 2D profile, there will be no fluxes in the direction perpendicular to the wave direction for this simulation.

3.2.2 Waves

The waves will be generated according to a spectrum. There are different types of spectra XBeach is capable of working with. The type used is a parameterized spectrum, called Joint North Sea Wave Project (JONSWAP). This spectrum consists of two main parameters which describe the waves. These are the significant wave height (H_{m0}) and the a wave period (T_p). XBeach makes use of the freak peak frequency which is one divided by the wave period.

3.2.2.1 Nonlinear shallow water equations

The shallow water equation describes the propagation of the waves, which is simply the propagation of the water surface elevation. The wave height is relativity small compared to the wave length (the reason why it is called shallow water equation). The equation is derived from the Navier-Stokes equations (Navier-Stokes describe the motion of fluids and can be seen as Newton's second law of motion for fluids) with a few simplifications: water is incompressible and pressure is hydrostatic.

3.2.2.2 Hydrodynamics options

XBeach has two modes: a hydrostatic and a non-hydrostatic mode. The main difference is the way the pressure is calculated. In the hydrodynamic mode the pressure of the water column is calculated as an depth average. In the non-hydrodynamic mode the pressure differs over the column length due to flows and gravity. In the hydrostatic mode, the short wave amplitude variation is solved separately from the long waves, currents and morphological change. This saves considerable computational time, at expense that the phase of the short waves is not simulated. A more complete model is the non-hydrostatic model which solves all processes including short wave motions. (Deltares, 2017)

Because the initial model of XBeach works with hydrostatic pressure there are made some corrections in the model which makes it possible to simulate with non-hydrostatic pressure (P.B. Smit, 2014).

The main advantage of the non-hydrostatic approach is that every wave is calculated individually, which makes the model more accurate. However, due to the calculation on an individual wave scale, the model grid size has to be relatively small, making the non-hydrostatic approach computationally expensive, and therefore not suitable for all modelling cases.

3.2.3 Run up

The run-up (and run-down) isn’t directly calculated in XBeach. It is derived from the last wet point. A wet point is determined by the parameter ‘Rugdepth’, if there is more water on a cell than described in the parameter, XBeach will handle it as a wet cell. In all the simulations the value for ‘Rugdepth’ is 6 mm. With this parameter XBeach will give an output of the last wet point for every second.

How high a wave is running up the slope is calculated according to the friction the slope is causing. The friction coefficient (c_f)is a dimensionless coefficient which can be calculated from different sources. The different options are, the Chezy coefficient, the Manning's Roughness coefficient and the grain size. In the simulations is made use of the grain size because for the different options the values weren’t very clear for the different materials. In Equation 1 the formula for the friction coefficient is given.

$$c_f = \frac{g}{\left(18 \log\left(\frac{12h}{3D_{90}}\right)\right)^2}$$

Equation 1: formula for the friction coefficient calculated with the D90 grain size

With the c_f the shear stress of the slope in the x and y direction is calculated. Because the simulation is only in 1D[1] the stress will only be calculated in the x direction. This stress will be used to compute the decreasing energy of the wave. The loss of energy determines how high the wave will run-up.

3.2.4 Sediment transport

In the model there is made a distinguish between two different types of sediment transport, the bed load transport and the suspended load transport. Bed load transport is the transport of particles close to the bed, the sediment has contact with the bed. Due to high stress, caused by breaking waves in the soil, it is also possible that bed load transport doesn't consist of lose particles. The suspended load transport is the transport of particles freely floating in the water column.

XBeach models the actual sediment concentration in a water column as depth average of the column separately for the bed load and the suspended load. For both transport types the actual concentration is calculated, this is called the equilibrium concentration. If the actual concentration is lower than the maximum concentration then material will be removed from the bed. The other way around: if the actual concentration is higher than the maximum concentration material will be deposited. If the maximum sediment concentration is higher more material can be transported.

The actual sediment concentration depends on the grain characteristics and flow conditions. The actual concentration can be calculated by combining two equations, with both the same idea. If the calculated velocity is bigger than the critical velocity value, which is a value at which the material starts to move, the particles will move. The velocity is calculated by the flow velocity, the orbital velocity near the bed and the velocity of falling particles.

Described above is the way XBeach models the sediment behaviour in one cell. But there is also transport between cells, which can be divided in two directions: the direction along the shore (longshore) and the direction perpendicular to the coast (cross-shore). Because there is worked only in with a 2D profile the longshore transportation isn't present. Due to the motion of the waves, wave asymmetry, wave skewness, and the retuning flow of water there will be created a flux of sediment to other cells (Trouw, Zimmermann, Mathys, Delgado, & Roelvink, 2012).

3.2.5 Bottom updating

Due to the sediment fluxes, generated by the sediment transport equation, the bottom will change. As said before the calculated concentration will be compared to the maximum concentration. An important option for the bottom updating is the morphological acceleration factor. This factor speeds up the running time of the model. This factor divides all time parameters internally in the model. At the end the result will be multiplied with this factor. In other words, if the morphological acceleration factor is 6 then the model runs every hour 10 minutes and the result will be multiplied by 6. This saves a large amount of computing time, but the use of the morphological acceleration factor is only useful for tests for which it is not necessary to have the output at every time step.

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[1] Although the model uses a 2D profile, the water and sediment processes are simulated in 1D, this means that the model works with a depth average value for every cell.

3.2.5.1 Avalanching

A part of the bottom updating is the avalanching. This part calculates the amount of slumping material. This accounts for the falling down of large parts of material due the fact that the slope is steeper than the material can handle. For both wet and dry material it is possible to set a critical slope. It is thought that wet material is more prone to slump and therefore the value is lower (0.3). The value for a dry slope has a default setting of 1. The critical value for both slopes is defined according to Equation 2 and Figure 8.

$$C = \frac{\Delta Z}{\Delta \mathrm{X}}$$

Equation 2: Critical slope

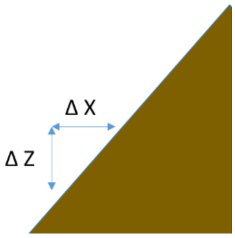


Figure 8: way delta x and z are defined

When this critical slope is exceeded, material is exchanged between the neighbouring cells. This happens up to the point where the amount, that is needed to bring the slope back to the critical slope, is reached. In order to prevent large shockwaves in the water, caused by the slumping of large amounts of material, there is a maximum speed for the change of the slope.

4 Erosion process in the flume.

As said in chapter 2.3 the focus will be on the three experiments were there was a lot of erosion. This chapter is based on material D, Waterboard I and Waterboard II. In this chapter there will be focused on the first sub question:

"How is the erosion of a dike (made of cohesive material) occurring in the GWK?"

4.1 Observations

The observations were made during the experiments which were done in the large wave flume. There were conducted three experiments with nearly the same eroding materials. All three experiments had a duration of 6 hours, divided in runs of 1,5 hour. After the 1.5 hour the flume was drained, so the erosion underneath the water table could be observed.

As can be seen in Figure 9, the dike isn't eroding homogeneous. This is because the sides of the dike are made of very cohesive clay (the darker soil in Figure 9). This is done because the material used in the test isn't cohesive enough to stick to the sides of the flume. In the first test run, with a different material, nearly the whole sides of the slope of the dike were eroded after 1,5 hour. The layer of clay did effect the waves, as it isn't eroding with the same speed as the other materials. This effect is clearly seen in Figure 9, as there are 3 places that eroded. The two holes on the side could be explained by the fact that the waves are running up the good clay and then smash down, causing more erosion in this way. Because this is a drawback of the test, the focus will be on the middle segments of the dike.

Figure 9 dike after 1,5 hour of testing waterboard I

The way of eroding isn’t in small parts, but large chumps are falling off. Water has found a way through and then the material will be hit every time by the force of the waves. Because of the materials being very flexible, every time a wave hits the materials it is moved quite a lot, but it doesn’t erode.

The eroding process can be divided in two stages. During the first stage, when the dike is still in its original shape, the erosion process could be described in four stages, as can be seen in Figure 10. Waves slam into the slope of the dike. The force of the breaking wave causes a hole in the dike (see Figure 10 A & B). The retracting of the waves will put a force on the material. Eventually the force of the waves will erode the material until there will be a horizontal plane.

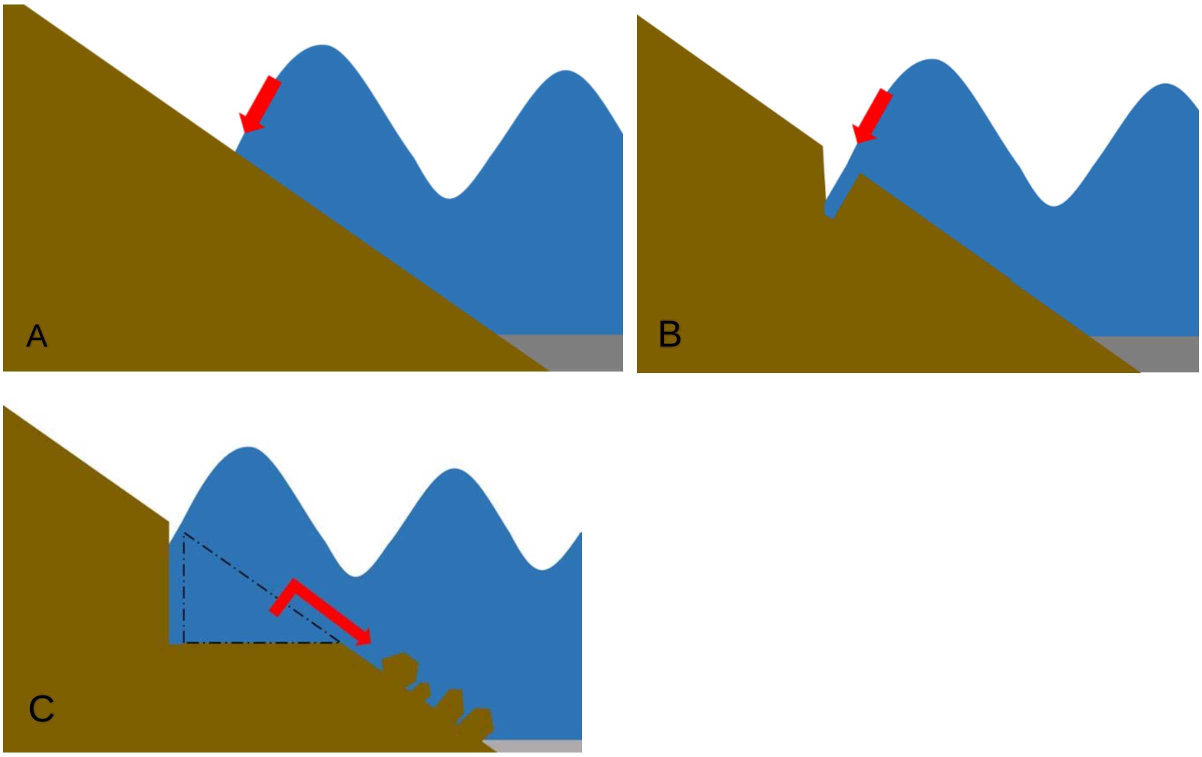


Figure 10: model of the first stage of the erosion process

Figure 11: slope after 3 hours

In Figure 11 the same dike is shown three hours of testing later. It can clearly be seen that the whole slope of the dike is eroded and that the waves are eroding the material under the top of the dike.

Figure 12: the way material is left on the slope

After the first process is finished the toe of the dike is eroded. A nearly vertical wall will be left. This wall is above the water level, therefore the waves will hit on the vertical wall. There will be erosion underneath the dike crown, this causes protrusion. By the force of gravity the material will crack at the crown of the dike. When the cracks are big enough, the material will fall down. After the material has fallen, down it will dissolve in the water because of the force of the wave. As can be seen in Figure 12 the material will be left on the slope or on the bottom of the flume. The whole prosses is schematized in Figure 13.

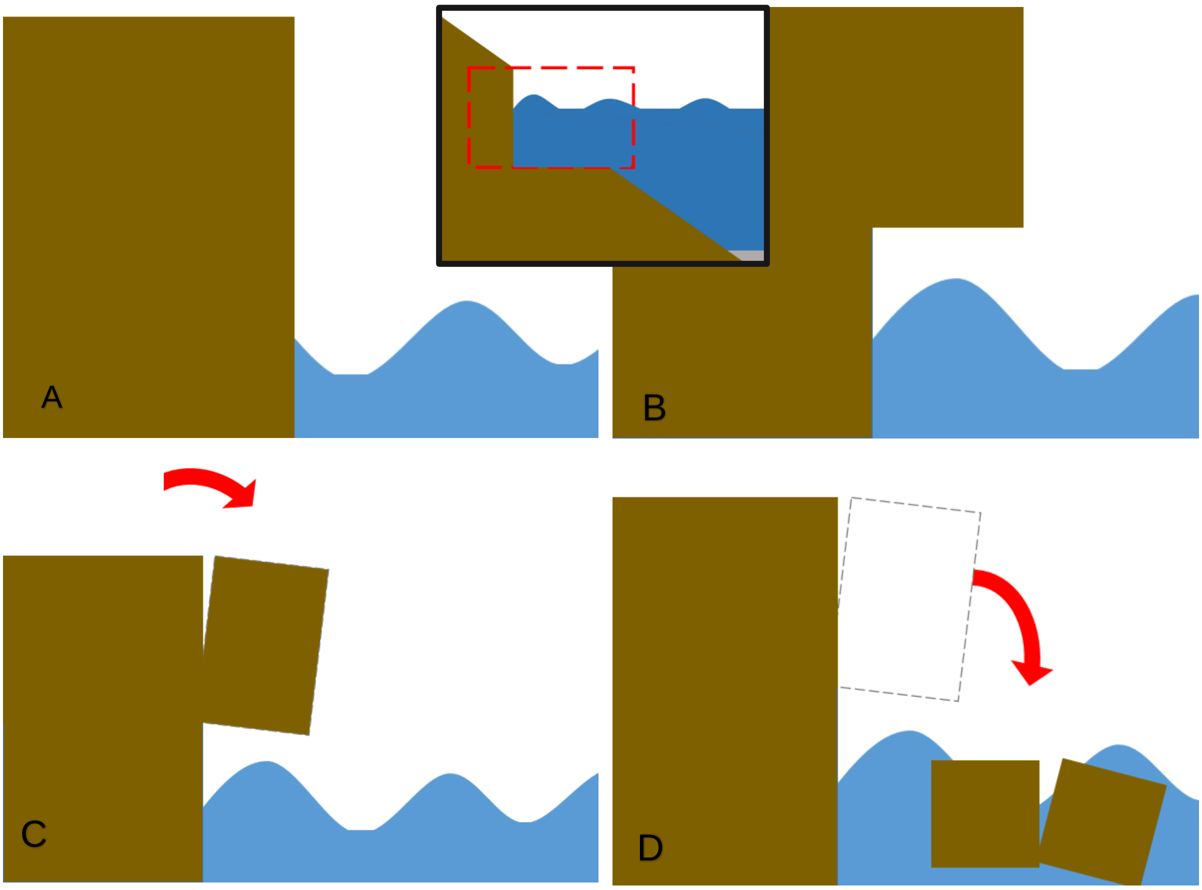
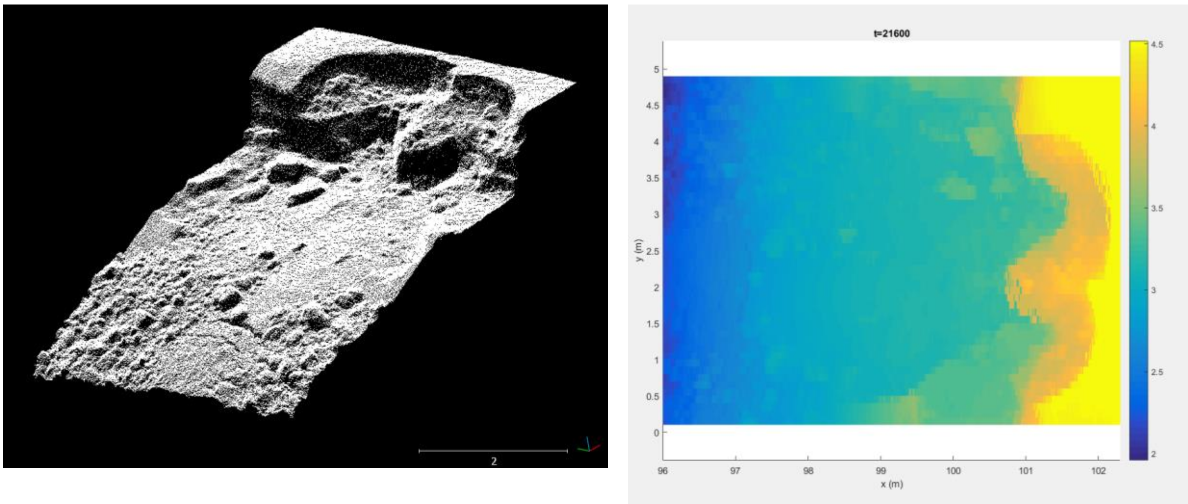


Figure 13: model of the second stage of the erosion process

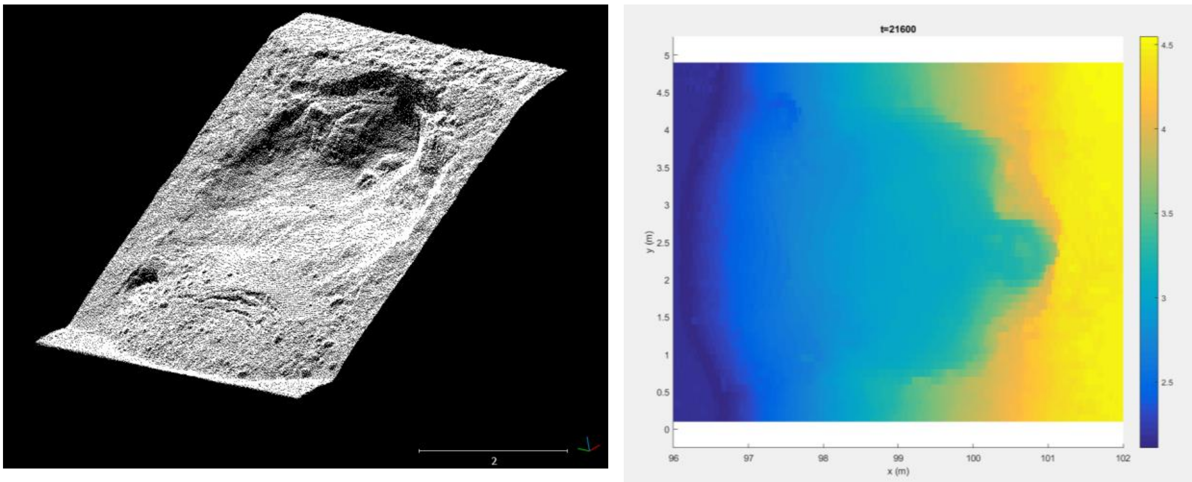
4.1.1 Measured erosion

In Figure 14 the results of the experiments are shown (both 3D and top view). What clearly can be seen are the influences of the material placed on the sides of the dike. This also could be an explanation of the fact that holes are cut in the material. Because good clay is used the sides aren't eroding at all. Because the slope is still intact on the sides the waves will run up and slam down towards the middle of the dike, which creates more erosion just behind the good clay. What also can be seen in Figure 14 is that the speed of the erosion process is different for the different materials, Waterboard II has a lot more of erosion than the other materials.

Material D



Waterboard I



Waterboard II

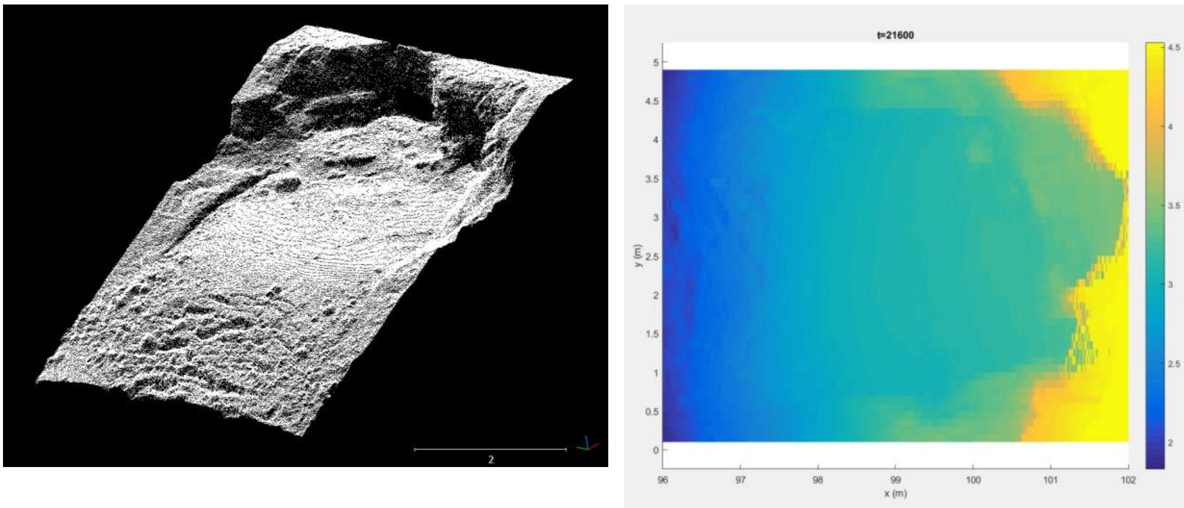


Figure 14: the measured erosion with 3D scan after 6 hours

4.2 Conclusion

The erosion process of a dike is simply divided in two stages. During the first stage the toe of the dike is eroding, due to the breaking of the wave and the run-up and down. The toe of the slope will erode, which creates a very steep slope. This slope will be hit directly by waves which will dig a hole under the material. When the hole is big enough, the material will collapse. By the force of the waves the material will dissolve. There is a difference between the different materials that are used: the way of eroding is nearly the same for all the materials, but the speed of eroding is different as can be seen in Figure 14.

5 XBeach simulating the run up

In order to answer the question: **“To which extent can XBeach simulate the hydrodynamics of the GWK?”** the outcome of the model XBeach will be validated against the run-up of the waves. 1To which extent can XBeach simulate the run-up on the dike in the GWK?

5.1 Run-up

The run-up of the XBeach will not be validated with data of the experiments because this isn’t possible. Therefore the outcome of the model will be validated with the overtopping manual.

The simulation is done in 1D, because the run-up should be homogeneous over the entire length of the dike. In figure… the bathometry of the dike can be seen. The angle of the slope in the model is the same as the angle in the flume. In the model the slope is made longer, to assure that there won’t be an overtopping wave as is the case in the flume.

For this test there will be worked with a non-erodible surface, which makes it be possible to have the same run-up during the whole test run. The model will be set to non-hydrostatic pressure. The model will now use the non-hydrostatic pressure term and fully resolves all wave motions, so the run-up will be solved completely.

5.1.1 Validation

In Figure 15 the result of the simulation of the run up can be seen. The run up height is the vertical distance measured from the water level. In the figure only 800 seconds of the total simulation time of 3600 seconds are shown. This is because otherwise the image would be too crowded. The other time series are similar to this one.

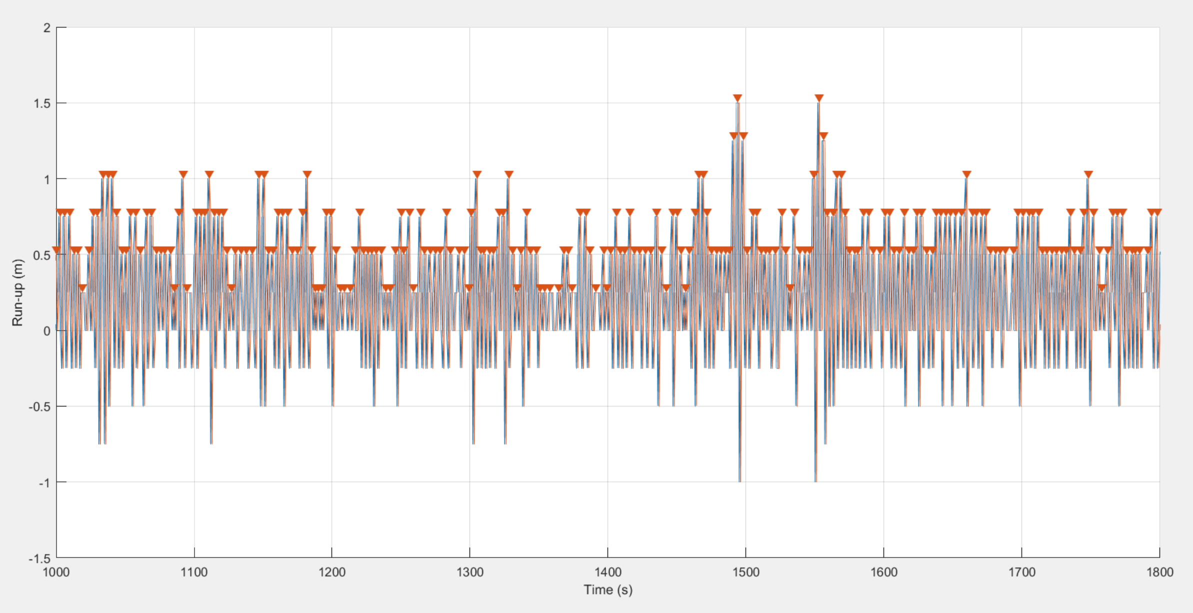


Figure 15: Run-up from 1000 to 1800 second

The outcome from the overtopping manual (calculation in attachment) for the top 2% run up on such a slope, with this wave characteristics, would be 1.975 meter. The outcome of the simulation is that the top 2% run-up of approximately 1000 run-ups is 1.275 meter This value is lower than the overtopping manual.

5.1.2 Sensitivity

As Said in 3.2.3 the friction coefficient is calculated from the D90 grain size. In order to get an idea how the model works with the different values the grain size.

Tabel 3 outcome of sensitivity

D90	Setting	2% run-up
0.0001	Min	1.3125
0.0003	Default	1.2750
0.0015	Max	1.2625

As expected, when the grainsize is smaller, the slope will be smoother and the drag coefficient is smaller. The problem is that the grain size of the used material is smaller than the range XBeach can work with. This could have a great influence on the run up height.

5.2 Conclusion

As the outcome of the run up differs from the over topping manual, XBeach isn’t very good in simulating the run up. The difference could have multiple causes, arising from the simplifications in XBeach of the dike and of the model. The making of the grid could be the problem, because the distance between each x grid point is 0.25 meter. Also the grain size parameter in XBeach isn’t capable of running with the grainsize that was actually used. This could explain the difference between the outcome of the model and the overtopping manual. The difference could also be explained by the fact that the waves used are quite steep and the calculation method of the overtopping manual is nearly on the edge of what is allowed.

6 Sensitivity of XBeach

In this chapter there will be looked in the sub question:

“How sensitive is XBeach for parameters of sediment transport and avalanching?

For this question there will be looked in the parameter which control the sediment transport and the avalanching

6.1 Sediment transport

As said in 3.2.4, there are a lot of processes which can have an influence on the sediment transport. Most of these influences are not directly related to one parameter, but are derived from the waves and the bed layout. There are two parameters which have a direct influence on the sediment transport. The first one is the maximum allowed sediment concentration (C_{max}). The second one is the minimum time to absorption (Ts_{min}).

6.1.1 Maximum allowed sediment concentration

Tabel 4 different settings for the maximum allowed sediment concentration

Settings	Value
Default	0.1
Max	1
Min	0.01

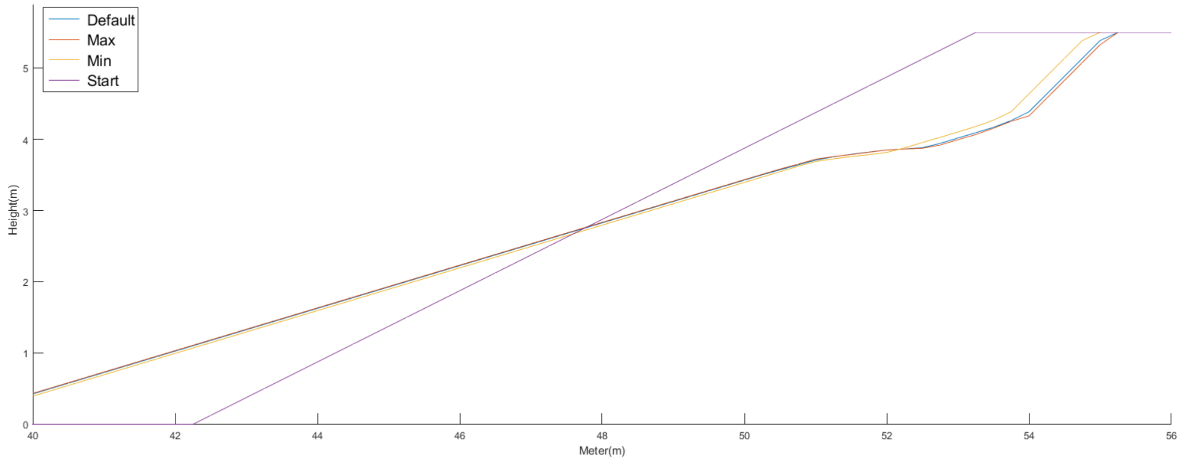


Figure 16: different settings for the maximum allowed sediment concentration

Figure 16 shows the different settings for the $C_{max,}$ compared to the start bathymetry. There could be said that the change of the maximum allowed sediment concentration has a small effect on the erosion process. The default setting gives a result that doesn’t differ much from the maximum setting. This would mean that the value of the default setting won’t be exceeded very often during a simulation.

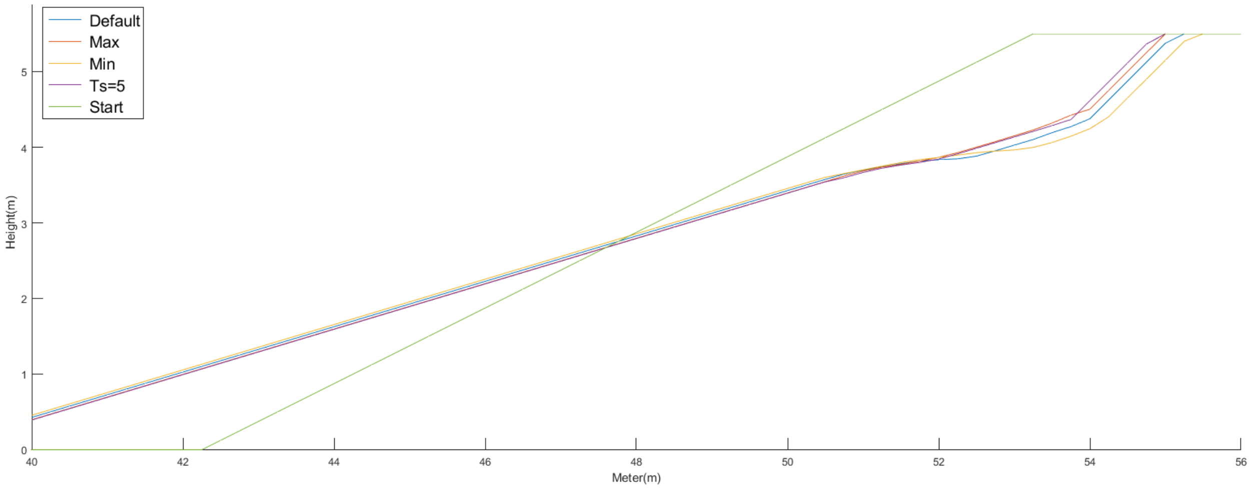


Figure 17: different settings for the minimum absorption time

In Figure 17 the different settings for the adsorption time are compared with the start bathymetry. There could be concluded that the change of the absorption time factor has a small effect on the erosion process. Therefore it would the best to use the default factor.

6.2 Avalanching

As said in 3.2.5.1 XBeach has a module which accounts for the slumping of material. There are three parameters which have an influence on the end result: the value for the dry slope, the value of the wet slope and the value for maximum amount of slumping material.

In the Figure 18 the difference between turning avalanching on and off is shown for the XBeach model.

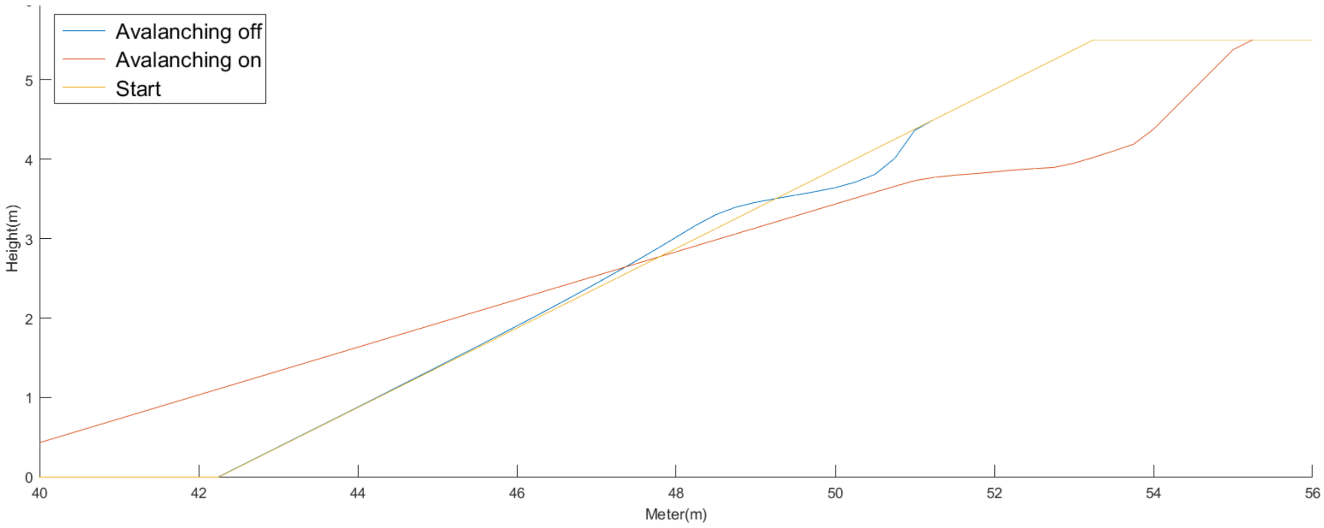


Figure 18: difference between turn avalanching on and off

6.2.1 Critical slope

In Figure 19 and Figure 20 the parameter change for the critical wet and dry slope compared to starting slope. In Table 5 the different settings used for the critical slope can be found.

Table 5: different settings for the critical dry and wet slope

Settings	Value dry slope	Value wet slope
Default	1	0.3
Max	2	1
Min	0.1	0.1

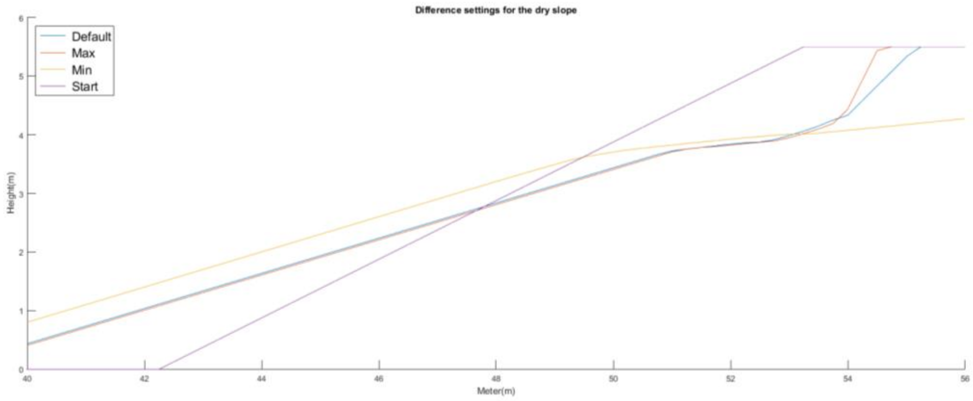


Figure 19: different setting for the critical dry slope

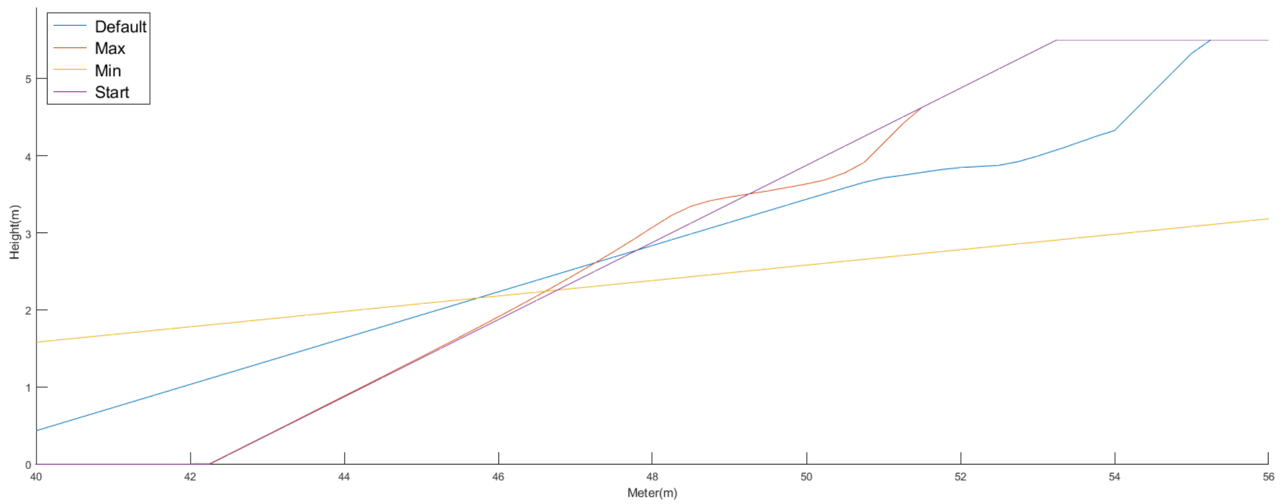


Figure 20: different setting for the critical wet slope

There are a few striking points. First of all, for both the wet and dry slope, the minimum value is less than the starting slope. So this already causes a lot of erosion due to the chosen starting profile. Another issue is that the default value of the wet slope is lower than the slope itself, so even without wave attacks this creates slumping of material by itself. Wet slope on maximum setting also a very little erosion because large part of the erosion by wave attract is under wet condition therefore the material won’t slump because the critical value isn’t reached. Furthermore, the effect for the dry slope between the default and maximum setting isn’t very high.

6.2.2 Maximum slope change per second

In Figure 21 the different settings for the maximum slope change per second is compared with the starting bathymetry. The difference between the default and the maximum isn't very big. Apparently the effect of the avalanching, causing shockwaves, isn't very big. Clearly can be seen, as expected, that with a minimum value of the maximum slope change there isn't a lot of erosion.

Tabel 6 different settings for the maximum slope change per second

Settings	Value
Default	0.05
Max	1
Min	0.001

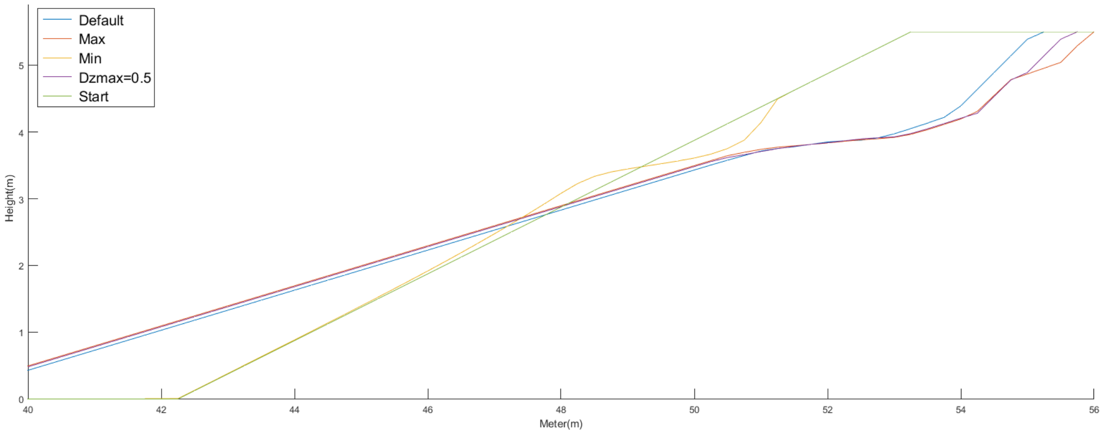


Figure 21: different settings for the maximum slope change per second

6.3 Conclusion

Slopes have a huge influence on the outcome of the simulated erosion. It would be necessary to find the right value for both the wet slope and the dry slope in order to get a simulation which is capable of simulating the erosion process as seen in the flume. For the dry slope the value should be around the value of the real slope (around 0.5). The value for the wet slope should be at the maximum.

It looks as if the default value of the maximum slope change is nearly large enough to let all the material erode. Therefore it is recommendable to use the default setting. It is hard to say something about the value of the Cmax. The differences between the various values aren't very big and it is also necessary to have a measurement of the maximum amount of sediment in the water during an experiment. Therefore the default value is recommendable for the Cmax. Also for the Tsmin parameter it is hard to determine a good value. The difference between the various values aren't very big, considering the large change of the parameter. Therefore more research should be done to find out whether the absorption speed of the used material is different from the absorption speed of sand.

7 The difference between modelled erosion and the measured erosion in the GWK

In this chapter the following sub question will be answered:

“How well can XBeach simulate the sediment dynamics of a dike made of cohesive material in the GWK?”

The way the erosion process occurs in the flume during the experiments looks completely different form the way sand is eroding. But the way XBeach has been made numeric, gives some opportunity to find out whether it is possible to simulate the experiments with XBeach. For answering this question the following parameters will be used. They are derived from chapter 6

Tabel 7: the paraments used for the simulation in this chapter

Parameter	Value
Dzmax	0.05 m/s/m
Dry slope	2
Wet slope	0.5
Simulation time	21600 (s)
morfac	1
D90	0.0001 (m)
Hm0	0.4 (m)
Fp	0.3 (s^{-1})
D90	0.001 (m)

Because it isn’t possible to enter the parameters of the different materials in XBeach there will be worked with only one simulation, using the parameters that are shown in the table above.

In the figures below the erosion process of the different materials can be seen in comparison to the modelled erosion of XBeach. Because the erosion varies along the width of the flume, there is chosen to use three places were the erosion profile is gathered from. This is the middle of the flume and 50 cm left and right of the middle as can be seen in Figure 3.

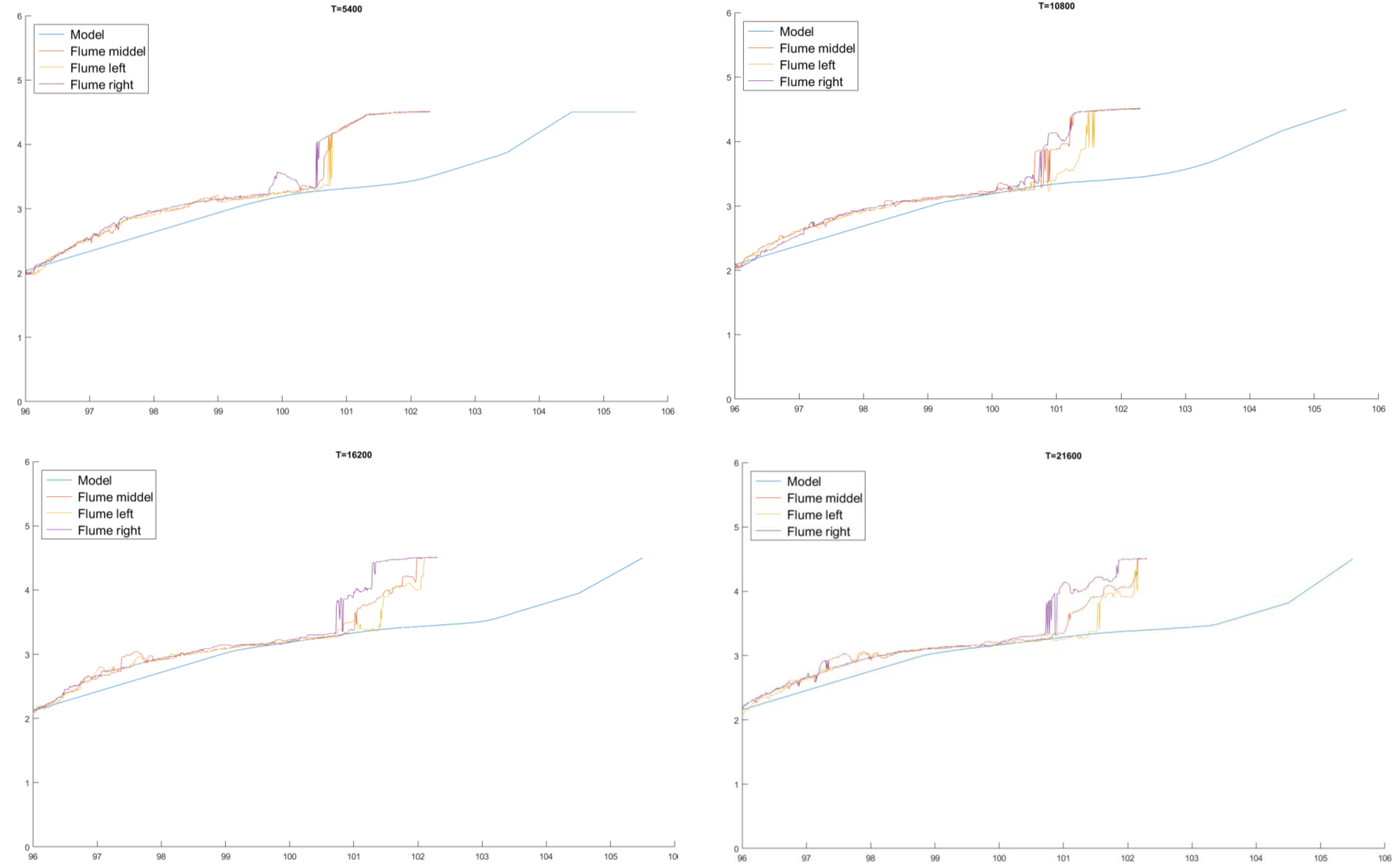


Figure 22: measured erosion for material D

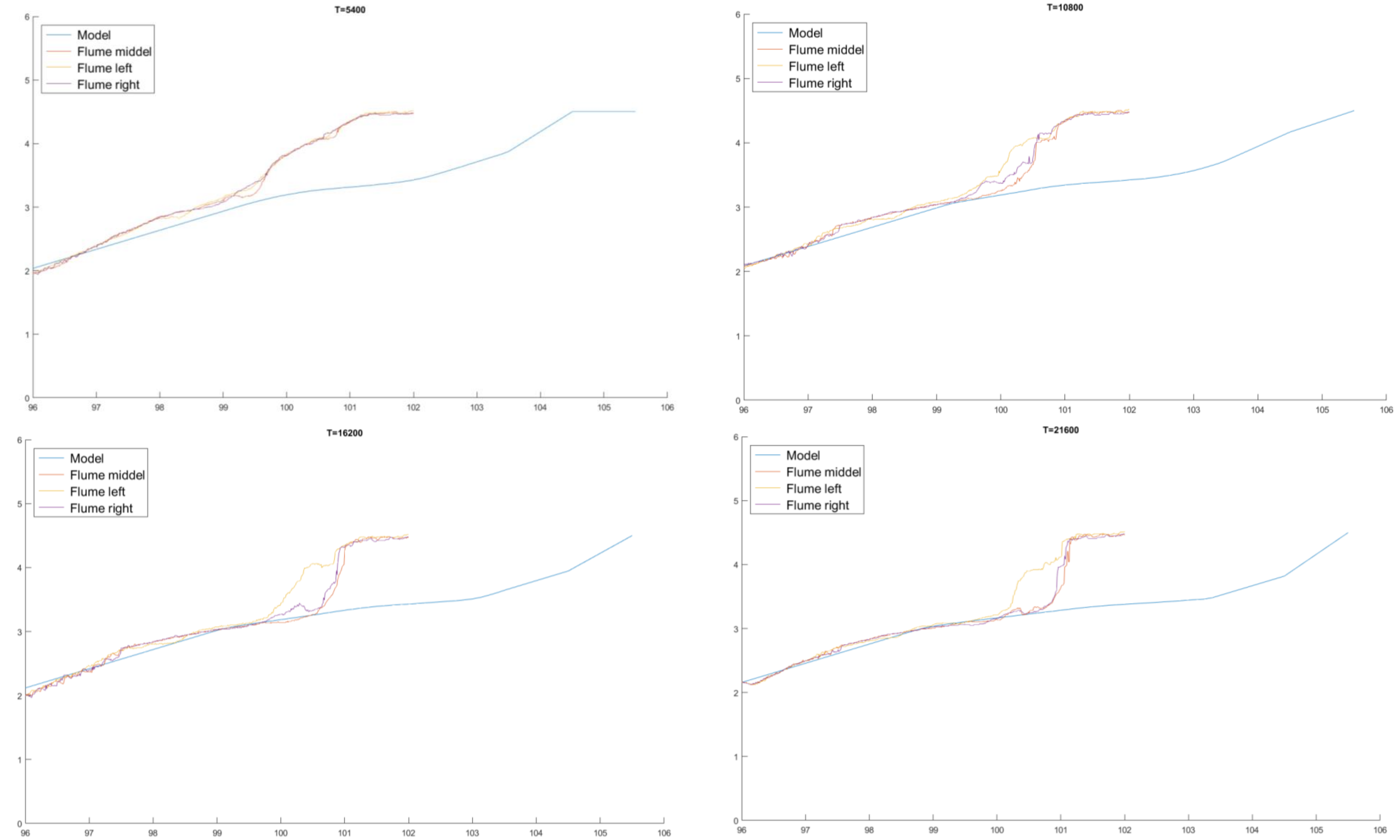


Figure 23: measured erosion for material waterboard I

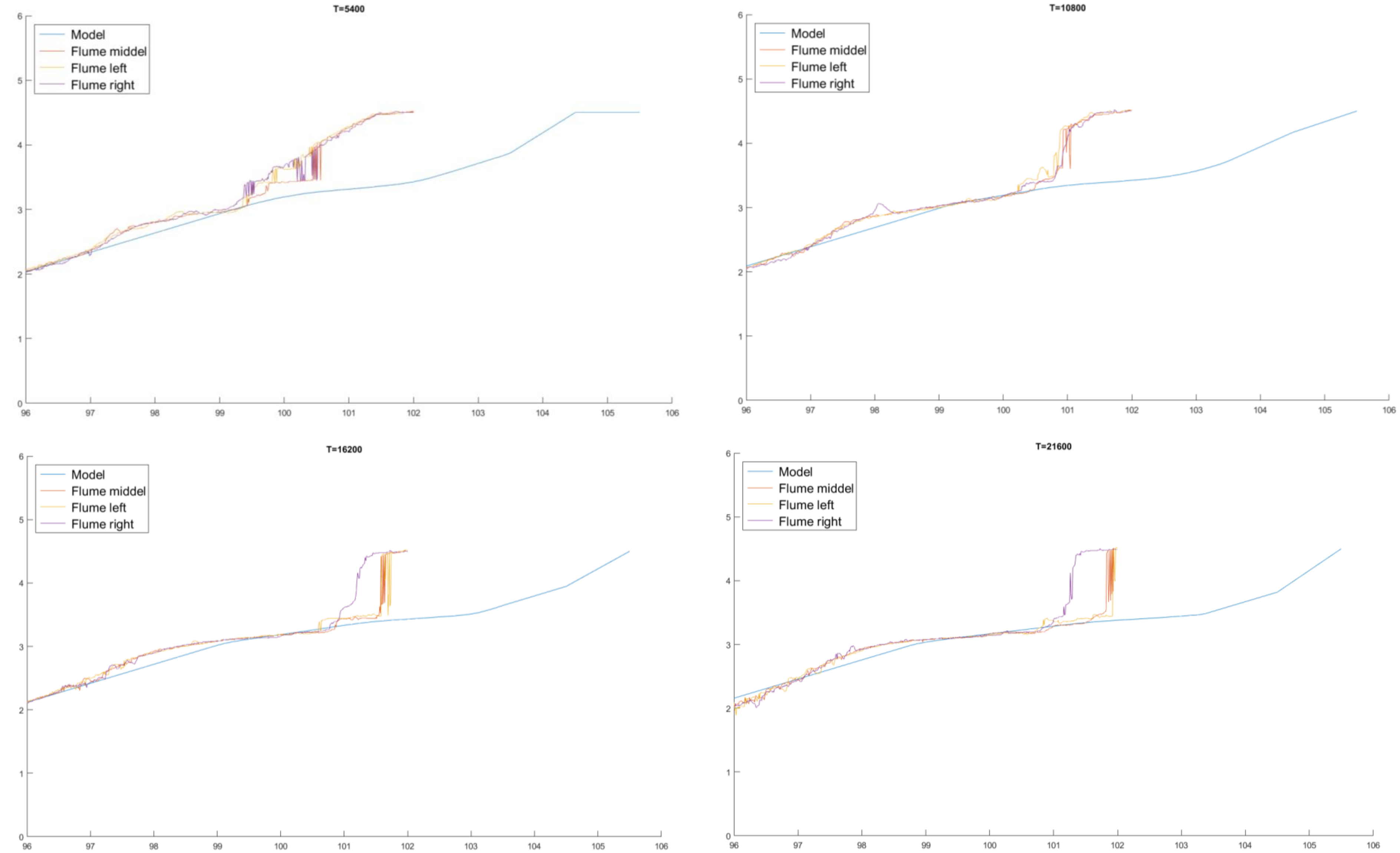


Figure 24 measured erosion for material waterboard II

The data gathered from the 3D laser scan weren't always completely correct, as could clearly be seen in Figure 22 T=21600. The sudden changes of the slope around x=101.5 are probably measurements errors.

For all the different materials could be concluded that the first stage of the experiment could be modelled quite well. But when the slope is getting too steep, the model fails.

For material D XBeach is quite good to model the erosion left and right of the middle of the flume but the erosion in the middle isn't very good modelled by XBeach.

7.1 Conclusion

In the first stage of the experiments XBeach is a good attempt in trying to simulate the erosion process as the slope is still intact. When the slope has been eroded and there is a vertical wall XBeach fails completely to simulate the circumstances in the flume. This mean XBeach isn't really capable of simulating cohesive material because the vertical wall is something which is quite characteristic for cohesive material. There are two main problems. The biggest problem is that the slope of the material used in the flume could be way steeper than the slopes XBeach can work with. The second point is that XBeach accepts that the eroding is deep into the dike. One of the explanations way is because the maximum slope isn't sufficient for the material and therefore it will avalanche before it did in the flume which caused more erosion.

It isn't really possible to put in the characteristics of the material into the model, because the grain size that XBeach can handle isn't the same as the grain size of the material used in the flume. The minimum value for the grain size in XBeach is 0.1 mm and the grain size of the material used in flume is between 0.002 mm and 0.050 mm.

Also the way XBeach handles the material is different from what happened in the flume. The material in the flume sticks to each other. This is completely different from the way XBeach is working, in the model all the grain are loose and don't stick together. Even if this would be the case, the way the waves would hit the nearly vertical slope will be different from what is possible in XBeach, because XBeach can't handle the profile that is needed for a vertical wall. Also the difference in the erosion in the flume makes it difficult to say something about XBeach. For one of the profiles of material D the XBeach simulation is a quite good indication of the measured erosion.

8 Discussion

The greatest drawback is that the waves are only simulated in 2D and in the real world waves are a 3D process. Also there are always drawbacks to the use of numeric modelling. The governing equation are simplified and also there are made assumptions to make it even possible to solve the equations. Another problem with the numerical model is that there is a need for a grid to be used. The resolution of this grid simplifies the model. furthermore, for some tests there is made use of the morfac speed up factor in order to get a better running time for the model, but this makes the outcome of the model not as accurate as it could be. Finally, the hydrodynamics aren't tested well enough to see whether the simulation is really simulating the situation in the flume good enough.

In research done by Bendoni (2015) to the possibility for xbeach to simulate the erosion Salt marsh edge. these salt marsh edge are also made of cohesive material. salt marsh edge also have very steep near vertical slopes as is similar to the second stage of the erosion process.

9 Conclusion

To *which extent can XBeach be used to simulate the erosion of a dike made of cohesive material in the GWK*?"

In the present version of XBeach it isn't possible to simulate cohesive material. There are many differences between the way in which sand and the used materials erode. XBeach is only capable of roughly giving an indication of the first 1 to 1.5 hour of the experiments. After.; this the model fails completely.

Physical process looks completely different but in the numerical part there are some things which have the same purpose The way the numericalisation is made might give the possibility to be used for different materials. More research will be needed for this. The greatest challenge is to make the model work with cohesive materials. Of course this will affect all the ways in which the material and the model are behaving.

But as could be seen in research done by Bendoni (2015) it is possible to make the XBeach model capable of simulating cohesive material. also Bendoni made XBeach capable with simulating steep, near vertical slope. With the work done from Bendoni combined with more research on the materials and process it could be possible to make XBeach capable of simulating a dike made of cohesive material

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Attachment: overtopping manual

For the validation of the run-up there will be made use of the overtopping manual (Van der Meer, et al., 2016) In this manual there is a formula given which can be used to calculate the top 2% of the wave run-ups. These formal is diverted and validated with different (small-scale) experiments in flumes all over the world. The formula is given Equation 3 and in Table 8 the explanation of the parameters is given.

$$\frac{R_{u2\%}}{H_{m0}} = 1.65 * \gamma_b * \gamma_f * \gamma_\beta * \xi\text{m} - 1{,}0$$

Equation 3

Table 8

Parameter	Explanation
$R_{u2\%}$	Run-up level exceeded by 2% of incident waves
H_{m0}	Significant wave height
γ_b	Berm factor
γ_f	Slope Friction factor
γ_β	Angle of wave attack
$\xi\text{m} - 1{,}0$	Wave steepness
$L_{(m\text{-}1.0)}$	Spectral wave length in deep water
g	Acceleration due to gravity
$T_{m\text{-}1.0}$	Spectral wave period

The value for can be calculated with the following equation

$$\xi\text{m} - 1{,}0 = \tan(alfa)\ /(\text{H}_{\text{m0}}/\text{L}_{\text{m}\ -\ 1{,}0})$$

$$\xi\text{m} - 1{,}0 = \frac{\tan\alpha}{\sqrt{H_{m0}/L_{m-1.0}}}$$

$$L_{m-1.0} = \text{g} * \frac{\text{T}_{m-1.0}^2}{2\pi}$$

The $R_{u2\%}$ is the value which is necessary. In the experiments used in this case there is now berm present. This mean the factor is 1. Also due to the smoothness of the slope the slope friction factor isn't of influence on the run-up.

Calculation

For the run-up there will be made a calculation out of the overtopping manual. The wave run-up height is in this formula defined as the vertical difference between the highest point of wave run-up the water level. It will give the height were 2% of the waves will go past.

$$L_{m-1.0} = \mathrm{g}\frac{\mathrm{T}_{m-1.0}^{2}}{2\pi} = 9.81\frac{3.03^{2}}{2\pi} = 14.33$$

$$\xi\mathrm{m}-1{,}0 = \frac{\tan\alpha}{\sqrt{H_{m0}/L_{m-1.0}}} = \frac{1/2}{\sqrt{0.4/14.33}} = 2.99$$

$$\frac{R_{u2\%}}{H_{m0}} = 1.65 * \gamma_b * \gamma_f * \gamma_\beta * \xi\mathrm{m}-1{,}0 = 1.65 * 2.99 =$$

$$R_{u2\%} = 4.93 * 0.4 = 1.975$$