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 mathematics

A Realistic Simulation of a Waterlens using Comflow

Bachelor's Project Mathematics

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Abstract

The worldwide demand for energy grows and so does the need for reusable energy. Methods using water to generate electricity, such as hydroelectricity, are a clean alternative to other methods. A water turbine needs a height difference of water to work properly and therefore is not always feasible in the Netherlands due to the flat landscape. A waterlens is a way of overcoming this problem by creating the height difference from a smaller wave. The waterlens can create this height difference by letting small waves flow through a narrowing channel. The water will be 'caught' in a tank and stored until it is used to generate energy. In this study the effects of different narrowing channels are observed and compared to each other. Simulations are made in ComFLOW in 3 dimensions. In the simulations different ratios and shapes of the narrowing channel are observed and the optimal ratio and shape is determined. The narrowest channel seems the most effective. Different waves can have different impacts, so a 2nd order Stokes wave will be compared to a 5th order Stokes wave. Once the optimal channel is determined, the optimal point to 'catch' the water will be determined for this optimal channel. It seems that this point is near the end of the channel.

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1 Introduction

A lot of water flows through the rivers in the Netherlands. Most of this water cannot be used for the generation of electricity directly, as a certain height difference is needed: a water turbine needs at least 2 to 3m of height difference to generate electricity. Therefore something is needed to increase the wave height without absorbing too much energy. A water lens can be used to create this height difference. [1] The water lens is divided into two parts: The 'Golf Generator', a part that generates waves, and the 'Golf Concentrator', a part that concentrates the resulting waves into one point. These 2 parts work in the following way:

- The Golf Generator creates a wave by letting water through periodically. This can be done for example by placing a dam in a river and letting water through only at certain parts of the dam.
- The resulting wave flows through the Golf Concentrator. The Golf Concentrator can be seen as a narrowing channel that concentrates the wave into a small area.

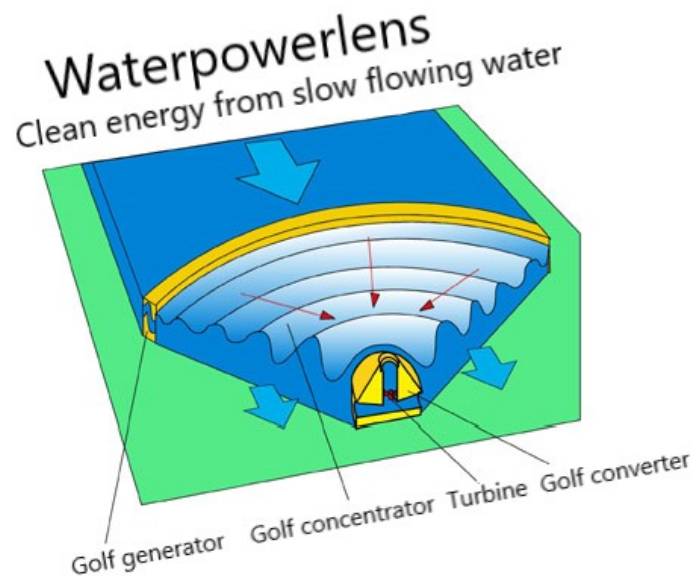


Figure 1: Schematic of a water lens adopted from [1]

At the end of the narrowing channel a water tank collects all of the water that reaches a certain height. The water in this water tank can, in turn, be used in a water turbine to generate electricity. The advantage of this method is that the water collected by the water tank does not immediately have to be used to generate electricity in the water turbine. It can be stored until energy is actually needed. There might be some places where waves already exist, but without a height big enough to be used in a water turbine. If the waves already exist, the golf generator is not needed, but the waves can be propelled in a narrowing channel to a height that is high enough to be used in a water turbine.

Jacob van Berkel from Entry Technology introduced the water lens as a way to generate electricity once it is needed and to make use of the amount of water flowing through the rivers in the Netherlands. He created a scale model of the water lens showing the effect of the waterlens. [1] Emma Cleary has done a study into the golf generator comparing different lenses with the goal to optimize the velocity. [2] In the present research we assume the golf is already created and we focus on the golf concentrator. The aim of this research will be on increasing the height of the waves and to maximize the amount of water collected in the water tank.

2 Comflow

The increase of wave heights by the application of a water lens will be studied using Comflow. Comflow is a program for numerical simulations of fluid flow. The simulations are based on the Navier-Stokes equations. Originally the Comflow software is created by the University of Groningen to study sloshing of liquid fuel in space crafts. The program has been developed further, including the application of waves, which will be used in the simulations in this thesis. [3] The Navier-Stokes equations describe the motion of a fluid. Since all of the simulations in this thesis are done with water, which is an incompressible and Newtonian fluid, the Navier-Stokes equations are given by:

$$\text{Conservation of mass: } \nabla \cdot \vec{u} = 0$$

$$\text{Conservation of momentum: } \rho \frac{D\vec{u}}{Dt} = -\nabla p + \mu \nabla^2 \vec{u} + \rho \vec{g}$$

In these equations, \vec{u} is the velocity vector in 3 dimensions, p is the pressure, μ is the dynamic viscosity, ρ is the density and \vec{g} the gravitational acceleration.

In Comflow the domain is covered by a Cartesian grid. The pressures are defined in the centres of the cells and the velocity components on the cell boundaries. The cells in the Cartesian grid are given labels that describe the cell: Fluid cells, Boundary cells and Exterior cells. The boundary cells denote the solid geometric entities that can be placed in the domain. The fluid cells can be divided into cells that are Empty (no fluid, for example containing air), Surface cells and Fluid cells. These labels are re-determined at every time step. [3]

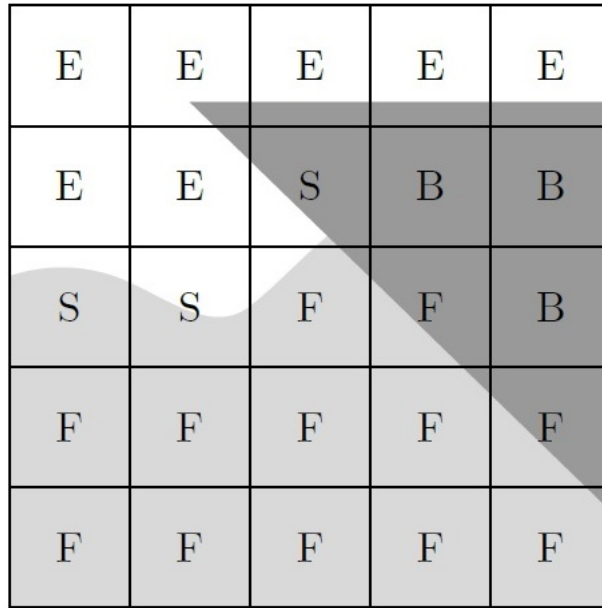


Figure 2: Cell labeling, adopted from [3]

In figure 2 the dark area denotes a solid body (in this case a ship), the shaded area denotes water and the white area denotes the air. The Empty(E), Fluid(F), Surface(S) and Boundary(B) cells can be distinguished.

The Navier-Stokes equations are discretised in time and space. For the spatial discretisation the finite volume method is used. The simulations in this paper use a 1st order upwind discretisation. For the time discretisation the Forward Euler method or the Adams-Bashford method is used. Once the Navier-Stokes equations have been discretised, a Poisson equation for the pressure has to be solved for every time step. In the simulations in this study the BiCGSTABB pressure solver with ILU preconditioner is used. The BiCGSTABB pressure solver has to be used because one of the boundary conditions used in the simulations is an absorbing outflow boundary condition, which prevents spurious reflections of an outgoing wave back into the domain. [3]

The domain of the simulation has a box-like shape. In this box like-shape geometric entities can be placed to shape the environment. In order to run a simulation Comflow needs two input files. One input file is used for the geometric entities that can be added to the domain. In 3

dimensions 5 different geometric entities can be placed: a tetrahedon, wedge, brick, ellipsoid and (elliptic) cylinder. These geometric identities can be defined as solid structures or parts that are open for the flow of a liquid. The other input file contains all of the data needed for the simulation: such as the definition of the domain; the boundary conditions at the in- and outflow; parameters for the solvers; initial liquid configuration; the wave configuration; boundary conditions; information on which data to store; information about the placement of monitor points and when to take snapshots. [3]

3 Research questions

A higher wave may have a much bigger energy yield due to the bigger potential energy the water possesses. Therefore it is important to investigate what the impact of a narrowing channel is on the increase of the wave heights. There are a lot of different factors that might influence the wave height.

As a start let a simple narrowing channel be defined. The first step is to change the proportions of the channel and measure the resulting impact on the wave height. The proportions can be changed in different ways: both the narrowness and the length of the channel might impact the wave height. In the first set of simulations the length of the narrowing channel is changed and the effect on the wave is compared. These simulations will be covered in section 5.2.1. In the second set of simulations the narrowness of the channel is changed and compared. These simulations will be covered in section 5.2.2.

The expectation is that the length of a channel has no effect on the height of the wave. Only the length of the channel changes, not the narrowness. On the other hand it is expected that the narrower a channel becomes, the higher the wave becomes. The wave in the narrower channel has less space to occupy over time. As the channel becomes narrower the water is pushed through a tinier space. The 'excess' water then has to go up.

It is also important to measure how much the wave increases compared to a straight channel. If the increase is only marginal, there is no reason to make the channel any narrower. But in case of a considerable increase of the wave height, say twice as much, the narrow channel would have a significant impact on the wave height.

Not only the proportions might influence the wave height, also the shape of the channel could have an impact. Therefore the effect of a different shape on the height of the wave is also investigated. An increasingly or decreasingly narrowing channel could have a different effect on the additional wave height than a consistently narrowing channel. It is expected that an increasingly narrowing channel results in lower wave height along the beginning of the channel, but overtakes the height of the waves of the other channels towards the end of the channel. For the decreasingly narrowing channel the opposite is expected: at the beginning of the channel the decreasingly narrowing channel is expected to have a higher wave than the other channels, but towards the end the wave height will be lower or equal. Both an increasingly narrowing channel and a decreasingly narrowing channel are compared with a consistently narrowing channel and a straight channel. These simulations will be covered in section 5.3.

There is a large variety regarding wave types and a different wave might behave differently when it flows through a narrowing channel. Realistically we want all waves to behave more or less the same way, as the channel would not be practical in usage if only one type of wave can become higher. This can be simulated by taking one simple narrowing channel and observe what happens when the type of wave is changed. The behaviour of these two different types of wave will be compared to each other. The simulations will be covered in section 5.4.

The goal of the water lens is to increase the netto gain of energy generated by the water turbine. The more water is used in the water turbine, the more power can be generated. The water turbine can only use water up from a certain height. It is useful to ask how much water can be collected from a certain height on. Therefore it is important to determine the most optimal place in the narrowing channel to collect the water. The most optimal place to collect the water will be determined in section 6.

All of these concepts lead to the following research questions:

- What is the effect of different ratios of the narrowing channels?
- What is the effect of different shapes of the narrowing channels?
- What is the effect of different waves?
- What is the optimal place to catch the water?

4 Setup of the reference channel

Initially a reference channel is defined. The simulations will be done in 3 dimensions. All of the simulations will take place in the same domain. In the x-direction (length) from -90.0m to 231.79m; in the y-direction (width) from -50.0m to 50.0m; in the z-direction (height) from -80.0m to 30.0m.

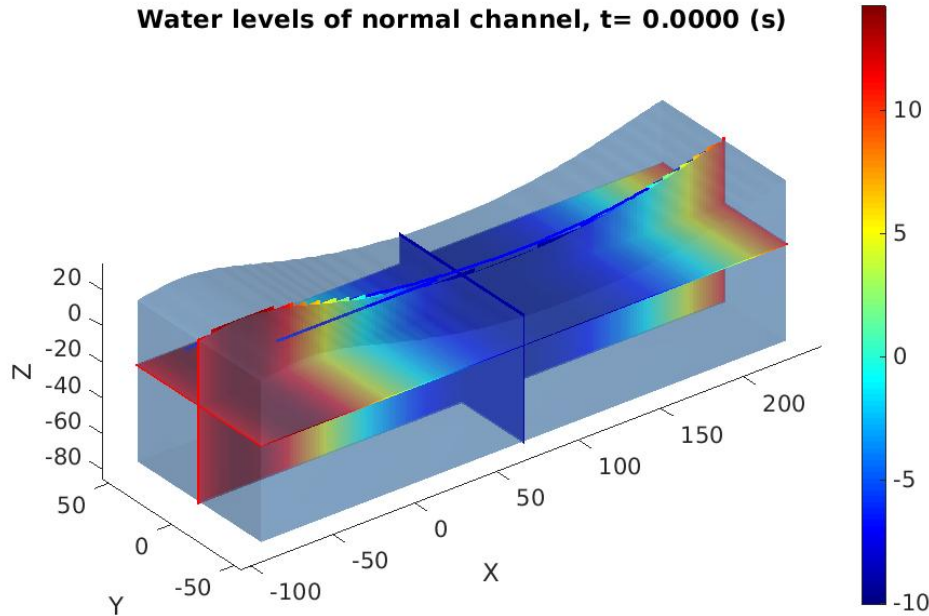


Figure 3: Initial setup of the channel

The wave used is a 5th order Stokes wave. The wave has a period of 14.5 seconds and a wave height of 24.5m. The crest of the wave at $t = 0$ is set at -65m along the x-axis. The wave length is 321.79m, which is the length of the domain. This can be seen in the figure 3 as we can only observe one full wave.

A 5th order Stokes wave can be seen as a wave that is build up from multiple sinuses, so basically a wave that is build up from a lot of tiny waves. Stokes waves are typically waves that have a relatively low height compared to the length of the wave, which will make them applicable to the waves obtained in rivers.

There is an inflow of water at the yz-plane at $x = -90.0$. The boundary condition given here is a Dirichlet boundary condition, which describes the incoming wave which travels in the positive x-direction. The other end has an outflow at the yz-plane at $x = 231.79$. The boundary condition here is an absorbing boundary condition. A (generating) absorbing boundary condition is a special boundary condition that provides the least amount of reflection of waves at the outflow boundary back into the domain. In figure 4 the direction of the flow can be observed.

In Appendix A the input code for a narrowing channel can be found. The input code also contains the monitor boxes from section 6.1.

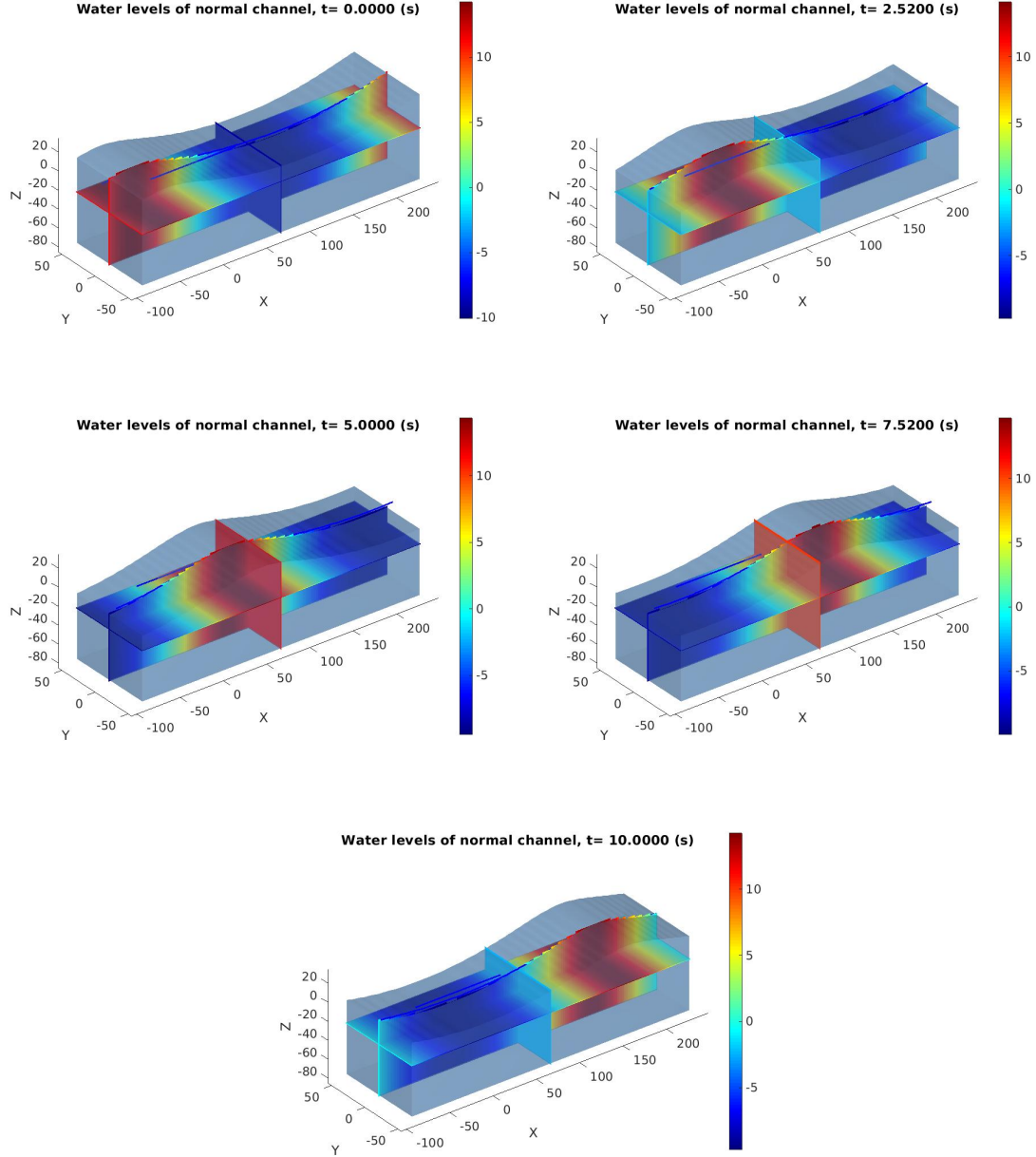


Figure 4: Propagation of a 5th order Stokes wave in a straight channel. Snapshots are taken at $t=0$, $t=2.52$, $t=5.0$, $t=7.52$ and $t=10$.

4.1 Refining of the grid

The chosen grid for all the simulations is 160 grid points in the x-direction, 55 grid points in the y-direction and 50 grid points in the z-direction. We want to know if this grid is fine enough, which is investigated by comparing a simulation for this grid setup with the same simulation of a finer grid. The finer grid chosen is 320 grid points in the x-direction, 110 grid points in the y-direction and 100 grid points in the z-direction. We use the simulation of a wave going through a narrowing channel with two obstructions of 40m at the end of the channel to compare these grid setups.

The shapes of the graph of the coarser and finer grid are quite similar, as can be seen in figure 5. Only at the end of the channel (around 200m) the graphs seem to differ a bit. At 120m the wave heights differ only 0.1m, which is roughly 0.5%. At 200m the wave heights differ 0.7m at most. This seems to be the result of the reflection of the waves at the outflow boundary. Even though the boundary condition used is the absorbing boundary condition, the reflection of the waves still seem to affect the results slightly, especially towards the end of the channel. Since all of the experiments in this research are done at multiple monitor points, we can still use the solutions

at the end of the channel. However, it is important to keep in mind that the solutions towards the end of the channel are less accurate.

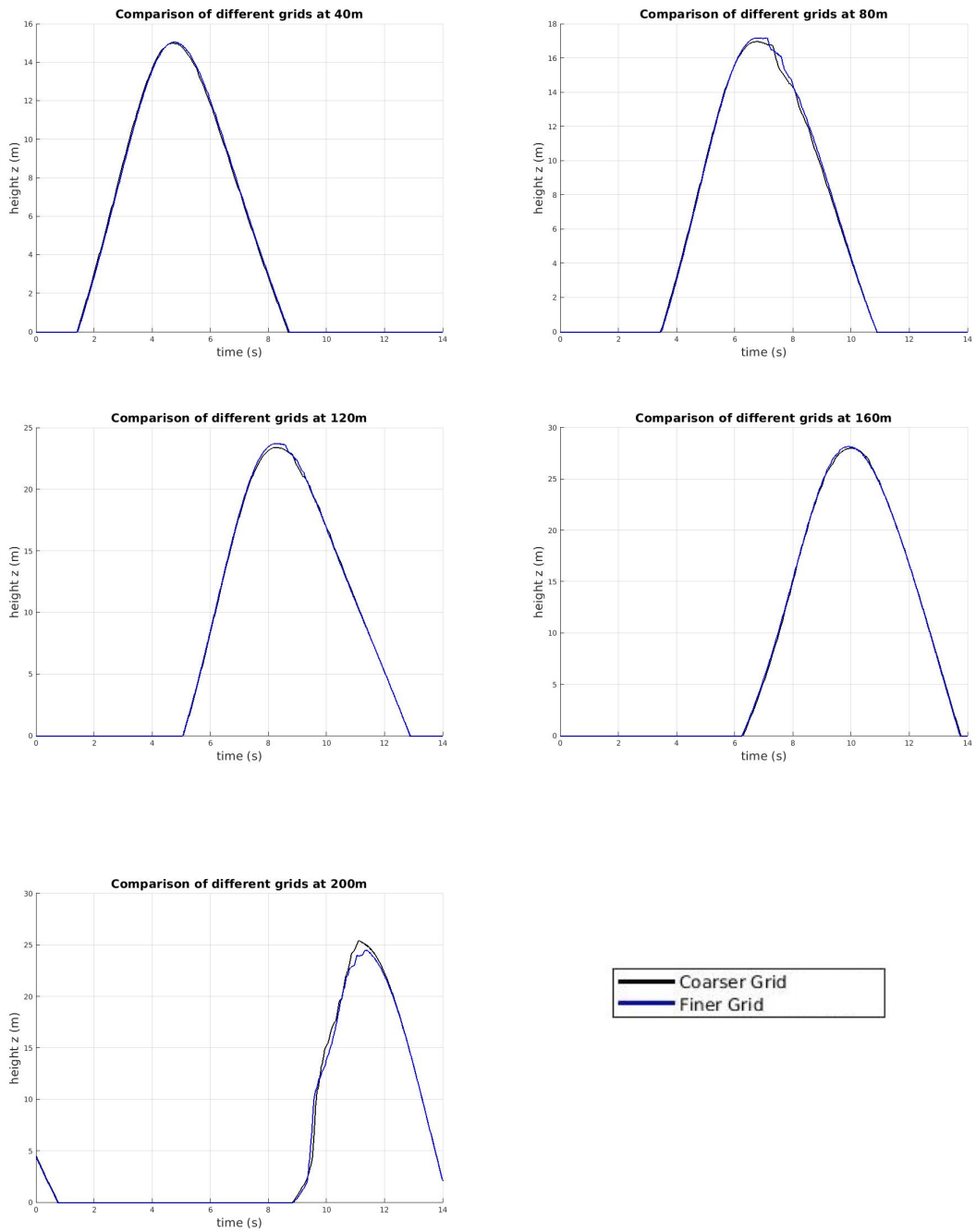


Figure 5: Grid comparison of the finer and coarser grid at 40m, 80m, 120m, 160m and 200m.

5 Comparing various channels

5.1 Monitor points

In these different simulations the height of the wave has to be measured somehow and compared to the height of the wave in other channels. In the simulations monitor points are used to measure the height of a wave over time. These monitor points measure the wave height at certain locations in the domain. All of these locations are centered in the middle of the channel ($y=0\text{m}$). In the x -direction 5 different monitor points are distinguished: at 40m, 80m, 120m, 160m and 200m measured from the start of the narrowing part of the channel. The monitor points can be observed in figure 6. The dark blue rods denote the monitor points.

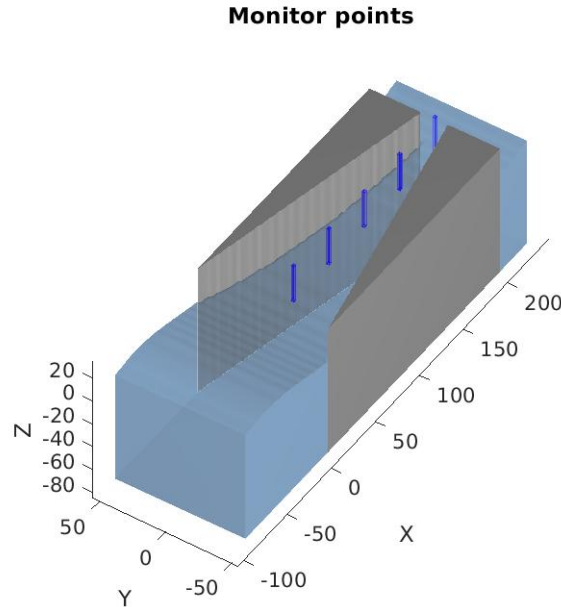


Figure 6: Monitor points are positioned at 40m, 80m, 120m, 160m and 200m on the centerline ($y=0\text{m}$).

5.2 Different ratios

In sections 5.2.1 and 5.2.2 narrowing channels with different ratios are simulated and the water height of these narrowing channels are compared to each other. All of these narrowing channels are built in the same way: two wedges are placed in the reference channel discussed in section 4. These two wedges are placed in such a way that the channel becomes narrower towards the end. In figure 7 we see an example of a narrowing channel with a length of 200m and a width of 40m per wedge.

5.2.1 Different lengths

For the first set of simulations the length of the narrowing channel is changed. The lengths of the narrowing channels are 40m, 120m and 200m. The height of the wave is measured immediately at the end of the narrowing channel. All narrowing channels have the same wave configuration, which is the same as in section 4. The width of the wedges in the narrowing channels is 40m. In figure 8 the wave height of the channels is plotted against the time.

The 3 waves seem to have the same shape and approximately have the same maximum height. The monitor points are taken at the end of each channel. This means that for the channel with length 40m the wave is measured at 40m after the channel becomes narrower. The shift in time can be explained by the fact that the waves are monitored at the end of each channel.

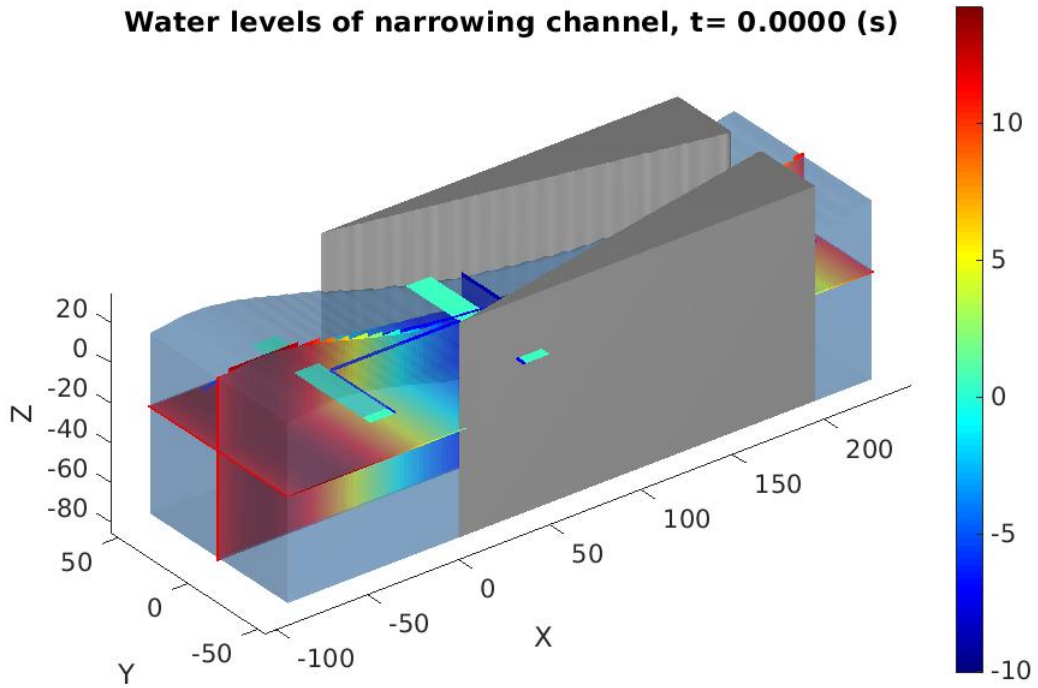


Figure 7: Setup of a narrowing channel using wedges

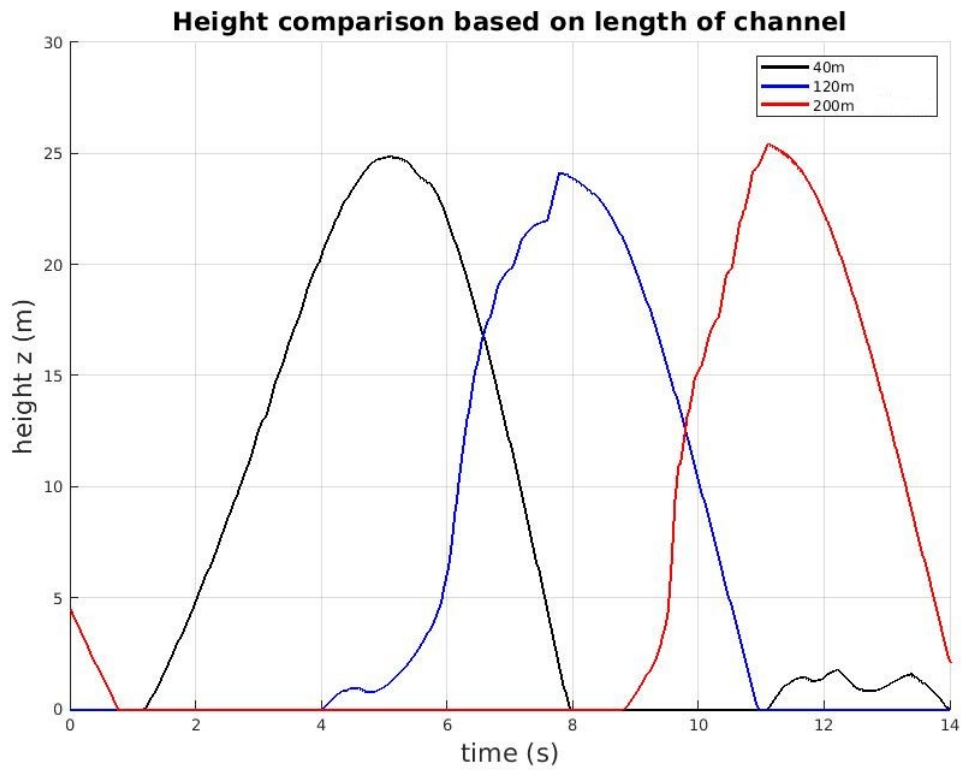


Figure 8: Wave height comparison of narrowing channels varying in length

5.2.2 Different narrowness

For the second set of simulations the narrowness of the channel is altered. The narrowness of the channel can be changed by changing the width of the wedges used to make the narrow channel. The width of the wedges belonging to the channels that are compared are 40m, 30m, 20m and 10m. In this way, the obstruction of the width of 100m is 80%, 60%, 40% and 20%. All narrowing channels have the same wave configuration, which is the same as in section 4. The length of the wedges in the narrowing channels is 200m.

In figure 9 the wave height is plotted against the time. In the legend the narrow channels are denoted by the width of the wedges. The narrowest channel provides the highest wave at the monitor point at 160m. The waves become higher the narrower the channel becomes.

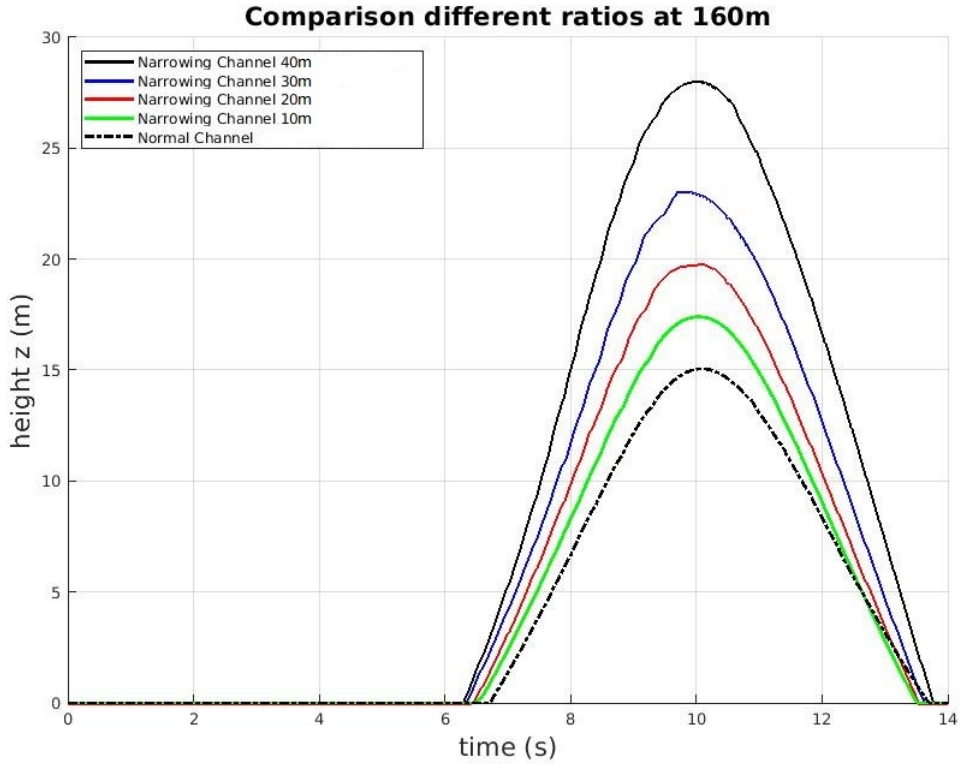


Figure 9: Wave height comparison of narrowing channels varying in narrowness.

In table 1 the maximum wave heights are compared for all of the narrowing channels. In the leftmost column we can see the width of the wedge used to narrow the channel. The first entry of 0m means that there is no wedge, hence the channel belonging to this entry is straight. In the rightmost column the percentage increase of the maximum wave height is given relative to the maximum wave height of the reference channel. The narrowest channel has an increase of 86.7% of the maximum wave height of the reference channel.

Wedge width (m)	Maximum wave height (m)	Percentage increase compared to reference channel
0	15.0558	0%
10	17.3950	15.5%
20	19.8104	31.6%
30	23.0547	53.1%
40	28.0145	86.7%

Table 1: Comparison different channels at 160m.

5.3 Different shapes

The narrowest channel from section 5.2 is compared to different shapes of the obstruction. Instead of a constantly narrowing channel an increasingly and decreasingly narrowing channel are created. These channels are made in the same way the earlier narrowing channels are made but with different curved shapes.

The concave channel is made by first defining a solid brick structure. An elliptic cylinder is subsequently used to cut out a part of the brick. This elliptic cylinder is defined as a liquid structure, so water can flow through this part. The resulting channel has a concave shape as indicated in figure 10.

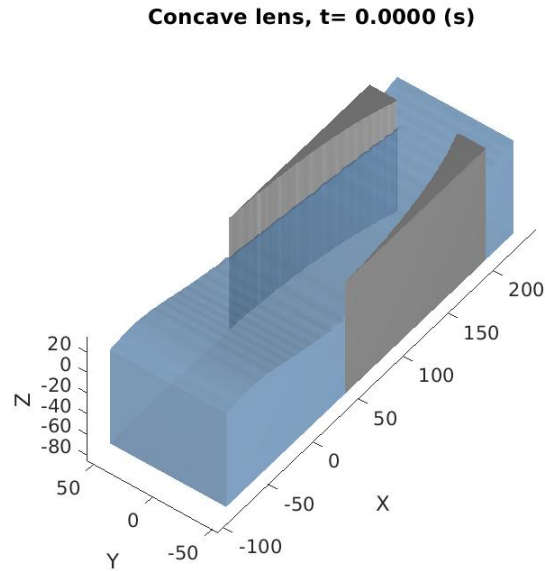


Figure 10: A concave lens

The convex channel is made by defining two solid elliptic cylinders. The middle point of the cylinder is placed at the edges of the domain at the end of the x-axis. In this way only $\frac{1}{4}$ of the elliptic cylinder is placed on the domain. The resulting channel has a convex shape as indicated in figure 11.

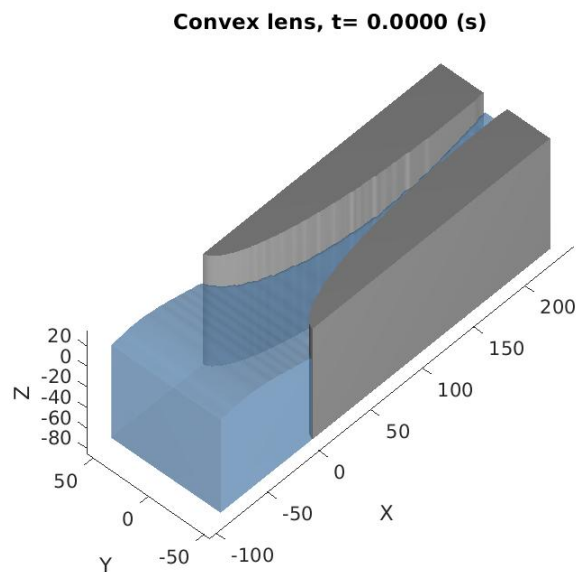


Figure 11: A convex lens

The simulations are done with the same wave configuration as in section 4. The same monitor points at 40m, 80m, 120m, 160m and 200m are used to determine the wave height of the narrowing channels. The wave height of the convex, concave, constantly narrowing and normal channel at these locations are plotted in figure 12.

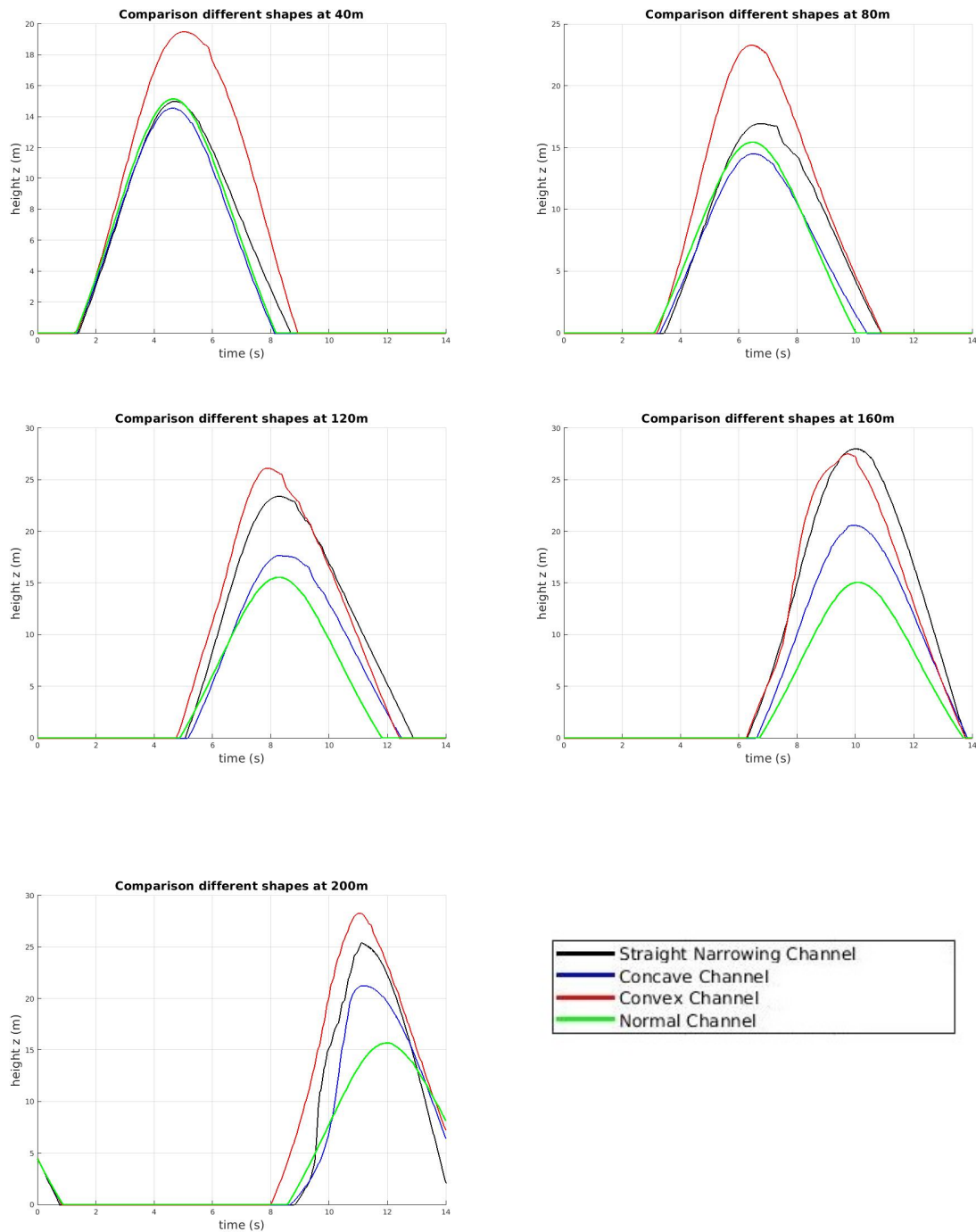


Figure 12: Wave height comparison of the convex, concave, straight narrowing and normal channel at 40m, 80m, 120m, 160m and 200m.

From figure 12 it is observed that the convex channel immediately has the highest wave at the beginning of the channel, as expected. We also see that the concave channel has the lowest wave at the start, as expected. The convex channel keeps having the highest wave at all of the monitor points, with exception of the monitor point at 160m, as can be seen in figure 13. The wave of the concave channel seems to increase a lot towards the end of the channel as in the first three monitor points it stays quite close to the normal channel. The convex channel does seem to have the highest wave compared to the other channels, which might be due to the amount of space this

channel takes up compared to the other channels. The convex channel takes up less space than the other channels and this translates into a lower wave height.

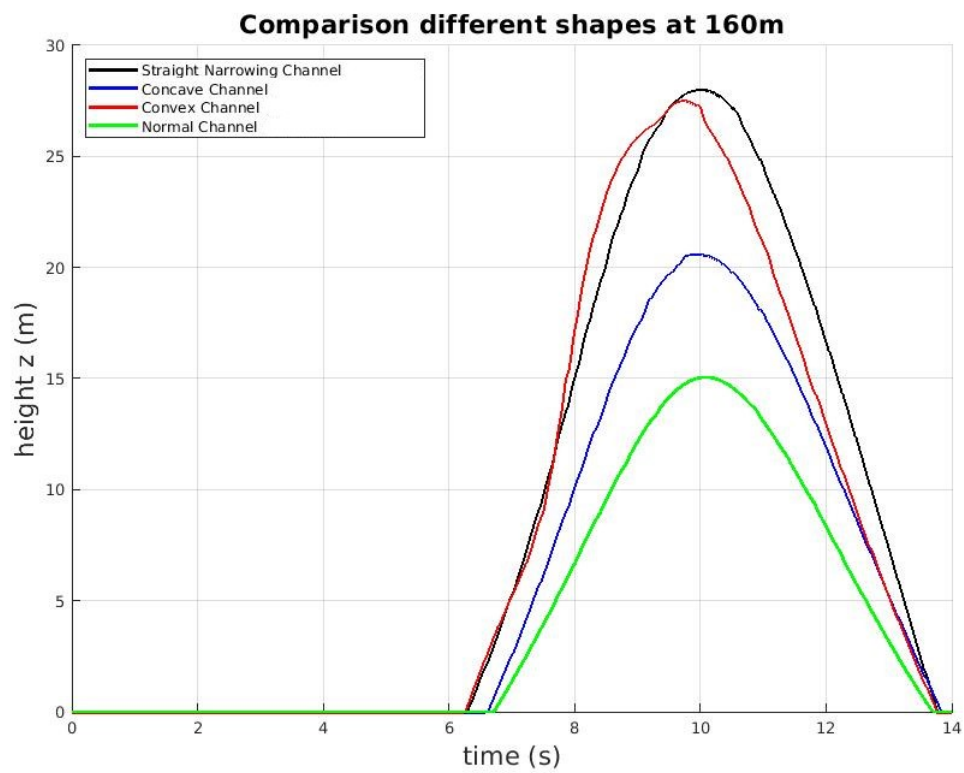


Figure 13: Wave height comparison of the convex, concave, straight narrowing and normal channel at 160m.

5.4 Different waves

The wave that is used so far in the simulations is a 5th order Stokes wave. In the next simulations the 5th order Stokes wave is compared to a 2nd order Stokes wave. Both of these wave types will be simulated in a straight narrowing channel with an obstruction of 40m. In section 4 a Stokes wave is defined as a wave built up from multiple sinuses. The 5th order Stokes wave is built up from more sinuses than the 2nd order Stokes wave. Therefore the 5th order Stokes wave is expected to be more accurate. In figure 14 the wave height of both waves is plotted against time.

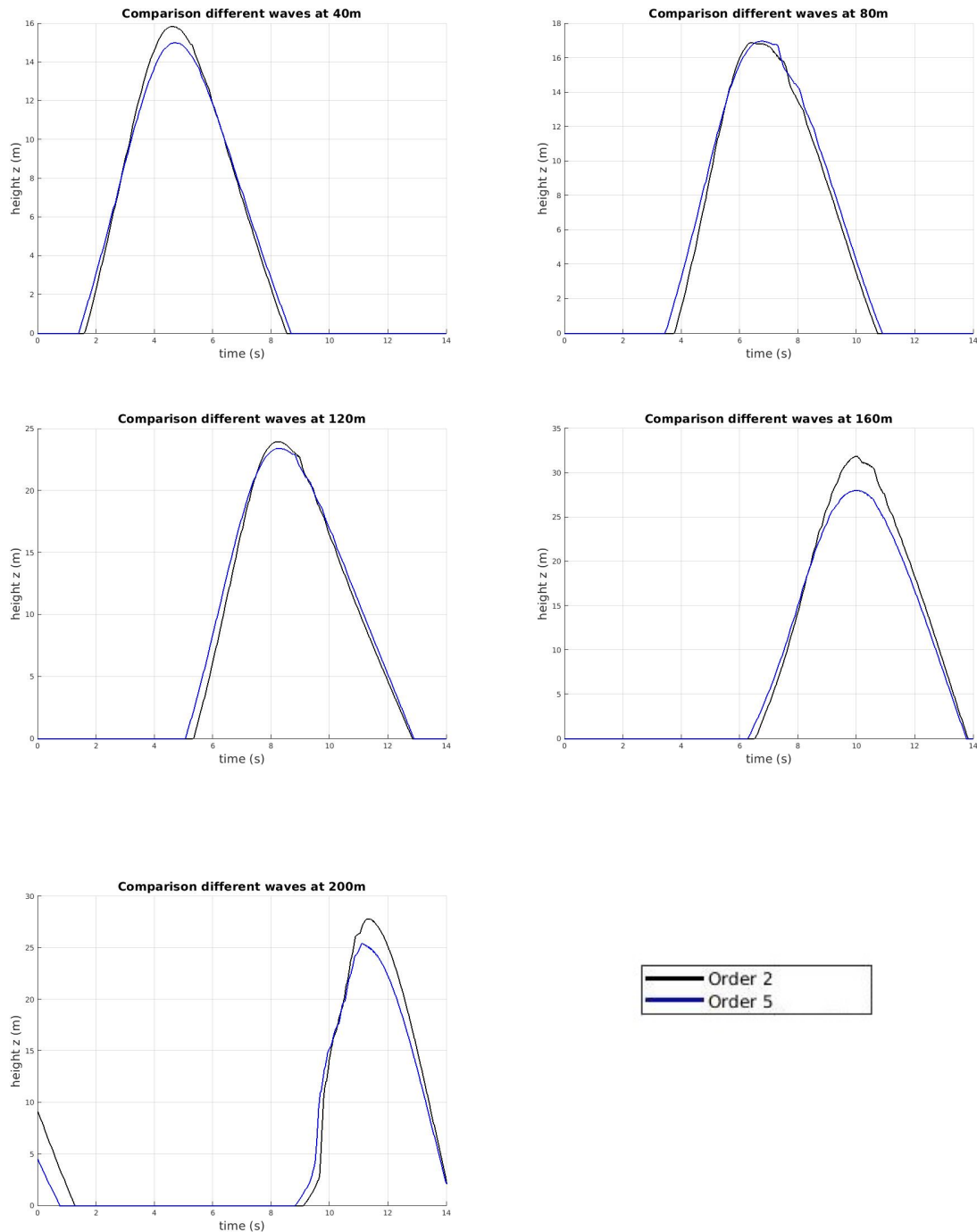


Figure 14: Comparison of the wave height of a 2nd order Stokes wave and a 5th order Stokes wave at 40m, 80m, 120m, 160m and 200m.

In figure 14 it is immediately clear that both waves increase in height. However, the 2nd order Stokes wave has a bigger increase in height than the 5th order Stokes wave. For the first three monitor points the waves behave quite alike, but for the other two monitor points the 2nd order Stokes wave becomes a bit higher, up to 20% roughly. The difference can clearly be seen in figure 15.

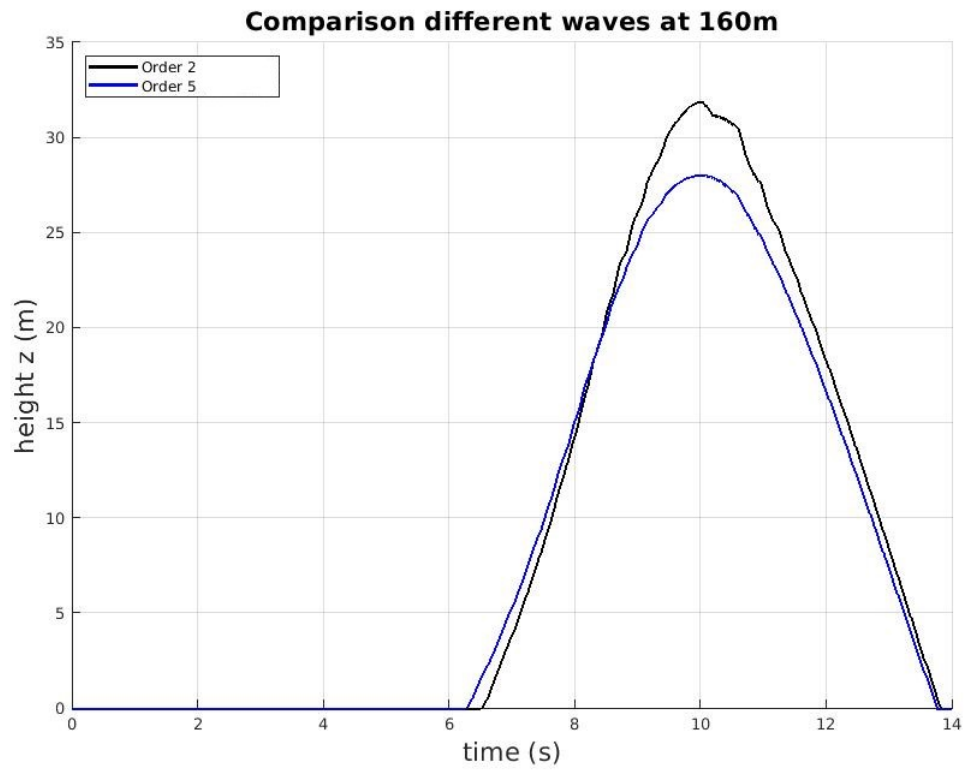


Figure 15: Comparison of the wave height of a 2nd order Stokes wave and a 5th order Stokes wave at 160m.

6 Optimal placement of the water tank

6.1 Monitor Boxes

The optimal place to collect water will be determined in a similar way as the wave height. The wave height was measured at certain points in the domain using monitor points. Since the amount of water is measured in 3 dimensions we cannot use points, but have to use boxes. In figure 16 33 monitor boxes are placed in the middle of the channel over the length of the channel:

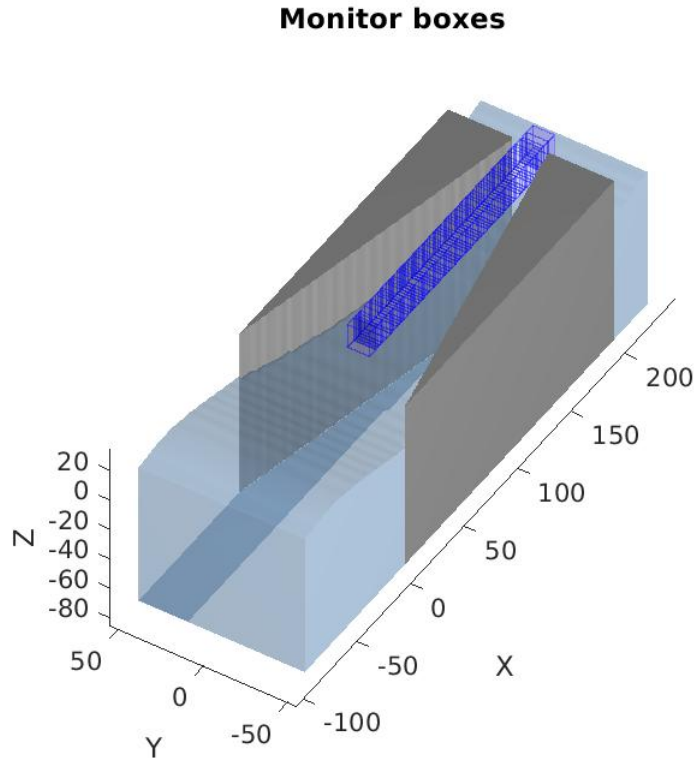


Figure 16: Monitor boxes are placed every 5m at the centerline ($y=0$).

The boxes are 10m long, 10m wide and 15m high. The boxes are placed in the middle of the channel, ranging from 40m-200m in the x-direction, from -5m to 5m in the y-direction and from 15m to 30m in the z-direction. Every 5m a box is placed. This means that the boxes in figure 16 are overlapping each other. The amount of liquid passing through these boxes is plotted against time in figure 17.

The boxes in figure 17 are distinguished by the placement of the x-axis. The first box is placed from 55m-65m. Not all monitor boxes are taken, since it would be too chaotic to read anything. The highest fill rate seems to be obtained in the box placed at 155m-165m. This means that in this case the optimal place to put the water turbine would be near the end of the channel, but before the end of the channel.

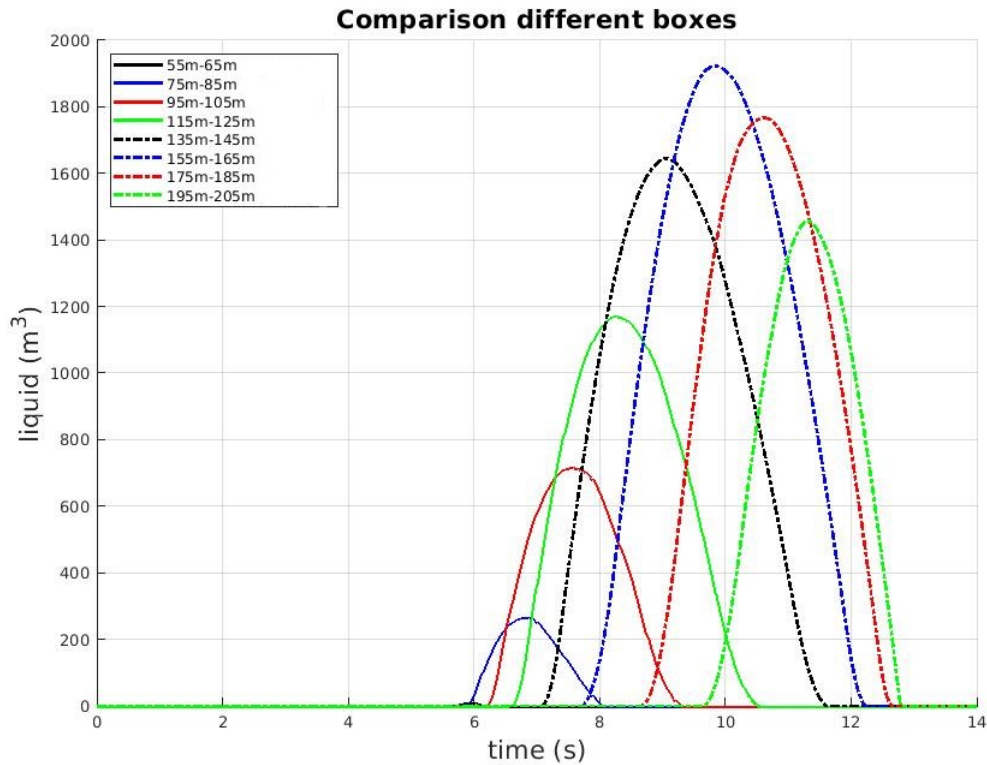


Figure 17: The amount of liquid passing through various boxes. The placement of the boxes on the x-axis can be read from the legend.

7 Conclusion

Reviewing the results of the simulations the following conclusion can be made:

The length of the channel does not impact the height of the wave.

As shown in section 5.2.1, the height of the wave near the end of the channel stays the same for narrowing channels with different lengths.

A narrower channel heightens the wave length.

As seen in section 5.2.2, the wave height increases at every point when a narrower channel is taken. An 80% obstruction has an 86.7% increase on the maximum wave height.

A convex shape increases the wave height at the beginning of the channel. Conversely, the concave shape increases the wave height at the end of the channel.

From the graphs in section 5.3 it is apparent that the convex shape increases the wave height considerably in the beginning of the channel (around 40m-80m) compared to the reference channel and does not increase a lot more after that. The concave shape however results in the same wave height as the reference channel in the beginning of the channel (around 40m-120m) and increases a lot more towards the end of the channel (around 160m-200m).

The optimal place to put a water tank is near 160m.

For a channel with a length of 200m and a narrowness of 20m (the wedges are 40m wide, so the 100m wide channel will slim down to 20m wide) the optimal place to put a water tank is near 160m. The water tank in this case is 10m long, 10m wide and 15m high.

8 Discussion

Some remarks have to be made regarding the numerical experiments conducted in this study. The simulations are done with only 2 types of waves: Stokes 5th order waves and Stokes 2nd order waves. In a more realistic simulation more different wave types have to be observed to conclude something about the influence of the channel.

Since the time used to do simulations was only limited, the grid can only be refined up to a certain refinement. Every doubling of the grid would take 8 times as much time due to all of the simulations taking place in a 3 dimensional domain. By increasing the number of monitor points and boxes the accuracy of the results can also be increased.

Even with the absorbing boundary conditions some disturbance occurs at the end of the channel. This could be solved by taking a domain that has twice the length of the wave length, while keeping the channel at the same length. This would result in twice the amount of computational time needed to carry out the simulations.

In chapter 5.3 different shapes of the channel are compared to a straight channel. The Comflow software only has a finite amount of shapes to use, thus limiting the options. However, even with this limited amount of shapes an infinite amount of channel configurations could be built. Only a couple of simple configurations were treated in this study. When considering shapes, a lot more different and complex shapes can be studied.

One thing that also seems to influence the wave height is the volume the obstruction of a narrowing channel takes up. For example, the convex shape in section 5.3 took up more volume than the concave shape. Consequently the maximum wave height of the convex shape is higher than the maximum wave height of the concave shape at the end of the channel. For a next investigation the amount of volume the obstructions take up in the channel should be considered as a research topic.

The optimal place of a water tank was determined for one of the narrowing channels. A lot of factors come into play, which could be extended in another study. The height, length, width and placement of the box all influence the amount that will be caught. But also the type of wave, type of channel, narrowness of the channel and shape of water tank will influence the water collected in this water tank. Next to that, also the influence of a water turbine under the water tanks has to be investigated.

Nonetheless, the experiments conducted in this study are a good first step into the exploration of the effect of narrowing channels on wave height and hence on the application for water lenses for generating energy.

Appendices

A Comflow code

```
-- Title -----  
Optimal placement water box  
-----  
slosh  mvbd    twph  nproc  
1      0      0     4  
-----  
-- domain definition -----  
xmin  xmax    ymin  ymax  zmin  zmax  
-90.0 231.7889 -50.0 50.0 -80.0 30.0  
-----  
-- green water parameters -----  
grnwtr  
0  
-----  
high  low    length  
0.0   0.0    0.0  
-----  
width  a      b  
0.0   0.0    0.0  
-----  
-- definition initial liquid configuration -----  
liqcnf lqxmin lqxmax lqymin lqymax lqzmin lqzmax  
1      0.0    1000.0 -30.0  30.0   -290.0  0.0  
-----  
-- definition of incoming wave -----  
wave  vwstart  period  wheight  xcrest  waterd  ramp*  order  curr  beta  
5     1        14.5   24.3     -65.0   80.0    0      10     0.0  0.0  
ramp  val1    val2  
0     0.0    0.0  
-----  
-- definition of in- and outflow boundaries -----  
nrio  
2  
i/o  plane  xmin    xmax    ymin  ymax  zmin  zmax  
1    1      -90.0   -90.0   -50.0 50.0  -80.0 30.0  
11   1      231.7889 231.7889 -50.0 50.0  -80.0 30.0  
-----  
-- partial slip -----  
pscnf psl  
0 0.0  
-----  
-- absorbing boundary condition -----  
bcl bcr gabc a0 a1 b1 kh1 kh2~ alfa1 alfa2  
1 1 1 1.05 0.12 0.31 1.345 5.0 0.0 0.0  
-----  
-- definition of numerical beach in positive x-direction -----  
numbch damp* slope  bxstart  
0      0      0.0    0.0  
-----  
-- physical parameters -----  
rho1  rho2  mu1  mu2  sigma  theta  patm  gamma  
1.0e3 1.0   1.0e-3 1.71e-5 0.0   90.0  1.0e5 1.4  
-----  
-- grid parameters -----  
griddef  
1
```

```

imax    jmax    kmax    xc      yc      zc      sx      sy      sz
160     55     50      25.0   0.0    12.26  1.0    1.0    1.0
-----
-- numerical parameters -----
eps     omega   itmax   alpha   feab0   feab1   feab2   nrintp  fslinext
1.0E-6  1.0      10000  1.0     0.0    1.0     0.0     3       1
-----
-- numerical parameters two-phase flow -----
solver  extrap  restol  imptol  upwind  imprel  irhoav  itscr
5       0       1.0E-7 1.0E-3  1       1.0    1       0
-----
-- time parameters/cfl number -----
dt      tmax     dtmax   cfl     cflmin  cflmax  divl
0.01    14.0    0.058  1       0.2     0.5     0
-----
-- free surface methods -----
vofmth  vofcor  divl
1       2       0
-----
-- gravitation -----
gravx   gravity  gravz   ginrt   finrt
0.0     0.0     -9.81  0       0
-----
-- motion of coordinate system -----
motionframe
0
amplx   freqx   amply   freqy   amplz   freqz
0.0     0.0     0.0     0.0     0.0     0.0
-----
omex    omev    omez    x0      y0      z0
0.0     0.0     0.0     0.0     0.0     0.0
-----
-- autosave -----
load    nsave
0       2
-----
-- post-processing: snapshots/screen print/center of mass -----
npm2d   npm3d   compr   nprnt   ntcom
0       140    0       140     0
-----
npmslic nyz     nxz     nxy
0       0      0       0
planeyz
planexz
planexy
-----
-- directory name for snapshots -----
pathname snapshot data:
data/
-----
-- fill boxes, force boxes and flux boxes -----
nfillb  ntfill
33      1400
xl      xr      yl      yr      zl      zr
40.0    50.0   -5.0    5.0     15.0    30.0
45.0    45.0   -5.0    5.0     15.0    30.0
50.0    60.0   -5.0    5.0     15.0    30.0
55.0    65.0   -5.0    5.0     15.0    30.0
60.0    70.0   -5.0    5.0     15.0    30.0
65.0    75.0   -5.0    5.0     15.0    30.0
70.0    80.0   -5.0    5.0     15.0    30.0

```

```

75.0  85.0  -5.0  5.0  15.0  30.0
80.0  90.0  -5.0  5.0  15.0  30.0
85.0  95.0  -5.0  5.0  15.0  30.0
90.0  100.0 -5.0  5.0  15.0  30.0
95.0  105.0 -5.0  5.0  15.0  30.0
100.0 110.0 -5.0  5.0  15.0  30.0
105.0 115.0 -5.0  5.0  15.0  30.0
110.0 120.0 -5.0  5.0  15.0  30.0
115.0 125.0 -5.0  5.0  15.0  30.0
120.0 130.0 -5.0  5.0  15.0  30.0
125.0 135.0 -5.0  5.0  15.0  30.0
130.0 140.0 -5.0  5.0  15.0  30.0
135.0 145.0 -5.0  5.0  15.0  30.0
140.0 150.0 -5.0  5.0  15.0  30.0
145.0 155.0 -5.0  5.0  15.0  30.0
150.0 160.0 -5.0  5.0  15.0  30.0
155.0 165.0 -5.0  5.0  15.0  30.0
160.0 170.0 -5.0  5.0  15.0  30.0
165.0 175.0 -5.0  5.0  15.0  30.0
170.0 180.0 -5.0  5.0  15.0  30.0
175.0 185.0 -5.0  5.0  15.0  30.0
180.0 190.0 -5.0  5.0  15.0  30.0
185.0 195.0 -5.0  5.0  15.0  30.0
190.0 200.0 -5.0  5.0  15.0  30.0
195.0 205.0 -5.0  5.0  15.0  30.0
200.0 210.0 -5.0  5.0  15.0  30.0

```

```

-----
nfrcb  ntfrc
0 0
xl      xr      yl      yr      zl      zr      mv  meth

```

```

-----
nfluxb ntflux
0 0
xl      xr      yl      yr      zl      zr

```

```

-----
nrelwh ntrelwh
0 0
xl      xr      yl      yr      zl      zr

```

```

-----
-- stream line/particle path -----
npartp npartl npartc ntpart
0 0 0 0
xpt  ypt  zpt  tstrt          <- points
xl   xr   yl   yr   zl   zr   tstrt <- lines
xc   yc   zc   radius orient tstrt <- circles

```

```

-----
-- monitor points -----
nmntrp nmntrl nmntrc ntmntr.mvp
0 0 0 400 0
xpt  ypt  zpt          <- points
xl   xr   yl   yr   zl   zr   <- lines
xc   yc   zc   radius orient <- circles

```

```

-----
-- special boxes -----
nrboxes tstart sbuvw
0 0.0 0
xmin  xmax  ymin  ymax  zmin  zmax

```


References

- [1] Entry Technology Support BV. https://web.tue.nl/cursor/bastiaan/jaargang48/cursor29/achtergrond/oz_2.html.
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- [3] B. Iwanowski T. Bunnik B. Duz H. van der Heiden R. Wemmenhove P. Wellens A. Veldman T. Helmholt-Kleefsman E. Loots J. Helder R. Luppens, P. van der Plas. *Manual Comflow Version 3.9X/4.0*. University of Groningen, November 2015.