GC mattress construction tests

Testing an execution method for free span remediation

BSc Thesis
Appendix report

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This thesis includes a main report and this separate appendices report. The main report will give a summary of what the information given in the appendices. References to the appendices are made by each chapter.

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Appendix A Literature study

Before starting to set up an experiment, a literature study must be done. In this study information regarding the subject is collected. In that way a good impression of the subject is created and the setup for the experiments can be made. In this appendix the results obtained from the literature study will be presented.

The main goal of this literature study is to collect the necessary information and insights for this project based on the research that has already been carried out.

This literature study will include the following reports:

H.J. Verhagen e.a. (2006). *Meetresultaten Kunststof GC-elementen.* Delft: TU Delft.

S. Geluk en K. Spits. (2013). *Haken of Kraken, onderzoek naar het aanbrengen van Ground Consolidators.* Arnhem.

Witteveen + Bos. (2013). *Memoradum results GC drop tests.* Rotterdam: Witteveen + Bos.

Witteveen + Bos. (2013). *Method Statement remediation of frees span with GCs.* Deventer.

For each report the objective, a summary and the test results will be processed. After that, a short conclusion will be given to evaluate the results and to describe how these insights will be implemented into the new project.

1. Hydraulic aspects of Anome Ground Consolidators

(H.J. Verhagen et al., 2006)

This report handles the results of the first experiments done with plastic GC elements in a small flume.

Objective

The objective of this experiment is to examine the properties of single plastic GC's and a package up to 400 GC's. The use of GC's as a solution to ground protection was tested as well.

Summary

In the experiment, the GC's with ribs of 0.05 m were used. Based on measurements, the density of these elements was calculated at approximately 1910 kg/m^3 (1.91 g/m^3). This was far less than the design properties, that stated a density of 2300 kg/m^3 (2.3 g/m^3) is required. Therefore some experiments couldn't be performed.

First, the experiments to evaluate the properties of the GC's in wet conditions were carried out. A single GC placed on the bed started to wash away at very low current velocities (approximately 0.1 to 0.2 m/s). During the tests with a package of 100 GC's, it was observed that several heaps occurred instead of a flat and homogeneous layer. When the current velocity increased, these islands washed away first, leaving some GC's on the bed. Because of the used construction material, some elements deform or broke during the increase of the current velocity.

The most important failure of the layer was that the toe would roll over the back part of the batch. When the toe starts moving, the whole package followed as a whole. The current velocity at failure was around 0.635 m/s (with GC's with a density of 1.91 g/m^3).

To check the reduction of the current velocity, some pigment was added to the water. The purple paint within the package had a longer residence time compared to the blue paint outside the package. This blue paint washed away quickly, as shown in Figure 1.

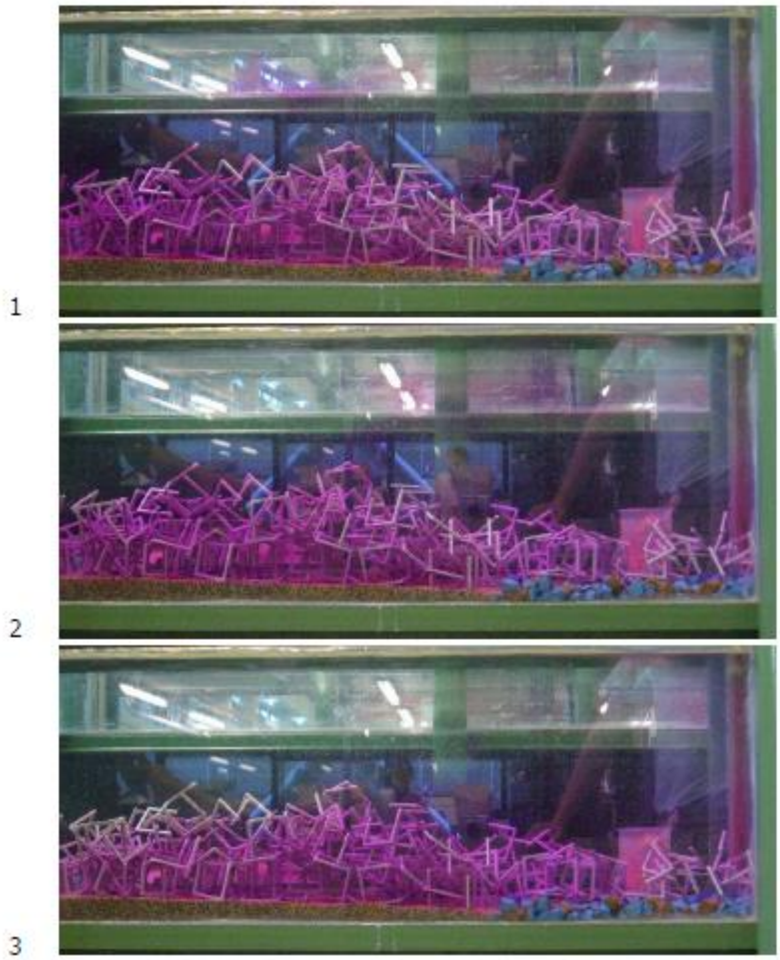


Figure 1 Residence time of water within the GC package

After the residence time was examined, some tests were performed to get insights in the use of GC's as a bed protection solution. Therefore, several soil layers were placed on the bed of the flume. These layers obtained their stability from the package of 400 GC's. Sand with a diameter of 0.001 to 0.002 m becomes instable at a current velocity of 0.45 m/s when it's protected by a GC package.

In these experiments, the flume with a width of 0.24 m was used. Because the elements were relatively large compared to the flume, the flume had a large effect on the results. Some weak spots in the package occurred at the sides of the walls, causing the package and the layer it needs to protect to become instable at a lower current velocity.

Some tests for the usage of GC's as a slope protection were performed as well. Because this part of the experiment is of less importance for this project, this part can be read in the original report.

Results
In this experiment the main instability mechanism, which occurs at a package of 100 or more GC's, was found. At a current velocity of 0.635 m/s, the toe of the package starts rolling over and the whole mattress collapsed.

To show how the package will reduce the current velocity inside, two colours were added to the water. The colour within the package had a long residence time compared to the colour above the package. Therefore it is concluded that the mattress in fact reduces the velocity.

The GC package can be used as a soil protection solution. Instable materials like sand, with a diameter of 0.001 to 0.002 m can hold current velocities up to 0.45 m/s when they are protected by the GC package.

Conclusion
The main assumption of this BSc project is based on the demonstrated function of decreasing velocities. Because this effect was observed during this experiment, the mattress as a whole will be assumed to be working in relation with the positive slowdown of the velocities. Therefore, this functionality won't be tested in this project.

As observed in this experiment, the main failure mechanism will be based on the rolling over of the mattress, starting by a movement in its toe. This effect will be checked by the experiments in this BSc project.

2. Final report "Haken of Kraken"

(S. Geluk and K. Spits, 2013)

This report was written in May 2013 and presents the results of a research on the execution methods of Ground Consolidators.

Objective

The objective of this report is to find a method to indicate the effectiveness of an execution method and to find the best execution method for handling the construction of a mattress of GC's.

Summary

In this report the GC's will come in parts, which need further assembly. With the use of a hand calculation, it was found that the breakeven point of the assembly (manual vs. mechanically) lies around 420.000 GC's.

The method of selecting an execution method is based on several criteria. The method will be tested on costs (both single and operational costs), reliability and production velocity, accuracy during construction and the number of possible applications.

In this report, three methods are tested. The first method is based on a pontoon with a tugboat. On the pontoon, a coconut layer will be placed that can be fastened to the tugboat. On the layer, the mattress will be constructed by hand. After the mattress is built up on the pontoon, the tugboat will drag the whole mattress to the front. Because of its weight, the mattress will reach the bed.

The second method is based on a special equipped crane that is positioned on a pontoon. This crane is provided with a pipe that can be rotated. This pipe will be loaded on the pontoon, and brought close to the already constructed mattress on the bed. By rotating the pipe along its axis, a complete string of GC's falls into the mattress.

The third tested method is based on a chain. The GC's will be place into the teeth at the chain. By rotating the chain, the GC's will be transported to the mattress. At the end of the chain, the GC's will fall off. The report comes with several clear figures of the usages of these methods.

After the methods are worked out, all three methods are tested in a flume. During these experiments, the selection criteria are tested, as well as the current velocity that leads to failure.

Results

As a conclusion, the execution methods were divided into scenarios, each with a different feasibility area. All three execution methods could be used, but the method based on a chain is only economical justified if it is used in projects containing more than 150.000 GC's.

Conclusion

For the construction situation in the BSc project, the amount of GC's will be less than 150.000. Current velocities during construction will be below 0.3 m/s, so based on this research the best execution method is the use of a rotating pipe. Because of the investment costs of this method, the execution method will be adapted for the specific pipeline project. In this BSc project, a regular clamshell (similar to a clamshell used for the handling of sand or stone), positioned on a pontoon is proposed as an execution method.

3. Method statement remediation of free spans with GC's

(Witteveen + Bos, Method Statement remediation of frees span with GCs, 2013)

This report states the proposed method for remediation of free spans with the use of GC's. This document is confidential, so in this literature study specific names and locations will be left out.

Objective

The main goal of this document is to describe and elaborate the proposed method for the remediation of a specific pipeline in the Waddensea that suffers from a free span. The focus of this document is on the execution method for placing the GC's and on the stability of the GC's once they have been placed.

Summary

In the coastal area of the Waddensea, an important pipeline suffers from two major free spans caused by the movements of the seabed because of erosion along the sides of the pipeline. Because of this free span, the pipeline is exposed to unwanted forces caused by the current.

At the location of the free span, the maximum current velocity is up to 1.1 m/s at spring tide (2.1 knots). When the high water level occurs, the current velocity is around 0.2 m/s (0.4 knots).

First, the pipeline will be lowered by removing soil at it supports. This will cause the pipeline to hit the sand bed and get support along its axis. In this way the free span height will decrease.

After lowering the pipe, a mattress constructed out of GC's will be placed on both sides of the pipeline. This mattress will stop the erosion because it slows down the current velocity. In this method statement, GC's with rib lengths of 0.3 m will be used.

The mattress will be placed with the use of a clamshell. This clamshell will drop the GC's in batches, approximately 1 or 2 meters above the final top level of the GC structure. Based on an average cycle time of 5 minutes for filling the clamshell, the net construction time will be around 13 hours for the largest mattress.

The stability is granted by the interlocking behaviour of the GC's. Once they are placed, they are likely to form a complete mattress that can resist the current velocities.

After construction, the mattress will be monitored because the use of GC's for this remediation is in pilot phase. This monitoring will be done with sonar. It is proposed to measure the top surface of the structure during placement and later on after a specific interval and after a storm.

The costs aren't available yet and will be provided in a later phase.

Results

The GC's will be used to protect the pipeline with a free span for future erosion and for the forces caused by the current movements around the pipeline. The mattress of GC's will be constructed out of batches that will be dropped from a clamshell at a height of 1 to 2 m. The dimensions (length x width x height) of the final and largest mattress will be 60 m x 10 m x 1 m. It is proposed to construct two batches on both sides of the pipeline, each with a width of 5 m.

Conclusion
Based on this document, the major objective of this BSc thesis becomes clear. In this experiment, both the behaviour of the GC's in wet conditions and the construction of a mattress near a pipeline will be examined to support this method statement.

The mattress will be tested on resistance against current velocities to examine if it is able to resist the spring tide conditions in the Waddensea. Another important conclusion is that the current at high water elevation is approximately 0.2 m/s. This means the mattress will always be constructed in currents, so this will be applied in the experiment conditions.

To compare the mattress properties constructed in this experiment with the proposed properties of the mattress, it is important to know which volumetric parameters should be realized. Therefore, besides the layer height, also the length of the mattress, the spreading and the density will be measured or calculated.

After lowering the pipeline there are still some small free spans left. To examine the behaviour of the pipeline near the free spans this part must be implemented in the experiment as well.

4. Results GC Drop tests

(Witteveen+Bos, 2013)

This report gives the results of the GC drop test performed at the Van Vliet wharf in Amsterdam. This test forms the basis of this BSc thesis.

Objective

The main objective of this experiment is to determine how well the GC's interlock with one another and what the parameters are which influences the interlocking. The cycle time of filling the clamshell will be examined as well.

Summary

On September the 3rd the tests were carried out at the wharf of Van Vliet in Amsterdam. A sand bed with a reference grid of 1 x 1 m^2 was made on the floor of the wharf. The GC's (transported to the wharf on pallets) were placed one by one. Each GC was rotated 90 degrees with respect to the previous GC and placed into the clamshell. The clamshell was then positioned 2 m above this bed, which resulted in a falling height of 2 m for the GC's in the clamshell. The amount of GC's in the clamshell and the opening speed of the clamshell (divided into phases, varying from slow to fast) were both varied.

Beside the falling behaviour of a single batch, also the construction of a mattress was tested. This mattress was constructed in stretching bond (Dutch: 'halfsteensverband') and with 60 GC's per clamshell.

At last, the filling method was changed from the rotation method (as described before) to a transportation orientation method. The GC's were placed in transportation orientation, so directly from the pallet into the clamshell.

Results

The tests performed within this experiment shows that the GC's already interlock inside the clamshell. So interlocking takes place directly after loading. When they fall down on the sand bed, more interlocking occurs as well. 88% of the GC's in the clamshell fall into a central heap. On average, 3.5 smaller heaps of 1 to 8 GC's occurred in the mattress on the floor.

When the clamshell is filled according to the transportation orientation method, the interlocking decreases, while the observed diversion of the mattress on the ground increases.

The spreading of the batch of GC's increases when the clamshell is opened fast. This effect is only tested with 30 GC's in the clamshell.

Unevenness of the surface of the clamshell will result in increased friction between the GC's and the clamshell. This leads to a reduction of the interlocking.

Approximately 20 GC's were loaded in the clamshell in 1 minute for the first filling method (so placing the GC's one by one, and each GC rotated 90 degrees compared to the previous GC).

Conclusion

Based on the test results, the clamshell will be adjusted for this project. The unevenness (especially the center ribs) will be removed so a smooth clamshell remains. To evaluate the results found in the GC drop tests, both the GC's and the clamshell will be scaled with a factor 8. This means that the GC's with ribs of 0.05 m and a clamshell with a width of 0.28 m will be used (see appendix K). Similar to the test at van Vliet, a sand layer must be placed on the bed of the flume.

This test was performed in the dry, so no effect of water was taken into account. To evaluate these results, the first experiment within this project is to expand the insights gained from this experiment with the influences of water (still and with a current). To check if differences can be observed from the dry situation at Van Vliet, the effect of the opening speed of the clamshell on the parameters of the batch will be tested as well.

Finally, the experiments where a mattress will be constructed (so experiment 2, 3 and 4) will include situations with and without construction in stretching bond. The filling method will be similar to the filling method in this experiment, so the GC's will be placed one by one.

Plan experiment 1 “Constructing in currents”

1. Introduction

This appendix deals with the experiment plan of the first experiment, “Constructing in currents”.

1.1 Objective

The objective of this experiment is to evaluate the measurements of the previous “full scale placement test in the dry” (Van Vliet, Amsterdam, 3-9-2013). This experiment expands the previous experiment by examining the behaviour of a batch of GC elements (GC’s) under water and with a current.

The results of this experiment gives insight in:

- The spreading of a batch of GC’s under water after falling in a current from a specific height (0.25 m).
- The composition of a batch of GC’s after falling down (interlocking behaviour, the number of loose and broken elements).
- The difference in composition of a batch of GC’s regarding to different opening speeds of the clamshell (slow ± 7 sec and fast ± 2 sec).

1.2 Main question

What is the difference in behaviour (spreading and interlocking) of a batch of GC’s while being placed in a current, from the moment of placing the GC’s in the clamshell until reaching the bed under different conditions, regarding falling of the GC’s in the “full scale placement test”?

1.3 Definitions

- The GC’s used in these experiments are scaled elements based on the design used in the full scale placement test. The full scale GC’s have outer dimensions of 0.4 x 0.4 x 0.4 m^3. The scaled elements have outer dimensions of 0.05 x 0.05 x 0.05 m^3. This results in a scaling of 1:8.
- “The hooking behaviour includes the amount of GC’s within a specific area after dropping and the entanglement of GC’s within this volume (in pairs, triplets etc.).” (Witteveen + Bos, Proposal for full scale placement tests in the dry, 2013)

1.4 Hypotheses

1. Based on the results of the reference experiment and the changes made on the scaled clamshell the batch of GC’s will interlock even more.
2. The batch will spread more if the clamshell is opened fast because the elements will swing to the outside of the containers.
3. Because of the current the loose elements will float away before the batch hits the bed, so that a large spreading will occur. This expected effect is shown in Figure 2.

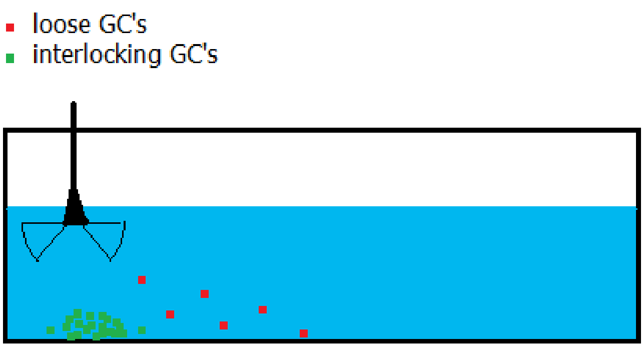


Figure 2 hypotheses of dropping GC's

4. Because of the importance of the filling method of the clamshell for the final shape of the batch, the behaviour found in this experiment is very similar to the behaviour in the

reference test. But because of the current, the spreading in groups and loose elements will increase.

2. Data collection

The following shows an overview of the required data that needs to be received from the experiment to make an analysis of the behaviour of a batch of GC's under water. For each measurement the method of measuring is described.

The height of the water plane

This can easily be measured by the available equipment in the laboratory for fluid mechanics. The measured height is the (average) height from the top of the sand bed to the water table. See Figure 3. This height will be measured along the flume at two specific spots, so the gradient of the water table can be calculated. The rulers are placed approximately 10 m apart from each other.

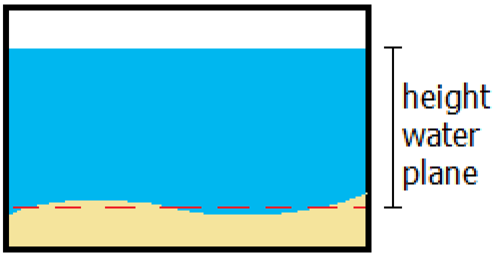


Figure 3 Height water plane

The falling height

This is the distance from the underside of the clamshell to the sand bed. In real life a falling height of 2 m was used, so at a scale of 1:8 this means a falling height of 0.25 m.

The total number of GC's in the clamshell

This is done by counting the amount of GC's in the clamshell. The batches will be tested in the following order; 3, 30, 40, 60, and 70 GC's. Because of the size of the clamshell it isn't possible to test 80 or more elements.

The cycle time of loading and opening the clamshell

With a stopwatch the time will be registered between the start of the loading process until the end, when the GC's lie on the sand bed. The following steps will be timed:

- Loading of the clamshell.
- Opening of the clamshell.
- Time in between opening and the first element reaching the sand bed.
- Time in between the last element moving and reaching the sand bed.

Using the footage made with the cameras, the exact opening and falling time will be calculated. This will be done with a computer program that works with frames, so the exact frame interval can be counted. The frame rate of 25 frames/second gives the time.

The falling time of the first element is the number of frames between the frame with the first element moving and the frame where that element hits the bed. This difference will be divided by the frame rate of the camera to get the desired falling time.

The falling time of the last element is the number of frames between the frame where the last element in the clamshell starts moving and the total batch is stable and stationary on the bed, divided by the frame rate.

Center of the batch

This position will be measured to estimate the center of the batch and then measure the position in x and y direction compared to the center of the clamshell.

Height of the batch

One can expect from the reference experiment that a complicated structure will appear once the batch reaches the bed. Therefore the average layer height and the four highest peaks will be measured.

The spreading of the batch

To get an idea of the spreading of the GC's, a blocked pattern will be used, similar (but scaled) to the screen in the reference experiment. The number of blocks filled with elements indicates the spreading. This grid will be implemented during the computer analyses of the camera recordings.

Figure 4 Transportation orientation

The orientation of the batch

This data is hard to measure, but will be described. After falling down the shape of the batch will be described. Apart from that, also the orientation of the elements will be checked to see if they remain in "transportation orientation" (orientation with high density). Figure 4 shows how the GC's lie in transportation orientation.

The number of GC's that interlock together

To check how many elements are interlocked, the GC's will be lifted one by one to check how many elements form a group. For each group, the total number of GC's in the string will be counted.

The number of loose and broken GC's

This data will be obtained by simply counting the number of elements that remain on the bed after lifting the groups of GC's. The definition of broken GC's is that one or more ribs are broken.

Density of the batch

To get a value for this parameter, the area under the batch and the average layer height will be measured as explained before. The density will be the total amount of GC's divided by the volume of the batch (area x average height).

3. Base of research

In this chapter the materials and equipment used for the execution of the experiment is listed. Also the setup is described and listed chronologically.

3.1 Materials and equipment

The used materials and equipment for this experiment include:

- One scaled clamshell (scale 1:8 based on drawing LH160-4500).
- One flume (large research flume in the laboratory for fluid mechanics, dimensions (width x height) 0.80 x 1.00 m^2).
- Sufficient GC's with dimensions 0.05 x 0.05 x 0.05 m^3.
- Equipment to hang the clamshell above the flume and hold it in place.
- Bed material e.g. sand or gravel (depends on current velocity).
- Three regular cameras (positioned on the side and above the flume and one for mobile usage).
- One underwater camera mounted on the sand bed.
- Equipment to mount and orientate the cameras (near and above the flume).
- One white plane with a grid (blocks of 0.125 x 0.125 m^2) for the sidewall.
- One claw or net to pick up the elements.
- One measuring rod to measure the height of the batch.
- One protection sheet near the end of the flume to catch loose elements.
- Equipment to measure the water table height in the flume.
- (Digital) equipment to measure the current in the flume. This measure instruments were mounted 0.18m above the bed.
- One stopwatch for measuring the time cycle.

3.2 Setup

The experiment setup is as follows:

- An even sand layer will be made on the bed of the flume. This bed is approximately 0.04 m.
- The clamshell is placed above the flume, in line with the flow direction. The distance between the bed of the clamshell and the sand bed will be measured. This must be 0.25 m.
- One camera will be placed at the side of the flume and one (under water) camera will be placed inside the flume at the upstream side of de sand layer, in line with the current direction.
- One camera will be placed on top of the flume at the holder near the clamshell to get an overall view.
- One camera will be placed at the side of the flume in front of the side window.
- One white plane will be placed at the opposite side from the camera side in the flume.
- Then the flow in the flume starts. The velocity depends on the type of experiment.

The following will be performed each test:

- Load the clamshell with the necessary amount of GC's. The clamshell is loaded according to the reference experiment, so one by one, and the next GC rotated over 90 degrees compared to the previous one. Measure the loading time with a timer.
- Make a picture of the loaded clamshell with the mobile camera.
- Hang the clamshell in place and measure the falling height. This must be 0.25 m.
- Measure the position of the clamshell relative to the origin.
- Start filming on all cameras.
- Open the clamshell (slow or fast) and wait until the batch of GC's reaches the bed.
- Stop the cameras.
- Make pictures with the mobile camera from the top of the batch.

- Measure the highest points of the batch (from the bed).
- Catch the elements one by one (as random as possible) and count the number of interlocking strings (double, triplets etc.).
- Count the remaining loose and broken elements.

The following will be done with the analyses of the footage and stills:

- In paint.net the photos of the fallen batches can be opened and analysed by measuring the width of a GC in pixels and compare this to the real size of 0.005 m of the width of a GC. With this factor the position in x- and y-coordinates can be calculated by drawing a line from the batch center to the x- and y-axis.
- With the same methods as described above a plane can be drawn in paint.net over the surface of the GC's. The border of this plane is drawn over the border of the surface of the GC's. The amount of pixels in this plane is displayed in paint.net and converted with the factor to cm^2. With this method the area of the batches is calculated.
- With a still of cam 1 (the camera with the side view of the flume) the layer height can be measured. With the same method as described above. A GC will function as a reference to determine the conversion factor. The height of the batch is measured with a line drawn from top to bottom and converted with the factor.
- Determine the opening time and the falling time of the first and the last element in the clamshell.

These tests will be performed as described in Table 1. Because a higher accuracy seems to be needed for the tests in still conditions, the number of measurements will be five instead of three.

water condition	number of GC's in clamshell	opening clamshell	number of measurements per situation
dry	3, 30, 40, 60, 70	fast & slow	3
still	3, 30, 60	fast & slow	5
current (0.25 m/s)	40, 60	fast & slow	3
current (0.35 m/s)	40, 60	fast & slow	3

Table 1 Number of experiments en measurements

3.3 Layout

Below several figures of the experiment setup are displayed.

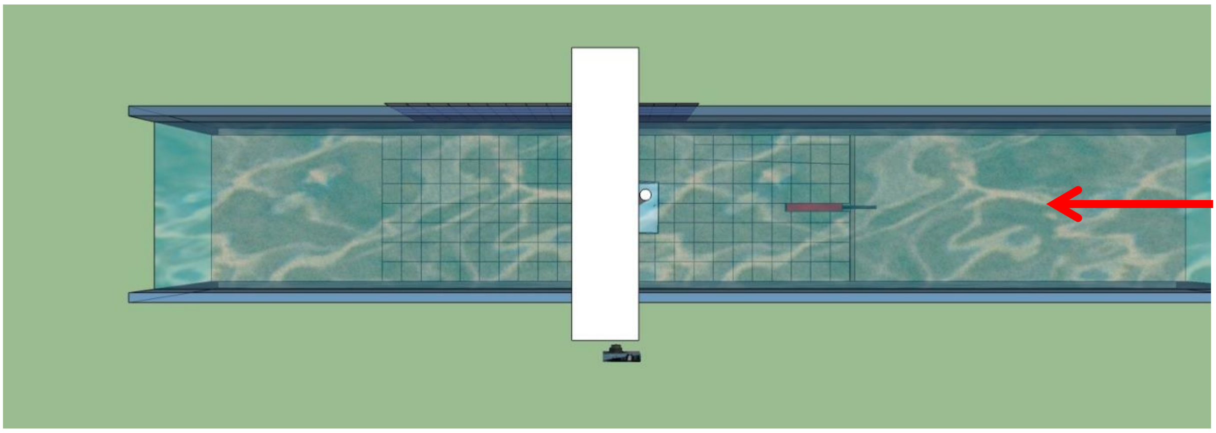


Figure 5 Top view of flume with clamshell and reference grid

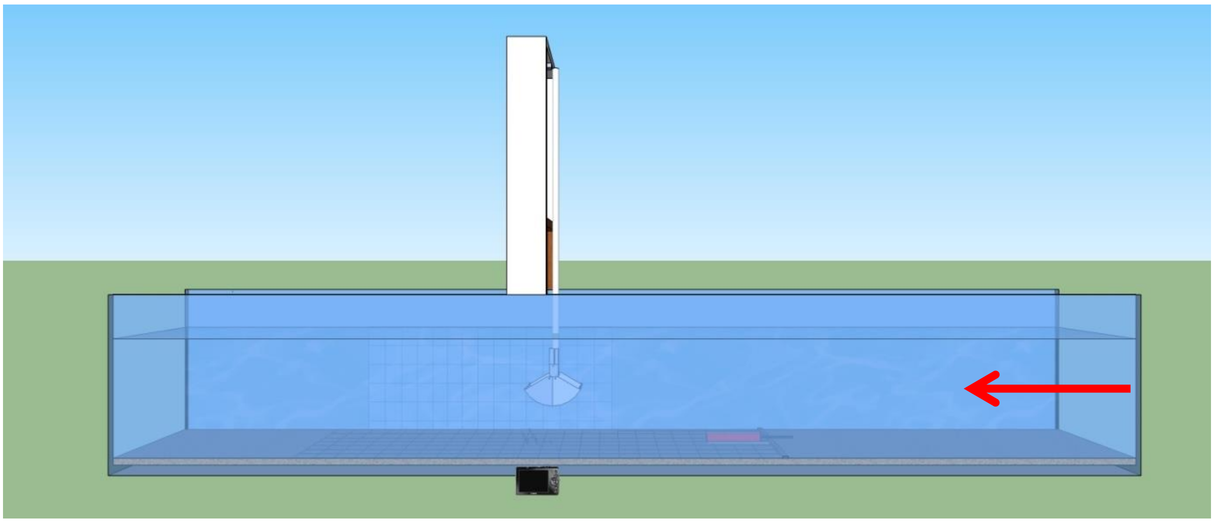


Figure 6 Setup of experiment side view

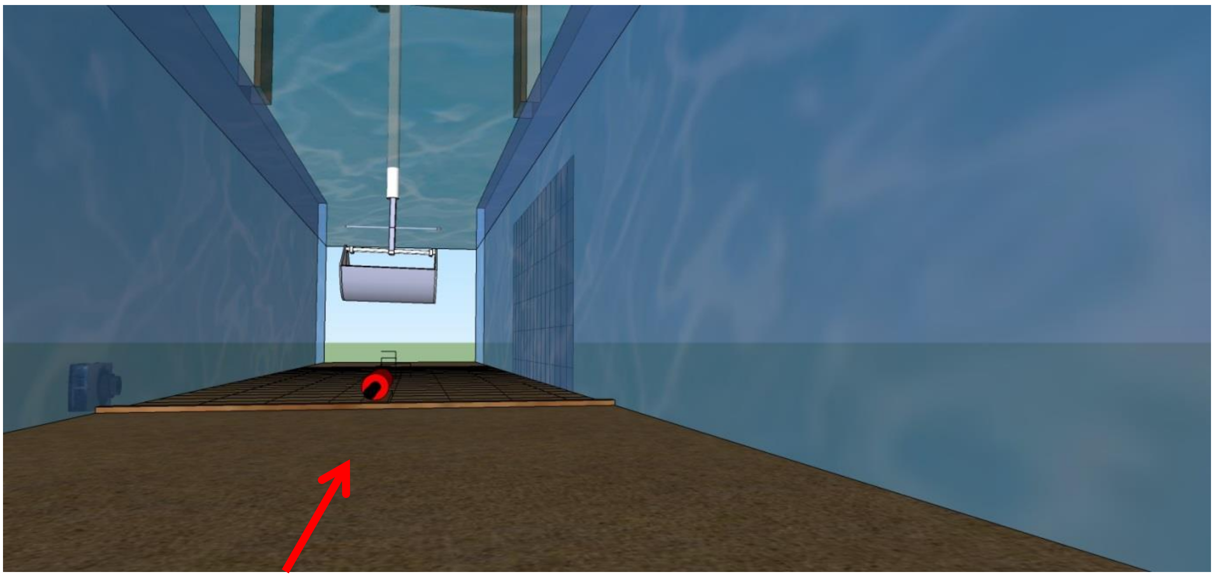


Figure 7 Setup of experiment inside the flume in current direction

3.4 Statistic relations

Once the experiment results are obtained, some statistic tests will be executed to check if the relations can statistically be supported and to get an idea of the significance of the data. These statistics will be executed in the statistic program IBM SPSS Statistics 22.

Once a relation is plotted in a chart or is listed in a table, the variables on the y-axis (the dependent values) will be checked in relation to the variables on the x-axis (the independent values). To see if they are normally distributed in relation to each other, a Shapiro-Wilk test for normality (suited for small samples) will be executed. Based on these results (if the results have a significance of 0.05 than a normal-distribution occurs), the right correlation test will be chosen.

If the data is non-normal distributed, and the values on the x-axis aren't continuous, the Shapiro-Wilk test will be executed. This test will check the null-hypothesis, which states that the values of the dependent variables follow the same distribution, so the independent values don't affect the distribution of the dependent values and the observed differences are likely to be based on a coincidence. If however, the null-hypothesis has a significance of 5%, the null-hypothesis could be rejected and the distribution differences are in fact caused by the independent variable.

If the data is normal distributed, the t-test can be performed, which works almost the same as the Shapiro-Wilk test.

As soon as the independent variables are continuous, the correlation between the variables will be checked with the Spearman (non-normal distribution) or the Pearson test (normal distribution). This test will find a correlation coefficient and a significance level. If the significance is lower than the chosen significance level, the variables are in fact correlated.

When data is displayed in charts or in tables, the average values and the reliability interval will be given, to compare the values and the standard deviations. The reliability interval is based on a significance level, which is chosen to be 95% in this experiment.

If the relation isn't significant, the effect of the independent variables on the dependent variables aren't scientifically found. When this happens, only an indication will be given based on the charts.

Appendix C. Results experiment 1 "Constructing in currents"

Experiment 1 was performed from 16-9-2013 until 23-9-2013 in the TU Delft Laboratory for Fluid Mechanics. This appendix gives an overview of the test results and will also check some statistic relations between the main parameters. This will result in a recommendation in the handling method of the clamshell and will give average values of parameters that can be used in the following experiments.

1. Experiment execution

In the following figures an overview of the setup of the experiment is shown.

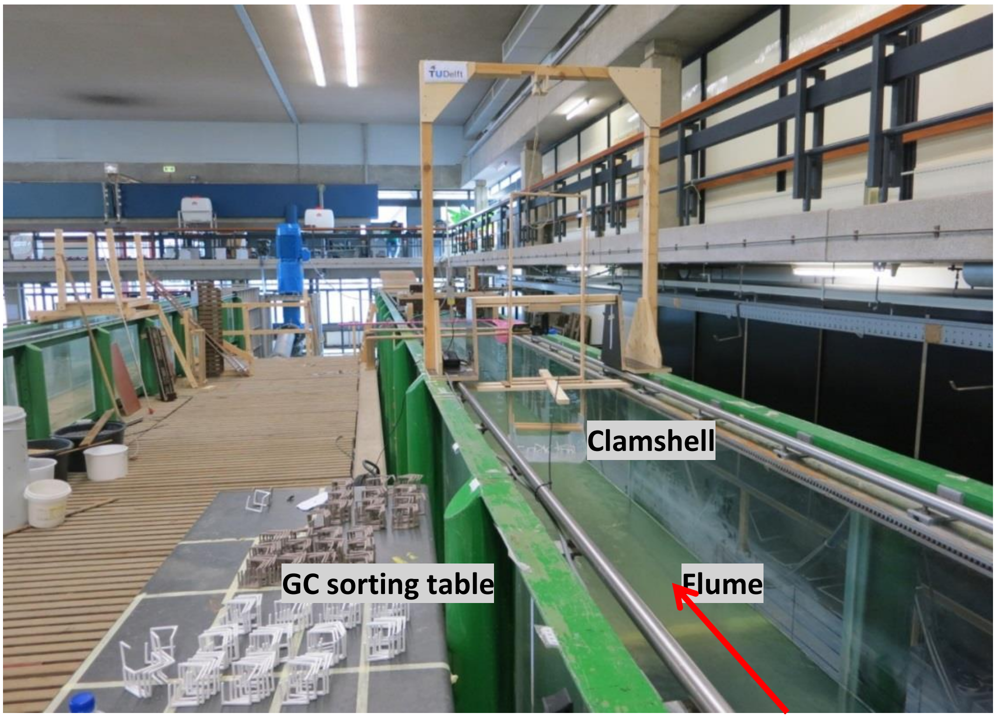


Figure 8 Overview execution experiment 1

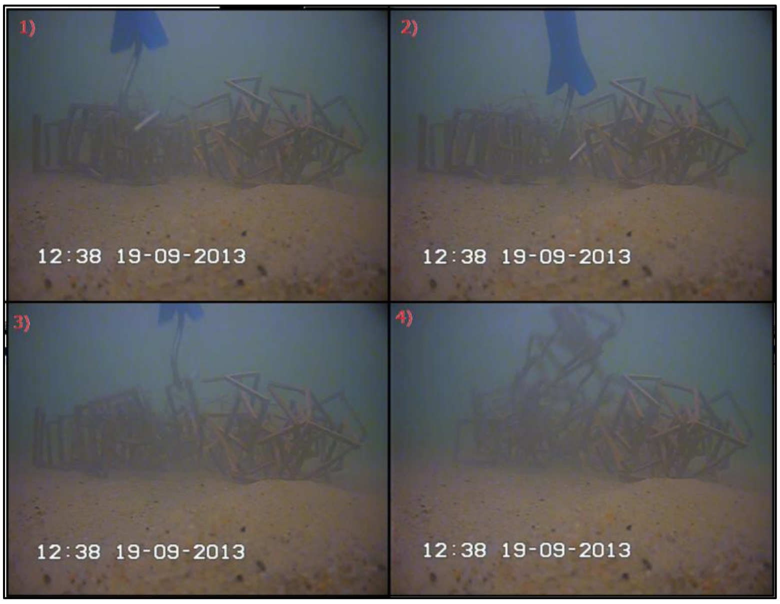


Figure 9 Method for pulling out the strings

2. Calculation methods

Some parameters must be calculated during the data preparation before they can be used in the charts. These parameters are described in the following alineas:

Batch volume properties

The definition of the batch volume properties is the spatial volume properties of the batch on the bed of the flume. This can be described in terms of layer height, spreading (the area of the batch) and density. The method for measuring the layer height and the spreading are described in the experiment plan.

The density is defined as the number of GC's per volume (in this case cm^3). The volume of the batch is the average layer height along the x-axis of the flume, times the area of the batch.

The batch orientation is also part of the batch volume properties. It is the coordinates of the batch center measured from the origin. It describes the final position of the batch in x- and y-coordinates.

In the exploitation phase, the compaction factor of the mattress will be around 1.8, so the desired density of the GC's with ribs of 0.4 m will be around 28.1 GC/m^3 (2.5 GC's per axis, a compaction factor of 1.8, so $(2.5)^3$ x 1.8 = 28.1 GC/m^3). This compaction factor of 1.8 holds a desired density of 20 x 20 x 20 x 1.8 = 14400 GC/m^3 for the mattress in this experiment (based on the scaled GC's with ribs of 0.05 m). This means a required density of 0,0144 GC/cm^3. This value will be used to check how the batches relate to this density.

Interlocking

To check the interlocking behaviour, the batch was decomposed and divided into strings during the experiment. A string consists out of GC's that interlocked with each other while performing the experiment. In this analysis, the decomposed strings were dived into groups. The amount of GC's in a string determines its group. The groups are listed in Table 2.

Group	GC's	Group	GC's
1	0 – 5	**6**	26 – 30
2	6 – 10	**7**	31 – 35
3	11 – 15	**8**	36 – 40
4	16 – 20	**9**	41 – 45
5	21 – 25	**10**	46 – 50

Table 2 Interlocking groups

3. Analysis

3.1 Amount of GC's per clamshell

Between certain parameters there is a clear relationship that can be seen and has an influence in the experiment. First, the relation between the amount of GC's in the clamshell and the volume properties of the batch (in terms of layer height, density and spreading) will be examined. To do so, some variables have to be kept constant. In this first analysis, the situation in the dry will be examined. Besides that the opening speed of the clamshell will always be slow, in order to exclude influences of that parameters on the behaviour.

Volume properties of the batch constructed in the dry

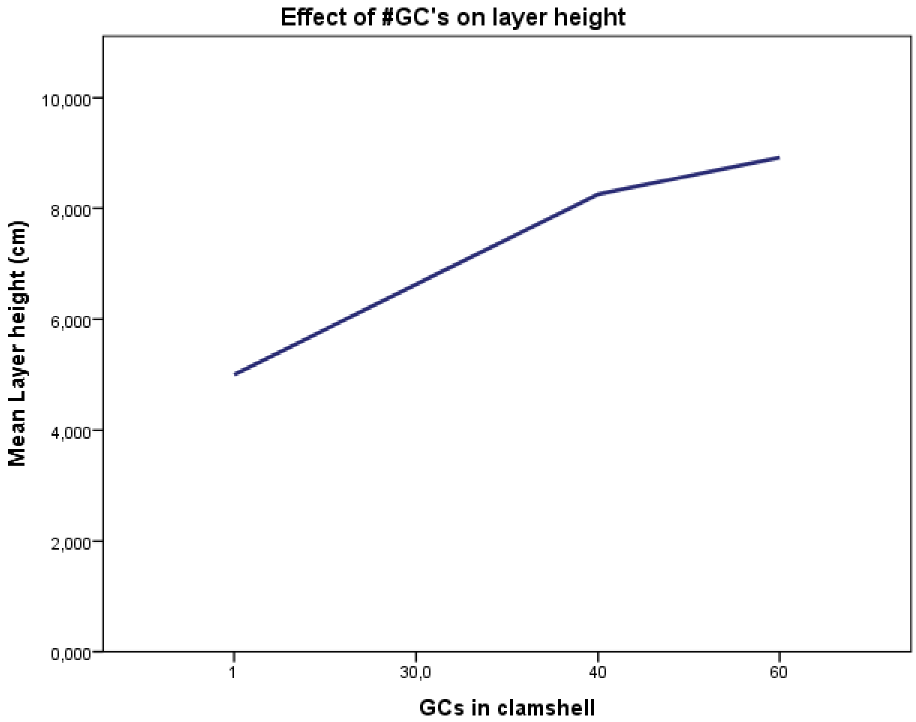


Figure 10 Effect of the amount of GC's on the layer height

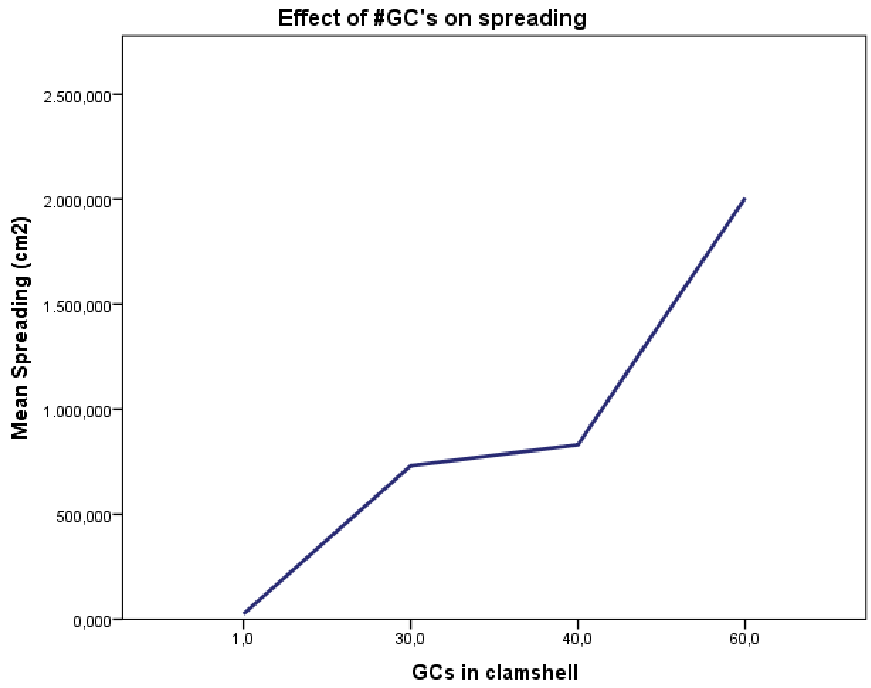


Figure 11 Effect of the amount of GC's on the spreading

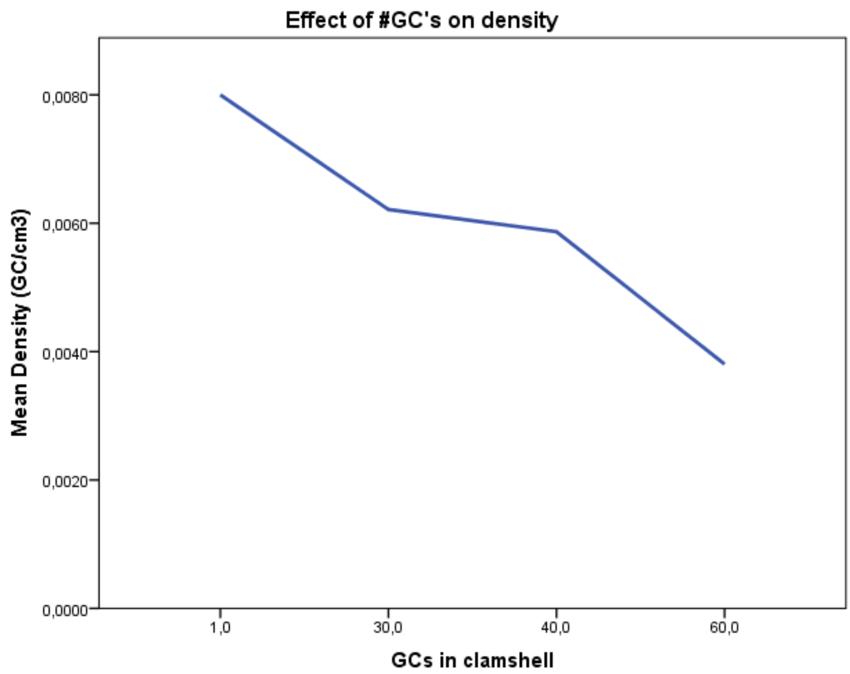


Figure 12 Effect of the amount of GC's on the density

Figure 10, 11 and 12 show the relation between the amount of GC's in the clamshell and the average layer height of the batch, the average spreading and the average density.

To check if this relation, based on the data from the experiment, is significant, a correlation test will be performed. To find out which test can be applied here, the variables along the x- and y-axis of the graphs will be checked for a normal distribution with help of the Shapio-Wilk method (for small samples). This test shows that all the variables (spreading, layer height and density) are non-normal distributed under the amount of GC's in the clamshell.

The spearman's test for significance gives the correlation coefficient between the amount of GC's in the clamshell and the variables that belong to the batch volume properties.
This is listed in Table 3.

	Correlation coefficient	Significance (2-tailed)	N (number of tests)	Correlation is significant (level 0.05)
Density	-0.881	0.0	13	Yes
Layer height	0.949	0.0	13	Yes
Spreading	0.932	0.0	13	Yes

Table 3 Correlation coefficients relation GC's in clamshell and batch volume properties

Volume properties of the batch constructed in the wet
To check if the volume properties of the batch differs from the situation in the dry after construction in still water, the same analysis as described above will be performed.

Now, the data from the experiment in the wet will be used. The opening speed of the clamshell remains slow.

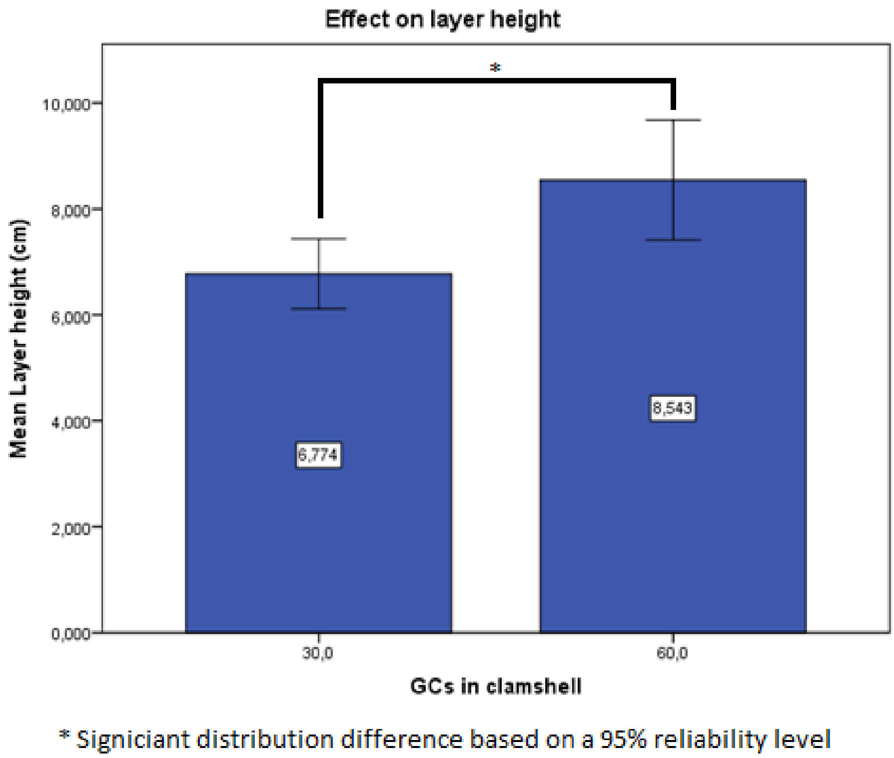


Figure 13 Effect of amount of GC's on the layer height of the batch

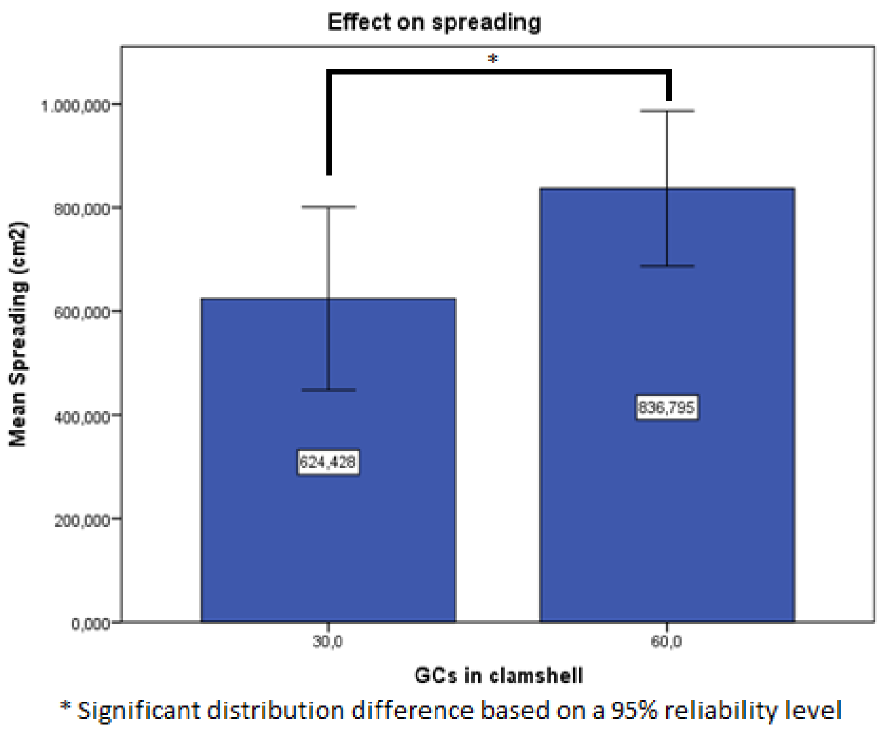


Figure 14 Effect of amount of GC's on the spreading of the batch

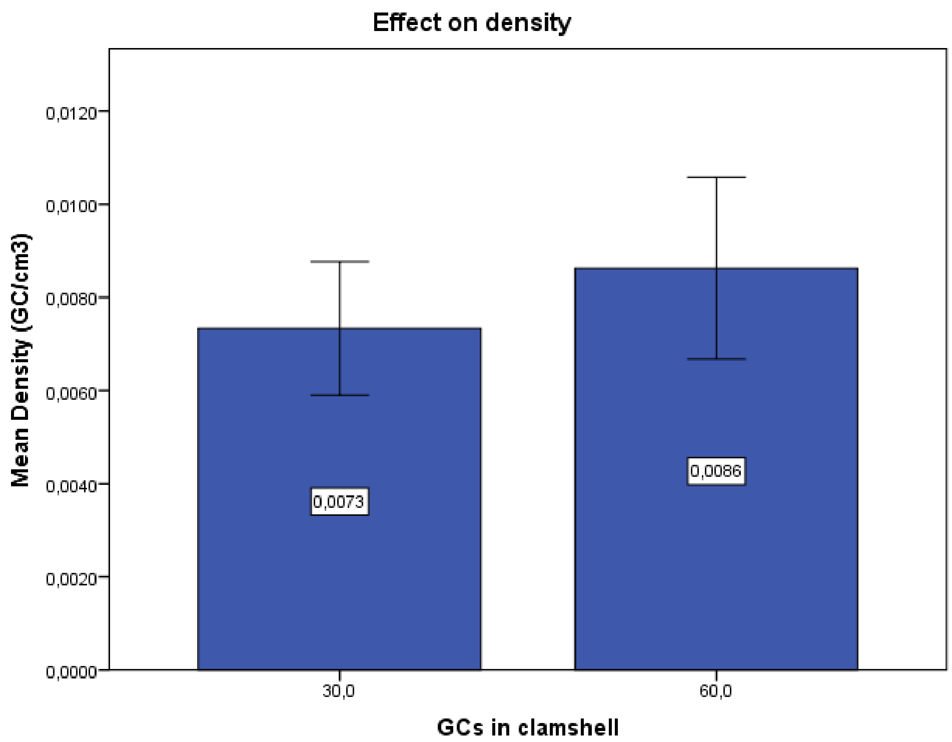


Figure 15 Effect of the amount of GC's on the density of the batch

Because the situation in the wet was only tested with 30 and 60 GC's in the clamshell, a bar chart will be used here. Figure 15 shows this bar graph for the realized layer height, density and spreading in still conditions. The displayed error bar is the error that belongs to a 95% reliability interval. This bar gives the upper and lower error boundary of the mean-value.

To check the significance of these results, a statistic Mann-Whitney U test will be used because all the variables are non-normal distributed. Table 4 shows the outcome of the Mann-Whitney U test for these relations. A significance level of 0.05 and 0.1 is used here.

Null hypothesis (H_0)	Significance	Decision
The distribution of density is the same across the amount of GC's per clamshell	0.222	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of layer height is the same across the amount of GC's per clamshell	0.032	**Significance level of 0.05; reject H_0**
The distribution of spreading is the same across the amount of GC's per clamshell	0.032	**Significance level of 0.05; reject H_0**

Table 4 Mann-Whitney U test batch orientation

Interlocking

Again, the situation in the dry and in the wet will be analysed. To exclude the influence of the opening speed, this will be kept constant again. Therefore, only the data from the slow opening speed will be used.

Figure 16 and 17 show the effect of the amount of GC's in the clamshell on the interlocking behaviour.

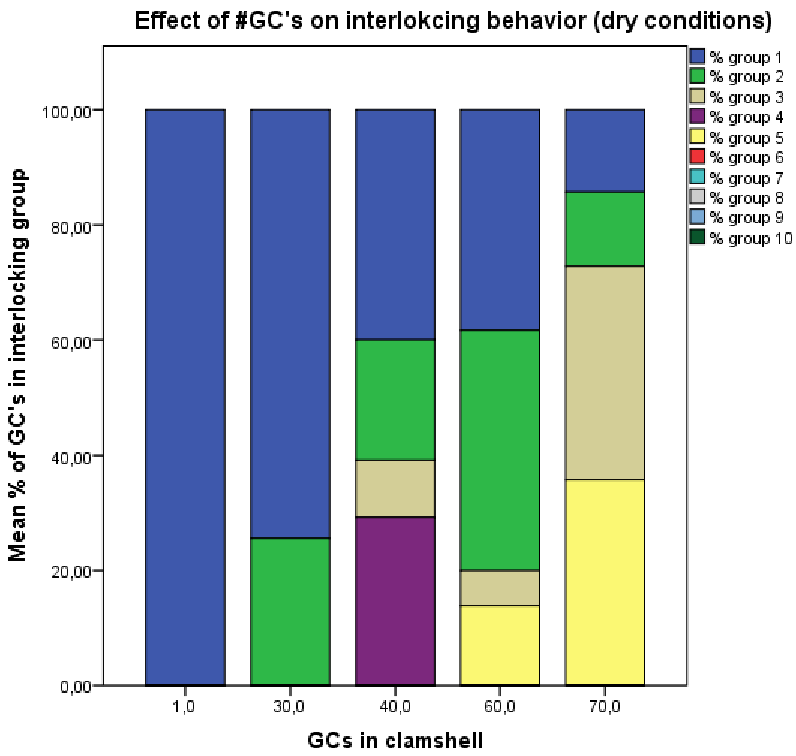


Figure 16 Effect of the amount of GC's on the interlocking in dry conditions

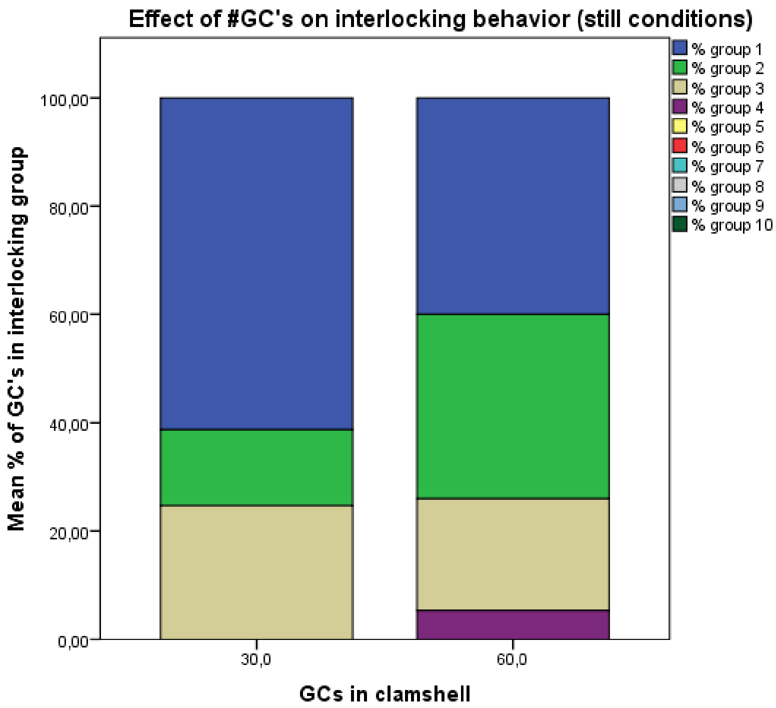


Figure 17 Effect of the amount of GC's on the interlocking in still conditions

To check the significance of this interlocking results, an independent samples Kruskal-Wallis test can be executed. The results are listed in Table 5.

Null hypothesis (H_0)	Significance	Decision
The distribution % group 1 is the same across the amount of GC's per clamshell	0.057	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution % group 2 is the same across the amount of GC's per clamshell	0.268	Significance level of 0.05; retain H_0 Significance level of 0.10; retain H_0
The distribution % group 3 is the same across the amount of GC's per clamshell	0.187	Significance level of 0.05; retain H_0 Significance level of 0.10; retain H_0
The distribution % group 4 is the same across the amount of GC's per clamshell	0.125	Significance level of 0.05; retain H_0 Significance level of 0.10; retain H_0
The distribution % group 5 is the same across the amount of GC's per clamshell	0.161	Significance level of 0.05; retain H_0 Significance level of 0.10; retain H_0
The distribution % group 6 until 10 are the same across the amount of GC's per clamshell	All 1.0	Significance level of 0.10; retain H_0

Table 5 Results Kruskal-Wallis test on the interlocking behaviour

Conclusion

From the information given above a conclusion can be drawn. All these conclusions are based on the effect of the amount of GC's in the clamshell. From Table 4 it can be concluded that there is indeed a significance in the relation between amount of GC's and the layer height and the spreading of the batch. This states that a better result in height and spreading can be realised with a higher number of GC's in the clamshell.

From Table 5 it can be concluded that it is significant to state that when the clamshell contains more GC's there will be less loose elements. This is a very important conclusion, it means that when more

GC's is used the batch on the sand bed is significant more complete and won't have as much loose elements which don't belong to the mattress. Therefore the stability of this batch will be higher than by a batch which is built out of less elements. The reason as for why this is, is that when the clamshell opens the elements will fall and roll over each other to interlock, but eventually the way they are put in the clamshell will have the most influence. When 30 elements lie in the clamshell they will be independently from each other, because there is so much room for the GC's that they won't have to lie over each other to fit in. When the clamshell opens, the elements will slightly interlock but most of all they will go their own way and this will eventually lead to loose elements on the bed. But when more GC's are used they won't have the free space in the clamshell and will be forced to interlock with other elements in order to fit in the clamshell and therefore they will move as one when falling out of the clamshell.

With these conclusions it can be stated that the optimal amount of GC's in the clamshell will be as much as possible. This can't be an infinite number of GC's because the clamshell has its limitations. In other words with the experiments it was clear that there wouldn't fit anymore GC's in the clamshell than 75 at most. With the latter experiments in the current it was clear very soon that even such an amount wouldn't do because the elements on top would float away in the current before the clamshell was hung in place. With 70 GC's the clamshell was filled to the brim and when opening the clamshell the elements would hung over the ribs of the clamshell and wouldn't drop. So eventually the recommended amount of GC's will be 60.

3.2 Opening speed clamshell

In this first experiment, the influence of the opening speed of the clamshell on the volume properties was examined as well.

In this experiment, two opening velocities were tested. To get an idea of the opening times (fast and slow), Table 6 shows the averages of these opening times.

Opening speed clamshell	Average (s)	Deviation (s)	Number of samples (N)
Fast	1.85	2.01	26
Slow	3.23	2.97	31

Table 6 Opening speed clamshell

The influence of the opening speed on the batch orientation and the interlocking will now be examined. This will be done while keeping the amount of GC's per clamshell constant (at 60 GC's) and using the data from still water conditions.

Batch volume properties

Figure 18, 19 and 20 show the effect of the opening speed on the batch volume properties (the mean layer height, the mean spreading of the batch and the mean density). The deviation bars are based on a 95% reliability interval.

To check the significance of this relation, the data on the axis will be tested for normality. Only the density follows a normal distribution, according to the Shapio-Wilk method. Therefore, the non-normal distribution method of Mann-Whitney U will be used here to check if the differences in distribution are significantly different from each other. The results are listed in Table 7.

Null hypothesis (H_0)	Significance	Decision
The distribution of the layer height is the same across the openings speed	0.222	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of layer height is the same across the amount of GC's per clamshell	0.310	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of spreading is the same across the amount of GC's per clamshell	0.095	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**

Table 7 Results Mann-Whitney U test

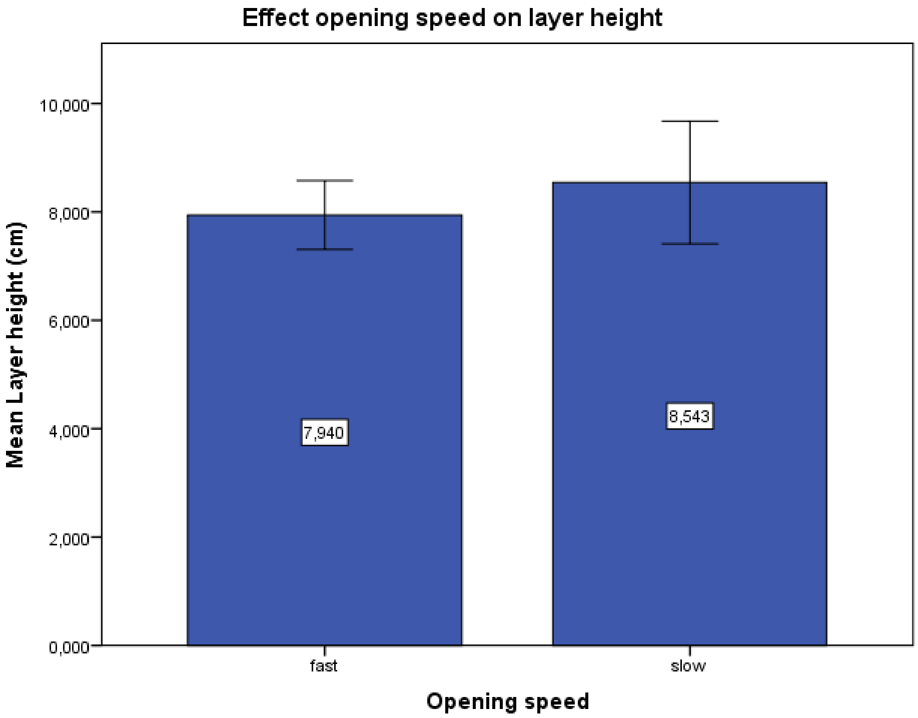


Figure 18 Effect opening speed on layer height, constructed in still water

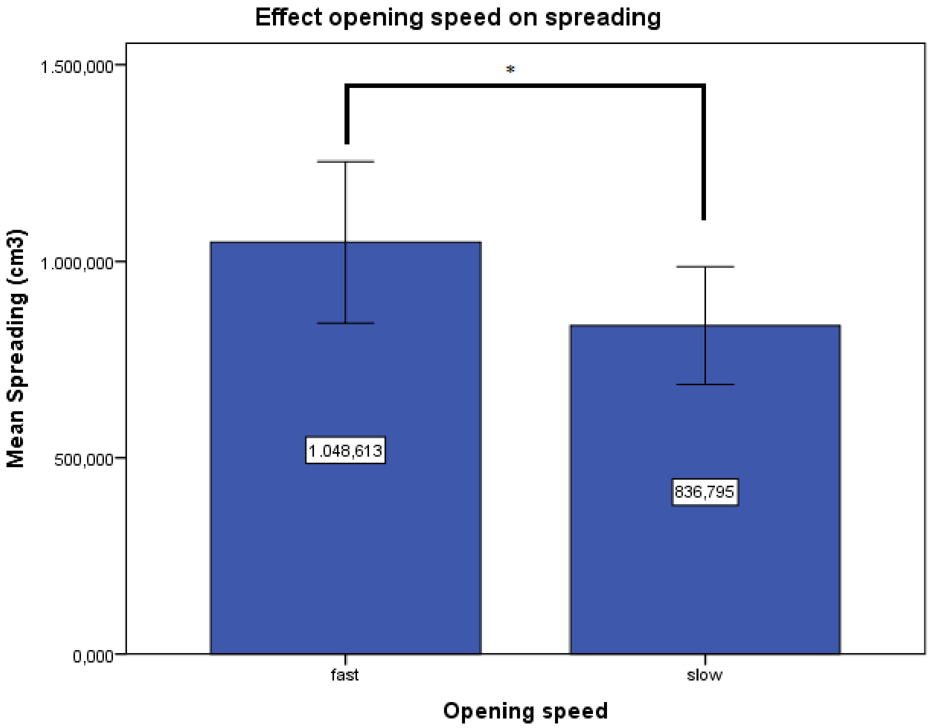


Figure 19 Effect opening speed on spreading

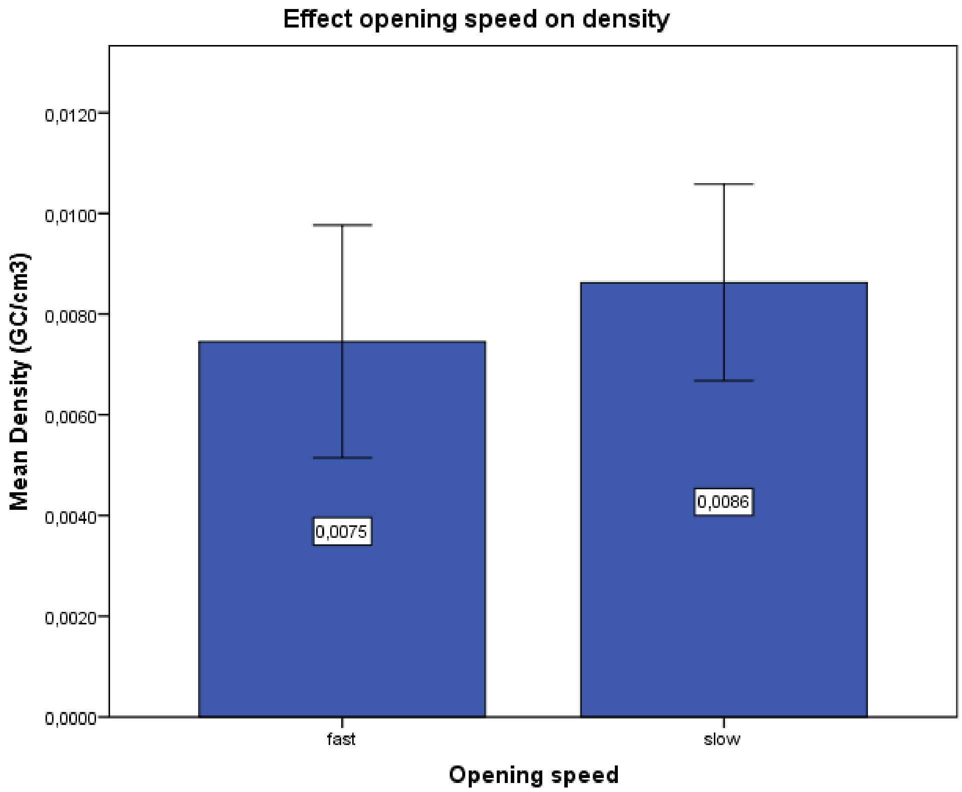


Figure 20 Effect opening speed on density

Interlocking

Figure 21 shows the division of the strings of the batch in groups (the same groups as shown in Table 2 were used here) due to fast and slow opening of the clamshell.

To check the significance of this relation, the variables along the axis will be tested for a normal-distribution. Based on the Shapio-Wilk method, only the values in group 3 and 4 are normal distributed. Therefore, a non-normal distribution method will be used here to find the significance of the result.

Table 8 shows the results of the Mann-Whitney U test. The P-value of this test is 0.05.

Null hypothesis (H_0)	Significance	Decision
The distribution % group 1 is the same across the amount of GC's per clamshell	0.056	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution % group 2 is the same across the amount of GC's per clamshell	0.222	Significance level of 0.05; retain H_0 Significance level of 0.10; retain H_0
The distribution % group 3 is the same across the amount of GC's per clamshell	0.690	Significance level of 0.05; retain H_0 Significance level of 0.10; retain H_0
The distribution % group 4 until 10 are the same across the amount of GC's per clamshell	All 1.0	Significance level of 0.10; retain H_0

Table 8 Results Mann-Whitney U test on the interlocking behavior

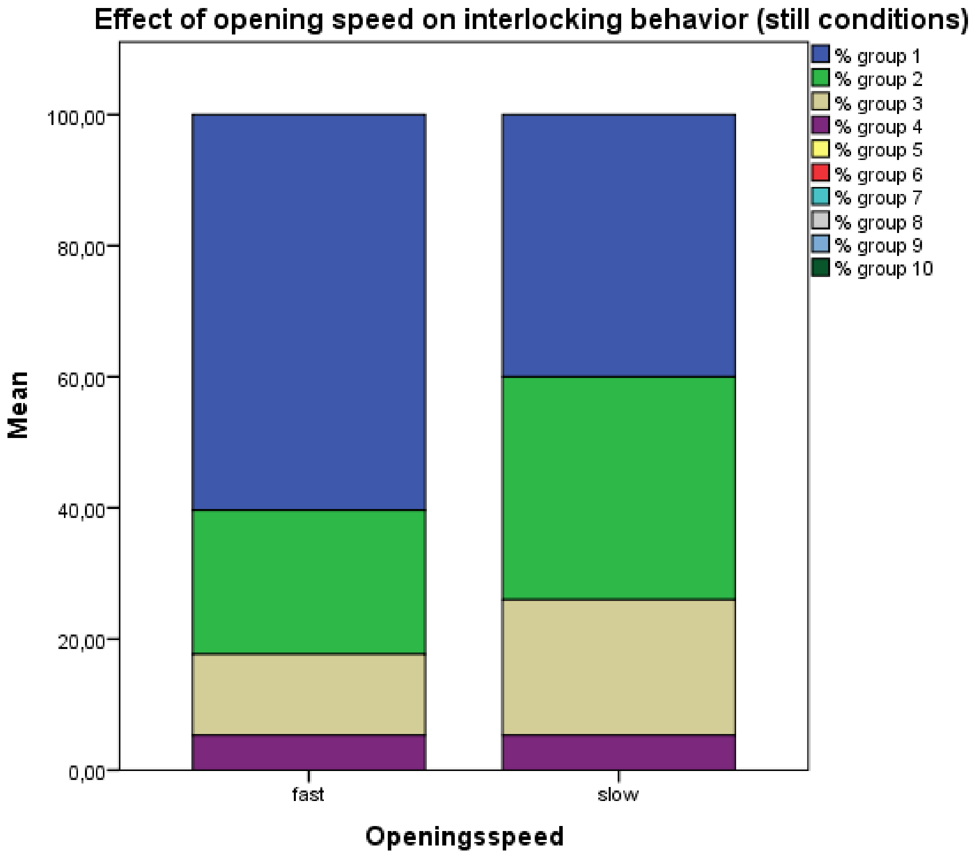


Figure 21 Influence of opening speed on the interlocking behaviour

Conclusion
From the information given above, some significant conclusions can be drawn in relation with the opening speed of the clamshell. In accordance to Table 7 it can be concluded that the influence of the opening speed of the clamshell has indeed some effect on the batch. When the clamshell is opened slowly the spreading is better, or in other words the density is higher and the batch is much firmer.

Also it is clear that the opening speed has some influence on the spreading of the different groups. With an opening speed that is slow there are significantly less loose elements (string belonging to group 1). This is an important conclusion, because as is said before how firmer the batch on the bed the more stable the batch, and eventually the mattress, will be.

From observations the differences could be explained by observing the opening width of the clamshell over time. In still conditions, due to the intertia caused by the buyoancy, the GC's will start falling all together after the clamshell is fully opened. Because the clamshell is opened fast, there is no rolling over effect and the GC's fall just as they were positioned during loading.
When the clamshell is opened slowely, there is a point where the clamshell opens wide enough to help the first GC's rolling out of the clamshell. Because this gap width increases slowly, the GC's will start rolling over each other and interlock during their way out of the clamshell. This effect is displayed in Figure 22.

So as to say if the opening speed of the clamshell has an influence on how the batch will behave on the bed. Yes, it has and a significant influence it is. Not only on the spreading but on the entire batch.

Based on our conclusions on the opening speed of the clamshell, we recommend that the clamshell must be opened slowly.

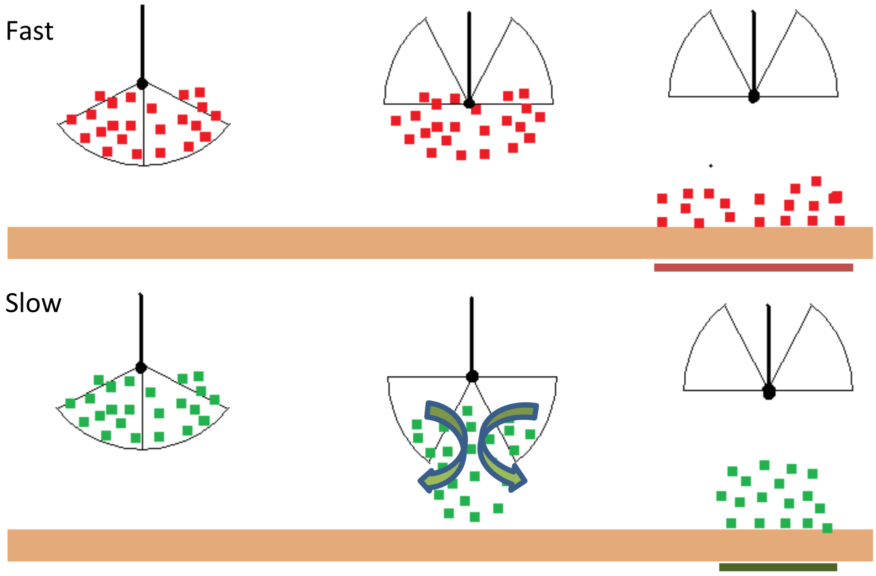


Figure 22 Observed rolling effect GC's during opening

3.3 Used filling method

All the GC's were placed loosely in the clamshell, in the recommended method, so one by one. At first the GC's were orientated 90 degrees from each other. To prevent that the GC's remain on the ribs of the clamshell, relatively more GC's were placed on the upstream side of the clamshell.

Especially at smaller amounts of GC's (30, 40) in the clamshell, the filling method influences on the eventual batch on the bed. When the GC's are placed in heaps in the clamshell, those heaps remain visible on the bed. At larger amounts of GC's (60), this effect is less visible. The filling velocity has an average of 2 seconds per GC. For the entire conclusion of the amount of GC's in the clamshell, read the conclusion of "Amount of GC's per clamshell".

Conclusion

Based on observations, the maximum amount of GC's in the scaled clamshell is 60. When an amount of 75 GC's is used, the GC's starts falling out of the clamshell. When using an amount of 70 GC's, some GC's stick to the ribs of the clamshell and remain in the clamshell after opening.

Therefore, the optimal amount of GC's in this clamshell is around 60 – 70 GC's. Because the total amount of GC's that was available for this experiment is 360, the amount of GC's per clamshell will be kept at 60.

3.4 Influence of current velocity

Falling position

For the accuracy of the construction near the pipeline, the falling position of the batch is important and needs to be estimated. At sea there will be a specific current that can be measured. With this information, the position of the clamshell in relation to the pipeline and the designed mattress can be chosen. Especially positioning close to the pipeline will be difficult because there might occur gaps because of the increase in current.

The goal of experiment 1 is to evaluate the influence of the amount of GC's in the clamshell and the opening speed and the current, in relation to the falling position of the batch center along the axis of the flume.

Theoretical falling position

First, based on simple mechanics, the position of an object in a current will be calculated.

This will be done with the following model, based on Figure 23.

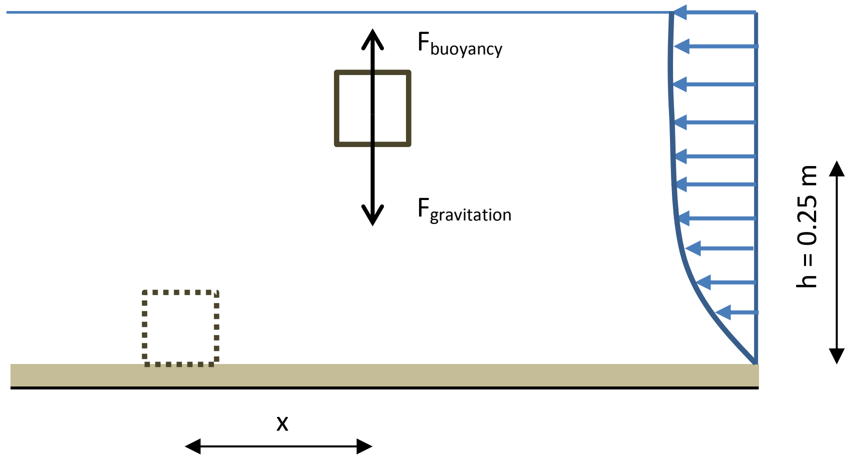


Figure 23 Schematization of the theoretical falling position

Because the element is beneath the water table, the gravitation force as well as the buoyancy force occur. The means the resulting force in vertical direction will be:

$$F_{vertical} = F_{gravitation} - F_{buoancy} = mg - \rho g V = g\,(m - \rho V)$$

This relation will cause the falling time, so for the falling time it holds that:

$$F_{vertical} = m\,a \;\rightarrow a = \frac{F_{vertical}}{m}$$

$$h = a \cdot t^2 \;\rightarrow t = \sqrt{\frac{h}{a}} = \sqrt{\frac{h \cdot m}{F_{vertical}}}$$

In horizontal direction, the current will move the object until it reaches the bed, so during the falling time.

This means for the x-position of the element in relation to the current v:

$$x = v\,t = v\sqrt{\frac{h\,m}{g\,(m - \rho V)}}$$

In the real situation, the current velocity profile is logarithmic because of the friction along the bed. Therefore, the current velocity will be a function of the time itself. For this estimation, the profile will assumed to be constant along the height, with an average current of ‘v’. In practice this means that the falling position will be less than this estimation.

For a batch that consists out of 60 GC’s, the total weight will be around 0.563 kg (see also appendix K). The total volume of the GC elements in the clamshell (so the net volume), is based on the volume of a single element (6.6 10^{-6} m^3). The total volume of 60 GC’s is 3.9 10^{-4} m^3. Therefore, the theoretical falling position of 60 GC’s that fall as one batch, will meet the following equation:

$$x = 126 \cdot v \quad [\text{cm}]$$

Experimental falling position

For the analyses of the falling position the amount of GC’s in the clamshell will be kept constant at 60 GC’s. The opening speed in this analyses is slow and only the data from the tests with brown GC’s (so all with approximately the same volume properties) will be used. The relative falling position is defined as the position of the batch center, along the x-axis, relative to the x-coordinate of the middle of the clamshell when the GC’s were released.

Figure 24 shows the influence of the current velocity on the relative falling position of the batch center. The displayed deviation bars are based on a confidence interval of 95%.

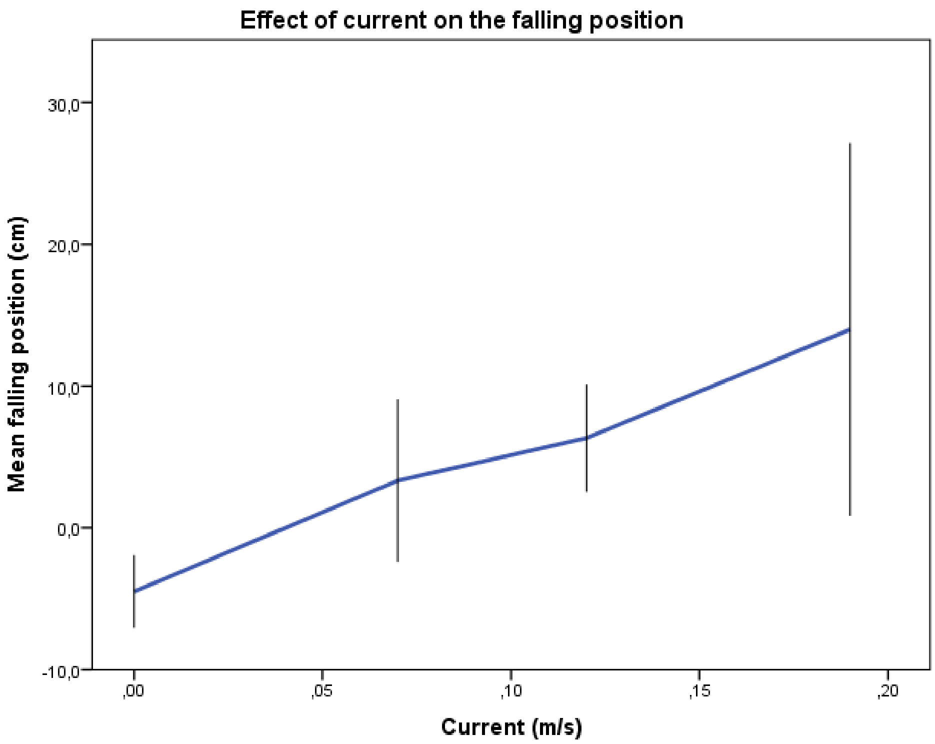


Figure 24 Influence of current velocity on the relative falling position

To check the correlation between the current velocity and the relative falling position of the batch center, both parameters will be checked for a normal distribution. Based on the Shapio-Wilk method, only the values belonging to a current velocity of 0.07 m/s are normal distributed in relation to the current velocity. Therefore, the non-bivariate Spearman correlation method will be used here to check the correlation. Besides the Spearman correlation, a linear regression analyses will be performed as well to find a regression formula for the influence of current velocities on the falling position. The result can be found in Table 9 and 10.

Relation	Correlation coefficient	Significance (2 tailed)	N
Current velocity and relative position batch center	0.929	0.00	17

Table 9 Correlation results current velocity and falling position batch center

Regression analyzes	Constant	Coefficient
Current velocity (m/s) and relative position batch center (cm)	**-4.376**	**95.963**

Table 10 Regression analyzes on current velocity and falling position batch center

Effect on batch orientation

Unfortunately, the influence of the current velocity on the batch orientation isn't documented in all of the seventeen tests that were performed to get insight in the falling position. Therefore, only the data from the still and 0.25 m/s conditions can be used to examine the effects on the batch orientation.

Effect on interlocking

The effect of the current velocity during construction and the interlocking behaviour is displayed in Figure 25. In this figure, the division criteria from Table 2 were used.

In this chart, the % of loose elements is displayed next to the string groups 1 to 10. This loose elements remained on the bed after the strings were lifted. This amount is also processed in the value of group 1 (1 – 5 GC's).

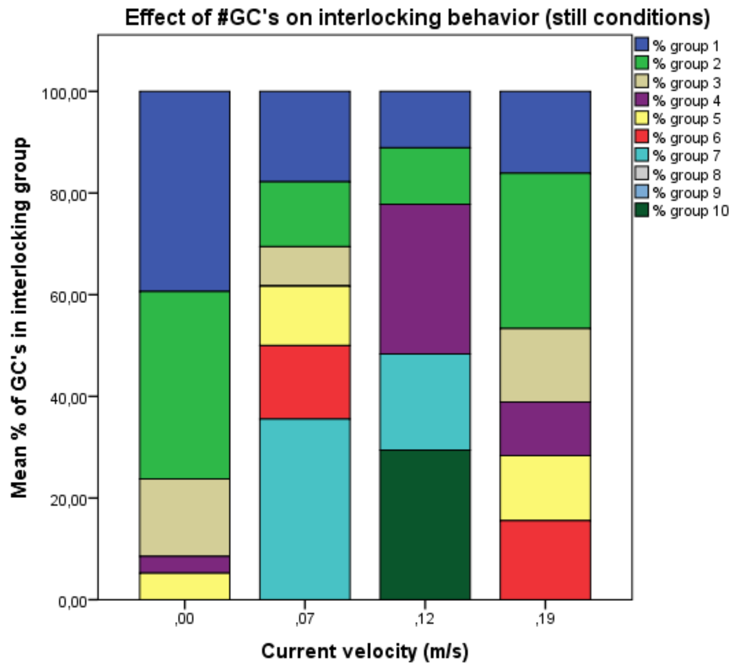


Figure 25 Effect of current velocity on interlocking

Null hypothesis (H_0)	Significance	Decision
The distribution % group 1 is the same across the amount of GC's per clamshell	0.018	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution % group 2 is the same across the amount of GC's per clamshell	0.10	Significance level of 0.05; retain H_0 **Significance level of 0.10; reject H_0**
The distribution % group 3 is the same across the amount of GC's per clamshell	0.450	Significance level of 0.10; retain H_0
The distribution % group 4 is the same across the amount of GC's per clamshell	0.269	Significance level of 0.10; retain H_0
The distribution % group 5 and 6 are the same across the amount of GC's per clamshell	All 0.408	Significance level of 0.10; retain H_0
The distribution % group 7 is the same across the amount of GC's per clamshell	0.164	Significance level of 0.10; retain H_0
The distribution % group 4 until 10 are the same across the amount of GC's per clamshell	All 1.0	Significance level of 0.10; retain H_0
The distribution loose elements is the same across the amount of GC's per clamshell	0.114	Significance level of 0.10; retain H_0

Table 11 Results Kruskal-Wallis test for influence current velocity on interlocking behavior

Conclusion

The conclusion for this experiment can be drawn accordingly tot the information given above. From Table 11 the information about the relation between the velocity of the current and the interlocking of the batches is shown. It is clear that the velocity has in fact an influence on the interlocking. By a higher velocity there is a bigger chance that the elements will be in one of the two lowest groups. This means that by a higher velocity the elements won't interlock to one big batch on the sand bed. So it is important that when building the mattress the velocity of the current isn't that high so the elements have a chance to interlock to one batch.

3.5 Orientation of the clamshell

In all experiments, the clamshell was opened in line with the current direction. This was done because of the dimensions of the flume. A fully opened clamshell, positioned perpendicular to the current only fits in the middle axis while a clamshell positioned in line with the current can be placed next to each other.

The differences between a clamshell positioned in line with and perpendicular to the current direction are displayed in Figure 26.

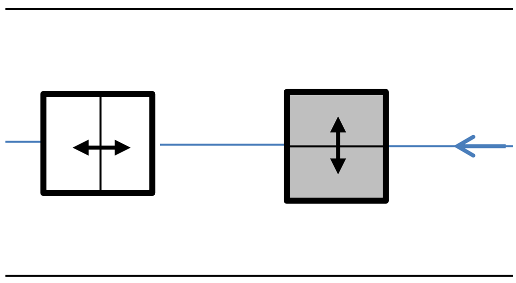


Figure 26 Definitions positioning clamshell

To check if this choice has any effect on the interlocking behaviour of the eventual batch, two extra tests were carried out. In these tests, the clamshell (filled with 60 GC's) was rotated 90 degrees, so the opening direction went from in line with to perpendicular the current direction.

The data from these tests will be compared to the data from the regular experiment with 60 GC's.
In the following analyses, the data from the situation with a current velocity of 0.25 m/s and a slow opening speed of the clamshell will be used.

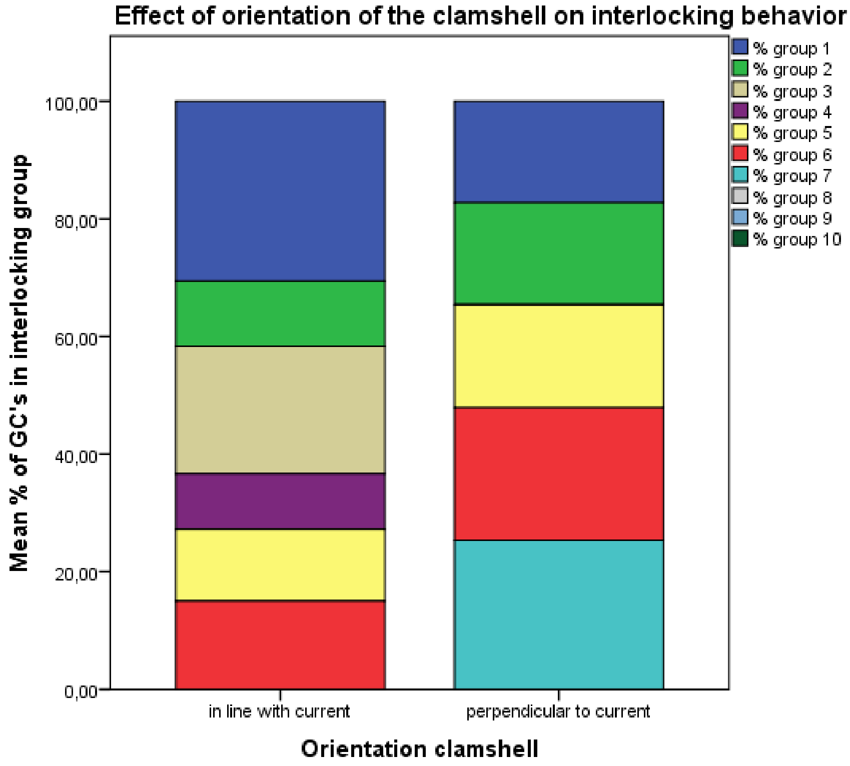


Figure 27 Effect of orientation on the interlocking

According to the Shapiro-Wilk test, none of the data in Figure 27 is normal-distributed. Therefore, the Kruskal Wallis test can be used to find the significance of the relation of the interlocking. The results are listed in Table 12.

Null hypothesis (H_0)	Significance	Decision
The distribution % group 1 to group 7 are the same across the orientations of the clamshell	All 0.406	Significance level of 0.1; retain H_0
The distribution % group 8 to 10 are the same across the amount of GC's per clamshell	All 1.0	Significance level of 0.10; retain H_0
The distribution % loose elements is the same across the amount of GC's per clamshell	0.406	Significance level of 0.10; retain H_0

Table 12 Result Kruskal Wallis test

Conclusion

The conclusion about whether to open the clamshell parallel or perpendicular to the current is very easy to see from Table 12. There are no significant differences, so it can be concluded that the orientation of the clamshell doesn't affect the behaviour of the batch at all.

So if this doesn't matter, the choice to make will be made on other conditions. This can be done on variables such as the dimensions of the flume used in these experiments. Because the clamshell will have a much larger width when opened perpendicular to the current than when opened parallel with the current, the choice is easy regarding later experiments. In experiment 2 tests will be done for making an entire mattress built out of two or more batches. When these has to be put together the clamshell must fit side by side in the width of the flume. This can only be accomplished when the clamshell is held parallel to the current.

4. Additional observations

Besides the relations that where examined before, some other observations were made during the execution of the experiment:

- At a current of 0.35 m/s in the flume (so approximately 1.0 m/s at sea), even a batch of 60 GC's will wash away completely. The batch hits the bed, but won't slow down enough to prevent the batch for tumbling over and moving away until the end of the flume. Some strings stick (approximately at 2.2 m from the clamshell) behind a screw that protrudes from the bed.
- The height of the water table was limited because of the visibility from the camera positions. This is the reason why the water table was kept constant between 0.5 and 0.6 m during this experiment.
- Several times, the GC that comes on top of the batch was loose and didn't interlock with the batch underneath.
- No GC's were snapped during these experiments.

5. Hypotheses and conclusion

Before starting this experiment four hypotheses were made:

1. Based on the results of the reference experiment and the changes made on the scaled clamshell the batch of GC's will interlock even more.
2. The batch will spread more if the clamshell is opened fast because the elements will swing to the outside of the containers.
3. Because of the current the loose elements will float away before the batch hit the bed, so a large spreading will occur.
4. Because of the importance of the filling method of the clamshell for the final shape of the batch, the behaviour found in this experiment is very similar to the behaviour in the reference test. But because of the current, the spreading in groups and loose elements will increase.

Now, after the experiments are done the truth of the hypotheses can be checked.

1. The interlocking of the GC's are different per situation. For the situation of the optimal conditions, with 60 GC's in the clamshell, slow opening speed of the clamshell and a velocity of the current of 0.25 m/s it is clear that the interlocking is very high. If it is higher than the experiments done in Amsterdam it is hard to say, because they didn't measure the interlocking the way it is done in these experiments. Although the experiments in Amsterdam are very much alike with the experiments done in the dry. When a comparison is made between GC's in a current and in the dry, there is definitely a difference in interlocking. Therefore, this hypothesis is true.
2. This was a hypothesis based on the experience gained by the experiments in Amsterdam. When testing in the dry this was exactly what happened en therefor the hypothesis is true for the experiments in the dry. However when testing in the current, something completely different happened. Instead the elements just stayed in place while opening the clamshell fast and dropped when the entire clamshell was gone. It dropped like it lied in the clamshell, just loose elements. When opening the clamshell slowly the elements would roll over each other and form a firm batch before falling out of the clamshell.
3. This was also partly true. This depends on the velocity of the current. With a velocity of about 0.35 m/s the GC's would in fact drift away before forming a batch, but with the optimal velocity of 0.25 m/s even the loose elements would stay in place when dropped in the current.
4. This hypothesis states that with a current the spreading in groups and loose elements will increase. As said in answer to hypothesis three, with the current velocity of 0.25 m/s the

elements won't drift away so the GC's in group 1 won't increase, they will stay approximately the same. And with the answer to hypothesis 2 it is stated that the with opening in the current there will be an increase in the amount of GC's in the main batch. So the strings in the batch will be with a much higher GC number. So in that the hypothesis is correct, there will be an increase of the spreading in groups and loose elements.

6. Discussion

- Because of the white paint was very heavy the white GC's had different features than the original brown ones. This leaded to different falling positions, but besides that it didn't influence the measures much.
- The string for opening the clamshell sometimes got stuck on the screws or other things. This had some influence on the opening speed of the clamshell, the clamshell would go open really slow.
- When pulling the strings out of the water sometimes some of the GC's would hook on to the string but drop halfway out of the water. To say that these elements were part of the string was sometimes hard to say.
- Another problem of the discussion point from above was that when the GC's dropped from the string they would fall back in the mattress. This meant that the next string would contain a higher number of GC's. Overall the GC's fallen on top of the mattress would lie loose from the rest of the mattress and these GC's wouldn't be part of the mattress.
- While pulling the GC's out of the flume the hook would create small waves which made it difficult to see the sand bed and the mattress. While trying to get the next string the hook would sometimes go to deep and touch and thereby influence the mattress. Overall this wasn't really a problem because the hook wouldn't go hard into the mattress.
- The composition of the GC's weren't entirely conservative, because the strings were pulled vertical out of the water. In the real situation, if there at all would be any force on the GC's, this force will be directed in horizontal direction. But these vertical experiments certainly gave a nice idea of how well the GC's would interlock.
- In the first few tests the strings holding the clamshell in place were made from wool. Because of the wool has some elasticity in it the clamshell would vary in height. Especially with more than 30 GC's in the clamshell it was very clear to see that the clamshell height varied under the weight of the GC's. Every time the height of the clamshell was measured and adjusted so it would have the height that was required. After a day or so the wool was replaced with a cord with almost none elasticity and this problem was fixed.

Appendix D Plan Experiment 2 “Making a mattress”

1. Introduction

This appendix deals with the experiment plan of the first experiment, “Making a mattress”.

1.1 Objective

The objective of this experiment is to use the results of experiment 1 “unloading in currents” to look further and determine how to create a mattress of GC’s on the seabed.

This experiment will give insight in:

- How well the GC’s will interlock with each other when one batch after another is placed.
- The placement of the clamshell with respect to the previously fallen batches of GC’s.
- The order in which the GC’s must be placed (first upstream then downstream or vice versa, etc.).
- The homogeneity and stability of the created mattress.

1.2 Main question

What is the behavior of the single batches and of the batches together when creating a mattress on the seabed, when being placed in a specific order and manner?

1.3 Definitions

- The used GC’s are scaled elements based on the design used in the full scale placement test. The full scale GC’s have outer dimensions of 0.4 x 0.4 x 0.4 m^3. The scaled elements have outer dimensions of 0.05 x 0.05 x 0.05 m^3. This means a scaling of 1:8.
- The mattress is made from many batches of GC’s that interlock together and actually form a whole, new, huge batch of GC’s.

1.4 Hypotheses

1. The batches must be placed first downstream and then upstream so the latter batch can roll into the first batch.
2. The different batches will interlock with each other as good as the internal interlocking of one batch.
3. Loose elements will be interlocked eventually when other batches are placed.

2. Data collection

The following shows a list of data which needs to be kept in mind when setting up experiment 2. The optimal values for these data are tested in experiment 1, so these are the previous values that are used for experiment 2 as well.

- The height of the water plane.
- The falling height.
- The total number of GC's in the clamshell.
- Center of the batch.
- Height of the batch at several points along the x-axis (intervals of 0.10 m).
- The area under the batch.
- The orientation of the batch.
- The number of GC's that interlock together.
- The number of loose and broken GC's.

The following shows an overview of the required data that needs to be received from this experiment to make an analysis of the behavior of the batches of GC's in the mattress. For each measurement the method of measuring is described.

Center of the batch

The way to do this is already determined in experiment 1, but it is also required for experiment 2 when more than one batch is lowered into the water. In this experiment the position will be measured with an x and y position of the center compared to the center of the clamshell. The position of the clamshell will be point (0,43).

Distance between two batch centers

In experiment 1 the center of one batch was measured. For this experiment it is needed to measure the distance between two centers, so it is possible to see if the different batches can be placed in the same way.

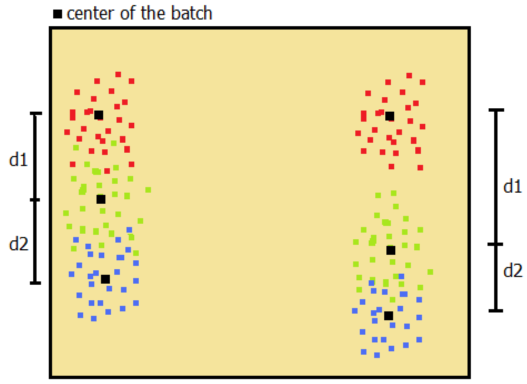


Figure 28 Distance between centers

As shown inFigure 28, on the left is the optimal placement of the batches where distance d1 = d2. On the right is a worst-case scenario where d1 is so large that the red batch and the green batch can't hook together. So this measurement consists out of two parts:

- Determine the maximum distance between two batch centers.
- Determine if more than two batches have the same distance between the centers.

Height of the mattress

In experiment 1, the heights of individual batches were measured. This data is very useful for experiment 2, but it needs to be extended to an overview of the height along the mattress. In other words, the mattress must be measured every 0.10 meters and be put in a graph. This needs to be done to check the height at the point where two batches overlap.

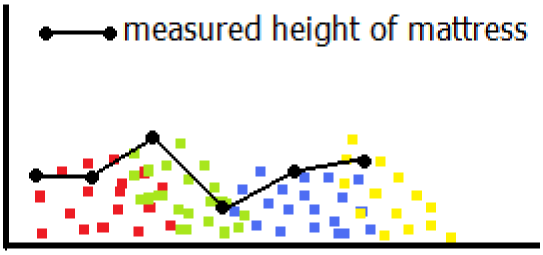


Figure 29 Height mattress

Something as shown in Figure 29 might happen, when a straight line is desired, because that insists on a constant divided average layer height.

The size of the mattress
To get an idea of the surface the GC's will cover, the same reference plane on the sand bed is described in experiment 1. The reference plane will be added by the photo editing afterwards. The area needs to be counted according to the grid on the bed.

The number of GC's of different batches that interlock together
To check how many elements are interlocked, the GC's will be lifted one by one once the mattress is made, to check how many elements form a group. For each group, the total number of white and grey GC's in the string will be counted.

The number of loose and broken GC's
This data will be received by simply counting the number of elements that remain on the bed after lifting the groups of GC's, the number and elements that float away. The definition of broken GC's is that one or more ribs are broken.

The total amount of GC's in the clamshell, the flow velocity in the flume and the specific order of placing the GC's is yet to be determined and will depend on the results of experiment 1.

3. Base of research

In this chapter the materials and equipment used for the execution of the experiment is listed. Also the setup is described and listed chronologically.

3.1 Materials & equipment

The used materials and equipment for this experiment include:

- One scaled clamshell (scale 1:8 based on drawing LH160-4500).
- One flume (large flume in the laboratory for fluid mechanics, cross section (width x height) 0.80 x 1.00 m^2).
- Sufficient regular GC's for creating an mattress with outer dimensions of 0.05 x 0.05 x 0.05 m^3.
- At least 60 scaled GC's (0.05 x 0.05 x 0.05 m^3) with a different colour. In this experiment this colour is white.
- Equipment to hang the clamshell above the flume and hold it in place.
- Bed material (sand) with a depth of 0.04 m.
- Two regular cameras (positioned on the side and above the batch on the clamshell).
- One underwater camera mounted in the current direction.
- Equipment to mount and orientate the cameras (near and above the flume).
- One white plane with a grid (blocks of 0.125 x 0,125 m^2) for the sidewall.
- One reference grid in the flume (0.125 x 0.125 m^2).
- One claw or net to catch the elements.
- One measuring rod to measure the height of the batch.
- One protection sheet near the end of the flume to catch loose elements.
- Equipment to measure the water table height in the flume.
- (Digital) equipment to measure the current in the flume, mounted on two places along the x-axis. This measure instruments were mounted 0.18m above the bed.

3.2 Setup

The experiment setup is as follows:

- An even sand layer will be made on the bed of the flume. This bed is approximately 0.04 m.
- Two rulers will be put up on the side wall of the flume.
- The clamshell is placed above the flume, in line with the current direction. The distance between the bed of the clamshell and the sand bed will be measured. This must be 0.25 m.
- One camera will be placed at the side of the flume and one camera will be placed at the center of the clamshell with a clear view on the bed.
- One camera will be mounted in the flume, in line with the current direction.
- Then the current in the flume starts. The velocity depends on the type of experiment.

The performing of the test:

In this experiment, two different tests needs to be done to investigate the interlocking. First, the interlocking of two batches will be investigated, to ensure that several batches interlock and form one batch. Second, the construction of the mattress with three batches will be tested. This will expand the knowledge about the interlocking between several batches.

The following will be performed each test:

- Start filming on all cameras.

The following must be repeated a few times. The amount of times depends on the experiment and how big the mattress will be, so starting with the two batches and for later tests three batches:

- Load the clamshell with 60 GC's. The clamshell is loaded according to the reference experiment, so one by one, and the next GC rotated over 90 degrees compared to the previous one.
- Hang the clamshell in place according to the specific situation and open the clamshell slowly.
- Measure the position of the center of the batch.
- Measure from the right side of the mattress every 0.1 m along the x-axis, the height of the mattress.
- Load the clamshell with 60 GC's, hang the clamshell in place and open it slowly.
- Stop the camera and label the movie.
- Make pictures (stills) from both camera positions and label them.

<u>For the first tests with two batches:</u>

- Interpret the spreading by counting the area under the batches.
- Catch the elements with the hook, to see if the batches interlock. Sort the elements, for each string, in white and brown.
- Count remaining loose and broken elements.
- From the data measured earlier, calculate the distance between the centers.
- Determine from the received data what the maximum distance between centers is.
- Calculate the density of the mattress with the height and the covered surface.

<u>For the tests for making a mattress:</u>

- Count the number of clamshells needed for the mattress.
- Measure from one side of the mattress every 0.1 m along the x-axis, the height of the mattress.
- From the data measured earlier, calculate the distance between the centers.
- Measure the surface the mattress covers.
- Count the remaining loose and broken elements.

The following will be done with the analyses of the footage and stills:

- In paint.net the photos of the fallen batches can be opened and analyzed by measuring the width of an GC in pixels and compare this to the real size of 0.005 m of the width of a GC. With this factor the position in x- and y-coordinates can be calculated by drawing a line from the batch center to the x- and y-axis.
- With the same methods as described above a plane can be drawn in paint.net over the surface of the GC's. The border of this plane is drawn over the border of the surface of the GC's. The amount of pixels in this plane is displayed in paint.net and converted with the factor to cm^2. With this method the area of the batches is calculated.
- With a still of cam 1 (the camera with the front view of the flume) the layer height can be measured. With the same method as described above. A GC will function as a reference to determine the conversion factor. The height of the batch is measured with a line drawn from top to bottom and converted with the factor.
- Determine the opening time and the falling time of the first and the last element in the clamshell.

The loose elements counted by the tests with one batch in experiment 1 and those counted by the tests for creating a mattress must be compared. In the hypotheses is stated that the loose elements formed by dropping one batch will be hooked in another batch, so by comparing test 1 with test 2 the hypothesis can be confirmed, or of course invalidated.

The tests for making a mattress must be divided, to test in which order the elements must be placed.

The last hypothesis states that a formed mattress is stable and won't float or curl. This will be tested by observing the behavior in the flow after making the mattress.

These tests will be performed as described in Table 13.

Situation	Number of GC's in clamshell	Opening clamshell	Number of measurements per situation
Exp 2a situation 1	60	slow	3
Exp 2a situation 2a	60	slow	3
Exp 2a situation 2b	60	slow	3
Exp 2a situation 3a	60	slow	3
Exp 2a situation 3a	60	slow	3
Exp 2a situation 4a	60	slow	3
Exp 2a situation 4b	60	slow	3
Exp 2b situation 1a	60	slow	3
Exp 2b situation 1b	60	slow	3
Exp 2b situation 2a	60	slow	3
Exp 2b situation 2b	60	slow	3

Table 13 Number of experiments en measurements

3.3 Geometry

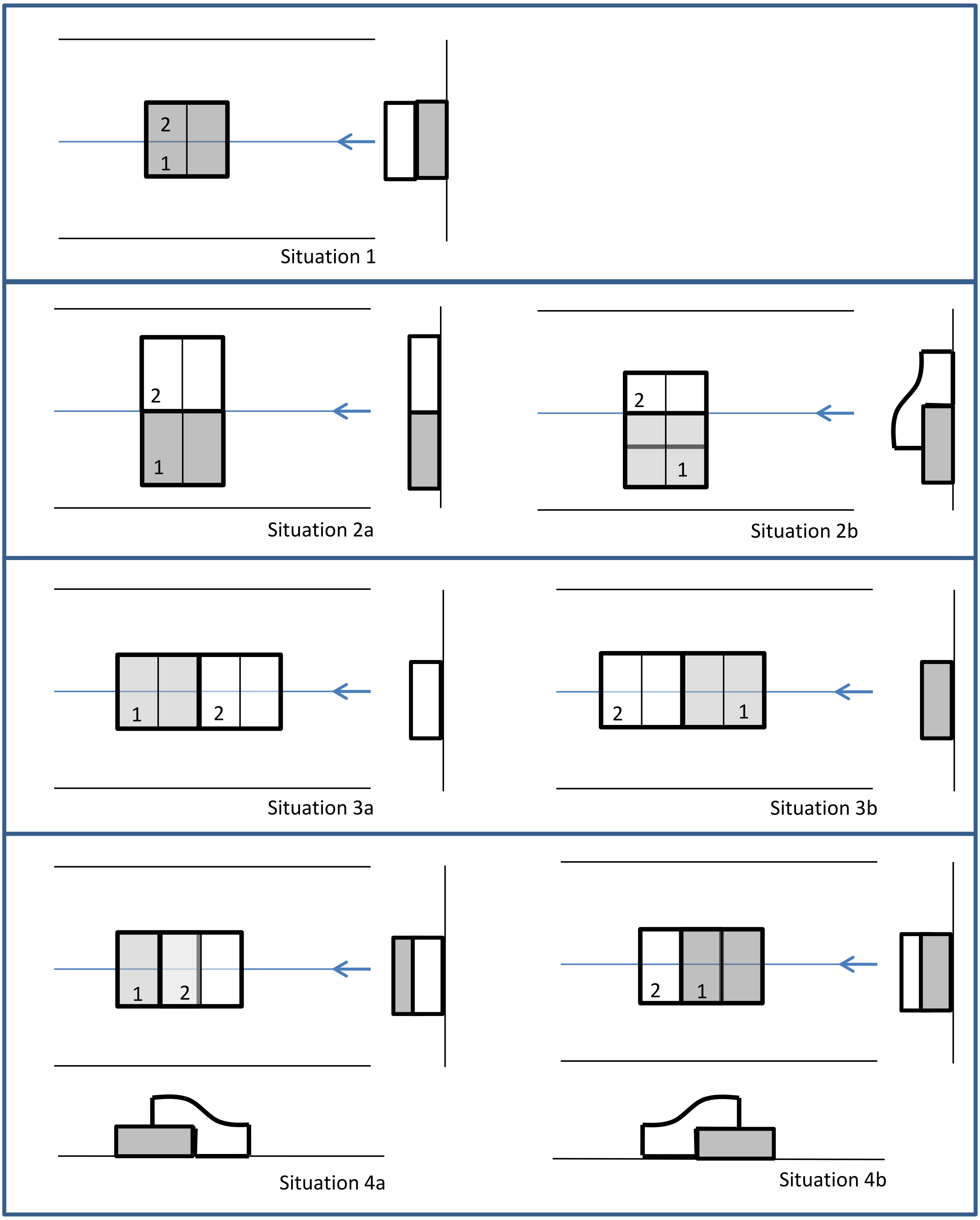


Figure 30 Geometry experiment 2a

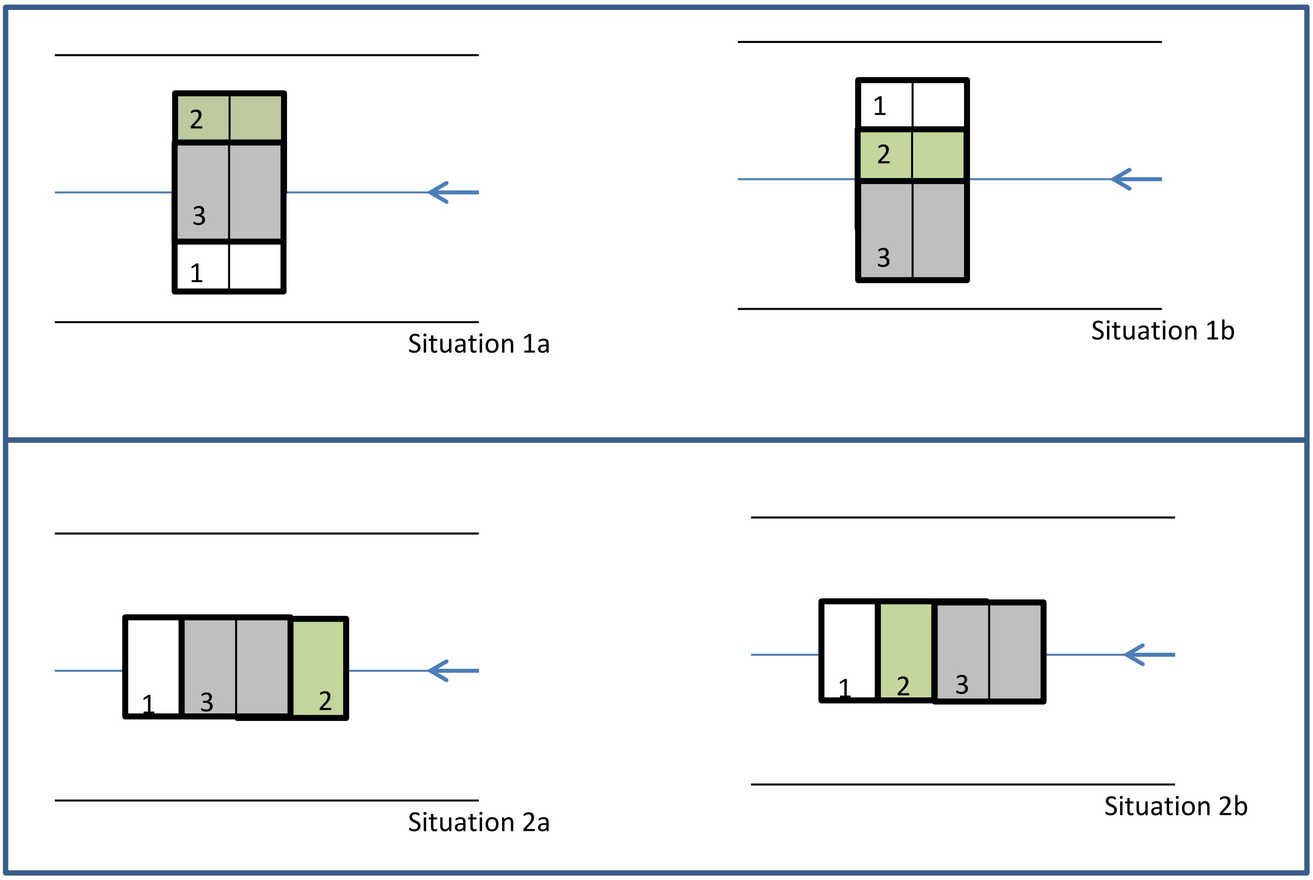


Figure 31 Geometry experiment 2b

In the figures above the geometry for experiment 2 is shown. The batches used in these tests all consist out of 60 GC's. The numbers in the figures show the order in which the batches are dropped in the flume. The different colors stand for the different batches that are used and correspond to the three colored batches used in the experiment (the brown, the green and the white batches).

3.4 Layout

The layout will be the same as in experiment 1.

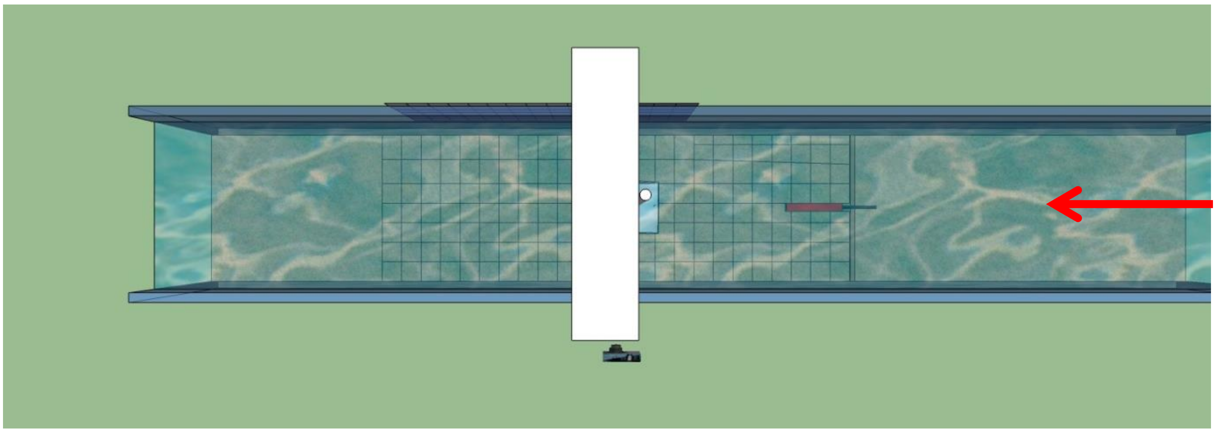


Figure 32 Top view Flume

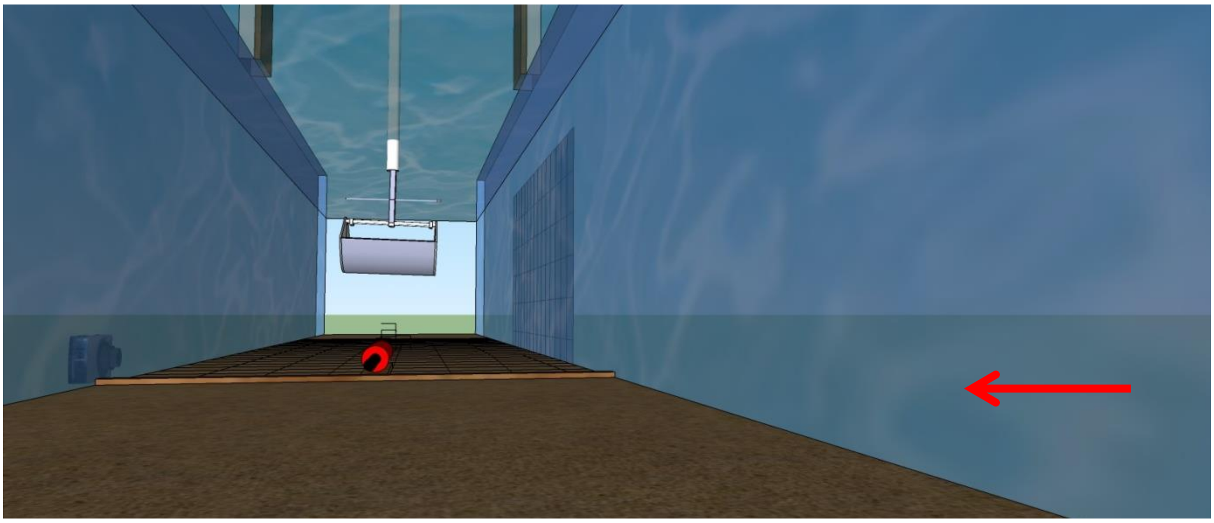


Figure 33 Front view Flume

3.5 Statistic relations

Once the experiment results are obtained, some statistic tests will be executed to check if the relations can statistically be supported and to get an idea of the significance of the data.

This statistics will be executed in the statistic program IBM SPSS Statistics 22.

Once a relation is plotted in a chart or is listed in a table, the variables on the y-axis (the dependent values) will be checked in relation to the variables on the x-axis (the independent values). To see if they are normally distributed in relation to each other, a Shapiro-Wilk test for normality (suited for small samples) will be executed. Based on these results (if the results have a significance of 0.05 than a normal-distribution occurs), the right correlation test will be chosen.

If the data is non-normal distributed, and the values on the x-axis aren't continuous, the Shapiro-Wilk test will be executed. This test will check the null-hypothesis, which states that the values of the dependent variables follow the same distribution, so the independent values don't affect the distribution of the dependent values and the observed differences are likely to be based on a coincidence. If however, the null-hypothesis has a significance of 5%, the null-hypothesis could be rejected and the distribution differences are in fact caused by the independent variable.

If the data is normal distributed, the t-test can be performed, which works almost the same as the Shapiro-Wilk test.

As soon as the independent variables are continuous, the correlation between the variables will be checked with the Spearman (non-normal distribution) or the Pearson test (normal distribution). This test will find a correlation coefficient and a significance level. If the significance is lower than the chosen significance level, the variables are in fact correlated.

When data is displayed in charts or in tables, the average values and the reliability interval will be given, to compare the values and the standard deviations. The reliability interval is based on a significance level, which is chosen to be 95% in this experiment.

If the relation isn't significant, the effect of the independent variables on the dependent variables aren't scientifically found. When this happens, only an indication will be given based on the charts.

Appendix E. Results experiment 2 “Making a mattress”

Experiment 2 was performed from 24-9-2013 until 1-10-2013 at the TU Delft Fluid Mechanics Laboratory. This appendix gives an overview of the results of this second experiment. Besides analyzing the data relations, some statistic tests for significance will be checked as well.

First, the calculation methods for the data preparation will be explained. Next, the results of the construction of the mattress out of two batches will be analyzed. After that, the construction with three batches will be analyzed in the same way. Then some extra observations will be given and finally the hypotheses and the main question will be answered in the final conclusion.

In these experiments, some parameters were kept constant. All the mattresses are constructed under de conditions described in Table 14.

Parameter	Average value during construction	Deviation
Current velocity (m/s)	0.243	0.0063
Water table height (m)	61	0.62
Sand layer height (m)	0.04	0
Falling height above the bed (m)*	0.25	0
* In some situations, the clamshell was lifted + 0.1 m, so in that case the falling height was 0.35		

Table 14 Conditions in the flume during construction

1. Experiment execution

In the following figures the experiment execution is shown. The experiment execution is almost the same as in experiment 1, with a few adjustments.

Figure 34 shows the overview of the flume, similar to experiment 1.

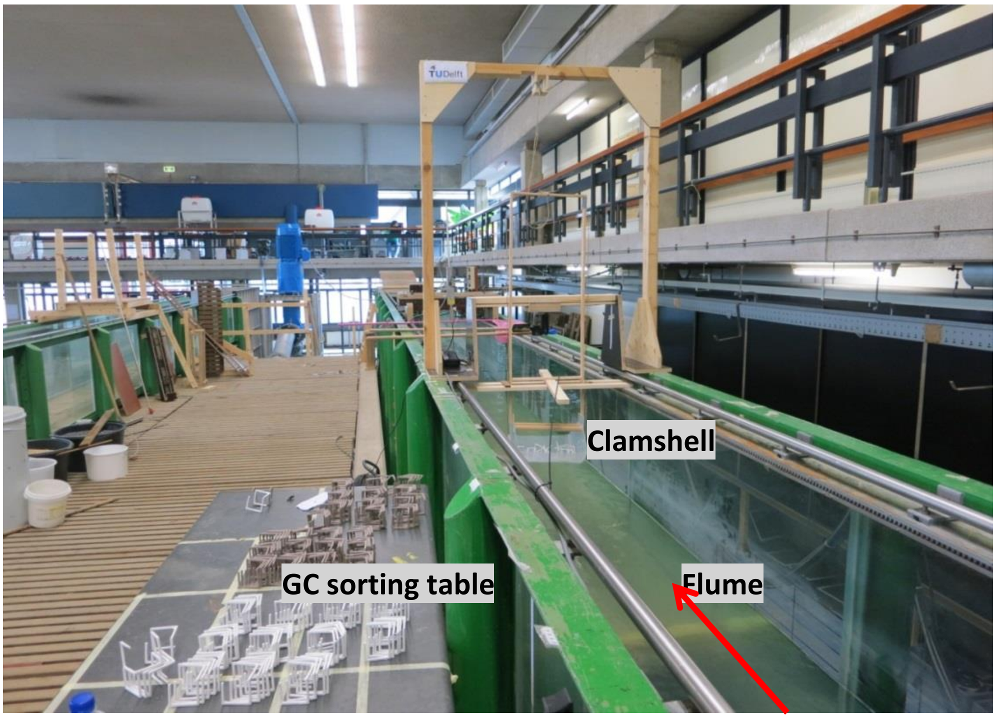


Figure 34 Overview execution experiment 1

Because of the reflection from the windows and the lights above the flume, a new camera position was invented. This new position is based on a closed box with a construction to hold the camera inside. Because of this closed position, the quality of the recordings made from the camera position alongside the flume increased. Figure 35 shows this new camera position.

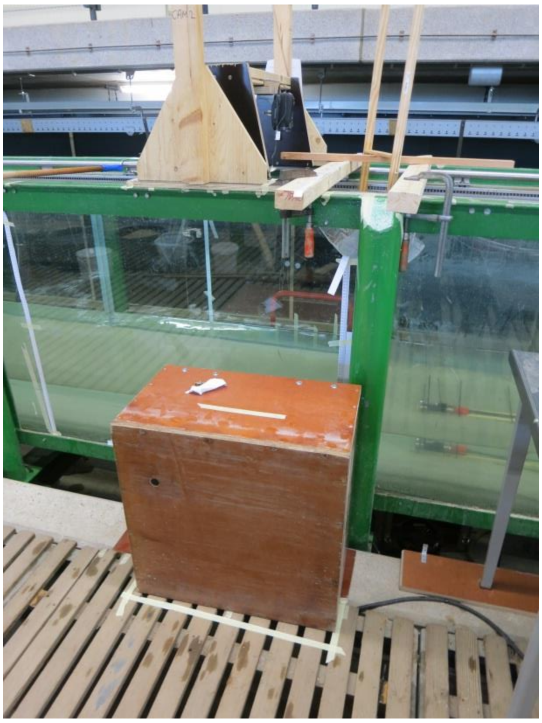


Figure 35 New camera position on the side wall of the flume

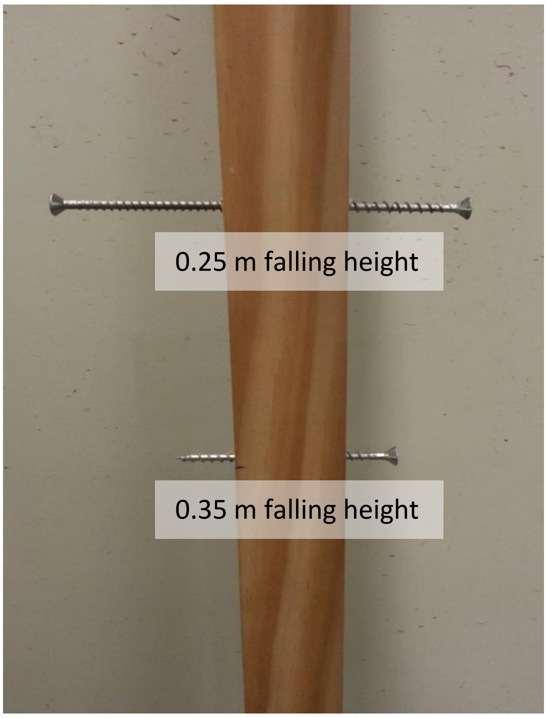


Figure 36 Screws for adjusting the falling height

Another adjustment to the setup were the screws placed in the clamshell. With these screws the clamshell could be placed in the water and the screws would lie upon the beams across the flume. The screws were placed in a way that the falling height of 0.25 m was realized when the clamshell was placed. Another pair of screws were placed ten centimeters below the first screw, so the clamshell would lift 0.1m when these screw were used to hold the clamshell in place. This was for the later part of the experiment where a batch had to be placed on top of several batches. As seen in Figure 36.

2. Calculation methods

Before the analyses can be carried out, rough experiment data must be modified. The main parameters that will be used in these results are the mattress volume properties and the interlocking behaviour. The volume properties is build up out of the volumetric parameters, such as the layer height, the spreading and the density.

The spreading was measured in the computer picture analysis after the experiment. The mean spreading is the average spreading out of the three tests per situation.

The layer height is the average layer height of the mattress, measured according to the described method in the experiment plan. Each situation was tested three times, so the average value in this chart is the mean value of the average layer heights.

The density is defined as the amount of GC's per volume. In this case, the volume is calculated by multiplying the spreading with the average layer height. The density is the amount of GC's in the mattress (120 GC's) divided by the calculated volume. This is done for each test. The displayed average is the mean value of these densities.

To examine the interlocking behaviour, the hooked strings were analyzed during the experiment. When there was more than one colour in the string, the string was labeled as "mutual interlocked". If not, then it was labeled as only grey or only white interlocked. The loose elements that remained on the bed were marked as "not interlocked".

3. Construction with two batches

In the first part of experiment 2, two batches were used to get insight in the interlocking behaviour between batches. In this experiment, several construction methods were tested to get insight in the differences and characteristics of the method.

In this first analysis, the construction with two batches (so with a total amount of 120 GC's), will be examined.

The tested situations can be divided into methods that construct perpendicular to the current directions (situations 1, 2a and 2b) and in methods that construct in line with the current direction (situations 3a, 3b, 4a and 4b).

3.1 Perpendicular to the current direction

Influence on the mattress's volume properties

Each construction situation will result in different characteristics of the mattress in terms of layer height, spreading along the sand bed and density.

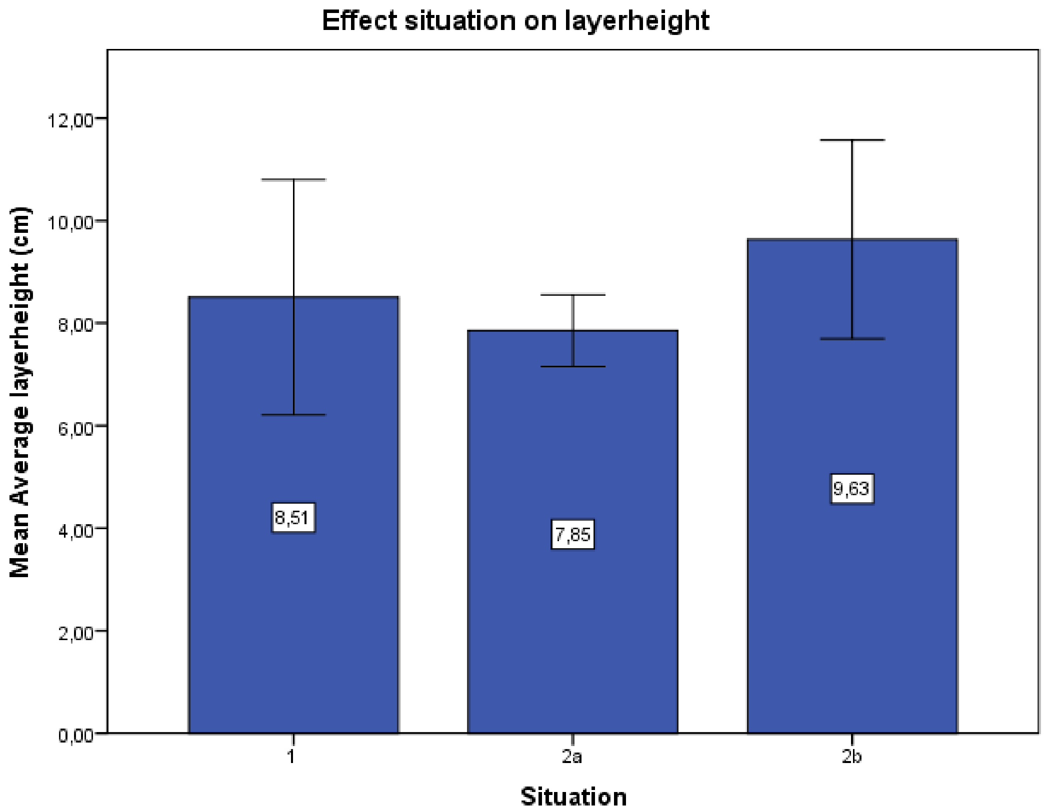


Figure 37 Effect on layer height

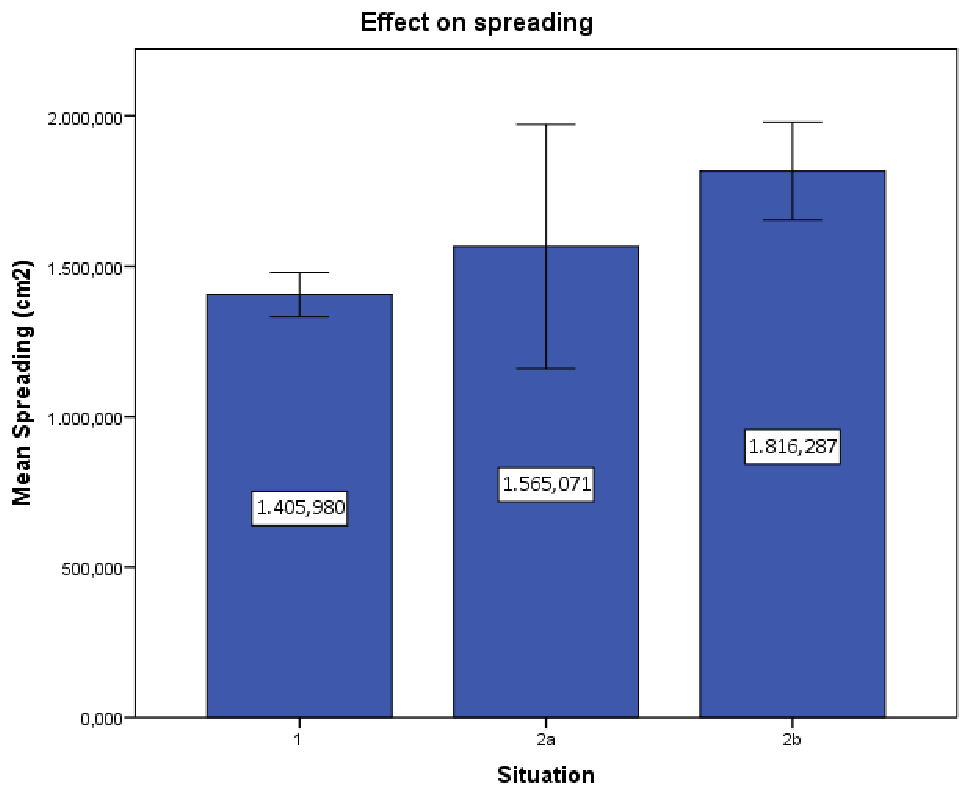


Figure 38 Effect construction situation on spreading

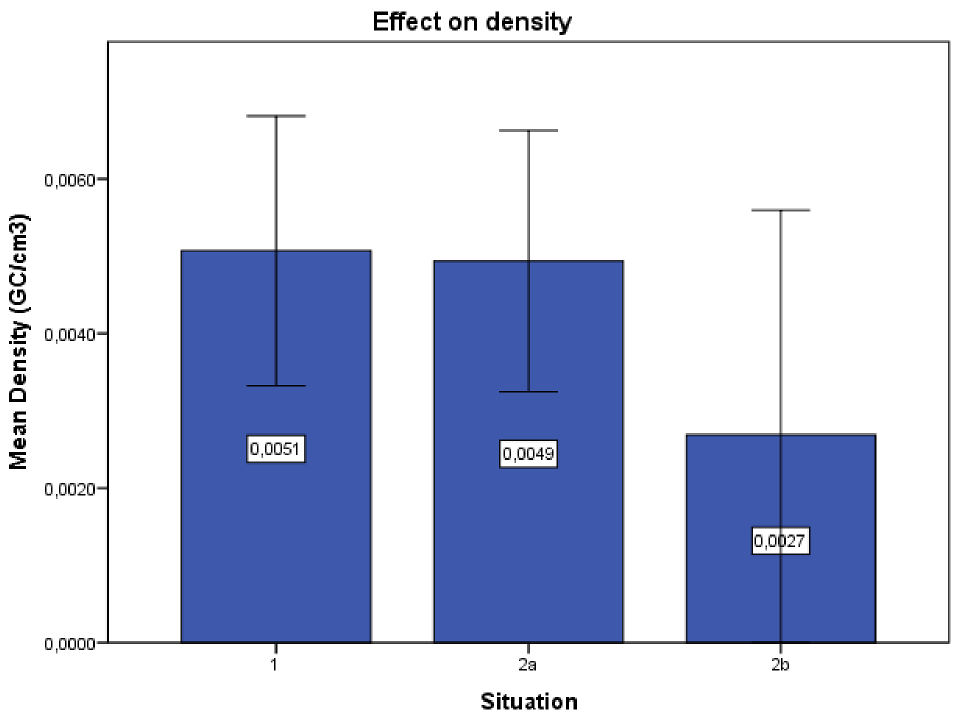


Figure 39 Effect construction situation on the density

Figure 37, 38 and 39 give an overview of the spreading, the layer height and the density in relation to the construction situations. The error bars are based on a 95% reliability interval.

To check the significance of the displayed differences between the construction situations, the Kruskal-Wallis test will be executed. This is done to check if the distribution of the value along the y-axis depends on the situation along the x-axis or that the distribution is more or less equal for all situations. This will help to conclude that the results are or aren't significant and if the situations do or don't affect the parameter.

Null hypothesis (H_0)	Significance	Decision
The distribution of the average layer height is the same across situations	0.641	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the spreading is the same across situations	0.045	**Significance level of 0.05; reject H_0**
The distribution of the density is the same across situations	0.628	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 15 Results Kruskal-Wallis test for significance on mattress orientation

Table 15 shows the results of the Kruskal-Wallis test. In this test, two significance levels are used to evaluate the null hypothesis (H_0). Based on the chosen level (5% or 10%), H_0 is retained or rejected, and so the distribution differences, as displayed in Figure 40are significant or not.

Influence on interlocking

Figure shows the effect of the construction situation on the (average) mutual interlocking. The displayed error bars belong to a 95% reliability interval. The measured amount of GC's that meets the group requirement is displayed in each bar. The total amount of GC's in the mattress is 120.

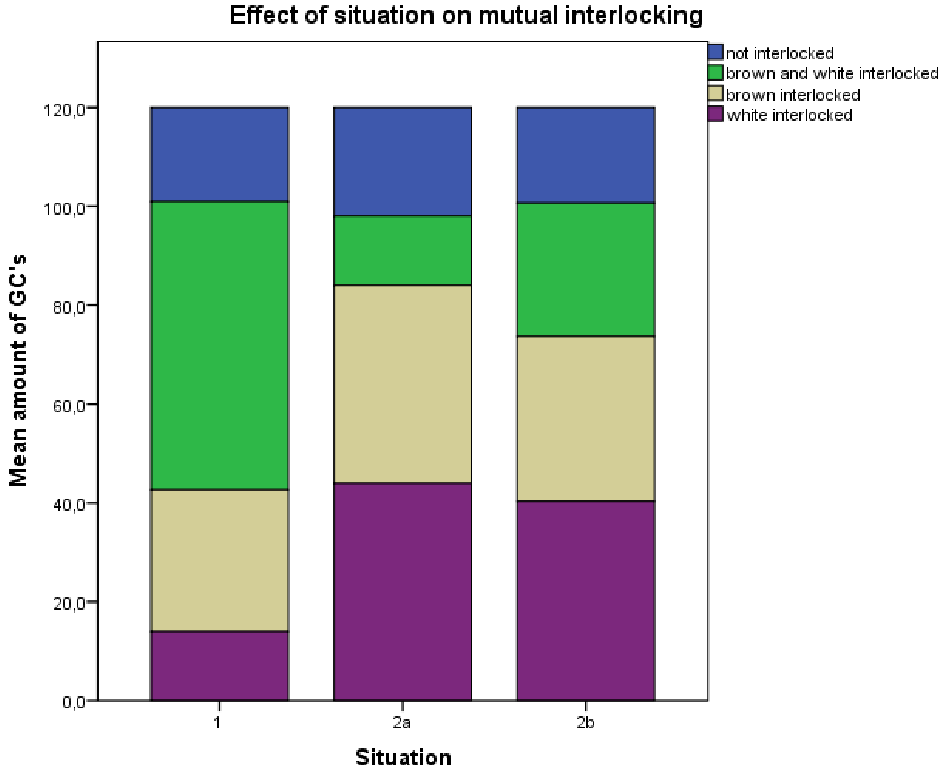


Figure 40 Mutual interlocking, construction perpendicular to current

To check the significance of this outcome, the Kruskal-Wallis test will be executed (because the division in groups isn't normal distributed, based on the Shapio-Wilk test). The results of this test are listed inTable 16.

Null hypothesis (H_0)	Significance	Decision
The distribution of brown and white interlocked is the same across situations	0.095	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution of brown interlocked is the same across situations	0.797	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of white interlocked is the same across situations	0.063	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution of not interlocked is the same across situations	0.628	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 16 Results Kruskal-Wallis test on the interlocking behaviour

Conclusion

From what is stated above conclusions can be drawn concerning the relations to the different situations. From the information in Table it is clear that the differences between the interlocking of the different batches are in fact significant, what means that there are differences between the different situations. With this in mind and looking back at Figure conclusions about what situation is best to use.

Looking at the main objective of this experiment it is a necessity that the brown and white GC's interlock together. So the higher the interlocking the better the situation. So when looking at Figure 41, it can be concluded that situation 1 has the highest interlocking between two batches.
But with an eye on the composition of this situation it can't be said this is the desired situation to be used. The interlocking is maybe the best, but the batches will be too high and the spreading too low.

So when also looking at the composition of the other situation it is clear that the 2b is the best option. Because approximately 33% of this batch must be interlocked (when looking at the mattress from top view it is clear that 33% of the batch overlay). This is true for this situation and with regarding to the remaining part of the batch it is clear that the interlocking internal is high enough to create a stable mattress. So, in conclusion the best situation to use is situation 2b.

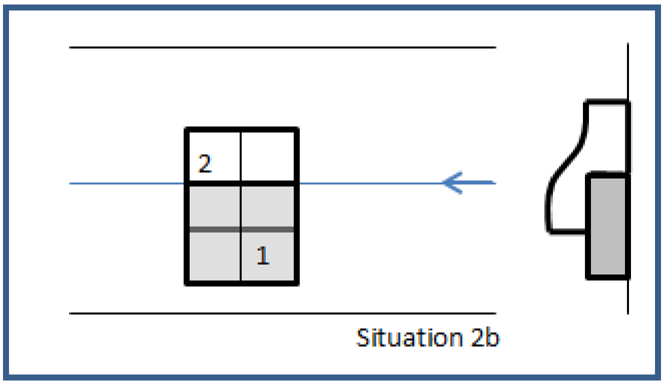


Figure 41 Situation 2b

3.2 In line with the current direction

Influence on the mattress volume properties

Figure 42 shows the volume properties of the mattress for the situations 3a, 3b, 4a and 4b. These situations are all constructed in line with the current direction.

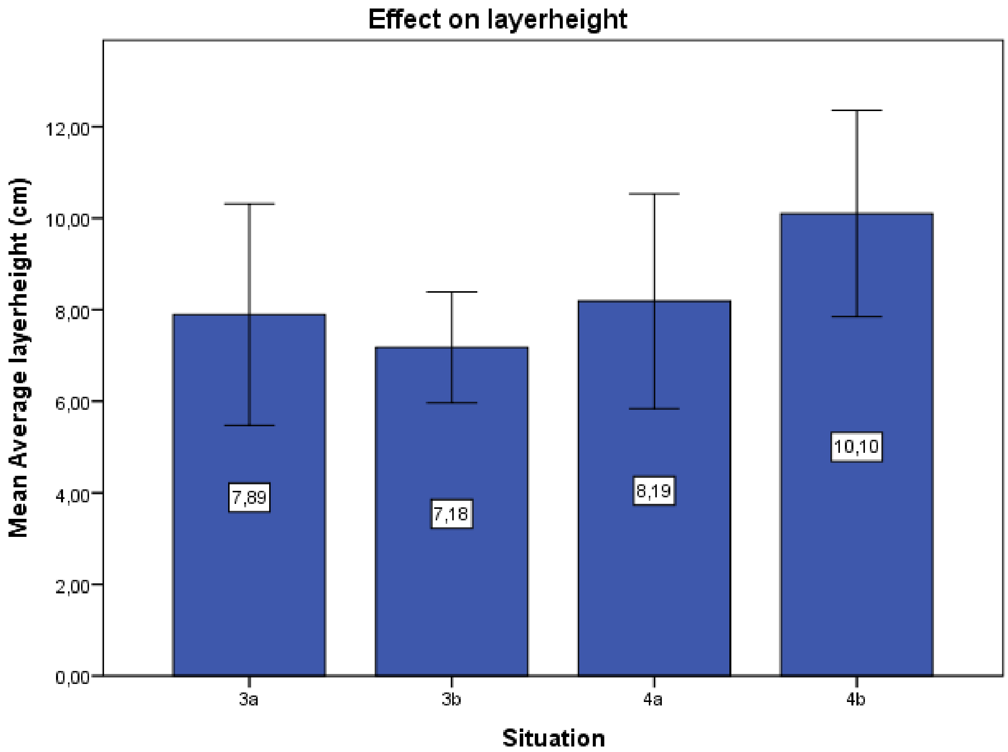


Figure 42 Effect construction situation on the layer height of the mattress

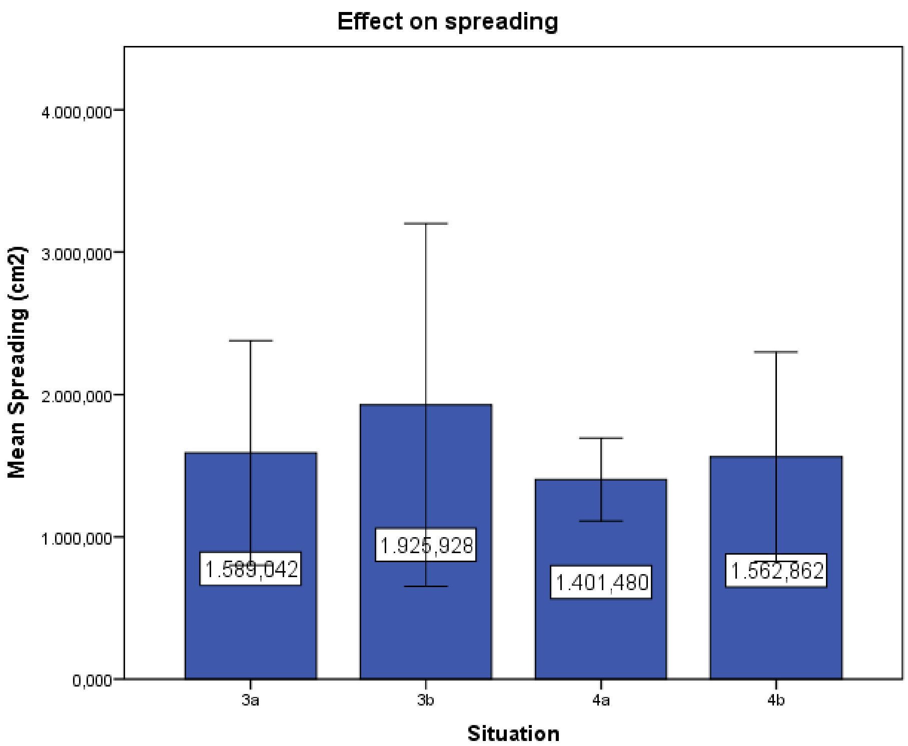


Figure 43 Effect construction situation on the spreading

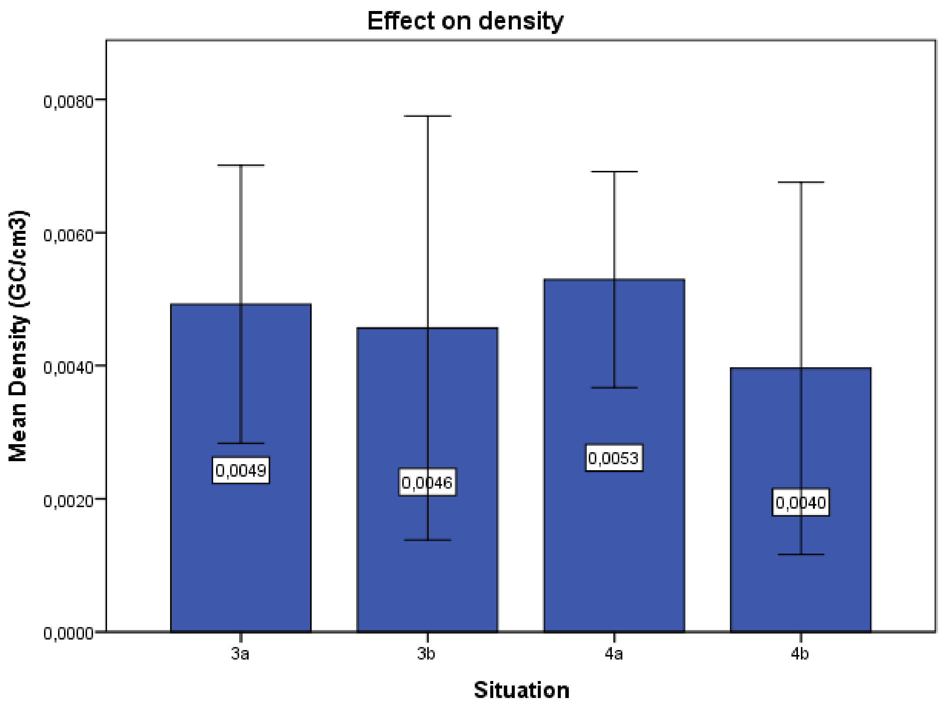


Figure 44 Effect construction situation on the density

Figure 42, 43 and 44 results in terms of the mattress volume properties. The average values are displayed inside the bars. The displayed error bars belong to a 95% reliability interval.
Again, to check the significance of the displayed differences, the Kruskal-Wallis test will be executed. Table 17 gives the result of this test with the significance levels of 5% and 10%.

Null hypothesis (H_0)	Significance	Decision
The distribution of the average layer height is the same across situations	0.066	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution of the spreading is the same across situations	0.319	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the density is the same across situations	0.057	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**

Table 17 Result Kruskal-Wallis test on the mattress orientation constructed in line with the current direction

Influence on interlocking

Figure 45 shows the mutual interlocking for the construction of the mattress in line with the current direction. The method for calculating this interlocking behaviour is the same as described before. Again, the mattress is built up out of 120 GC's.

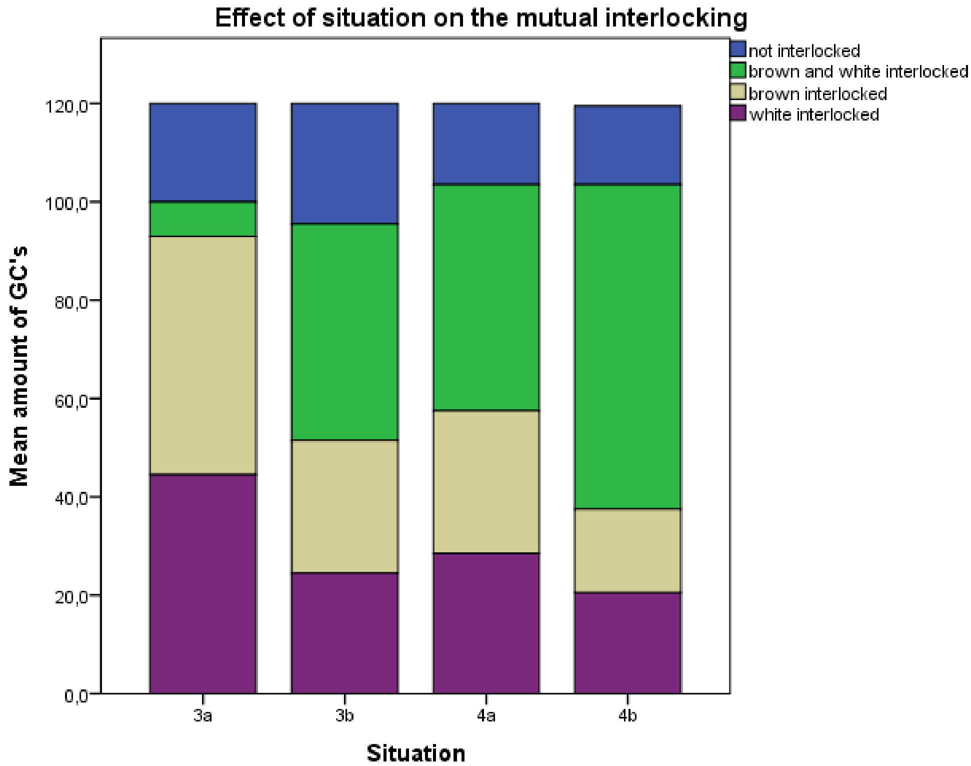


Figure 45 Interlocking behaviour for tested situations in line with current

The significance of this outcome can be checked with the Kruskal-Wallis test. The tested hypotheses are displayed in Table 18.

Null hypothesis (H_0)	Significance	Decision
The distribution of brown and white interlocked is the same across situations	0.095	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution of grey interlocked is the same across situations	0.797	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of white interlocked is the same across situations	0.063	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution of not interlocked is the same across situations	0.628	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 18 Result Kruskal-Wallis test on the interlocking

Conclusion

From the information above a conclusion can be drawn about the situation in line with the current direction. From Table 18 it is shown that indeed there is a significant difference between the situations, especially in the differences of the interlocking between brown and white GC's.

When looking at situation 3a and 3b there should be a larger surface and it is expected that the interlocking with the two batches is almost null, because the batches actually lie next to each other without touching each other. When looking at Figure it is clear that this is in fact what happens by situation 3a, but by situation 3b the current has an influence. The current pushes the second batch in the first batch so there is indeed an interlocking. This interlocking is however not large enough for a good density. This is shown in Figure 46.

When looking at situation 4a and 4b it is clear that the spreading is much lower. However this isn't a problem because the batches should fall on top of each other, so the desired layer height is achieved in one situation. Situation 4a has a good enough interlocking mechanism and a very high density. Situation 4b has a very high interlocking between the brown and white GC's. This is an important factor. On the other hand the density of this situation isn't that high. Thus in one way it can be stated that this is the best situation. But taking in consideration that in the latter phase of the experiments the batches should be dropped in front of a pipeline it is advisable to first drop a batch against the pipeline and built the mattress from there on against the current direction in.

So the recommendation from these experiments is that situation 4a should be used by placing the batches in line with the current direction. In Figure 46 the best situation is shown.

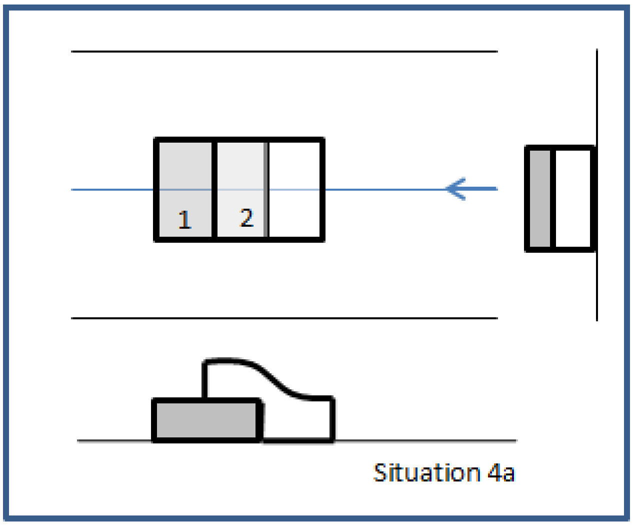


Figure 46 Situation 4a

4. Construction with 3 batches

Now, the data obtained from the construction with three batches will be analyzed. This will be done similar to the experiment with two batches.

4.1 Perpendicular to the current direction

The mattresses in situation 1a and 1b are constructed perpendicular to the current direction.

From direct observations during the experiment, it was stated that the third batch in situation 1a didn't fall on top of the mattress when its falling height (0.25 m form the bed) was the same as the batches 1 and 2. Therefore, three additional tests were carried out to optimize the falling position of the third batch. In these additional tests, the third clamshell was lifted 0.1 m (the estimated layer height), so the falling height for the third batch became 0.35 m. This situation is labeled as situation 1a_+10.

Influence on mattress volume properties

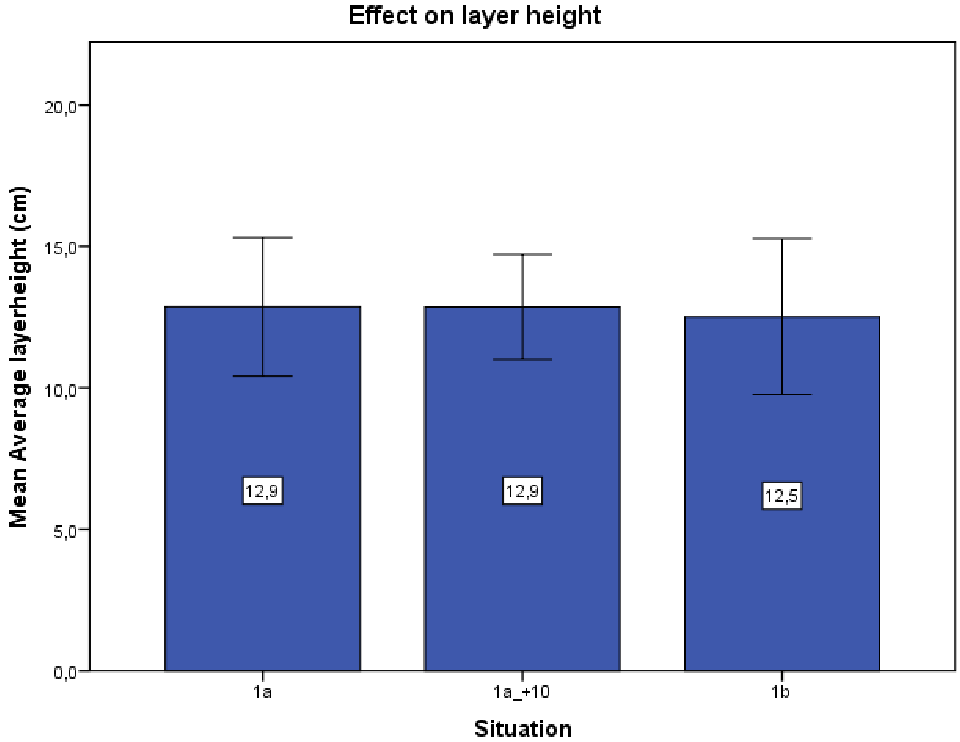


Figure 47 Effect construction situation on the layer height of the mattress

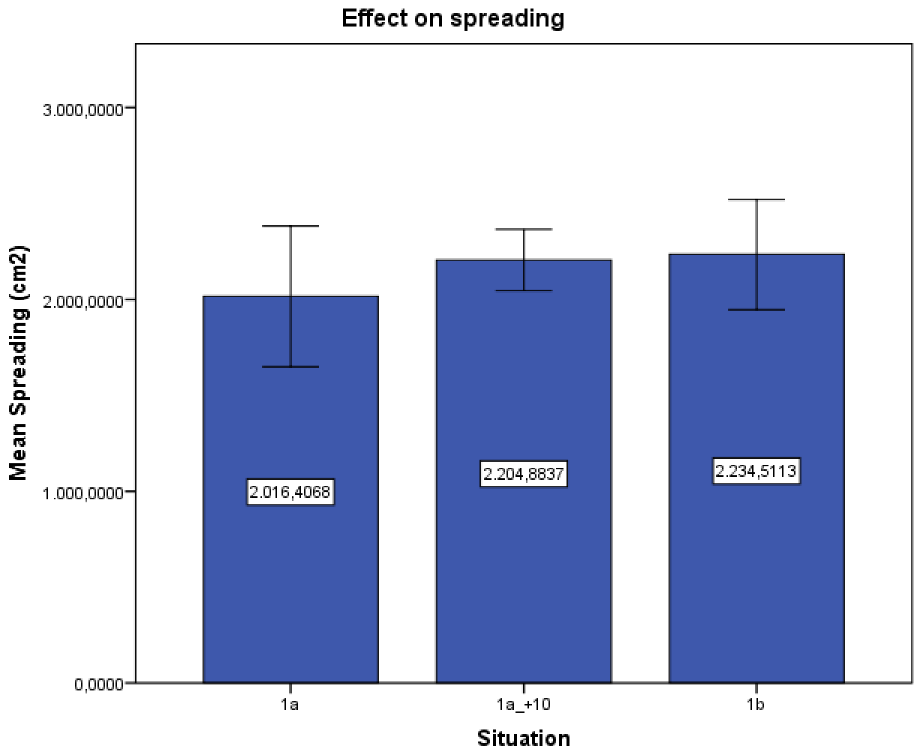


Figure 48 Effect construction situation on the spreading of the mattress

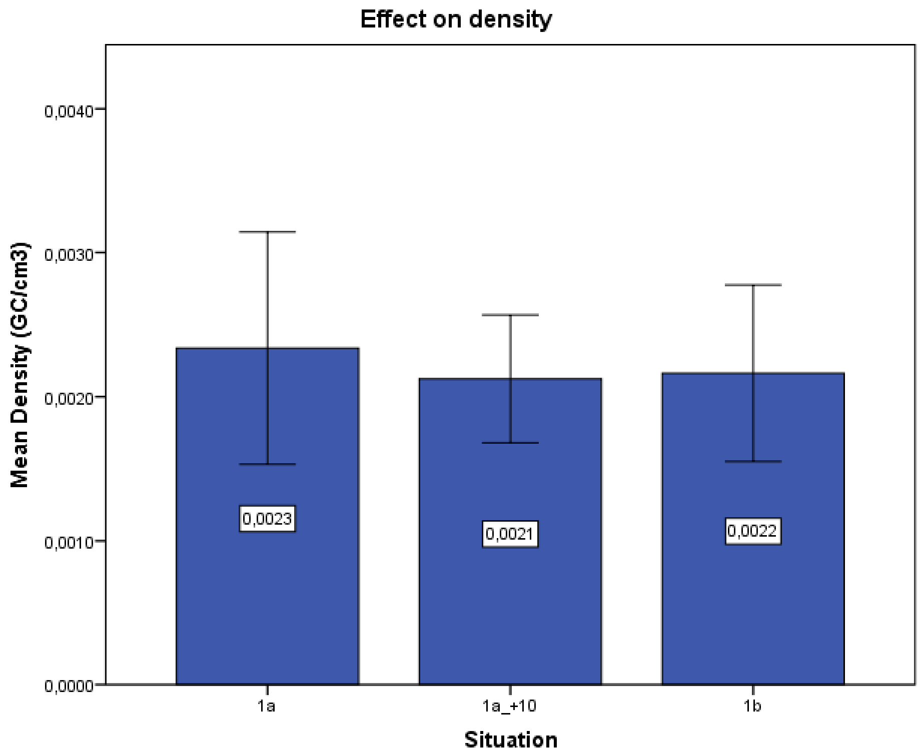


Figure 49 Influence of construction situation on the orientation of the mattress

Again, the values along the axis aren't normally distributed, so the significance of this outcome can be checked with the independent samples Kruskal-Wallis test. The results can be found in Table 19.

Null hypothesis (H_0)	Significance	Decision
The distribution of the average layer height is the same across situations	0.756	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the spreading is the same across situations	0.177	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the density is the same across situations	0.587	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 19 Results Kruskal-Wallis on the mattress orientation constructed perpendicular to the current direction

Influence on interlocking

To check the interlocking between the batches, the same method will be used as described before. Because the mattress consists out of three batches, the interlocking groups are slightly different.

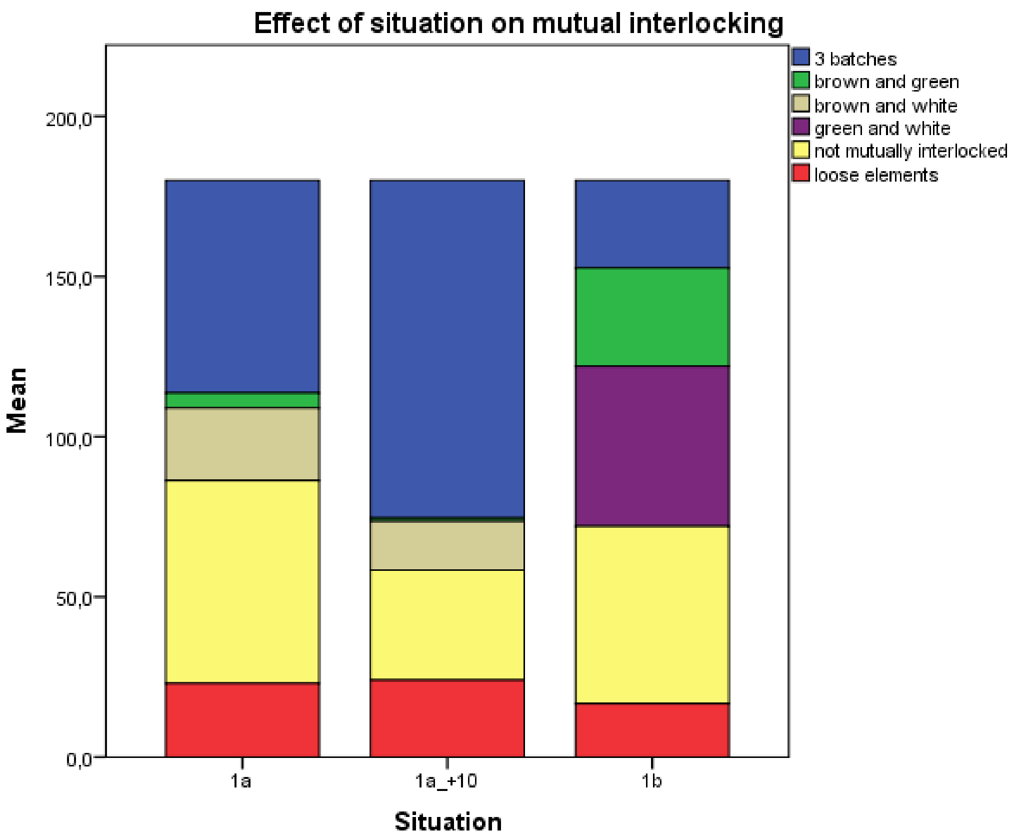


Figure 50 Effect of situation on interlocking

According to the Shapiro-Wilk test, the data of the three batches interlocked in situation 1b and the data of interlocking of brown and green in situation 1a_+10 follow a normal distribution. Because the other data isn't normally distributed, the Kruskal-Wallis test will be executed here to find the significance of the results shown in Fgure 50. The results of this test for significance are listed inTable 20.

Null hypothesis (H_0)	Significance	Decision
The distribution of 3 batches interlocked is the same across situations	0.111	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of brown and green interlocked is the same across situations	0.046	**Significance level of 0.05; reject H_0** Significance level of 0.1; retain H_0
The distribution of brown and white interlocked is the same across situations	0.120	Significance level of 0.05; retain H_0 Significance level of 0.1; reject H_0
The distribution of green and white is the same across situations	0.10	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution of not mutually interlocked is the same across situations	0.561	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of not loose elements is the same across situations	0.288	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 20 Results Kruskal-Wallis test for interlocking

Conclusion

The conclusion according to the information above is as follows. From Table 20 it is clear that not all the differences are significant. However the differences in the distribution of the brown and green interlocking and the green and white interlocking has a significant difference. From this information it can be concluded that the composition of the mattress in fact varies per situation.

Between situation 1a and 1b it is clear that the spreading and the layer height are almost completely similar and therefor the best situation must be described based on the results of Figure 51. It is immediately clear that situation 1a_+10 has the highest interlocking between three batches. So the conclusion is simple in the matter of the best situation with three batches perpendicular to the current direction, situation 1a_+10 is the best situation to use. In Figure 51 this situation is shown, it has the same top view as situation 1a.

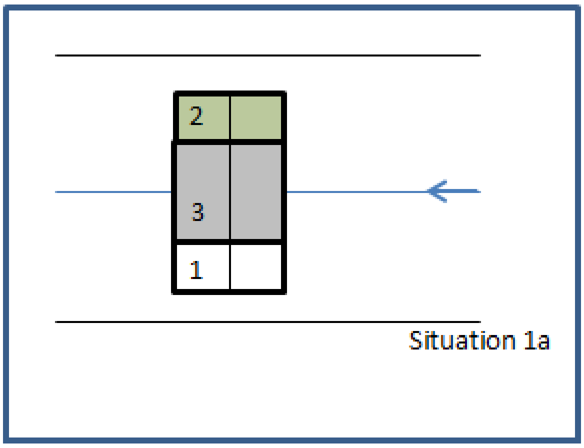


Figure 51 Situation 1a

4.2 Construction in line with the current direction

Situation 2a and 2b are constructed in line with the current direction.

Again, from brief observations, the third batch in situation 2a didn't fall on top of the mattress but remained on the side of batch two. To optimize this during the experiment, three additional tests were executed. In these extra tests (labeled as situation 2a_+10), the third batch had a falling height of 0.35 m.

Influence on mattress volume properties

Figure 52, 53 and 54 show the results of the mattress volume properties on the layer height, the spreading and the density of the mattress constructed in line with the current direction. The displayed error bar is based on a 95% reliability level.

To check the significance of these results, and to see if the differences are in fact caused by the different situations, the Kruskal-Wallis test will be performed.

Null hypothesis (H_0)	Significance	Decision
The distribution of the average layer height is the same across situations	0.670	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the spreading is the same across situations	0.288	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the density is the same across situations	0.574	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 21 Results Kruskal-Wallis test for volume properties of the mattress constructed in line with the current

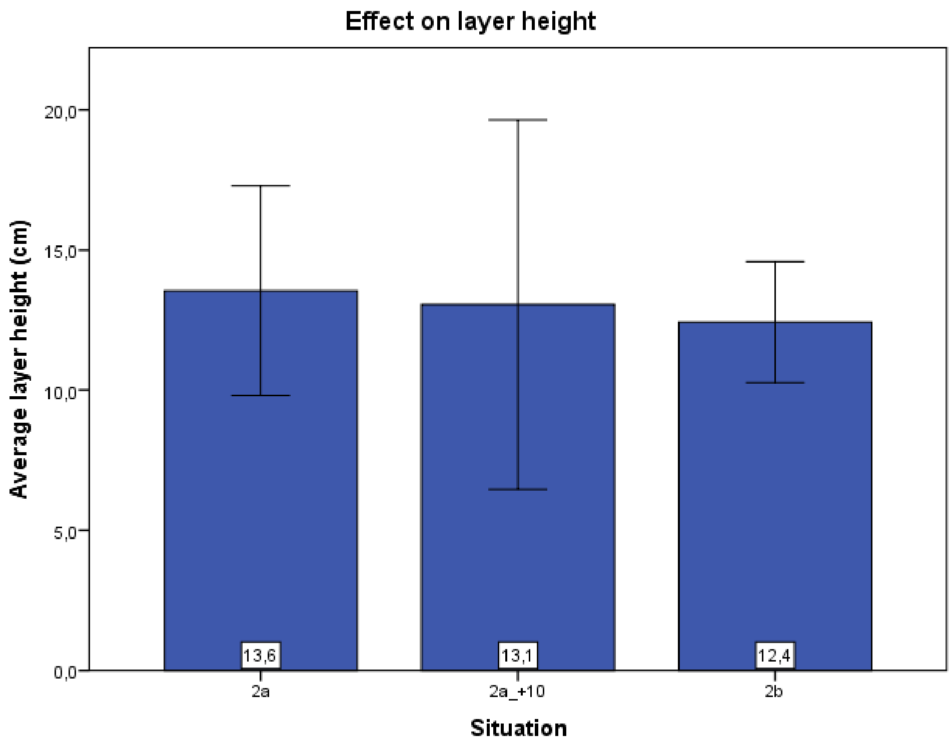


Figure 52 Effect of construction situation on the average layer height

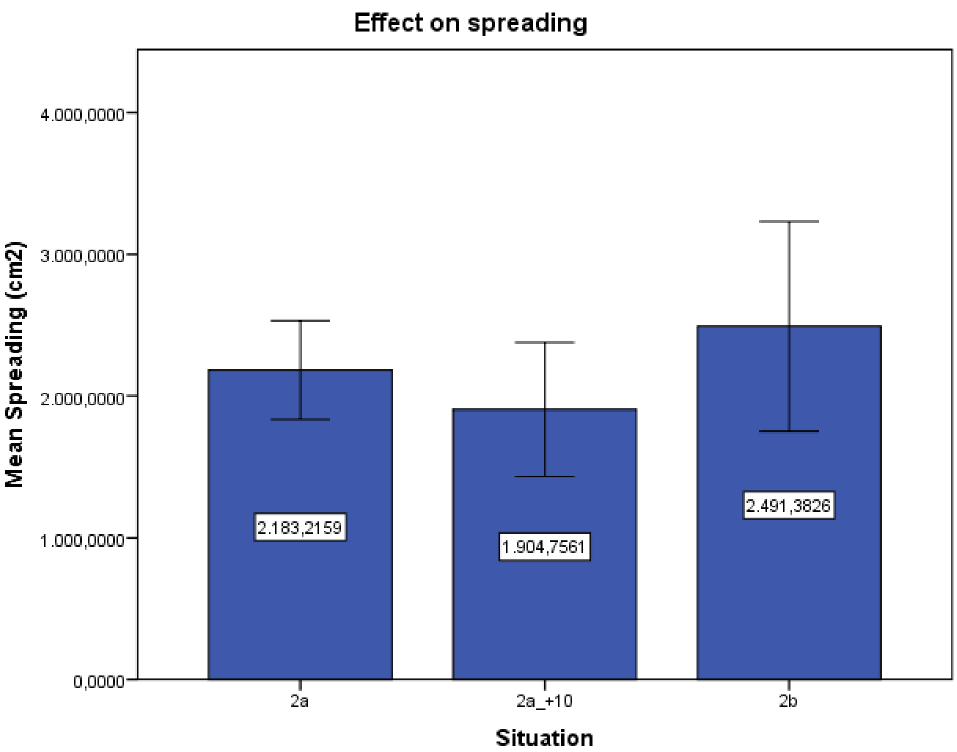


Figure 53 Effect of construction situation on the spreading

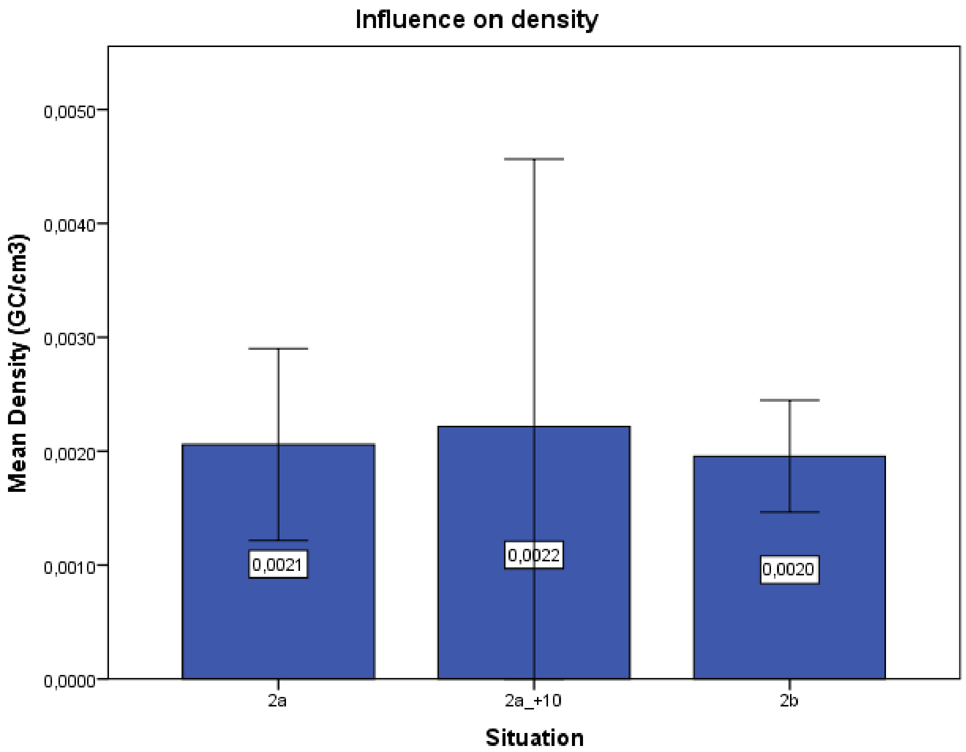


Figure 54 Effect of construction situation on the mean density of the mattress

Effect on interlocking

As described in the experiment plan, the interlocking behaviour of the mattress is examined as well for this experiment. Here, the same method as described in the interlocking statement of three batches constructed perpendicular to the current is used.

To check the significance of the relations, the Kruskal-Wallis test will be performed to check if the distribution is effected by the different situations. In Table 22, the results of this test are listed.

Null hypothesis (H_0)	Significance	Decision
The distribution of 3 batches interlocked is the same across situations	0.237	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of brown and green interlocked is the same across situations	0.105	Significance level of 0.05; reject H_0 **Significance level of 0.1; reject H_0**
The distribution of brown and white interlocked is the same across situations	0.024	**Significance level of 0.05; retain H_0** Significance level of 0.1; reject H_0
The distribution of green and white is the same across situations	0.363	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of not mutually interlocked is the same across situations	0.105	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**
The distribution of not loose elements is the same across situations	0.069	Significance level of 0.05; retain H_0 **Significance level of 0.1; reject H_0**

Table 22 Results Kruskal-Wallis test for significance of the interlocking behaviour

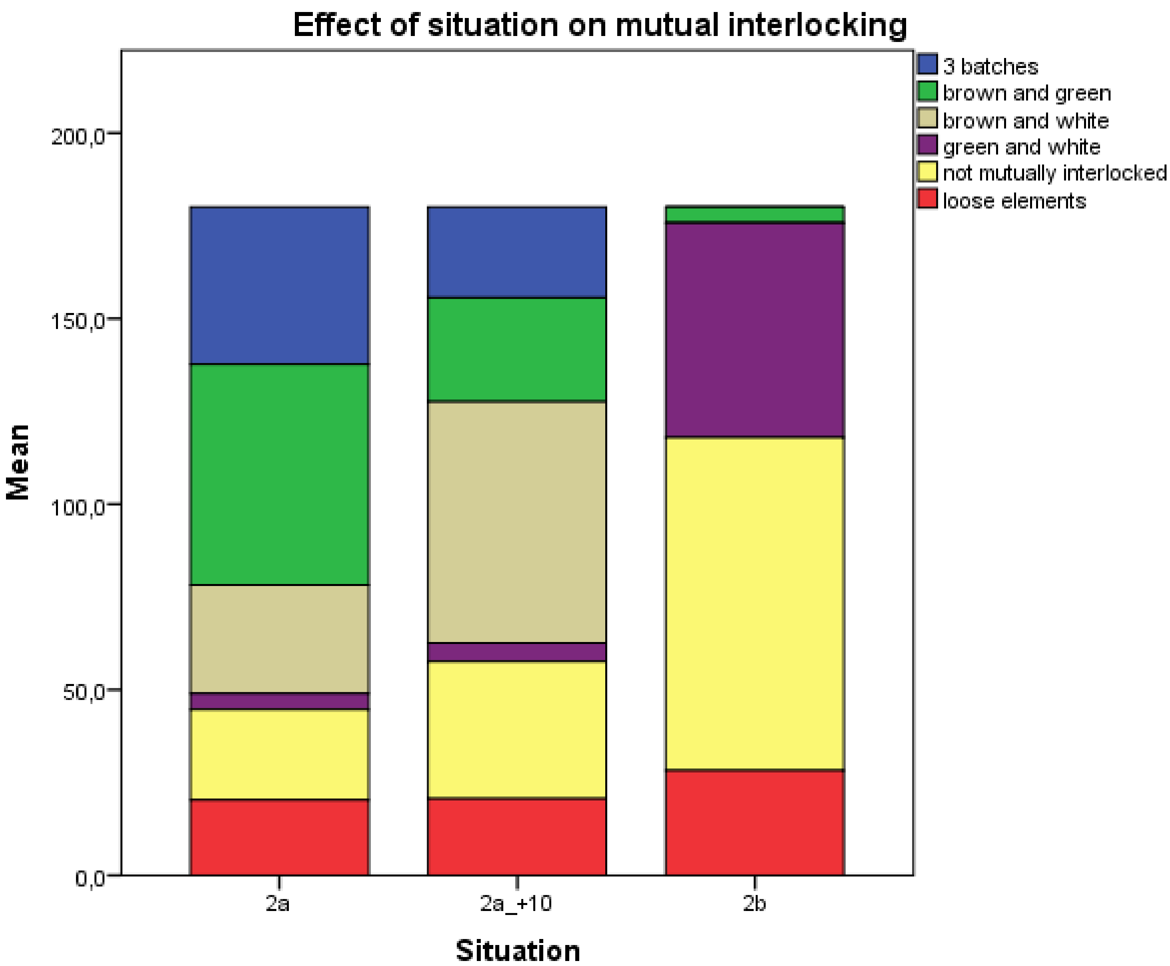


Figure 55 Effect construction situation in line with the current on the interlocking behaviour

Conclusion

From the information above the conclusions about the situation of three batches in line with the current direction can be drawn. In Table 22 the significance of the differences of the situations are listed. Almost every difference is significant so a conclusion can be drawn based on these differences.

When comparing the situations based on the density there is not much of a difference to see. So the conclusion for the best situation to be used must be based on the information of the interlocking shown in Figure 56. Some bars pop out, especially the bar from the not mutually interlocked GC's by situation 2b. This means that the strings pulled out of the flume in this situation were almost the batches as were dropped in this experiment. This in not at all what is desired so this situation will not work.

As for situation 2a and 2a_+10 they are almost the same, the interlocking of both of the situations is very high and also the loose elements are almost the same in the situations. So both situations might be used for further experiments. But when looking at the density the situation 2a_+10 has a slightly better density and therefor the recommendation for best situation with three batches in line with the direction of the current would be situation 2a_+10. In Figure 56 this situation is shown, it has the same top view as situation 2a.

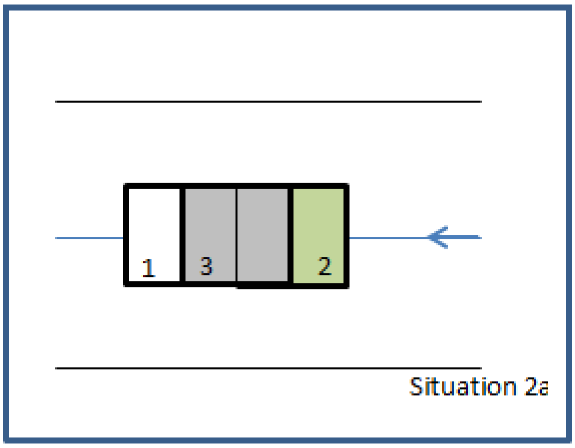


Figure 56 Situation 2a

5. Similarities between two and three batches

The similarities between two and three batches are difficult to describe, because of the different composition and method measuring the interlocking. However some conclusion can be drawn and relations can be seen between the first half of experiment 2 and the latter half. It is clear that the best method for dropping two batches and dropping three batches are associated with each other. From the first experiments it could be seen that it is required to place two batches in stretching bond. This in both directions, as well in line with as in perpendicular to the velocity direction. This method of building the mattress returned when making the mattress with three batches. These also had to be built in stretching bond.

Also a comparison between the densities of the best situations can be made. In Table 23the densities of the different situations are given. It is clear that the density is a lot lower by three batches than by two. This is not entirely strange. With a higher surface there is a lot more space for pores. Those pores can occur under the mattress or in the middle but is taken with the measurement of the surface. Also the layer height with three batches is done in another method than by two batches.

	Two batches	Three batches
Perpendicular to current direction	0.0049 GC/m³	0.0021 GC/m³
In line with current direction	0.0053 GC/m³	0.0022 GC/m³

Table 23 Densities best situations

6. Additional observations

- The camera position of camera 1 (the front view camera) is improved in these experiments. A case was installed around the camera to deflect the light from above. A plane was set on the other side of the flume also to deflect light coming in from that side.
- The white batch was always dropped at first as to not distort the other batches if it would fall after those batches. Because of the higher density of these white GC's they would immediately influence the batches underneath and that wouldn't be a fair measure.

7. Hypotheses and conclusion

The hypotheses that were made in the experiment plan were as follows:

1. The batches must be placed first downstream and then upstream so the latter batch can roll into the first batch.
2. The different batches will interlock with each other as good as the internal interlocking of one batch.
3. Loose elements will be interlocked eventually when other batches are placed.

In answer to the question if these hypotheses are true:

1. This is proven in quite a few conclusion to be true. As is foretold in the hypothesis this indeed will happen. When placing the first batch downstream the second will indeed roll into the first batch and they will interlock very well. When doing this the other way around the two batches wouldn't make contact with each other and almost none interlocking would occur.
2. This depends on the situation. It is not easy to say that they will interlock as good as the internal interlocking of a batch, but the interlocking is high enough to create a desired density and therefor it can be said the interlocking is approximately as good as the internal interlocking.
3. This hypothesis cannot be statistically proven with these experiments, because no interlocking was tested before the second or third batch would fall into the first batch and therefor fall into the loose elements.

8. Discussion

- Because of the quite heavy paint used to paint the white GC's the characteristics of these GC's were very different from the characteristics of the brown ones. This meant that there was a difference in the falling positions of these GC's. This didn't have a very large impact on the results, because in the experiments these differences were taken into account.
- As said before the current velocity measurement instruments weren't at all accurate. They fluctuated very much and therefor the graphs made out of this data weren't so accurate and a trend line had to be used to make a good estimation of what the current velocity was.
- In the plan for this experiment there was described how the distances between batch centers should be measured. When analyzing the results of the experiment a conclusion was drawn that wasn't a value which was important for the experiments and therefor wasn't used after all.
- The in the plan described method for measuring the average layer height using paint.net was used in the first part of the experiment. In the latter half the decision was made to calculate this average height by measuring the heights each ten centimeters directly at the flume. This method gave a lot higher heights and therefor it cannot be said that these heights are indeed correct.

Appendix F. Plan experiment 3 “Instance of instability”

1. Introduction
Below the plan for creating experiment 3 “Instance of instability” is listed.

1.1 Objective
The objective of this experiment is to find the moment of instability and the failure mechanism of a mattress of GC’s that is constructed in a specific order, and at which velocity of the current.

This experiment gives insight in:
- The current that leads to the moment the mattress becomes instable and drifts away.
- The observed failure mechanism of the mattress at the moment of instability.
- If there is a relation between the layer height and the moment of instability.
- Differences between a mattress build out of one batch and one build out of three batches.

1.2 Main question
What is the velocity of the current that leads to the instability of a mattress and what is the failure mechanism?

1.3 Definitions
- The velocity of the current that leads to the moment of instability is the velocity of the current that occurs at the moment the mattress is fully displaced and doesn’t stabilize again regarding its position during construction.

1.4 Hypotheses
5. If a mattress is constructed out of several batches, it will wash away by a higher velocity than a mattress constructed out of a single batch.
6. The mattress will first become instable at its toe (the base of the mattress, which is closest to the sand bed), and will roll over. This will lead to the failure mechanism.
7. If a mattress consists out of one or more peaks, it will become instable at a lower current.

2. Data collection

The following shows a list of data which needs to be measured during experiment 3:

- The height of the water table.
- The total amount of GC's in the clamshell.
- The height of the mattress, measured each 0.1 m along the x-axis.
- The velocity of the current in the flume during construction.
- The current trajectory, starting from the moment of increasing the velocity of the current until the moment of instability.

The following shows an overview of the method of measuring the data collection described in the list above.

Height of the water table

This height is measured in a similar way to the previous experiments 1 and 2. Along the x-axis of the flume, two rulers are placed on the side windows of the flume. The height of the water table is assumed to be the average of those two rulers.

The total amount of GC's in the clamshell

Before filling the clamshell, the total amount of GC's must be sorted to prevent errors. The total amount of GC's in the clamshell will be held constant at 60 (because this is the maximum amount of GC's that fits in this clamshell, as already shown in experiment 1 and 2). Each batch consists out of GC's with the same characteristics, so all white, green or brown.

Height of the mattress

This height will be measured according to the method described in experiment 1. The height of the mattress must be measured every 0.10 m along the x-axis. The measured height will be the highest visible point along the x-axis. Figure 57 shows this method, with an interval of 0.10 m.

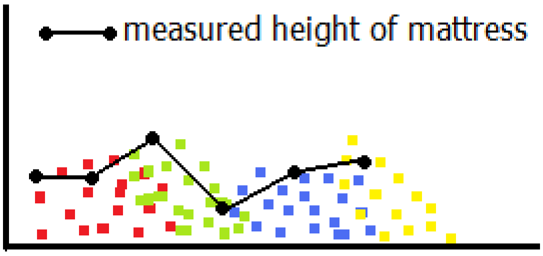


Figure 57 Average layer height mattress

The current trajectory

To find the moment of instability, the current trajectory needs to be measured. Two current measurement instruments are placed along the axis of the flume. Once the mattress is built on the bed (at a constant current velocity of approximately 0.21 m/s), the velocity of the current in the flume will be increased by opening the inlet of with approximately 15 dm^3 / 10 seconds. Before the inlet opens, both the measure instruments will start recording the real time current. Later, during the computer analysis, the current that leads to the moment of instability will be estimated by linking the frame on the camera to the mean current at that timeslot.

The total amount of GC's in the clamshell will be kept constant at 60 GC's. The current velocity in the flume during construction will be around 0.21 m/s. The filling method will be similar to the method used in experiment 1.

3. Base of research

3.1 Materials & equipment

The used materials and equipment for this experiment include:

- One scaled clamshell (scale 1:8 based on drawing LH160-4500).
- One flume (large flume in the laboratory for fluid mechanics, cross section (width x height) 0.80 x 1.00 m^2).
- At least 180 regular GC's for creating an mattress with outer dimensions of 0.05 x 0.05 x 0.05 m^3.
- Equipment to hang the clamshell above the flume and hold it in place.
- Bed material (sand) with a depth of 0.04 m.
- Two regular cameras (positioned on the side and above the batch near the clamshell).
- Equipment to mount and orientate the cameras (near and above the flume).
- One plane for the sidewall and a container to fit the side camera. This equipment will increase the visibility of the cameras.
- One claw or net to catch the elements.
- One grid at the side window to measure the heights along the x-axis with an interval of 0.1 m.
- One protection sheet near the end of the flume to catch loose elements.
- Two rulers, placed on the side window, to measure the water table height in the flume.
- (Digital) equipment to measure the current in the flume, mounted on two places along the x-axis. This measure instruments were mounted 0.18m above the bed.

3.2 Setup

The experiment setup is as follows:

- An even sand layer will be made on the bed of the flume. This bed is approximately 0.04 m.
- Two rulers will be put up on the side wall of the flume to measure the height of the water table.
- A plane is placed at the side window to ensure no disturbing things can be seen from the camera position.
- One camera will be placed at the side of the flume and one camera will be placed at the center of the clamshell with a clear view on the bed.
- The current in the flume starts. The velocity during construction will be kept constant at approximately 0.21 m/s.

The performing of the test

In this experiment, two different instabilities will be tested. First, the instability of a single batch will be investigated and second, the instability of a mattress constructed out of three batches will be tested.

The following will be performed each test:

- Load the clamshell with 60 GC's. The clamshell is loaded according to the reference experiment, so one by one, and the next GC rotated over 90 degrees compared to the previous one.
- The clamshell is placed above the flume, with its opening perpendicular to the current direction. The distance between the underside of the clamshell and the sand bed will be kept constant. This must be 0.25 m. Its position depends on the specific situation.
- Start filming on all cameras.
- Open the clamshell slowly.
- Stop filming on all cameras

- Measure the position of the center of the batch.
- Make pictures (stills) from both camera positions and label them.
- Measure from the right side of the mattress every 0.1 m along the x-axis, the height of the mattress.
- Repeat this several times (depending on the situation).
- Start the recording of the flow measure instruments and start filming on all cameras.
- Open the inlet of the flume with approximately 15 dm^3/ 10 seconds (turn the wheel ¼ round each 10 seconds).
- Wait until the mattress becomes instable.
- Stop the cameras and label the movie.
- Return the current of the flume to 0.21 m/s.

The following will be done with the analyses of the footage and stills and with the ascii files of the current measure instrument:

- For each test, the frame with the moment of instability (according to the definition described before) and the associated current will be described.
- Also as described in the method above the moment of compression can be calculated. This is the moment that the batches only move horizontal over the sand bed and instead of becoming instable they will compress into a better mattress with a much higher density. In the time between this point and the point of instability the batch will only be compressed.
- The ascii files will be analysed with a python program that reads the data and converts it to a graph. With this program and the moment of stability found with the method described above the associated speed of instability can be found.
- The average layer height of the batches before increasing the velocity of the current must be calculated. This is done in the same way as before. In paint.net the stills of cam 1 can be opened and analysed by measuring the height of an GC in pixels and compare this to the real size of 0.05m of the width of a GC. With this factor the height of different points in of the batch can be calculated. The height will be measured in about six different point with the same distance between these points. With those six heights the average height can be calculated.

3.4 Geometry

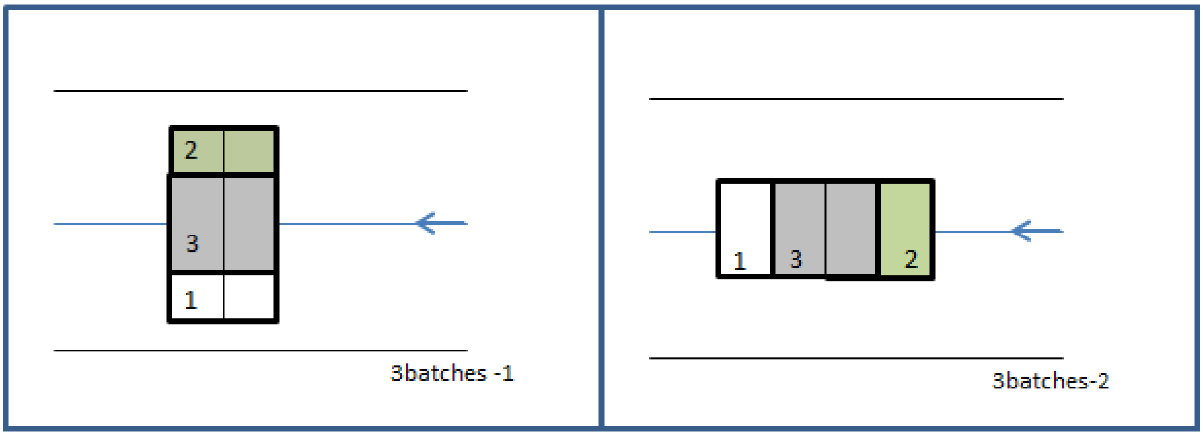


Figure 58 Geometry experiment 3, 3 batches

The first half of experiment 3 was tested on one batch in the flume, with 60 GC's. For testing the stability of a (small) mattress three batches were used. In Figure 58 the geometry of the latter half of experiment 3 is shown. The situation with 3 batches-1 was tested two times the other situation with 3 batches-2 was tested one time.

These tests will be performed as described in Table 24.

Situation	Number of GC's in clamshell	Opening clamshell	Number of measurements per situation
1 Batch	60	slow	3
3 Batches	60	slow	3

Table 24 Situations performed

3.5 Layout

The layout will be the same as in experiment 1, with the adjustment of a few extra GC's for making the mattress. Figure 59 and 60 show the layout for experiment 3.

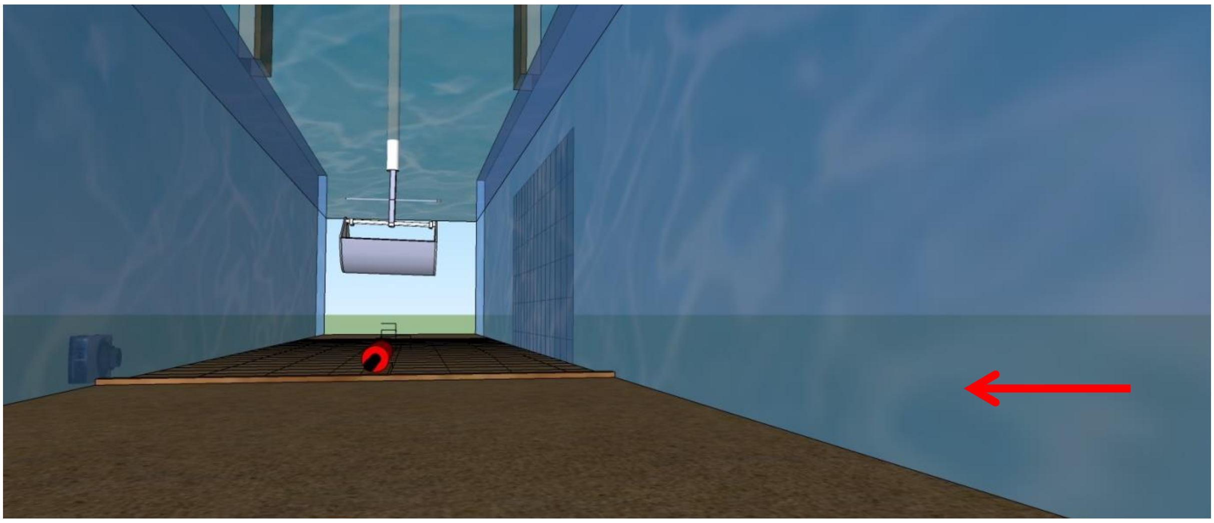


Figure 59 Front view layout experiment 2, with pipeline mounted on the bed

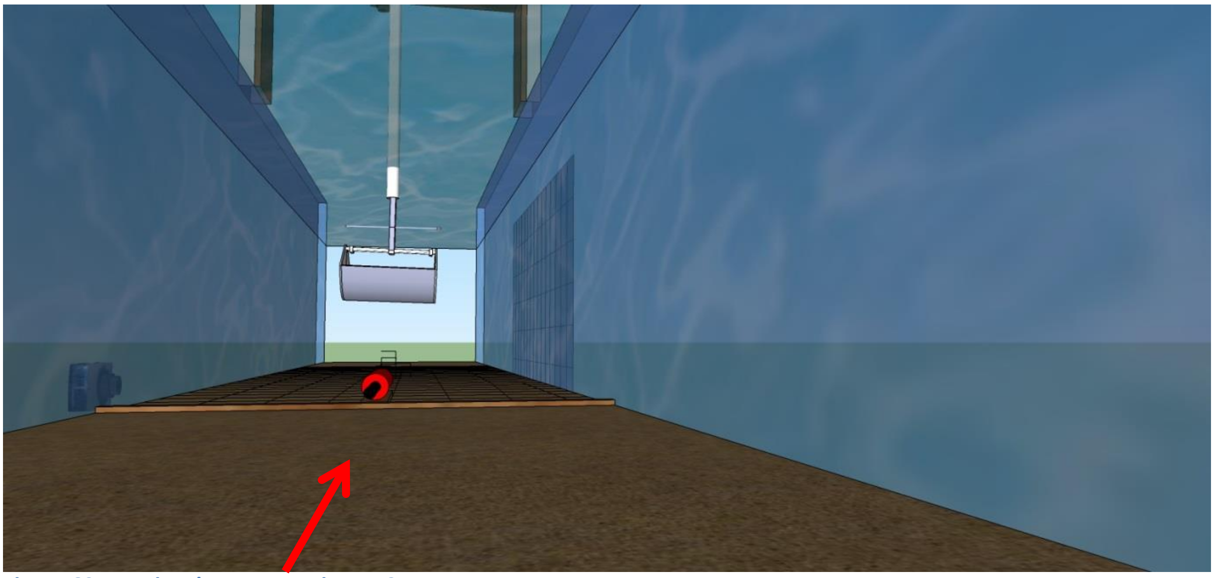


Figure 60 Top view layout experiment 2

3.6 Statistic relations

Once the experiment results are obtained, some statistic tests will be executed to check if the relations can statistically be supported and to get an idea of the significance of the data.

This statistics will be executed in the statistic program IBM SPSS Statistics 22.

Once a relation is plotted in a chart or is listed in a table, the variables on the y-axis (the dependent values) will be checked in relation to the variables on the x-axis (the independent values). To see if they are normally distributed in relation to each other, a Shapiro-Wilk test for normality (suited for small samples) will be executed. Based on these results (if the results have a significance of 0.05 than a normal-distribution occurs), the right correlation test will be chosen.

If the data is non-normal distributed, and the values on the x-axis aren't continuous, the Shapiro-Wilk test will be executed. This test will check the null-hypothesis, which states that the values of the dependent variables follow the same distribution, so the independent values don't affect the distribution of the dependent values and the observed differences are likely to be based on a coincidence. If however, the null-hypothesis has a significance of 5%, the null-hypothesis could be rejected and the distribution differences are in fact caused by the independent variable.

If the data is normal distributed, the t-test can be performed, which works almost the same as the Shapiro-Wilk test.

As soon as the independent variables are continuous, the correlation between the variables will be checked with the Spearman (non-normal distribution) or the Pearson test (normal distribution). This test will find a correlation coefficient and a significance level. If the significance is lower than the chosen significance level, the variables are in fact correlated.

When data is displayed in charts or in tables, the average values and the reliability interval will be given, to compare the values and the standard deviations. The reliability interval is based on a significance level, which is chosen to be 95% in this experiment.

If the relation isn't significant, the effect of the independent variables on the dependent variables aren't scientifically found. When this happens, only an indication will be given based on the charts.

Appendix G. Experiment 3 results

Experiment 3 was performed on 4-10-2013 and 7-10-2013 in the TU Delft Laboratory for Fluid Mechanics. This appendix gives an overview of the test results.

1. Experiment execution

The same setup as in experiment 2 will be used here. For the figures of this setup, see appendix E.

The only difference between the experiments is the use of the velocity meters, these will be used more intensively. This is done with the help of the computer program DASYLab. Figure 61 shows the used architecture of this computer program.

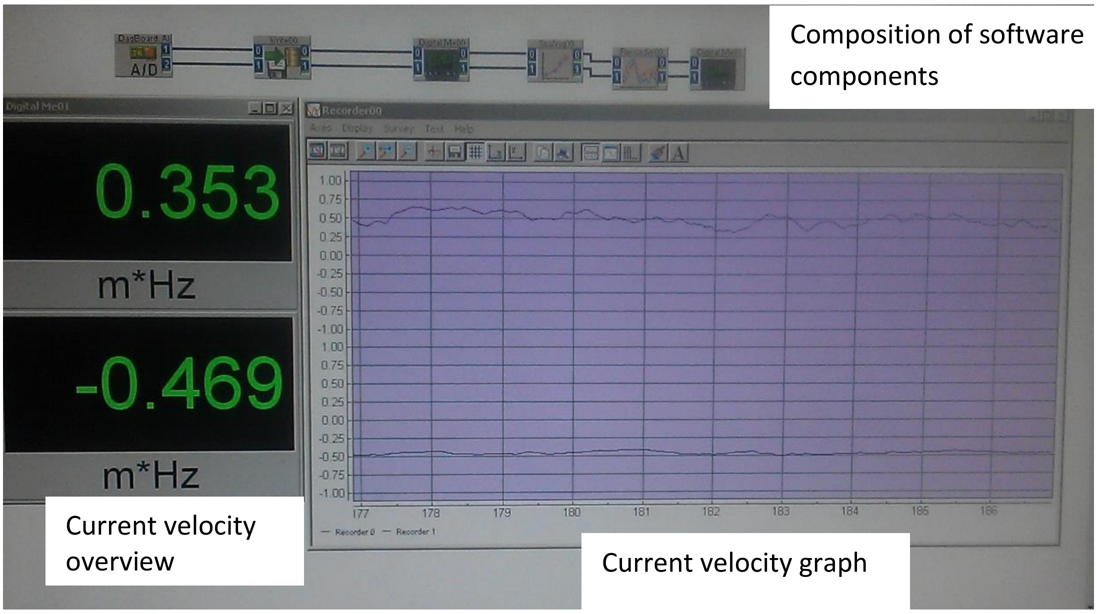


Figure 61 Used architecture computer program DASYLab

2. Experiment conditions

During the construction of the mattress, some parameters were kept constant to exclude influences on the behaviour. Table 25 lists all the parameters that where held constant in the construction phase of the experiments.

Parameter	Average value during construction	Deviation
Current velocity (m/s)	0.21	0.0
Water table height (m)	61	0.62
Sand layer height (m)	0.04	0
Falling height above the bed (m)	0.25	0
* In the construction situations with 3 batches, the clamshell was lifted + 0.1 m, so in that case the falling height was 0.35		

Table 25 Conditions in the flume during construction of the mattress

3. Analysis

3.1 Effect of amount of GC's

In the first part of the experiment (carried out with batches of 60 GC's), the current velocity that leads to instability and the failure mechanism are examined.

To do so, the velocities and the camera recordings were linked during the data preparations according to the method described in the experiment plan. Because of the inaccuracy of the velocity meter, the mean trajectory had to be calculated from the data. This mean velocity is used here to estimate the velocity that leads to instability.

During the video analyses, some compression was observed inside the batches (as defined in the experiment plan). Therefore, the current velocity that occurred during the major compression is listed in Table 6 as well.

The average results can be found in Table 26.

Construction	Number of tests	Average height (cm)	Average compression velocity[1] (m/s)	Average instability velocity[1] (m/s)	Average instability velocity at sea[2] (m/s)
1 batch (60 GC's)	3	8.04 ± 0.95	0.33 ± 0.02	0.36 ± 0.25	1.01
3 batches (180 GC's)	3	9.2 ± 0.21	0.37 ± 0.08	0.49 ± 0.05	1.38

[1] Average value and standard deviation found in the experiment results
[2] Converted value based on the hydrodynamic scaling (see also Appendix J)

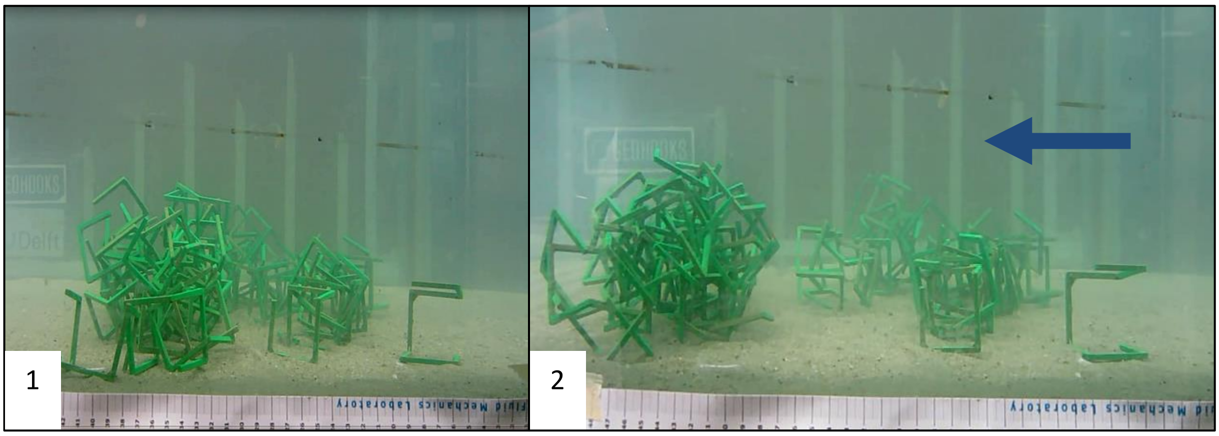
Table 26 Results moment of instability

Instability mechanism

It's hard to quantify the mechanism that leads to instability. Therefore, a qualitative observation will be stated here, based on the analyses of the camera recordings.

Instability of one batch

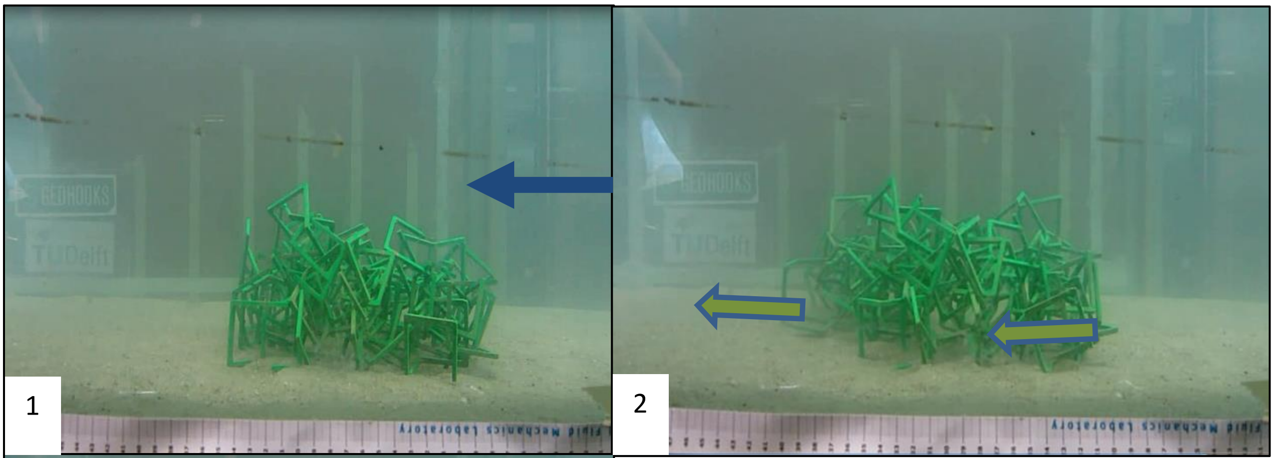
After analysing the three movies from the tests with three batches, some statements could be made regarding to the trajectory up to instability of the batch on the bed. In two tests, even though the batch of 60 GC's seemed interlocked, the batch didn't act as a whole mattress after the current velocity increased. Some heaps started rolling, while others remained stable on the bed. After some velocity increases, the batch was disintegrated into several heaps. This effect of disintegration can be observed in Figure 61.

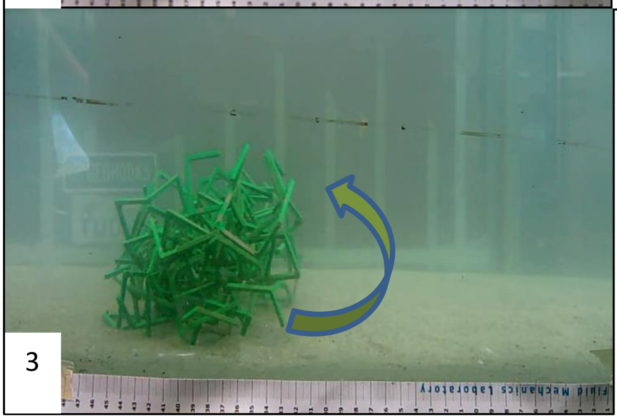


1. Batch after construction **2. Batch at ± 0.31 m/s (after velocity increases)**

Figure 62 Disintegration single batch (situation 1, test 2)

The main observed failure mechanism, in all tests with one batch, is based on the upstream side and the downstream side to start moving simultaneously. Because of the increased momentum, the current can get under the GC's at the toe, causing them to raise. After the toe rolls over, the area under the batch decreases and the whole batch entirely rolls over. This mechanism is shown in Figure 63.





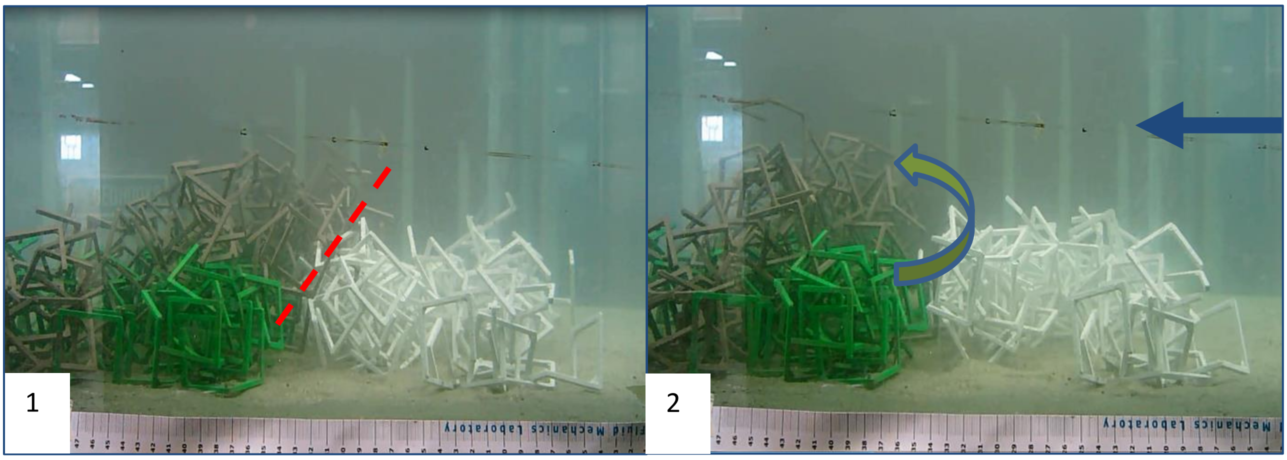
Situation: 1 batch, test 3

1. Batch directly after construction.
2. Single GC's at upstream and downstream side starts moving.
3. Area decreases and batch toe starts rolling over at velocity of ± 0.36 m/s

Figure 63 Instability mechanism single batch

Instability of three batches
When the mattress is built up out of three batches (so with a total of 180 GC's), some differences in the instability mechanism can be observed.

In the situation where one batch is placed upon a layer of two other batches, the parts of the top batch that didn't interlock with the batch underneath will be the first to start moving and roll over. These loose parts are all situated at the upstream toe of the top batch. Because some parts of the top batch are in fact interlocked with the batches underneath, the rolling stops and the top batch stabilizes from moving. This is shown in Figure 64. When the current velocity increases, the batch at the upstream side starts moving at its toe, causing the entire mattress to move horizontally in the current direction.



1. No interlocking between brown batch (on top) and white batch

2. The brown batch rolls over and stabilizes because of the interlocking with the green batch

Figure 64 Effect of interlocking between batches on mechanism

Once the entire mattress is moving horizontally, the downstream batches burrows themselves into the sand bed. This leads to a velocity difference (the velocity of the downstream side decreases) at both sides of the mattress, which will cause the upstream side to raise and roll over. The complete rolling over effect isn't visible because the entire mattress is washed away horizontally before the rolling over process could develop.

The batch that links the batches on the bed (so the third batch in this experiment) cause the batches to act as a mattress and hold both batches together. Once the upstream batch starts rolling, the connecting batch will push away the upstream batch.

Conclusion
From the information gathered above it can be concluded that the batches of GC's have in fact a quite high stability. In other words they don't drift away at the slightest currents. Also there is in fact a great difference between a single batch and an actual mattress (made out of three batches). For the single batch it took only 0.36 m/s to make it drift away and with a mattress it takes 0.49 m/s to make it drift away. From these results it can be concluded that the batches find stability by the batches surrounding them. Before the batches are instable they compress. This is only good for the

batch and the density. Because there were so few tests in this experiment it cannot be said this result is significant. But it is clear that a mattress can hold out against a quite high velocity.

3.2 Effect of layer height

To check the relation of the layer height with the moment of instability, both parameters will be plotted to see if a relation exists. Figure 65 shows this plot. In this analysis, only the situation with one batch will be examined to exclude to influence of the weight of the mattress.

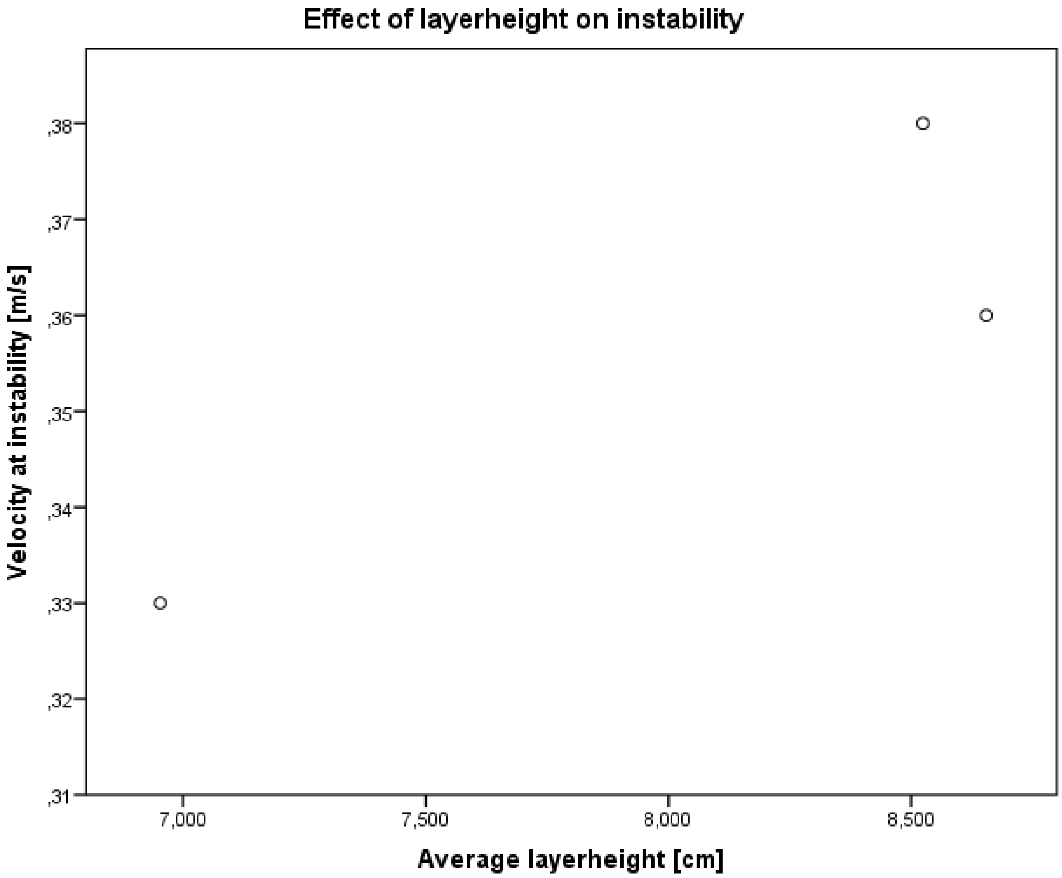


Figure 65 Effect of layer height on the moment of instability

To check if this result is significant and both parameters are in fact correlated, the Spearman's method will be used here. In Table 27 this result is displayed.

Parameter	Correlation coefficient	Significance
Velocity of instability and average layer height	0.5	0.667

Table 27 Result Spearman correlation

Conclusion

One could observe from the chart in Figure 65 that an increased layer height results in an increased resistance against instability. Because only three tests were performed with this situation, this relation is far from significant (significance of 0.667). The relation between the average layer height and moment of instability can therefore not be stated from this experiment.

4. Other observations

- Some GC's that didn't interlock with the main batch after construction, will be protected by the main batch when they are located at the downstream side. These GC's will wash away once the entire batch washes away, while other loose GC's around the bed starts moving separately from the batch and at lower current velocities.
- Once a GC's loosens from the main batch at the upstream side, it will interlock again at the downstream side of the batch.
- In the first experiment, the upstream batch was built up out of white GC's. These GC's have an increased weight (see also appendix K) of approximately 10%. This increased weight is situated at the toe of the mattress, and the mattress didn't roll over a the maximum current velocity of the flume.

5. Hypotheses and conclusion

Before starting these tests three hypotheses were made:

1. If a mattress is constructed out of several batches, it will wash away by a higher velocity than a mattress constructed out of a single batch.
2. The mattress will first become instable at its toe (the base of the mattress, which is closest to the sand bed), and will roll over. This will lead to the failure mechanism.
3. If a mattress consists out of one or more peaks, it will become instable at a lower current.

In answer to the question if these hypothesis are true:

1. This is already discussed in the results above. This will indeed happen to a larger batch. The more batches in the mattress the more stable the mattress will be. This because the batches will find stability in the surrounding batches.
2. This is also proven in the figures in 'Effect of amount of GC's '. First the batches will compress at the same time. They will move as one in the horizontal direction. At a certain point the toe will be lifted so the front batch will be pressed against the batch behind. This batch will burrow itself in the sand and when it cannot hold on any longer the toe will be rolled over the batch behind hooking in everything it comes close to and dragging the rest along.
3. This cannot be concluded because there is no significant relation found between the velocities at the instance of instability and the layer height. Therefor this hypothesis cannot be stated true or false.

The most important conclusion that can be stated based on this experiment is that a batch of 60 GCs will float away at a current velocity of 0.36 m/s. This will limit the possible construction conditions because on cannot construct the mattress at a velocity above this value.
Another thing that can be concluded from this experiment is that the batches in fact move away as a whole mattress and that more GC's in line with the current direction increases the stability.

6. Discussion

- Because of the size and the characteristics of the used flume in the hydromechanics laboratory, it was hard to operate the inlet. Therefore, the accuracy described in the experiment plan couldn't be achieved. The wheel at the inlet was small compared to the diameter of the inlet pipe, so a small rotation caused a heavy increase of the current velocity, making it hard to get an uniform increase in velocity. The current had an uneven impact on the mattress, so it is possible that a sudden increase in velocity causes the toe of the mattress to vibrate and move, which led to the failure mechanism at a lower current velocity compared to a situation with an uniform increase.

- Because the flume is approximately 40m long, the current needs some time to adjust (in terms of velocity and water table height) to the new situation after the inlet opens. Therefore, the velocity increase won't increase totally uniform.
- When the current velocity increases, both the speed meters started to vibrate because of friction along it's tube. This led to inaccurate data regarding the specific velocity at a certain timeframe. With help of computer software, it was possible to get an average trajectory out of the data, but the accuracy of the whole experiment would increase of the rough data wasn't that oscillating. Figure 66 shows an example of this oscillating effect and the trend line that was drawn inside this rough data chart with help of the computer.
- The main part of the data (the current velocity at instability) had to be obtained during the computer analysis after the experiment. There are some differences in the accuracy of the time indication on the camera recordings and the trajectory from the velocity meter. Therefore it is possible that the frame with the instability wasn't linked properly to the velocity.

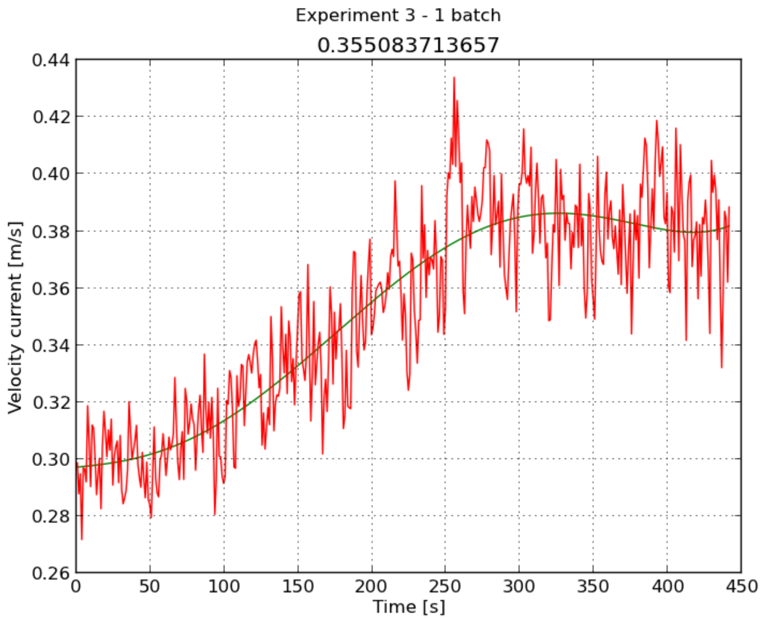


Figure 66 Example of oscillating velocity meter

- Especially the results from the construction situation with three batches aren't significant. Even though this situation was carried out three times, each test had slightly different conditions that influenced the results. The first test was performed with white GC's. These GC's are painted by hand and therefore heavier than the regular GC's. This caused a different failure mechanism and a higher current velocity of instability. The third test was constructed perpendicular to the current direction instead of in line with the current direction. This means there was less material on the upstream side of the mattress, and the mattress had a lower moment of instability.
- It can be very interesting to investigate the effect of the average layer height of the mattress on the current velocity that leads to instability. As one can see from the analyses before, this experiment wasn't suited for this relation because the number of tests wasn't sufficient and the way of measuring the layer height wasn't accurate enough to focus on the peaks of the mattress. Because the effect can be interesting for the estimation of the deviation in layer height during construction a new experiment setup must be setup to focus just on this relation. In this new experiment, one must focus on the building of the mattress in terms of heaps and peaks and one must choose a flume that can be set more accurately.

Appendix H. Plan experiment 4 “Placing around a pipeline”

1. Introduction

Below the plan for creating experiment 4 “Placing around a pipeline” is listed.

1.1 Objective

The objective of this experiment is to combine everything learned and measured in one experiment to evaluate what the ideal method is for placing a mattress around a pipeline. With the insights found before this next experiment can be set up.

The results of this experiment gives insight in:

- How different batches of GC’s must be placed regarding to the previous placed batches.
- How the desired height of the batch can be realized.
- How stable the mattress really is and in which velocity of current the stability is gone and the mattress will flow away.

1.2 Main question

“What is the behaviour (interlocking and stability) of a mattress of GC’s placed in a current around a pipeline, from the moment of placing the GC’s in a current until the moment of instability at a to high velocity”?

1.3 Definitions

- The GC’s used in these experiments are scaled elements based on the design used in the full scale placement test. The full scale GC’s have outer dimensions of 0.4 x 0.4 x 0.4 m^3. The scaled elements have outer dimensions of 0.05 x 0.05 x 0.05 m^3. This results in a scaling of 1:8.
- Interlocking in this experiments is not a measured value, it is part of the stability tested in this experiment. When the interlocking is high enough the mattress will be as a big batch of GC’s. That results in that the mattress will flow away wholly at the point of instability, as one big heap of GC’s including all the batches used to build this mattress.
- Point of instability. For this experiment when the mattress lies on the sand bed the velocity of the flume will be increasing and at a certain point this velocity will be so high the mattress won’t stay in place and will drift away.
- Free span**.** The pipeline in the flume is based on the pipeline in the Waddensea which has the problem of a free span. This means the pipeline doesn’t lie on the seabed any longer. There is a space between the pipeline and the sand that needs to be recreated in the scaled experiments.

1.4 Hypotheses

5. Before reaching the point of instability, the loose elements will start to move, but this will result in a higher density of the mattress. This is because the loose elements will interlock after all with the mattress.
6. When starting to build the mattress it is always necessary to start building on the upstream side, therefore the increased current over the flume and under won’t have any influence on the mattress. The rest of the mattress can be build supporting on this first stable part.
7. The batches need to be placed in two layers to reach the desired height.

2. Data collection

The following shows an overview of the required data that needs to be obtained from the experiments to make an analysis of the behaviour of a batch of GC's under water. For each measurement the method of measuring is described.

The height of the water plane

This can easily be measured by the available equipment in the fluid mechanics laboratory. The measured height is the (average) height from the top of the sand bed to the water table. See Figure 67. This height will be measured along the flume at two specific spots, so the gradient of the water table can be calculated. Along the x-axis, the rulers are placed approximately 10m apart from each other.

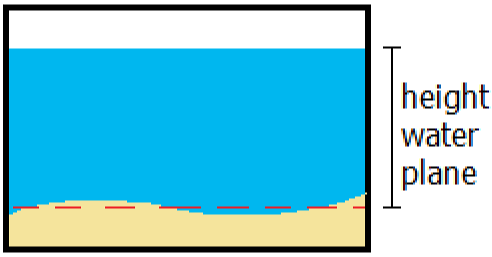


Figure 67 Height water plane

The falling height

This is the distance from the underside of the clamshell to the sand bed. In the reference experiment a falling height of 2 m was used, so at a scale of 1:8 this means a falling height of 0.25 m.

Number of batches to build a mattress

For the ideal mattress around the pipeline many batches are needed to come to the desired height, width and length of the mattress on two sides of the pipeline. Regrettably the only GC's available were not at all enough to complete an entire mattress. In total there were about 350 GC's, so a mattress made out of six batches could be realized.

The total number of GC's in the clamshell

From previous experiments it can be concluded that the ideal number in the clamshell is 60. For this experiment the restrictions lay with the number of GC's available, this was about 350. Eventually the batches used for making the mattress consisted out of 57 GC's.

Height of the batch

One can expect from the reference experiment that a complicated structure will appear once the batch reaches the bed. Therefore the average layer height and the four highest peaks will be measured.

3. Base of research

3.1 Materials & equipment

This experiment is based on the previous experiments and uses the same materials and equipment, with extension of some items. The used materials and equipment for this experiment include:

- One scaled clamshell (scale 1:8 based on drawing LH160-4500).
- One flume (large research flume in the laboratory for fluid, dimensions (width x height) 0.80 x 1.00 m).
- Sufficient GC's with outer dimensions of 0.05 x 0.05 x 0.05 m^3, for six batches.
- Equipment to hang the clamshell above the flume and hold it in place.
- Bed material e.g. sand or gravel (depends on flow speed).
- Two cameras (positioned on the side of the flume and one for mobile usage).
- Equipment to mount and orientate the cameras (near and above the flume).
- One white plane with a grid (blocks of 0.125 x 0.125 m^2) for the sidewall.
- One claw or net to pick up the elements.
- One measuring rod to measure the height of the batch.
- One protection sheet near the end of the flume to catch loose elements.
- Equipment to measure the water table height in the flume.
- (Digital) equipment to measure the flow in the flume. This measure instruments were mounted 0.18m above the bed.
- One stopwatch for measuring the time cycle.
- One pipeline scaled from 1m diameter to 0.125 m.

3.2 Setup

The experiment Is an extension of the previous experiments and will use the already made setup in the flume.

- An even sand layer will be made on the bed of the flume. This bed is approximately 0.04 m in height.
- The clamshell is placed above the flume, in line with the flow direction. The distance between the bed of the clamshell and the sand bed will be measured. This must be 0.25 m.
- One camera will be placed at the side of the flume.
- At the other side as where the camera position is, there will be lines in a grid set up for measuring of the height of the batches.
- Then the flow in the flume starts and the velocity in the flow will be set to 0.25m/s.

The following will be performed six times each test, because the mattress will be built out of six batches:

- Load the clamshell with the necessary amount of GC's. The clamshell is loaded according to the reference experiment, so one by one, and the next GC rotated over 90 degrees compared to the previous one. Measure the loading time with a timer.
- Hang the clamshell in place, by measuring the position from the origin.
- Start filming on all cameras.
- Open the clamshell slow and wait until the batch of GC's reaches the bed.
- Stop the cameras.
- Make pictures with a mobile camera from the top of the batch.

The following will be done when the mattress is built on the bed with the six batches:

- Make pictures with a mobile camera.
- Measure the height of the batches from the side.
- Measure the length of the batch, with a ruler from pipeline till the last element of the batch.

- Start the current measure instrument and the cameras.
- Start to increase the velocity of the flume bit by bit.
- When noticed the batches drift away stop the measurements, the camera and the current.
- Hook the batches out of the water.
- Untangle the six batches and divide them into six new batches for the next run.

The following will be done with the analyses of the footage and stills and with the ascii files of the flow measurer:

- For each test, the frame with the moment of instability (according to the definition described before) and the associated current will be described.
- Also as described in the method above the moment of compression can be calculated. This is the moment that the batches only move horizontal over the sand bed and instead of becoming instable they will compress into a better mattress with a much higher density. In the time between this point and the point of instability the batch will only be compressed.
- The ascii files will be analysed with a python program that reads the data and converts it to a graph. With this program and the moment of stability found with the method described above the associated velocity of instability can be found.
- The average layer height of the batches before increasing the velocity of the current must be calculated. This is done in the same way as before. In paint.net the stills of cam 1 can be opened and analysed by measuring the height of an GC in pixels and compare this to the real size of 0.05m of the width of a GC. With this factor the height of different points in of the batch can be calculated. The height will be measured in about six different point with the same distance between these points. With those six heights the average height can be calculated.

These tests will be performed as described in Table 28.

Situation	Number of GC's in clamshell	Opening clamshell	Number of measurements per situation
Exp 4a situation 1	60	slow	3
Exp 4a situation 2	60	slow	3
Exp 4a situation 3	60	slow	3
Exp 4a situation 4	60	slow	3
Exp 4a situation 5	60	slow	3
Exp 4b situation 1	60	slow	3
Exp 4b situation 2	60	slow	3

- **Table 28 Number of experiments en measurements**

3.3 Geometry

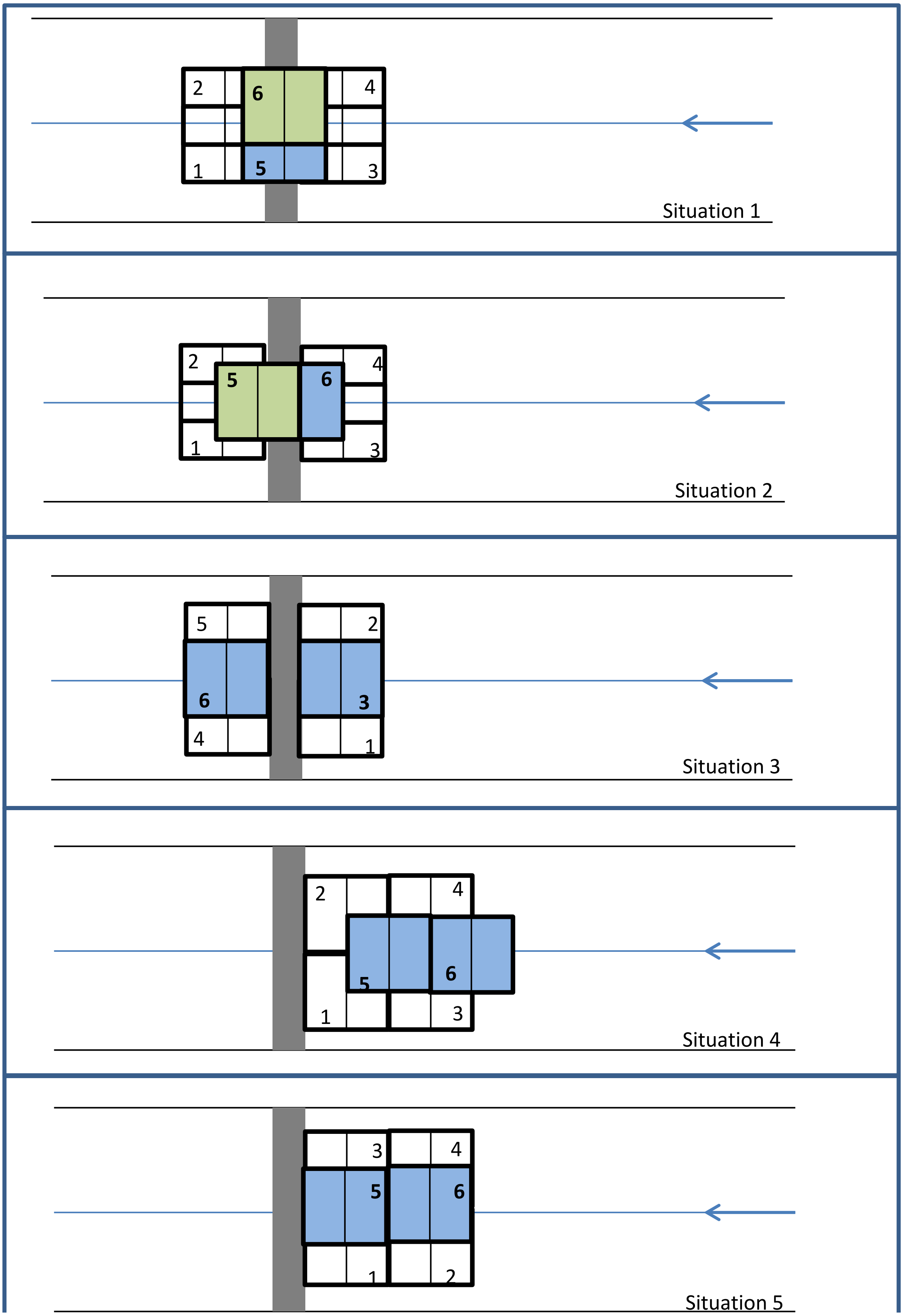


Figure 68 Geometry experiment 4

The first half of experiment 4 will be tested with a pipeline mounted on the sand, so without a free span. All the construction situation displayed in Figure 68 will be tested here.
In the second part, the pipeline will be raised by its diameter (0.125 m), so a free span situation will be simulated. In this part, only the situations 3 and 5 will be tested (the orientation of the pipeline remains perpendicular to the current direction).

3.4 Composition of the clamshell

Because this experiment will be performed with 6 batches that consists out of 60 GC's per batch, the total amount of GC's that was donated to this experiment needs to be used. To get a homogenous composition of GC's in the clamshell and to reduce the influence of the white GC's on the mattress, the GC's in the clamshell will be mixed. Therefore, each clamshell contains brown, white and green GC's. Table 29 gives this composition.

Batch	Amount of Brown GC's	Amount of White GC's	Amount of Green GC's
1	36	10	11
2	36	10	11
3	36	10	11
4	36	10	11
5	35	11	11
6	30	16	11

Table 29 Composition of batches

3.5 Layout

In the following two figures an overall view of the setup is displayed, as it was used in the previous experiments. The only addition to the setup is the pipeline. The pipeline as displayed below doesn't have a free span yet, this is only in the latter part of the experiment. This is the base for experiment 4.

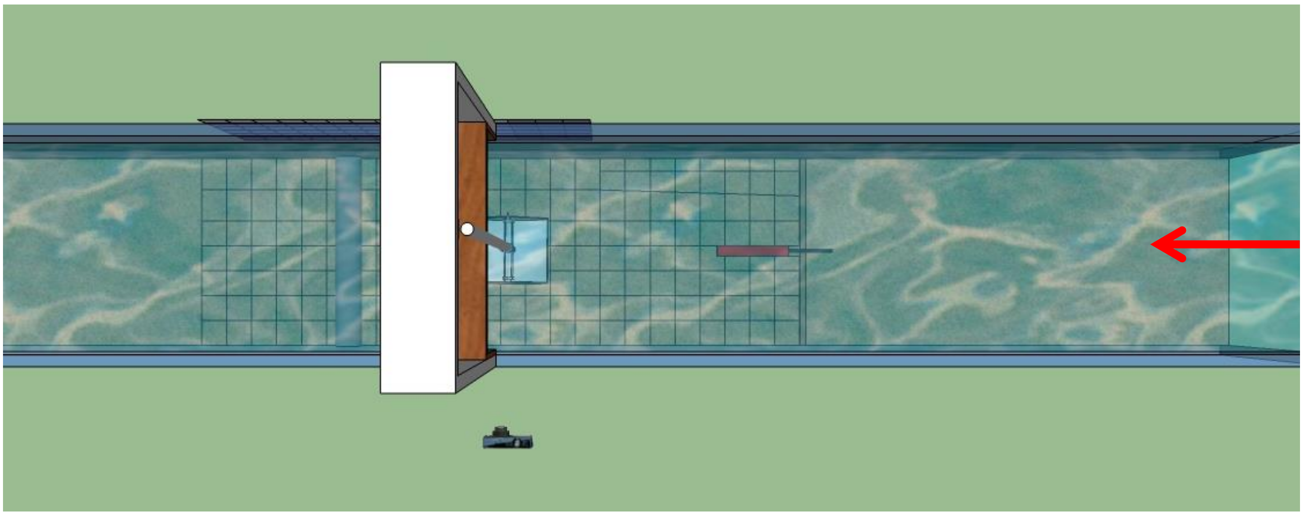


Figure 69 Top view flume

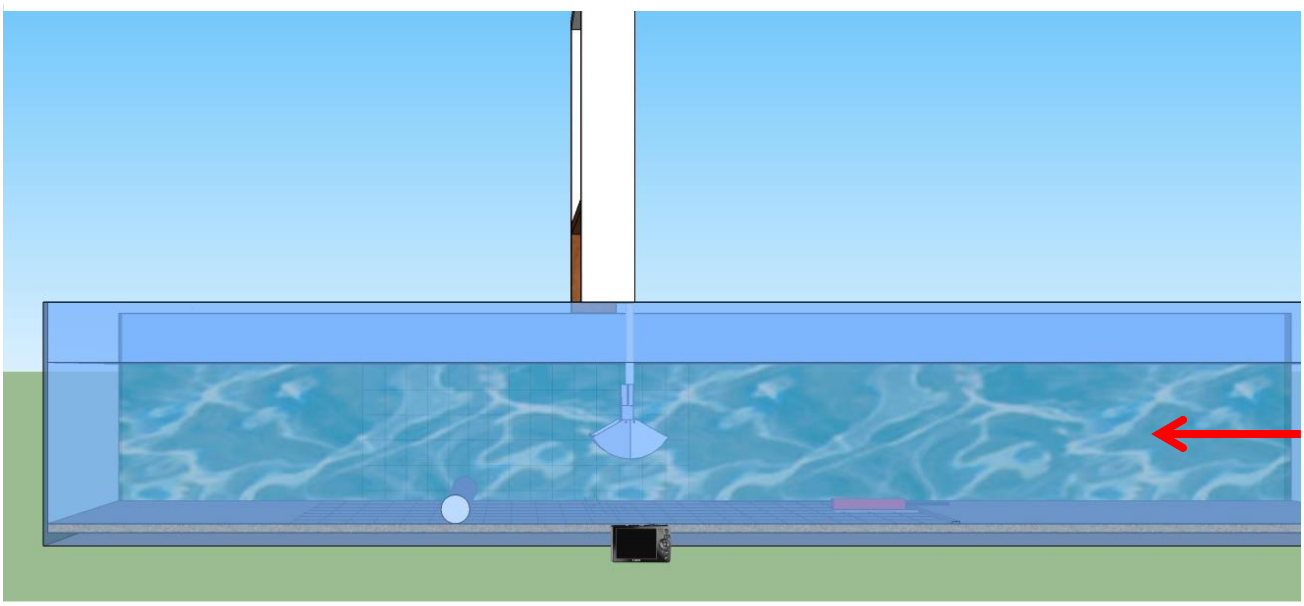


Figure 70 Side view flume

3.7 Statistic relations

Once the experiment results are obtained, some statistic tests will be executed to check if the relations can statistically be supported and to get an idea of the significance of the data.

This statistics will be executed in the statistic program IBM SPSS Statistics 22.

Once a relation is plotted in a chart or is listed in a table, the variables on the y-axis (the dependent values) will be checked in relation to the variables on the x-axis (the independent values). To see if they are normally distributed in relation to each other, a Shapiro-Wilk test for normality (suited for small samples) will be executed. Based on these results (if the results have a significance of 0.05 than a normal-distribution occurs), the right correlation test will be chosen.

If the data is non-normal distributed, and the values on the x-axis aren't continuous, the Shapiro-Wilk test will be executed. This test will check the null-hypothesis, which states that the values of the dependent variables follow the same distribution, so the independent values don't affect the distribution of the dependent values and the observed differences are likely to be based on a coincidence. If however, the null-hypothesis has a significance of 5%, the null-hypothesis could be rejected and the distribution differences are in fact caused by the independent variable.

If the data is normal distributed, the t-test can be performed, which works almost the same as the Shapiro-Wilk test.

As soon as the independent variables are continuous, the correlation between the variables will be checked with the Spearman (non-normal distribution) or the Pearson test (normal distribution). This test will find a correlation coefficient and a significance level. If the significance is lower than the chosen significance level, the variables are in fact correlated.

When data is displayed in charts or in tables, the average values and the reliability interval will be given, to compare the values and the standard deviations. The reliability interval is based on a significance level, which is chosen to be 95% in this experiment.

If the relation isn't significant, the effect of the independent variables on the dependent variables aren't scientifically found. When this happens, only an indication will be given based on the charts.

4. Special equipment

4.1 The pipeline

To recreate the real situation in the Waddensea a scaled pipeline was needed. The pipeline in the Waddensea has a diameter 1.05m and scaled with the factor of 1:8 the pipeline in the experiment must have a diameter of 0.125m. The pipeline lies on the bottom of the Waddensea and therefore the first experiments will be with the scaled pipeline on the bed. To see how the pipeline has an influence on the mattress and how to work with this influence.

After those first tests the problem of the free span will be recreated. The free span is at its maximum about one diameter between pipeline and sand bed and this is the situation that will be recreated in the tests in the latter part of experiment 4. In Figure 71 the pipeline with the free span is shown.
The pipeline has compared to the sand bed a relatively smooth surface, this is also recreated in the material used to make the pipeline. This is important for testing how the GC's react when they lie against the pipeline.

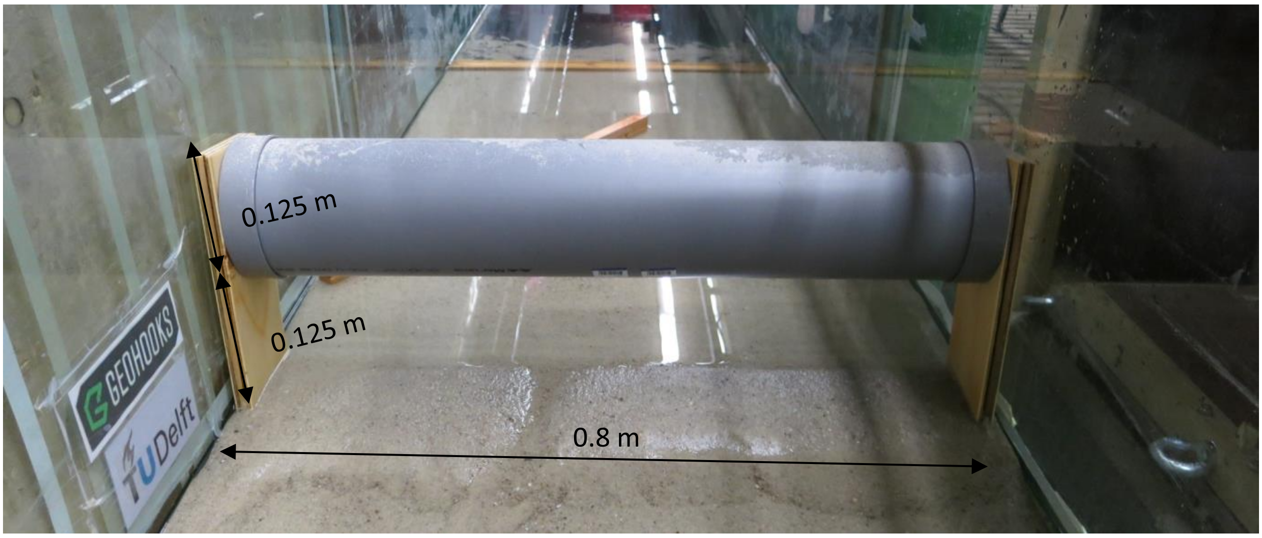


Figure 71 Free span scaled pipeline

Results experiment 4 “Placing around a pipeline”

Experiment 4 was performed from 7-10-2013 until 15-10-2013 in the TU Delft Laboratory for Fluid Mechanics. This appendix gives an overview of these tests.

1. Experiment execution

The experiment execution is based on the previous experiments. The only adjustment was that a pipeline needed to be placed in the flume. In Figure 72 the setup with the pipeline is shown.

Figure 72 Execution with pipeline

2. Experiment conditions

During the experiment execution, some variables were kept constant to exclude the influence on the experiment results. Table 30 shows these constant variables.

Parameter	Average value during construction
Current velocity (m/s)	0.21
Water table height with pipeline on the bed (m)	0.60
Water table height with free span (m)	73.5
Top of pipeline (placed on the bed) (m) above the bed	0.125
Top of pipeline (with frees pan above) above the bed (m)	0.25
Sand layer height (m)	0.04
Falling height above the bed (m)*	0.25
* In some situations, the clamshell was lifted + 0.1 m, so in that case the falling height was 0.35 m.	

Table 30 Experiment conditions

3. Analyses

In this part, the data from the experiments will be analysed.

3.1 Pipeline mounted on the sand bed

First the results from the situation with a pipeline mounted on the sand bed will be analysed. The moment of instability is defined in the experiment plan. The effect of the construction situation and the effect of the average layer height on the current velocity at instability will be visualized. Next, the failure mechanism will be described in a more qualitative way. Because of the knowledge gained from experiments 2 and 3, the batch that is supposed to be on top of the mattress is placed with an increased falling height of 0.35 m above the bed, so the clamshell is lifted with 0.1 m for these top batches.

Volume properties of the mattress

The volume properties of the mattress are described as the layer height, the spreading and the density. For this experiment only the layer height was measured because the density and spreading were already analysed in previous experiments. The layer height on the other hand is important to check if the desired height is maintained and to check how accurate the mattress was constructed.

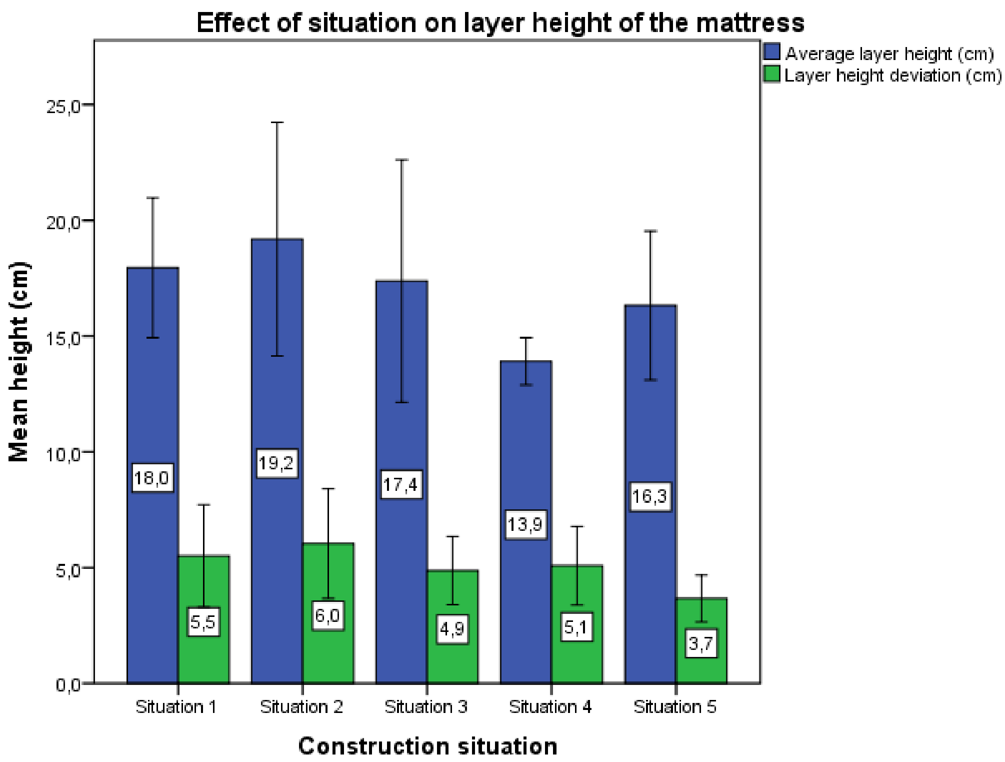


Figure 73 Effect of construction situation on layer height

Figure 73 shows the layer height of the mattress after construction. In this figure, the average layer height of the mattress (based on the eight measuring points along the flume) and the standard deviation are displayed. This standard deviation will be used as a measure for the evenness of the mattress. The displayed error bars are based on a 95% reliability interval, so this is the modified standard deviation.

For the situations 3, 4 and 5 the length of the mattress along the axis of the flume was measured according to the experiment plan. Figure 74 shows the average values of these lengths. Because in situation 3 the mattress was constructed on both sides of the pipeline, the length of that mattress is summed.

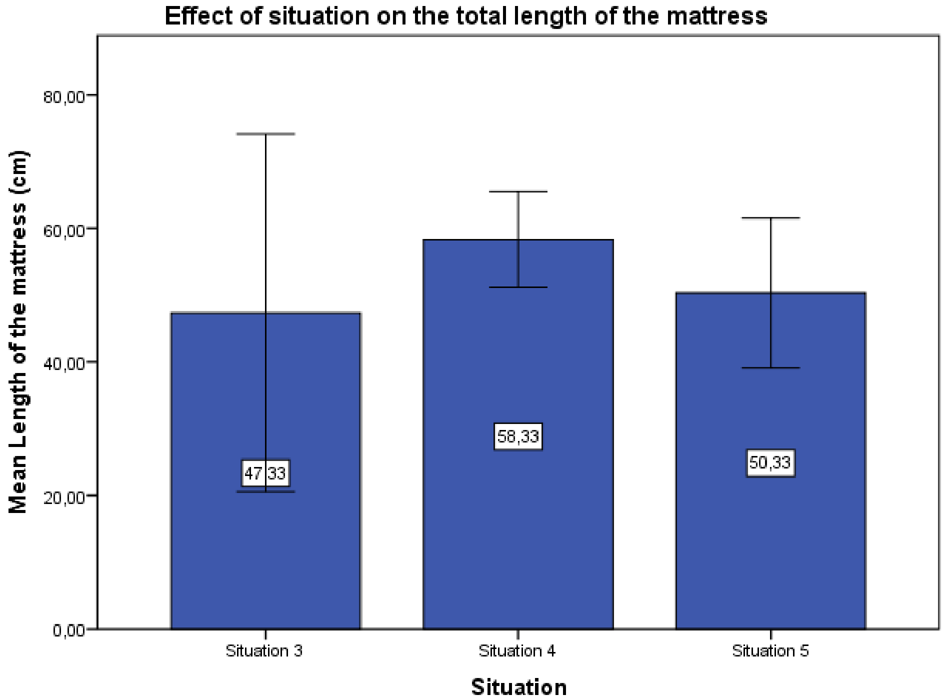


Figure 74 Total length of the mattress

Instance of instability

This term is used to describe the moment when the mattress will become instable. Instability will take place when the major part of the mattress drifts away. When the current velocity starts to increase, the cameras will start recording and the flow measurement instrument will start measuring. The instance of instability will be described as a moment in time viewed on the footage. By linking the data received from the instruments (plotted in a python graph) and the moment determined by the footage, the velocity associated by the moment of instability was found.

Instance of compressing

As same as the instance of instability the instance of compressing was found by the footage. This term describes the moment the current velocity is high enough so that smaller movements can be observed within the mattress. To get an overview of the instability trajectory, the current during the first movements is measured and analysed as well.

Situations 1,2 and 3

First the situations 1, 2 and 3 will be analysed. These situations are similar because they both have one batch width on both sides of the pipeline. This means the effect of extra weight in line of the current is more or less excluded. Figure 75 shows the current velocities that leads to the first movements within the mattress and the instability moment. The displayed error bar belongs to a 95% reliability interval.

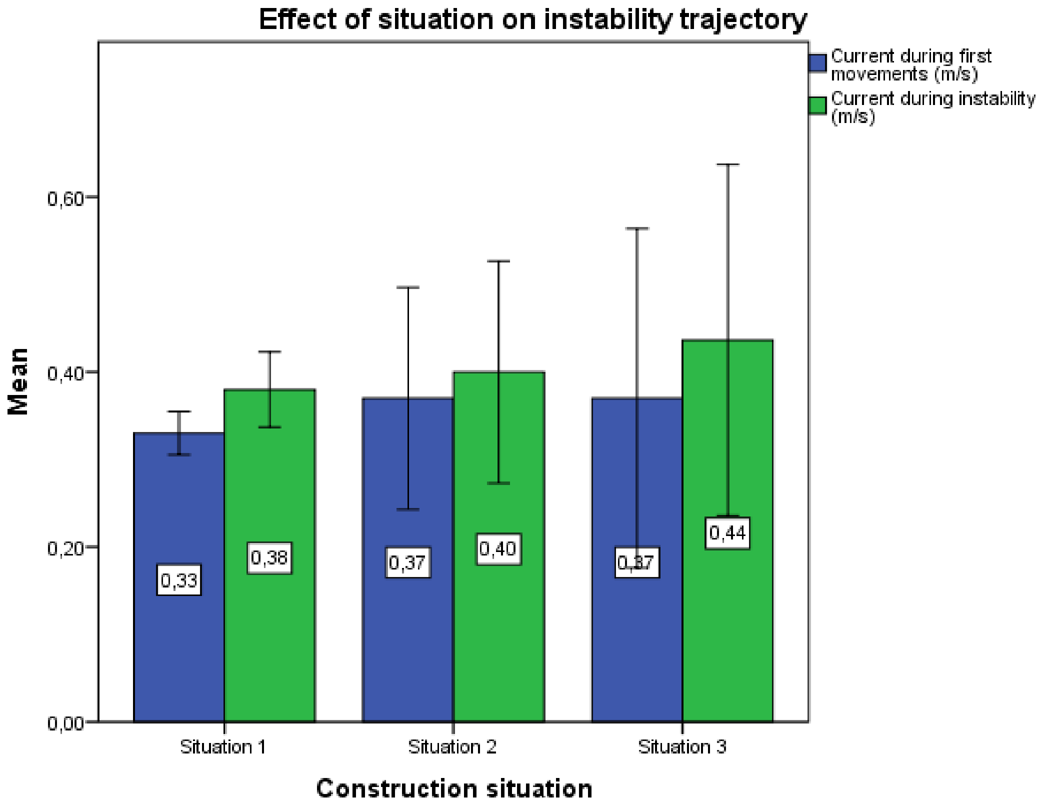


Figure 75 Effect of situation on the instability trajectory of situation 1, 2 and 3

To check if the results are statistically significant, the Kruskal-Wallis test for independent samples will be performed. Table 31 shows these results.

Null hypothesis (H_0)	Significance	Decision
The distribution of the current during first movements is the same across the construction situations	0.354	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the current during instability is the same across the construction situations	0.383	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 31 Results Kruskal-Wallis test

Situations 4 and 5

These situations are based on similar principles. All the batches are positioned on the upstream side of the pipeline, so in both cases the weight of the mattress is almost equal. Figure 76 shows the instability trajectory of the construction situations 4 and 5.

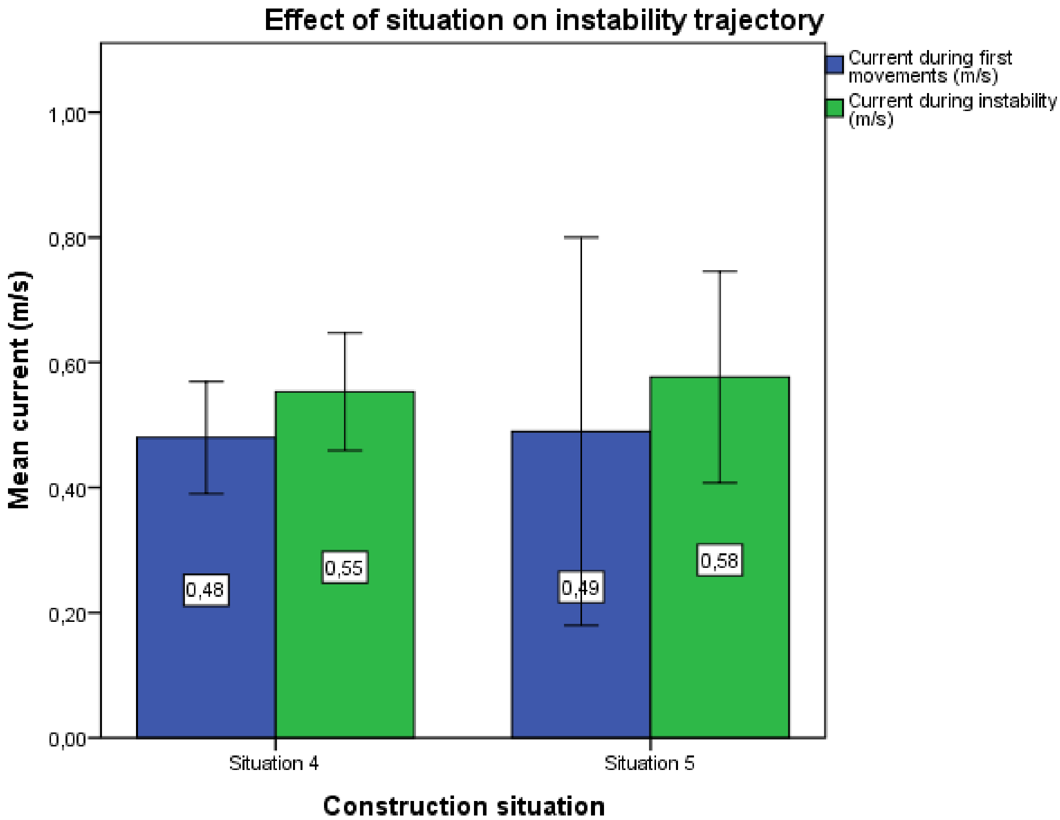


Figure 76 Effect of situation on the instability trajectory of situation 4 and 5

To check the significance of this result, a Mann-Whitney U test for independent samples will be performed. This result is listed in Tabe 32.

Null hypothesis (H_0)	Significance	Decision
The distribution of the current during first movements is the same across the construction situations	0.700	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the current during instability is the same across the construction situations	1.0	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 321 Results Mann-Whitney U test

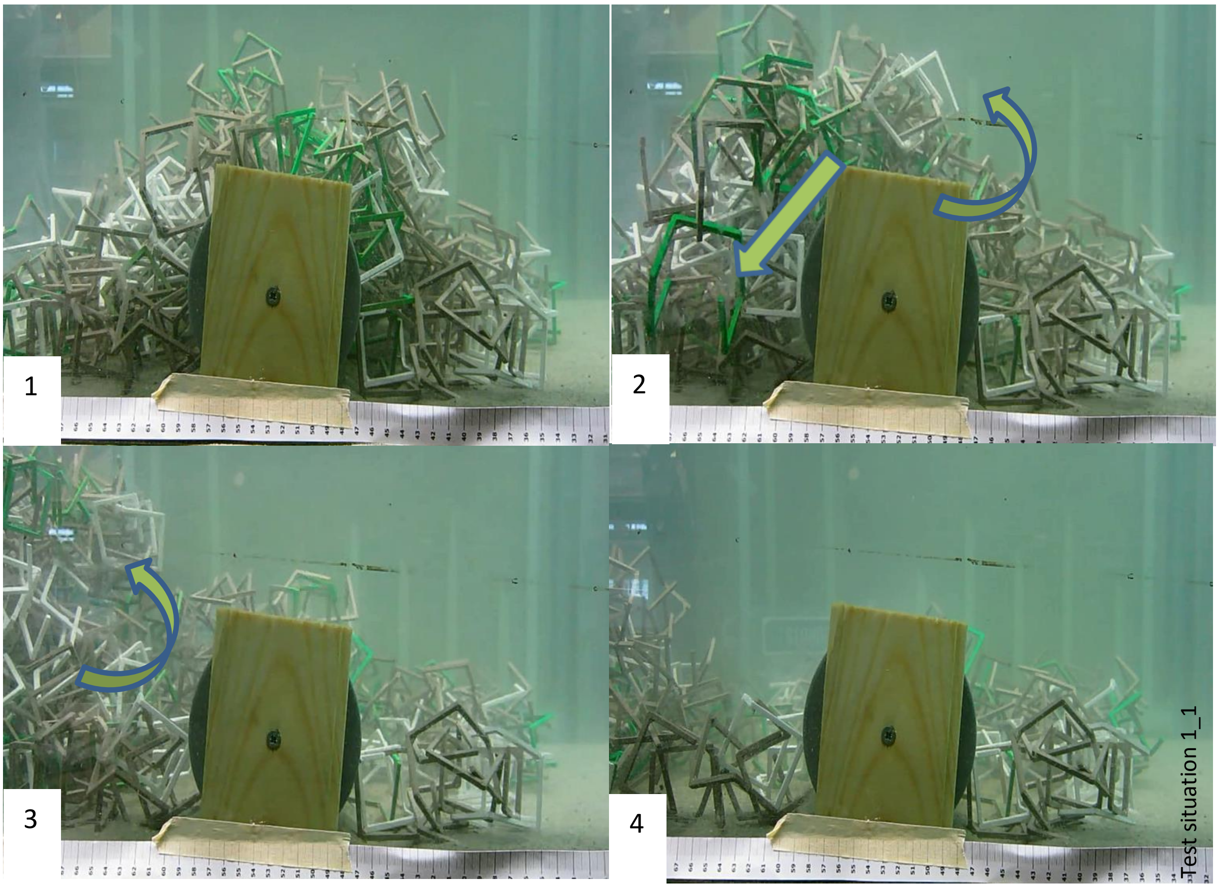
Failure mechanism

Based on the camera recordings, the observed failure mechanism for each situation will be described here. This will be done with a qualitative analysis, so the observed mechanism will be described with help of frames.

Construction situation 1

Based on the three tests that were executed with this situation, some similarities between the failure mechanisms were observed and will be analysed with the recordings from test situation 1.

Figure 77 shows the observed failure mechanism of construction situation 1. The batches that are situated on top of the pipeline start moving first at a current velocity of 0.33 m/s. They roll over the pipeline and pick up the interlocked GC's at the upstream side of the pipeline. This movement caused compression in the upstream mattress. Because of the compression the GC's tend to interlock. After the top batch is completely on the other side of the pipeline, the whole mattress washes away. This horizontal movement is accompanied with a rolling of the total mattress. This floating away of the complete mattress was observed at an average current velocity of 0.38 m/s.

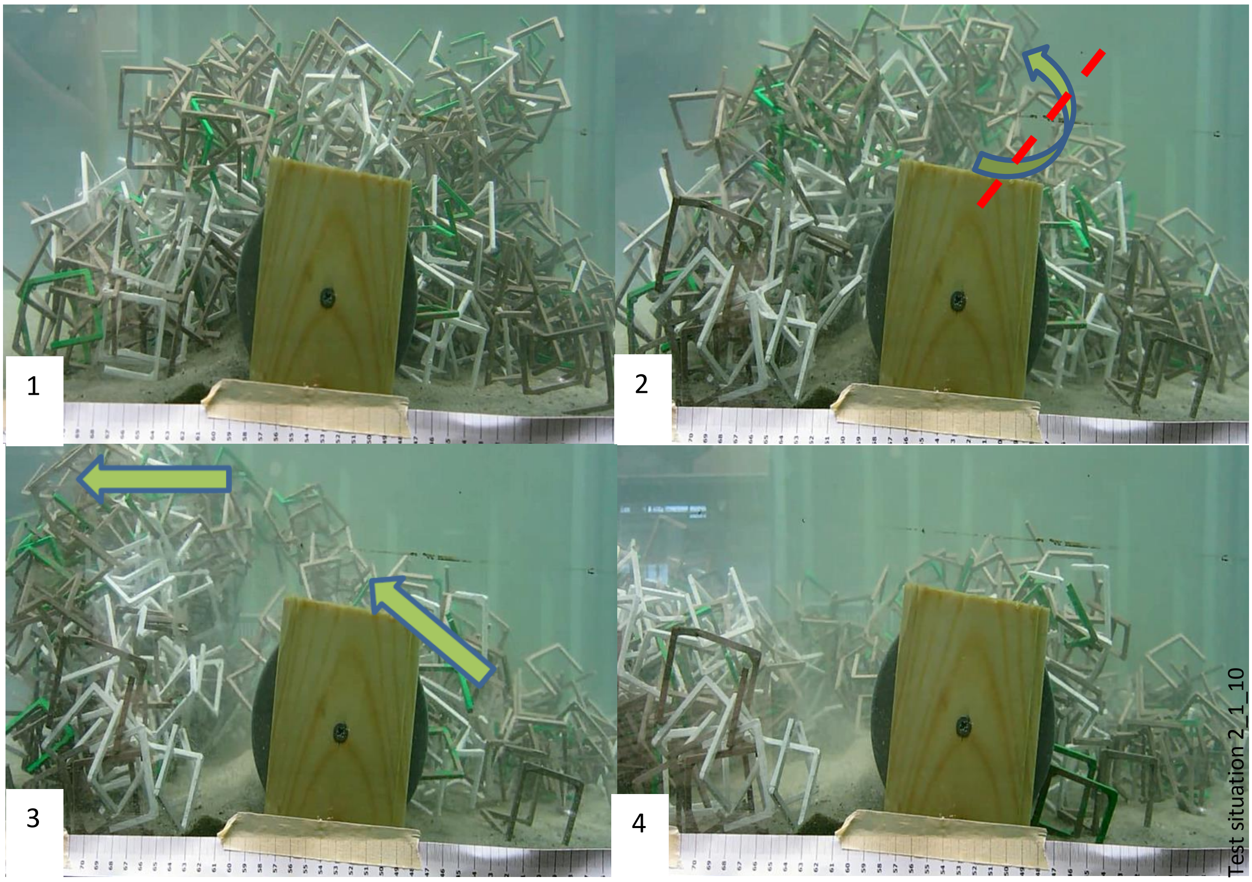


1. Mattress after construction.
2. Top batch starts moving and rolls over, compression in upstream batch.
3. Entire mattress interlocks and rolls over.
4. Final situation after instability, several GC's remain on the bed.

Figure 77 Failure mechanism observed at construction situation 1

Construction situation 2

Some similarities in failure mechanism between situation 1 and situation 2 occurred during the demolition phase of the experiment. The mattress started moving on top of the pipeline as well, but this time the top batch picked up a larger amount of strings at once from the upstream side of the pipeline. Similar to construction situation 1, the entire mattress rolled over and moved horizontally at the instability velocity. For situation 2 this instability velocity was about 0.4 m/s.

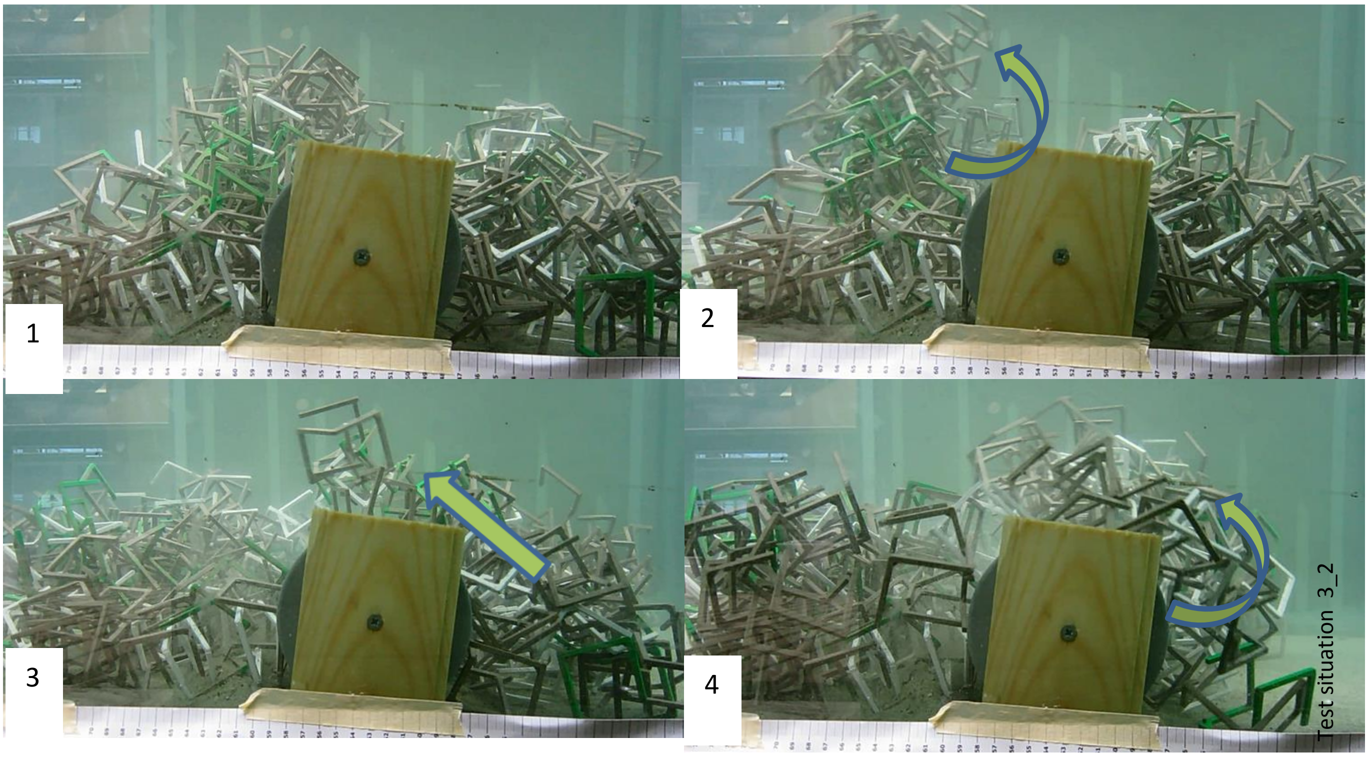


1. Mattress after construction.
2. Top batch starts moving and rolls over, gab emerges which divides mattress in 2 pats.
3. Mattress forms one peak that starts moving horizontally on top. Several strings a upstream side are picked up.
4. Final situation after heap is washed away, several GC's remain on the bed.

Figure 78 Failure mechanism observed at construction situation 2

Construction situation 3

Figure 79 shows the observed failure mechanism that occurred in all three tests with construction situation 3. If a heap near the top of the pipeline exists, the mattress starts rolling at that point and stabilizes again on the bed at the downstream side of the pipeline. After this stabilization, some GC's on the upstream side of the mattress starts moving over the pipeline causing the entire batch to roll over. This moment occurs at a current velocity of 0.44 m/s. After this moment, no upstream mattress remains.



1. Mattress after construction.
2. Downstream batch rolls over at a current velocity of 0.37 m/s. Downstream side stabilizes.
3. Upstream batch starts moving over the pipeline.
4. Entire upstream batch rolls over at a current velocity of 0.44 m/s. No upstream GC's

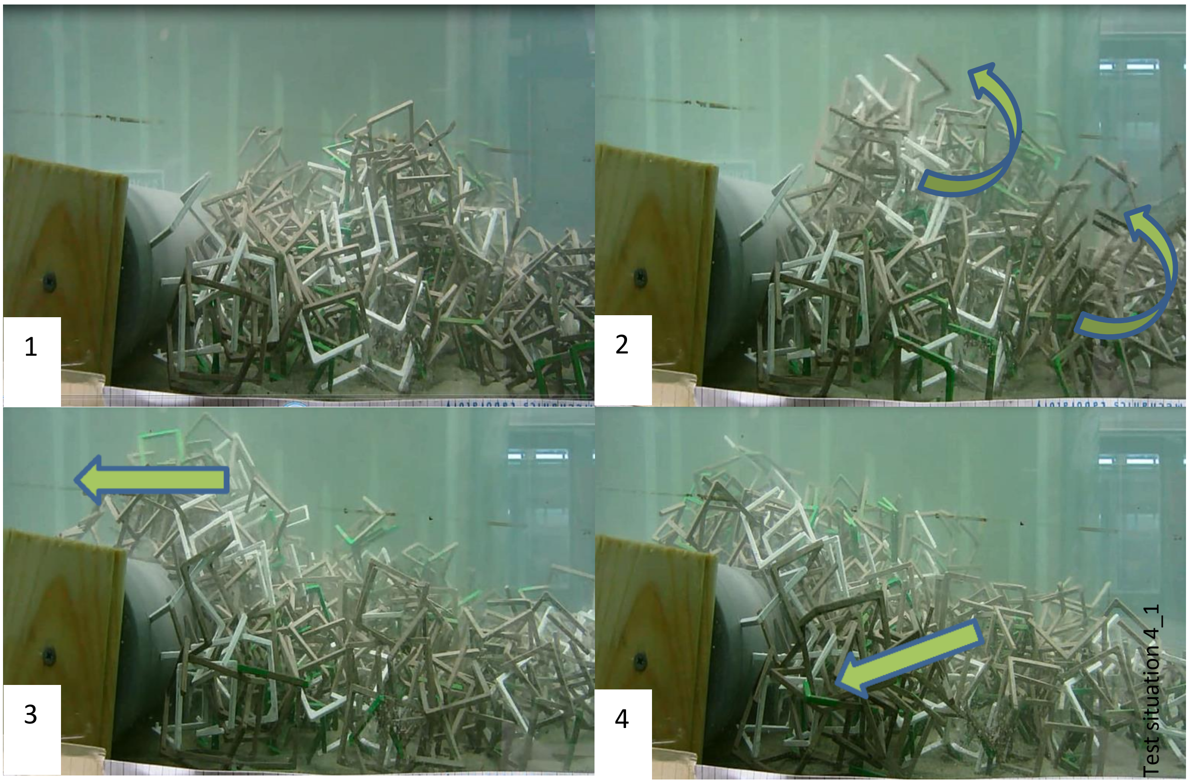
Figure 79 Failure mechanism observed at construction situation 3

Construction situation 4

Because situation 4 was constructed on the upstream side of the pipeline, the camera position at the side of the flume was moved. Therefore, the downstream situation was hard to observe from the camera recordings.

Again, situation 4 was tested three times. The following mechanism description is based on general observations of the three mechanisms.

The movement of the mattress started at the highest peak of the mattress, situated near the pipeline. This peak starts rolling over and falls over the pipeline. Simultaneously, the batch situated at the toe of the mattress starts rolling over as well. This batch interlocks again and stabilizes. Next, they move over the pipeline and stays in place. From that moment, the whole mattress moves in the current direction and compresses against the pipeline.

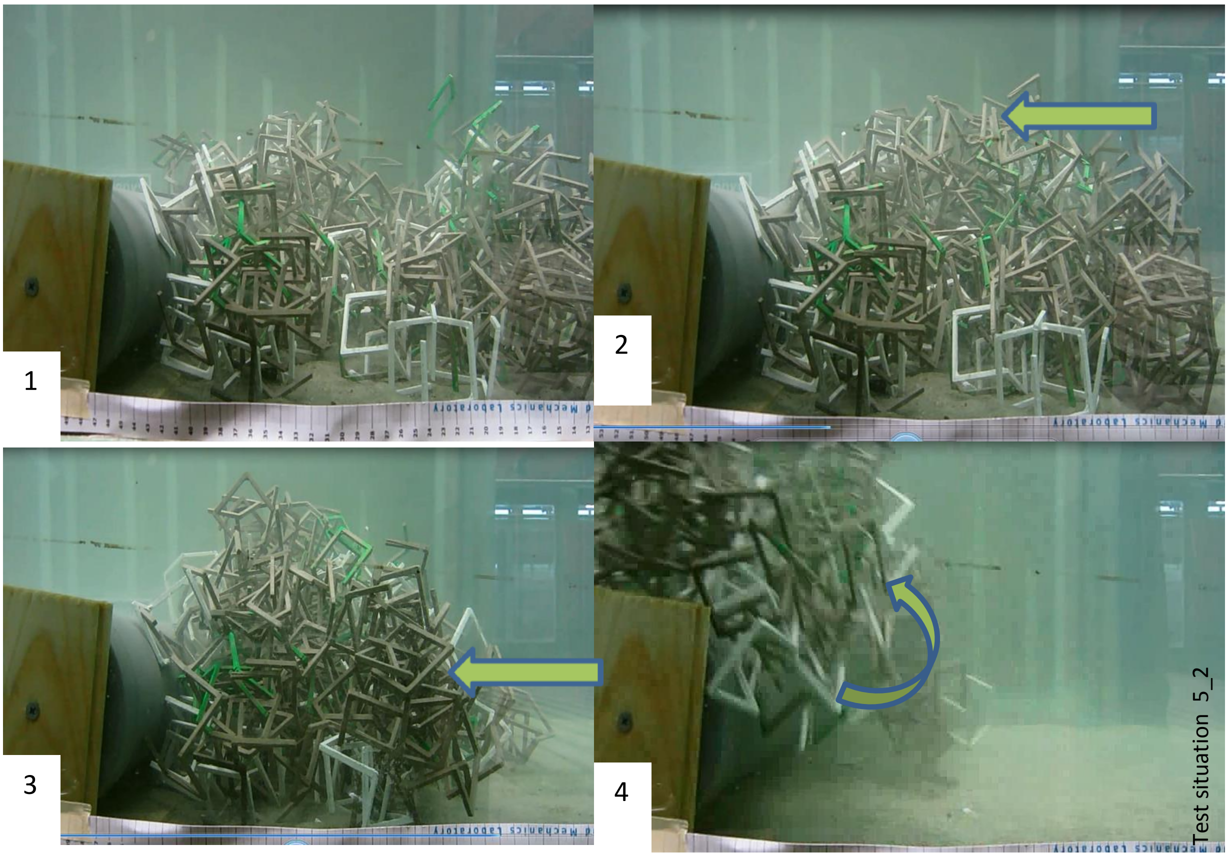


1. Mattress after construction.
2. Top batch and toe starts moving simultaneously at a current velocity of 0.48 m/s.
3. Several strings roll over the pipeline and stabilize at the downstream side.
4. Final situation, the upstream batch compresses against the pipeline.

Figure 80 Failure mechanism observed at construction situation 4

Construction situation 5

During construction, it was hard to position the top batches exactly on the batches below. Therefore, some gaps inside the mattress, between the batches, occurred. During the increase of the current velocity, these gaps disappeared. This started at a current velocity of approximately 0.49 m/s. After that, the whole mattress started to move sideways. This movement was stopped by the pipeline, so from that moment no major movements within the mattress were visible. Finally, during the instability moment, the entire batch rolled over the pipeline. Some loose GC's remained on the bed at the upstream side. Figure 81 shows the general failure mechanism that occurred in all three tests with situation 5.



1. Mattress after construction.
2. Gab between batches disappears.
3. Entire mattress compresses against pipeline. Width of mattress decreases.

Figure 81 Failure mechanism observed at construction situation 5

Conclusion

Based on volume properties, instability trajectory and instability mechanisms a conclusion can be drawn for which situation is the most suitable for making a mattress.

Based on observations from the failure mechanisms, the most important property that leads to a premature failure of the mattress (so before the toe starts rolling over) is both the height and the amount of peaks. When a peak exists within the mattress, this will become the first part of the mattress that starts moving, causing the entire mattress to follow because of the interlocking. Based on Table 31 and 32 it is clear that there are no significant differences between the different situations

First, the situations 1, 2 and 3 will be evaluated because these situations were tested where batches would also be dropped on both sides of the pipeline.
In situations 1 and 2, high peaks occur at the top of the pipeline compared to situation 3. Because of these high peaks, and the increased velocity on top of the pipeline, these situations have the lowest current of instability. This can also be observed in Table . Besides that, the trajectory of instability is must shorter for situations 1 and 2. So, once a GC's starts moving at the top, it pulls out the entire mattress causing a relative short compression time.

This means that it's important to avoid high peaks and unevenness in the mattress near the pipeline. When situations 1, 2 and 3 are compared, construction situation 3 results in the most stable mattress that can hold velocities up to 1.24 m/s.

When focusing on situation 3 it was observed that the positioning of the upstream batch was hard because of the increased currents around the pipeline and the limited falling height of the clamshell. This resulted in a gap between the pipeline and the mattress and an increased deviation of the mattress length. This can also be observed in Figure . This means the unloading of a clamshell, with a current of 0.21 m/s during construction in the upstream direction is much harder to design and to predict compared to situations 4 and 5, where the whole mattress was constructed in the upstream direction. This includes less accuracy around the pipeline and more heaps near the part with the highest velocity, resulting in a failure mechanism at that location.

When comparing situations 4 and 5 in Table 33 it is immediately clear that situation 4 and 5 have a larger velocity at which the mattress will become instable. The same holds for the moment of compressing. With this information it can be said that the length of the mattress in the current direction has an effect on the moment of instability.

Situation	First movements in experiment (m/s)	First movements at sea [1] (m/s)	Instability in experiment (m/s)	Instability at sea [1] (m/s)
1	0.33	0.93	0.38	1.07
2	0.37	1.05	0.40	1.13
3	0.37	1.05	0.44	1.24
4	0.48	1.36	0.55	1.55
5	0.49	1.38	0.58	1.64

[1] Based on the hydrodynamic scaling method described in appendix J

Table 33 Overview current trajectories at sea

When taking other aspects into account as the layer height, it can be seen that situation 5 has the least average deviation and therefore the least heaps inside the mattress. It can be concluded by this information that situation 5 is the best to use to make a mattress. In Figure 82 this situation is shown.

With this best situation for building the mattress the overall mattress on both sides with the required length can be made. Because the conclusion of these tests is that the batches should all be dropped on the upstream side of the pipeline. It is advised to build the mattress in the current direction, so when the tide turns and the current direction is directed to the opposite side the GC's should be placed on the other side of the pipeline.

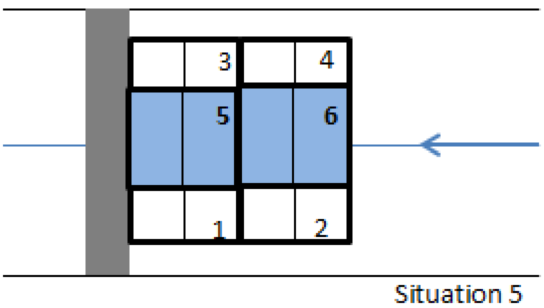


Figure 82 Situation 5

3.2 Pipeline with a free span

In this experiment, two situations were tested with a free span (see for the tested situations Appendix H). The pipeline got another mechanism to hold it into place. This mechanism created a free span of about a diameter in height.

Volume properties of the mattress

As for the first part of experiment the layer height was measured according to the experiment plan. Figure 83 shows both the average layer height and the standard deviation. The displayed error bar is based on a 95% reliability interval.

Figure 84 shows the total length of the mattress, measured along the axis of the flume. Because situation 1 constructed on both sides of the pipeline, this length is the summation of the lengths on both sides.

With help of these charts, the mattress volume properties can be evaluated. This will be done in the conclusion.

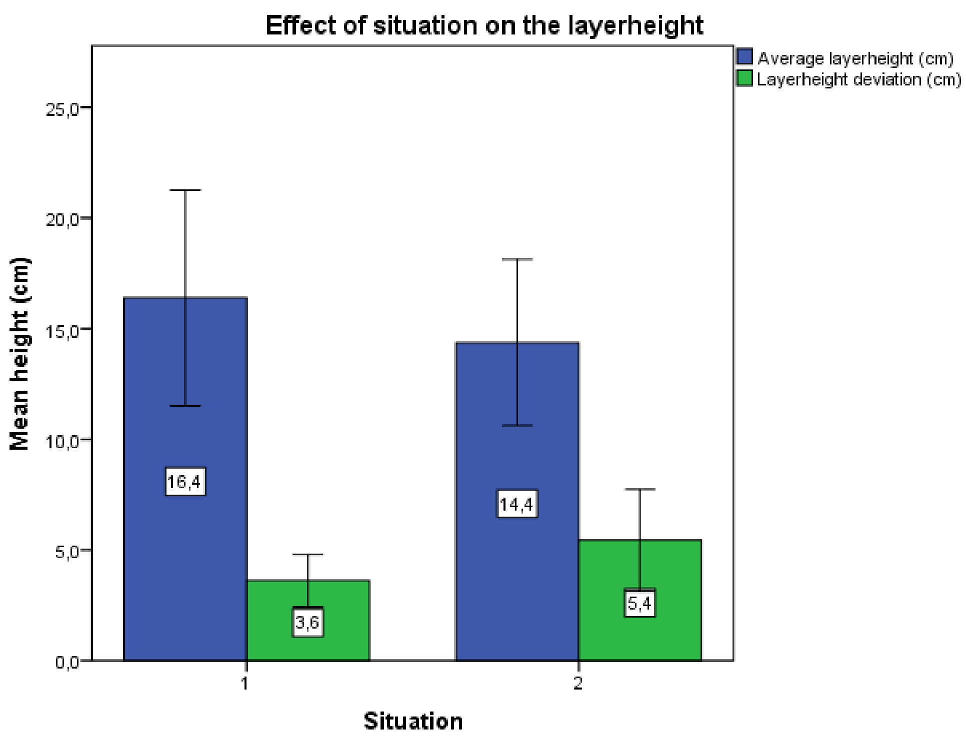


Figure 83 Effect of situation on the average layer height for situation 1 and 2 with a free span

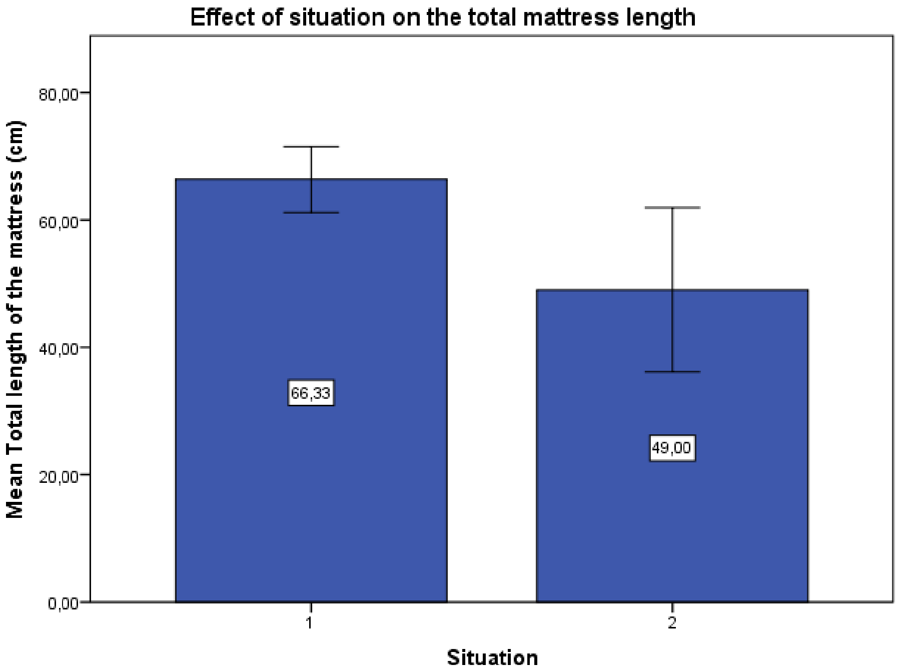


Figure 84 Effect of situation on the total length of the mattress

Instance of instability
As is described before, the instance of compression and instability will be calculated and analysed in the same manner.

Figure 85 shows the observed currents for the situations with a free span. To check the statistical significance of this result, a Mann-Whitney U test for independent samples will be executed. Table 34 shows these results.

Null hypothesis (H_0)	Significance	Decision
The distribution of the current at first movements is the same across the construction situations	0.2	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0
The distribution of the current at instability is the same across the construction situations	1.0	Significance level of 0.05; retain H_0 Significance level of 0.1; retain H_0

Table 2 Result Mann-Whitney U test

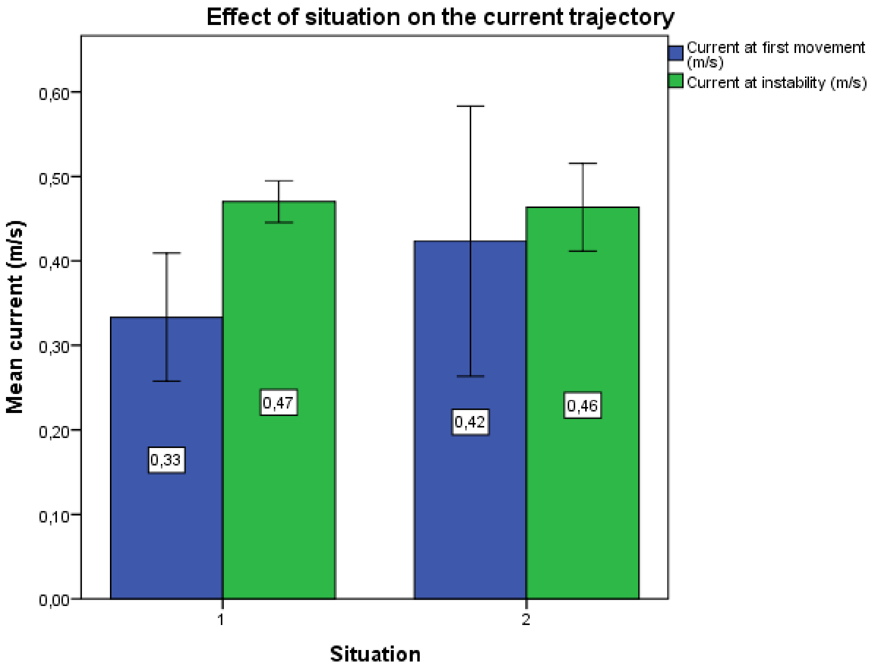
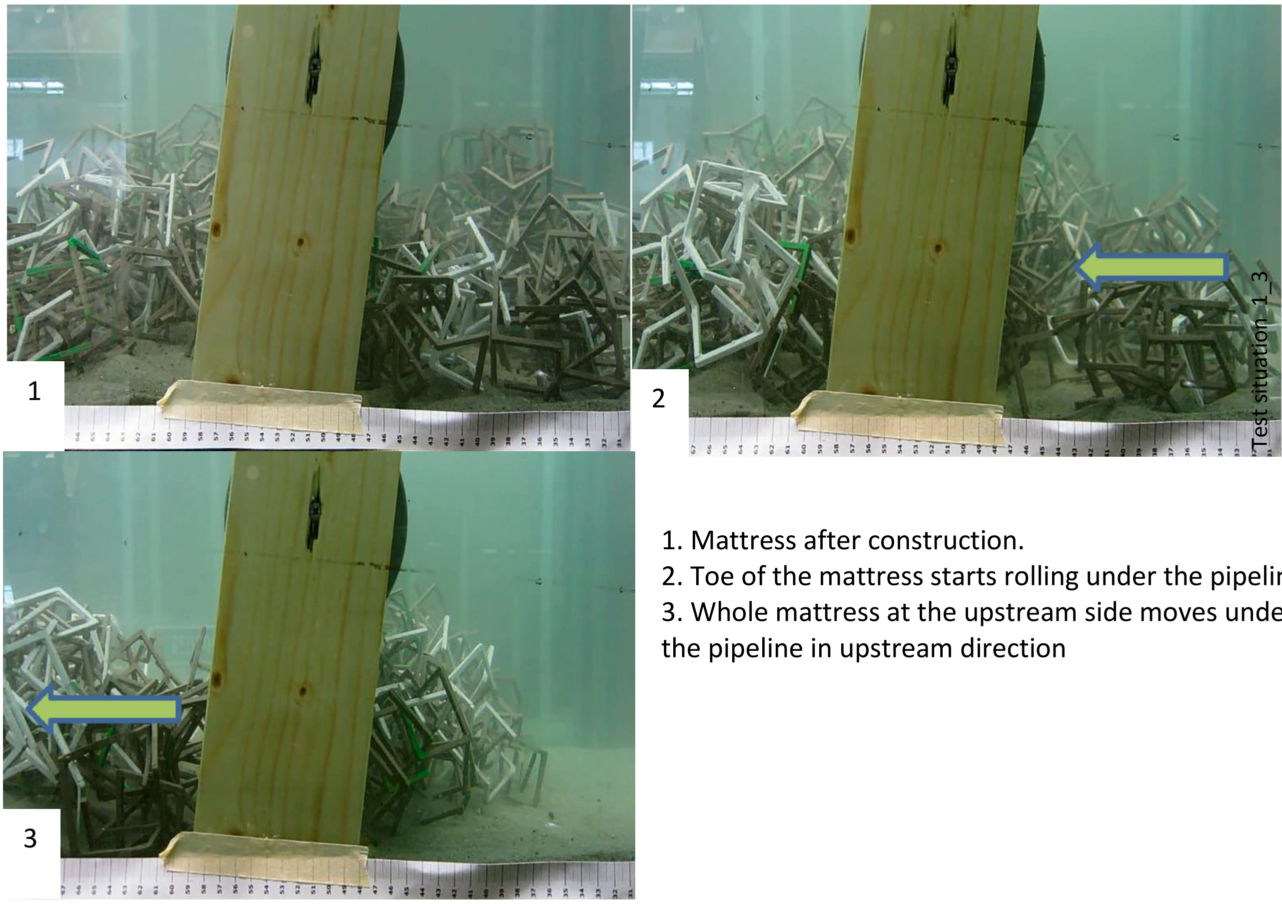


Figure 85 Effect of situation on the instability trajectory

Failure mechanism

The failure mechanism will be analysed in a qualitative way. Each situation was tested three times, so a general mechanism (based on general observations) is described here.

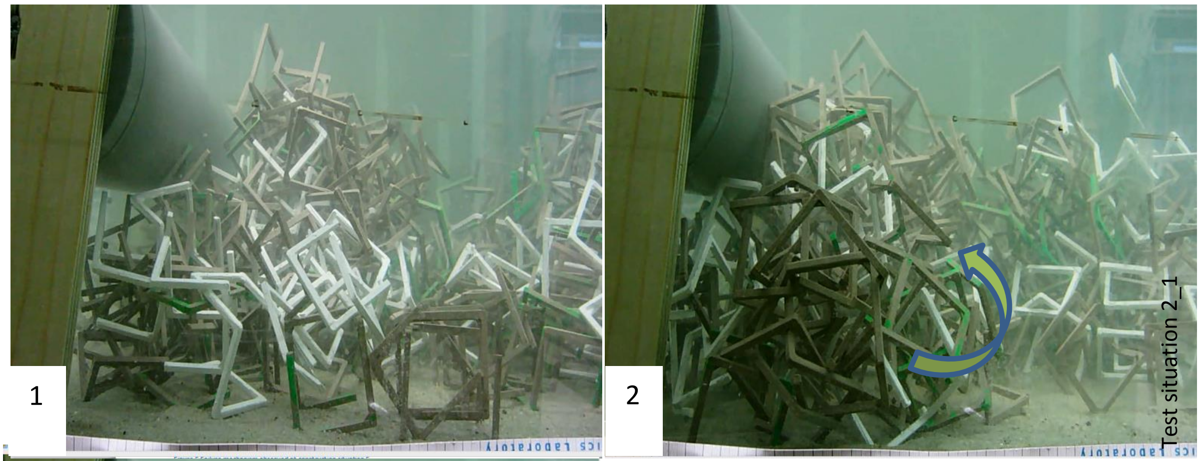
Construction situation 1



1. Mattress after construction.
2. Toe of the mattress starts rolling under the pipeline
3. Whole mattress at the upstream side moves under the pipeline in upstream direction

Figure 86 Construction situation 1

Construction situation 2



1. Mattress after construction.
2. Batch positioned at the side starts rolling under the pipeline.
3. Batch at toe moves towards the pipeline.

In this case the flume wasn't able to wash away the mattress.

Figure 87 Failure mechanism observed at construction situation 2 with a free span

Conclusion

Based on the failure mechanism it is observed that if a mattress reaches the pipeline it will stick to it and then it holds the entire mattress in place. Because of side effects, the batches on the left and right side of the axis that didn't reach the pipeline will start rolling under the pipeline. When an entire mattress doesn't reach the pipeline, it will float away horizontally under the free span.

With this information conclusions can be drawn concerning the best situation for building a mattress around a pipeline with a free span. In Table 35 the averages per situation are listed. With this table the differences are easily noted and the situations can be compared. First of all it is clear that the instability moments of both mattresses are almost the same. The only differences lay in the first movements. The mattress created on only one side of the pipeline compresses at a later stadium than when the two batches are placed on both side.

Situation	First movements in experiment (m/s)	First movements at sea [1] (m/s)	Instability in experiment (m/s)	Instability at sea [1] (m/s)
1	0.33	0.93	0.47	1.32
2	0.42	1.18	0.46	1.29
[1] Based on the hydrodynamic scaling method described in appendix J				

Table 35 Experiment results related to the currents at sea

Because both situation have the required properties in layer height and they also are both resistant enough against the current both situations would qualify for using in the real situation. So instead of using only one situation, the situations can be combined to a new situation.
This combined situation is shown in Figure 89. The situation can be extended on the up and downstream side of the pipeline until the required length of the mattress is achieved.

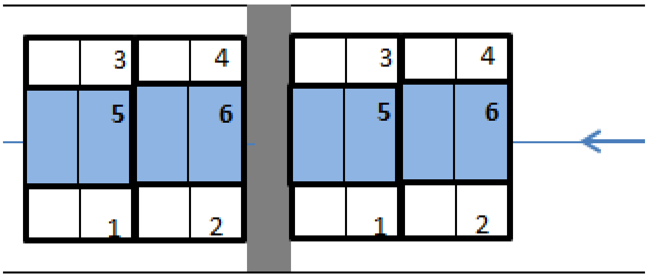


Figure 88 Combined situation 1 and 2

3.3 Comparison behaviour with and without free span

To compare both situations two subjects must be discussed, the instance of instability and the failure mechanism. In the conclusion of the situations with the free span both situation 1 and 2 came out as equally good. For comparison with the situations without the free span the values of situation 5 were used, because this one was laid on only one side of the pipeline, as it was the best situation without a free span.

Situation	First movements in experiment (m/s)	First movements at sea [1] (m/s)	Instability in experiment (m/s)	Instability at sea [1] (m/s)
Without free span	0.49	1.38	0.58	1.64
With free span	0.42	1.18	0.46	1.29
[1] Based on the hydrodynamic scaling method described in appendix J				

Table 36 Comparison with and without a free span

As can been seen in Table 36, the situation without a free span is much more stable. This is easily explained. The mattress will be pushed by the current horizontal towards the pipeline. When the pipeline lies on the sand bed the mattress will be pushed in the corner of the pipeline and the sand bed, where it will lie stable until the current velocity reaches a value of 0.58 m/s which is equal to a velocity of 1.64 m/s in the Waddensea. When no major heaps occurred after construction, the mattress won't roll over but compresses against the pipeline. When the compression reaches a maximum, the toe starts rolling over.

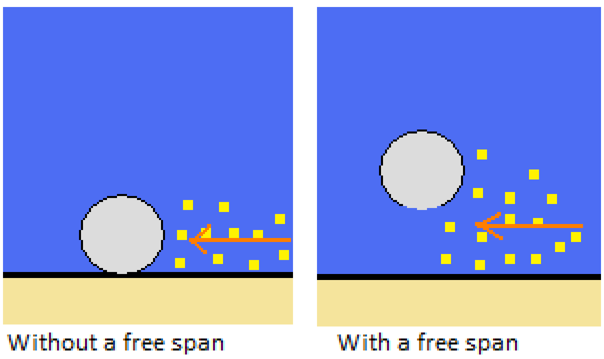


Figure 89 Effect of currents on mattress around the pipeline

But when the mattress is pushed by the current when there is a free span the batch will stick to the pipeline for a while, but when compressed the batch will just slide under the pipeline. This will happen with a velocity of 0.46 m/s which is equal to a velocity of 1.29 m/s in the Waddensea. This effect is shown in Figure 89.

With this knowledge it can be concluded that a mattress will be more stable around a pipeline without a free span.

4. Additional observations

- During the experiments, the positioning of the batches tend to be hard because of the current velocity during construction. Especially the top batch and the batches situated at the downstream side of the pipeline were hard to position in the right place. Therefore, the eventual mattress didn't quite correspond with the theoretical mattress plan in most cases, which made it hard to design the mattress properly.
- When the batch on top of the pipeline was positioned, the clamshell hits the pipeline and wasn't able to open it properly. The clamshell was lifted 0.1 m in that case.
- During the increasing of the current velocity, the water table reached the maximum possible height, where the flume started to flood at the inlet position. In that case, it wasn't possible to wash away the mattress.
- With the amount of GC's available in this experiment it wasn't possible to get a layer height that exceeded the height of the pipeline with a free span.
- The sand layer under the pipeline washes away during the experiment. A large gap occurred under the pipeline. After each experiment, the sand layer had to be evened.

5. Hypotheses and conclusion

The hypotheses made for this experiment are listed below.

8. Before reaching the point of instability, the loose elements will start to move, but this will result in a higher density of the mattress. This is because the loose elements will interlock after all with the mattress.
9. When starting to build the mattress it is always necessary to start building on the upstream side, therefore the increased and difficult flow over the flume and under won't have any influence on the mattress. The rest of the mattress can be build supporting on this first stable part and the pipeline.
10. The batches need to be placed in two layers to reach the desired height.

In answer to the question if the hypotheses are true:

1. From the results from this experiment this hypothesis can be stated true. For this behaviour a term is developed in the results, the instance of compression. Because in every footage it was shown that loose or small strings will compress into the larger batches if they fall out at the downstream side. Because of the decompression and these loose elements hitting the mattress at upstream positions, the density will probably increase.
2. From the results of the analyses with and without the free span it can be concluded that this is also true. Every situation should be built from the upstream side of the pipeline. Because the mattress will find stability on the pipeline. From then on other batches can be laid against those, upstream from the first batch.
3. The desired height for the mattress is in real life 1 m, so scaled to the experiments this will be 0.125 m. This could be reached with only one batch. However a second batch must be placed on top of the first batches not to guarantee the desired height, but to guarantee the interlocking between those batches and therefore the stability of the mattress. This is because some gaps can be found in between the batches. When constructing near a free span, the height of the mattress much reach the top of the pipeline to prevent the mattress from moving entirely under the pipe.

Another conclusion that can be made is that the situations without batches on top of the pipeline (situation 3) as well as the situations with the free span, the reached velocities at the moments of instability and compression are way higher than the highest velocity in the Waddensea. At spring tide the velocities will reach a value of 1.1 m/s and this is lower than the moment of compression in these tests. Therefore the mattress will be stable at the velocities of springtide at all time.

6. Discussion

- Because the flume was not that wide there were some side effects around the pipeline and the sides of the flume. Here the velocity of the current was much higher than average in the flume. Therefore the falling position were somewhat higher than calculated.
- Because in some tests the mattress couldn't be washed away because of the flume capacity, the maximum current velocity in the flume was described. This means the mattress wasn't instable at that velocity, so in fact the exact moment of instability is still unknown. In two tests (total performed tests with situation 4 and 5 was six), this was the case. This means a conservative influence on the average values.
- In the first part of the experiment where the pipeline was positioned directly on the sand bed. However the current underneath the pipeline was so strong the sand would drift away in this current, so an area eroded between the pipeline and the sand bed. The current would float through there with a higher velocity than above the pipeline and some of the GC's on the downstream side of the pipeline would be a little influenced by this current.

Appendix J. Hydrodynamic scaling

1. Introduction

The main goal of this project is to get insight into the behaviour of GC's under water, to evaluate if the GC's can be used as a construction to protect a pipeline with a free span in the Waddensea. For this goal, some simulations will be executed in the laboratory for fluid mechanics. While doing these tests, the natural conditions that will occur in the Waddensea must be scaled in such a way that the conditions in the experiments are similar to the condition in the sea. This appendix explains more about the used (hydrodynamic) scaling method.

2. Scaling

In the experiments the GC's have dimensions of 0.05 x 0.05 x 0.05 m^3. The GC's that will be used in the Waddensea project are larger, with dimensions of 0.4 x 0.4 x 0.4 m^3. This means a linear scaling with factor 1:8 will be used, because the ribs of the GC's in the experiment are eight times smaller. For similarity between the current condition in the flume and the current condition in the Waddensea, the Froude number is used.

The Froude number is defined as follows:

$$Fr = \frac{U}{\sqrt{g \cdot d}}$$

In which:

Fr = Froude number	[-]
U = current	[m/s]
g = gravitational acceleration	[m/s²]
d = length of object	[m]

The Froude number for the natural conditions must be equal to the Froude number in the flume, so:

$$Fr = \frac{U}{\sqrt{g \cdot d}} = \frac{U^*}{\sqrt{g \cdot d^*}}$$

In this equation, the parameters for the flume are marked with a '*'.

The current in the flume, U* can be calculated with:

$$U^* = U \cdot \frac{\sqrt{g \cdot d^*}}{\sqrt{g \cdot d}}$$

The linear scaling of 1:8 shows that:

$$d = 8d^*$$

This means for the current velocity in the flume:

$$U^* = \frac{\sqrt{10 \cdot d^*}}{\sqrt{10 \cdot 8d^*}} \cdot U = \frac{\sqrt{10}}{\sqrt{80}} \cdot U \approx 0.354 \cdot U$$

Thus, a scaling factor of 0.354 must be applied to simulate the natural current conditions in the Waddensea.

Table 37 shows scaled currents that will be used in the flume.

Natural current [m/s]	Current used in Experiment [m/s]
1.1 (spring tide)	0.39
0.2 (high water level)	0.07

Table 37 Natural and experimental currents

Appendix K. Properties of the clamshell and the GC's

1. Ground consolidators

The basic shape of a GC is displayed in Figure 90. It exists out of seven ribs of a hollow cube. On it's own it doesn't do much, but put thousands of these elements together and an entire mattress can be built. This mattress can provide a whole new method for ground- and pipeline protection. Instead of the commonly used gravel. Gravel has disadvantages as it is just a temporarily solution to the problem, because of the high possibility of erosion of the underlying sand caused by high current velocities and turbulence. Therefor is the solution with GC's invented. The GC's will provide a stable mattress surrounding the area that needs protection. The current in the water will flow through the mattress because of all the small, open spaces in the mattress. The current will lose its large velocities in the mattress and therefore won't disturb the underlying area. The area needed protection won't be affected.

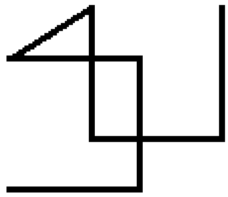


Figure 90 Basic shape GC

This new invention is still in its early stage of development and therefore hasn't been used as a real solution to a problem. Because of this, experiments must be done to prove the usage of these elements. First, experiments will be done to evaluate the execution method in the laboratory for fluid mechanics at the TU Delft. From the information received, experiments will go further at Deltares.

1.1 GC's used at the TU Delft experiments

The GC's used in experiments at the TU Delft were scaled versions based on the real GC's. When used at sea the GC's will have an outer dimension of 0.40 x 0.40 x 0.40 m³. In the experiments in the laboratory for fluid mechanics a version with scale 1:8 is used. This means they have outer dimensions of 0.05 x 0.05 x 0.05 m³.
The GC's were based on the GC's used in the beginning of the project, with square ribs, as shown in Figure 91. The GC's were injection molded and made out of one piece.

Figure 91 GC used at the TU Delft

Because the experiments were extended to make sure the mattress would consists out of one big batch of GC's instead of different heaps the batches of GC's that were dropped in the water needed to be checked on interlocking. This could only be done when there was a clear difference to be seen between the batches. Therefor the different batches got different colors (white, green and the original brown color). This is shown in Figure 92.

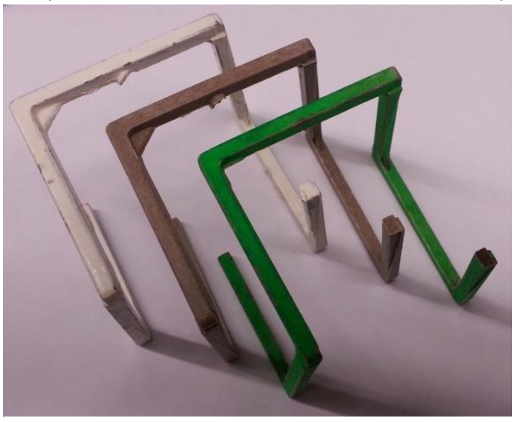


Figure 92 Three colors GC's

The green ones were painted with a very light spray paint and therefore they had the same properties as the brown ones. The white ones however were painted with a much heavier, synthetic paint so there properties did in fact differ from the brown and green ones. As shown in Figure 92, the rib thickness of the white GC is larger than the brown and green one, because a quite large layer of paint is set on the GC.

	Mass [g]	Volume [m³]	Density [g/m³]	Standard Deviation [%]	Max. too light [%]	Max too Heavy [%]
Brown GC	9.432	6.60	1.470	1.096	-7.2	0.6
White GC	10.181	7.15	1.488	1.046	-6.0	1.8

Table 38 Properties GC at the TU Delft

In Table 38 the properties of the used GC's at the TU Delft are shown. It is clear that the white GC's are heavier. The properties are based on an average of 40 brown GC's and 40 white GC's. The mass was measured on a very accurate scale. The volume was measured by putting the GC's in an accurate measuring cup and calculate the differences in the water volume. The density was calculated from these tests by dividing the mass by the volume.

Figure 93 Effect of injection molding method

All the GC's were started as the GC on the right in Figure 93. After a while, some changes on the ends of the GC's were observed. All the edges started rounding, as shown on the GC on the left in Figure . Because of the biodegradable material, this effect is probably caused by composting of the material. The GC's were lifted and dropped back into the water several times a day, so the water and air concentrations inside the material changed constantly, helping the bacteria's to grow and feed from the natural material.

The construction process of the GC's is based on injection molding in one piece. Therefore, it is stated that the material couldn't reach to outer edges results in the observing of this effect on the edges of the elements. This resulted into a hollow structure near the edges, making it easier for the water and the air to get inside.

This problem influenced the weight and volume of the GC's which caused the deviation and change that a GC was too light. Besides that, the interlocking behavior was effected as well because some ribs were only half of the regular size.

1.2 GC used by Deltares

The experiments done by Deltares will be based on the results of the experiments at the TU Delft. A scaling factor of 5.25 will be used here. In these experiments, the scaled GC's will be based on the latest design of the GC's. This design will probably be used in real conditions when making the mattress at sea.

This design is based on two different rib orientations that will be stabilized by extra brackets to guarantee extra stability. These extra brackets form a truss structure, as can be seen in Figure 94 (Pezi product innovation). The GC's are made out of Ubrackets and Ibrackets. The Ibrackets are used as a connection element between the Ubrackets.

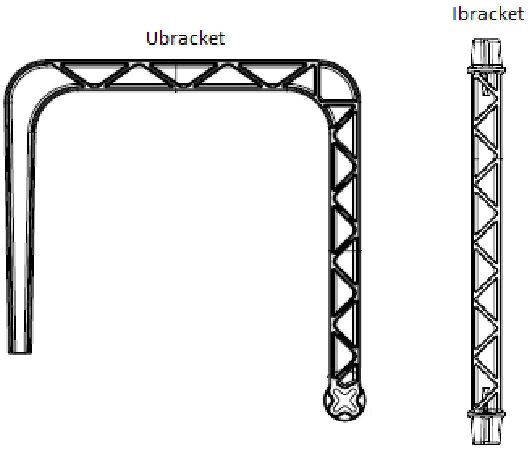


Figure 94 GC's used by Deltares

Because of the limitations of the injection molding machinery, it isn't possible to scale the truss structure properly with the scaling factor of 5.25. Because this results in an increase of the weight of the GC, the density must be lowered (compared to the real scale GC) to compensate the effect on the eventual behavior.

In Table 39 the properties of these GC's are listed. The GC's used by Deltares are scaled with a factor 1:5. This means the volume and the mass would be higher than of those used in Delft. The density should be almost the same. But as one can be see, the density by the ones used by Deltares is somewhat higher than the GC's used in this BSc thesis project. This is because of the extra brackets used in the new design.

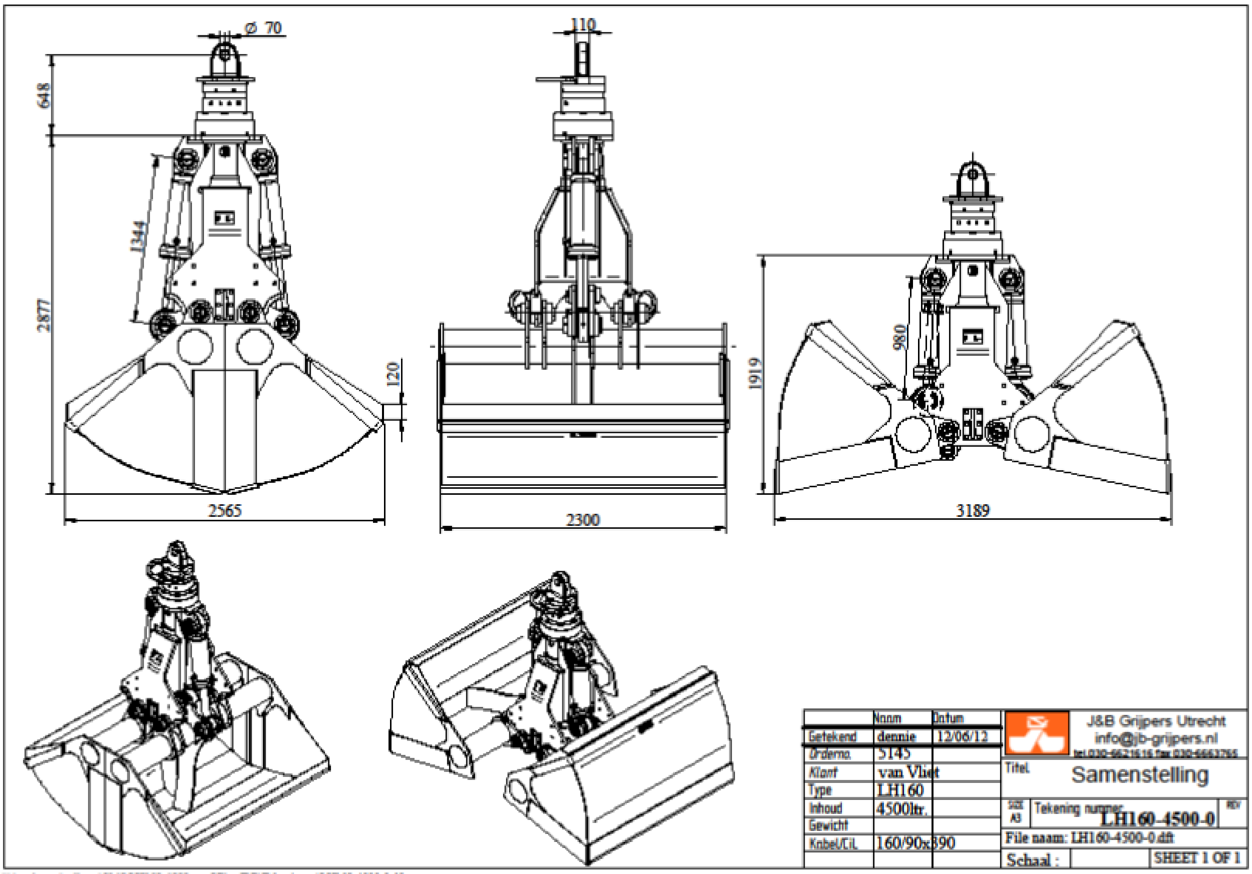
	Mass [g]	Volume [m³]	Density [g/m³]	Max. too light [%]	Max too Heavy [%]
GC8 Density 1.50	10.41	6.94	1.50	-5.3	2.6
GC8 Density 1.52	10,56	6,94	1,52	-3.9	4.1

Table 39 Properties GC's used by Deltares

2. Clamshell

2.1 Real size clamshell

For dropping batches of GC's in the water some execution method must be developed so a stable construction can be created. The solution was to use a clamshell with an open top so the GC's could be placed inside in the specific order. Than the clamshell can be lowered in the water and be hold steady at the right place to drop the GC's. The clamshell used for dropping the real size GC's into the water is basically a hydraulic clamshell with two rotating centers. See for a detailed drawing Figure 95 (J&B Grijpers Utrecht). This clamshell was used by the tests at Van Vliet in Amsterdam, for dropping batches in the dry.



X:\projecten\grijpers\5145 LH160-4500 van Vliet (DJ)\Tekeningen\LH160-4500-0.dft

Figure 95 Detailed drawing clamshell

The used clamshell wasn't optimized for the handling of GC's. In Figure 96 (Witteveen + Bos, Memoradum results GC drop tests, 2013) the experiment in Amsterdam is shown with the clamshell. This clamshell had extra ribs in the containers on which the elements would hook and by which the GC's were influenced on their way out. They would just hung on the container and wouldn't come out as one batch. These ribs were over the entire width of the clamshell and also there were ribs vertically that were there to bring extra stability to the clamshell.

Figure 96 Clamshell used by experiments Van Vliet

In the method statement, it was stated that about 300 GC's could fit in the clamshell with a volume of $4m^3$ (Witteveen + Bos, Method Statement remediation of frees span with GCs, 2013). The density of this clamshell will be 300 / 4 = 75 GC/m^3 in that case.

2.3 Clamshell used at the TU Delft

The clamshell for the experiments at the TU Delft was based on the real clamshell. Because the containers needs to be smooth so there won't be any influence of ribs or other things in that matter, the clamshell was created out of wood and Plexiglas. As seen in the experiments by Van Vliet this was a necessity to apply on the scaled clamshell. The clamshell was also scaled with the same factor as the GC's, so 1:8. The results can be found in Figure 97, which also displays the associated dimensions.

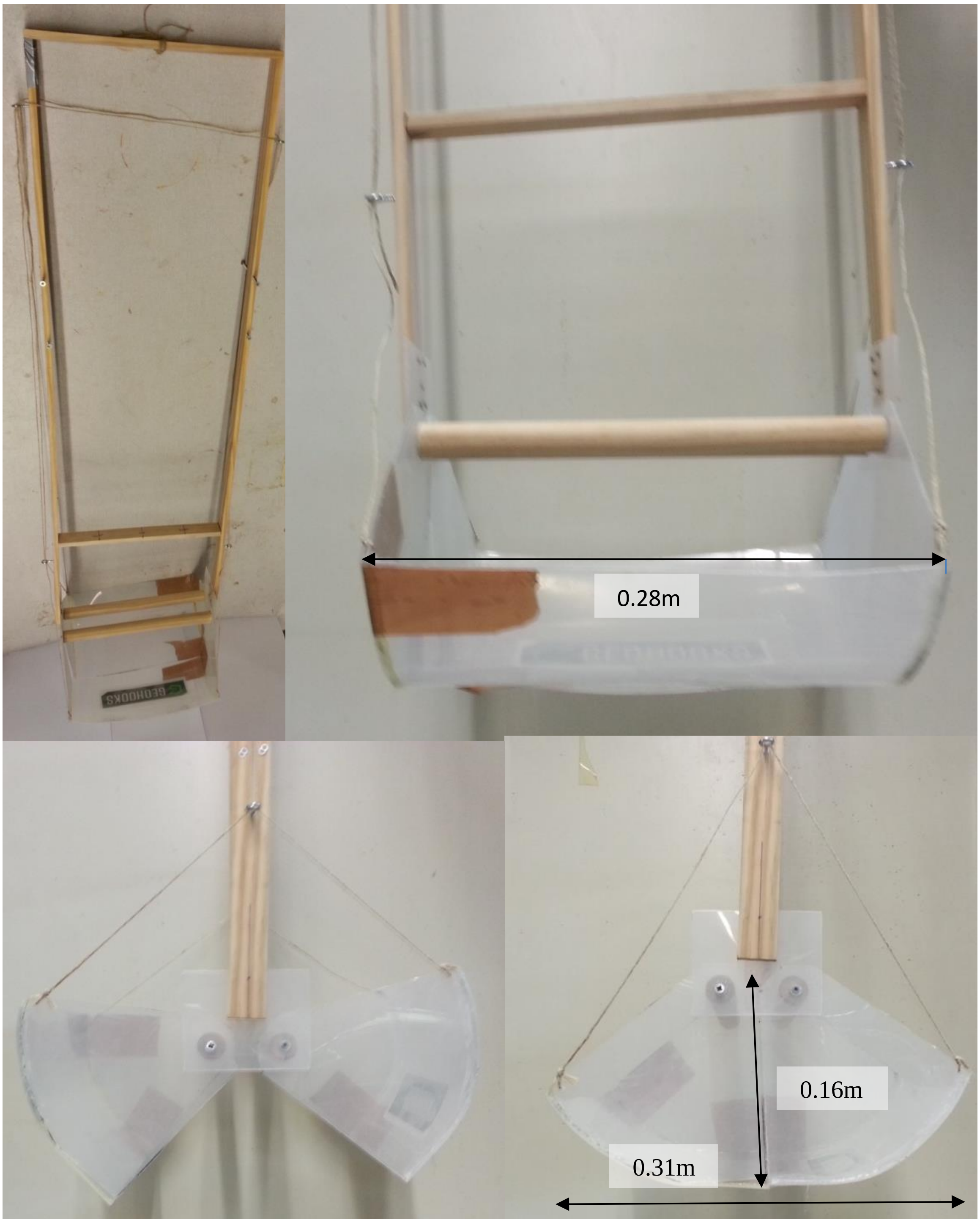


Figure 97 Properties of the clamshell used at the TU Delft

This clamshell has, as can be seen, smooth containers. Also the rotation centers were scaled to the right size. The internal volume of the clamshell is calculated as follows:

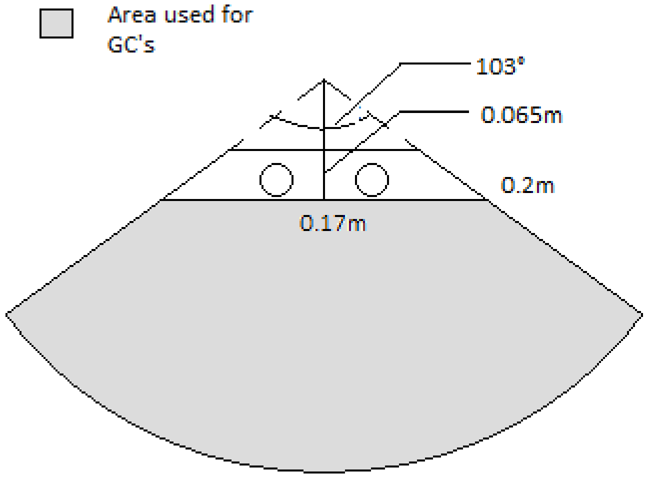


Figure 98 Calculation of the volume of the clamshell

In Figure 98 the area of the side of the clamshell used for filling the GC's is displayed.
With the equation to calculate the surface of a circle and the equation to calculate the surface of a triangle the surface of the used area for GC's can be calculated.

$$Acircle = \pi r^2 \ (1)$$

$$Atriangle = \frac{1}{2} \cdot h \cdot w \ (2)$$

The rewritten calculation for the grey surface will be:

$$A = \frac{103}{360} \cdot \pi \cdot r^2 - \frac{1}{2} \cdot h \cdot w \ (3)$$

With the values:

r = 0.2m
$h = \frac{\frac{1}{2} * 0.17}{\tan\left(\frac{1}{2} * 103\right)}$ = 0.07m
w = 0.17m

So when solving equation (3), A would be: 0.03 m².
So the entire volume of the clamshell will be the area multiplied by the length of the clamshell, which is 0.28m. So the total volume would be: $8.41*10^{-3}$ m³.

When using 60 GC's the density is 60 / $8.41*10^{-3}$ = 7134.364 GC/m³. This is the density of the scaled GC's. Scaled to the real size GC's, the density would be 7134.364 /8^3 = 13.93 GC/m³.

When comparing this to the real size clamshell this seems like a very low density. When the volume of the scaled clamshell is scaled back to the real size, the clamshell would have a volume of $8.41*10^{-3} * 8^3$ = 4.36 m^3. When the volumes of the scaled clamshell and the real clamshell (volume = 4 m³) are compared it is clear that they are almost the same. This means that the scaled clamshell can indeed hold as many as 300 GC's in the clamshell. From tests it is clear that how higher the density in the clamshell the higher the density of the batch on the sand bed. This however is not proven to be realistic, because when large amounts of GC's are placed into the clamshell and are than dropped, the GC's will stick on the edges and the strings of the clamshell.

Appendix L. Process report

1. Introduction

This report shows the process of this BSc project. The main objective of this report is to display the steps that were taken to get the end results and to give some tips and tricks for future experiment executions.

2. Daily processes

The following table shows the daily process within this project. Only the dates from actual experiment execution are elaborated. All the information is based on the experiences gained from the long research flume in the laboratory for Fluid Mechanics at the TU Delft.

Date	Activities	Evaluation
12-9-2013	Instructions of the flume and the laboratory by Jaap van Duin.	- The Lab Manual was handed over and the importance of safety was made clear by Jaap. Always wear safety shoes (they can be borrowed from the TU Delft for free). - The pumping chamber can be used without assistance. The lab personnel will connect the pipes to the flume and show the on/off button on the switch panel. The pumps can adjust themselves according to the demand of the flume. For this experiment, the pumps in ring one were made available.
13-9-2013	Preparation for the experiment were set up.	- First, the side windows of the flume were cleaned by hand. This was done on the wrong side of the flume, too close to the inlet. Always make sure the experiment setup is located far away from the inlet to prevent the influence of turbulences (in this case approximately seventeen windows from the inlet) on the results - Secondly, the sand layer was constructed on the bed of the flume. This was done by assembling two wooden slats on the bed. Because of the water, the wood will expand. Therefore, always design the slats with a tolerance to prevent the window from breaking. When placing sand in the flume, always ask someone from the staff to operate the cranes. They can position a container near the flume, so the transferring of the sand will be more comfortable. - To clean the windows of the flume it is advised to first flush the flume with a high velocity before placing the sand layer. In this experiment it was too late to start flushing. - In this project, much time was spent on creating the equipment out of wood. There is a sawing department located below the laboratory, but with limited opening times. It is advised to first look around in the laboratory to check if the materials and equipment available (from previous experiments) can be used for your needs. Instead of making your own construction which takes a lot of time and in the end wouldn't be used at all.
16-9-2013	Preparation of the experiment setup, first experiments	- Some changes were made on the equipment. The fixed camera positions were installed and placed along the flume. The TU Delft only had one simple video camera available. The underwater camera was placed on the bed of the flume.

		- The pumps were started for the first time. Because this was done too quickly, the sand layer started washing away, making the water muddy and resulting in decreased sights on the camera recording. It is advised to first close the outfall of the flume, than to place the bulkheads at the end and only then to open the inlet slowly (up to 25 dm^3/s). This will result in a homogeneous filling of the flume. After the water table is at the desired height, the outfall can be opened and the current velocity can be increased.
17-9-2013	Experiment 1	- Several tests were performed today. Because of the large amount of GC's in the clamshell, a sorting table was created to sort the strings after pick up. This sorting table consists out of a grid made taped onto a table. - The flume can be used overnight, but the pumps must be switched off, so only still conditions can be tested. In this experiment, the flume was always emptied to make sure the water could deposit inside the tanks.
18-9-2013		No experiment were performed this day
19-9-2013	Experiment 1	- Today, the first tests with a current velocity in the flume were performed. The laboratory personnel can help to adjust the flow measurement instruments along the flume. There is software available on the computer at the flume to write this data to a file. The personnel can give a quick start on this. - At first, the scaling was forgotten, so the tests were performed at a current velocity of 0.3 m/s. This caused the GC's to simply wash away before hitting the bed. Therefore, the influence of scaling came to mind. In this case, the Froude number was used. The factor between the current at sea and the current in the flume is approximately 0.354. - The flow measurement instrument at the inlet isn't accurate because of the wrong assembly on the inlet pipe. The sonar couldn't develop in a right way. The results can only be used to get the same conditions in the flume as the day before.
20-9-2013	Experiment 1	Several experiments were done. The cycle time of experiment 1 is optimized to approximately 10 minutes by a better task division and some increased skills on the untangling of the mattress.
23-9-2013	Experiment 1	
24-9-2013	Experiment 2	- Because the flume had no weir, the water table height was set by some wooden planes at the end of the flume. There are only some standard planes available, it is important that the desired height of the planes is calculated before the current starts. When the current is present, it's not possible to remove the planes.
25-9-2013	Experiment 2	- To ease the empting of the flume a new method was invented. When the flume is still operational, the outfall was closed, so the water table at the end of the flume increased. Once the water table was even on both sides of the weir, the wooden planes were simply lifted due to buoyancy. After the

		planes were removed, the outfall was opened again to empty the flume.
26-9-2013	Presentation and experiment 2	
27-9-2013	Experiment 2	- Based on the pictures used in the presentation, Dirk advised to improve the quality of the camera recordings. This is implemented by creating a container around the camera position on the side of the flume. This resulted in a decrease of reflection from the lights at the ceiling and from the daylight from behind the camera. Also, a black plane was positioned on the back of the flume, so the lights on the opposite side wouldn't shine through.
30-9-2013	Experiment 2 and 3	
1-10-2013	Experiment 3	- It is logical that the water table rises when the current velocity is increased. The maximum possible water table is around 0.9 m in height. At that point, small waves starts coming over the inlet position of the flume.
2-10-2013		No experiments were performed this day
3-10-2013		No experiments were performed this day
4-10-2013	Experiment 4	
7-10-2013	Experiment 4	
8-10-2013	Experiment 4	
9-10-2013	Experiment 4	
10-10-2013	Experiment 4	
11-10-2013	Experiment 4	
14-10-2013	Experiment 4	
15-10-2013	Tidy up the experiment setup	- Again, it's advised to first ask the personnel to think of a solution to clean the flume. In this case, the crane was used to position a large container (used for waste) near the flume. The wet sand could easily be shoveled out of the flume and into the container. - The leftovers can easily be removed by flushing the flume once again.

Appendix M. Besprekingen begeleiders

Onderstaand een samenvatting van de besprekingen met de begeleiders.

Bespreking 1

Datum	3-9-2013
Locatie	Citg
Aanwezigen	Jeroen van den Bos, Cindy, Gerben

Samenvatting bespreking

Tijdens deze startbespreking wordt door Jeroen van den Bos uitgelegd wat het project gaat inhouden. De oorspronkelijke opdracht zoals naar ons gecommuniceerd blijkt 3 jaar geleden reeds door studenten uitgevoerd te zijn. Wel staan er nog enkele andere vragen open die het team door ons uitgezocht wenst te hebben. Allereerst moet onderzocht worden, met de gekozen uitvoeringstechniek om de GCs met een grijper in het water te laten , welke kluwen ontstaan.
Daarna is het wenselijk om ook de vorming van een tapijt onder water te onderzoeken wanneer meerdere kluwen los worden gelaten uit de bak.

Dit alles zal in een korte tijdspanne moeten gebeuren. Op 3 oktober zal een meeting zijn met de Duitse autoriteiten.

Jeroen van den Bos legt kort de voordelen van GCs uit boven het conventionele stortsteen. Bij het gebruik van stortsteen als bodembescherming ontstaat grotere erosie aan de randen van het gebied, waardoor uitspoeling ontstaat en de laag stortsteen instabiel kan worden. Bij GCs is de verwachting dat er, door invangen van zand, een egalere zandlaag ontstaat en dus minder erosie. Daarnaast kunnen GCs van bio plastic gemaakt worden wat langzaam afbreekt. Ook is op dit moment een 1:1 proef bezig met een kunstmatig rif in het markermeer om daar een ecologische zone te realiseren.

Bespreking 2

Datum	6-9-2013
Locatie	Citg
Aanwezigen	Jeroen van den Bos, Tom Wilms, Dries Hof en Dirk Boogaard, Cindy, Gerben

Samenvatting bespreking

Allereerst wordt de context van het onderzoek door de aanwezigen verder uitgewerkt. Het onderzoek volgt op eerder onderzoek van Stefan Spits en Kees Geluk over het kiezen van een geschikte uitvoeringsmethode voor het maken van bodembedekking onder water. Het team heeft besloten verder te gaan met een grijper vanaf een ponton, deze onderzoeksmethode zal verder uitgewerkt worden.
Voorafgaand aan de bespreking zijn proeven gedaan in Amsterdam, waarbij de vorming van een kluwen GC elementen is achterhaald bij een open valproef. De resultaten en de filmpjes worden tijdens deze meeting kort doorgenomen, maar dienen nog uitgewerkt te worden door Tom Wilms. De filmpjes laten zien dat de GC elementen inderdaad als kluwen vallen en dat er kettingen gevormd worden van GC elementen die aan elkaar blijven haken.
Een van de belangrijkste conclusies op voorhand is dat de grijper een gladde wand moet hebben (dus geen tussenribben) en dat de kluwen voornamelijk vooraf in de bak moet worden gevormd.

Voor de tijdsplanning is het belangrijk om 2 oktober 2013 vast te houden als datum waarop een (voorlopig) rapport kaar dient te zijn. Op die datum is de presentatie voor de Duitse autoriteiten, waarbij de verkregen meetresultaten van onze test worden geïntegreerd in de uitvoeringsmethode.

Ons deel van het onderzoek omvat in eerste instantie 2 elementen. Allereerst dient het vallen van een kluw GCs onder water onderzocht te worden. Deze resultaten dienen te worden vergeleken met de resultaten van de open val proef. Als dit gedrag bekend is dan dient onderzocht te worden hoe 2 kluwen een mat kunnen vormen.

Deze resultaten zijn belangrijk voor de Duitse autoriteiten. Een vervolg onderzoek is daarna mogelijk en zal gaan over het ontwikkelen van een methode om onder water aan te tonen dat een bepaalde laagdikte is gerealiseerd.

Omdat Jeroen van de Bos de komende periode niet aanwezig is zal Tom Wilms de verdere begeleiding verzorgen voor de opstart van de proeven. Naar alle waarschijnlijkheid gaat het lukken om de grote stroomgoot in het TU waterlab te reserveren voor de proeven. Vanwege het minimaliseren van randeffecten heeft deze grote goot de voorkeur.

Bespreking 3

Datum	11-9-2013
Locatie	Citg
Aanwezigen	Tom Wilms, Cindy, Gerben, Sander van de Vree (deels)

Samenvatting bespreking

Doel van deze bespreking is het doornemen van het onderzoeksplan dat aan Tom Wilms is doorgestuurd op 10-9-2013.

De belangrijkste inhoudelijke wijzigingen zijn:

- Het model van de grijper zoals in karton gemaakt voldoet waarschijnlijk niet i.v.m. een te brede opening. De scharnierpunten in de oorspronkelijke grijper zitten lager. Het schaalmodel kan een probleem worden voor de planning. Hierover met Dirk Boogaard contact opnemen over mogelijkheden bij Boskalis;
- voor de camerapositie in de grijper voldoet het om de camera aan het ophangmechanisme te plaatsen, zodat deze niet onder water komt;
- het is de bedoeling om het openen van de grijper onder water te testen. Daarbij is het ook van belang om na te gaan of de snelheid van inbrengen van de grijper onder water van invloed is op de vorm van de kluwen;
- er dient ook met 1 GC getest te worden;
- de stroming in de goot moet waarschijnlijk constant aan staan i.v.m. inregeltijden;
- ook de valsnelheid dient bepaald te worden;
- eventueel kunnen er ook proeven gedaan worden met een (schaalmodel) van een pijpleiding;
- de methode van inbrengen mag worden gevarieerd en komt minder nauw.

Tijdens het referentie experiment, uitgevoerd bij van Vliet blijkt de vulsnelheid van de grijper ongeveer 40 GC's / min. Dit zal volgens Tom ook ongeveer bij de schaaltest het geval zijn.
Daarnaast is het belangrijk om zo snel mogelijk uit te zoeken hoeveel tests van elk type nodig zijn en om vanuit daar een planning te hebben.

Sander geeft het advies om deze week de proefopstelling te maken en direct te starten met "hand" proeven, waarbij nog geen grijper benodigd is om het meten in te regelen.

Voor het tweede experiment is het de bedoeling om de vorming van het tapijt te bepalen en te beproeven. Uit experiment 1 komt de vorming van 1 kluw naar voren. Deze informatie zal eerst moeten worden geanalyseerd zodat voor test 2 een uitvoeringsmethode kan worden bedacht die daarna getest wordt. Bij deze 2de test is het van belang om de stabiliteit (laagdikte) te bepalen voor verschillende methoden van aanbrengen.

Bespreking 4

Datum 16-9-2013
Locatie Citg, waterlaboratorium
Aanwezigen Tom Wilms, Cindy, Gerben

Samenvatting bespreking

Doel van deze bespreking is het doornemen van het masterplan, het experiment 2 plan en het bekijken van de proefopstelling die is geprepareerd op 13-9-2013

Tom Wilms heeft het masterplan volledig doorgenomen en stelt enkele verbeteringen voor. Naast wat problemen met het gebruikte Engels (met name de specifieke waterbouwkundige termen als current, flume en seabed) wordt met name het copyright aangedragen. Omdat het hier een olie pijpleiding betreft, met de bijbehorende belangen, moeten alle documenten worden voorzien van een confidential waarmerk. Ook dienen specifieke namen van bedrijven en locaties van de pijpleiding niet benoemd te worden. Tom zal over de precieze inhoud overleggen met Romke Bijker, die namens Gassco dit project begeleidt.

De opstelling is goed gekeurd voor gebruik bij de experimenten. Ook de onderwater camera van Boskalis blijkt dermate gestroomlijnd (een ronde buis) dat deze de stroming waarschijnlijk niet in extreme maten zal beïnvloeden.

Het plan van experiment 2 dient nog enigszins gewijzigd te worden. Aangeraden wordt om de mogelijke grijper configuraties uit te tekenen. Metingen dienen voorzien te worden van een absoluut 0 punt, van waaruit posities kunnen worden vastgelegd.

Bespreking 5

Datum 27-9-2013
Locatie Citg, waterlaboratorium
Aanwezigen Tom Wilms, Cindy, Gerben

Samenvatting bespreking

Doel van deze bespreking is het evalueren van de afgelopen week en het opstarten en verfijnen van het plan voor experiment 2.

De afgelopen week zijn veel metingen gedaan. Deze werden echter ook geteisterd door opstart problemen. De stroomgoot bleek niet goed afgesteld bij de afvoerkleppen, het inregelen van de stroming in de goot heeft veel tijd gekost ivm het plaatsen van schotten bij de afvoer en ook bleek in eerste instantie niet goed geschaald, zodat met te hoge snelheden is gemeten. Tom geeft aan dat mocht de tijd meer metingen niet toelaten, dat dan enkele metingen overgeslagen mogen worden. Zo is het waarschijnlijk voldoende om met 40 en 60 GC's te werken en nog maar te meten bij 2 stoomsnelheden.

Voor het plan voor experiment 2 wordt door Tom geholpen met het schetsen van situaties van de grijper. Experiment 2 zal worden opgedeeld in 2 delen Allereerst zal bij deel 2a zonder pijpleiding gewerkt worden en wordt eerst de interlocking van 2 batches getest, daarna wordt dit uitgebreid met 3 batches. Vervolgens kan getest worden met de pijpleiding. Om de verschillen tussen de batches visueel te krijgen stelt Cindy voor om 70 GC's wit te schilderen.

Tot slot helpt Tom met het maken van een opzetje voor de Powerpoint presentatie die Romke Bijker gaat gebruiken bij de presentatie voor de autoriteiten. Dit opzetje laat in 4 slides zien waar dit project over gaat, waar de metingen worden uitgevoerd en wat eerste resultaten zijn. Cindy zal een compilatie maken van de verschillende camera posities.

Bespreking 6

Datum 10-10-2013
Locatie Citg, waterlaboratorium
Aanwezigen Tom Wilms, Gerben

Samenvatting bespreking

Bij deze bespreking komt Tom Wilms met name de voortgang van de experimenten waarnemen.

7-10-2013 is gestart met het bouwen van een matras rondom de pijpleiding. De laatste constructie bleek dermate succesvol dat de ervaringen hierover met Tom worden gedeeld. Het kunnen inschatten van de valpositie van de batch blijkt een belangrijk struikelblok die op 8-10-2013 is overwonnen door een extra serie proeven te doen. Op deze manier kan de positionering van de batches t.o.v. de pijpleiding beter worden ingeschat. Tom geeft aan dat dit waarschijnlijk zal resulteren in een advies om bij doodtij rondom de pijpleiding aan te leggen omdat met name het positioneren dichtbij de pijpleiding zeer nauw komt.

Daarbij is uitgelegd dat bij de proeven met de pijpleiding niet meer wordt getest hoe de batches onderling samenhaken. Het doel is om de laagopbouw te meten en ook het moment van instabiliteit en het faalmechisme te beschrijven. Het samenhaken tussen batches is reeds onderzocht bij 2 en 3 batches.

Daarnaast is Tom zeer geïnteresseerd in de aanbouwvolgordes evenwijdig aan de stroomrichting. Hiervan zijn de resultaten op dit moment nog niet bekend, maar deze zijn wel onderzocht bij het experiment met 3 batches. Tom hoopt dat met een advies kan worden gekomen over het opbouwen van de mat in beide richtingen.

Van Tom komt het advies om een procesverslag in de bijlage bij te voegen. Dit procesverslag bevat per dag een overzicht van de activiteiten, de tegenslagen en de leerpunten. Met name de leerpunten kunnen zeer nuttig zijn voor toekomstige proeven. Ook kan in dit procesverslag ook alle overige informatie en observaties kwijt over de procesgang van het experiment. Dit procesverslag zal worden toegevoegd aan het appendices rapport.

Gerben geeft aan dat het voor dit rapport ook belangrijk is om de brug te slaan met Deltares en de GC's die daar gebruikt gaan worden. De informatie is beschikbaar bij Geohooks. De haken bij Deltares zijn iets anders voorgegeven, en de verschillen zijn dus belangrijk om te benoemen.
Daarnaast wordt aangehaald dat de manier van vullen van de clamshell nog relevant is, omdat hierbij toch verschillen ontstaan. Dit meenemen in de aanbeveling en aangeven dat hier eventueel nog verder onderzoek naar zal moeten worden gedaan.

Bespreking 7

Datum 18-10-2013
Locatie Citg, waterlaboratorium
Aanwezigen Jeroen van den Bos, Tom Wilms, Dries Hof en Dirk Boogaard, Cindy, Gerben

Samenvatting bespreking

Het doel van de bespreking is om de proeven in het waterlab te evalueren en om enkele tussenresultaten te delen met het team.

Eerst worden door Gerben en Cindy kort de genomen experiment stappen doorgenomen. Er is begonnen met het uitvoeren van experimenten met 1 batch om zo het gedrag te kunnen evalueren en eventueel verschillen met de valtest bij van Vliet te bepalen. Daarna is experiment 2 uitgevoerd, waarbij ook daadwerkelijk een matras is opgebouwd uit 2 en 3 grijper ladingen.

Dirk vraagt zich af welke methode op dit moment het beste lijkt. Dit zal waarschijnlijk situation 1a worden voor het bouwen haaks op de stroomrichting, en situation 2a voor het bouwen in de richting van de stroming. Allen gebaseerd op het halfsteens aanleggen van de batches.

Bij experiment 3 en 4 vraagt het team zich af wat de invloed van omstandigheden van het experiment (in een stroomgoot met beperkte breedte), is op de resultaten. Jeroen geeft aan dat bij schaalproeven met stortsteen de buitenste 5 cm buiten beschouwing worden gelaten omdat daar randeffecten zichtbaar zijn (verminderde stabiliteit). Omdat bij het uitvoeren van de experimenten ook met een marge van de wanden is gewerkt zal het effect van de rand worden verminderd. Echter blijft de buitenste rand instabieler, en zijn de waardes dus waarschijnlijk te progressief.

Qua aanbouw methode blijkt dat het aanleggen van een matras bovenop de pijpleiding leidt tot een lagere bezwijk stroming. Om die reden zal dat minder gunstig zijn voor de daadwerkelijke situatie op zee. Opvallend was dat het matras aan de bovenstroomse kant, tijdens bezwijken, in zijn geheel over de pijpleiding heen wordt getrokken door de verbindende laag.

Jeroen geeft aan dat voor de pijpleiding op de Waddenzee louter GC’s links en rechts van de pijpleiding geplaatst zullen worden. Er worden dus geen GC’s onder de pijpleiding geplaatst. Het hoofddoel van het matras zal dan ook zijn om de ontgronding te stoppen en de stoomsnelheid af te remmen, zodanig dat vermoeiing in de pijpleiding wordt tegen gegaan. Het invangen van zand is hierbij niet van belang voor het probleem van de free span.

In het vervolgtraject, nadat het eindrapport door Cindy en Gerben geschreven is, zal een afspraak worden gemaakt met Deltares om de proefopzet te bepalen en ervaringen uit te wisselen.

Appendix N. Masterplan: Ground consolidators project

1. Introduction

Nowadays it is common to use a layer of gravel or sand under water for protection of seabeds, slopes and pipelines. Gravel has many advantages and is an efficient way to protect the bed because of its high density and weight. There a big disadvantage. On the sides of the gravel layer there is a change of erosion of the underlying sand because of high water velocities and turbulence. Thus the gravel is a short time solution and eventually it will dissolve and the protection will be gone. Therefore another solution was invented, the Ground Consolidator (GC's).

This whole new kind of protection exists out of a large number of GC's which looks like a hollow cube with only seven ribs, see Figure 99. The GC's hook together and form a kind of mattress which lies on the area that needs protection. Because of the hollow structure of the GC's the water can flow through, but much slower which causes the sand in the flow to settle down between the elements (sedimentation). After some time a layer of sand will lie in between and over the GC's, guarantying the stability and the protection of the area or the coverage of the pipeline.

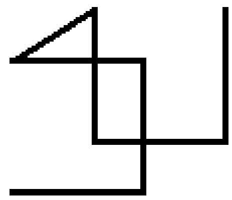


Figure 99 Basic shape GC

In theory that's how the GC's should work. Previous experiments and projects show that the GC's in fact attract the sand and work as protection. However the invention is just in an early stage of development. This means there is not yet a method for execution of these GC's on al large scale and in a large project.

It is proposed to protect a pipeline in the Waddensea with GC's. GeoHooks started a pilot to find out if the GC's are suitable for a stable protection layer. The goal of this pilot is to find an execution method for the placement of a GC mattress on top of the pipeline and to make sure this method can compete with a conventional layer made of gravel or sand.

2. Project description

This project follows in a long path of development and scale tests on the use of GC's for Civil Engineering purposes. Within the wide range of possible applications, our focus will be on the use of GC's in the hydraulic engineering, especially in pipeline protection and seabed enforcement. The main question in this project is based on the search for an execution and handling method for the GC's under water to be able to get a strong and stable mattress.

2.1 Previous experiments

Prior to this project, a couple of interesting experiments and conclusions were made by several researchers. First, Verhagen did some scaled experiments in the flume at the hydromechanics laboratory in Delft in 2006. The main conclusion was that GC's can form a stable mattress if the flow velocities remain under a certain rate (1.4 m/s). The GC mattress indeed slows down the flow of the incoming water, so sand and gravel can settle down on the seabed. Also, Verhagen concluded that steel isn't a good material for the GC's because of rusting. The team decided to develop the GC's out of biological polymers. (Verhagen 2009)

Later on, an experiment was performed by Witteveen + Bos in the Yangtze harbor in Rotterdam. Here, a large geotextile with a layer of GC's was drawn into the water to see if the GC's protects the geotextile under wave conditions. The focus in this project was on the slope stability of the mattress.(Bos 2011)

To check if the GC's could be used in real time conditions, an artificial reef was built in the Markermeer area.

For implementation of the GC's in a large scale project, an execution method needs to be designed. For their bachelor thesis, Stefan Spits and Kees Geluk designed and examined a couple of possible execution methods. With these results, the project team decided to focus on the use of a clamshell. (Geluk 2013)

To research the behavior of a batch of GC's placed by a clamshell on a sand layer, Witteveen + Bos performed an experiment in the dry at Van Vliet, Amsterdam. Here, they examined the forming of a batch with a falling height of 2 m. This research shows that the clamshell should be smooth. Also, when the opening speed increases, the spreading of the batch increases as well. (Bos 2013)

2.2 Problem

For applying the GC's on a large scale and, for instance, in the Waddensea pipeline project, there are a lot of factors to consider. First of all the GC's must be placed under water at sea, which means there will be a current and the seabed will not be even. The contractor wants to use a ship with a clamshell that drops the GC's under water with a falling height of approximately two meters. The orientation and composition of one batch of GC's after dropping under water in relation to the amount of GC's in the clamshell, the opening time and falling height is uncertain and needs to be determined. Besides that, the behavior of the GC's in a closed clamshell under water is unknown as well.

The second problem within this project comes with the creation of the mattress under water. Several execution methods, especially in relation to the orientation of the clamshell and the order dropping, needs to be examined under the influence of a current. This is because there is a lack of knowledge about the interlocking of several batches under water. This second problem is important for the overall implementation of GC's in the Waddensea pipeline project.

2.3 Objective

The objective of this research in general is to formulate answers for the problem described above. This means the interlocking process of a batch of GC's under water will be examined and tests will be performed for several execution methods for the production of the mattress on the seabed. With this information it is shown and predicted how real GC's will interlock on the seabed and at the end a proposition is made for an execution method for the mattress on the seabed.

2.4 Main questions

What is the difference in behavior (composition, orientation and interlocking) of a batch of GC's while being placed under water and in a current, from the moment of placing the GC's in the clamshell until reaching the bed regarding falling of the GC's in the "full scale placement test in the dry" (Van Vliet, Amsterdam, 3-9-2013)?

Second, what is the best method to drop several batches in the water in such a way that they form a stable mattress? More detailed, how will several batches interlock and form a mattress in relation to its execution order?

2.5 Assumptions

Based on previous researches and tests, and to define this project, some assumptions before will be made.

The first assumption is based on the flow of the sea water during execution of the mattress. The construction will be done at a current velocity of 1.4 m/s. Based on research done by Witteveen + Bos, the maximum current velocities in the area near the pipeline are up to 1.1 m/s a spring tide. (Bos 2013)To find conservative values, a current velocity of 1.4 m/s will be used as an upper limit.

Second, some assumptions on the seabed situation near the pipeline will be made. This bed is assumed to be more or less flat and it consists only out of sand (so no other soils will be tested).
To simplify the situation, the pipeline is totally supported by the seabed, so no free span will occur in this experiments. This differs from the real time situation.
The flow direction is assumed to be in line or perpendicular to the pipeline, so no corners will be taken into account.

During placement, the clamshell is assumed to be fixed at a certain point, so no displacements will occur during opening. In the real situation, the clamshell is mounted on a ship that moves because of the waves.

2.6 Relevant stakeholders

The project is initiated by GeoHooks. This company is a co-operation of Boskalis and Anome Projects. Their main goal is to develop the GC's and to find applications in the Engineering field.

Anome BV is the inventor and patent holder of the design of the GC's. This company was founded to accommodate the ideas of Jos Hoebe. The goal of Anome BV is to find a field of application for its GC's.

Boskalis leads the execution part of the project and wants to know how to place the GC's on the seabed, how many GC's fits in a square meter and how the client can be convinced in the reliability and safety of the mattress. Together with Anome projects, Boskalis is a partner in the joint-venture called GeoHooks. This joint-venture is responsible for the implementation and sales of the GC's.

Witteveen + Bos consults in this matter and helps to find and develop methods for the use of GC's on a large scale. This company advises in research plans and performed several tests, like the test in the Yangtze harbor and the falling test at Van Vliet, Amsterdam.

Gassco, the Norwegian state company in gas is the owner of the pipeline in the Waddensea. Gassco needs to find solutions for the free span threat of its pipeline and thinks of GC's as a feasible solution for the free span problem.

Authorities

Because the pipeline is situated in a territory, the authorities play an important role in the approval phase of the pipeline project. An important presentation will be held by the team on 2th October to prove the safety and possibility of the GC's. The knowledge from this BSc project will be used in the presentation.

Deltares is the institute that reviews the data from this BSc project in a large scale test with more realistic conditions and situations.

3. Methods and techniques

3.1 Approach

Literature study

This project starts with a literature study and an inventarisation of the available data on this topic. Several tests are already performed, so the main goal is to receive the tips and tricks from these tests. Another objective is to find out what parts of the study is already known and how this project can be seen in its context. This study results in a map of available data and conclusions of previous tests.

First experiment

After the literature study the first experiments can begin in the fluid mechanics laboratory at the faculty of Civil Engineering at the TU Delft.

This first experiment will answer the first main question and is an expansion of the previous experiment of Van Vliet Amsterdam, 3-9-2013. This means the starting point for these experiments will be with the same design, but scaled with a factor of 1:8, to check if the same behavior occurs in this scaled test. Next, the same tests will be performed with stationary water and with three different flow velocities in the flume. These experiments will give information about the shape of one batch of GC's depending on the opening speed of the clamshell and the amount of GC's in the clamshell.

With this information a prediction can be made on how the GC's will behave under water during placement. For the second experiment this data is relevant, so the best execution method can be proposed.

Analyses

The data from the first experiment will be elaborated, so the behavior and shape of a batch under water is clear. With this information some possible execution methods can be found (in terms of clamshell orientation, batch order and flow) for the realization of a mattress on over the pipeline. These analyses results in a couple of methods that needs further testing.

Second experiment

After the analyses, the execution methods can be tested and from this can be concluded which one gives the best (in terms of stability and economy) mattress on the bed. This will be done by testing the height of the mattress and the eventual flow when the layer collapses. To simulate the real time situation for this project, there will also be a test for the forming of the mattress with a scaled pipeline on the sand layer.

Conclusion

With the obtained results the main question can be answered and a proposal can be made for an execution method for the construction of the GC mattress on the pipeline. The outcome of the first and second experiment will be tested again at the Deltares laboratory.

4. Planning

Figure 100 and 101 show the planning for this project.

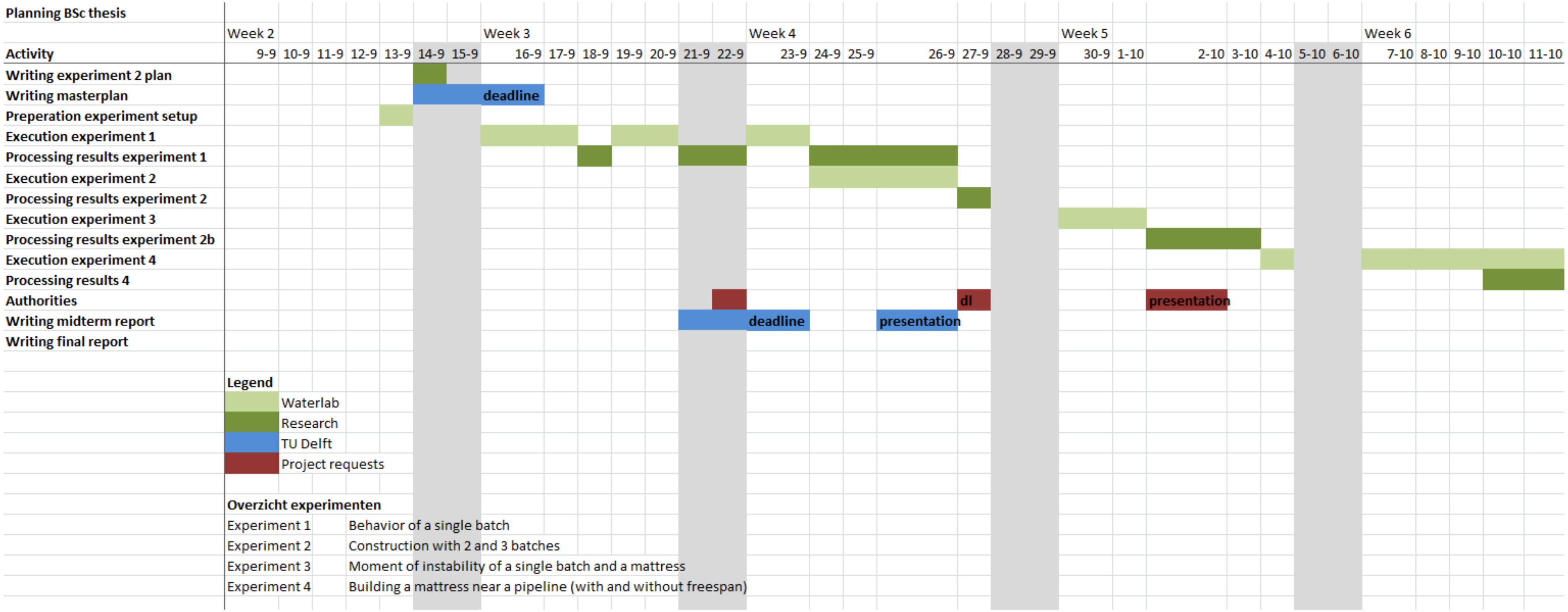


Figure 100 Gantt diagram project planning BSc thesis

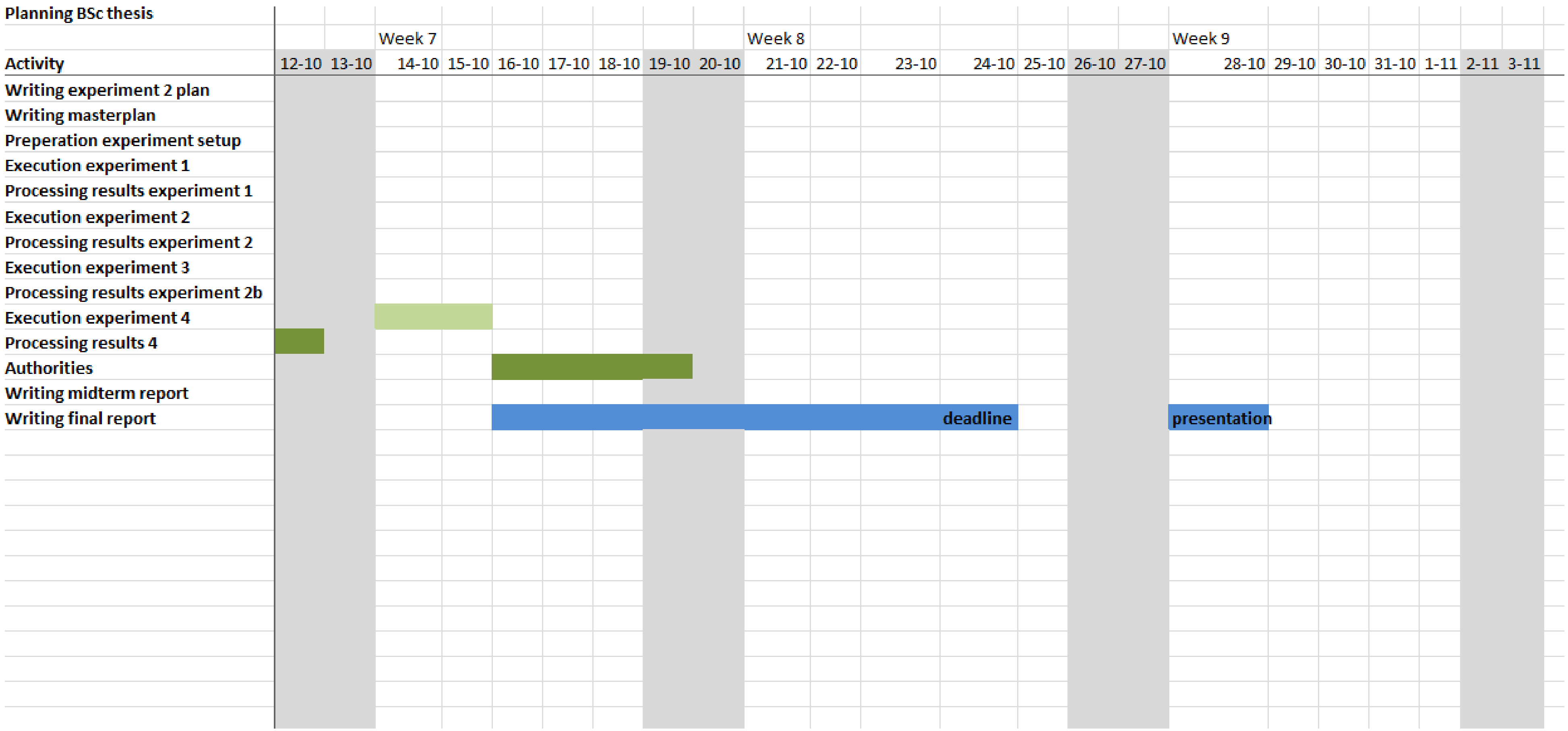


Figure 101 Gantt diagram project planning BSc thesis

5. Report format

The following list shows the format of the end report that has to be handed in on 24th October.

1. Foreword
2. Table of contents
3. Summary
4. Introduction
5.1 Results literature study
5.2 Design experiments
5.3 Results experiment 1
5.4 Results experiment 2
5.5 Results experiment 3
5.6 Results experiment 4
6. Conclusion
7. Recommendations
8. Literature
9. Appendixes
    - A Literature study
    - B Experiment 1 plan
    - C Experiment 1 results
    - D Experiment 2 plan
    - E Experiment 2 results
    - F Experiment 3 plan
    - G Experiment 3 results
    - H Experiment 4 plan
    - I Experiment 4 results
    - J Hydrodynamic scaling
    - K Characterization clamshell and GC's (TU Delft and Deltares)
    - L Process report
    - M Evaluation
    - N Master plan
    - O Besprekingen begeleiders
10. List of symbols
11. Glossary
12. Register

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