Fieldwork Hydraulic Engineering

Artificial Islands Asparuhovo, Bulgaria

CIE5318 Fieldwork Hydraulic Engineering
Varna, October 2012
Delft, December 2012

Preface

This report is the result of the course 'CIE 5318 Fieldwork Hydraulic Engineering'. During the master Hydraulic Engineering students follow most of the time theoretical courses. This Fieldwork course is a great opportunity to use all the theoretical knowledge learned during other courses in 'real life'.

In the first week of October 16 students from the TU Delft went to Varna, Bulgaria. Together with 4 students from the University of Varna we execute field measurements in the coastal zone area of Varna.

Many thanks to ir. H.J. Verhagen and ing. M. Voorendt from TU Delft, Boyan Savov and his son Boyan Savov jr., from Bulgaria. We would like to thank you for the organisation of this instructive week and for the support, assistance and enthusiasm during this fieldwork.

Delft, December 2012

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Summary

In October 2012 a group of sixteen Dutch students from Technical University of Delft and 4 four Bulgarian students from Varna Free University did fieldwork in Hydraulic Engineering in the surroundings of Varna, Bulgaria. Various activities were executed around St. Constantine and Asparuhovo Beach.

Sirius Beach and Azalea Beach are beaches situated north of Varna in Bulgaria. The beaches have names of hotels situated at the beach. The hotel owners describe large scale erosion at the beaches over the years. Throughout the years groups of students from Delft have measured the waterline (by GPS) and the cross sections. The beaches are strongly influenced by the waves, because there is insignificant tidal motion. This wave domination is variable over the seasons (winter versus summer).
For Azalea Beach only the waterlines were measured and the waterline was comparable to 2010. So, the erosion mentioned in 2010 is not monitored anymore. The waterline of Sirius beach shows erosion patterns in the north which has stabilized over the years. And the accretion in the south (mentioned in 2010 and 2011) has stopped. The cross section measurements show the same trends as the waterline measurements. Though it is hard to draw conclusions from the data. The seasonal variablility and the lacking accuracy of the measurements are the biggest problems.
What is more, at Sirius Beach the test measurements of the wave pressure meter took place. This meter is used for the first time in de Bulgaria fieldwork series. The test close to the water line show breaking of waves, which is obvious in the coastal zone. At the end, the meter would be used in the water in front of Asparuhovo Beach.

Asparuhovo Beach is a beach South of the city centre of Varna. It is a populair place in the summer as it is close to the city. At the Asparhovo Beach the interest goes to the development of the beach and the possible erosion. The measurements for this beach include the waterline measurements with GPS, the cross section measerements and the wave measurements. Except for the lateral measurement, the measurements of this year have been compared to the measurements of the previous two years. From these comparisons the conlusion can be drawn that the North side of the Asparuhovo Beach is hardly changed in the last three years. The South side of the beach does show significant change in the bathymetry and the waterline. Due to the large change in the waterline it is unclear if these changes are due to season variabiblity. In the coming years it would be recommended to take extra measurements in this area.

Furthermore, the wave pressure meter was used in front of this beach in deep water. The data would provide a significant wave height (1.76m) and a peak period (7.32s) at approximately 8m water depth. The mentioned numbers are used for the design of the island. Addionally, in the analysis the SWAN 1D model is runned. Input data are shore orientation, depth profile (perpendicular to the shore) wave heigth and peak period. The wave heigth and period are decreasing due to shallowing water and are zero on the water line.

Between the North Side of the Asparuhovo Beachand and the entrance channel of the port of Varna a breakwater is situated. This breakwater is analyzed and the technical state of the breakwater is compared to the findings of the last two years. By comparing the pictures of the last two years with the most recent pictures the breakwater is in poor condition and is descending very quickly. The main reason for this condition is the poor quality of concrete used and the poor construction. With the experience of this breakwater the recommondations for future breakwaters are to create a better foundation for the breakwater, to use sufficient coverage for the reinforcement steel and to use better quality tetrapods to surround the breakwater.

Measuring of the groyne of St. Constantine gave insight in how hard it is to exactly measure its dimensions. Especially between contractor and client much discussion can take place about the

delivered works. The PIANC can be of help but even measuring in the way described, there will remain some inaccuracy. Due to the tetrapods, which were placed randomly over the groyne, the measuring 'turtle' is less applicable. However, the PIANC describes a way of measuring a well constructed groyne, which was here not the case.
The rock armour stones on the groyne are too small for the design wave height and are moved every year. This year the top of the concrete slab was damaged and therefore (we assumption is that) they have placed tetrapods. An insufficient amount of tetrapods is placed on top of the stones. This has two negative impacts on the characteristics of the construction with tetrapods:

- During the storms, the small stones can still move. This causes a wash out of the stones between the concrete slab and the tetrapods. Besides movement of stones, the stones are also rocking during storms, which finally results in breaking of stones. So, the stones become smaller, which will results in even more damage during storms.
- The tetrapods have no interlocking function which greatly decreases the strength of the top layer.

For the sieve analysis the evolving Sirius Beach is used. To investigate the change the beach is going through, it is important to know the grain size distribution and the $D_{50}$of the sand. Consequently, the results are compared with the results of previous years.
To obtain samples of the different locations, a piston was used, and for the sieving of the samples, a sieving machine. From the weight that was left in the sieves with the different diameters a cumulative mass percent distribution is made. When the data is plotted with the sieve diameter on the horizontal axis on a log scale and the cumulative mass percent distribution on the vertical axis a sieve curve is obtained.
The first thing that can be concluded is that the sand on the beach is finer than the sand in the water or on the waterline. This can be explained by the fact that the finer sand particles are washed away at the waterline because of wave action, so the coarser material remains behind.
To compare the results with the years 2008 and 2009 the results of the grouped and averaged sieve curves are used to obtain the D_{10}, D_{50} and D_{60}. With this the mean diameter (D_{50}) and the grading (D_{60}/D_{10}) of the sand can be computed. The results are coarser sand and a higher grading. A conclusion can be that the beach has suffered from erosion during the last three years, which means that smaller particles are washed away. Accordingly, the sand becomes more coarse over the years.

During the fieldwork, echo soundings have been made near the marina at the east end side of Lake Varna and at Asparuhovo Beach. With the use of the program Surfer it is possible to get an image of the bathymetry there, and possibly compare it with the previous years and years to come. If the bathymetry at Lake Varna is compared with 2010, the shape of the depth contours is indeed very similar. But since no (artificial) zero-depth line was constructed back then, it is hard to compare both images since the depths are slightly shifted, especially near the coast. The entrance to the marina seems to be as deep as the year before at about 5.5m.
Comparing the bathymetry of Asparuhovo Beach with 2011, it can be concluded that here as well the depth contours have a very similar shape. Looking at the possibilities for creating an artificial island, this year a much bigger area was considered so no comparison is possible here. As to whether the shoreline has moved in- or outwards compared to the previous years, the results according to the echo sounding and GPS here are not sufficiently accurate.

Bulgarian developers have plans to construct an artificial island near the city of Varna. The idea is to build housing on the island and its main purpose is to add recreational and touristic value to Varna. In this report two possible locations for the island are chosen, one in Lake Varna and one in the bay of Varna in front of the southern cape. Considering data (bathymetry, wave heights / directions, material), demands (recreational opportunities, housing, coastal protection) and design requirements (navigability, current / erosion, shape / height island, hard sea defense / breakwater, material) the two options are analyzed and compared. The conclusion of this is that much more material is needed to build an island in the bay of Varna and that it is also more difficult to construct the island in the bay, because of the rougher circumstances (more downtime during construction). It appears that situating the artificial island in Lake Varna has the preference. Furthermore some considerations are made about which sort of material is available for constructing the island. Using sand looks to be difficult because of insufficient sand mining opportunities nearby.

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1 Introduction

In the east of Bulgaria there are some problems along the coast of the Black Sea. During this fieldwork research is done in the surroundings of the city Varna. Sirius Beach and Asparuhovo Beach are investigated for erosion, some structures are investigated and a visit to the quarry is made to do some measurements of the rocks.

1.1 Project area

The research is been done at the east coast of Bulgaria at the surroundings of Varna, which is indicated in **Error! Reference source not found.**.

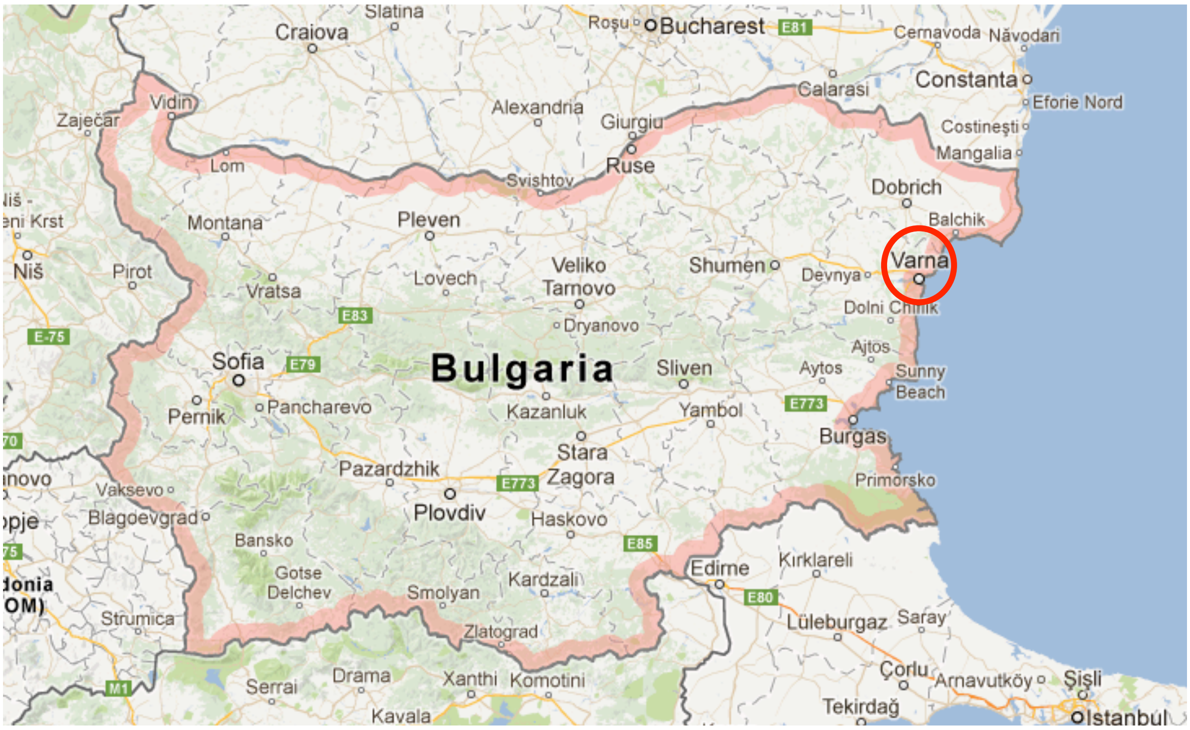


Figure 1-1 Map of Bulgaria with indication of the project area

Varna is located at the Black Sea. The Black Sea has only several small connections with the Mediterranean Sea and Aegean Sea, therefore the tidal influences can hardly penetrate into the Black Sea and can therefore be neglect.

The surroundings of Varna are famous because of the sandy beaches and resorts, which are good places for tourists in summertime. Therefore it is very important to maintain the beaches to keep up with the increase of tourism.

So students from Technical University Delft and University of Varna did some research to the state of the beaches and some constructions. Thereby some research in the quarry is done to verify if the stones from the quarry are suitable to construct the breakwaters with.

1.2 Research

The research is done at several locations. Sirius Beach is the first location where some beach measurements were done to answer the question of the hotel owner whether the beach is eroding or not and if so, how much it erodes.

At the second location, Asparuhovo beach, the same measurements as at Sirius beach were done to conclude whether the beach is eroding or not. Some sand samples were made to investigate the composition of the sand. With a boat echo sounding measurements were done to generated the depth contours in front of the beach, but also in the lake. The breakwater at the beach is also investigated for the damage.

The third location is close to Sirius Beach. It is the Groin of St. Constantine which is severely damaged due to several storms and is not maintained. It is investigated how many stones lost during these storms and if the groin is constructed well in the first place.

The last locations of the research are the quarries. Here the stones of the quarry has been measured to investigate if the stones are sufficient to make an artificial island.

1.3 Structure of the report

In chapter 2 the measurements of Sirius Beach are shown and explained. For Asparuhovo Beach the measurements and results can be read in chapter 3. There are measurements taken by echo sounding at Asparuhovo Beach and the lake near Asparuhovo Beach. These results can be seen in chapter 4. In chapter 5 the groin of St. Constantine is being discussed. Some sand samples were collected at both Sirius Beach and Asparuhovo Beach. These samples are sieved in the lab of TU Delft of which the results can be read in chapter 6. In chapter 7 the measurements and the results of the stones in the Marciana quarry are explained. Varna likes to have an artificial island. In chapter 8 the size and location of this island is discussed. In chapter 9 and 10 there are some recommendations and conclusions of the fieldwork. In the Appendix the wave records of Asparuhovo Beach can be found.

2 Sirius Beach

Sirius Beach and Azalea beach are white sandy beaches situated north of Varna, in the town of St. Constantine and Helena. The town is known for its beaches and mineral water sources. Therefore, the town attracts many tourists every year. A lot of hotels are situated close to or at the beach. Subsequently, the beaches are of great importance to the town and the hotel owners. Furthermore, the beaches are of importance for protection of the hinterland. The two beach names come from hotels situated at the beaches.

Figure 2-1 Map of St. Constantine and Helena

Sirius Beach is located south of Azalea beach, as can be seen in Figure 2-1. The beaches are separated by two small groynes, which were constructed in the past to trap some of the long shore transported sediment. Sirius Beach is 300m long and runs from the above mentioned groynes (near hotel Sirius Beach) in the north to the jetty south. Azalea beach runs from the groyne near Sirius Beach in the south to the breakwater of a small harbour in the north, around 1200m in total.

2.1 Beach profile

The two beaches have a strong seasonal variance. Since there is hardly any tide in the Black sea, the beach profiles are fully determined by the waves. Wave action is different in winter and summer, strong storms in winter versus calmer wave climates in summer. The beaches respond to the waves, this results in flatter, wider beaches in summer and steeper, smaller beaches in winter (summer and winter profile, see Figure 2-2).

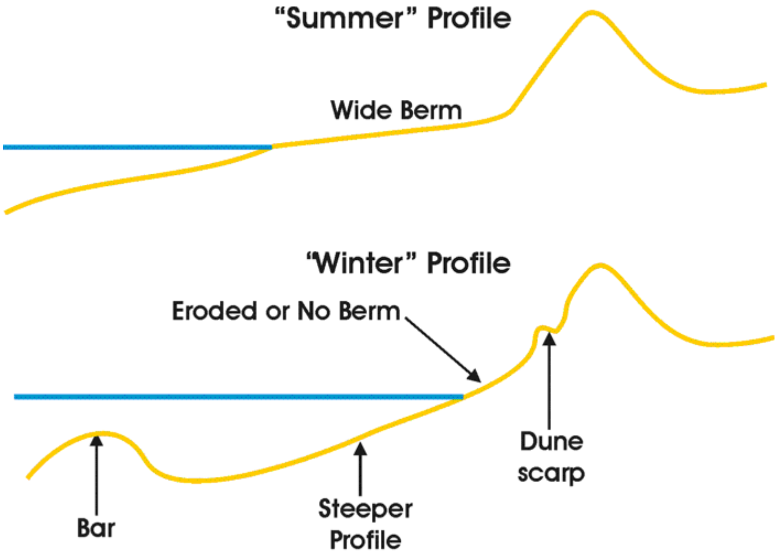


Figure 2-2 Winter and summer profile (source: State of Main Gove)

However, besides this seasonally variance, the local people state that the beach is suffering from structural erosion. To investigate whether this is the case, beach measurements have been done every year since 2002. Every year, in October, the waterline is measured and several cross sections are determined. In the first week of October 2012 these measurements were executed again, and in this chapter the results will be presented. By comparing the results to the measurements of the last years, conclusions can be drawn on the long term evolution of the beach cross sections and waterline.

Since the measurements are executed every year in October (autumn), the beaches are expected to be starting to transform from the summer into the winter profile. This makes it hard to compare them, since the profile depends on the state of transformation. Storms during autumn and winter erode sediment and transform the beach profile. In which state of the transformation the beach profile is at the time of measurements, depends on the number of storms that have taken place at the coast.

Beneath the storm data for the years 2010, 2011 and 2012 are given in Figure 2-3. The numbers of days with a specific wind speed are indicated with different colours. Since the measurements always take place at the beginning of October, the chart for October is not so relevant. In the reports of last years, the months in 2010 were described as mild stormy season, while the same period in 2011 was described as normal stormy season. 2012 is somewhere in between, so will be labelled as mild/normal stormy. This should be visible in the measurements for the cross sections and waterline.

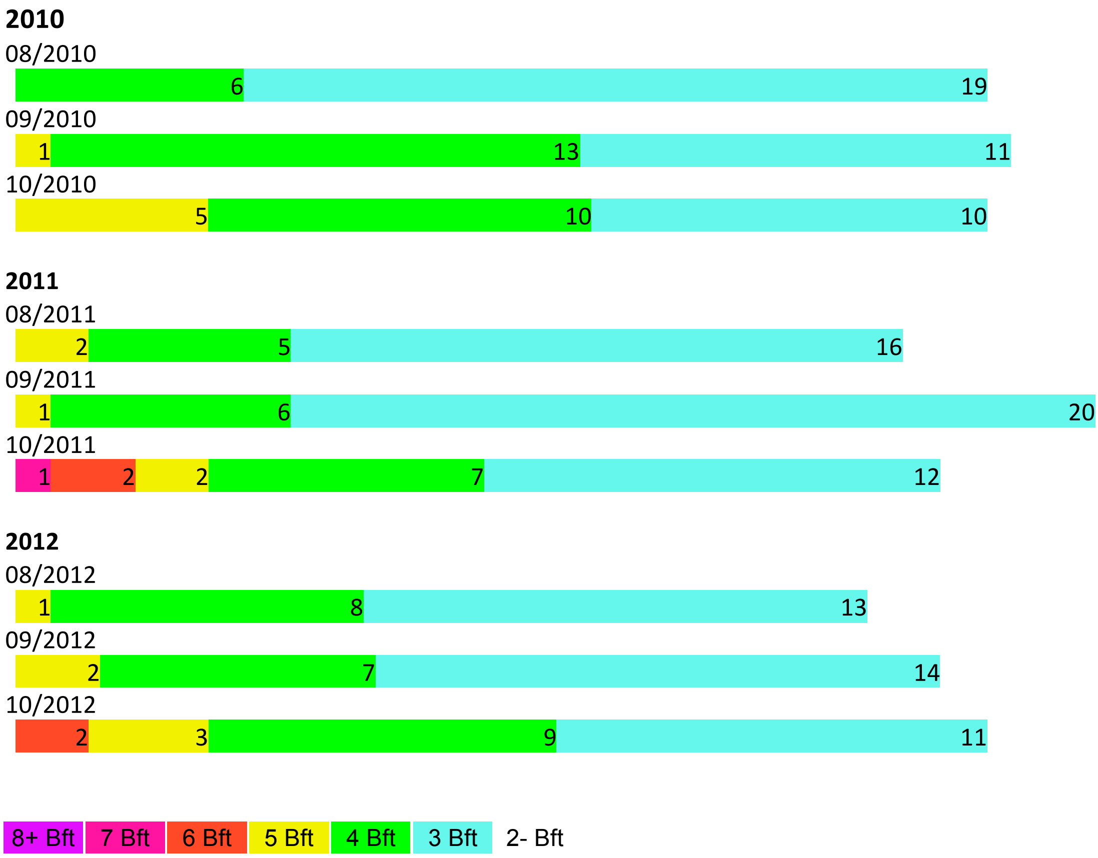


Figure 2-3 Number of days with certain wind speed at Golden Sands (north of Varna), source: Windguru

2.2 Waterline measurements (GPS)

The waterline is defined as the still water line, excluding individual waves. This waterline was measured using a handheld GPS device. The GPS receiver has an option to save the current location every fewm. So, when walking around with the receiver in your hand, your route is saved. Several people took a GPS device and walked the waterline while there locations were saved. This resulted in several measurements of the waterline. Some remarks should be made; the GPS devices have an accuracy of approximately 5m. Also, every individual will walk a slightly different route. This does not make the measurements very accurate. However, the measurements can be used to give an estimate of the location of the waterline, and can therefore be compared to the measurements of the last years (same devices were used last years). These estimates give a good indication of the trend: whether the waterline is retreating, or not, over the years.

2.2.1 Sirius Beach

The waterline at Sirius Beach is measured annually since 2003. This year we did two measurements, one at the beginning of the week (monday 1st of October) and one later that week (friday 5th of October). The red line is the waterline at the beginning of the week. We clearly see that the waterline has retreated during the week. The first days of our stay the waves were relatively high by visual observation, which could have caused erosion. So in that sense it is possible to see a retreat of the coastline in a week. However, in Figure 2-4 it seems like the waterline has retreated for almost 15m. This enormous difference is probably also caused by inaccurate walking of the people that carried the device. It seems that they did not follow the waterline properly the second walk on Friday. This can also be concluded when we look at the comparison of the two new waterlines with the years before. The waterline which was measured that Friday is by far the most landward waterline of all. While the waterline measured on Monday is comparable to the waterlines of the last years. Concluding, some retreat of the waterline might have taken place that week, but the effects are exaggerated by inaccurate walking.

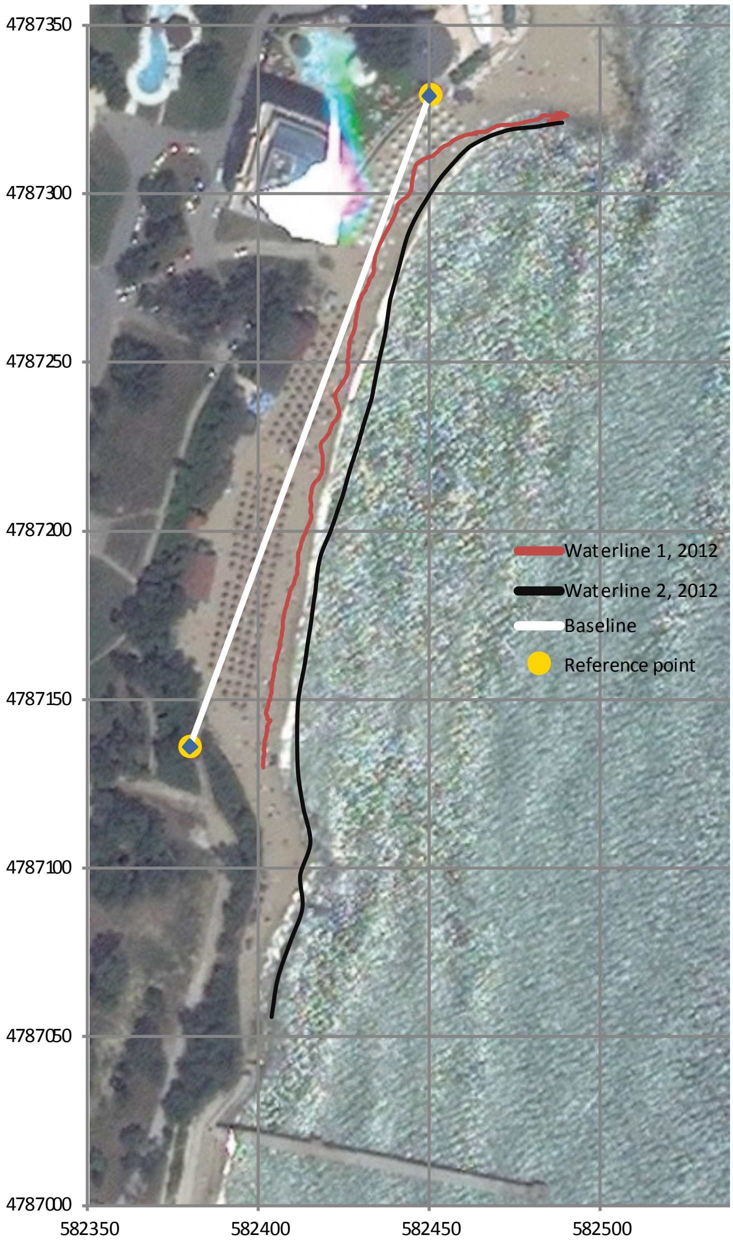


Figure 2-4 Waterlines Sirius Beach

In Figure 2-5 beneath the waterline over the last years are drawn. Also the measured cross sections are indicated perpendicular to the base line. When we compare the measured waterlines to the results of last year we only focus of the waterline obtained at the beginning of the week, because of reasons explained above. In 2003 beach nourishment has taken place at Sirius Beach, which is clearly visible in the figure, especially in the north, where the 2003 waterline lies most seaward. The results of 2012 are close the results of the other years (very similar to 2007). In the north it looks like erosion took place from 2003 till 2007, but from then on the beach stablized and no structural erosion takes place anymore. However, seasonaly variance can still cause problems for the hotel, because the beach is very narrow there. When going more south (until the southern reference point), there was some accretion discorved the last years. However, in 2012 it seems like the waterline is at the same position as 2003 again. At the far south side the beach is more or less stable of the last few years.

For Sirius Beach there is not a clear trend visible over the years. Erosion has taken place in the north from 2003 onwards, but from 2007 it seems like the beach has stabilzed there. In the southern part (near the southern reference point) the beach profile seems to be close the position of 2003 again, which indicates erosion of the last few years. Howerer, seasonal variance is of great importance here, which makes it hard to say something about this dataset. More data (measure several times a year) is needed to say something about long term effects.

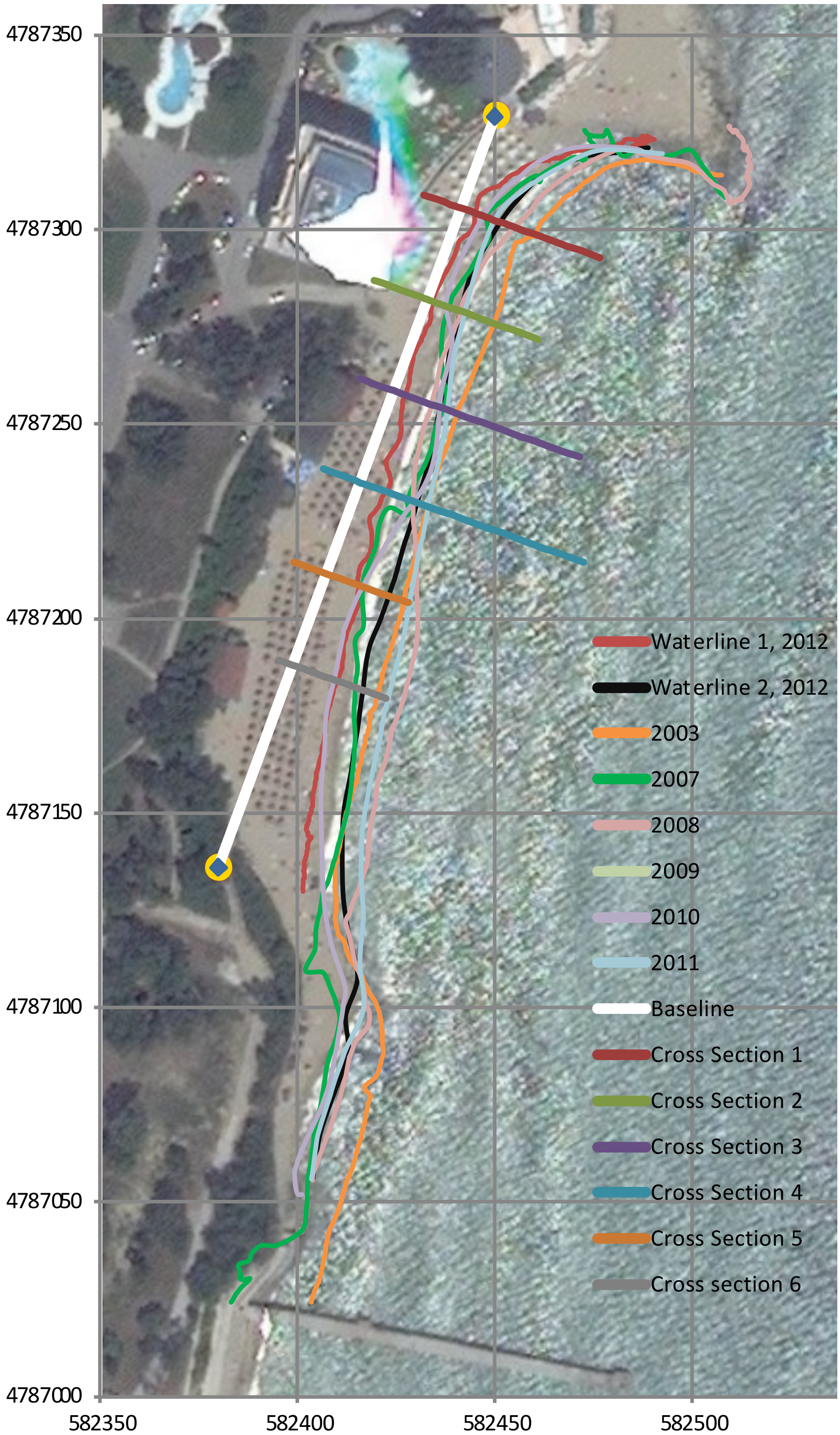


Figure 2-5 Waterlines, baseline and cross-Sections

2.2.2 Azalea Beach

On Azalea Beach the waterline was also measured twice, one on Monday (waterline 1) and once on Friday (waterline 2). We see some difference in the measurements, but it is less extreme than for Sirius Beach. Which makes the measurements on Sirius Beach even more doubtfull. Since Azalea beach is also transisting from summer to winter profile, the beach is constantly changing. Waterline 1 is more seaward than waterline 2, which indicates some erosion, as for Sirius Beach (see Figure 2-6). Futhermore, there are some other effects which were not mentioned yet: wave run up and water set up may play a role in the position of the waterline as wel.

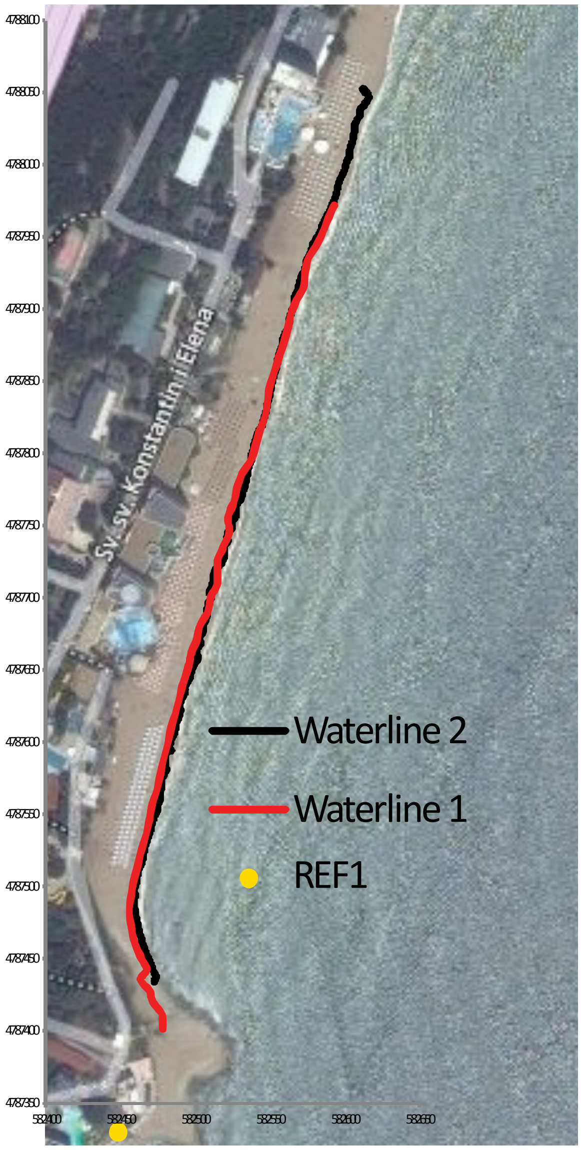


Figure 2-6 Waterlines Azalea Beach

Comparing the obtained data to the years before must be done with great care, since the measurements are very sensitive to weather circumstances, transition of the profile and measurement errors. In the report of 2010 eroding behaviour was mentioned. When looking at Figure 2-7 we can observe an erodion trend from 2009 to 2010. However, the waterlines of 2012 are very close to the waterlines of 2010, which would indicate the stop of this erosion. More data is not available at this moment, which makes it hard to draw conclusions. The waterline should be measured the coming years. However, as we have seen for the coastline of Sirius Beach, it might still be hard to identify a trend.

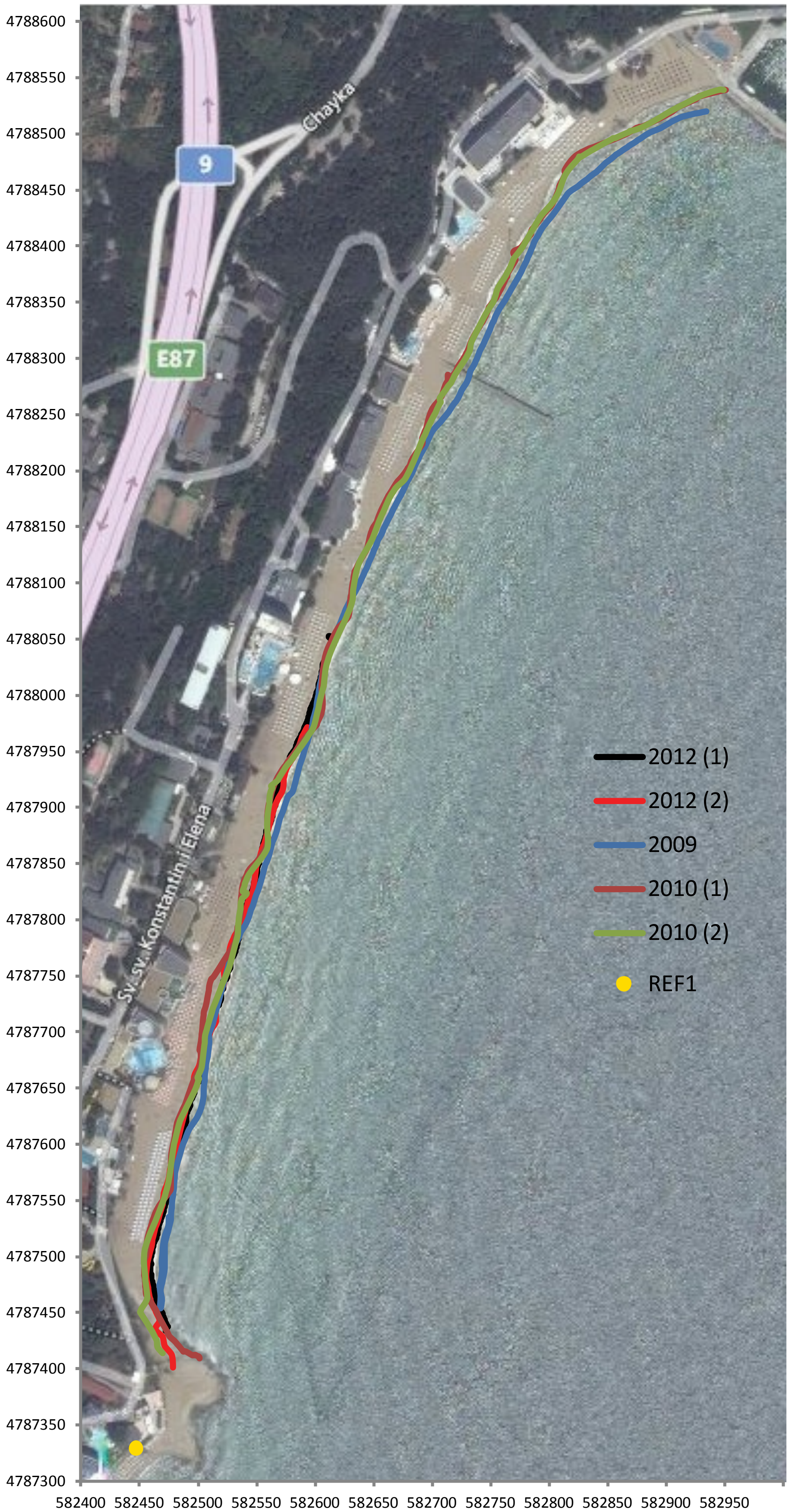


Figure 2-7 Waterlines Azalea Beach (2009, 2010, 2012)

2.3 Cross-sections

This year there are no cross-section measurements executed at Azalea beach, so there is nothing to compare. However, along Sirius Beach several cross-sections were determined. These cross-sections will give a more detailed description of the profile of the beach, and thus about the coastal development.

The cross-sections can be determined by measuring vertical positions at specific points. Several years ago two reference points were chosen at the beach (see Figure 2-8). Reference point one is near the staircase to the swimming pool of the Sirius Beach hotel (35T, 582450 m east, 4787329 m north) and the other one at the south end of Sirius Beach (35T, 582380 m east, 4787136 m north).

Figure 2-8 Reference points on Sirius Beach

By using these two points again, we can guarantee that our measurements are taken at the same distances as last year, which makes them comparable. The reference points are used to determine the baseline; a straight line between these two points. The reference point at the staircase was chosen as our zero point, because this was done last year as well. The years before several other zero points were used, but we decided to use last year's zero point again. From there on, 6 poles were placed with a mutual distance of 25m. From these six poles (all on the baseline) six cross shore profiles were measured, perpendicular to the baseline. In the figure below the reference points, baseline and cross-sections are visible.

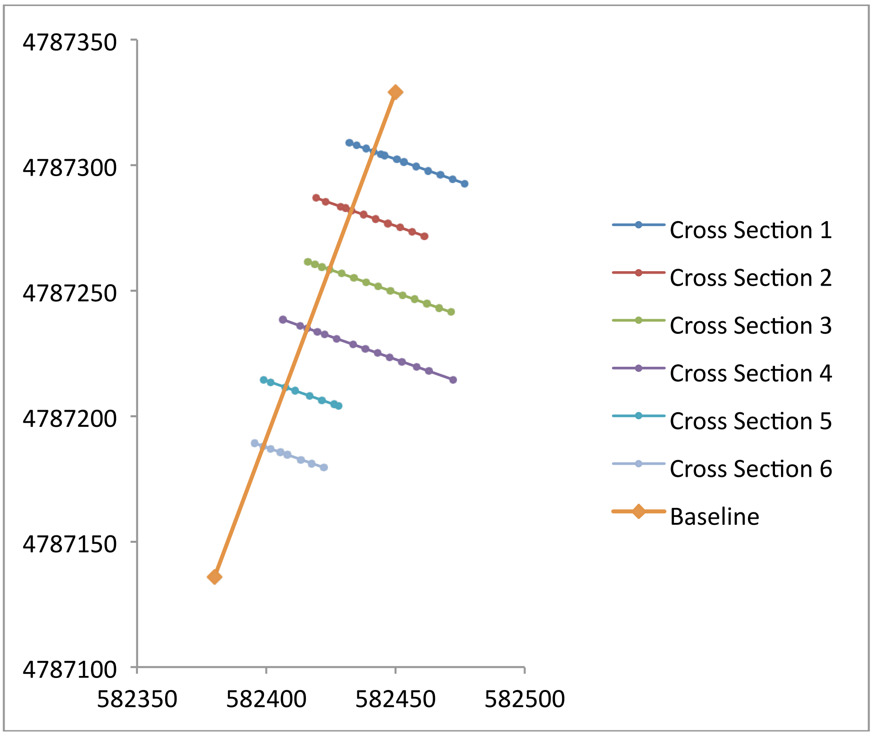


Figure 2-9 Baseline with the six cross-sections measured

The cross-shore profiles are measured by measuring the vertical distance at several locations in the cross shore direction (see Figure 2-9). The distance between the measuring locations is not fixed. Only at the 'interesting' locations measurements are needed. When there is a long constant slope, two measurements are sufficient: one at beginning, and one at the end of the slope. When there are more hills or bumps in the profile, more measurements are needed. This was decided for every cross-section individually.

Figure 2-10 Measuring pole (left) and equipment used to guarantee profiles perpendicular to the baseline (right)

The vertical positions are measured by the eye using a theodolite and a measuring pole. The reference point (ref point 1) at the staircase is a fixed point, and the height above mean sea level is known for that point (2.705 +MSL). The theodolite was positioned at a fixed point on the beach and the height was decided by looking at the reference point. From then on, the theodolite was used to measure the vertical position by looking through the theodolite at a measuring pole. The measuring pole was placed at a point from where the distance to the baseline was known, and by looking the vertical position was then decided. In this way the horizontal (X,Y) and vertical position are known. This was done for many points along the cross sections, resulting in six cross shore beach profiles.

Figure 2-11 Use of the theodolite

2.3.1 Cross-shore profiles

Beneath all six cross-shore profiles are plotted, together with results of previous years. It should be noted that the accuracy of the measured data is not very high. The measuring equipment and way of measuring introduces errors. Also the position of the cross-shore profiles might not be measured at exactly the same locations as last year. Furthermore, there might be differences in transition states, from summer to winter (as explained earlier), over the years. However, the profiles give an indication of the positions of the cross-sections and can be used to investigate trends.

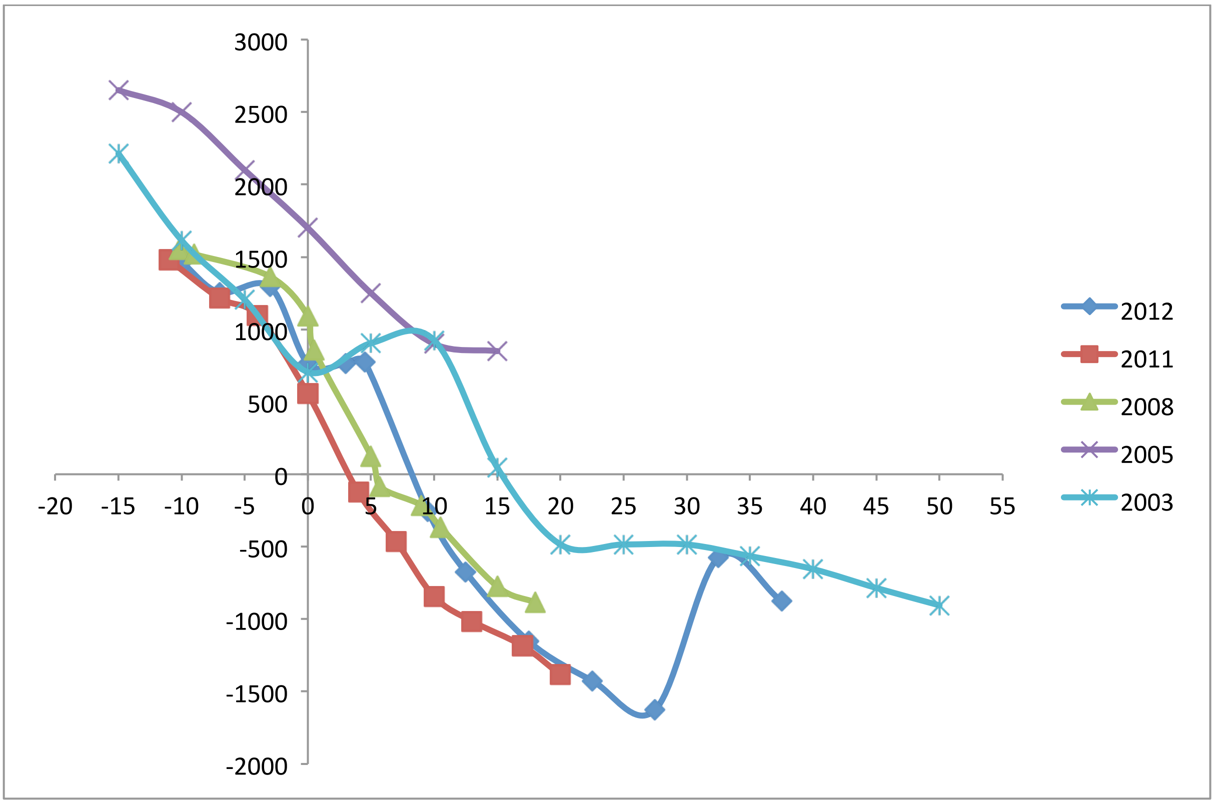


Figure 2-12 Cross-shore profile pole 1, 25m from reference point 1

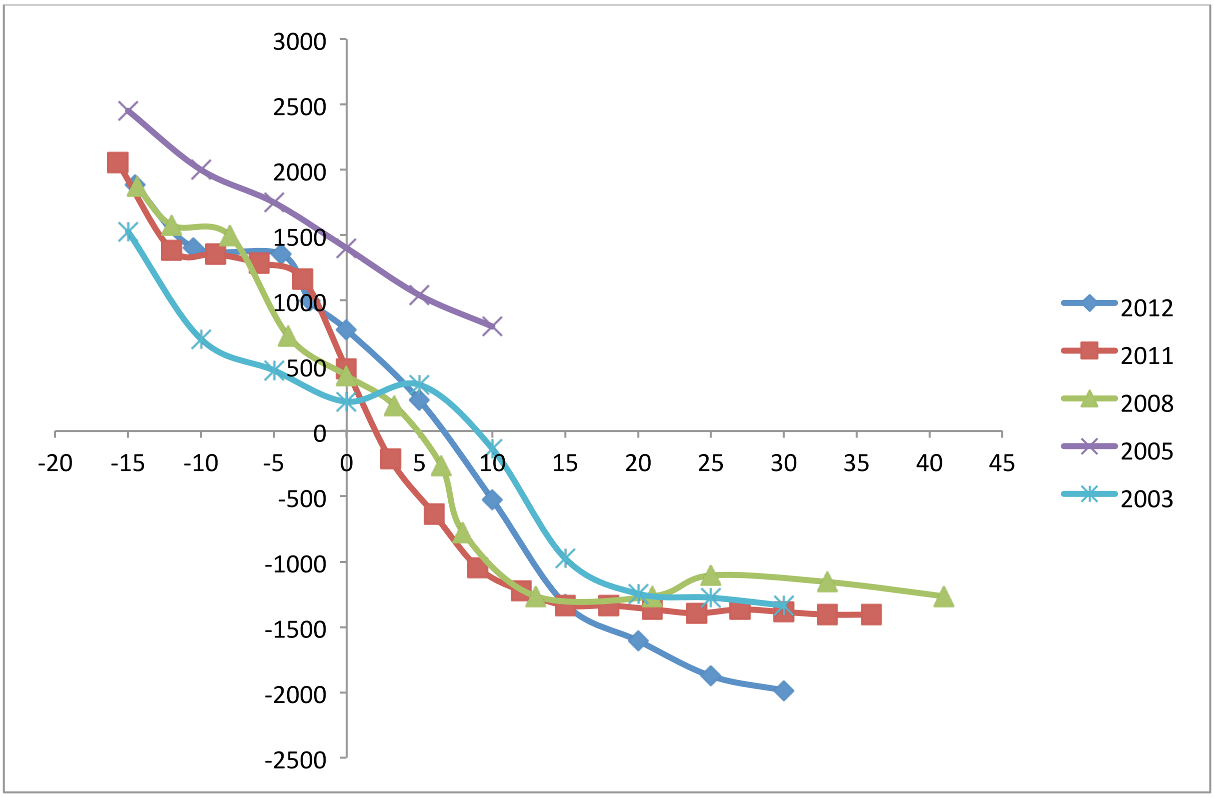


Figure 2-13 Cross-shore profile pole 2, 50m from reference point 1

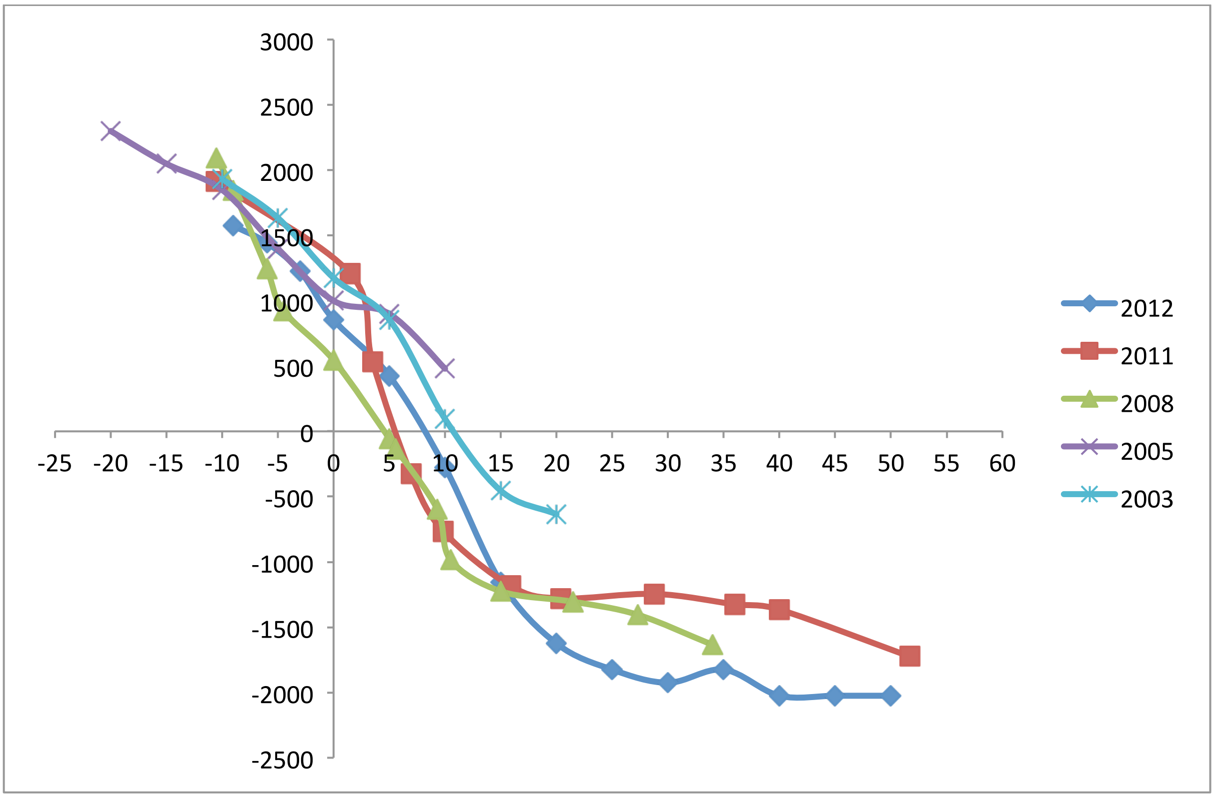


Figure 2-14 Cross-shore profile pole 3, 75m from reference point 1

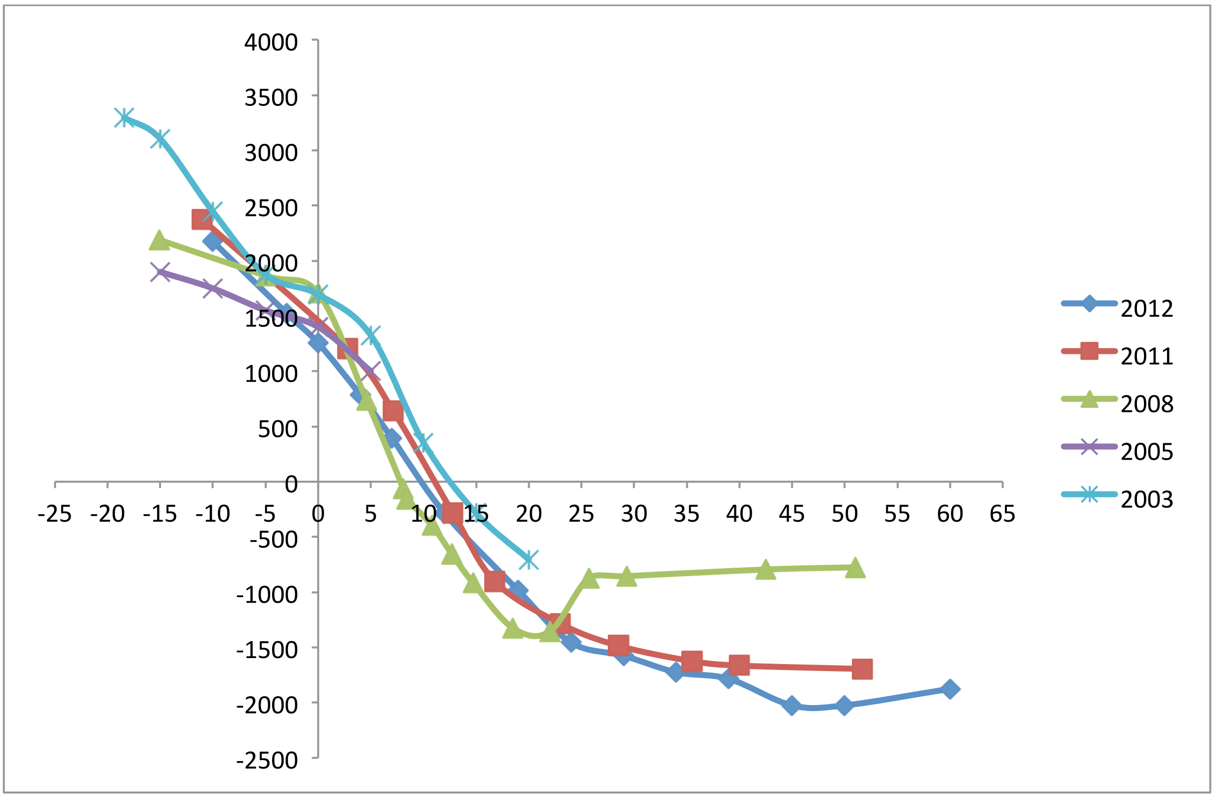


Figure 2-15 Cross-shore profile pole 4, 100m from reference point 1

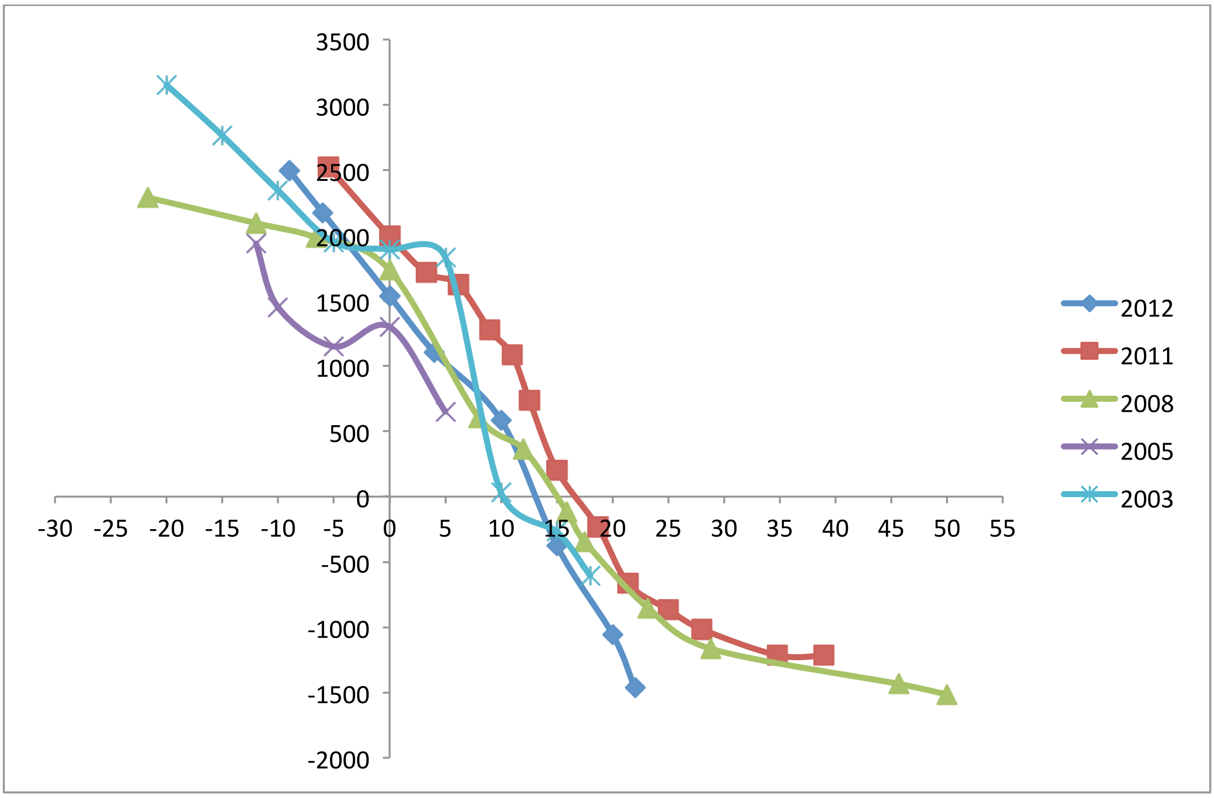


Figure 2-16 Cross-shore profile pole 5, 125m from reference point 1

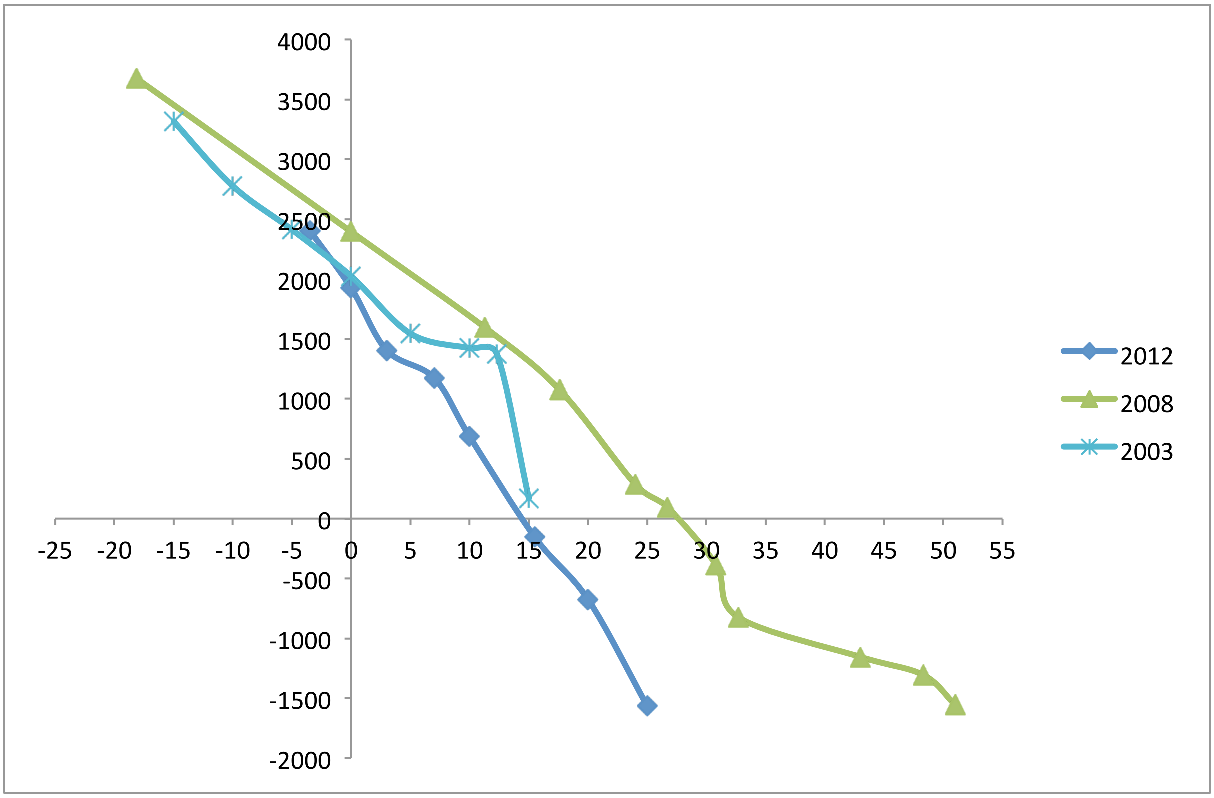


Figure 2-17 Cross-shore profile pole 6, 150m from reference point 1

For the first pole, close to reference point 1, we can see that the beach has eroded from 2003 onwards. However, the last years, it seems like the beach has stabilized and is in some kind of an equilibrium. The measurements are close to the profiles of 2011 and 2008, only this year the profile was measured further into the sea. No comparison can be made at that location, but a sand bar is clearly visible in the results. This gives an indication that the cross section is already in its (or near its) winter state, since it is a steep profile with a sand bar in front. (See figure of summer and winter profiles).

For cross-sections 2 and 3 we see some accreation in the upper part of the profile and some erosion in the lower part (in comparison to last year). This gives the indication that the profiles are in another state of transition now than they were last year. The beach at pole 4 looks stable, which was also concluded last year. At pole 5, the seaward movement of last year is not visible anymore. The beach has eroded again. The cross-section at pole 6 was not measured often over the years. In the years 2003-2008 there was a strong seaward movement, but this year the beach has again moved landward near the position of 2003.

For all profiles the measured cross section of 2003 is the most seaward lying profile, which is obvious because of the nourishment that took place back then. Overall it can be concluded that the beaches are still changing from year to year, but the changes are not very large anymore. For some profiles we see a small landward movement (pole 5 and 6), some are constant (pole 4) and for some the sand is redistributed over the cross section (poles 1, 2 and 3).

2.4 Wave measurements

Three test measurements were performed in front of Sirius Beach, which are treated in this section.
This year the wave data at Sirius Beach were obtained with use of a pressure meter instead of visual observation. The visual observation was impossible due to the damage of the jetty at St. Constantine and Helena (see Figure 2-18). On this jetty one group of students was able to insert a jalon in the sea while the other group of students did the observation from a breakwater at some distance on the right of the jetty with a theodolite in order to measure the water surface movement in vertical direction. This paragraph treats the data obtained with the pressure meter and the results following from the data. In Appendix A – Wave measurements more information about the wave pressure meter, the linear wave theory and the wave characteristics is given. Three test measurements were performed in front of Sirius Beach, which are treated in this section.

Figure 2-18 Jetty at St. Constantine and Helena

2.4.1 Results and data

At Sirius Beach the wave pressure tests is measured at two depths, like 28m and 40m from the baseline of Sirius Beach. The meter is two times placed at the distance of 28m. The depth of this location was approximately 2m. With use of the pressure meter the data in Table 2-1 is obtained.

Table 2-1 Summary Wave Data Sirius Beach

	28m (1)	28m (2)	40m
m_0 (-)	0.0287	0.0290	0.0270
H_{m0} (m)	0.6779	**0.6809**	0.6568
H_{rms} (m)	0.4794	0.4814	0.4644
T_m (s)	4.4466	4.3829	4.3216
$T_{0,1}$ (s)	4.6994	4.6294	4.5174
$T_{-1,0}$ (s)	5.2317	5.1651	4.9139
T_{peak} (s)	5.9140	**6.1338**	5.2209

In this table m_0 is the zeroth-order moment of the variance density spectrum, H_{m0} is the significant wave height calculated by m_0, H_{rms} is root-mean-square value of the wave height, T_m is the mean wave period, $T_{0,1}$ is the wave period from the zeroth- and first-order moment of the variance density spectrum (m_1/m_0), $T_{-1,0}$ is the period obtained from the first-order negative moment ($T_{-1,0} = m_{-1} / m_0$) and T_{peak} is the peak period. H_{m0} is described as the average of the highest third part of the wave in a wave record (Schiereck & Verhagen, 2012). Moreover, T_{peak} origin is the wave spectrum (energy density spectrum) instead of probability density function.

Shallow water can be determined by the rule of thumb:

$$L_0 = \frac{gT^2}{2\pi} = \frac{9.81 \cdot 6.13^2}{2\pi} = 58.67m$$

$h < 0.05L_0 \rightarrow 0.05 > \frac{h}{L_0} = \frac{2}{58.67} = 0.034$ (OK!)
and for deep water

$$h > 0{,}5L_0$$

At Sirius Beach there was measured in shallow water, so the waves were influenced by the bottom and were breaking. By observation this was also noticed. Because of this the linear wave theory cannot be applied.

2.5 Conclusions

For Azalea beach not much data is available. When comparing the waterlines which were measured over the years it can be concluded that the waterlines of 2012 are very close to the waterlines of 2010, which would indicate the stop of the erosion mentioned in 2010.

For Sirius Beach the waterline measurements show the erosion in the nothern part since 2003 which has stabilized over the years. This can also be concluded when looking at the results of the cross section measurements. Furthermore the waterline measurements show that the accreation which was mentioned in 2010 and 2011 has stopped at the southern part of the beach. The waterline lies more landward this year, close to the measurements of 2012. This can also be concluded when comparing the cross-sections. Pole 5 and 6 show erosion in comparison to the last year's measured profiles. Therefore it can be concluded that the waterline and the cross-sections measurements show the same trends at Sirius Beach.

Still it is hard to draw conclusions based on these measurements. The seasonal variability and accuracy of the measurements are the biggest problem. More measurements should be done throughout the year to make comparison of the profiles less sensitive to the seasonal variance. Also, the measurements should be done with great care. Over the years, the position of the measured profiles has shifted and sometimes measurements are not taken as accurate as possible. Therefore, it is advisable to use the same zero point from now on, and measure the profiles at the same locations as done in 2011 and 2012.

The wave measurements at Sirius Beach was a test. It was meant to try the wave pressure meter and to see the any results. The two locations were in shallow water, the waves were breaking and affected by the bottom. In this case the linear wave theory cannot be applied due to orbital motion at the bottom, which is increasing (under the crest) and decreasing (under the trough) the wave pressure at the bottom. So, non-linear theories should be applied to this area.

3 Asparuhovo Beach

In the south of Varna is Asparuhovo Beach (see Figure 3-1). Compared to Sirius Beach this beach is much wider. There are some restaurants near the south of Asparuhovo Beach. Similar to the Sirius Beach the restaurants are looking in a bad state. It is possible that this is just because of the moment of visit. Because there are far more people in this region during summer. Further to the south of the beach there are some little wooden cabins. They are mainly used by fishermen.

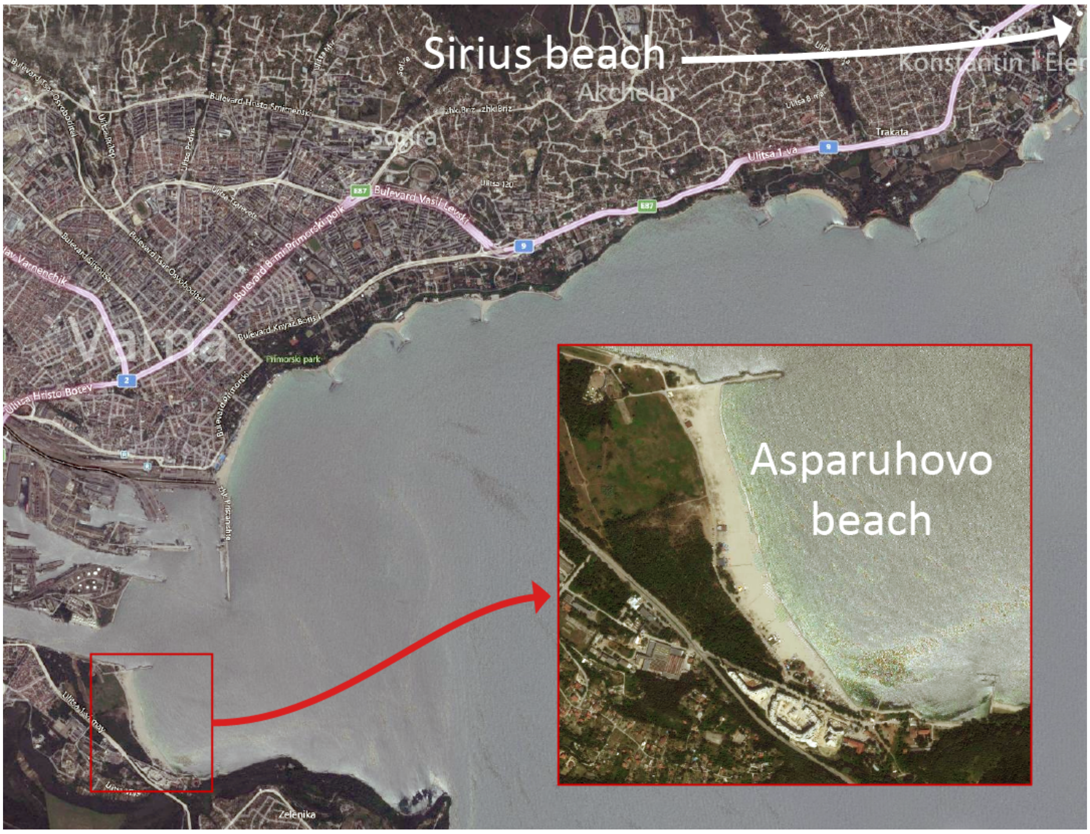


Figure 3-1 Overview of Asparuhovo Beach

Measurements on the beach of Asparuhovo was requirement for the idea of making island in front of it. Therefore, the bathymetrie is measured by hand en boat (echosouding). What is more, a wave record is taken by the wave pressure meter for 4 hours on one day. The significant wave characteristics are used to design the protection of the island in the design stage.

3.1 Measurements of Asparuhovo Beach

This year it is the third year that Asparuhovo Beach is measured. To draw conclusions from the measured data it is necessary to measure the same specific measurements. Similar to Sirius Beach, there are three main points of measurements. These are:

- Waterline measurements
- Cross-section measurements at certain points
- Bathymetry measurements in front of the beach
- Sand samples of the beach
- Investigation of the breakwater

3.2 Waterline measurements

This is the third year the waterline of Asparuhovo Beach is measured. Because the measurements are done at more or less the same moment of the year, they might be comparable.
As explained in “Waterline measurements (GPS) – Sirius Beach”, the measurements of the waterline are done with a GPS handheld. It should be known that the accuracy of these devises can differ a lot. Depending on the amount of satellites the accuracy is somewhere between 3 and 15m.
The waterline is defined as the line between wet and dry sand. In Figure 3-2 the measured data is plotted on the satellite view of Asparuhovo Beach. The northern part of the beach has not really changed over the last three years. The differences between the years in this part of the beach are negligible.

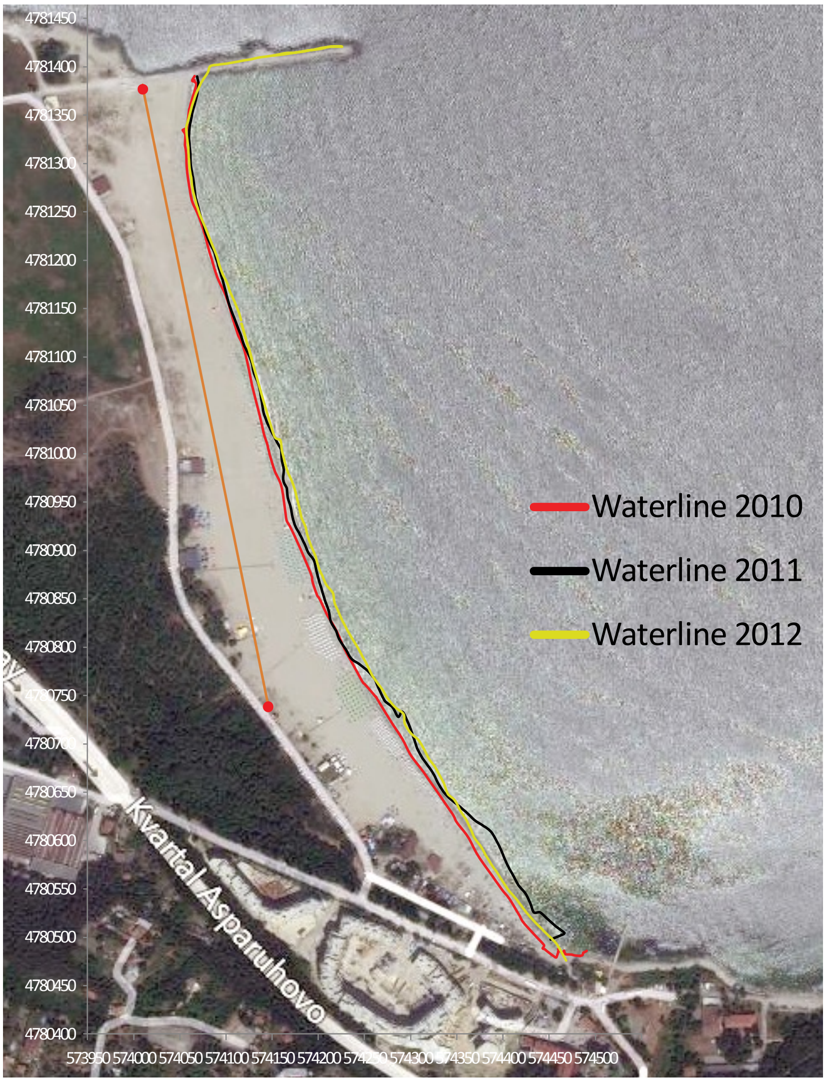


Figure 3-2 Waterlines Asparuhovo

The southern part of the beach is more interesting. In 2010 the beach was the narrowest. One year later in 2011 the waterline has shifted easterly. Because of this, the report of 2011 conclude that this might be an indication of accretion. After the measurements of this year it can be said that the changes were just temporarily. The beach is now somewhere between the state of 2010 and 2011.

3.3 Cross-section measurements

This is the third time cross-section are measured at Asparuhovo Beach. The way the cross-sections are measured is explained in “Cross-section measurements – Sirius Beach”. The amount of places where cross-sections should be taken, depends on the variability of the beach. Asparuhovo Beach is a consistent beach. There are not much height differences from north to south. That is why this beach is only measured at three points.

In 2010, eight cross-sections were measured. One year later in 2011 only four were taken. Between 2010, 2011 and 2012, only two cross-sections points are taken at the same place. Three cross-sections will be viewed in the report.

3.3.1 Reference points

There are three main reference points. These are reference point 0.1 (used as an reference point for the height) and reference point 1 & 2 (for the baseline). Reference point 0.1 is marked on a small building located inland (Figure 3-3). The location of the building is marked in the picture next to it.

Figure 3-3 Reference point for height

Figure 3-4 Location of reference point 0.1

To be sure that the cross-sections are taken at the same place, two reference points are defined. The first reference point is marked on the breakwater. Because the reference point of 2010 & 2011 was not at a usable position, it is moved 20m inland. The new exact GPS location of the reference point is: “35T, EAST: 574010, WEST:4781377”. Reference point 1 is also shown in Figure 3-5, the GPS points marked in the picture are translation from UTM to LAT/LON, these values can be used in Bing and Google maps. Reference point 2 is viewed in Figure 3-6 the location of this point is: “35T, EAST: 574146, WEST:4780739.

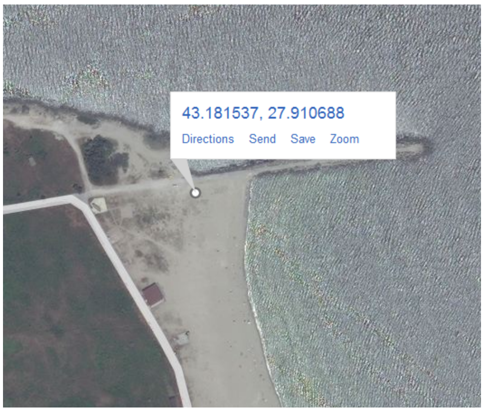


Figure 3-5 Reference point 1

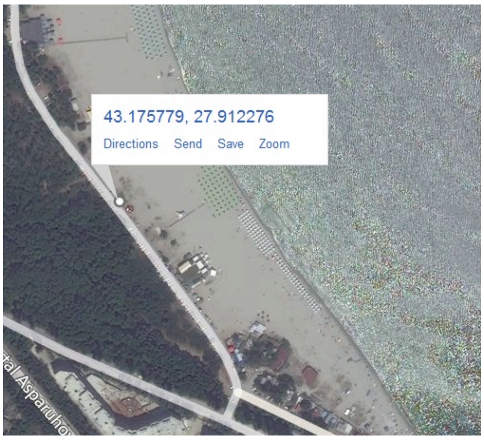


Figure 3-6 Reference point 2

3.3.2 Baseline

Between reference point 1 and 2 the baseline is drawn. This baseline is the reference line for the cross-sections. Because reference point one is moved, the angle of the baseline is different. This will result in a slight incorrectness of the point and the angle taken for the cross-sections.
The "new" baseline is viewed in Figure 3-7.

Figure 3-7 Baseline

The cross-sections are taken along the baseline at a specific distance from reference point 1. The three distances that are chosen are: 50m, 200m and 400m.

3.3.3 Cross-shore profiles

All the cross-sections are measured with reference point 0.1 as height is zero. As with the measurements at Sirius Beach, this level should be corrected to MSL (mean sea level). It would be great if next year the difference between the height of reference point 0.1 and the MSL can be calculated.

Overview of the location of cross-section:

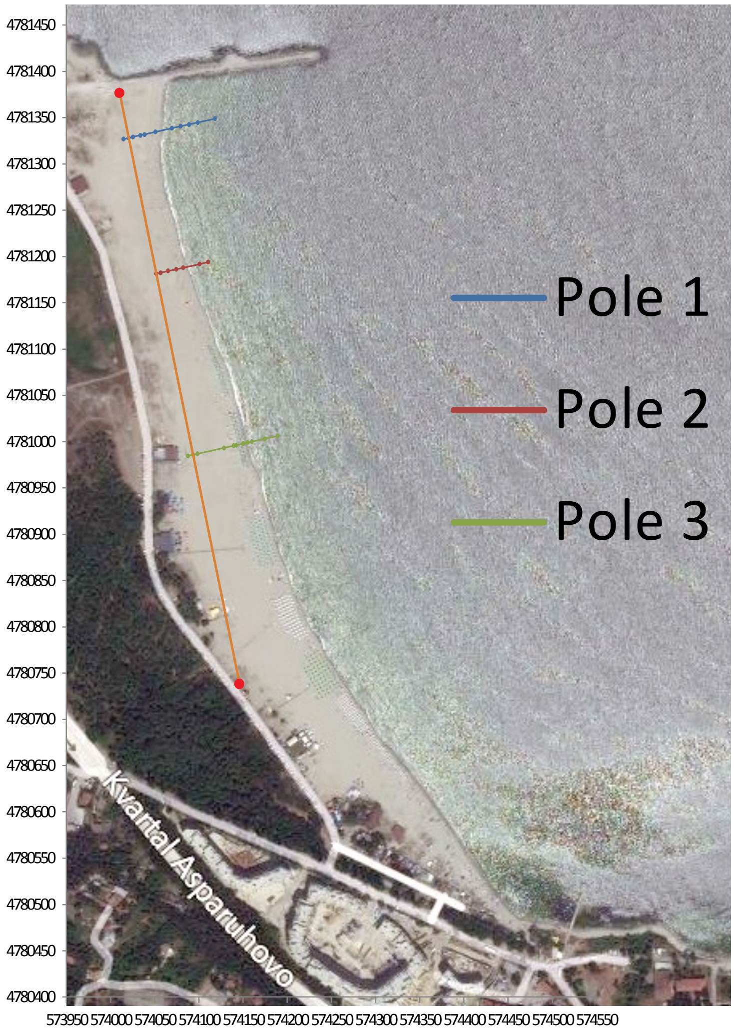


Figure 3-8 Overview of cross-section locations

The next three plots are of the cross-sections of Asparuhovo Beach. Two are with multiple lines. These lines indicate the other two years (2010 and 2011). As noted in the cross-sections paragraph of Sirius Beach: the measuring equipment and the way of measuring are sensitive in errors.
In every

In each plot there is a faded red rectangle plotted. This rectangle is in reality a square. It is plotted in the graph to visualize the amount of difference between the x and y axis. Because this difference is really big in some plots, faulty conclusion are easily made.

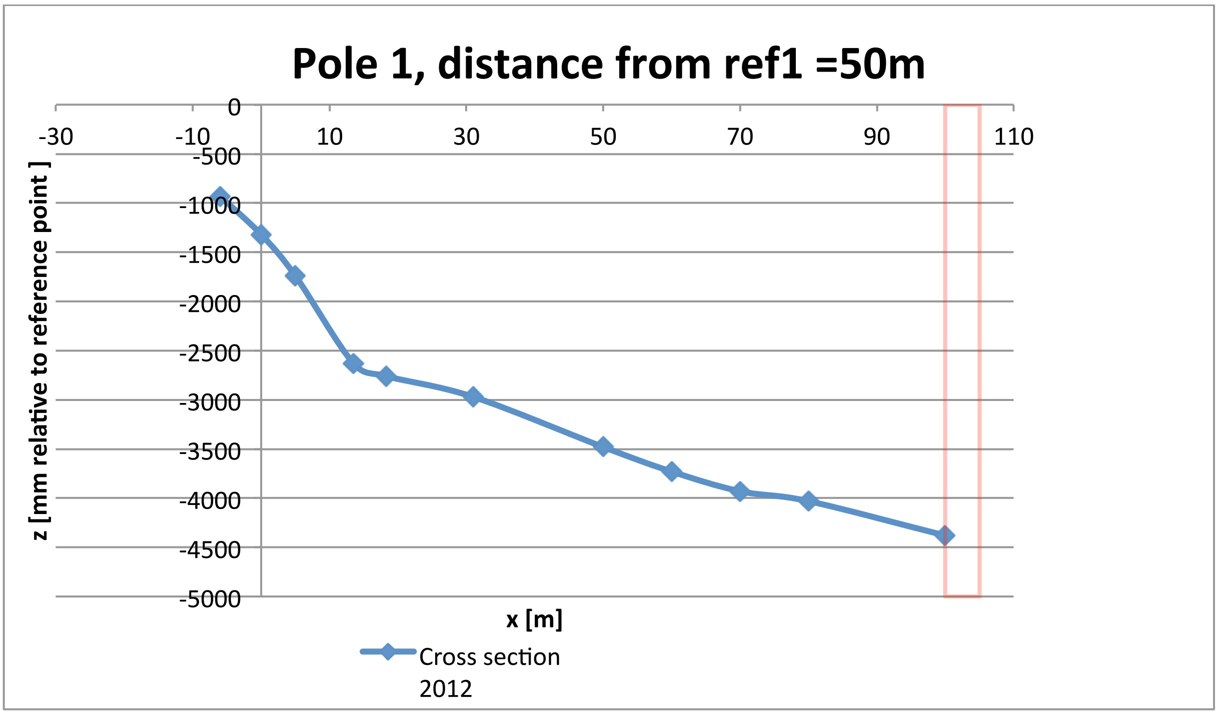


Figure 3-9 Cross-shore profile pole 1, 50m from reference point 1

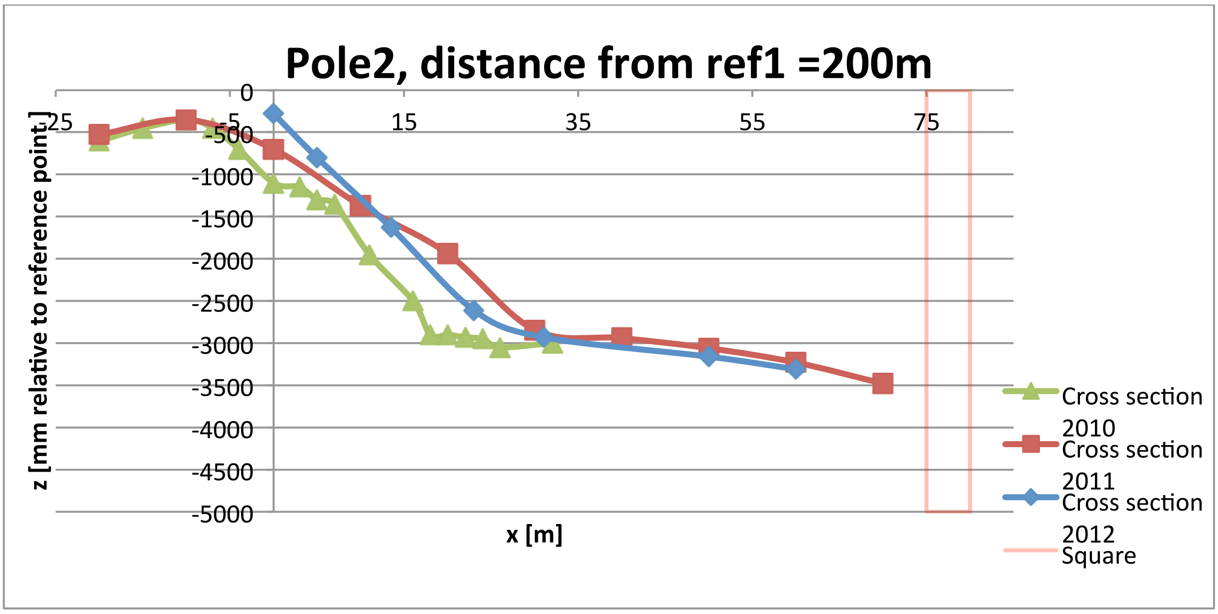


Figure 3-10 Cross-shore profile pole 2, 200m from reference point 1

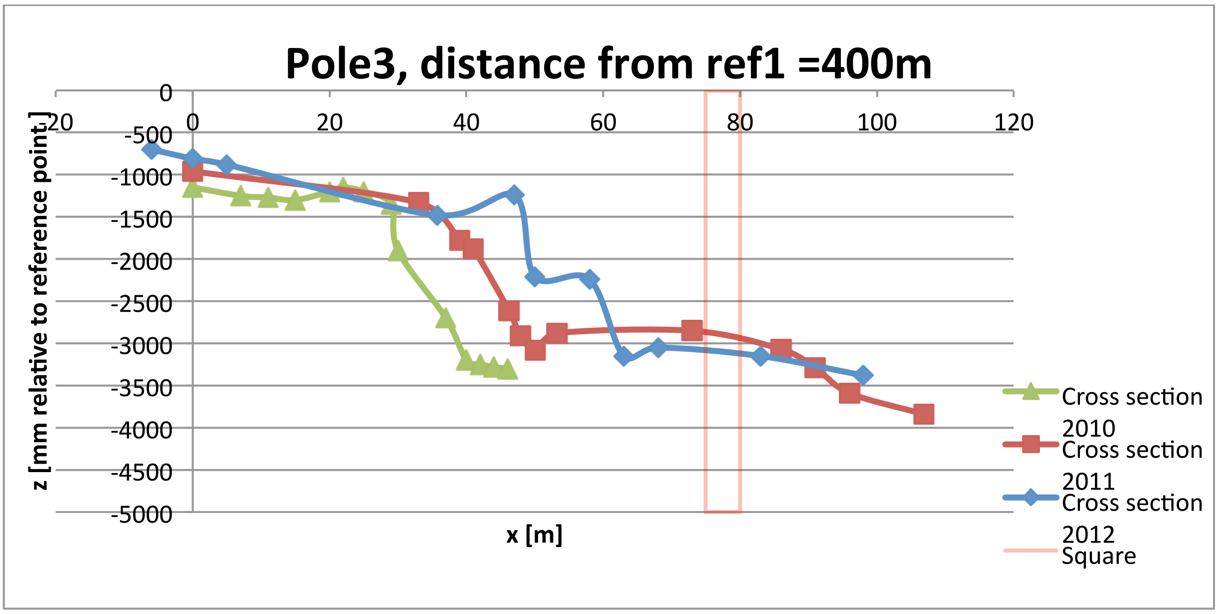


Figure 3-11 Cross-shore profile pole 3, 400m from reference point 1

3.4 Wave measurements (Asparuhovo Beach)

This is the first year that the waves at Asparuhovo are observed. The waves are measured with a wave pressure meter as mentioned in the previous sections. With use of these measurements wave characteristics in that area could be obtained. The reason of these measurements are the plans and requirements for building islands in front of the beach. In this paragraph the data from the measurements are discussed. Information about the wave pressure meter, the linear wave theory and the wave characteristics is given in Appendix A – Wave measurements.

3.4.1 Results and data

At Asparuhovo Beach there was one location chosen to measure waves with sufficient depth of approximately 8m (see Figure 3-12).

Figure 3-12 Location Wave Measurement Asparuhovo Beach (by Google Earth)

At this place (decimal UTM coordinates 43.182850E, 27.917476N) the pressure is measured four times. The duration of one measurement is twenty minutes and after one hour the instrument started to measure for the next time. In Table 3-1 the obtained wave characteristics are given for four windows. The short-term period is not representative for a wave climate. This must be at least one year. More detailed information about the analysis of this data can be found in Appendix A – Wave measurements.

Table 3-1 Summary Wave Data Asparuhovo Beach

Measurement	1	2	3	4
m_0 (-)	0.1125	0.1755	0.2174	0.1946
H_{m0} (m)	1.3414	1.6758	1.8649	**1.7646**
H_{rms} (m)	0.9485	1.1850	1.3187	1.2478
T_m (s)	5.6974	3.7828	3.7828	3.9252
$T_{0,1}$ (s)	5.9103	4.1883	4.1883	4.3946

$T_{-1,0}$ (s)	6.3118	5.2656	5.2656	5.5778
T_{peak} (s)	**7.3248**	2.5019	2.5019	2.5019

Shallow water can be determined by the rule of thumb:

$h < 0{,}05L_0,$

and for deep water:

$$L_0 = \frac{gT^2}{2\pi} = \frac{9.81 \cdot 7.33^2}{2\pi} = 83.88m$$

$h > 0{,}05L_0 \rightarrow 0.05 < \frac{h}{L_0} = \frac{8}{83.88} = 0.095$ (OK!)

At Asparuhovo the depth was 8m, which seemed to be by observation deep enough for the waves not be affected by the bottom. For instance, the waves did not break at that place. So, the linear wave theory could be applied and used to calculate the desired characteristics.

For the design of the island a significant wave height is required. For safety reasons and a lack of sufficient wave records the (maximum) significant wave height (H_s) of 1.76m and the peak period (T_{peak}) of 7.32s is used. An appropriate assumption of the maximum wave height (H_{max}) is twice the significant wave height. Accordingly, it is 3.52m. Mind that these assumption has high uncertainty due to the fact that the wave climate is not known.

3.4.2 SWAN 1D

This programme determines wave characteristics for a given depth profile, significant wave height and peak period. In Figure 3-13 measured waves are present at UTM 43.182850E, 27.917476N, assuming to arrive from North-East (winter wind). Note: direction is not measured.

With refraction the waves will following the grey line, which is 90 degrees to the contour lines in the coastal zone. The location where the waves run-up the shore will provide the depth profile (the red line perpendicular to the coast line).

The outcome of the SWAN 1D model are wave heights and wave periods over 600m. Additionally, the model gives XZ data only (z is the water depth and x the distance to the measuring point).

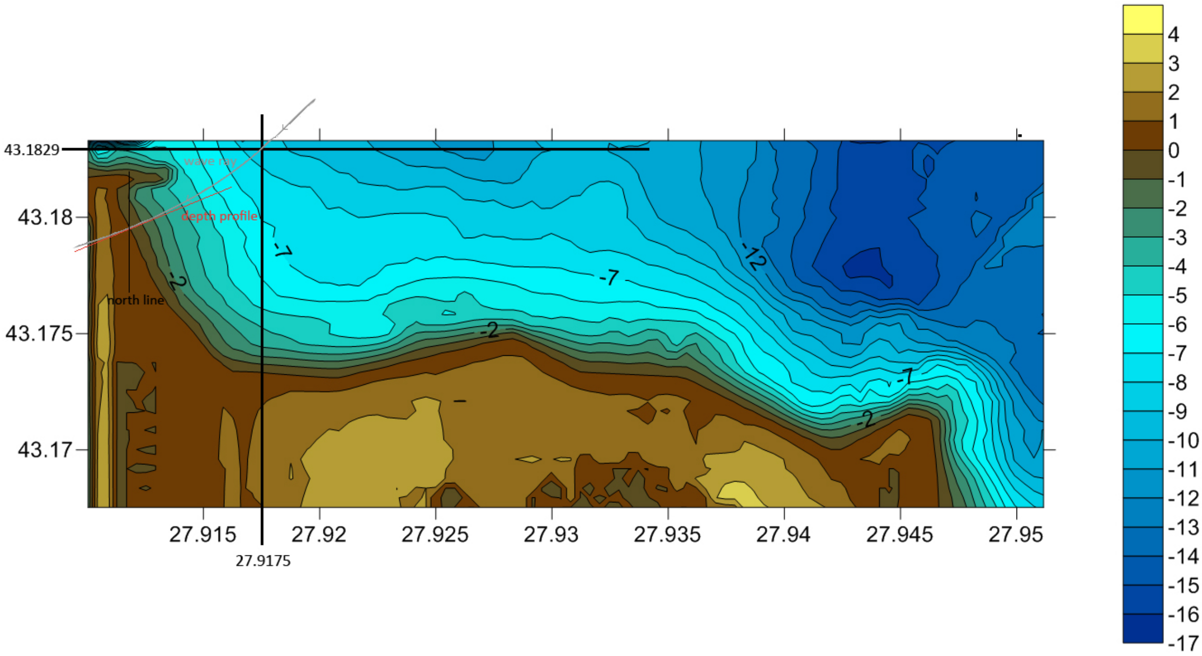


Figure 3-13 Contour map of Asparuhovo Beach with wave ray

Other input data:

- coast orientation is 250 degrees (horizontal line rotated clockwise)
- no currents (assumption)
- deep water wave height (Hm0 = 1.76m) and a deep water peak period (Tp = 7.32s)
- waves 45 degrees to the north line
- no wind (assumption)
- spectral parameters at 150, 300, 450 and 600m

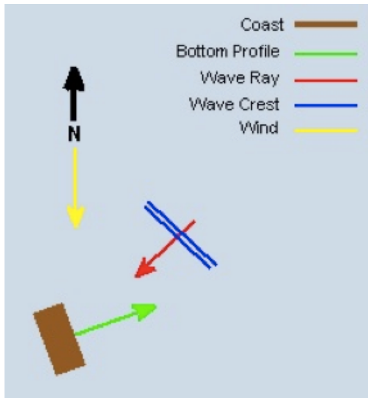


Figure 3-14 Shore line orientation and wave direction

The ray plots are the result of running this program given in Appendix A.6 - SWAN 1D. It can be seen that:

- the wave height decreases towards the shore continuously
- the mean period decreases towards the shore less continuously
- the wave spectrum developed at 150, 300 and 450, because 600m is the water line
- the deeper the water the more dominating is a higher wave

3.5 Conclusions and advice

As can be seen in the waterline measurements, the northern part of Asparuhovo Beach is not changing that much. This can also be seen in the second cross-section. The height difference between 2011 and 2012 is at maximum around 30cm's, a remarkable low value when the sometimes hard measure situation is taken to account. This might be due to that this part of the beach is protect by the seaport of Varna. Most of the bad weather comes from the north east and the northern part of the beach is in the lee of the port.

At pole 3 there are more differences noticeable between the past three years. This part of the beach is less stable at the waterline (as can be seen in the report of 2010). Because the big differences are at the waterline point, this is most likely due to seasonal variability (see winter/zomer profile Sirius Beach).

Overall: the south part of the beach is the more interesting/exposed part of the beach. As an advice for next year: move the cross-section measurements southwards.

Asparuhovo coastal waters and another location will be used to design islands in. To construct a stable and safe island wave characteristics are required. From analysis the significant wave height of 1.76m, the maximum wave height of 3.52m and the peak period of 7.32s have to be used. But the values are not representative for the wave climate, for the reason that only on measurement with four wave windows of 20 minutes is used. Hence, the maximum and minimum wave height could not be determined directly from the spectrum or probability distribution. The maximum wave height is therefore determined by a rule of thumb. The waves were measured in deep water. So, the waves were not breaking and the wave characteristics could be determined with use of the linear wave relation. The resulted wave characteristics are used for designing the islands in the coast of Asparuhovo.

3.6 Breakwater

In this chapter the breakwater at Asparuhovo Beach is analysed. This has been done for the past two years. First there will be a brief introduction of the breakwater, after this introduction there will be a description of the different kind of protecting layers that are used in this breakwater, after that the technical state of the breakwater will be discussed with all the different material and falling mechanism. After the technical state of the breakwater there is a section with a calculation about the design wave height, which will be calculated by the size of the tetrapods, and at the end there will be a conclusion with respect to the previous years and how to maintain this breakwater.

3.6.1 Introduction

The breakwater at Asparuhovo Beach is situated at the north side of the beach. The breakwater has two main functions: maintain the channel entrance for the port of Varna and maintain the beach at Asparuhovo. The overview of the breakwater is shown in Figure 3-15. In this picture A is the breakwater, B is Asparuhovo Beach and C is the main channel. The channel north of the breakwater is main connection with the port of Varna and the black sea. The breakwater prevents siltation of this very important channel. The secondary task is the prevention of erosion of the beach during storms.

Figure 3-15 Overview

3.6.2 Protecting layers

The break water at Asparuhovo exists out of different types of protecting layers. This is because at a wave attack the waves at the end of the breakwater are much larger than at the land side of the breakwater. In the picture below, Figure 3-16, there are four different layers of protection specified. These layers will be further more investigated.

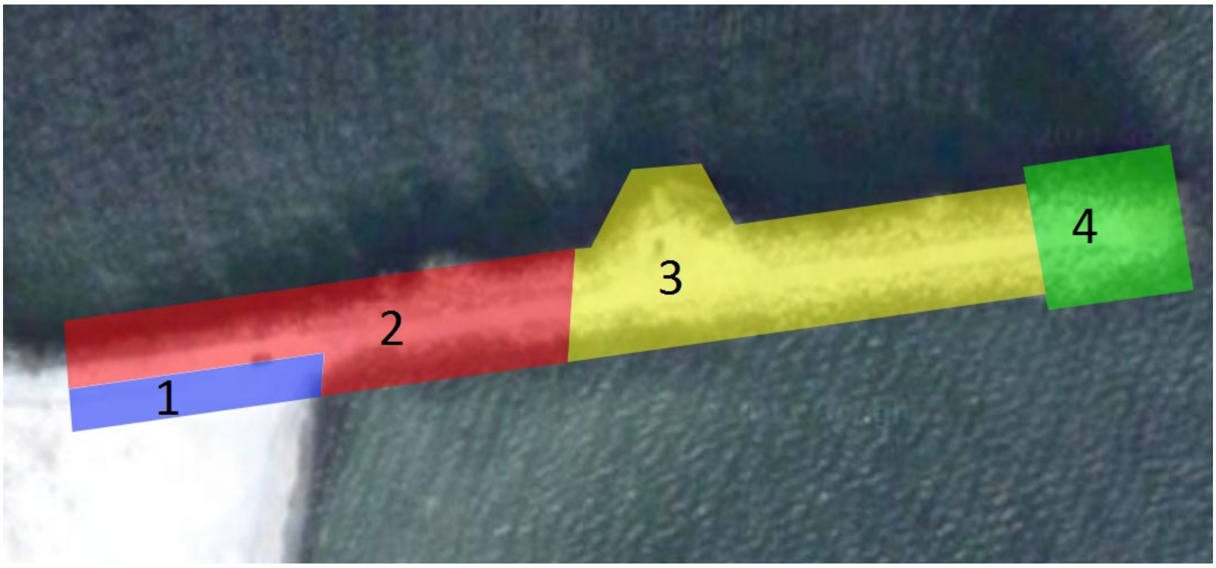


Figure 3-16 Different sections breakwater

Section 1

This is the first part of the south side of the breakwater. This part is protected by mainly the beach itself, as shown in Figure 3-17. This layer of protection can be quite weak because of the shelter that it is in. This part is about 60m long. There are a few natural stones with a d_{n50} of around 30cm. These are rocks that has moved their by the sea.

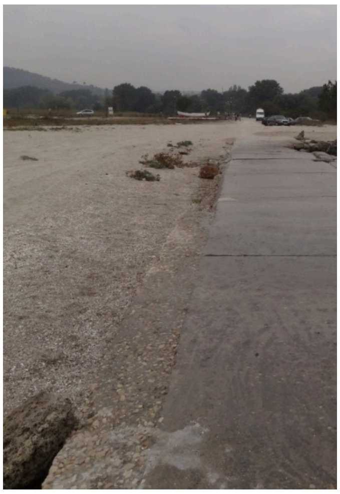


Figure 3-17 Beach protection

Section 2

The second section is much heavier defended than the first section. Because at the first section there are almost no waves and section 2 is more open for waves. The protection is still smaller than at the end of the break water because the biggest waves will break at the end of the break water. This part of the breakwater is mainly defended by natural stones with a d_{n50} of about 40cm, as shown in Figure 3-18. The gaps between these rocks are mainly filled with sand. This sand comes from the sand that the waves take with them when it hits the breakwater. The dimensions on the north side are about 120m and on the south side 60m.

Figure 3-18 Section 2

Section 3

This section is protected by concrete cubes. At the beginning the cube size is 1m*1m*1m, assuming that the concrete has a density of 24000 kg/m³ the total mass of these cubes is 2.4 tons per element and at the end where the waves can be bigger the cubes have the dimension of 1.19m*1.23m*1.42m, this gives a total mass of 5.0 tons per element. These cubes are randomly placed at both sides of the breakwater, see Figure 3-19. At the north side (channel side) there are also placed some old reinforced rubble to protect the breakwater, as shown in Figure 3-20. In this section there is also a widening of the breakwater. The exact reason for this widening is not clear; the only guess that can be made is that this was created for truck passing during construction. In the Netherlands you would not find such widening. This section has a length of 120m.

Figure 3-19 Randomly placed cubes

Figure 3-20 Old reinforced rubble

Section 4

At the end of the breakwater is section 4. This section is the most protected part of the breakwater. This part is protected by mostly tetrapods and also some cubes. The cubes are randomly placed between the tetrapods, but they are also clearly moved by a storm at some places. The tetrapods have an overall height of 2.79m. There are several layers, especially at the end of the break water there are 2 layers, as shown in Figure 3-21.

Figure 3-21 Tetrapods

3.6.3 Technical state of the breakwater

To start with the conclusion the breakwater is in a bad condition', this is actually an understatement, it is much worse. This was already the conclusion of the report from the last two years. This is due to constructional mistakes, poor quality of the material that has been used and the lack of maintenance. In order to confirm this statement there will be pictures compared from the previous two reports with the actual situation.

It starts with a crack from the beginning to the end of the breakwater due to an iron pipe that goes through the breakwater. In the three pictures below, from left to right: 2010, 2011 and 2012, it is clear that the crack get bigger each year.

Figure 3-22 Crack 2010

Figure 3-24 Crack 2011

Figure 3-23 Crack 2012

The surface plates are the most week points at this breakwater. There are also parts that are totally destroyed. Each year it gets in a worse state as shown in the picture below. These surface plates are all connected with each other. The surface plates have a foundation of natural rocks. This combination of inner connection and foundation creates big upward stresses when waves come in. This in combination with settlements that does not uniform drop and the natural rocks underneath the surface plates that are washed away due to storms causes the fail of the surface plates.

Figure 3-25 Surface plates 2010

Figure 3-26 Surface plates 2012

The tetrapods that are used are also from bad quality. In the picture below there is a tetrapod with a breaking line. This breaking line is in all probability a construction fault. The constructor of this tetrapod probably take a break when it was filling it with concrete, maybe he even waited for the weekend to past. That way the tetrapod did not become one solid block but instead it consist more the less out of two parts. There are also some tetrapods with broken legs; this is because the tetrapods move due to the storms. The teachers with us told that he have seen them move.

Figure 3-27 Broken tetrapod

3.6.4 Design wave height

To make the story complete the design wave height of this breakwater has to be calculated. To find the biggest design wave height the heaviest armour layer has to be taken in to account. These are the tetrapods. To calculate the design wave height the Hudson formula for stability of breakwater will be used. Because the slope of the breakwater was not measured, we use a slope of 1:4. For the value of K_d we use 0.7, this is the value at the trunk of the breakwater. This is the highest value that will occur so it is the dominating value to get the highest waves.

The Hudson formula for the design wave height is the same as in chapter 'Groin St. Constantine':

$$M_{50} = \frac{\rho_s H_s^3}{K_D \Delta^3 \cot\alpha} \rightarrow H_s = \sqrt[3]{\frac{M_{50} K_D \Delta^3 \cot\alpha}{\rho_s}}$$

To find the mass and the volume of the tetrapod, the book from the course 'Introduction to bed, bank and shore protection' is used.

$C = 0.477 * H$
$V = 0.280 * H^3$

With:
C = is the leg length of tetrapod
H = is the total height of the tetrapod
V = the total volume of the tetrapod

We have measured C=1.33 m at the breakwater
We assume that the mass of the concrete is 2400 kg/m^3, these results in the following;

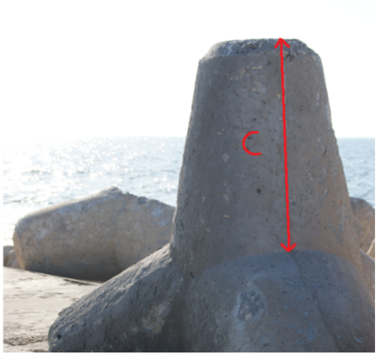


Figure 3-28 Leg length of tetrapod

H = 2.79 m
V = 6.25m^3
M_{50} = 6.25 * 2400 = 15000 kg
Now we can calculate the design wave height with the formula of Hudson using the following values;

M_{50} = 15000 kg
ρ_s = 2400 kg
K_D = 7
Δ = relative density $((\rho_{s-} \rho_w)/\rho_w)$ = 1.33
Cot α = slope of breakwater (we assume a design slope) of 1:4 = 4

From this it will follow that the design wave height for the groin is 7.44 meter. This is a much higher value than they found last year.

The damage coefficient of the tetrapod will be much lower, because this is for a double layer. There are two layers of tetrapods but these are not well placed, this could explain a bit of the different. Besides this a lot of the tetrapods are already broken after a maximum of one year at the groin. This will decrease the design height even more. The strange part is there H value for the tetrapods are much lower. Or there is a mistake made or they have dropped new tetrapods at the break water.

Last year they found a value between 3-4 meter for the significant wave height. The different is almost twice as high.

3.6.5 Conclusion

From this chapter it is clear, even already mentioned, that the breakwater is in a very miserable state. This is mainly because of the poor construction of the breakwater. One of the biggest failures of the breakwater is the steel pipe that goes through the service plates. Because of this pipe the whole breakwater has already a fracture. The state of all the concrete is actually poor. Everywhere you could see that the concrete was failing, even the, mostly very strong, tetrapods were broken. The lack of maintenance causes the breakwater to fail even more.

If the government of Bulgaria want to maintain this breakwater it is clear that they have to maintain it better. In the picture of this year in comparison with the last 2 years you can see that the quality of the breakwater is descending very quickly. If they want to fix it they have to create a better protection around the breakwater with high quality tetrapods. They also have to fix the surface plates and most of all fix the foundation beneath it.

For the next time they create such a breakwater they first have to create a solid foundation. The foundation from natural rocks is not bad at all but then you have to make it flat and with a geo textile. That way you prevent inner stress in your surface plates and you prevent the flush of your foundation. They also have to use enough coverage of your steel in your concrete so it would not corrode. For the outside they have to use good quality tetrapod. If you use poor quality and they brake it makes no sense at all to use such big and expensive armour.

4 Echosoundings

In this chapter we consider the bathymetry at Asparuhovo Beach and the east side of Lake Varna near the marina. The measurements are carried out by use of an echosounder, which was possible thanks to the good weather circumstances. After collecting, refining and processing the data with the use of Surfer, we were able to create a visualisation of both areas. In the following paragraph we will consider the measurements and results near the marina and in the next paragraph those at Asparuhovo Beach. Also the results from previous years are shortly considered. To finalize the chapter we dive a little deeper in the used interpolation method to create the images.

4.1 Lake Varna

At the marina several measurements were done during the day, considering mainly the in- and outlet of the marina and an area of about 300 by 400m close by. A total of 906 measurement points were used and to represent the coast line we created another 140 artificial data points (depth 0). The used coordinate system is UTM 35T and is measured inm (see Figure 4-1 Measurement and artificial points near the marina).

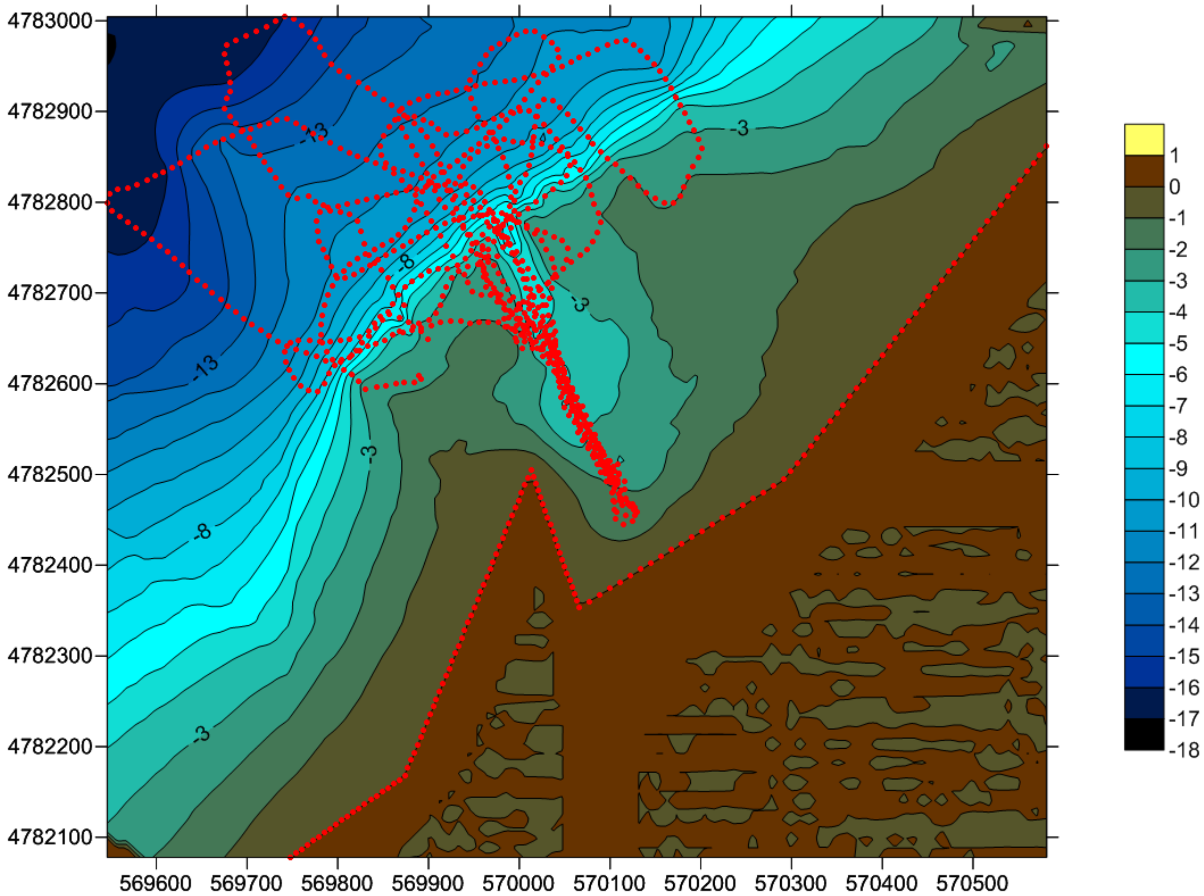


Figure 4-1 Measurement and artificial points near the marina

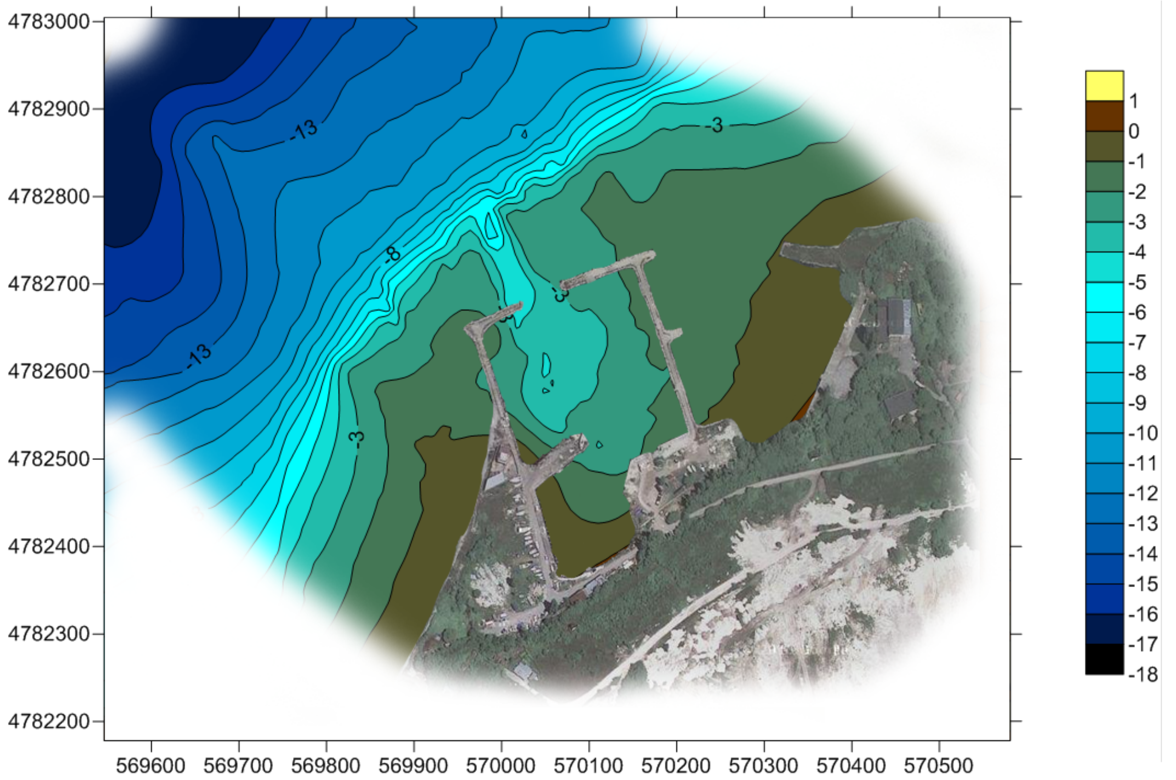


Figure 4-2 Depth contours near the marina at Lake Varna

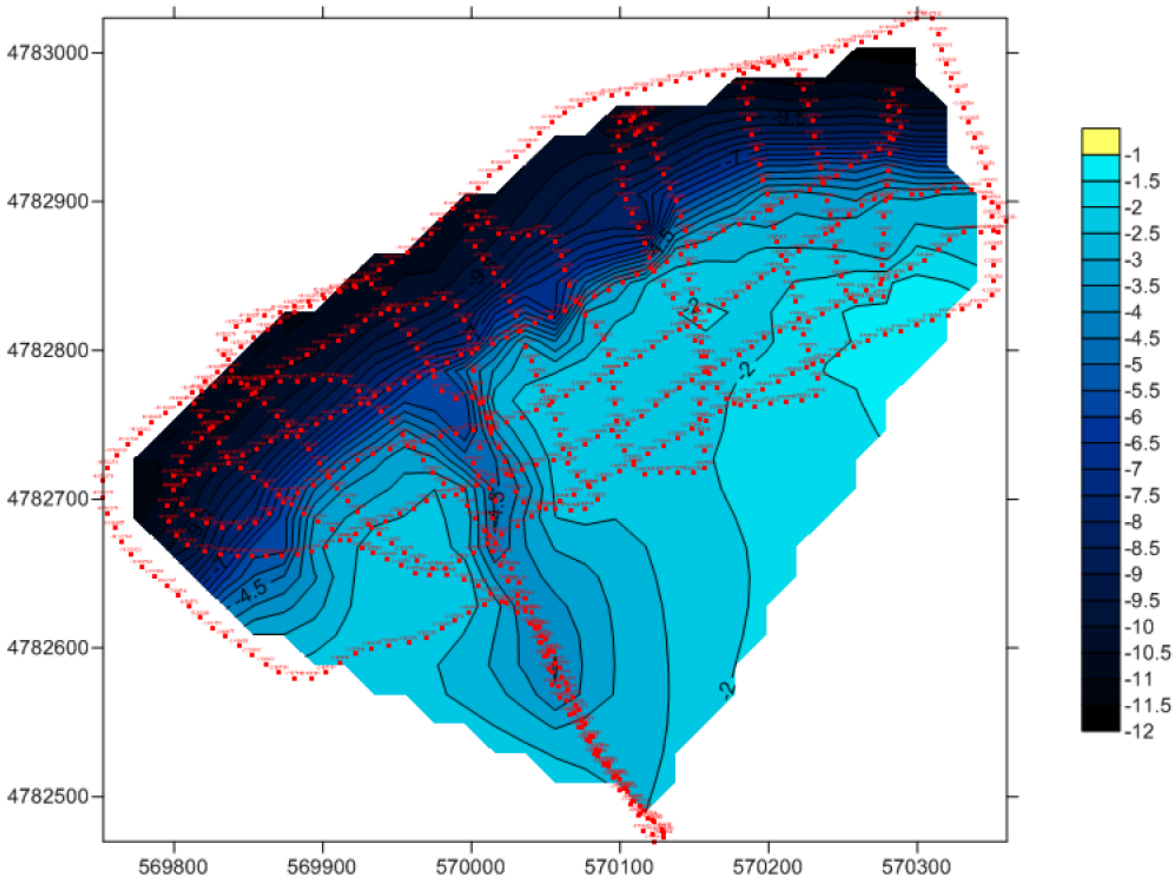


Figure 4-3 Depth contours and measurement points (2010)

As is seen on the picture above, some depth contours are not very relevant, since they are merely an extrapolation of the other data points. Furthermore, to get an idea how the marina is situated we made a total picture with the relevant depth contours and the marina. This is shown on the next page. Also a picture of the measurements done in 2010 is provided. When the pictures are compared two remarks can be made. First of all, the measurements in 2010 had a more structured pattern and considered a somewhat larger area, especially in the north-east corner of the picture. Second, the overall depth contours have relatively the same shape, but other values, since in 2010 no artificial (or measured) zero-contours were added to the data. This means that there is not any land and the depths are considered to be larger there than they actually are.

4.2 Asparuhovo Beach

At the coast near Asparuhovo measurements were done over an area of about 600x2500m. This to get an image where it is possible to review the bathymetry along the entire coast there. Over 18000 data points were used provided by the Echosounder and a GPS walk on the beach. For the other coast lines about 200 artificial zero points were added. The coordinate system is in decimal degrees. The measuring points are shown in Figure 4-4 below.

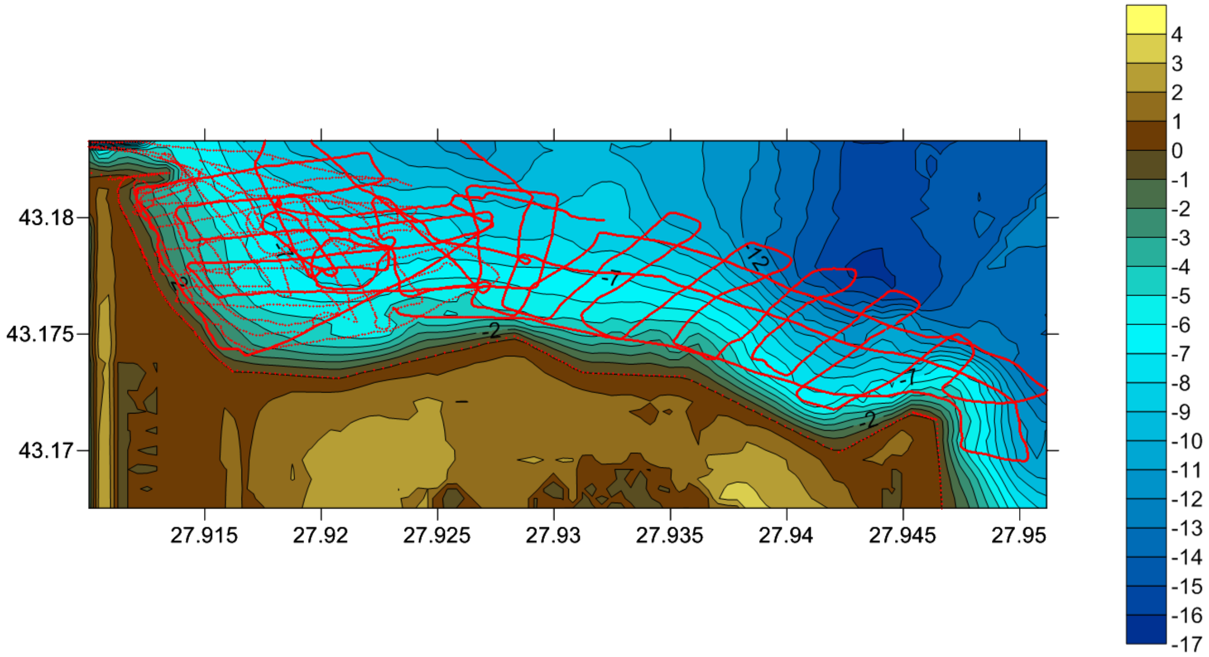


Figure 4-4 Measurement- and artificial points near Asparuhovo Beach

If we now consider only the valid depth contours, in other words the contours at which there are actually measured points, we get the following picture. Notice that also a conversion has been made from the decimal degrees to UTM 35T. Decimal degrees do not work orthogonally, so you get a somewhat stretched image that way. On the next page we will discuss this result with the plots from the previous years.

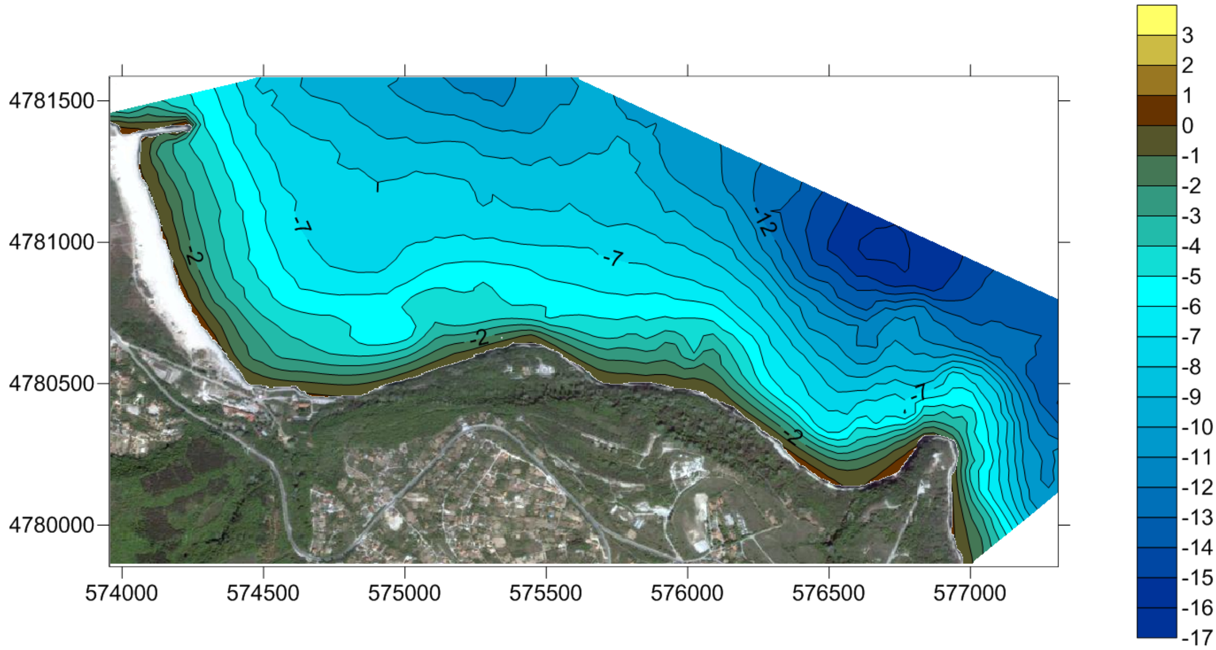


Figure 4-5 Depth contours near Asparuhovo Beach (UTM)

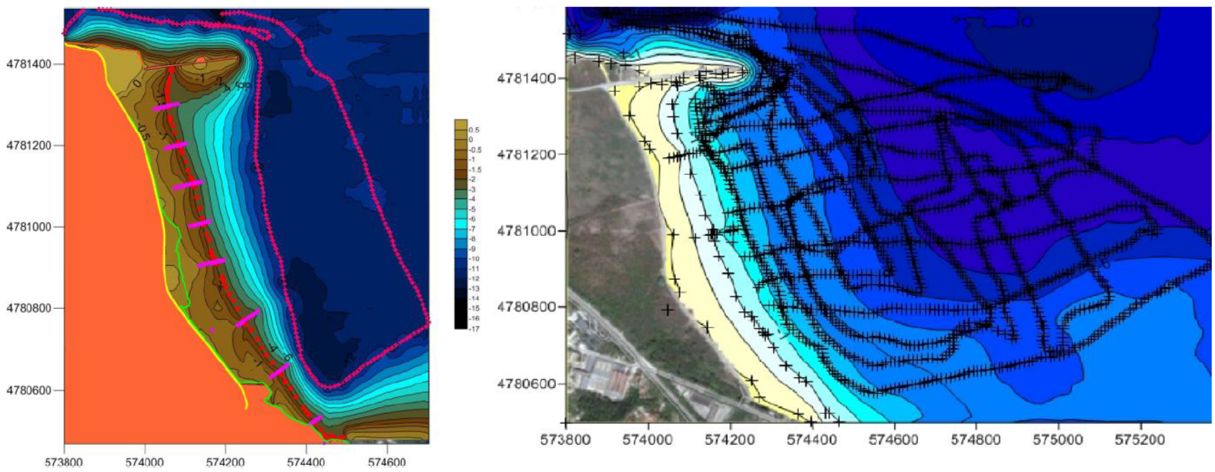


Figure 4-6 Depth contours at Asparuhovo Beach (2010 left, 2011 right)

In Figure 4-6 above both the plots from 2010 and 2011 have been added, they can also be found in the reports from those years. We can conclude that the picture from 2010 is more or less worthless to compare with, for several reasons. First of all, no clear zero-line has been added, so the depths are not comparable. There is a zero-line, but certainly not at the waterfront. Secondly, only one round has been made with the echosounder, so no detailed bathymetry is given from the plot. The only thing that the plot from 2010 does provide is the gradual bottom slope, but near the breakwater this is also pretty inaccurate compared to the plots from 2011 and this year.

If we look at the plot from 2011 (we took this one, because the 3D plot was nice, but not very handy for this purpose) we can see the area which is 'echosounded'. This area is densely measured, but a lot smaller than our area. Also clearly visible is the zero-line, although the amount of data points is limited. Considering the zero-points along the shoreline, we can try to estimate a difference in the coastline compared to last year. For this purpose we consider the East-coordinates at North-coordinates 4781200, 4781000 and 4780800 respectively. From this simple analysis we can conclude that according to this data there is no significant difference between 2011 and 2012. It can either be the case that there is no difference or the GPS zero-coordinates differs too much to notice it.

In the chapter considering the cross-sections at Asparuhovo Beach more attention is paid to this.

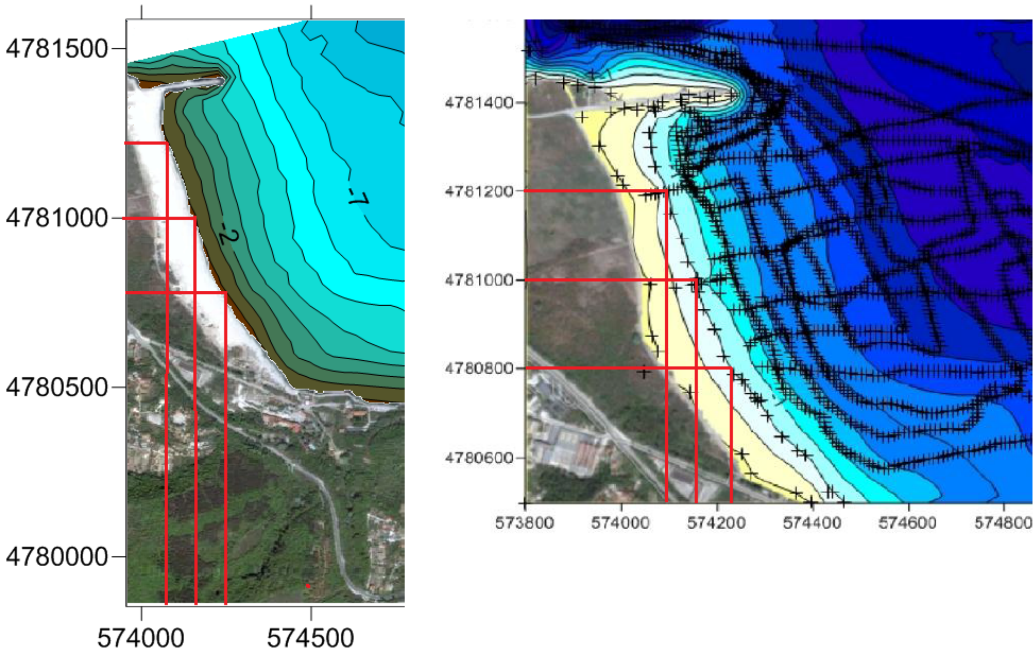


Figure 4-7 Coastline difference with echosouding and GPS data

4.3 Explanation of interpolation methods within Surfer

To be able to plot the recorded data on a map, Surfer uses different interpolation and extrapolation techniques. The first step done is to analyze the available data and to plot a grid using the available data points and thereby slightly extrapolating outside the area. The next step is to use (optionally different) numerical operators to translate the random data points (XYZ-values) to the nodes of the grid. These interpolated and extrapolated data points (in the grid) are used to create isoclines of equal height. These lines can be plotted to present the recorded data visually.

There are different numerical operators which can create the data points on the grid. Surfer 9 supports the following twelve techniques: Inverse Distance to a Power, Kriging, Minimum Curvature, Modified Shepard's Method, Natural Neighbor, Nearest Neighbor, Polynomial Regression, Radial Basis Function, Triangulation with Linear Interpolation, Moving Average, Data Metrics and Local Polynomial. From these techniques the following three techniques (see also Figure 4-8) produced the best results:

- Kriging
- Minimum Curvature
- Radial Basis Function

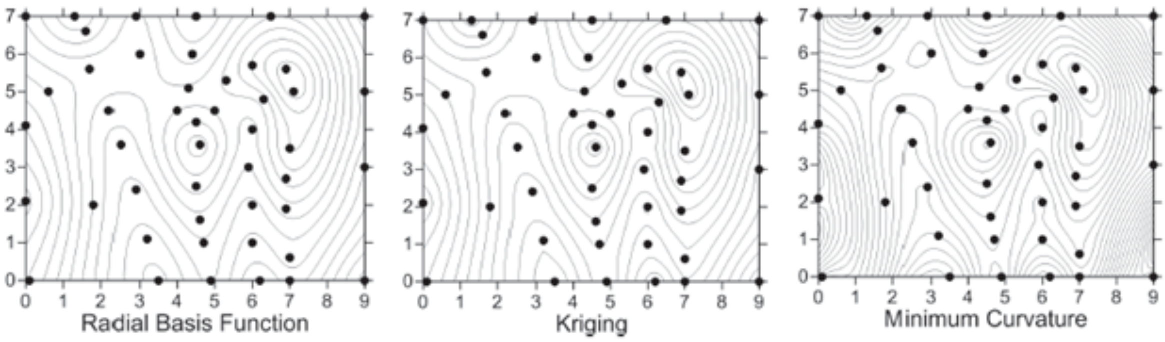


Figure 4-8 Three good numerical operators to use in Surfer 9

4.3.1 Kriging

Kriging attempts to express trends suggested in your data, so that, for example, high points might be connected along a ridge rather than isolated by bull's-eye type contours. There are two different types of Kriging: Point Kriging and Block Kriging. Point Kriging gives sharper shaped images in contrast to Block Kriging. The images at Lake Varna and Asparuhovo Beach are plotted with the use of Point Kriging. This technique resulted in fairly sharp but smooth images.

4.3.2 Minimum Curvature

The interpolated surface generated by minimum curvature is analogous to a thin, linearly elastic plate passing through each of the data values with a minimum amount of bending. Minimum curvature generates the smoothest possible surface while attempting to honor your data as closely as possible.

4.3.3 Radial Basis Function

In terms of the ability to fit your data and produce a smooth surface, the multi-quadric method is considered by many to be the best. All of the Radial Basis Function methods are exact interpolators, so they attempt to honor your data. To smoothen the surface, a smoothening factor can be applied.

5 Groin St. Constantine

In this chapter we will evaluate the groin at the beach of St. Constantine. This groin is situated close to the Sirius Beach hotel, were we stayed during the trip. As shown in the figure below the groin is located approximately 400m south of the hotel. This groin is around 25 years old. Furthermore we will tell a little about the harbour located 300m south of the groin in front of Grand Hotel Varna. This harbour is still "under construction" and it probably will be for years to come. A fun fact about the hotel in front of the harbour: They could not get a permit to build the hotel, so the main function of het hotel is actually to prevent landslides due to high water.

Figure 5-1 Overview of the area

5.1 Groin

Compared to the report of 2011 a lot has happened at the groin. As seen on a picture of last year (further in the report), there were no tetrapods at the groin. Also we had to take another baseline because the place where the old one was, is now covered with rocks as can be seen in the figure below. The right part of the groin in this picture was used last year for the measurements. Probably this is because of heavy storms which moved a lot of rocks. First we will tell a little about the base layer and the tetrapods. This will be followed by the measurement of the cross-sections and the volume of the groin.

Figure 5-2 Groin anno 2012

5.1.1 Base layer

The base layer consist of natural stone and the core of the groin is made of caissons. Last year they calculated the D_{50} of the stones. This was 0.54 meter and the weight is 378 kg. They concluded that a

design wave height of 1.86 was used for the groin. But just like this year they noticed that a lot of the stones are broken and replaced. This means the design wave height was probably higher.
This year, because of the new tetrapods, another calculation have to be made in order to find the new design wave height.

5.1.2 Base layer

When the groin was designed the Hudson formula was used. This was a fault during design, because Hudson is not valid for impermeable breakwaters such as breakwaters with a core of caissons. Instead of the Hudson formula the Van der Meer formula had to be used.

With the Hudson formula the design wave height can be calculated;

$$M_{50} = \frac{\rho_s H_s^3}{K_D \Delta^3 \cot\alpha} \rightarrow H_s = \sqrt[3]{\frac{M_{50} K_D \Delta^3 \cot\alpha}{\rho_s}}$$

First we have to find the M_{50} the tetrapod. This can be done using the formulas from the book of the course 'Introduction to bed, bank and shore protection;

C = 0.477 H

C = is the leg length of tetrapod
H = is the total height of the tetrapod
V = the total volume of the tetrapod

V = 0.280 H^3

We assume that the mass of the concrete is 2400 kg/m^3, this results in the following;

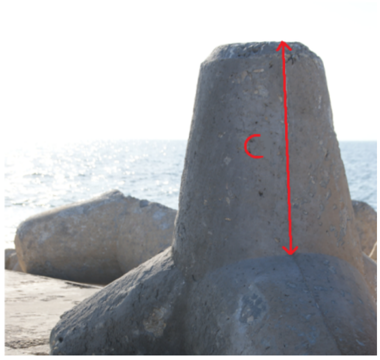


Figure 5-3 Leg length of tetrapod

C = 0.81m
H = 1.70 m
V = 1.38 m^3
M_{50} = 1.38 * 2400 = 3312 kg
Now we can calculate the design wave height with the formula of Hudson using the following values;

M_{50} = 3312 kg
ρ_s = 2400 kg
K_D = 7.2 (damage coefficient K_D; 7.2 is for a double layer tetrapods attacked by breaking waves (Breakwater and Closure Dams))
Δ = relative density $((\rho_s - \rho_w)/\rho_w)$ = 1.33
Cot α = slope of breakwater (we assume a design slope) of 1:5 = 5

From this it will follow that the design wave height for the groin is 4.89 meter. This is a much higher value than they found last year

The damage coefficient of the tetrapod will be much lower, because this is for a double layer. On the groin of St. Constantinee you can hardly call it a single layer because the tetrapods are randomly placed and have no interlocking function. This results in a lower design height.
Besides this a lot of the tetrapods are already broken after a maximum of one year at the groin. This will decrease the design height even more.

Last year they found a value of 2.04 meter for the significant wave height. This means that the value found this year is more than two times higher. Because of all the reasons that were given before the significant wave height will still be ±2.00 meter. It is hard to determine the exact value because of all the different stones that are used and the random placement of the stones.

5.1.3 Visual inspection

Compared to last year a lot happened at the groin. There were tetrapods placed and a lot of stones moved and/or were broken. The baselines of the previous years were not visible anymore, because rock was all over it as you can see on figure 5.4.

The stones were moved during storms from the south. Also on the north side stones were moved. Besides that the tetrapods are not heavy enough, the quality of the concrete is also not very good. A lot of them are broken as you can see in figure 5.5.

On the north side there were also stones moved. No tetrapods were visible here, so probably they were not placed on the north side.

Figure 5-4 Last year's baseline was at the right hand side

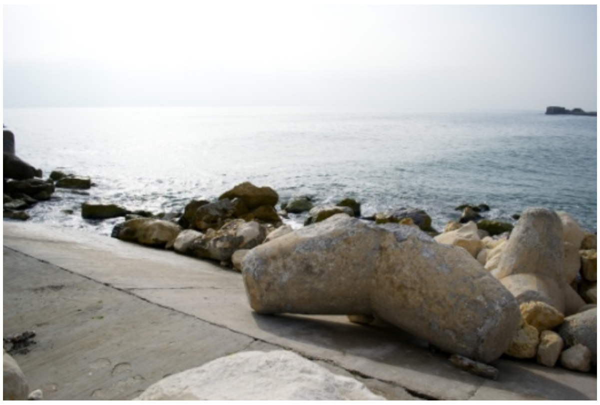


Figure 5-5 Broken tetrapod

5.2 Measurement setup

In 2002 the groin near St. Constantinee is measured for the first time. Last year (2011) they marked a base point at the groin, just before the bent in the groin see figure below. Comparing this photograph with this year’s photo, one can clearly see the difference of the concrete bar in the previous year. This is now completely gone. This year we were not able to take the same base point due to the damaged bar, so we had to move a little bit to get measurements. All measurements have still reference to the green point for correct comparison.

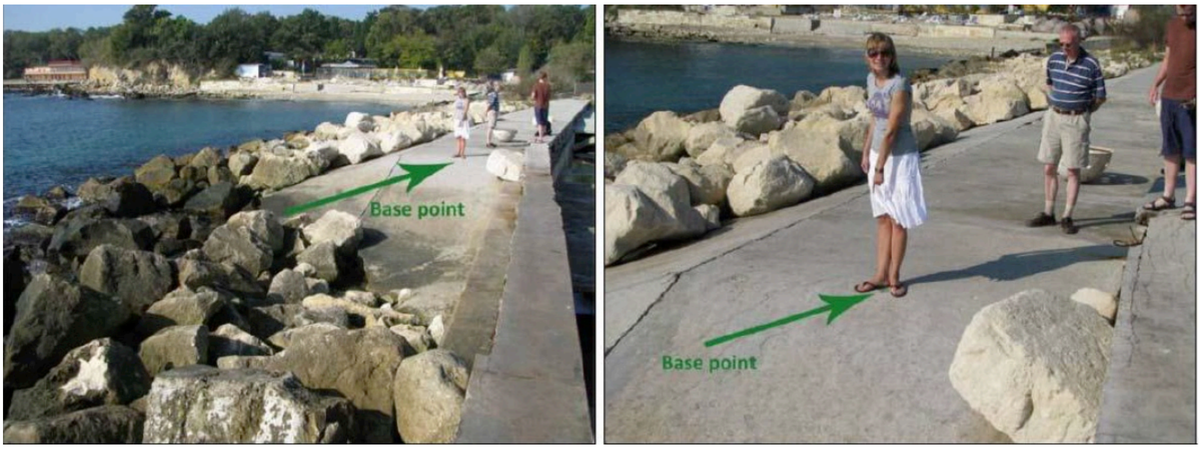


Figure 5-6 Base point 2011

Figure 5-7 South side of the groin (several (broken) tetrapods are visible)

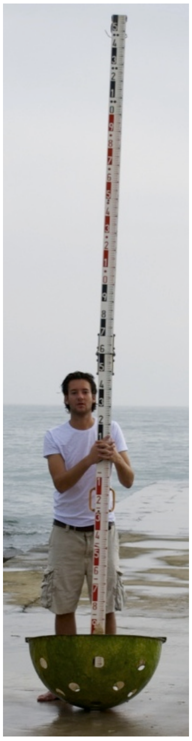


Figure 5-8 Theodolite

From the base point in the direction of the beach, a straight line over the crest of the groin, the base line is created with reference points every 10m. In the figure below an overview of the breakwater is given (source: report 2011). Cross-sections will be measured perpendicular to the base line.

This year (2012) the same cross-sections where measured as last year (2011) were they made a mistake. In the years 2002 to 2004 they measured at distances L = 5m, L = 15m, L = 25m, L = 35m, L=45m and L=55m from the reference point. This year the measured cross-sections are at: L = 0m (base point), L = 10m, L = 20m, L=30m, L=40m, L=50m, L=60m. Because different cross-sections where measured the other years it is not possible to make a comparison with the cross-sections of these years. However, with the measured cross-sections the volume can been calculated, in this way the volume can been compared with previous years.

The measurements are performed using a theodolite, a measuring rod fixed to a hemisphere and a measuring tape. Measurements are done relative to the base point and the mean sea level. The hemisphere at the end of the measuring rod (see picture on the right) is used to smooth the measured profile since it prevents that the rod is being positioned in a gap between two stones. The size of the hemisphere has to be around half the size of the rocks and thus satisfies. It does not satisfy to half the size of the tetrapods. It is relatively hard to determine a good size for the hemisphere due to the variety of stones and tetrapods.

The crest height is measured at every profile at the edge of the concrete slab. There was about 25 cm difference in height between the seaward side and the landward side of the groin. The height increased towards the landside. This height difference is negligible, since it will have no impact on the functioning of the groin. The height difference was also noticed in previous years.

5.2.1 Cross-section

Last year different cross-sections where measured in comparison with the years before. This year it is decided to do the same measurements as previous year. The comparison of the cross sections can thus only be done for these two years. However, the comparison for the volume is done for the last ten years as it is not dependent were the cross sections are measured.
To get a complete overview of the comparison of the cross-sections for the years 2002-2003-2008 reference is made to the report from the year 2012.

In the figures presented below the baseline is located at x=0. The negative values along the x-axis represent the northern side of the groin and the positive values represent the southern side. The concrete slab is assumed to be at a fixed level and is not included in the figures. The y-direction gives the height, where y = 0m is Mid Sea Level (MSL).

The north side of cross-sections L = 0m and L = 10m have not been measured due the relatively rough sea state condition. It was not safe to measure the groin in this side. For the cross-sections L = 20m, L = 30m, L = 40m and L = 50m both the north and south side of the groin is measured in previous and this year.

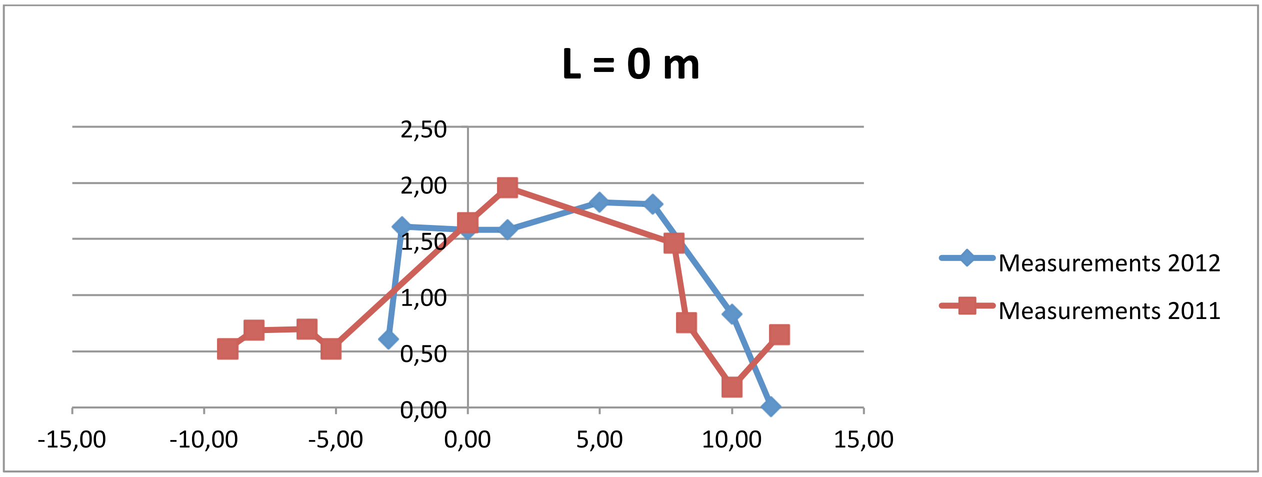


Figure 5-9 Cross section of breakwater on base point

For L = 0m are no significant changes are found in the comparison between this and previous year. For L =10m there is relatively large difference on the south side after approximately 10m from the reference point. When looking at the pictures from last year and this year, it can clearly be seen that there are tetrapods deposited on the south side of the groin. The top layer of last year can acts as an interlayer between the concrete slab and the tetrapods. However the tetrapods are placed directly on top of the concrete slab, so no after the winter it is expected that they are moved land inward. As mentioned earlier, no measurements were taken on the north side of the groin due to the rough sea state.

Figure 5-10 North side of the groin (almost no tetrapods are visible)

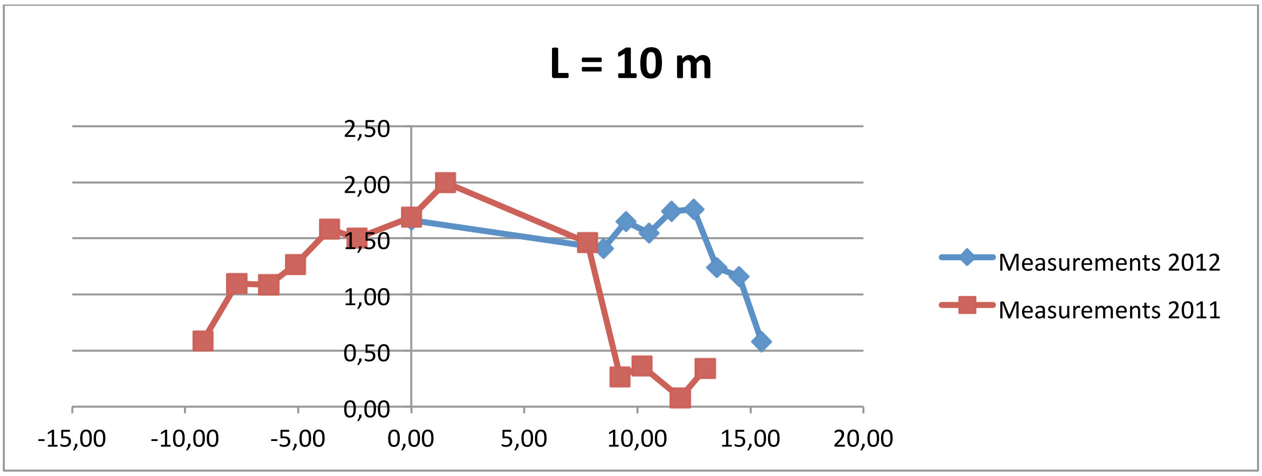


Figure 5-11 Cross section of breakwater L=10m

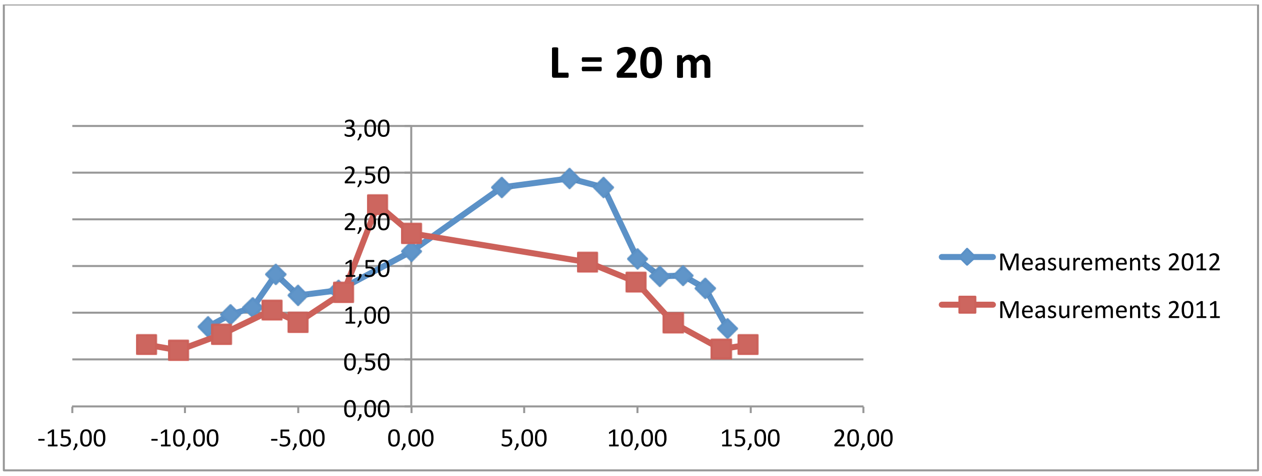


Figure 5-12 Cross section of breakwater L=20m

The same can be said here about the south side of the groin. On the north side no significant changes are found in the comparison between this and previous year.

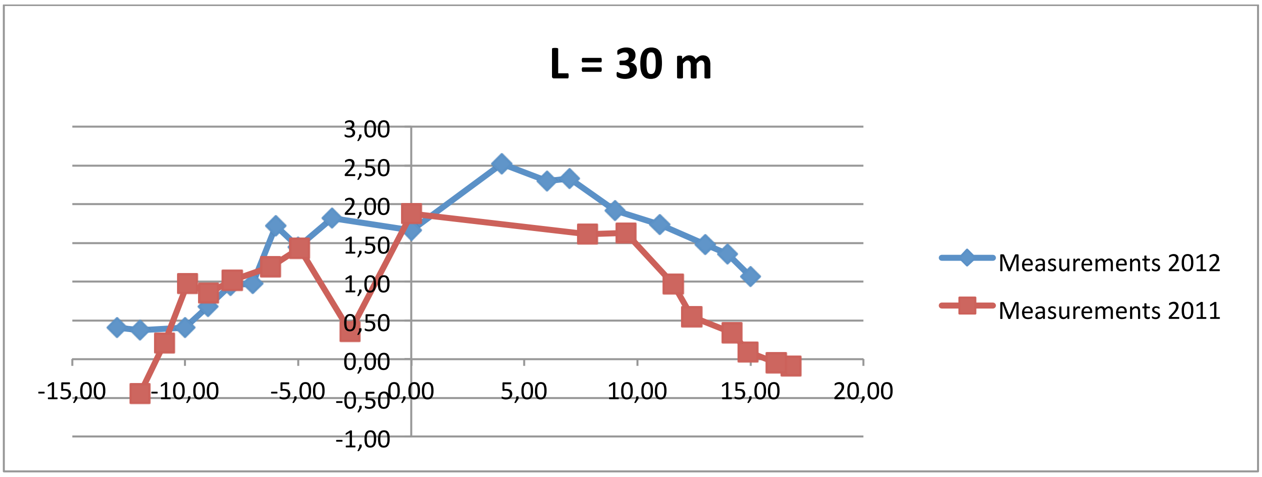


Figure 5-13 Cross section of breakwater L=30m

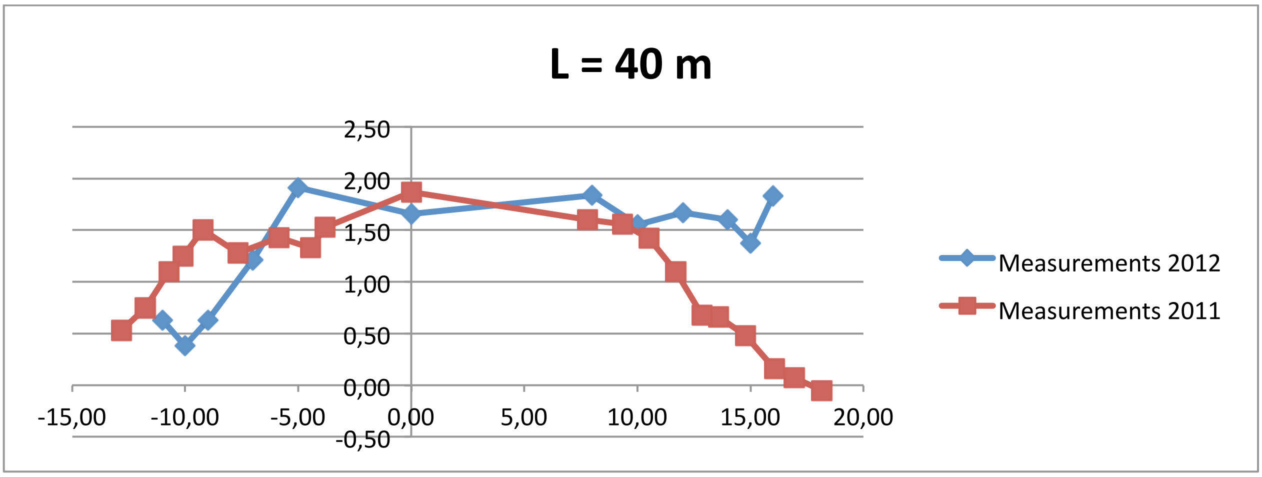


Figure 5-14 Cross section of breakwater L=40m

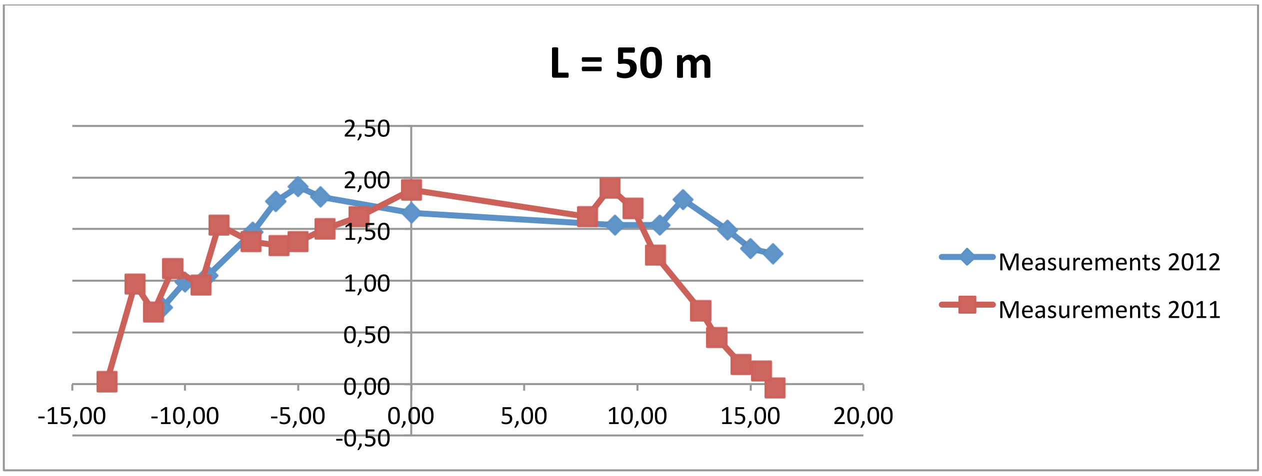


Figure 5-15 Cross section of breakwater L=50m

5.2.2 Change of volume

Within this paragraph the change of volume over the years will be elaborated. The north and south side of the groin will be looked at separately. Besides a difference between the north and south side, the groin is split up in sections of 10 meter (see Figure 5-16).

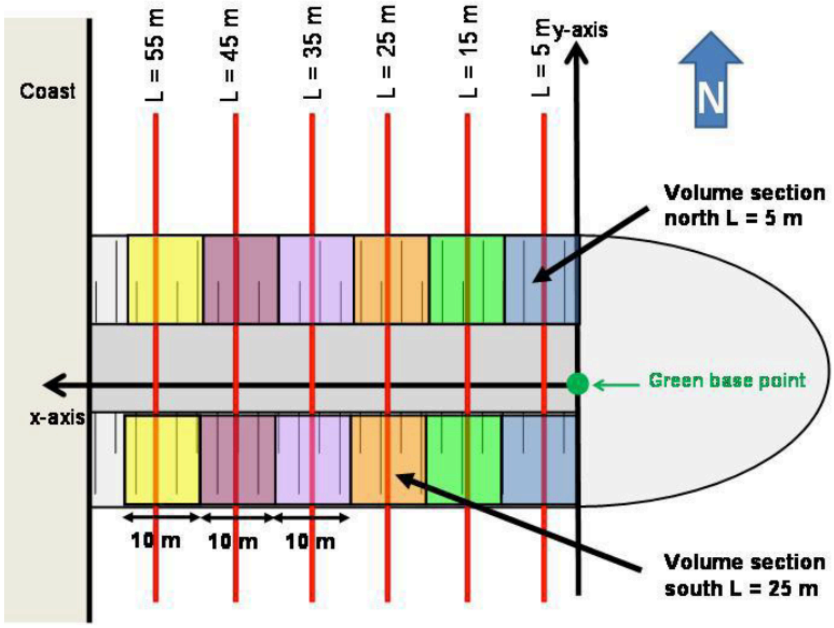


Figure 5-16 Overview of measurements of previous years

The volume is calculated the same as last year (source: report 2011):

- The volume above the water level is taken into account as the volume of the groin section. The water level of 2011 is used for all the years (such that comparison is possible).
- For the volume calculation of the years 2002, 2003 and 2004, the cross-section of L=5m is taken as normative for the volume of the first section (L = 0-10m), the cross-section of L=15m is taken as normative for the volume of the second section (L = 0-20m), and so on;
- For the volume calculation of this year, the average of the cross-sections L=0m and L=10m is taken as normative for the volume of the first section (L=0-10m), the average of the cross-sections L = 10m and L = 20m is taken as normative for the volume of the first section (L=10-20m), and so on.

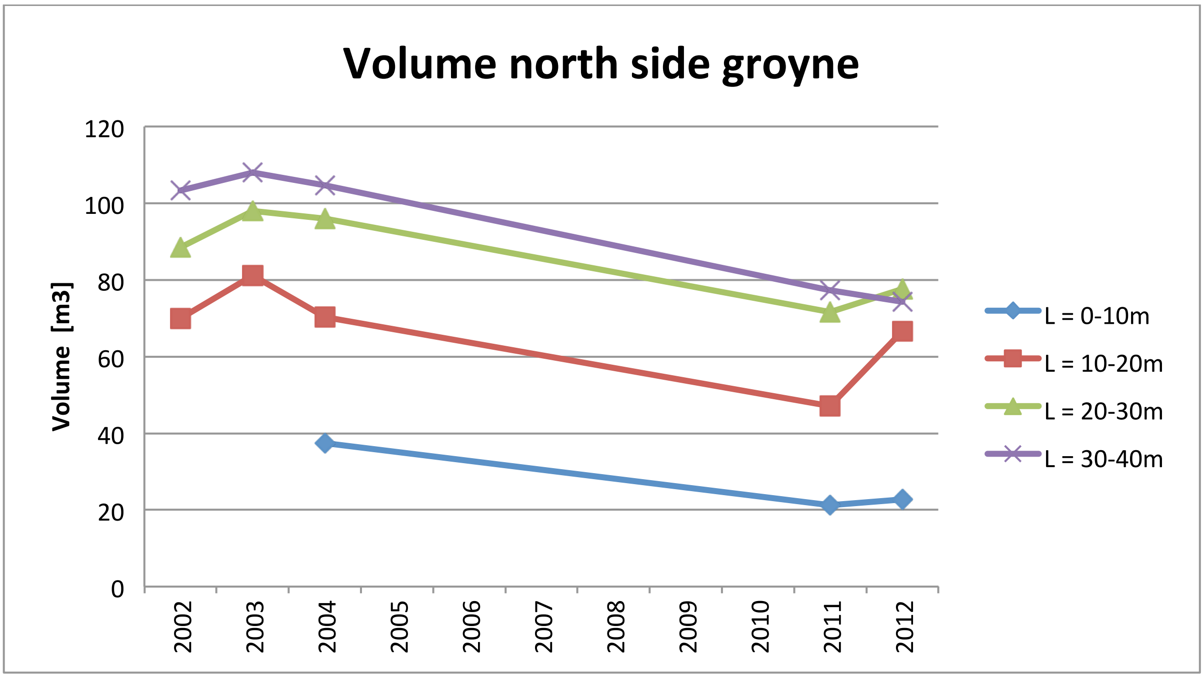


Figure 5-17 Volume of breakwater, North side

The volume change of the sections on the north side of the groin is given in Figure. At the north side of the groin no measurements were done at the first section in the first two years. The overall change that can been seen over the years for all the sections is as follows:

- An increase of volume in the first year;
- A steady decrease after 2003;
- A sudden increase this year.

The figure below gives the change in volume for the south side of the groin. On average a decrease of volume can been measured over the years. Again this year the volume has increased.

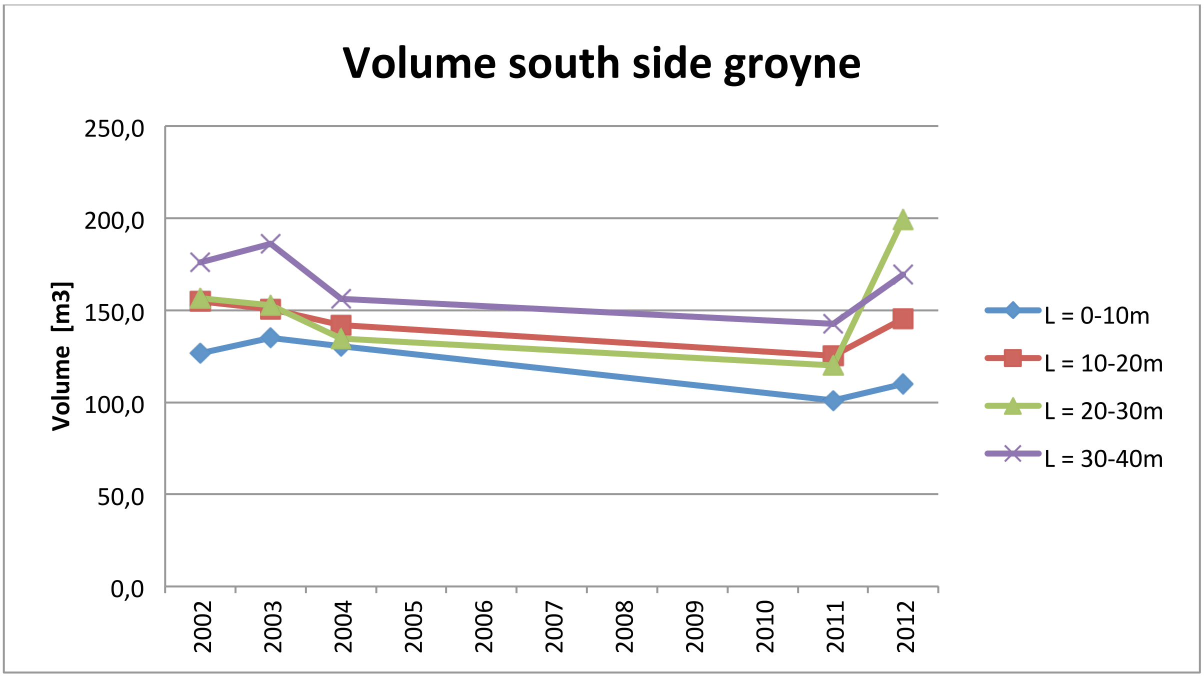


Figure 5-18 Volume of breakwater, South side

When looking at the pictures from last year and this year, it can clearly be seen that there are tetrapods deposited on the south side of the groin. Therefore the volume of the south side has increased considerably. Multiple reasons can be given as explanation of the change of volume, the most important ones are:

- Inaccurate measuring. Because of inaccurate measuring an increase (or decrease) of volume can be measured. Because of the rough surface differences because of different measuring points are easy acquired. Last year (2011) there was measured at random distances in the x-direction. This is not the right way of measuring. Next year they should (at this year) measure at fixed distances of the reference point.
- An increase of volume can be explained addition of the tetrapods. However, from a visual observation it can be concluded that still a relatively large amount of rock is replaced to the deeper part of the breakwater. The breakwater becomes wider and the upper part of the breakwater is less protected.
- The stones applied on the groin are too small to function as top layer. An insufficient amount of tetrapods is placed on top of the stones. This cause two negative impacts on the status of the breakwater:
    - Moving of the stones during the storms. This causes a wash out of the stones between the concrete slab and the tetrapods. Besides movement of stones, the stones are also rocking during storms, which finally results in breaking of stones. So the stones become smaller, which will results in even more damage during storms.
    - The tetrapods have no interlocking function which greatly decreases the strength of the top layer.

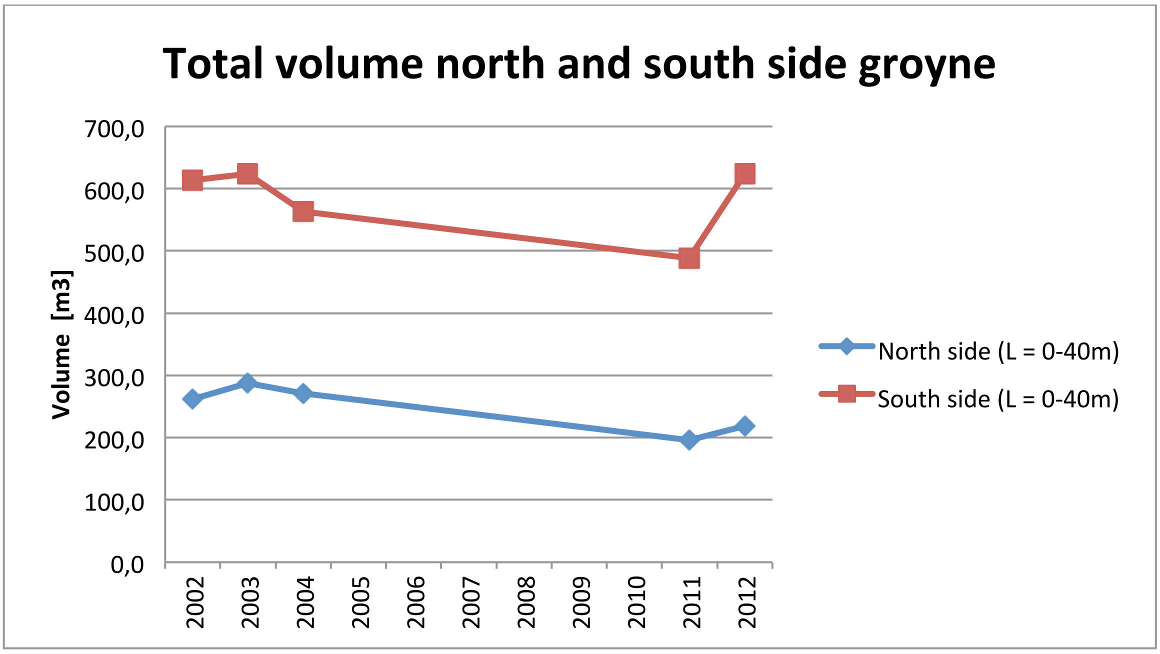


Figure 5-19 Volume of breakwater, total

From a coastal engineering point of view, the new tripod top layer is not placed sufficient. They have to add more tetrapods to cover the full top layer as tetrapods have an interlocking function which now is not used. The tetrapods added are clearly 'leftovers' from other projects which were deposited here to add more strength to the groin. In normal circumstances the wind on the black sea blows from the East South East. The breakwater is constructed in this place to maintain the beach on the south side which is in front of a hotel. The engineer who has designed this breakwater should read 'Breakwaters and closure dams; Henk Jan Verhagen et al.' and 'Coastal dynamics I; Judith Bosboom and Stive' to gain more knowledge on breakwaters and sediment transport.

The relative chance of volume is given in the table below. It can be concluded that the total volume increased 4% in 2003 (in comparison with 2002), the total volume decreased 8% between 2003 and 2004 (and 5% between 2002 and 2004). The breakwater has increased with 23% of its volume compared to 2011. In comparison with the first measurement in 2002 a total decrease of volume of 4% has occurred till now.

Table 5-1 Change of Volume of breakwater

	2002	2003	2004	2011	2012
2002	x	x	x	x	x
2003	4%	x	x	x	x
2004	-5%	-8%	x	x	x
2011	-22%	-25%	-18%	x	x
2012	-4%	-8%	1%	23%	x

5.2.3 Overall conclusions

- The stones applied on the groin are too small to function as top layer. A lot of movement occurs during the winter season.
- The breakwater is constructed in this place to maintain the beach on the south side which is in front of a hotel. Due to the relatively large sediment transport in the winter (going from

south to north), more sediment is deposited at the north side of the groin instead of the south side.

- Tetrapods are placed on top of the concrete slab on the south side, as well as on the toe of the north side of the groin
- The concrete bar on top of the groin is devastated. Probably due to wave action. Probably therefore they have placed the tetrapods.
- An insufficient amount of tetrapods is placed on top of the stones. This causes two negative impacts on the status of the breakwater:
    - Moving of the stones during the storms. This causes a wash out of the stones between the concrete slab and the tetrapods. Besides movement of stones, the stones are also rocking during storms, which finally results in breaking of stones. So the stones become smaller, which will results in even more damage during storms.
    - The tetrapods have no interlocking function which greatly decreases the strength of the top layer.

5.3 Recommendations

Compared with last year and the years before the groin has changed a lot. Because of constant moving of the rocks and breakage of the concrete slab tetrapods were placed to prevent this. The tetrapods were not placed right. They had no interlocking functions and the quality is poor. This results in moving and breaking of the tetrapods and therefore it is no sustainable solution. More tetrapods should be placed, close to each other, to prevent the rocks from moving and wash out from smaller stones. Also the concrete should be of a better quality.

It could be that the last years more severe storms hit the groin. On pictures from the year 2009 the groin looks good and even vegetation is growing on it. It is also visible that the concrete slab is still in one piece.

Figure 5-20 Groin in 2009

5.4 Harbour

There is a harbour close to the hotel Sirius. Probably this harbour was build for the loads of tourists that come to this place in the summer. It is clear that the harbour is unfinished. A lot of the material is piled up in front of harbour and from the caisson you can conclude that they are not connected the way they should be. The quality of the concrete elements is bad as well. A part of the elements are not reinforced and by those who are reinforced, the reinforcement is eroded.

Figure 5-21 Eroded elements

Figure 5-22 Unused material piled up

Figure 5-23 Overtopping and washed away elements

In front of the harbour a hotel was build. As was told in the introduction the main function of this hotel is as a land protection structure, because it was not allowed to built hotels to close to the shoreline anymore. On the figure below you can see the real function of the hotel. The harbour was intended to be used in the summer by tourists boats. Because the harbour was never finished it is now used by fisherman and there is hardly any boat.

Figure 5-24 Hotel in front of the harbour

There are a couple of problems at the harbour:

- Overtopping; By visual observation you could see that there is too much overtopping of the breakwater. All elements were wet and slippery and a lot of water entered the harbour is way. This could damage the boats if there were any. Probably the breakwater should be higher, but construction never came this far.
- Wave attack; The entrance of the harbour is not at the right place. During summertime, when there are boats in the harbour, the waves enter the harbour from the East South East. This is exactly where the entrance is. The incoming waves reflect on the concrete walls and move further into the harbour. This could damage the ships and the harbour and especially in the upper corner of figure 5-25 this will lead to severe wave energy.

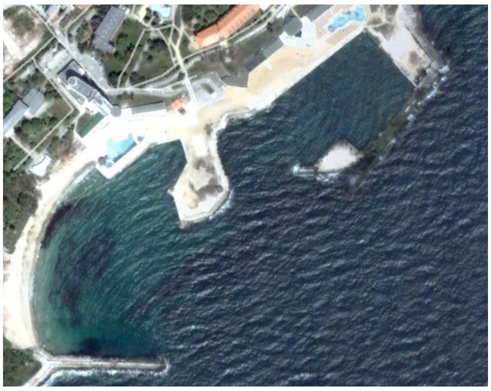


Figure 5-25 Incoming wave pattern

The final conclusion is that the design of the harbour is not good and is not in a good condition. This is partly because of the construction is stopped, but also because the quality of the concrete is not good. Another design would be better, but you could doubt if it would ever be profitable because the amounts of boats is overestimated.

6 Sieve Analysis

Sirius Beach is an evolving beach. To investigate the change the beach is going through, it is important to know the grain size distribution and the D_{50} of the sand. To analyse the change, these results are compared with the results of previous years.

6.1 Sampling Locations

In order to compare the results, samples must be taken at the same locations as before. In 2010 and 2011, samples were taken at Asparuhovo Beach. In those years, no measurements were made at Sirius Beach.

This year's aim for the sieve analysis was to determine the changes in grain size distribution and D_{50} of Sirius Beach. Therefore, the samples were taken at the same locations as in 2008 and 2009. These locations are shown in Figure 6-1.

Figure 6-1 Sampling Locations

The samples were taken at 4 points. In every cross-section, three samples were made. One sample 4 m offshore (numbered as A), a sample on the waterline (B) and the last sample 10 m landwards from the waterline (C). From the fourth point it was only possible to take one sample.

A limited amount of samples could be made, because the samples had to be transported to The Netherlands, to be sieved in the laboratory of the TU Delft.

6.2 Sampling and Sieving Method

6.2.1 Sampling

To obtain samples of the different locations, a piston was used (Figure 6-2). With this instrument it is possible to get a sand sample of approximately 0,5 m into the ground. The samples were taken and kept in numbered bags, in which they were to be transported to The Netherlands.

Figure 6-2 Piston

6.2.2 Sieving

The sieving of the samples was done in the laboratory of the TU Delft, whilst there are accurate measuring instruments available.
For the sieving of the samples, it is important these are completely dry. Therefore the samples were dried in an oven for 24 hours at a temperature of 105 ˚C.
Subsequently, the samples were sieved. For this, a sieving machine was used (Figure 6-3). On this machine, sieve trays with different mesh-sizes diameters were used. Based on experience of laboratory specialists, the samples were drilled in the sieving machine for 15 minutes.

The mesh-sizes of the sieving trays were chosen based on the results of previous years, availability and trial and error. The mesh-sizes used were: 3.35 mm / 2.8 mm / 2.0 mm / 1.7 mm / 1.4 mm / 1.18 mm / 1.0 mm / 0.71 mm / 0.5 mm / 0.25 mm / 0.18 mm.

These sieves were weighed before sieving a sample and afterwards. The difference of these weights is the amount of sand in that sieve.
The weighing balance in the laboratory has an accuracy of 0.1 gr.
To make sure the distributions are accurate, the whole sample was sieved. The samples were approximately 400 grams.

Figure 6-3 Sieving machine

6.3 Accuracy

There are several points in the process where inaccuracies can occur. To check if the results are trustworthy, the accuracy of the entire process is analyzed.

6.3.1 Sampling

First of all, deviations occur in the determining of the sampling locations. The last samples were taken in 2009, so it is plausible to assume the beach has changed and the locations are not exactly the same. At the moment of sampling, no GPS equipment was available, so the locations had to be approximated based on the figures in the old report.
At some points, there was a lot of coarse sand, which caused difficulties in taking samples with the piston.

6.3.2 Sieving

The sieving of the samples can be done quite accurate. The weighing of the seives was done with an accuracy of 0,1 gr, which is sufficient to obtain good results. The most important thing was not to loose sand from the seives after vibration, but this was not too hard because the seives with the sand were weighed instead of the sand only.

6.4 Sieving Results

From the weight that was left in the seives with the different diameters a cumulative mass percent distribution is made. In Table 6-1 the result is shown for the ten locations where the samples were taken.

Table 6-1 Cumulative mass percent distribution at the different locations

	cumulative mass percentage									
diameter [mm]	1A	1B	1C	2A	2B	2C	3A	3B	3C	4
3,35	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
2,8	96,6	95,5	99,5	72,0	97,4	99,6	36,7	92,3	97,9	88,2
2	95,5	94,3	99,3	68,1	95,4	99,6	25,4	88,8	96,9	87,2
1,7	92,7	88,3	97,7	56,6	85,2	98,8	8,3	75,3	92,7	85,0
1,4	83,3	82,3	96,4	49,5	75,5	98,1	4,7	65,9	88,6	83,6
1,18	76,2	70,1	92,8	39,8	58,7	96,1	2,7	49,2	79,3	80,2
1	69,0	57,3	87,5	32,3	44,5	93,5	2,0	46,9	67,3	75,9
0,71	47,1	40,5	77,4	23,9	31,0	88,5	1,4	21,6	47,8	67,5
0,5	22,6	16,4	50,6	12,0	15,5	71,7	0,7	7,2	14,2	41,1
0,25	6,8	4,6	16,5	4,3	6,6	39,2	0,2	3,0	2,1	14,3
0,18	0,6	0,4	0,5	0,4	0,8	1,3	0,0	0,8	0,4	2,0
0,1	0,2	0,2	0,2	0,2	0,4	0,4	0,0	0,5	0,2	1,2

When the data is plotted with the seive diameter on the horizontal axis on a log scale and the cumulative mass percent distribution on the vertical axis a seive curve is obtained. To compare the results whit each other the data of the different locations, but at the same distance from the waterline, are plotted in one graph. Figure 4, 5 and 6 are the seive curves for the different locations at respectively -4 meter, 0 meter and +10 meter from the waterline.

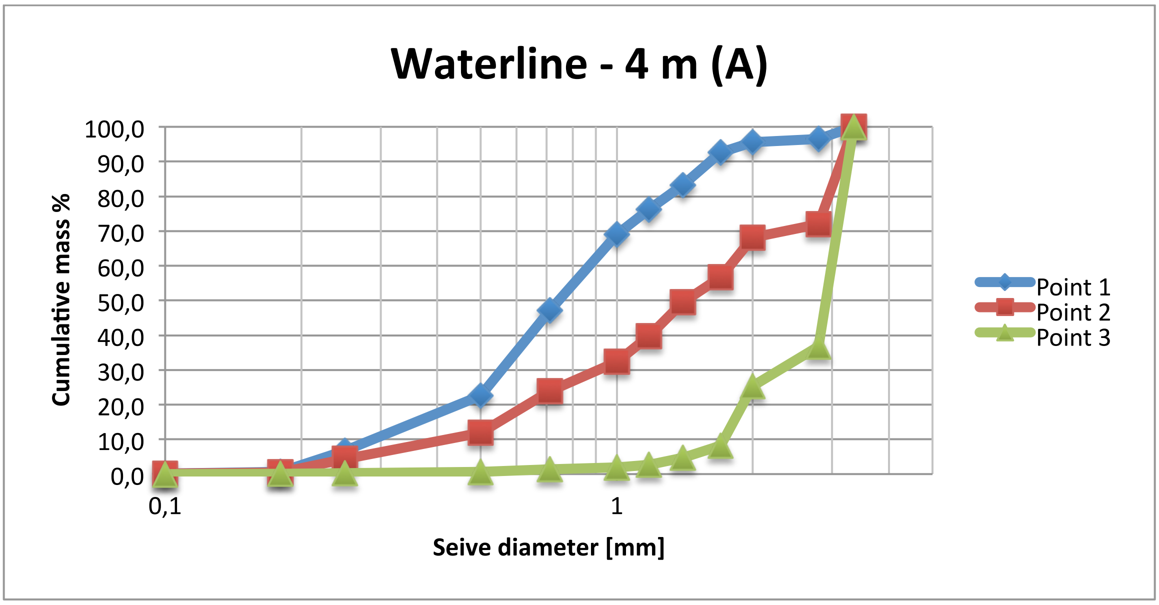


Figure 6-4 Cumulative mass percent distribution at -4 m waterlevel

As you can see in Figure 6-4 the sand from point 3 is very coarse. At this location it was impossible to take a sample with the piston so we grabbed some sand from the bottom, which was only very coarse material. For further analysis of the sand and to compare it with previous years this data set is not taken into account, because it would give strange values.

If we neglect the sample from point 3 we still see that there is a difference between the samples from point 2 and point 3. The coarseness of the sand at 4m offshore varied a lot along the beach so that is why these seive curves differ a lot.

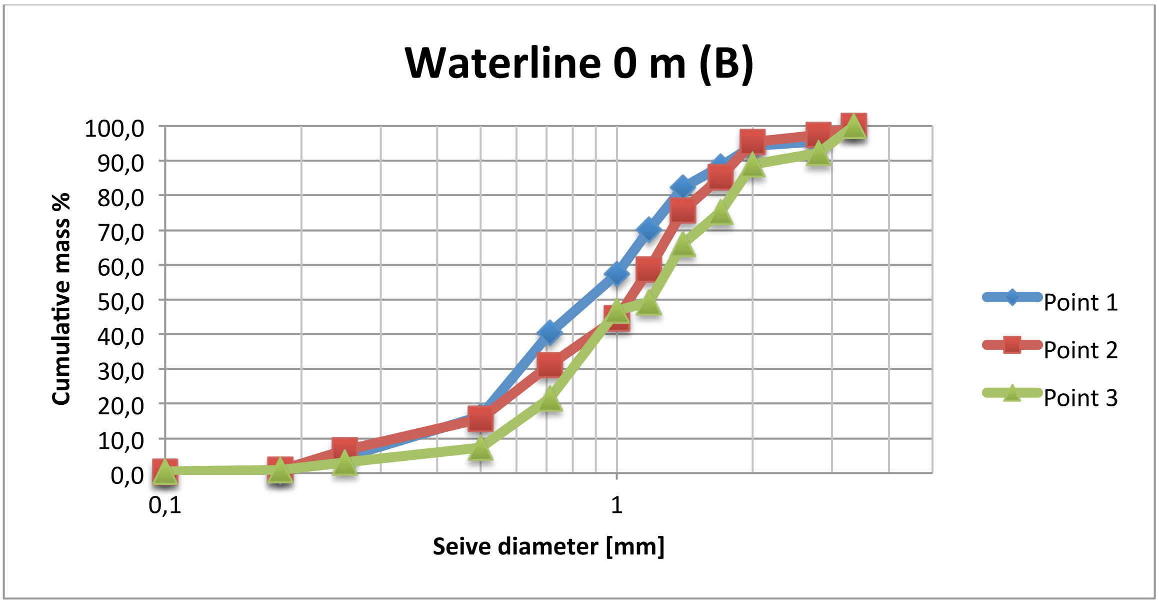


Figure 6-5 Cumulative mass percent distribution at 0 m waterlevel

In Figure 6-5 the seive curves at the different locations are close to each other. This means that the grading of the sand at the waterline is almost uniform along the beach.

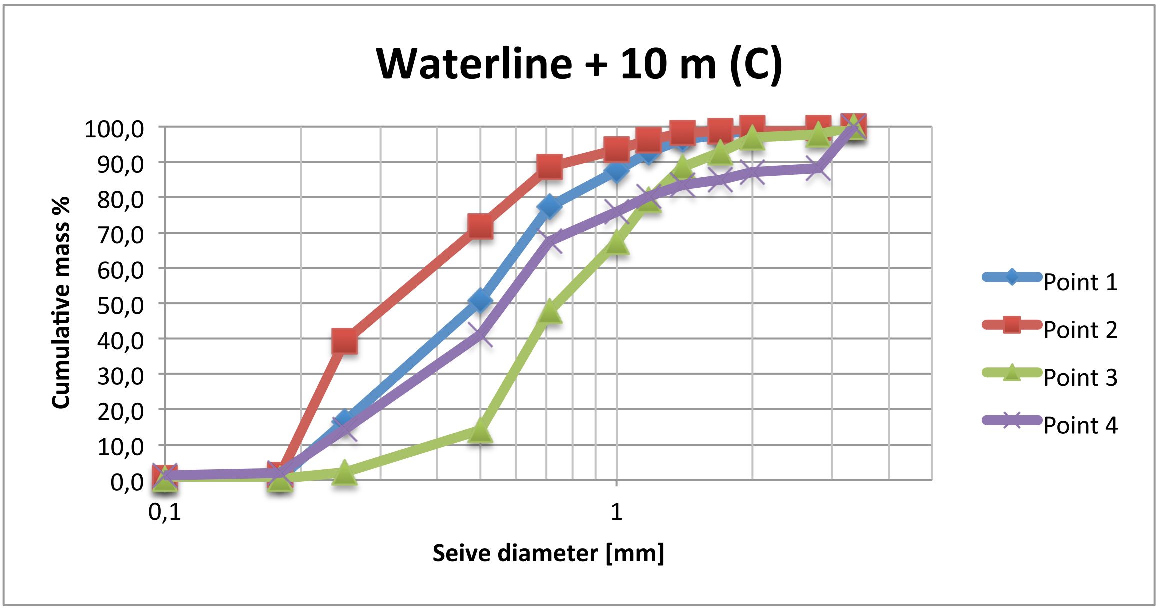


Figure 6-6 Cumulative mass percent distribution at +10 m waterlevel

In Figure 6-6 the seive curves at the different locations, including measuring point 4, still have quit a lot of difference. On the beach it was very hard to take samples with the piston, so that could be an explanation why the curves differ so much.

6.4.1 Comparison with previous years

To compare the results with previous years we used the data that was used in the fieldwork of 2009. This was the last year that sand samples were taken at Sirius Beach, so after three years it can be usefull to compare the results and see if there have been changes.

The grading of the samples is compared with the result from 2008 and 2009. The data from the different distances from the waterline (A, B and C) are grouped and averaged to obtain the averaged seiving curves, as can be seen in Figure 6-7.

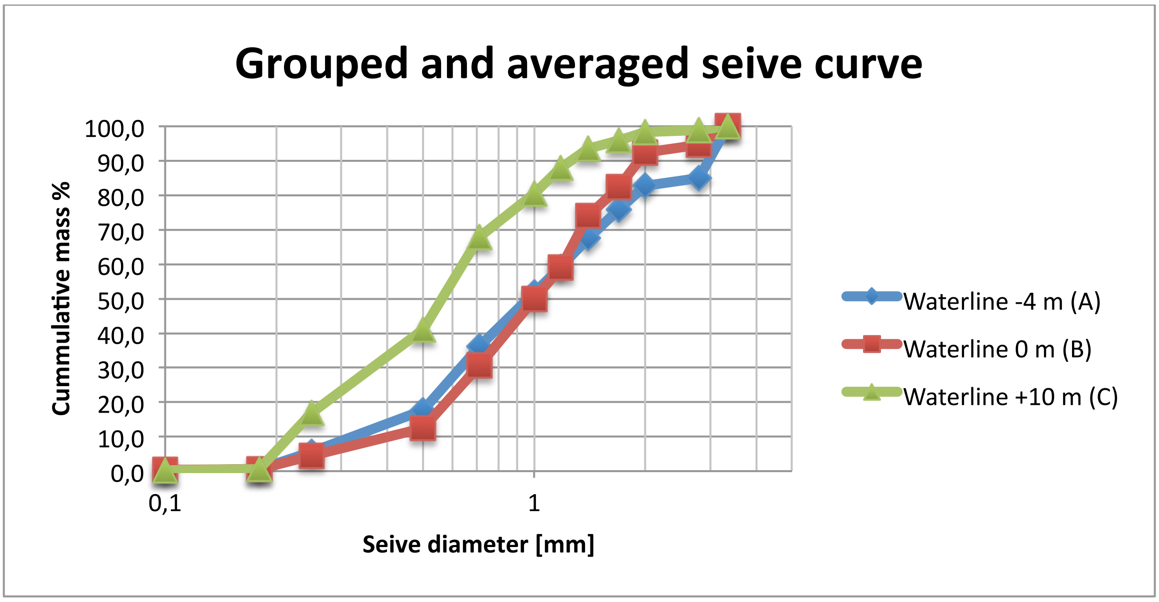


Figure 6-7 Grouped and averaged seive curve at the different distances from the waterlevel

The first thing that can be concluded is that the sand on the beach is finer than the sand in the water or on the waterline. This can be explained by the fact that the finer sand particles are washed away at the waterline because of wave action, so the coarser material remains behind.
To compare the results with the years 2008 and 2009 the results of the grouped and averaged sieve curves are used to obtain the D_{10}, D_{50} and D_{60}. With this the mean diameter (D_{50}) and the grading (D_{60}/ D_{10}) the sand can be computed. Another method to determine the grading is dividing the D_{90} by the D_{10} , so this is what we added this year as well. The result are shown in Table 6-2.

All the results from 2012 are higher than the previous years, especially at location B (the waterline). A conclusion can be that the beach has suffered from erosion during the last three years, which means that smaller particles are washed away. This means that the sand becomes more coarse over the years, which may not be favourable for recreation. A possible solution can be to nourish the beach with fine sand.

Table 6-2 Mean diameter and grading of the samples in the year 2008, 2009 and 2012

		A	B	C
D_{10}	2012	0,34	0,42	0,22
	2009	0,31	0,23	0,23
	2008	0,26	0,13	0,13
D_{50}	2012	0,97	1,00	0,57
	2009	0,75	0,40	0,38
	2008	0,60	0,24	0,22
D_{60}	2012	1,20	1,19	0,65
	2009	0,98	0,46	0,43
	2008	0,71	0,29	0,25
D_{60}/D_{10}	2012	3,53	2,83	2,95
	2009	3,16	2,00	1,87
	2008	2,73	2,23	1,92
D_{90}	2012	2,98	1,93	1,26
D_{90}/D_{10}	2012	8,76	4,60	5,73

7 Quarry

To determine the quality of the rocks which are available in Varna, Bulgaria, two quarries were visited. The Marciana quarry and the quarry Sini Vir were visited. From both quarries, small rocks were taken home to investigate and determine the specific density in the laboratory of the TU Delft.

Figure 7-1 Quarry

7.1 Specific Density

For the rocks of the quarries the specific density is determined in the laboratory of the TU Delft. Here, precise balances and measuring cups are available.

Three different types of rocks were taken to the laboratory for investigation. For the calculations, the (white-colored) rock of the Marciana Quarry is used. In order to get an accurate value, three small rocks were measured altogether. The weighing was done with a balance with an accuracy of 0,01 grams. The volume was measured using the Archimedes' principle. There were no very accurate measuring cups available, so a cup with an accuracy of 1 ml was used.

Also, the water absorption of the rocks was investigated. This was done by weighing the stones completely dry, and subsequently weighing them completely wet. To make sure the stones are completely saturated, they were put under water for more than 48 hours.
The two other tested stones were from the second-visited quarry. These were investigated out of curiosity: in this quarry there were yellow and black stones. These were investigated in the same way as the white-colored stones.

The specific density is computed by the following equation: $\rho = \frac{m}{V}$ [kg/m^3]
In which m = mass and V = volume.

Table 7-1 Measurements specific density

Stone	Dry Weight [g]	Wet Weight [g]	Water Weight [g]	Water Absorption	Volume [ml]	Density [kg/m^3]
White	306.73	323.48	16.75	5.46%	135	2272
Yellow	176.96	181.82	4.86	2.75%	75	2359
Black	86.44	89.17	2.73	3.16%	35	2470

7.1.1 Conclusions and comparison with previous years

Comparing the yellow, white and black stone, the water absorption of the white stones appears to be somewhat bigger than the yellow and black stone. On the other hand, the densities of the yellow and black stones are higher than the density of the white stone.

The densities of the yellow and grey stones were only also determined in 2008. Comparing these gives the following results:

Table 7-2 Comparison yellow and black stones

	Yellow stone	Black stone
2012	2359 kg/m^3	2470 kg/m^3
2008	2509 kg/m^3	2585 kg/m^3

The values of 2012 are a lot lower than 2008. Tough in both years the densities of the yellow and black stones are significantly higher than the white stones of the Marciana quarry.

Table 7-3 Comparison specific density with previous years

Year	Density [kg/m^3]
2012	**2272**
2011	2220
2010	2360
2009	2350
2008	2345

From the comparison with previous years, the main conclusion would be that there is a lot of variation. The values of 2008, 2009 and 2010 are close to each other. The value for 2012 is close by the value of 2011. Therefore, the next values will be compared with the values of 2011 only.

7.2 Rock measurements in Marciana Quarry

For a group of rocks the D_{n50}, elongation and blockiness has to be determined. In order to do this accurately, 20 average-sized stones were selected to analyze. For each stone, the weight and dimensions were measured. Because of the shape of the stone, it was not quite obvious what these dimensions exactly were. Therefore, all measurements were done twice. For the calculations, the average values are used.

Figure 7-2 Rocks aligned in Marciana Quarry

During the measurements and calculations, many creative solutions were used when something trivial like a pencil and paper are not forehanded. An example of this is shown in figure 3.

Figure 7-3 Rock no. 17

7.2.1 Volume

The volume of the rocks are computed by the following equation: $\rho = \frac{m}{V}$ [kg/m^3]

Table 7-4 Calculation volume rocks

Stone	Weight [kg]			Density [kg/m^3]	Volume [m^3]
	1st group	2nd group	average		
1	37	33	**35**	2272	0.015
2	29	26	**27.5**	2272	0.012
3	22	21.5	**21.75**	2272	0.010
4	27	25	**26**	2272	0.011
5	16.5	18	**17.25**	2272	0.008
6	27	29	**28**	2272	0.012
7	21	19	**20**	2272	0.009
8	42	35	**38.5**	2272	0.017
9	31	31	**31**	2272	0.014
10	12	12	**12**	2272	0.005
11	16	16	**16**	2272	0.007
12	23	21	**22**	2272	0.010
13	25	24	**24.5**	2272	0.011
14	34	35	**34.5**	2272	0.015
15	19	18	**18.5**	2272	0.008
16	18	16	**17**	2272	0.007
17	28	28	**28**	2272	0.012
18	23	22	**22.5**	2272	0.010
19	36	35	**35.5**	2272	0.016
20	21	22	**21.5**	2272	0.009

7.2.2 Blockiness

With the volume of the rocks, the blockiness can be calculated. The equation for blockiness is as follows:

$$Blockiness = \frac{Volume\ of\ the\ rock\ block}{X \cdot Y \cdot Z} \cdot 100\% = \frac{V}{X \cdot Y \cdot Z} \cdot 100\%$$

The blockiness is defined as the ratio of the volume of the stone and the smallest box in which the stone fits. The equation is based on the guidelines in the CUR 154 manual.

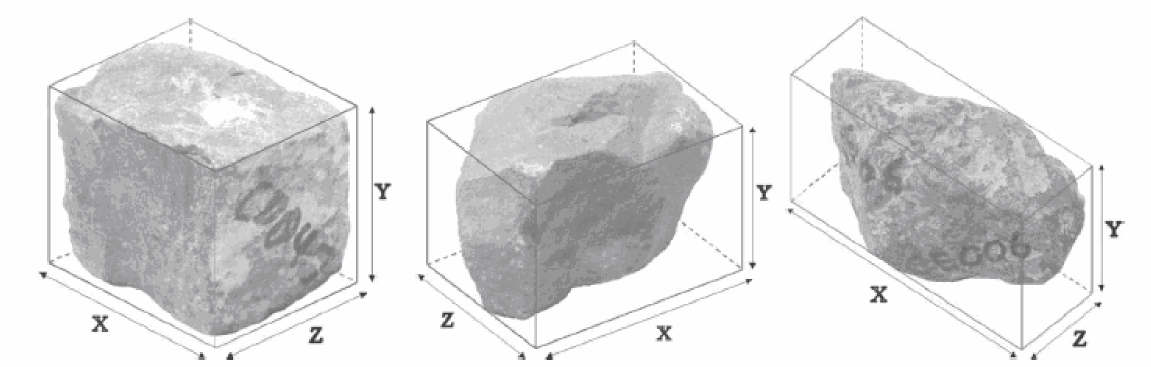


Figure 7-4 Visualization of the blockiness for several stones

Therefore, we need the X-, Y- and Z-coordinate of the stones. The calculation is shown inTable 7-5.

Table 7-5 Calculation Blockiness rocks

Stone	X [cm]			Y [cm]			Z [cm]			Blockiness
	Group 1	Group 2	Average	Group 1	Group2	Average	Group 1	Group2	Average	
1	57	52	**54.5**	39	37	**38**	14	12	**13**	57.6
2	33	34	**33.5**	31	25	**28**	28	26	**27**	48.2
3	41	40	**40.5**	28	28	**28**	19	21	**20**	42.3
4	34	36	**35**	28	30	**29**	27	26	**26.5**	42.7
5	38	38	**38**	23	22	**22.5**	23	20	**21.5**	41.8
6	46	45	**45.5**	31	28	**29.5**	23	20	**21.5**	43.4
7	43	35	**49**	34	32	**33**	19	15	**17**	41.5
8	38	38	**38**	30	34	**32**	26	28	**27**	52.5
9	39	44	**42.5**	35	36	**35.5**	20	14	**17**	55.8
10	34	30	**32**	27	25	**26**	17	13	**15**	44.0
11	37	39	**38**	29	28	**28.5**	22	19	**20.5**	31.9
12	29	33	**31**	29	29	**29**	20	20	**20**	54.2
13	37	32	**34.5**	27	30	**28.5**	26	28	**27**	40.8
14	43	40	**41.5**	32	32	**32**	31	26	**28.5**	40.7
15	45	45	**45**	24	22	**23**	20	22	**21**	37.5
16	34	32	**31**	25	31	**28**	22	19	**20.5**	39.9
17	36	39	**37.5**	29	26	**27.5**	26	26	**26**	46.1
18	43	43	**43**	26	24	**25**	16	17	**16.5**	55.9
19	39	35	**37.5**	32	30	**31**	28	28	**28**	48.9
20	43	43	**43**	31	31	**31**	20	15	**17.5**	41.5

7.2.3 Conclusions and comparison with previous years

From Table 7-5 one can obtain the blockiness of the stones. The average blockiness of the twenty stones, is 45.4 %. In 2011 a value of "almost 50%" was obtained, so this is similar.

Stones with a large blockiness are easier to handle while placing, so a large blockiness is preferred.

7.2.4 Elongation

Next to the specific density and the blockiness of the rocks, the elongation defines a rock. Elongation is defined as the ratio of the longest and the shortest axial length, and is important to determine the suitability of the stones for construction of coastal structures. In the Rock Manual, two requirements are described concerning elongation:

1. The quarry stone sample shall not contain more than 5% of stones with a length to thickness ratio (l/d) greater than 3;
2. The quarry stone sample shall not contain more than 50% of stones with a length to thickness ratio greater than 2;

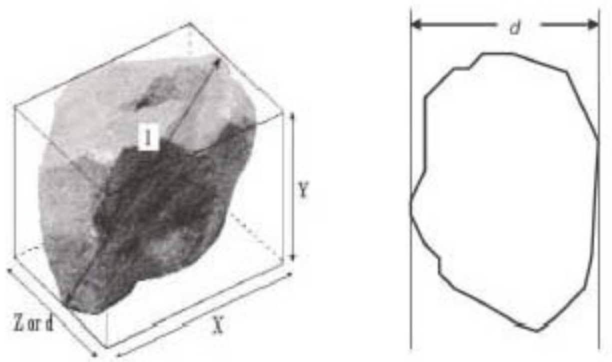


Figure 7-5 Visualization of the elongation for several stones: d is shortest side and l is longest side

The measurements which were used to compute the elongation, are shown in Table 7-6 on the next page.

Table 7-6 Calculation Elongation rocks

Stone	Longest side [cm]			Shortest side [cm]			Elongation
	Group 1	Group 2	Average	Group 1	Group2	Average	
1	58	55	**56.5**	15	13	**14**	4.0
2	35	35	**35**	26	26	**26**	1.3
3	41	42	**41.5**	22	25	**23.5**	1.8
4	36	40	**38**	25	25	**25**	1.5
5	40	40	**40**	23	21	**22**	1.8
6	49	46	**47.5**	20	23	**21.5**	2.2
7	46	45	**45.5**	20	15	**17.5**	2.7
8	43	40	**41.5**	30	28	**29**	1.4
9	49	47	**48**	21	20	**20.5**	2.3
10	35	36	**35.5**	18	18	**18**	2.0
11	46	43	**44.5**	19	18	**18.5**	2.4
12	41	41	**41**	20	19	**19.5**	2.1
13	46	44	**45**	27	33	**30**	1.5
14	48	46	**47**	32	33	**32.5**	1.4
15	48	42	**45**	21	14	**17.5**	2.6
16	38	36	**37**	25	25	**25**	1.5
17	40	37	**38.5**	30	25	**27.5**	1.4
18	45	44	**44.5**	19	21	**20**	2.2
19	40	42	**41**	34	33	**33.5**	1.2
20	45	44	**44.5**	28	20	**24**	1.9

7.2.5 Conclusions and comparison with previous years

In Table 7-6 the elongation of the rocks is shown. The average elongation of the twenty investigated rocks is 2.0. There is only one stone larger than 3 (first requirement Rock Manual), which is 5% for 20 rocks. For the second requirement, the number of stones with a ratio larger than 2 have to be checked: there are 9 stones with a l/d ratio larger than 2.

This is $\frac{9}{20} \cdot 100\% = 45\%$, so also the second requirement of the Rock Manual is okay.

In 2011 12% of the rocks had a ratio larger than 3, and no less than 62% of the rocks had an elongation of more than 2.

Both values have become less in one year. So, either the quarries have become better, or the measurement timing was just unlucky last year and lucky this year. Anyway, for this year, the collected samples are suitable for construction.

7.3 Nominal Diameter

The nominal diameter of the rocks D_{n50} can be computed with the following equation:

$$D_{n50} = \sqrt[3]{V} = \sqrt[3]{\frac{\rho}{m}}$$

With this equation a cumulative distribution can be made, by rating the stones in ascending order, as is done in Table 7-6. For the weight, the average value from Table 7-4 is used. For the calculation, the unrounded value of the volume is used.

Table 7-7 Stones ranked by weight in order to determine Dn50

Weight Stone [kg]	Volume [m^3]	D_{n50}	Cumulative Frequency [%]
12	0.005282	0.17	5
16	0.007042	0.19	10
17	0.007482	0.20	15
17.25	0.007592	0.20	20
18.5	0.008143	0.20	25
20	0.009803	0.21	30
21.5	0.009463	0.21	35
21.75	0.009573	0.21	40
22	0.009683	0.21	45
22.5	**0.009903**	**0.21**	**50**
24.5	0.010783	0.22	55
26	0.011444	0.23	60
27.5	0.012104	0.23	65
28	0.012324	0.23	70
28	0.012324	0.23	75
31	0.013644	0.23	80
34.5	0.015185	0.25	85
35	0.015405	0.25	90
35.5	0.015625	0.25	95
38.5	0.016945	0.26	100

7.3.1 Conclusions and comparison with previous years

From this, we can determine the D_{n50}, which is the value for the cumulative frequency of 50%. This is 0.21.

In 2011, the value of the D_{n50} was taken to be 0.20.

8 Artificial Island

Bulgarian developers have plans to construct an artificial island near the city of Varna. The idea is to build housing on the island and its main purpose is to add recreational and touristic value to Varna. There are two possible locations for the island, which have to be analysed. The two locations are shown in Figure 8-1.

Figure 8-1 Possible locations for the artificial island

Location 1 is situated in Lake Varna (Varnensko Ezero), near the small marina. Location 2 is situated in the bay of Varna, in front of the southern cape. It should be mentioned that the islands 1 and 2 in Figure 8-1 only give a first impression and are not on scale. Also the exact location of the islands is not presented by the figure. The following will elaborate on the more specific aspects of the two locations.

8.1 Design process

To create a new artificial island one has to go through the design process, along with the demands and requirements. See Figure 8-2 for the design process.

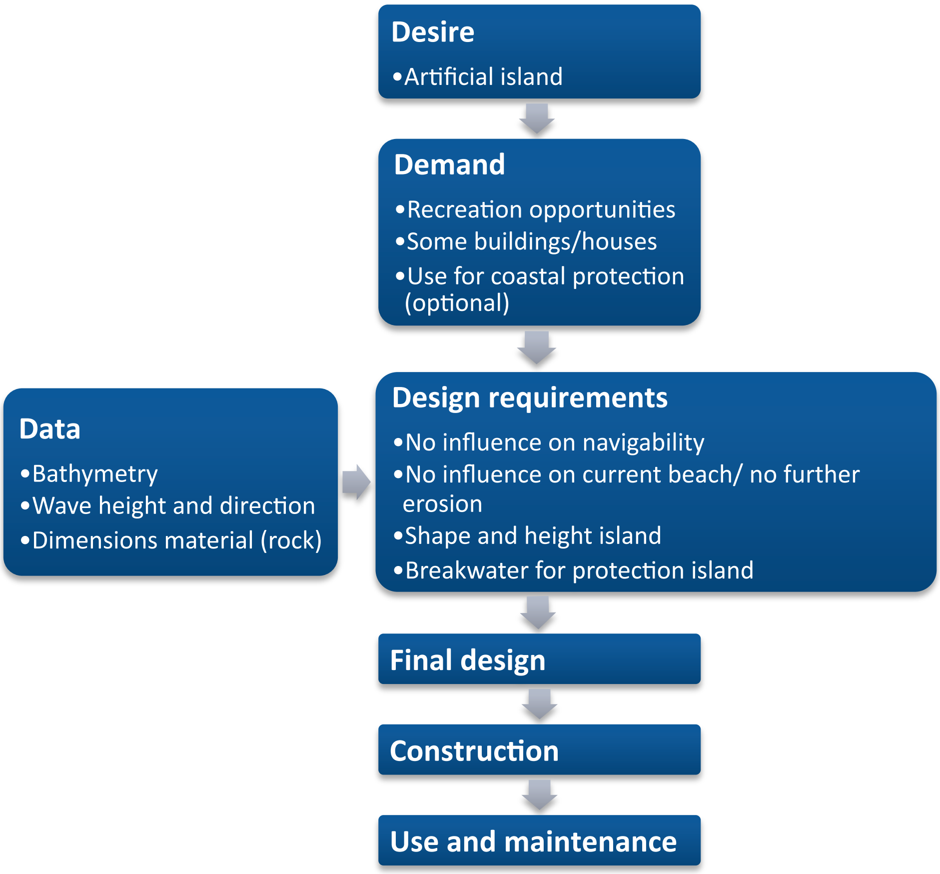


Figure 8-2 Design process

For the design requirement for the shape of the island an assumption is made. Assume a circular shape with a diameter of 750m. This results in a surface of roughly $4.4*10^5$ m^2.

8.2 Location 1 – Lake Varna

When zooming in on Lake Varna, the following prior conditions and constraints can be identified:

- Absence of (oceanic) waves
- Smaller water depth, compared to Varna Bay
- A deepened fairway for navigational purposes

8.2.1 Waves

Because of the land between the Black Sea and Lake Varna, the lake is sheltered from the (wind sea) waves that approach Varna from the sea. This implies that the only waves that the island has to withstand are depth and fetch limited wind waves which are generated within the basin of the lake. It can be assumed that the significant wave heights of these waves are not high enough that hard sea defense or a breakwater around the island is required. Nevertheless for the sake of completeness, calculations are made for a hard sea defense at location 1.

8.2.2 Water depths

The volume of sand that is required to construct the island depends on the dimensions of the surface area of the island and the (average) depth at the location of the island. Furthermore the depth may limit the dredging equipment that can be used. Figure 8-3 gives (limited) information about the depth contours of Varna Lake, near the marina.

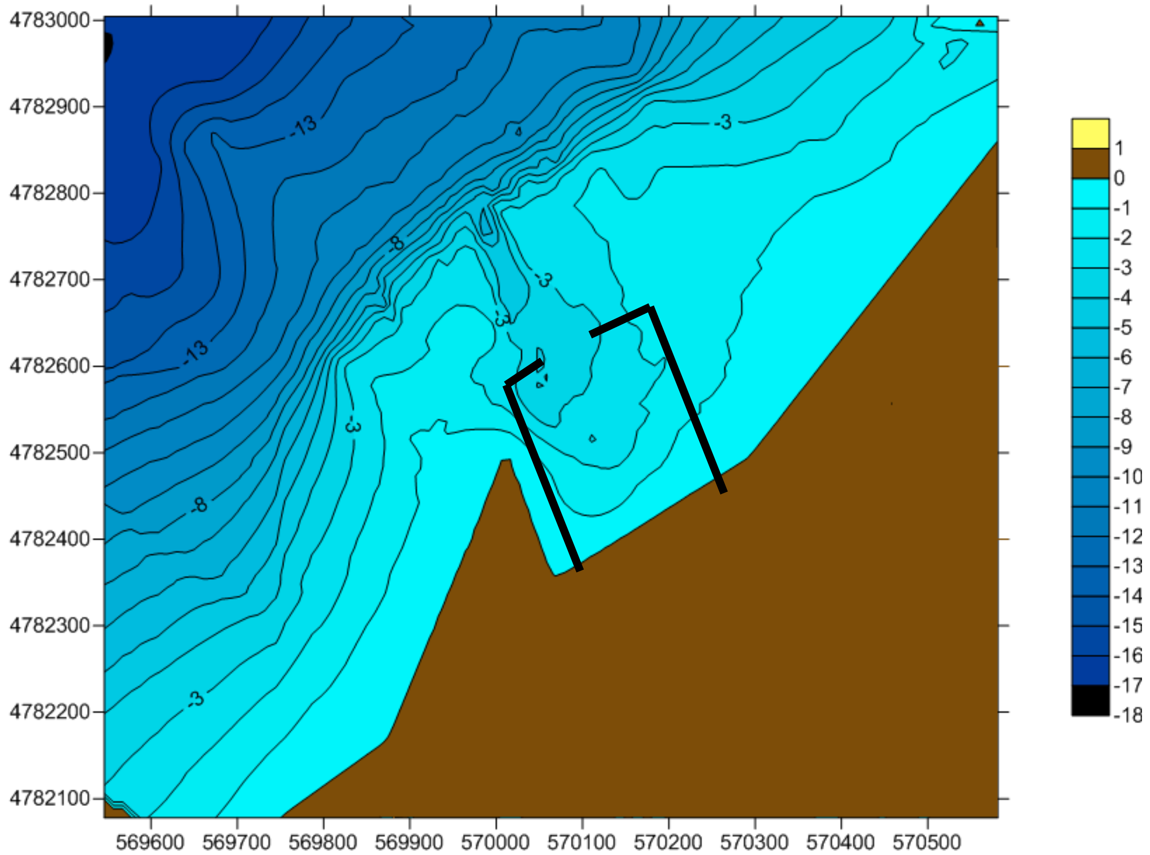


Figure 8-3 Depth contours Varna Lake, near the marina

Through Figure 8-3 an estimate can be made for the average depth of a possible location for the island. This estimate in combination with an assumption for the surface area of the island and the necessary parameters of the construction material (sand) enables us to make a rough calculation for the volume of construction material needed for the island.

Via the depth contours an indication for the best location of the island can be made. This location should be situated at the most shallow areas, which leads to less use of material and therefore less cost. Best locations can be seen in Figure 8-4, indicated by the red and orange circles.

8.2.3 Navigational route

A constraint for the construction of the island in Lake Varna is the deepened fairway for professional navigation. The navigational route has to be maintained in its original state. It is not desirable that ships have to leave their original route and travel around the island. This probably would require a new deepened fairway and furthermore it is not advisable that the island will be constructed at the deepest points of the lake. In Figure 8-4 the boundary of the navigational route is indicated by the yellow line.

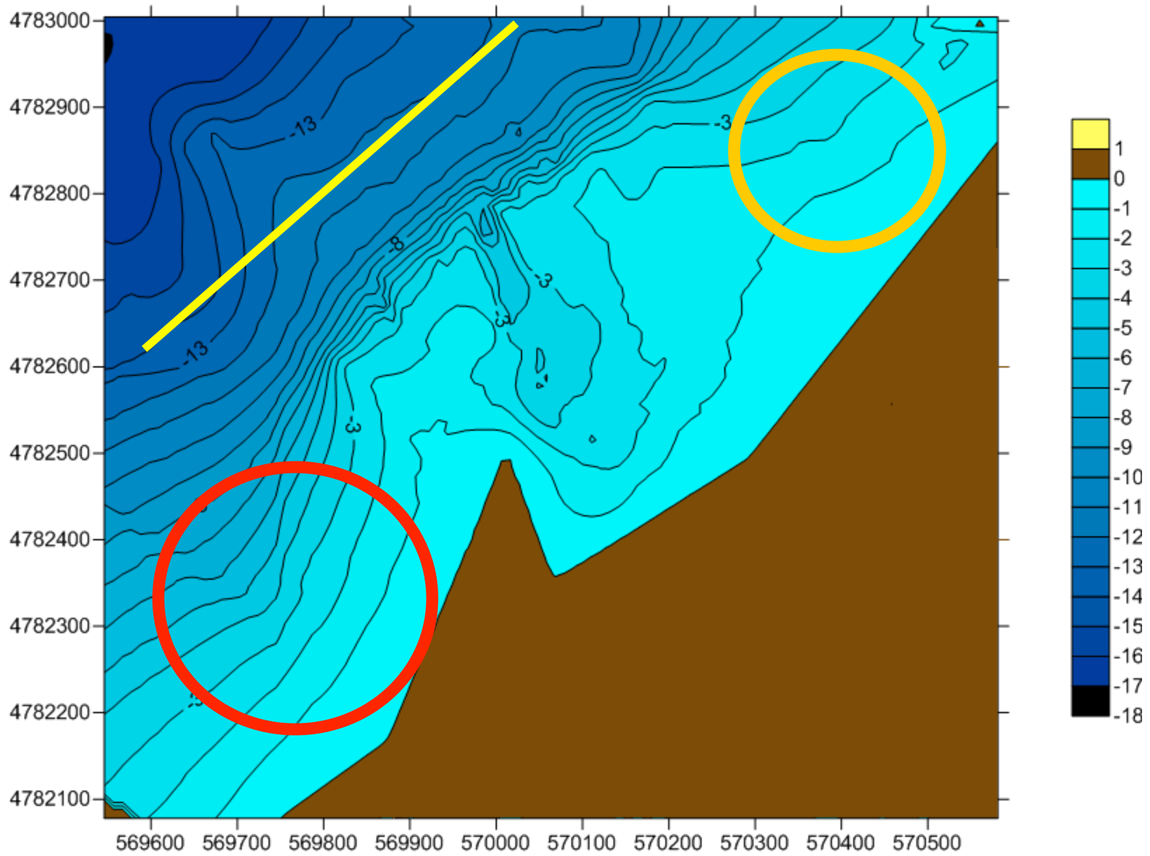


Figure 8-4 Possible locations for the artificial island

8.2.4 Design

It is chosen to situate the artificial island on the location which is indicated by the red circle in Figure 8-4. This is a favorable location considering the relative shallowness of the area and the location of the fairway. The orange circle is situated too near to the fairway, which can be seen in Figure 8-1 more clear.

8.3 Location 2 – Varna Bay

When zooming in on Varna Bay, the following prior conditions and constraints can be identified:

- Presence of (oceanic) waves
- Larger water depth, compared to Lake Varna (dependent on position in the bay!)
- A (deepened) navigational route towards the industrial harbour of Varna.

8.3.1 Waves

Obviously the bay of Varna is not sheltered from incoming (wind sea) waves from out the Black Sea. It is known that the significant wave heights of these waves in the Black Sea can reach high values easily, certainly in storms. In order to protect the island from washing away, a hard sea defense / a breakwater around the vulnerable part of the island must be constructed. The dimensions of this construction depend strongly on the wave climate and more specific on the significant wave height. The hard sea defense / breakwater probably has to be constructed around the seaward side of the island.

8.3.2 Water depths

The volume of sand that is required to construct the island depends on the dimensions of the surface area of the island and the (average) depth at the location of the island. Furthermore the depth may limit the dredging equipment that can be used. Figure 8-5 gives (limited) information about the depth contours of the bay, near Asparuhovo Beach.

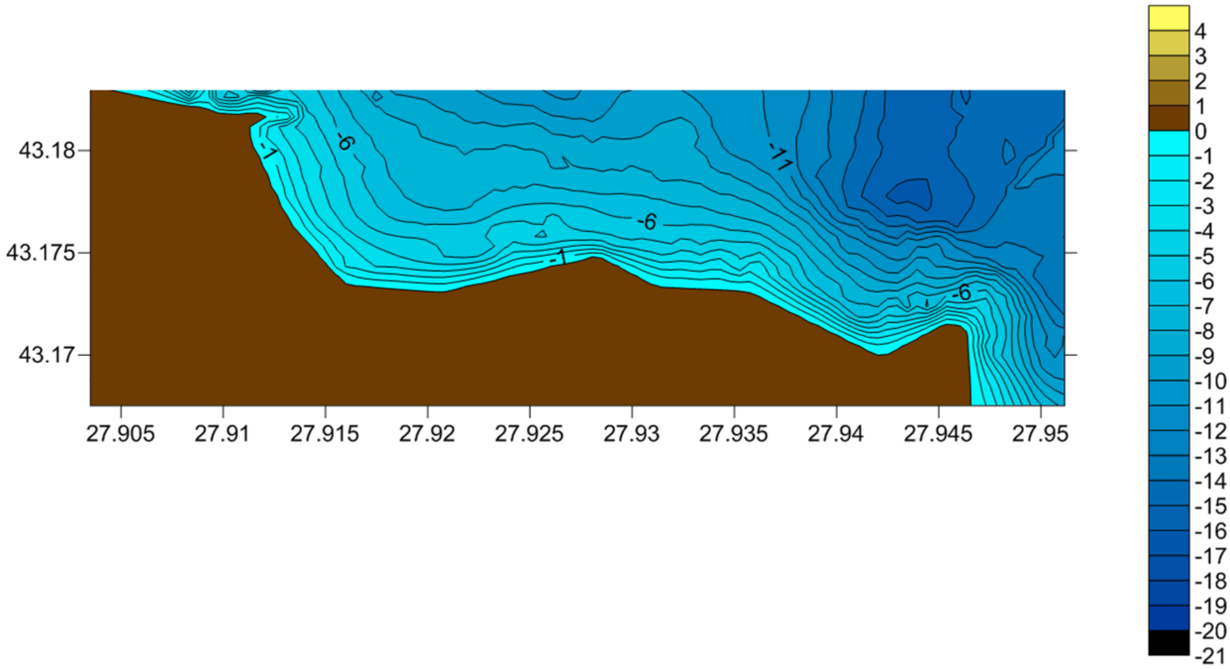


Figure 8-5 Depth contours Varna Bay, near Asparuhovo Beach

Through Figure 8-5 an estimate can be made for the average depth of a possible location for the island. This estimate in combination with an assumption for the surface area of the island and the necessary parameters of the construction material (sand) enables us to make a rough calculation for the volume of construction material needed for the island.

Via the depth contours an indication for the best location of the island can be made. This location should be situated at the most shallow areas, which leads to less use of material and therefore less cost. Best locations can be seen in Figure 8-6, indicated by the red and orange circles. The orange circle is not quite in a very shallow area, but is chosen due to the possibility of protection of the coast against erosion of the cape.

8.3.3 Navigational route

A constraint for the construction of the island in Varna Bay is the navigational route towards the industrial harbour of Varna. It is not desirable that the navigational route is disturbed by the island. In Figure 8-6 the boundary of the navigational route is indicated by the yellow line.

8.3.4 Design

The location indicated by the red circle in Figure 8-6 is probably more favorable than the location indicated by the orange circle. The expectation is that an island at the ‘orange’ location does not contribute significantly to protection of the cape and maybe even will induce extra erosion due to increase of flow velocities between the island and the cape. Furthermore the ‘red’ location is situated in less deeper water which is favorable for the use of construction material. The island must have a protection (breakwater / hard sea defense) against wave action.

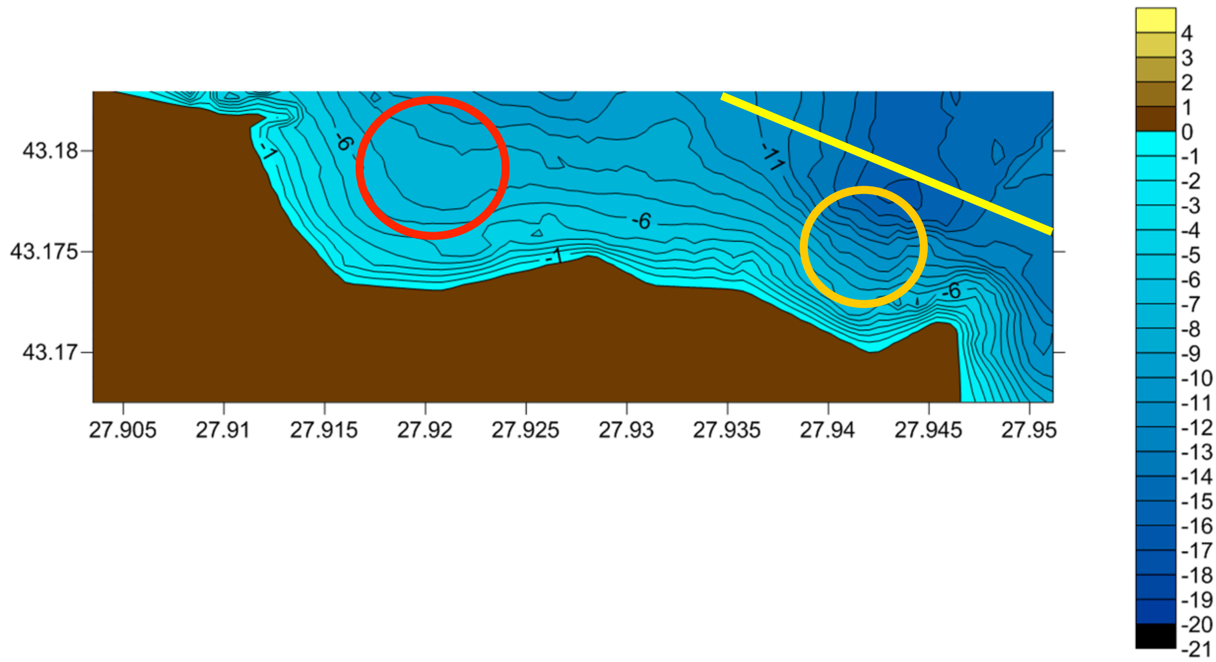


Figure 8-6 Depth contours Varna Bay, near Asparuhovo Beach

8.4 Breakwaters

As already mentioned in section 8.2 and 8.3 calculations will be made for the protection of the islands against wave action. In the lake only a few wind waves will attack the island, where for location 2 wave attacks on the island are probably the main cause of damage. To protect the islands a breakwater will be constructed around the part that is most attacked.

8.4.1 Wave heights

To calculate the necessary material, the wave heights in the sea and the lake has to be found. The significant wave height of the sea is calculated in a previous chapter. The wave heights in the lake are determined with Brettschneider. For this calculation it is assumed that the wind frequency is 1/500 per year.

8.4.2 Stone size breakwater

Rock is available in large quantities and large sizes. More coherent materials as placed stones and concrete are more difficult to find, more expensive and of bad quality in Bulgaria. In Bulgaria aesthetics also do not play a big role. Therefore rock will be used as material. To find the necessary rock diameter, the Van Der Meer formula is used.

$$\frac{H_{sc}}{\Delta d_{n,50}} = 6.2P^{0.18}\left(\frac{S}{\sqrt{N}}\right)^{0.2} \xi^{0.5} \text{ (plunging breakers)}$$

$$\frac{H_{sc}}{\Delta d_{n,50}} = 1.0P^{-0.13}\left(\frac{S}{\sqrt{N}}\right)^{0.2} \xi^{P}\sqrt{\cot(\alpha)} \text{ (surging breakers)}$$

Where:

- H_{sc} =1.38 m (loc. 1), 3.25 m (loc. 2) the significant wave height
- = 1.65(loc. 1), 1.58 (loc. 2); the relative density based on the density of rock (2650 kg/m^3) and water (1000 kg/m^3 in the lake, 1025 kg/m^3 in the sea)
- P =0.6 ; based on a homogeneous armor
- S= 3; damage level for small damage

- α =0.24 ; the slope of the breakwater based on a 1:4 slope

This gives for location 1: **D_{n50}= 0.72 meter**
And for location 2: **D_{n50}=0.84 meter**

8.4.3 Height breakwater

The crest level of the island is based on the maximum wave overtopping discharge. The idea of the breakwater is that there will be a small pool between the island and the breakwater. Therefore the overtopping water will not do much harm. Important though is to check if there is not too much wave transmission due to the small chosen maximum wave overtopping discharge.

The wave overtopping is calculated with the formulas defined by Owen (1980).

$$R^* = \frac{R_c}{T_m\sqrt{gH_s}}$$

$$Q^* = \frac{q}{T_m g H_s}$$

$$Q^* = a\exp\left(\frac{-bR^*}{\gamma_f}\right)$$

Where:

- R_c = the elevation of the crest above SWL
- q = 0,5 m^3/s per m; the average specific overtopping discharge,
- a = 0.067; dimensionless parameter for breaking waves
- b = 4.75; dimensionless parameter for breaking waves

This gives a crest height above SWL of

Location 1: **1.5 meter**
Location 2: **3.7 meter**

8.5 Material and cost

A difficult constraint for the artificial island near the city of Varna, independent of the location, is the construction material for the island itself. The Bulgarian coast area has no extensive sand resources from which sand can be mined. This is a problem that requires a creative solution. If a dredging vessel has to travel long distances to obtain sand, this will force up the dredging cost per cubic meter material by a considerable amount. A logical solution for this is to use dredged silt from the fairway and rock from the nearby quarries.

8.5.1 Cost

Since we know that there will be hardly any wave action in front of the island due to the breakwaters, it is now possible to make a first assumption for the relative costs of the islands. For these cost assumptions in this early stage of the design process two factors play a role: the amount of sand needed, and the amount of material for the breakwater needed. In this early stage, the material costs of the breakwater are representing the relative costs compared with each other. This gives a first insight in the differences of the two locations. Other protection methods will more or less have the same costs ratio.

8.5.2 Material for the island

We assume that the islands at both locations will have a diameter of 750 meter. The average depth in the lake (location 1, red circle) is 5 meter; the average depth in the sea (location 2, red circle) is 7 meter. Set-up due to wind neglected for both the lake (due to its small fetch length) and the sea (because the sea is very deep). It is assumed that the island has to be one meter higher than MWL to protect the island for floods at storm circumstances. Through the formula for the volume of a blunt cone a first approximation of the necessary construction material for the island can be given:

$$V = 1/3 \times \pi \times h \times (R^2 + R \times r + r^2)$$

Where:

- h = height island
- r = radius upper area island
- R = radius bottom area island

In order to calculate R from r we assume that the slope of the island has a value of 1:3. So R = r + 2 x 3 x h.

Location 1 (lake): 11.10^6 m^3
Location2 (sea): 15.10^6 m^3

8.5.3 Material for the breakwater

If we assume that for both locations the crest width is 2 meter, the length of the breakwater is 350 meter and the slope on both sides is 1:2 the amount of material can be estimated:

Location 1 (lake): $9{,}1.10^3$ m^3
Location 2 (sea): $14{,}9.10^3$ m^3

8.6 Conclusion

The results show that much more material is needed to build an island at location two (in sea). The stone classes needed for both locations can be found in quarries nearby, but for location 2 almost 1,5 times the amount of material is needed to protect the island. It is also more difficult to construct the island in sea, because of the rougher circumstances. This will cause more downtime during construction. So in this early stage of design, an island in the lake has from an engineering point of view the preference.

The big question is though, what the cost for the construction of an island will be. This will mainly depend on the cost of the enormous amount of sand that is preferred for the construction of the island. There is maybe an option to dredge some sand from the river nearby the locations, but it is very doubtful if that is enough to build a proper island. As mentioned before a logical solution for this is to use dredged silt from the fairway and rock from the nearby quarries.

A problem that is not yet studied is the transmission of waves behind the breakwater. This could cause some minor damage to the beach (especially at the sea location). Another point is the choice for the protection of the islands. We see that in the lake the protecting breakwater has a cress height of 1.5 meter. This is not very high, and could easily be replaced with a revetment or a wall placed directly on the new island. The problem with this solution is that it will not be possible to create a beach on the island that provides a comfortable walk into the water.

9 Conclusions and recommendations

This section provides the conclusions of all the activities of the fieldwork. These are including the recommendations over each section. Consequently, Sirius Beach, Asparuhovo Beach, the groin at Asparuhovo, the groin at St. Constantine, the Sieve Analysis and the island is treated.

The waterline measurements of Sirius Beach show the stabilized erosion patterns; when looking at the results of the cross section measurements. Furthermore, the waterline measurements of 2012 show that the accretion in 2010 and 2011 has finished at the southern part of the beach resulting in water lines at the same position. A few poles show erosion phenomena over the years concluding that the waterline and the cross-sections measurements show the same trends. Similarly, comparing the waterlines of Azalea Beach it can be concluded that the waterlines of 2012 are very close to the waterlines of 2010. This indicates that the erosion mentioned in 2010 is more or less ended.
Still it is hard to draw conclusions based on these measurements mainly due to seasonal variability and measurement inaccuracy. More measurements at the same location should be done throughout the year to make comparison of the profiles less sensitive to the seasonal variance. Therefore, it is advisable to use the same zero point from now on, and measure the profiles at the same locations as done in 2011 and 2012.
Additionally, the wave measurements at Sirius Beach were a test. It was meant to try the wave pressure meter and to see any results. The two locations were in shallow water, which meant wave breaking, which is concluded from the graphs. In this case the linear wave theory cannot be applied.

The waterline measurements show no change in the northern part of Asparuhovo Beach. The maximum height difference between 2011 and 2012 is around 0.3m, a remarkable low value during rough measurements. This might be due to the protection of the beach, which is in the lee of the port, from extreme weather conditions of the beach from north east by the seaport of Varna.
The most southern part of the beach seem less stable at the waterline (as can be seen in the report of 2010). Because of the large differences are at the waterline point, this is most likely due to seasonal variability. An advice for next year would be to move the cross-section measurements more to the south.
In addition, Asparuhovo coastal waters and another location will be used to design islands in. To construct a stable and safe island wave characteristics are required. From analysis the significant wave height of 1.76m, the maximum wave height of 3.52m and the peak period of 7.32s have to be used. But the few values obtained are not representative for the wave climate. Moreover, the maximum wave height are determined by a rule of thumb; twice the significant wave height. The waves were measured in deep water, approximately 8m. So, the waves were not breaking and the wave characteristics could be determined with use of the linear wave relation.

The groin of Asparahovo Beach is a poor constructed breakwater. One of the failures is the steel pipe that goes through the service plates with insufficient coverage which causes a fracture. Furthermore, the low quality of the concrete is providing large cracks and broken tetrapods. Encounting the lack of maintenance causes the breakwater to fail even more. The maintenance of Bulgarian governance is obviously not sufficient resulting in very quick descending of almost all the breakwaters. An advice for them is to use high quality concrete for the tetrapods providing enough coverage against corrosion, the fixation of the surface plates and the fixation of foundation beneath it. For construction a solid foundation has to be created first. For instance, a flat bad of natural rocks with geotextile. This kind of foundation prevents inner stress in your surface plates and the flush of your foundation.

The stones applied groin St. Constantine are too small to function as top layer. Therefore, a lot of movement occurs during the winter season. The groin has to prevent the beach in front of the hotel to erode. The large sediments in winter coming from the south are deposited at the north side of the groin.
For the construction of the breakwater the tetrapods are placed on top of the concrete slab on the south side, as well as on the toe of the north side of the groin. Meanwhile, the concrete bar on top of the groin is devastated. Probably due to wave action. Therefore they have placed the tetrapods. An insufficient amount of tetrapods seems to placed on top of the stones. This causes moving stones during the storms (resulting in wash out of the stones between the concrete slab and the tetrapods and breaking of stones and no interlocking function, which greatly decreases the strength of the top layer.

It can be concluded from the sieve analysis that the sand on Sirius Beach is finer than the sand in the water or on the waterline. This can be explained by the fact that the finer sand particles are washed away because of wave action, so the coarser material will remain. The grouped and averaged sieve curves of 2008 and 2009 are used to obtain the D_{10}, D_{50} and D_{60}. With this the mean diameter (D_{50}) and the grading (D_{60}/ D_{10}) the sand can be computed. Another method is added to the report, which determines the grading by dividing the D_{90} by the D_{10}.
All the results of 2012 are higher than the previous years, especially at the waterline. It can be said that the beach has suffered from erosion during the last three years, which means that smaller particles are washed away. The sand would become more coarse over the years, which may not be favourable for recreation. A possible solution can be to nourish the beach with fine sand.

The stone classes needed for the island at both locations (in the lake and at sea) can be found in quarries nearby. For the location at sea almost 1.5 times the amount of material is needed to protect the island. Moreover, rough circumstances at sea are making construction more difficult causing downtime. Therefore, the engineers advice is an island in the lake.
The cost for the construction of an island is an important issue. This will mainly depend on the enormous amount of sand. Although, there could be an option to dredge sand from the river nearby, but it is very doubtful if that is enough to build a proper island.
A problem that is not studied is the transmission of waves behind the breakwater. This could cause some minor damage to the beach (especially at the sea location). Another issue is the choice for the protection of the islands. The protecting breakwater in the lake has a cress height of approximately 1.5m. This could easily be replaced with a revetment or a wall placed directly on the new island. The problem with this solution is that it will not be possible to create a beach on the island that provides a comfortable walk into the water.

10 Reference List

Schiereck, G.J. & Verhagen, H.J. (2012) *Introduction to bed, bank and shore protection: Engineering the interface of soil and water*. Delft: VSSD.

Holthuijsen, L.H. (2007) *Waves in oceanic and coastal waters*. New York: Cambridge University Press.

Appendix A – Wave measurements

This annex treats seven wave measurements by a wave pressure meter at two location as mentioned in the main report. The first location was in front of Sirius Beach where the first tests took place. The three obtained data sets are showed, but not used in the design of the islands. In contrast, the measured data in the coastal waters of Asparuhovo Beach are to be taken into account in the design stage. These are the last four data sets. For both Sirius Beach and Asparuhovo Beach the data of the wave pressure meter is translated by Matlab scripts into wave characteristic figures.

First a short description of the wave pressure meter, the linear wave theory and the wave characteristics. These three sections are followed by the obtained data with the wave pressure meter for Sirius and Asparuhovo Beach.

A.1 - Wave pressure meter

A wave pressure meter is used to obtain wave data in general. The meter consists of different parts. In a plastic cylinder there are four batteries, electronics and a pressure sensor. The means used to get the meter into the water are an anchor, a rope, tireps and a buoy. The anchor was wrapped round the wave pressure meter with tireps. Consequently, the rope was used to connect the pressure meter to the buoy. In Figure A - 1 below the water pressure meter construction used is shown.

Figure A - 1 Wave pressure meter

When this was done the anchor with the pressure meter on top was placed onto the sea bottom. The pressure meter was assumed to be 0.1m above the bottom. This information is required to calculate potential water depths.

In the following picture the pressure meter is positioned (Figure A - 2). The meter measures: air pressure; hydrostatic pressure and pressure differences due to waves. It measures four times a second and saves the obtained data in portable memory locked in the electronics. With use of an analogue amplifier the signal from the sensor can be amplified. A simple computer program can be used to do this.

Figure A - 2 Placing the wave pressure meter at Sirius Beach

The sensor compares the various water pressures with the hydrostatic pressure (reference pressure). The pressure differences due to waves are not hydrostatic over the water depth. In Figure A - 3**Error! Reference source not found.** the pressure under the trough and crest are shown. It can be seen that the pressure under the trough reduces and under the crest increases.

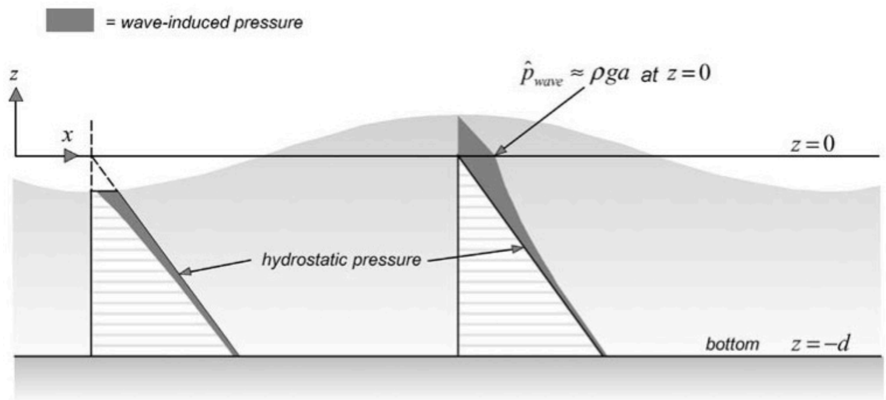


Figure A - 3 Wave-induced pressure distribution

The wave height can be calculated with the known pressures using velocity potential and Bernoulli equation of the linear relation (Holthuijsen, 2007). The linear wave theory formula for waves with gravitation as external force only:

$$p = -\rho g h + \rho g a \frac{\cosh k(h+z)}{\cosh kh} \sin \theta.$$

The first term represents the hydrostatic pressure and the second term represents the variation in pressure due to waves. Where:

k = $\frac{2\pi}{L}$ is the wave number.

A.2 - Linear Wave Theory

A short description of the linear wave theory is made in this section. This theory gives a linearized description of the propagation of gravity waves on the surface of a homogeneous fluid layer. The assumption in this theory are: a uniform depth of the fluid layer and that the flow is inviscid, incompressible and irrotational. It can be used to get a quick and rough estimation of wave characteristics and their effects.

The theory cannot be used in every condition. It is only valid for deep water and cannot be applied to steep waves. When the depth becomes very shallow the waves are going to feel the bottom due to orbital motion at the bottom, which is increasing (under the crest) and decreasing (under the trough) the wave pressure at the bottom Eventually breaking will occur with wave energy dissipation. These effects of waves will be described and estimated with non-linearities and not with the linear wave theory only. Furthermore, the amplitude of the wave must be small compared to the depth to be in deep water to fulfil the deep water requirement. This means:

$ak \ll 2\pi$ and $a \ll d$

In this, a is the amplitude of the wave and d is the water depth. With linear wave theory a wave can be described by a sine wave with the following form:

$$\eta(x,t) = \text{a}\sin(\omega t - kx)$$

Where η is the surface elevation, ω is the angular frequency and x is the distance from the origin (crossing elevation and x axes). In Figure A - 4 the used wave characteristics are shown.

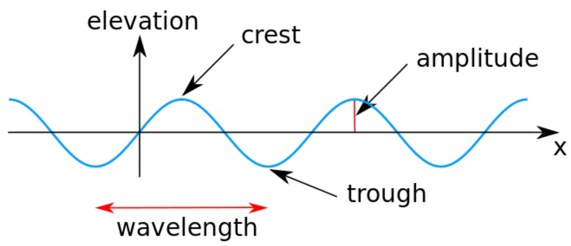


Figure A - 4 Wave characteristics

A.3 - Wave Characteristics

With use of the saved data record in the pressure meter the following characteristics of the waves can be given:

- Number of waves (N)
- Significant wave height (H_s)
- Wave period (T_s)
- Average wave height (H_m)
- Standard deviation (σ)
- Variance (σ^2)
- Minimum wave height (H_{max})
- Maximum wave height (H_{min})

Unfortunately, the wave climate is not known, because at least one year of measurements is required for this. In both cases the wave pressure meter has only measured for a few hours. The maximum and minimum wave height could only be determined when the wave climate is known. Otherwise the values will be invalid. In conclusion, the maximum and minimum wave height cannot be determined for Sirius and Asparuhovo Beach. Although it is said that the maximum individual wave height is twice the significant wave height.

In the following section the wave measurements is treated. The first wave record was created in front of Sirius Beach. The water depth was approximately 2m. In this area the waves where breaking; a sign of shallow water. The conditions belong to coastal water where the breaking waves are present and where the bottom is taking part in the behavior of waves. On the contrary, the waves in the deep waters of Asparuhovo Beach (8m water depth) are not affected by the bottom due to the large water depth. In this case the linear wave theory can be applied.

A.4 - Sirius Beach

The results of the wave data at Sirius Beach are discussed in the following sections.

Wave record 1

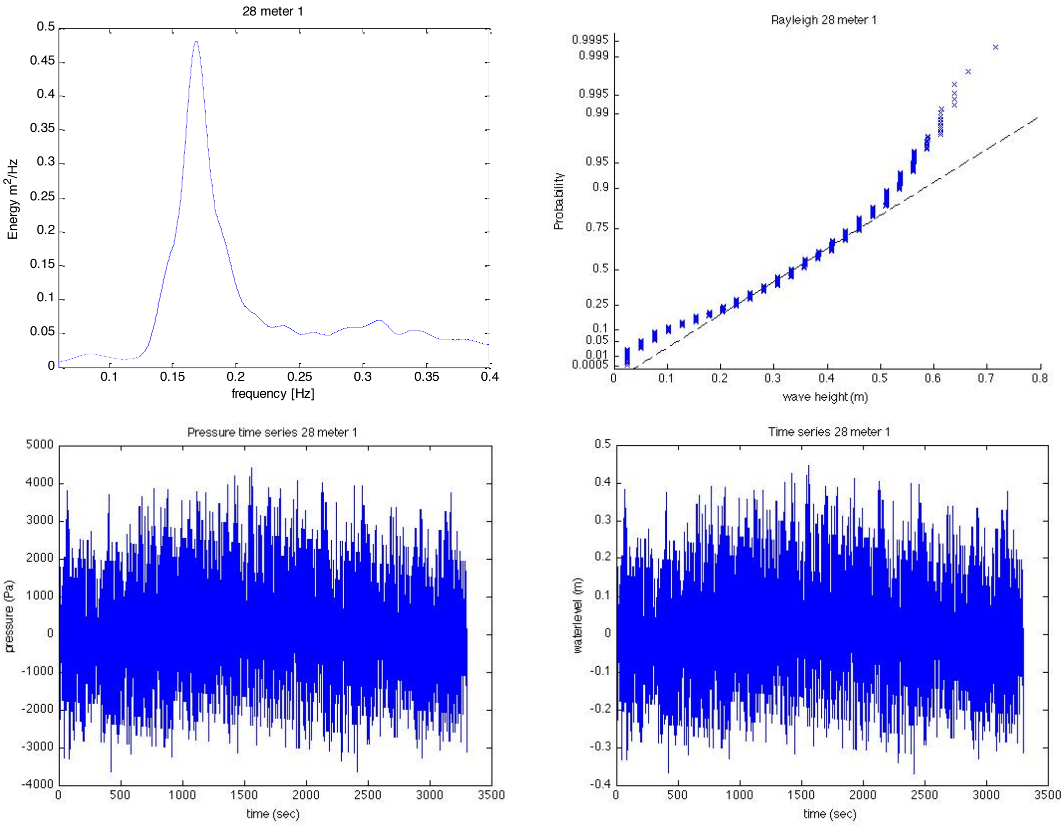


Figure A - 5 Wave data at 28 m from the baseline Sirius Beach (1)

The two most important picture of the four (see Figure A - 5*) are the variance density spectrum E(f) (upper right corner) and the Rayleigh probability density function with the gravity acceleration of 9.81 m/s^2 and water density of 1030 kg/m^3 (salty water). The pressure (lower right corner) and water level record (lower left corner) are translated into these.*

As can be seen the probability density function is not completely Rayleigh distributed. This is because the measuring period was too short (approximately one hour) and shallow water was at the location. The short period is unable to give data that is providing information about the wave climate.

The smaller waves seem to dominate in this period. This is because there are also short waves on top of the larger waves. What is more, larger wave are absent. The large waves break in shallow water when they are too steep. This is occurring in front of Sirius Beach and the spot of the wave pressure meter. Only around the wave height of 0.4m the distribution is perfectly Rayleigh.

The pressure and water level are less visible by the chosen time interval in the graphs. To see details the pictures has to be zoomed in, but this is for this report not required. The first two picture contain all the information required.

The wave variables from the data set is given in Table A - 1. m_0 is the zeroth-order moment of the variance density spectrum, H_{m0} is the significant wave height calculated by m_0, H_{rms} is root-mean-square value of the wave height, T_m is the mean wave period, $T_{0,1}$ is the wave period from the zeroth- and first-order moment of the variance density spectrum (m_1/m_0), $T_{-1,0}$ is the period obtained from the first-order negative moment ($T_{-1,0} = m_{-1} / m_0$) and T_{peak} is the peak period.

Table A - 1 Wave height and period SB (1)

Wave height (m)		**Wave period (s)**	
m_0	0.0287	T_m	4.4466
H_{m0}	0.6779	$T_{0,1}$	4.6994
H_{rms}	0.4794	$T_{-1,0}$	5.2317
		T_{peak}	5.9140

Wave record 2

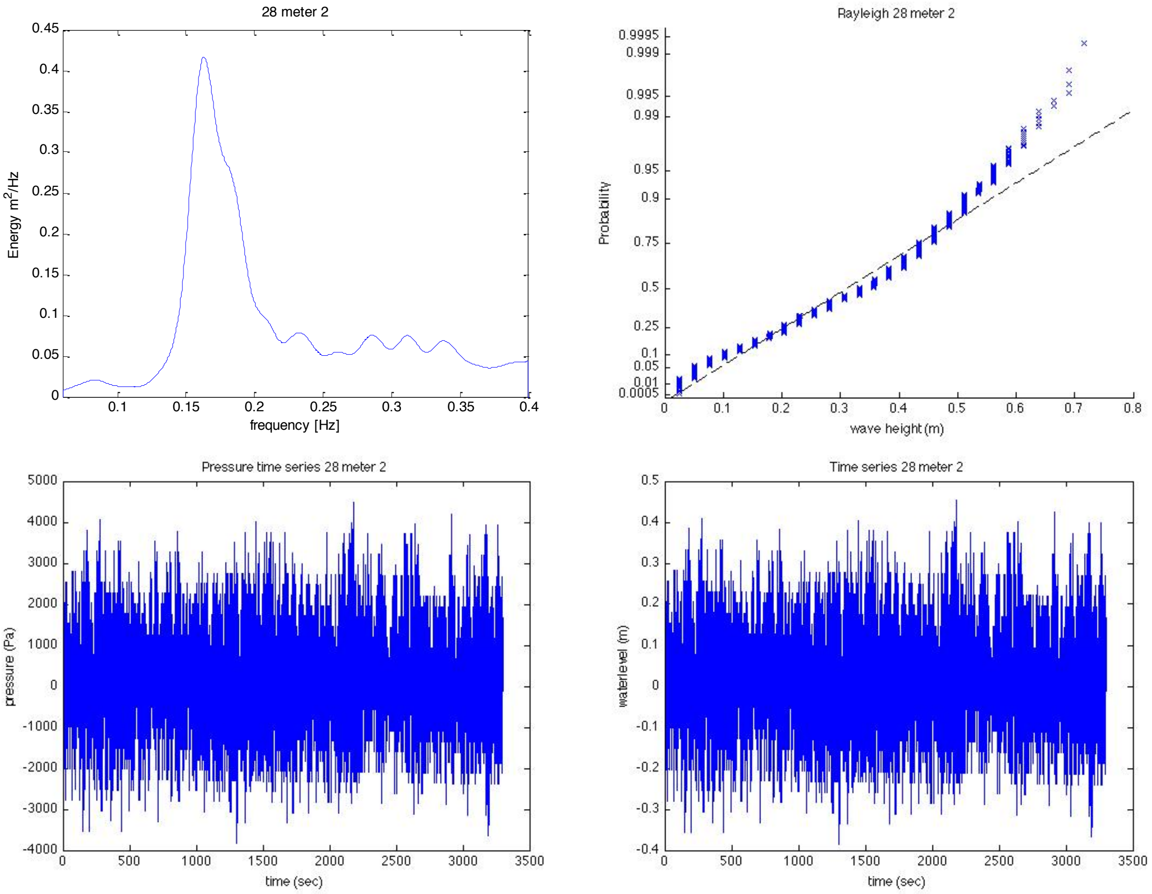


Figure A - 6 Wave data at 28 m from the baseline Sirius Beach (2)

The two most important picture of the four (see) are the variance density spectrum E(f) (upper right corner) and the Rayleigh probability density function with the gravity acceleration of 9.81 m/s^2 and water density of 1030 kg/m^3 (salty water). The pressure (lower right corner) and water level record (lower left corner) are translated into these.

This second measurement of Sirius Beach waves was done at the same location as the first one. It can be concluded from the variance density spectrum and probability density function (Figure A - 6) that the wind conditions changed Including the shallow water conditions the distribution of the empirical data will fluctuate along the Rayleigh line (dashed line). Owing to this, the resulting significant wave height is higher and the mean wave period is lower, when Table A - 1 and Table A - 2 are compared. If wind speed is increasing the waves will become steeper and within the wave period shortens.

Table A - 2 Wave height and period SB (2)

Height (m)		Period (s)	
m_0	0.0290	T_m	4.3829
H_{m0}	0.6809	$T_{0,1}$	4.6294
H_{rms}	0.4814	$T_{-1,0}$	5.1651
		T_{peak}	6.1338

Wave record 3

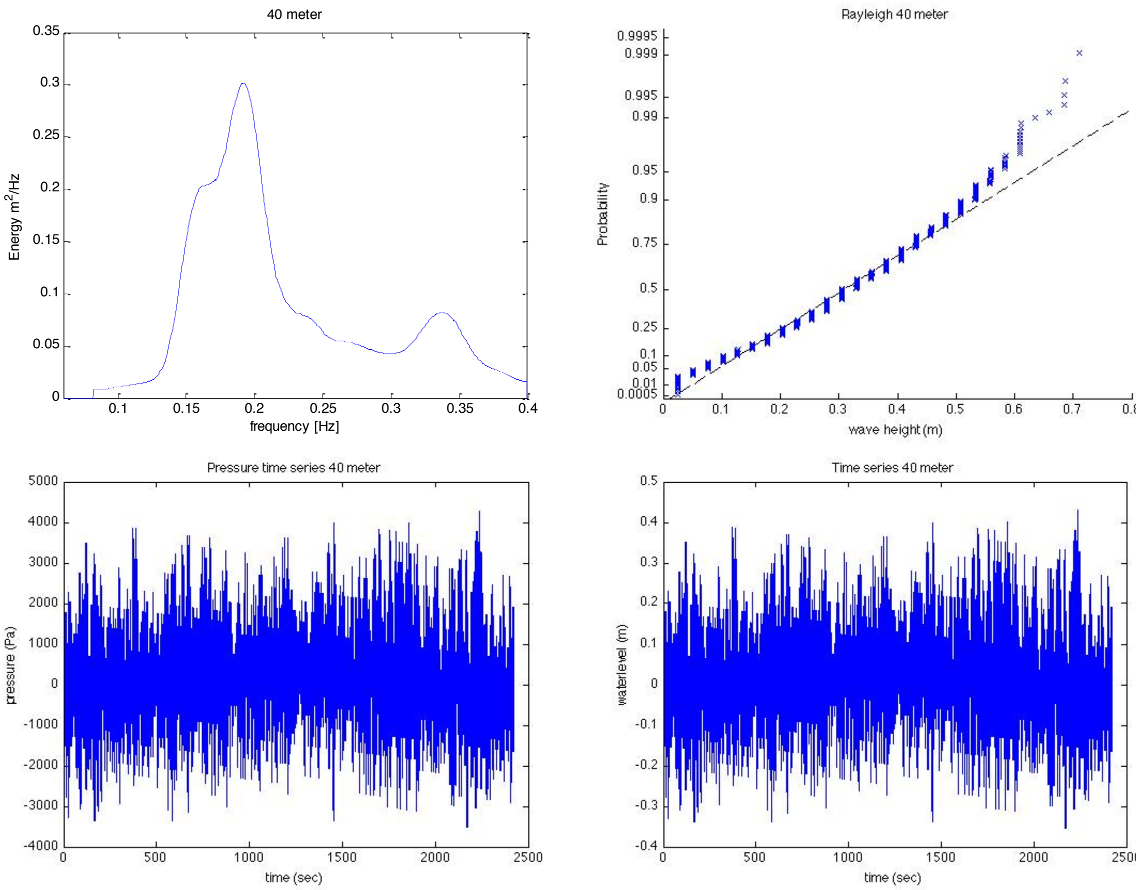


Figure A - 7 Wave data at 40 m from the baseline Sirius Beach (3)

The two most important picture of the four (see Figure A - 7*) are the variance density spectrum E(f) (upper right corner) and the Rayleigh probability density function with the gravity acceleration of 9.81 m/s^2 and water density of 1030 kg/m^3 (salty water). The pressure (lower right corner) and water level record (lower left corner) are translated into these.*

The third data set is measured with a larger distance to the baseline and deeper water (2.5m to 3m water depth). The wave meter was for a larger time in the water. Still the observed wave height (Figure A - 7) starts to deviate around 0.5m from the Rayleigh line. The wave characteristics from this measurement are given in Table A - 3.

Table A - 3 Wave height and period SB (3)

Height (m)		Period (s)	
m_0	0.0270	T_m	4.3216
H_{m0}	0.6568	$T_{0,1}$	4.5174
H_{rms}	0.4644	$T_{-1,0}$	4.9139
		T_{peak}	5.2209

A.5 - Asparuhovo Beach

The following four wave measurements were performed in front of Asparuhovo Beach. The wave pressure meter measured every hour 20 minutes.

Wave Record 1

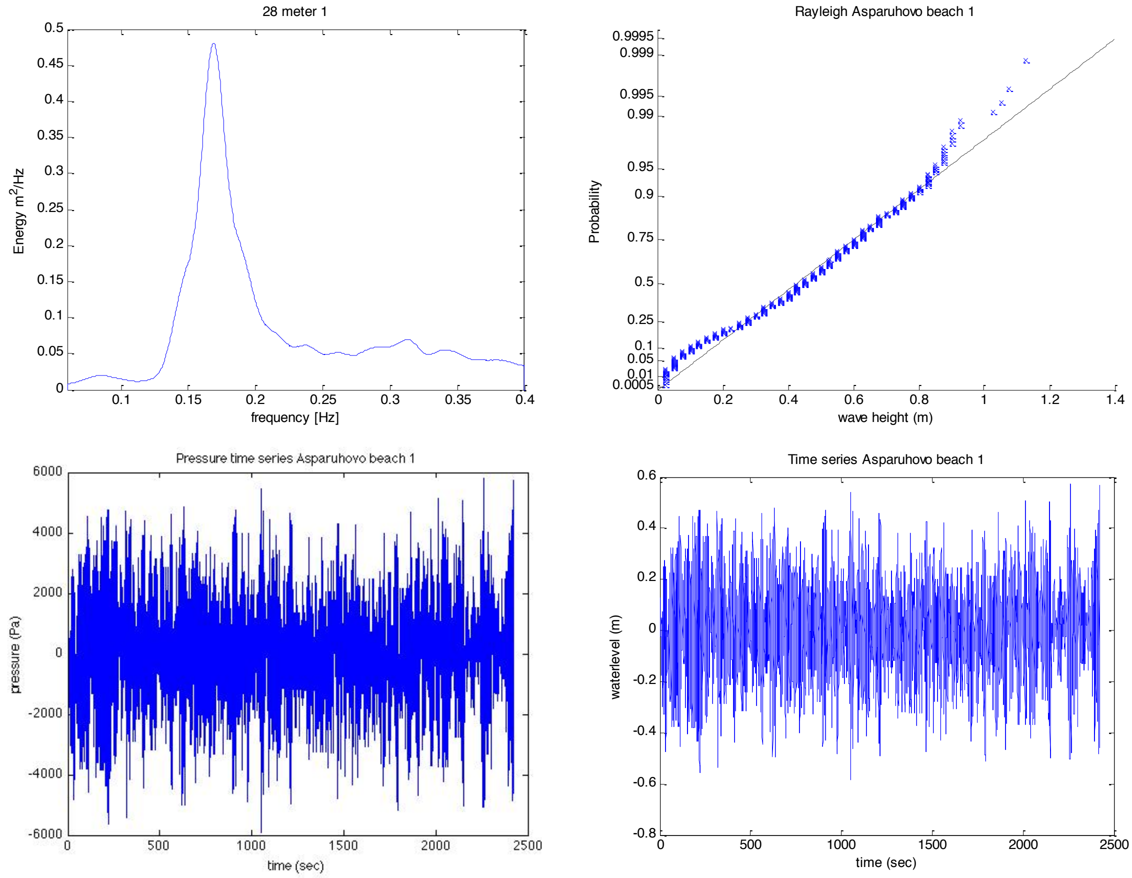


Figure A - 8 Wave data Asparuhovo Beach (1)

The two most important picture of the four (see Figure A - 8*) are the variance density spectrum E(f) (upper right corner) and the Rayleigh probability density function with the gravity acceleration of 9.81 m/s^2 and water density of 1030 kg/m^3 (salty water). The pressure (lower right corner) and water level record (lower left corner) are translated into these.*

The energy density spectrum shows an increase of the peak energy from 0.3 m^2/Hz (Sirius Beach) to almost 0.5 m^2/Hz. Accordingly, the average wave height becomes higher.

In the probability density function (Figure A - 8) the observation continues with the larger wave height of Asparuhovo in comparison with Sirius Beach (Figure A - 5), respectively 1.4m and 0.8m as maxima on the axes. These is as result of the deeper water of (around) 8m instead of 2m.

Another side issue is the scattering of the graph in the lower left and right corner. The pressure (later converted in wave height), for example, fluctuates more than at Sirius Beach. The result are given in the next Table A - 4.

Table A - 4 Wave height and period AB (1)

Height (m)		**Period (s)**	
m_0	0.1125	$\mathbf{T_m}$	5.6974
H_{m0}	1.3414	$\mathbf{T_{0,1}}$	5.9103
H_{rms}	0.9485	$\mathbf{T_{-1,0}}$	6.3118
		$\mathbf{T_{peak}}$	7.3248

Wave Record 2

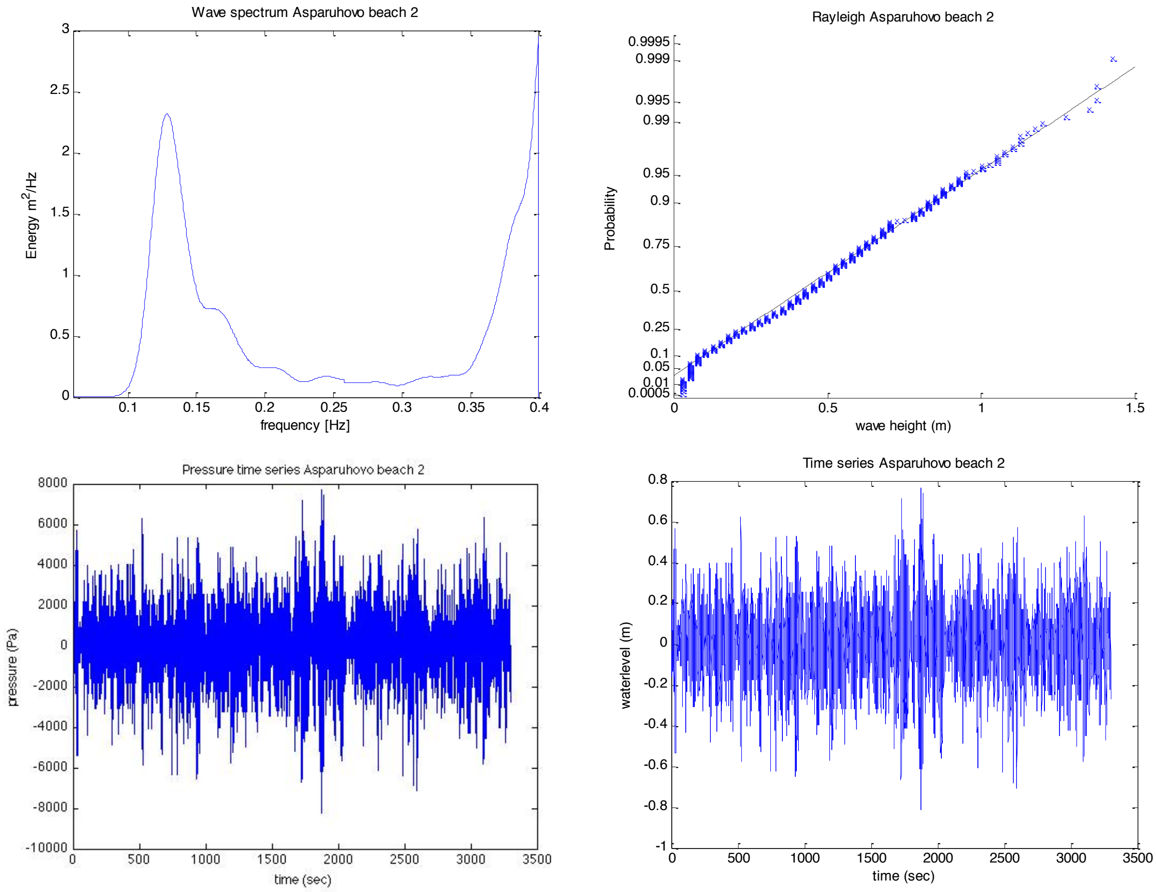


Figure A - 9 Wave data Asparuhovo Beach (2)

The two most important picture of the four (see Figure A - 9*) are the variance density spectrum E(f) (upper right corner) and the Rayleigh probability density function with the gravity acceleration of 9.81 m/s^2 and water density of 1030 kg/m^3 (salty water). The pressure (lower right corner) and water level record (lower left corner) are translated into these.*

The second measurement shows increasing pressure and water level differences. The data seems to fit the Rayleigh distribution, but still the smaller and largest wave heights tend to leave to dashed line. In deep water the smaller heights do not affect the meter, which is a accuracy issue and leads to less waves noticed.

The larger wave heights also scatter around the Rayleigh line (Figure A - 8 and Figure A - 9). After 1.2m to 1.4m wave heights the waves reaches there maximum for this location. The higher wave height and shorter wave period are given in Table A - 5.

An interesting phenomena are two peaks in the picture in the upper left corner. After 0.3Hz the graphs should be stopped, because ‘noise’ (short waves with high pressure fluctuation) results in high frequency waves with high amplitudes. These waves are on top of the actual waves and are therefore not part of the spectrum.

Table A - 5 Wave height and period AB (2)

Height (m)		**Period (s)**	
m_0	0.1755	$\mathbf{T_m}$	3.7828
H_{m0}	1.6758	$\mathbf{T_{0,1}}$	4.1883
H_{rms}	1.1850	$\mathbf{T_{-1,0}}$	5.2656
		$\mathbf{T_{peak}}$	2.5019

Wave Record 3

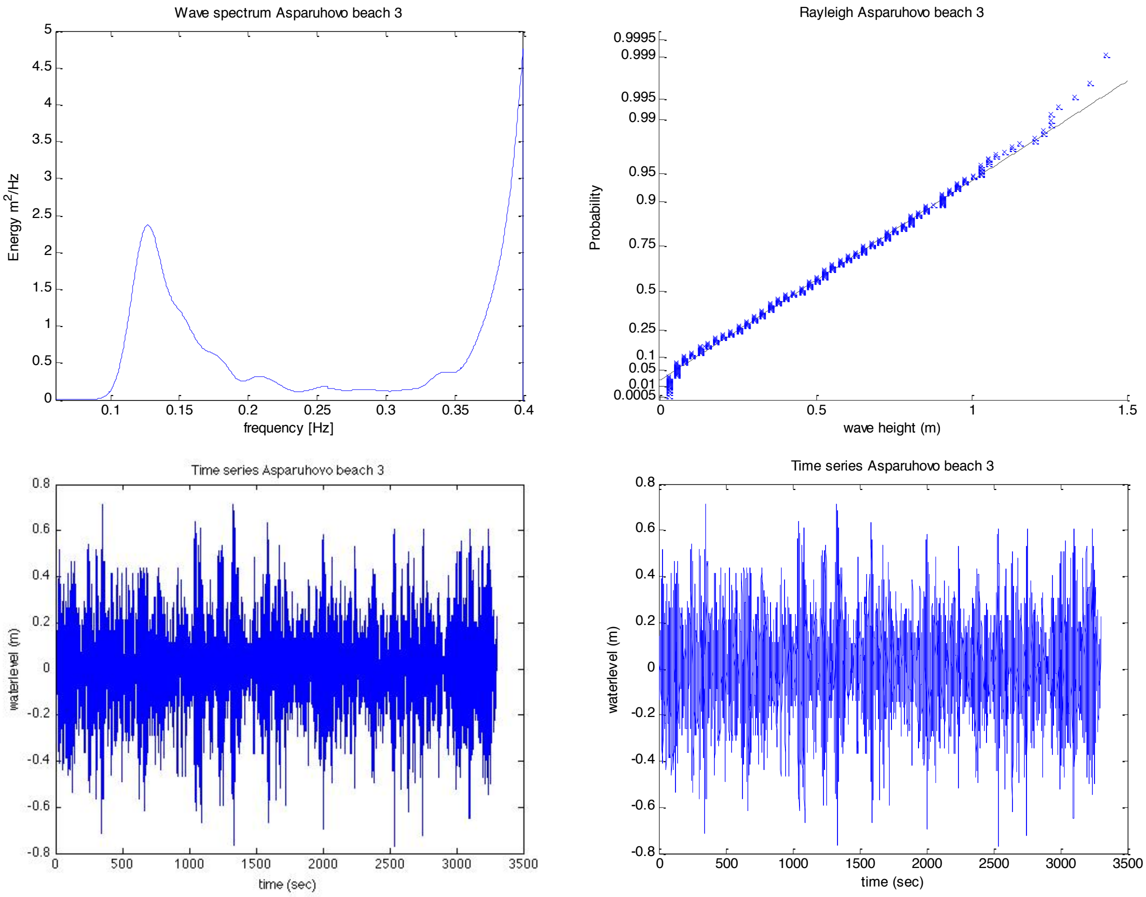


Figure A - 10 Wave data Asparuhovo Beach (3)

The two most important picture of the four (see Figure A - 10*) are the variance density spectrum E(f) (upper right corner) and the Rayleigh probability density function with the gravity acceleration of 9.81 m/s^2 and water density of 1030 kg/m^3 (salty water). The pressure (lower right corner) and water level record (lower left corner) are translated into these.*

The spectrum has the same peak in 0.4Hz as the previous observations (Figure A - 10). The curve cut at 0.3Hz as mentioned as earlier mentioned. It must be notified that the mean wave height is increased in this wave record and the wave period is more reduced (Table A - 6).

Table A - 6 Wave height and period AB (3)

Height (m)		**Period (s)**	
m_0	0.2174	T_m	3.6054
H_{m0}	1.8649	$T_{0,1}$	3.9712
H_{rms}	1.3187	$T_{-1,0}$	5.0341
		T_{peak}	2.5019

Wave Record 4

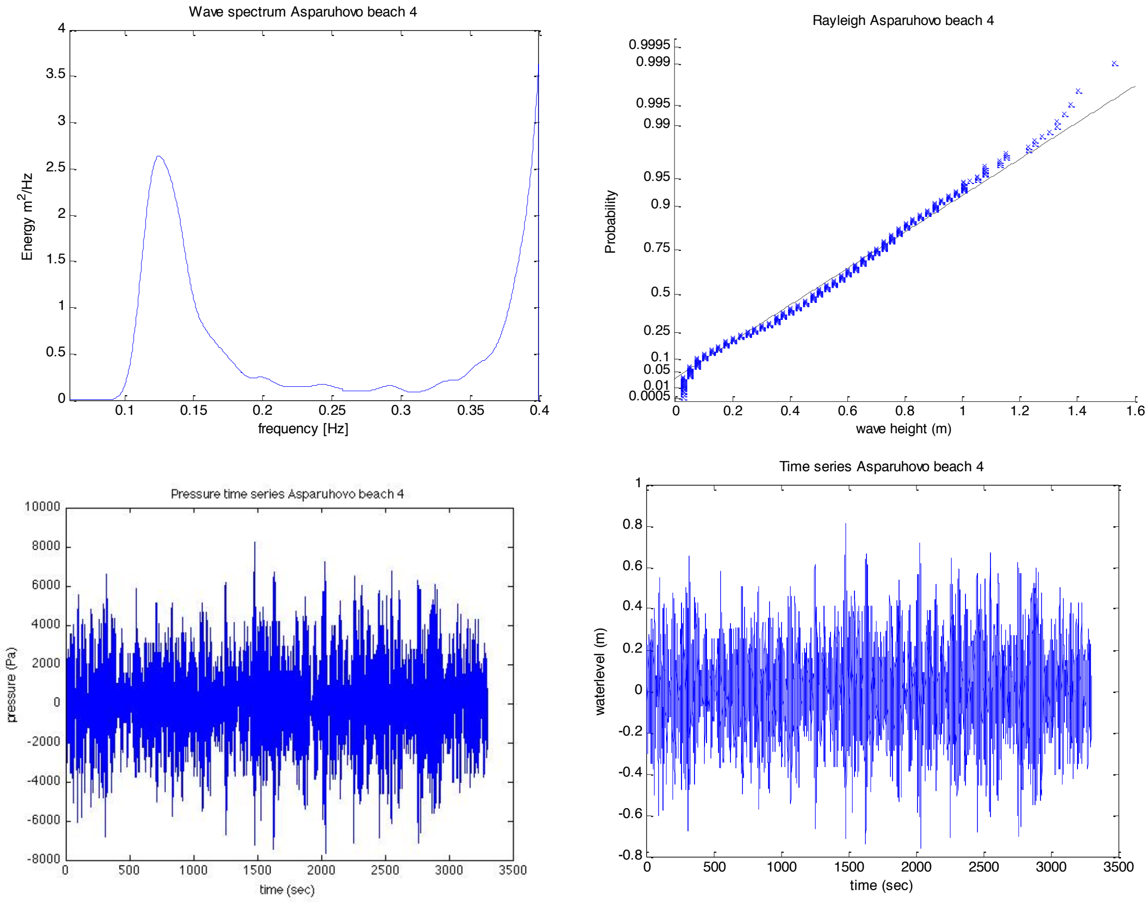


Figure A - 11 Wave data Asparuhovo Beach (4)

The two most important picture of the four (see Figure A - 11*) are the variance density spectrum E(f) (upper right corner) and the Rayleigh probability density function with the gravity acceleration of 9.81 m/s^2 and water density of 1030 kg/m^3 (salty water). The pressure (lower right corner) and water level record (lower left corner) are translated into these.*
The wind plays an important role in the wave height and decides steep or flat waves. For example, the waves become swell outside the storm location. The wind impact is in the last measurement less when the mean wave height becomes less en the wave period grows.

Table A - 7 Wave height and period AB (4)

Height (m)		**Period (s)**	
m_0	0.1946	T_m	3.9252
H_{m0}	1.7646	$T_{0,1}$	4.3946
H_{rms}	1.2478	$T_{-1,0}$	5.5778
		T_{peak}	2.5019

A.6 - SWAN 1D

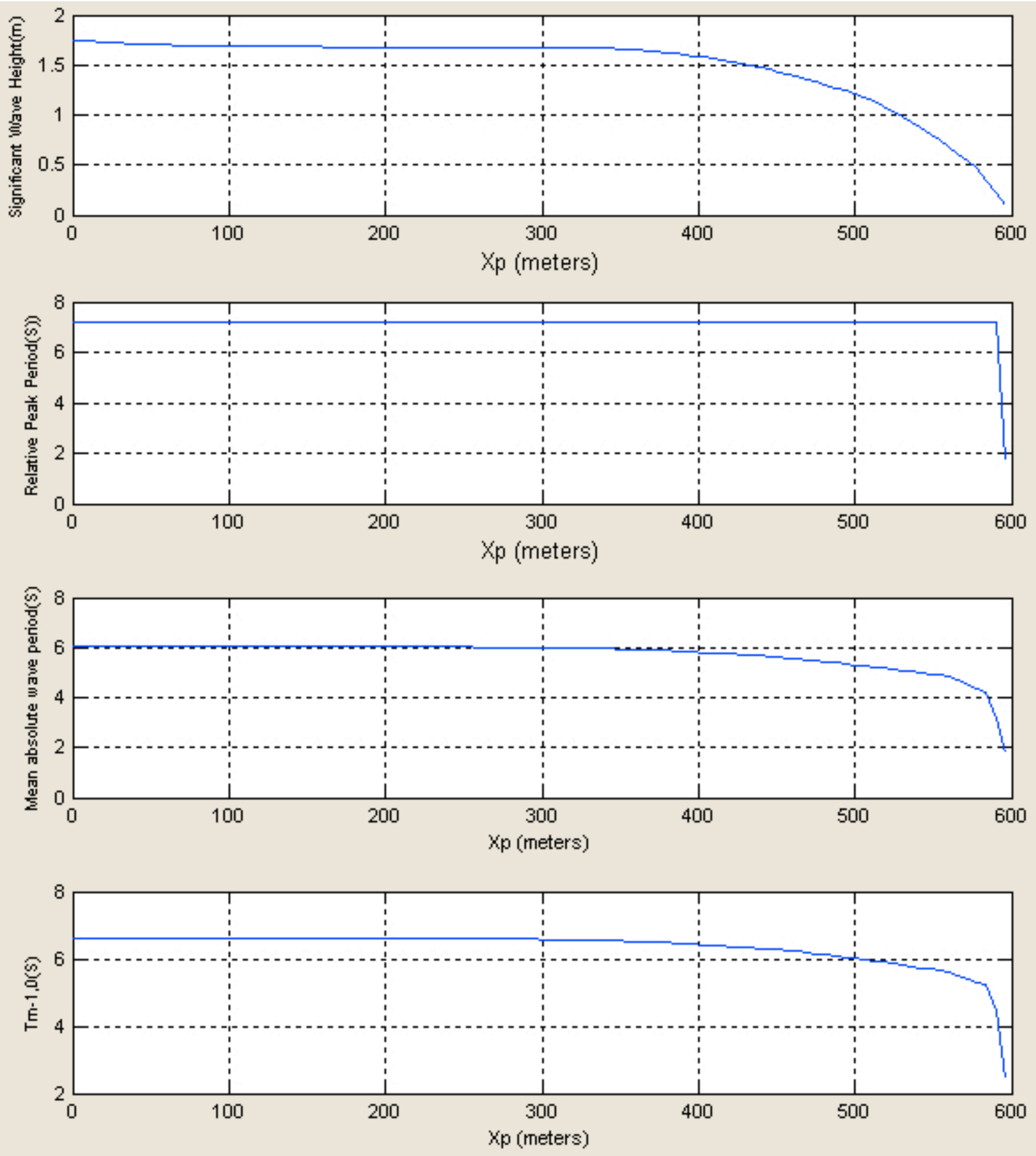


Figure 0-1 Significant wave height, relative peak period, mean absolute wave perioda dn Tm-1,0

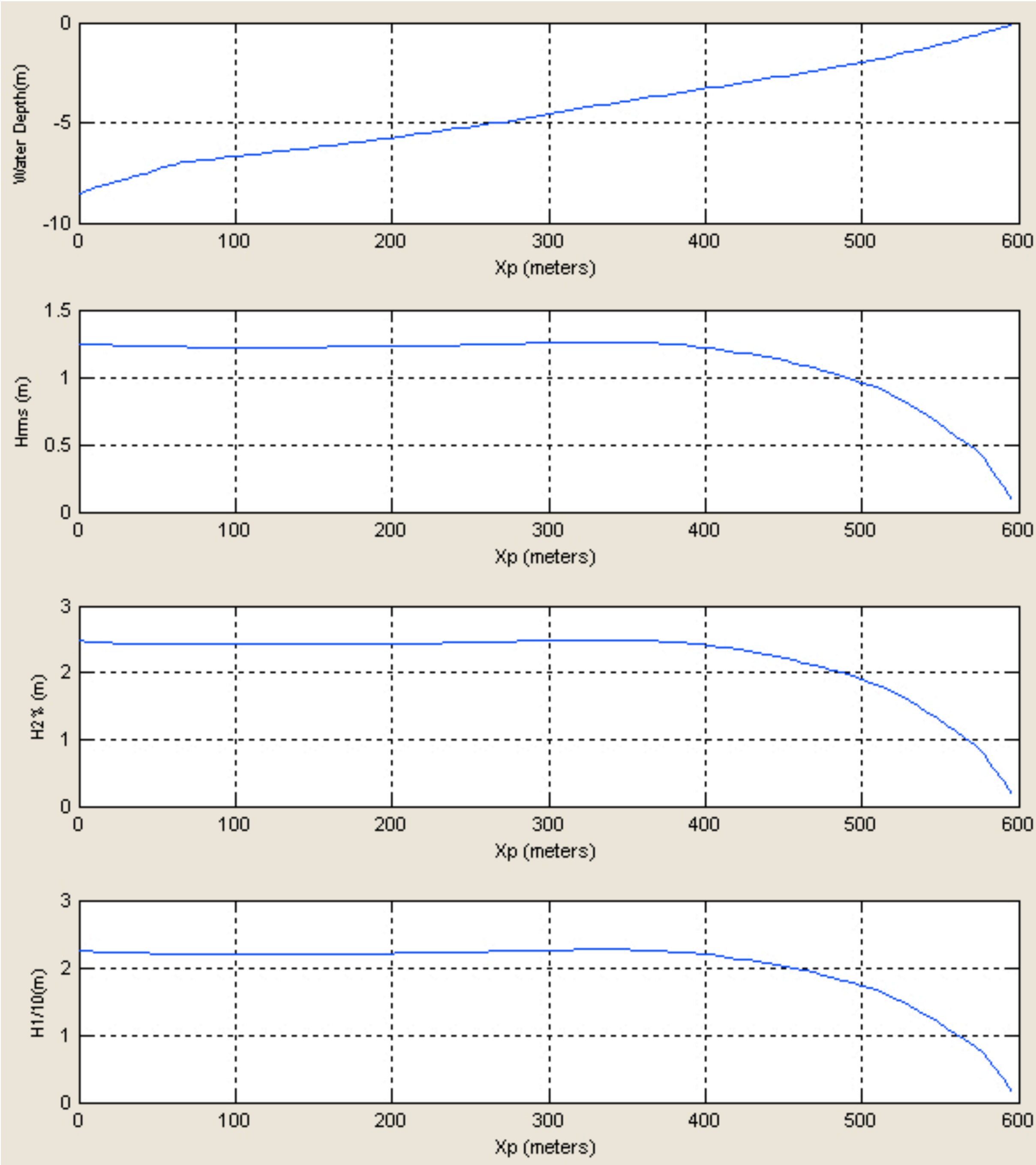


Figure 0-2 Water depth, Hrms, H2% and H1/10

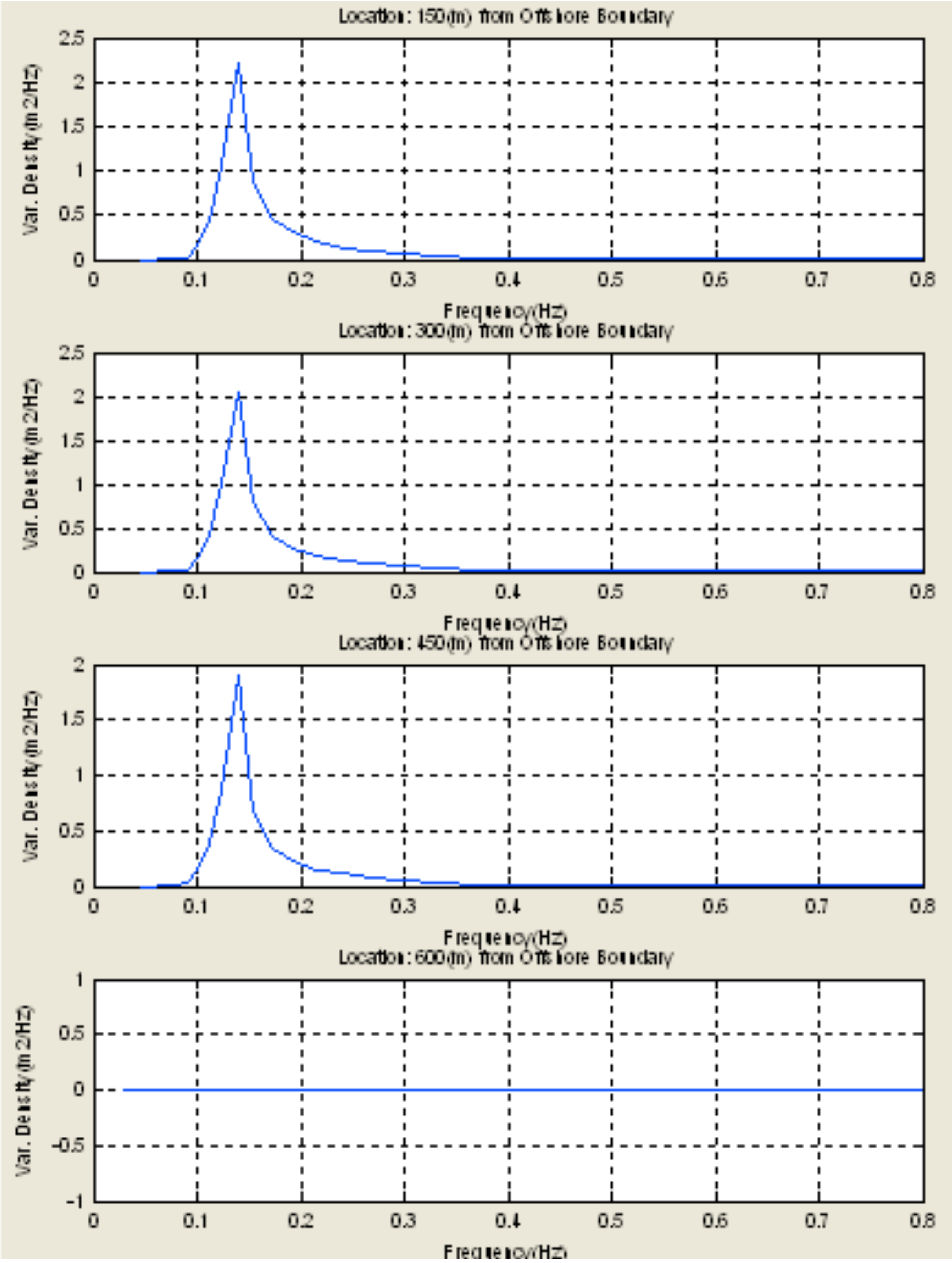


Figure 0-3 Variance density spectrum at 150m, 300m, 450m and 600m from the deep water wave measurement

Appendix B - OpenEarth

B.1 - Purpose

To order and compare collected data of previous years and years to come, use can be made of OpenEarth. This is an initiative by Deltares, which purpose is best described by quoting the main page of the Deltares OpenEarth site:

"OpenEarth is a free and open source initiative to deal with data, models and tools in marine & coastal science & engineering projects. In current practice, research, consultancy and construction projects commonly spend a significant part of their budget to setup some basic infrastructure for data and knowledge management. Most of these efforts disappear again once the project is finished. As an alternative to these ad-hoc approaches, OpenEarth aims for a more continuous approach to data & knowledge management. It provides a platform to archive, host and disseminate high quality data, state-of-the-art model systems and well-tested tools for practical analysis. Through this project-superseding approach, marine & coastal engineers and scientists can learn from experiences in previous projects and each other. This may lead to considerable efficiency gains, both in terms of budget and time."

This means that our uploaded data should be in English and clear on what the data is about. In this way people performing fieldwork in the next years will be able to recall that data and compare it to theirs, and thus get a picture of changes depth, wave heights or bathymetry over the years.

B.2 - How to?

To start using OpenEarth, first you need to create an account. This is possible via oss.deltares.nl where you can create an account by clicking in the top right corner. Once registered there you have access to the wiki, which can be found under publicwiki.deltares.nl. Here you have to click on the OpenEarthRawData repository.

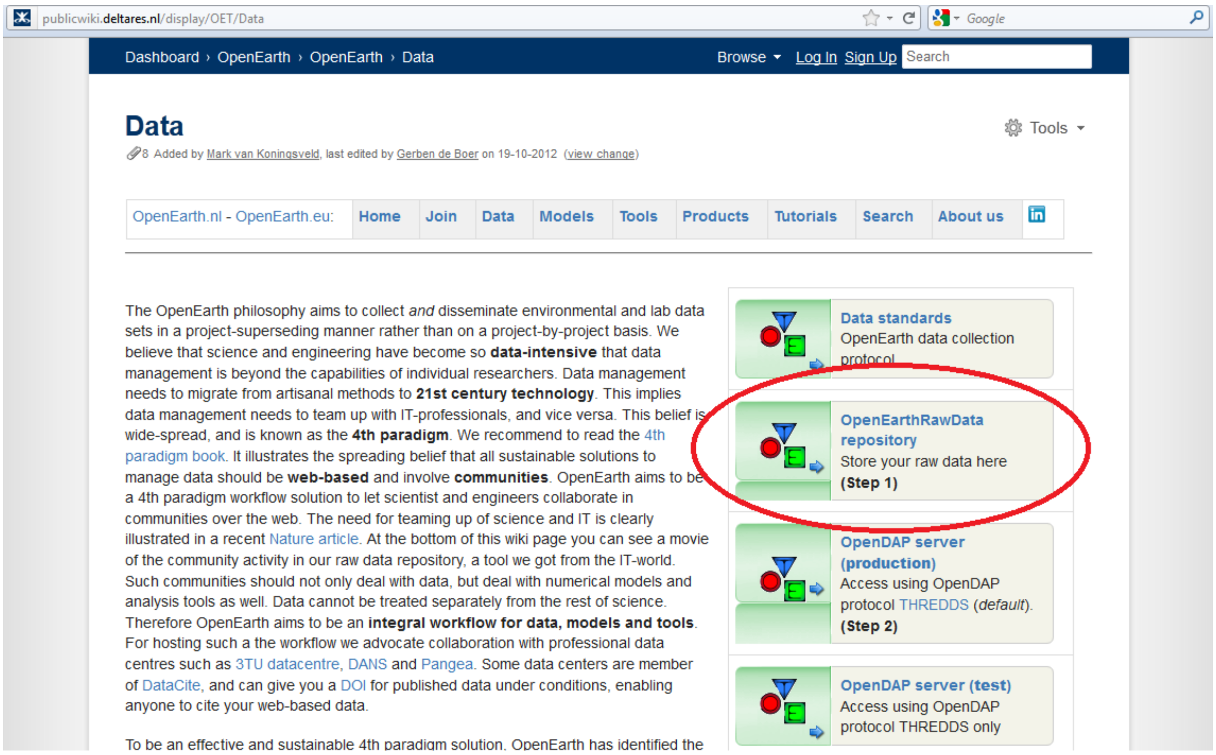
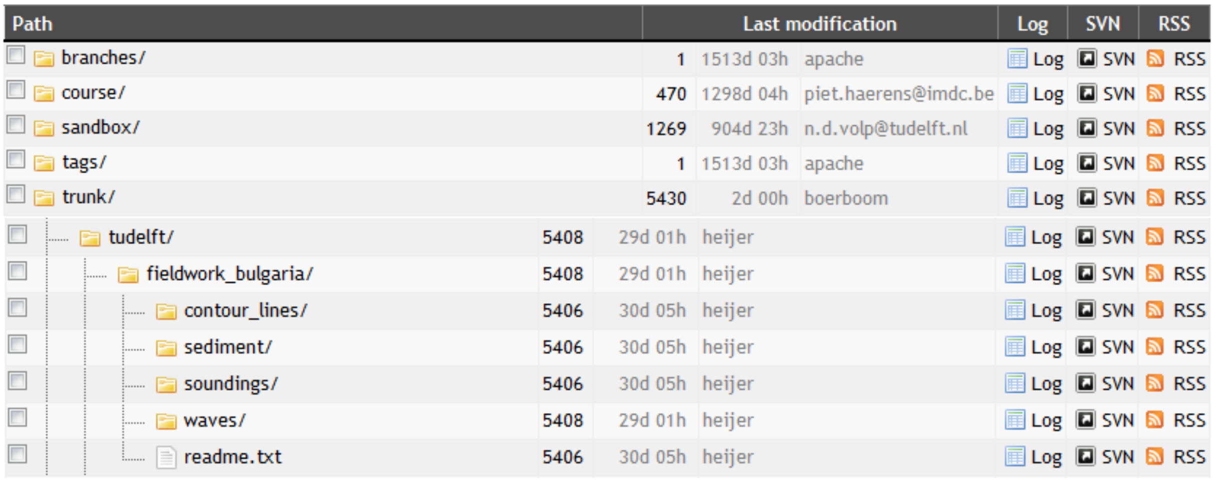


Figure B - 1 OpenEarthRawData repository

Once there, you can find the fieldwork data by clicking on the trunk map, guiding you to the fieldwork_bulgaria map via the tudelft map. See the picture below.



Path		Last modification		Log	SVN	RSS
branches/	1	1513d 03h	apache	Log	SVN	RSS
course/	470	1298d 04h	piet.haerens@imdc.be	Log	SVN	RSS
sandbox/	1269	904d 23h	n.d.volp@tudelft.nl	Log	SVN	RSS
tags/	1	1513d 03h	apache	Log	SVN	RSS
trunk/	5430	2d 00h	boerboom	Log	SVN	RSS
tudelft/	5408	29d 01h	heijer	Log	SVN	RSS
fieldwork_bulgaria/	5408	29d 01h	heijer	Log	SVN	RSS
contour_lines/	5406	30d 05h	heijer	Log	SVN	RSS
sediment/	5406	30d 05h	heijer	Log	SVN	RSS
soundings/	5406	30d 05h	heijer	Log	SVN	RSS
waves/	5408	29d 01h	heijer	Log	SVN	RSS
readme.txt	5406	30d 05h	heijer	Log	SVN	RSS

Figure B - 2 Subversion Repository

You can only find the data here, in order to upload and manage the data; you need the program Tortoise SVN. SVN stands for subversion, which means you can see who uploaded what and when.

- To start, you create a new folder on your own computer (you have to download Turtoise SVN first) or on a TU Delft computer, on which Tursoise is already installed.
- Click the right mouse button and choose SVN checkout. In the Checkout screen your input for the URL repository is: https://svn.oss.deltares.nl/repos/openearthrawdata/trunk/tudelft/fieldwork_bulgaria/ and use the local map as the Checkout directory.

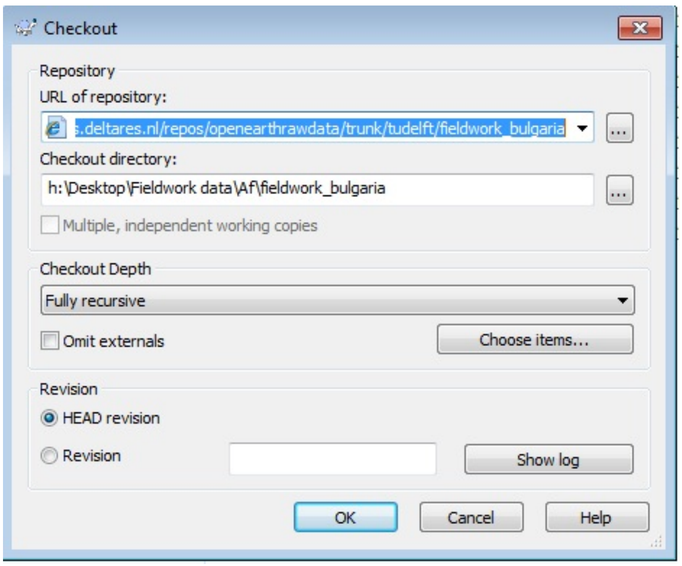


Figure B - 3 Checkout screen

- The maps from the database will now be put on your computer, which means the database is linked to that map (for comparison, this is pretty much the same idea as DropBox).
- Now you can add, change or remove files on your computer in the local map. Be sure the raw data is deposited in the raw data map and any MatLab scripts used to process the raw data is placed in the scripts folder. For every next year add a new folder (2012, 2013... etc.)

- If you want to synchronize with the Deltares database, commit the folders that have changed. To do so go to the main folder your created in step one, click the right mouse button and click SVN Commit, where you have to check the new folders and/or files and a comment about your change can be added (date, reason, etc.).
- By clicking ‘ok’ your local file is synchronized with the Deltares database.

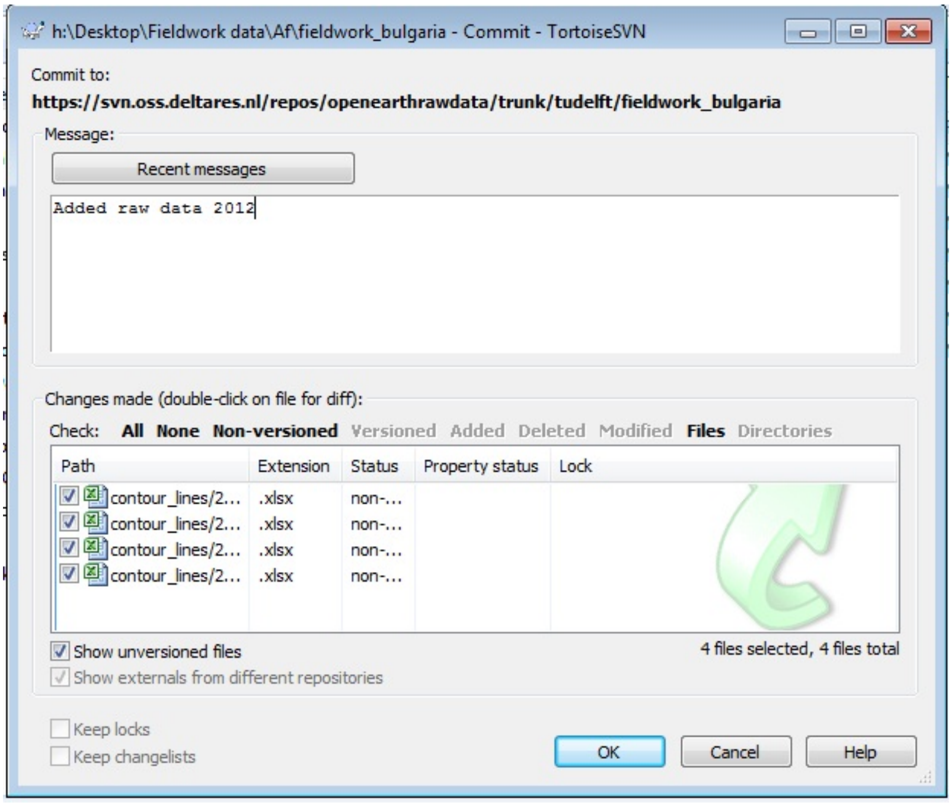


Figure B - 4 Commit screen