Fieldwork Hydraulic Engineering CT 5318
Bulgaria, Varna
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Preliminary design of an artificial island in the Black Sea

Delft University of Technology

Preface

The Hydraulic Engineering master education at Delft University of Technology consists of mainly theoretical courses. All kinds of physical phenomena are translated into mathematical expressions and formulations. One might graduate on topics that one has never seen in real life. The hydraulic engineering fieldwork supplies in this lack of experience. It allows a group of students to get in touch with engineering on a very basic level and in a very interesting environment.

From Sunday September 30th until October 7th, a group of 16 Hydraulic engineering students and one teacher went to Bulgaria. Three Bulgarian students and two Bulgarian teachers from Sofia University of Architecture, Civil Engineering and Geology joined them at their arrival in Varna. The students were given an assignment concerning the construction of an artificial island in the Black Sea to facilitate a new hotel. All kinds of measurements were done to aid in the preliminary design. Some of the data analysis had to be done in Bulgaria, but most was done afterwards in Delft. Additionally some excursions were made to nearby quarries, breakwaters and other interesting sites.

The objectives of the fieldwork are to teach the students to be able to make reasonable estimates of parameters of rocks, waves and other hydraulic features and one has to get a better feeling for dominant processes, sizes, scales and the accuracy of these estimates. Additionally the students learn to carry out simple measurements with rather unsophisticated measuring devices. Working in a foreign country and dealing with language difficulties was also a very interesting experience.

This report gives the outcomes of the measurements, an analysis of the results and conclusions on the assignments. It serves as a preliminary technical report about the assignment, which can be used to aid in the beginning of the design process.

Many thanks go to Mr. Henk Jan Verhagen, who so enthusiastically organised this fieldwork. It was a jubilee since it was the fifth time that he has done so. We are very grateful for his efforts and support during the week. The efforts of Mr. Boyan Savov and Mr. Kristjo Daskalov are also very much appreciated.

Delft, November 2007

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Summary

The fieldwork took place from September 30th until October 7th 2007 near Varna, Bulgaria. The students were given an assignment to give them experience in the practical aspects of hydraulic engineering. They were to make an analysis of the hydraulic conditions that influenced the designs with very simple means in an unknown environment. They trained a lot of practical abilities that are incredibly convenient for a hydraulic engineer. Examples are the estimation of sizes, dimensions, characteristics and values of parameters, communication with foreign engineers and non-engineers about hydraulic engineering topics, analyse under uncertainties and how to act when things are not going as expected.

Feasibility assignment

The assignment was to investigate the feasibility of the construction of a new artificial island in front of the coast of St. Konstantin I Elena. This island will serve to accommodate a new hotel and tourist activities. Some of the major components of the island were designed roughly to see if the orders of magnitudes were according to expectation. This seemed to be the case. The amount of required material, the height of the breakwaters and the shape of the island were considered, but it appeared that a lot of additional information is still required for a more detailed design of the island.

Measurements

To make an analysis to execute the assignment, information about the local conditions was required. To this purpose a series of relatively simple measurements were carried out. An overview of the measured features and the outcomes is given below.

- Sand characteristics

The sand is of sufficient quality to use for constructing a new island, but there is not enough available near the building site. The differences in the characteristics of sand at various locations gave insight in the forcing at these locations.

- Rock

The output of a nearby quarry, the Martsiana quarry, was investigated. It proved useful for the construction of an island and it is also of sufficient quality for the construction of breakwaters. The delivery however needs special attention to make sure it is of the required.

- Local constructions

The constructed objects in the surroundings gave insight in the order of magnitude of the loadings that may occur at the location of the artificial island. It seemed that waves of maximal 3 meters can occur and it was concluded that most of the designs were not efficient and over-dimensioned.

- Waves

With visual- and pressure measurements, an estimate of the wave forcing was made. With additional numerical computations it was determined that the wave height at the island location is about 1 meter under average conditions. A probabilistic analysis was made for the wave heights that correspond with various levels of safety. A lot of uncertainty remains in the accuracy of the found magnitudes.

- Bathymetry and beach profiles

The local bathymetry was measured and compared to earlier measurements. It was found that the bottom is rather stable and steep. The beaches near the location of the new island are quite gentle near the waterline but erode rather severely.

- Morphological processes

A simple analysis of the morphology was made and it was found that the beaches are eroding at some places and accreting less at other places. The magnitude of the processes is very uncertain and requires additional attention in the future.

Conclusions and recommendations

The construction of an artificial island in front of the coast of St. Konstantin I Elena seems, after the fieldwork is conducted and a feasibility analysis is made, a feasible plan. The fieldwork does however appoint several aspects that need further elaboration and research. The ongoing erosion at the beaches next to the building site of the island could be worsened by the construction and is an issue that needs to be taken into account with the construction. Also the water quality and island design need extra attention. What can be learned from existing local constructions is that a thorough analysis of the hydraulic features is important to create a good design and provide the required and wanted safety. Recommendations are to clearly state the demands before starting the design and construction phase of the project. Determining an acceptable failure chance is an important part. Again, this fieldwork is only a preliminary investigation carried out by students that are none yet professionals, but it shows which parts of the design and construction need further elaboration.

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1 Introduction

In this introduction, first of all the background of our project area is outlined. After an overall overview of Bulgaria is given, focus is on respectively Varna and St Konstantin I Elena, in paragraph 1.1. Subsequently, the purpose of the fieldwork, with its boundary conditions and demands is discussed in paragraph 1.2. In the last paragraph (paragraph 1.3) a set-up of the report is indicated.

1.1 Region

1.1.1 Bulgaria

Bulgaria is situated in south-eastern Europe on the west coast of the Black Sea. The country is bordered by Romania to the north, Greece and Turkey to the south, and Serbia to the west. The capital city of Bulgaria is Sofia. Other important cities are Plovdiv, Varna and Burgas. Figure 1 shows a map of Bulgaria.

Figure 1 Map of Bulgaria

1.1.2 Varna

Being the third largest city in Bulgaria, Varna and its surroundings contribute significantly to the GDP. There is a lot of industry that focuses for the larger part on transportation, shipbuilding and -repairing. This is due to the fact that Varna has the largest harbour of Bulgaria and an airport. Tourism is an even larger element in the local economy. In 2004 it was responsible for 61% of the local net income and this share is still increasing rapidly.

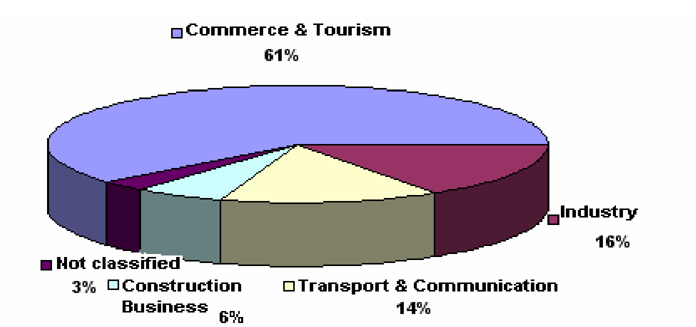


Figure 2 Division of net income per sector for Varna (www.varna.bg)

1.1.3 St. Konstantin I Elena

The St. Konstantin I Elena region, where the fieldwork took place, is developing rapidly into a big centre of tourism. Known for its mineral water sources, it attracts many tourists that visit spa and wellness centres. Among its most luxurious hotels is the Azalia hotel. It is located between the Sunny Day marina and the St. Elias marina at a beautiful location near the coast and the town. The participants of the fieldwork stayed here during their visit. Figure 3 shows a map of St. Konstantin and the location of Hotel Azalia.

Figure 3 Map of St. Konstantin I Elena and the location of Hotel Azalia.

1.2 Fieldwork

1.2.1 Assignment

The owner of the Azalia hotel is planning a new hotel in the area. To distinguish the new hotel from the others along the coast, it is to be built offshore. This way, the hotel offers an exciting view, a peaceful environment and a sense of exclusiveness. It was envisaged that the hotel is to be built on an artificial island at the tip of the groyne that is located directly north of the St. Elias marina. This location is shown in Figure 3 above.

The main purpose of the fieldwork is to investigate whether it is feasible to construct an island, on top of which the new hotel is to be built, at the designated location. A secondary purpose of the fieldwork is to consider the possible effects such an island may have on the environment.

It is stressed here that the assignment for this fieldwork is to make a preliminary investigation of the factors that play a role, from a hydraulic engineering point of view, in order to get an idea of the feasibility of such a structure. This report therefore will give only a preliminary and very conceptual design for the artificial island on which the hotel is to be built. It will focus solemnly on hydraulic engineering aspects of the problem. It is meant to serve as an indication of the feasibility of the plan and as a rough indication of dimensions, costs, risks and effects.

1.2.2 Boundary conditions

To obtain information about the governing hydraulic boundary conditions a series of measurements was carried out during the fieldwork. The different measurements are:

- Wave characteristics (determined both visually and using a pressure meter)
- Beach profiles
- Bathymetry survey
- Quarry output (determining the usability of rock and fill material at nearby quarries)
- Observation of nearby constructions (groyne measurement, visual inspections)

This data was roughly analysed on site in Bulgaria. A more thorough data analysis has been carried out at the University of Technology in Delft in order to arrive at a sound advice regarding the construction of the artificial island.

1.2.3 Demands

Below the functional and operational demands are given, as well as the demands on the influences the construction and presence of the artificial island has. These demands are partly given by the hotel owner and partly set up as guidelines for the fieldwork. The hotel owner is regarded as the client of this research.

Functional demands

The artificial island

- has a surface of (approximately) 15.000 m^2
- has to provide a solid foundation for a hotel
- has a private beach with sea view that is in direct sunlight for at least 10 hours per day during the tourist season

Operational demands

The artificial island

- has to be permanently accessible by truck during the tourist season
- may not be out of operation due hydraulic features during the tourist season
- may not be damaged by hydraulic features during the tourist season
- has to provide an acceptable level of safety to the people on the island

Influences

The construction and presence of an artificial island

- may not negatively influence the surrounding ecology
- may not negatively influence the surrounding beaches
- may not negatively influence the surrounding morphology

1.2.4 Boundary conditions

To obtain information about the governing hydraulic boundary conditions a series of measurements was carried out during the fieldwork. The different measurements are:

- Wave characteristics (determined both visually and using a pressure meter)
- Present beach profiles
- Present bathymetry
- Quarry output (determining the usability of rock and fill material at nearby quarries)
- Nearby constructions (groyne measurement, visual inspections)

This data was roughly analysed on site in Bulgaria to obtain quantitative information about the boundary conditions at the construction site. A more thorough data analysis has been carried out the University of Technology in Delft in order to arrive at a sound advice regarding the construction of the artificial island. The most relevant boundary conditions are:

- Waves
  - Seasonal variation of wave parameters
  - Long-term probability of occurrence of wave heights
- Water levels
- Beaches
  - Erosion / accretion
- Materials
  - Characteristics / quality
  - Availability
- Bathymetry
- Morphological processes

1.3 Report set-up

An introduction to the report is given in this chapter. A design of an artificial island requires accurate maps of the direct environment of the island and information about the processes, which occur in the region. This information is required for an estimate of the costs of the construction as well as the maintenance costs. Due to the dynamics in the coastal zone, the available maps can be outdated. Older maps are compared to recently generated maps in order to provide an insight in the processes that take place. These measurements are done to get the required information needed for insight in the processes around (the construction of) an artificial island.

The results of these measurements are presented in the following chapters. In Chapter 2 a number of characteristics of the sand at the beach are determined. Such information may be used in a morphological model of the beach. Also characteristics of the rocks in the Martsiana quarry are determined in order to determine their usability for the construction of a revetment. Finally the chapter investigates the structure of a nearby breakwater to determine if it may serve as a reference for the construction of the island. Chapter 3 presents the results of the wave measurements. Wave measurements have been carried out visually and using a pressure meter. Chapter 4 discusses the morphological aspects of the construction of the island. It presents the results of the bathymetry survey as well as the profiles that have been measured of the beaches near the groyne, where the hotel is to be built, and the groyne itself. The chapter also takes a closer look at the coastline and its morphological features and how the coastline may be influenced by the construction of the island. The preliminary design of the island is the subject of Chapter 5. In the chapter a number of aspects that need to be taken into account before making a final design for the island are mentioned. Chapter 6 finally presents the conclusion of the report and lists a number of recommendations. Appendices of the report can be found at the report and are referred to throughout the report.

2 Sand and rock characteristics

2.1 Introduction

Adjustments needed for the construction of an artificial island will create changes in the coastal morphology. To make a proper estimate of the coastal morphology and to predict these possible changes, it is necessary to know the characteristics of the sand. Values of the sand characteristics can be used in the morphology model. In order to find the sand characteristics of the beaches around the groyne, sand samples are taken from the bottom profile. Because gradation of sediment size of the sand can be different at different locations, three samples are taken from beach area at point E and three samples are taken from the beach located at point A (see Figure 4).

With the results obtained in this chapter, it is possible to say something about the processes that play a role in this area. These samples are investigated in the laboratory of Delft University of Technology. In Paragraph 2.1.1 a sieve analysis is made to determine the gradation of the sediment size of the sand found at the beaches around the possible island location. The rock characteristics are determined in Paragraph 2.2. This concerns rocks found in quarries near the Black Sea coast, these rocks can be used for the island construction. In Paragraph 2.3 tetrapods of the region are investigated, this gives an indication of the possibility to use tetrapods as protection for the island.

Figure 4 Overview of the beaches

2.1.1 Sieve analysis

To calculate the weight and the distribution of the grain diameter, a sieve analysis on the sand is executed. With the results of this analysis, some individual grain sizes can be calculated and it is possible to have a good view on the sediment gradation.

2.1.2 Method

In total six different sand samples were gathered:

1. On beach E
2. In the surf zone from beach E
3. Offshore from beach E
4. On beach A
5. In the surf zone from beach A
6. Offshore from beach A

The first phase of the sieving process is that every sand example should be completely dry (to measure only the dry weight). This is done with a heater. Next, some sieves with different mesh sizes are placed on a vibrating machine. The different mesh sizes are:

0,850 mm / 0,600 mm / 0,425 mm / 0,300 mm / 0,212 mm / 0,150 mm

After 15 minutes vibrating, the sand particles are distributed over the different sieves. The coarse material is left on the top sieve and the finest material is left on the bottom sieve. The material on every sieve is weighted and with the results, sand characteristics can be calculated.

Figure 5 Drying of the sediment, stack of sieves and sieve machine

2.1.3 Results

In appendix I, the numerical data from the sand characteristics are given. With this data, the sieving curves of the samples are shown in Figure 6 and Figure 7 .

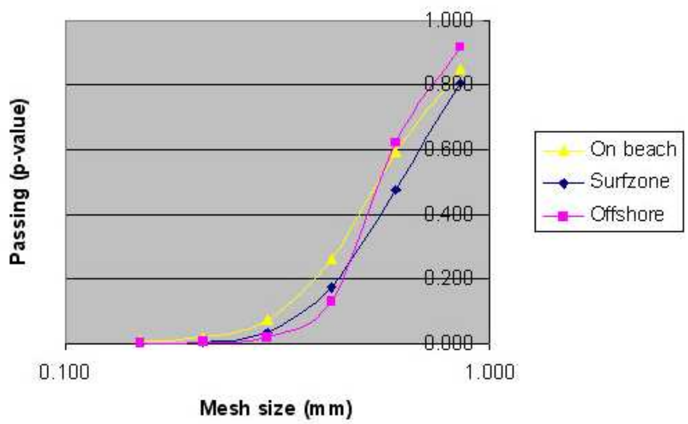


Figure 6 Sieving curves from the examples from beach E

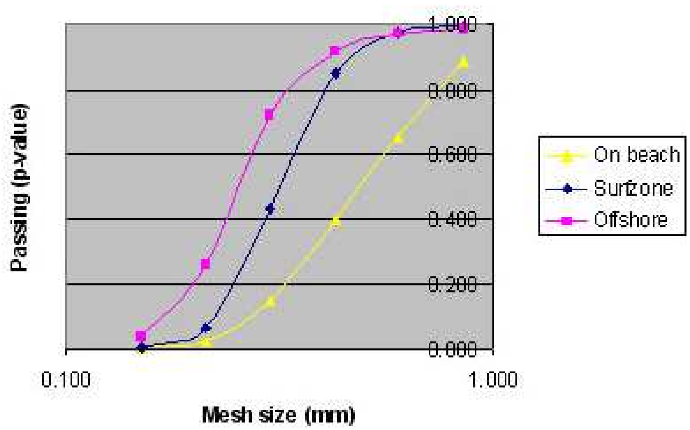


Figure 7 Sieving curves from the examples from beach A

From these figures it is possible to read the values of the individual grain sizes D_{10}, D_{50} and D_{60}. D_x indicates that x% of the mass is lighter than the value of Dx. The values are shown in Table 1 and Table 2

Beach E

	D_{10} (mm)	**D_{50} (mm)**	**D_{60} (mm)**
On beach	0,318	0,550	0,608
Surf zone	0,360	0,620	0,696
Offshore	0,390	0,557	0,592

Table 1 Values of the individual grain sizes at beach E

Beach E

	D_{10} (mm)	**D_{50} (mm)**	**D_{60} (mm)**
On beach	0,267	0,496	0,564
Surf zone	0,220	0,320	0,351
Offshore	0,168	0,258	0,277

Table 2 Values of the individual grain sizes at beach A

It is also possible to plot the results on a different scale (gauss –log scale). When this results in a straight line, the examples are well-graded, which means that there is an equal spread of the sand over the different grain sizes. Figure 8 and Figure 9 show the results on the gauss –log scale.

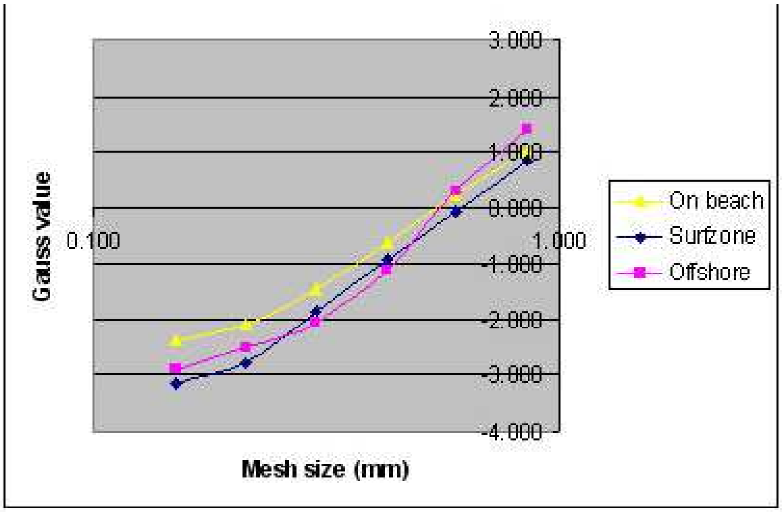


Figure 8 Gauss–log curves from the examples from beach E

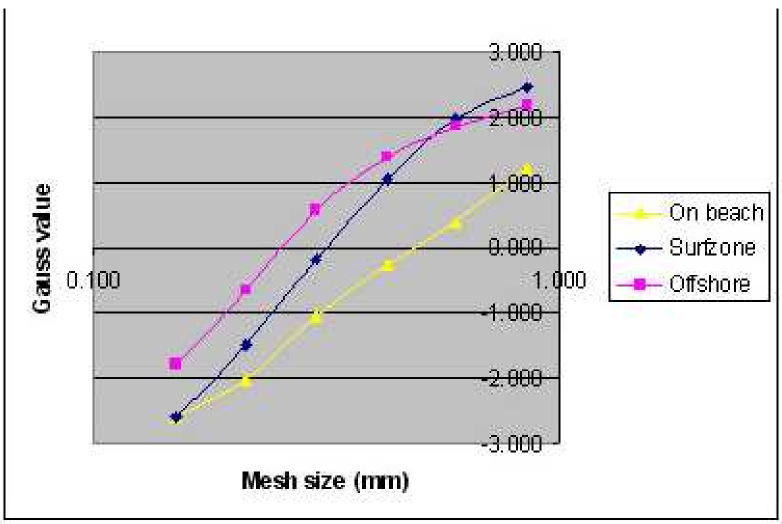


Figure 9 Gauss–log curves from the examples from beach A

2.1.4 Conclusions

All the sand is useful for constructing because the average grain size is large enough (more than 300 μm) and it does not consist of too many different particle sizes (narrow grading). Considering the sieving curves from beach E and A, it is clear that the lines from beach E are closer to each other. So beach E is a more undisturbed beach. Probably, the cross-shore dynamics of beach A are slightly bigger.

At both beaches, the offshore grain size is for most particle sizes larger than in the surf zone. This is due to the smallest waves near the waterline that can only carry very small particles towards the beach. Surprising is the difference between the grains at the dry part of both beaches. At beach E the grains are more or less the same size as in the water, but in beach A it is significantly larger. The reason might be that coarser sand particles are mostly transported during extremer events such as storms. The water level and waves are high during these events and particles can be moved high up shore. Intermediate events, that occur more frequently, can transport only the smaller fractions near MSL so that the coarser fractions remain unexposed at the higher beaches. Beach E suffers less from extreme events since it is more sheltered due to the presence of both the breakwater and the rock outcrop.

The gradation is in both cases not perfectly uniform as can be seen from the Gauss-log curves that are not very straight. The width of the grading on beach 1 is smaller (steeper slopes in the graphs) which is better for land filling purposes. For the production of concrete, a wider grading is more advantageous. Sand from both beaches is thus useful for the construction of the island or concrete elements. What still needs to be seen is whether there is enough sand available.

2.2 Rock characteristics

In a quarry nearby the Black Sea Coast near Varna rocks were studied to get an idea of possible building material for the artificial island. Rocks are usually produced and processed in large batches. Ideally these batches are very homogeneous in size, density, strength and other characteristics which are of interest in the design of (for example) a breakwater. Generally however, this is rarely the case and the batches have a less homogeneous composition. Sometimes the rock-properties deviate beyond usefulness: some rocks may be too small, too light or too oddly shaped to be of any use for application in e.g. a breakwater. Batches of rocks therefore need to be sampled, weighed, measured and tested (e.g. by crushing), to determine the specific characteristics.

2.2.1 Analysis of the rocks from the Martsiana quarry

It is interesting to know whether the stone can be used for the construction of a breakwater. Therefore the D_{n50}, aspect ratio and the blockiness must be determined. The blockiness is an indication of the size of the rock, the better the rock approaches a cube, the higher the blockiness factor.

For the feasibility of the artificial island it is important that enough material is locally available. Therefore the Martsiana limestone quarry (located about 25 km west of Varna) is visited and samples of rock are taken to investigate the quality of the stones from this quarry.

Figure 10 The Martsiana quarry

Figure 11 Conveyor belt on the Martsiana quarry

2.2.2 D_{n50}

At Delft University of Technology the specific density of the rock is determined; the rock from the Martsiana quarry has an average density of 2405 kg/m^3. During the Fieldwork project of 2006, executed in the same region in Bulgaria, approximately the same density was found.

When the density is determined, the D_{n50} can be found. Thirty stones of the Martsiana Quarry are measured and weighed (see Figure 12).

Figure 12 Stones from the Martsiana quarry for determining the rock density

First for every stone the d_n is calculated, with the following formula:

$$d_n = \sqrt[3]{V} = \sqrt[3]{M/\rho} \qquad (2.1)$$

in which,

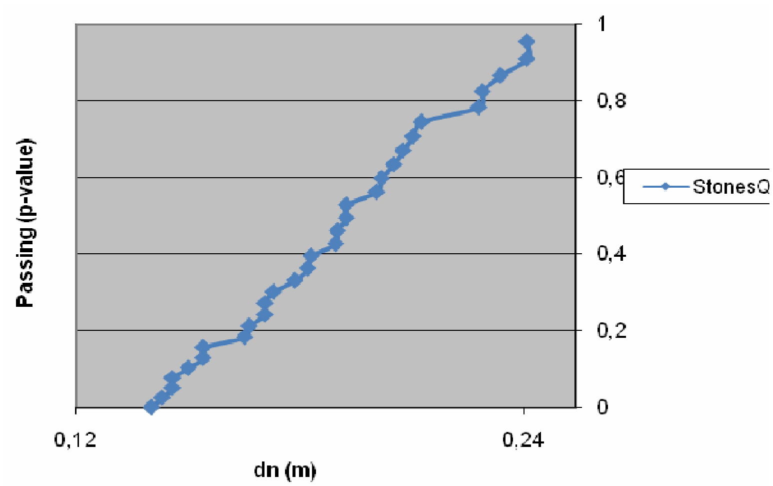
- V = Volume
- M = mass
- ρ = density

The values of the stone dimension and the rock density calculation can be found in Table 3.

	l_1 [m]	l_2 [m]	l_3 [m]	mass [kg]	d_n=(weight/rho)$^{1/3}$ [m]	E=l_1/l_3 or l_1/l_2 [-]
1	21	19	14	7,5	0,146	1,500
2	34	25	24	16,8	0,191	1,417
3	39	33	27	27,0	0,224	1,444
4	24	17	14	5,9	0,135	1,714
5	16	15	19	7,5	0,146	1,067
6	53	20	37	29,9	0,232	1,432
7	30	24	11	9,1	0,156	2,727
8	48	35	13	27,5	0,225	3,692
9	30	20	16	11,5	0,168	1,875
10	25	31	18	12,4	0,173	1,389
11	40	29	26	33,8	0,241	1,538
12	33	23	12	19,0	0,199	2,750
13	30	20	15	9,3	0,157	2,000
14	33	16	14	10,4	0,163	2,357
15	34	12	27	6,2	0,137	2,833
16	22	16	16	12,2	0,172	1,375
17	32	31	19	6,5	0,139	1,684
18	27	24	20	14,0	0,180	1,350
19	36	20	20	14,6	0,182	1,800
20	33	25	22	13,9	0,179	1,500
21	30	18	18	17,2	0,193	1,667
22	32	17	16	7,0	0,143	2,000
23	16	16	14	10,0	0,161	1,143
24	16	16	14	10,0	0,161	1,143
25	27	24	42	33,8	0,241	1,125
26	24	19	17	6,5	0,139	1,412
27	39	29	22	19,9	0,202	1,773
28	23	15	18	18,2	0,196	1,533
29	45	23	24	20,7	0,205	1,957
30	27	24	16	14,6	0,182	1,688

Table 3 Stone dimensions and rock density calculation

After those stones are ranked, the middle value found is approximately d_n=0,176, for this data set this is the D_{n50}. The values are plotted, with the d_n values on the X-axis and the normal gauss distribution on the Y-axis. Since this line is not completely linear, the sample of stones is not representative for the stones in the quarry, the D_{n50} of the quarry may differ a little from the D_{n50} calculated above.



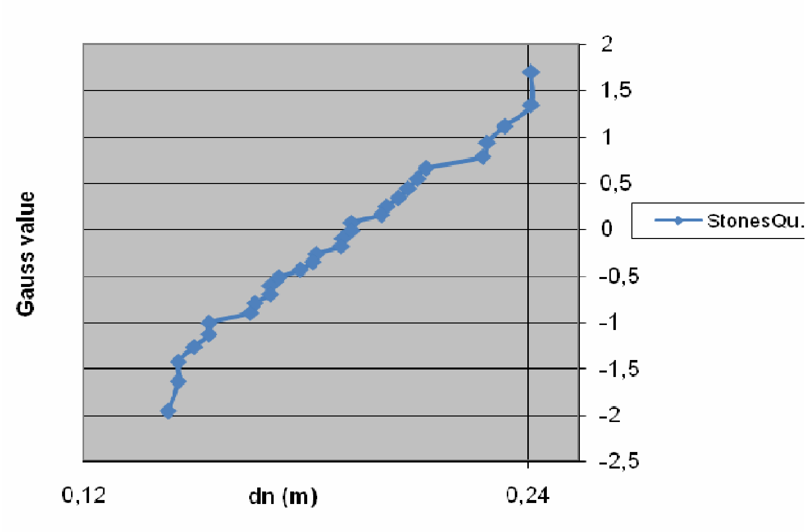


Figure 13 Plots of the D_n values and the Gauss values

2.2.3 Elongation

The length-to-thickness ration/ aspect ratio:

$$LT = \frac{l}{d} \tag{2.2}$$

with

- $l =$ maximum length
- $d =$ minimum distance between parallel line through which the particle would just pass, see Figure 14, the result are shown in Table 4.

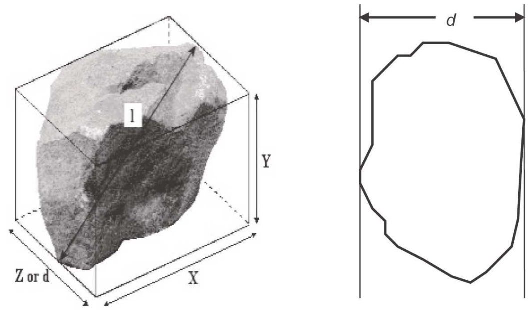


Figure 14 Elongation

Figure 15 Determination of elongation and blockiness

2.2.4 Blockiness

The size of larger stones, which could not be weighed, is estimated as follows. A virtual box is placed around the stone, then the size of this virtual box is measured (X, Y and Z). After this, an estimation of the so-called 'blockiness' of the stone is made: the relative volume of stone compared to the volume of the virtual box, see Figure 16.

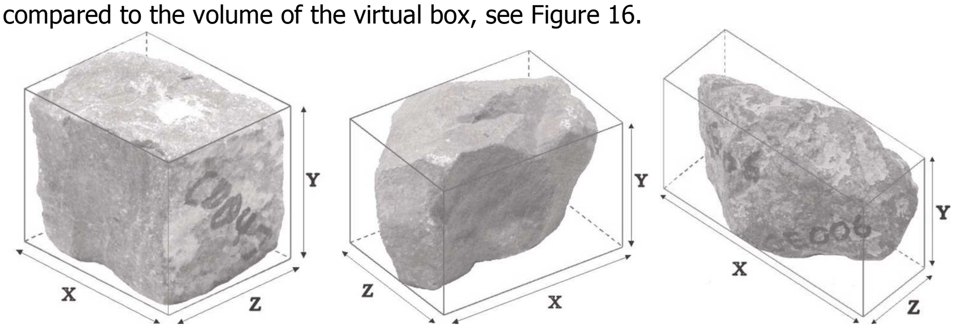


Figure 16 Examples of blockiness values (from left to right, BLC = 0.8, 0.6 and 0.4)

Five stones are measured like this, the results can be found in Table 4. In this case the blockiness is used to estimate the volume of the measured stones. Since the density of the stones is known the mass of the total stones can be determined, see Table 4.

length [m]	height [m]	width [m]	Blockiness [-]	volume box [m^3]	volume stone [m^3]	stone mass [kg]
0,38	0,50	0,64	0,73	0,122	0,09	212
2,52	1,64	1,45	0,50	6,007	3,00	7222
1,46	0,70	0,90	0,65	0,920	0,60	1438
2,50	1,50	1,50	0,50	5,625	2,81	6763
1,29	0,84	0,69	0,80	0,748	0,60	1438

Table 4 Stone dimensions for determining the blockiness

2.2.5 Conclusions

For the filling of the core of an artificial island stones with a low blockiness with a very narrow grading are preferred to fill large volumes with as little material as possible and reduce water pressures. On the other hand the stability of the material has to be secured to prevent loss. The stones in the Martsiana quarry are not ideal from this point of view. They are rather light and thus rather weak, the blockiness is high and the grading is very wide. The strength of the stones will probably be enough to fulfil the requirements for bearing the hotel and anything on the surface of the island. Unfortunately the two quarries can not be compared since measurements of these parameters were only done in the Martsiana quarry. The Martsiana quarry can in any case supply stones that will be sufficient for constructing an artificial island. Special arrangements with the supplier may improve the quality of the delivered stones to the required specifications.

Breakwaters can best be made form stones that have a high density. These stones are not so heavy. One needs really large size stones to withstand the most severe wave attacks. A high blockiness limits the interlocking of stones so that the porosity of the armour is very high but the stones are lying loose. This prevents on the one hand excessive water pressures but may cause severe displacement of rock in case of severe wave attacks, which is more likely to be a limiting design factor. The output of the quarry may suffice but careful inspection of the delivered stones is important to make sure they meet up with the requirements.

2.3 Analysis of tetrapods on the outer breakwater of the marina, St. Konstantin I Elena

Tetrapods are a type of artificial wave breaker-element which is commonly used throughout Bulgaria. The elements are made of concrete and exist in various sizes. They are shaped like four conus-shaped legs which connect at the centre of the tetrapod. Each leg makes an angle of 120° with each of the three other legs.

Tetrapods are designed to minimize wave-transmission, maximize energy dissipation through a breakwater or revetment and ensure stability of the armour-layer. The size of the breaker-element determines its weight and strength against wave impact. Consequently, the size of the tetrapod is designed in such a way that it can withstand the design wave without moving.

An analysis is done on several tetrapods at the marina of St. Konstantin I Elena to determine the design wave for which these elements are dimensioned, or investigate to what extend the tetrapods fulfil their purpose. Also the general quality of the elements is examined.

2.3.1 Size of the tetrapods

Two different sizes of tetrapods were found on the outer side of the breakwater which protects the marina. Obviously the tetrapods in most seaward direction suffer the most from severe wave attack. That is why these concrete units can be smaller closer to the caissons. Two overall sizes have been measured with a measuring tape: 2100 mm and 2500 mm.

Figure 17 Tetrapods at the marina St. Konstantin I Elena

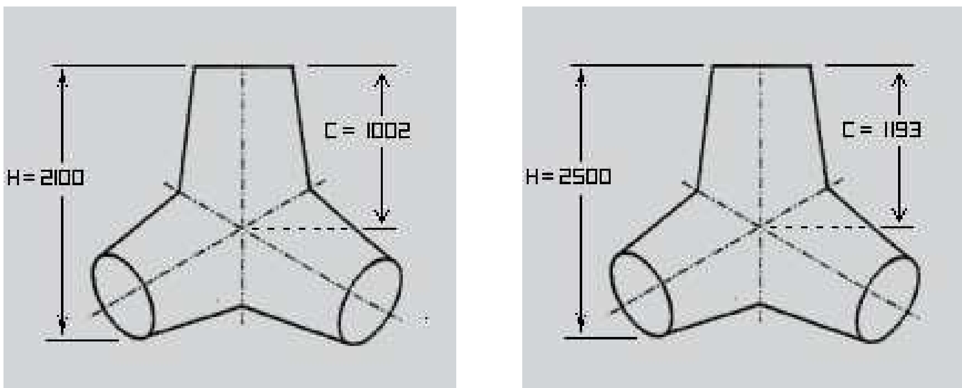


Figure 18 Small and big tetrapod

2.3.2 Mass of the tetrapods

From the overall size H, size C (length of one leg) can be calculated with the following relation from the Shore Protection Manual (1984):

$$C = 0.477*H \quad (2.3)$$

Also the volume V can be calculated with the following relation:

$$V = 0.280*H^3 \quad (2.4)$$

The density of the concrete of the tetrapods is assumed to be 24 kN/m^3. With this assumption one finds the following volume and weight:

	Volume in m^3	Weight in kN
Small Tetrapod	2,59	62,23
Big Tetrapod	4,38	105,00

Table 5 Volume and weight of the tetrapods

2.3.3 Calculation design wave height

What can be clearly seen from the breakwater is that the tetrapods in the St. Konstantin I Elena marina have not moved since this breakwater was built. Some damage to single tetrapods can be seen but that is likely caused in the production stage. It means that the design wave has not (yet) occurred and it is possible to calculate back the design wave that was assumed during the design process. For this calculation three methods will be used: Hudson, Van der Meer and Hanzawa.
This calculation will be done for the tetrapod that endures the biggest wave attack, the big tetrapods with a height of 2500mm.

Hudson

The formula from Hudson:

$$\frac{H_{sc}}{\Delta d} = \sqrt[3]{K_d \cot \alpha} \qquad (2.5)$$

This formula takes the slope and a damage factor K_d into account. The damage factor makes use of the following values from the Shore Protection Manual (SPM 1984):

K_d -values	Breaking waves	Non breaking waves
Trunk	7	8
Head	5	6

Table 6 K_d values for the Hudson formula

It is easy to see that factor K_d =5 is normative in this situation. Other parameters that need to be determined first are:

- $\Delta = \rho_s / \rho_w - 1 = 2400/1025 - 1 = 1,34$
- $\cot \alpha = 1,5$ (standard slope of breakwater)
- $d = 0,47 * H = 0,47 * 2,50 = 1,18m$

Insert these parameters in the general Hudson formula and the design wave height will be obtained, namely: $H_{sc} = 3,10m$

The Hudson formula is the most simple formula and therefore possibly not suitable for this situation. Another approach to determine the design wave height can be done with the Van der Meer equation, which takes into account the wave period and the permeability of the breakwater. With the fact that the breakwater is partly constructed with tetrapods, this permeability can have a serious contribution.

Van der Meer

The method of Van der Meer makes a distinction between plunging and surging breakwaters. Therefore the breaker index will be determined first with following equation:

$$\xi = \frac{\tan \alpha}{\sqrt{s_m}} = 2,98 \text{ with } s_m = 0,05 \qquad (2.6)$$

(s_m = wave steepness estimated for a standard wave at shallow water).

Because this breaker index is close to 3, the design wave calculation will be done for both plunging breakers ($\xi < 3$) and surging breakers ($\xi > 3$). Other parameters needed are:

- $N_{od} = 0{,}2$ (damage level 0,2 to 0,5 choose 0,2 because hardly any damage detected)
- $N = 6000$ (number of waves with 6s period during a 10h storm)

Plunging waves: $\frac{H_s}{\Delta d} = \left(8{,}6 \left(\frac{N_{od}}{\sqrt{N}} \right)^{0{,}5} + 3{,}94 \right) s_m^{0{,}2} = 3{,}80m$ (2.7)

Surging waves: $\frac{H_s}{\Delta d} = \left(3{,}75 \left(\frac{N_{od}}{\sqrt{N}} \right)^{0{,}5} + 0{,}85 \right) s_m^{-0{,}2} = 3{,}00m$ (2.8)

A difference of 0,80m is found, which is quite a lot. The calculation with surging waves has a value similar to Hudson. After using van der Meer the normative design wave height is still not entirely clear. Therefore another calculation is made with the method of Hanzawa.

Hanzawa

The method of Hanzawa is applicable especially for situations with tetrapods. It also takes number of waves and the damage into account, but it neglects the effects of the wave period.

$$\frac{H_s}{\Delta d} = 2{,}32 \left(\frac{N_{od}}{N_z^{0{,}5}} \right)^{0{,}2} + 1{,}33 = 3{,}22m \quad (2.9)$$

	Hudson	**Van der Meer**		**Hanzawa**
		Plunging	**Surging**	
H_s	3,10	3,80	3,00	3,22

Table 7 Significant wave heights in [m] using Hudson, Van der Meer and Hanzawa

The lowest value of the design wave height should be normative which holds in this case that one can say that a design wave height of 3,00 m was probably used in the designing phase of the tetrapods.

2.3.4 Maximum depth-limited wave

All visually observed waves with a height of approximately 1 meter broke at the breakwater and not already in front of this construction. That means that the water level is deep enough for these waves to reach the shore. With a design wave of 3 meters this depth may not be enough anymore so that the wave will brake. However these design wave heights only appear in severe storms and such storms will cause a wind set-up so that wave breaking will happen at the tetrapods again. The depth right in front of the breakwater is not exactly known and therefore it is not possible to calculate a maximum depth-limited wave.

2.3.5 Wave transmission

For wave transmission by overtopping of horizontal composite breakwaters the graph below can be used. This is for non-permeable breakwaters and gives a proportion, C_1, for the waves in the port due to overtopping.

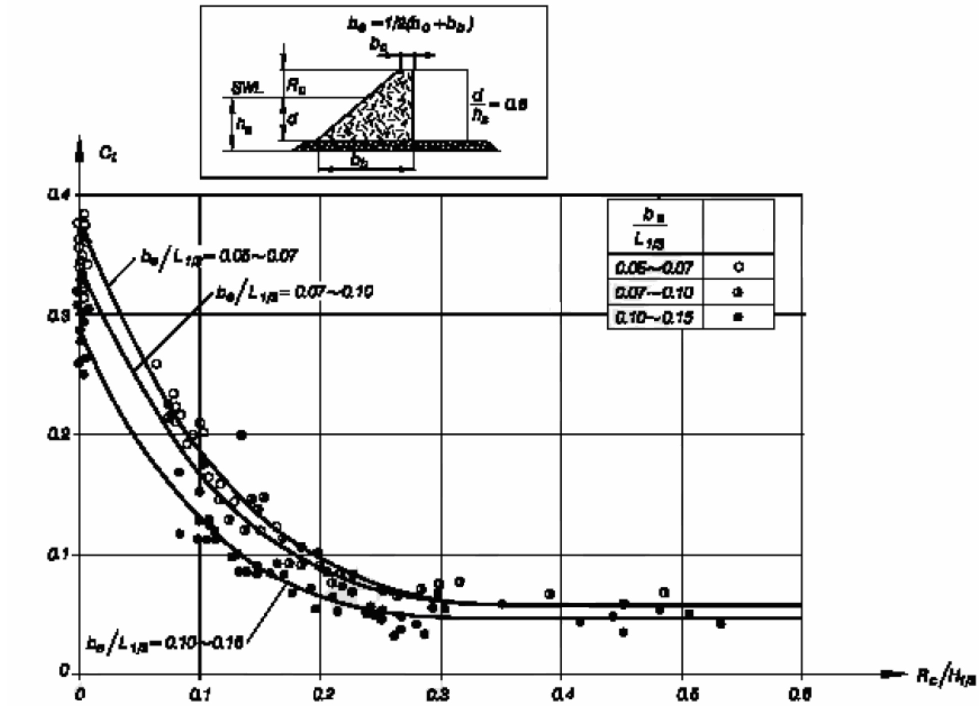


Figure 19 Wave transmission by overtopping of horizontal composite breakwaters armoured with tetrapods (Tanimoto, Takashi and Kimura, 1987)

Because the breakwater is relatively high compared with the design wave, it will end up in the right part of the graph with C_1 = 0,05 = constant. So a maximum wave of 3 meters high will lead to a wave in the port of 0,15 m.

2.3.6 Breakage

By using the breakage formula (Burcharth, 2000) an estimated percentage will be found for the number of tetrapods that are broken.

Burcharth 2000: $$B = C_0 * M^{C1} * f_T^{C2} * H_s^{C3} \qquad (2.10)$$

in which:

- B = relative breakage
- M = armour unit mass in tonnes: 10,5 tonnes.
- f_T = concrete static tensile strength in Mpa, estimated very low at 2 Mpa
- $C_0 = 0,00393$
- $C_1 = -0,79$
- $C_2 = -2,73$
- $C_3 = 3,84$

This gives a breakage of B = 0,0063. This indicates that 6 out of every thousand tetrapods are broken. That can be very well possible. There were (visually) no broken tetrapods detected but the inspected tetrapods were all situated quite a bit above the waterline.

A note should be made that there were several broken tetrapods at the St. Konstantin I Elena marina, but it was very obvious that the damage was caused by construction methods or the applied materials. A good example of this is the 'weekend-tetrapod': The hardening stages of different parts of the tetrapod started with quite a while in between (e.g. during a weekend). That makes the concrete very weak with a big crack as result.

Figure 20 Broken tetrapod

2.3.7 Discussion

The breakwater is at the time not constructed very economically because it is highly over dimensioned. At the side of the tetrapod-defence, the marina behind the breakwater is completely sheltered. However, for years now only one holiday ship uses the port. So one may wonder what goal this breakwater currently serves.

The fact that the concrete is of a very poor quality and that mistakes have been made during construction is therefore not a very big issue and the breakwater will stay there for years to come. For the future it is advisable for comparable constructions to make decent designs and to use good quality materials and production processes. This will lead to a safer and aesthetically nicer construction, which is desirable due to the still growing tourism industry.

For the construction of the artificial island can be learnt that the dimensioning of the island should be according to the expected function. Carefully used and constructed material increases safety of the island in use and efficiency of the construction process.

3 Wave measurements

3.1 Introduction

Wind generated waves produce the most critical forces to which coastal structures are subjected (except for seismic sea waves). A structure exposed to wave action should be designed to withstand the highest wave expected, if such a design is economically justified. Economic evaluations depend on frequency of occurrence of extreme events such as height and duration of extreme waves, damage potential of high waves and permissible risk.

Structures may be subjected to radically different types of wave action. Consequently, in order to understand and predict the forces acting on objects and beaches along the coast, information about the wave climate, like the wave heights, wave periods, and wave direction, are necessary. Preferably one would like to have also additional information about the seasonal variation and the probability of occurrence of wave heights, but this is mostly difficult to obtain since good measurements are scarce. Satellite information may provide general information on a large scale but can never give detailed, local wave information.

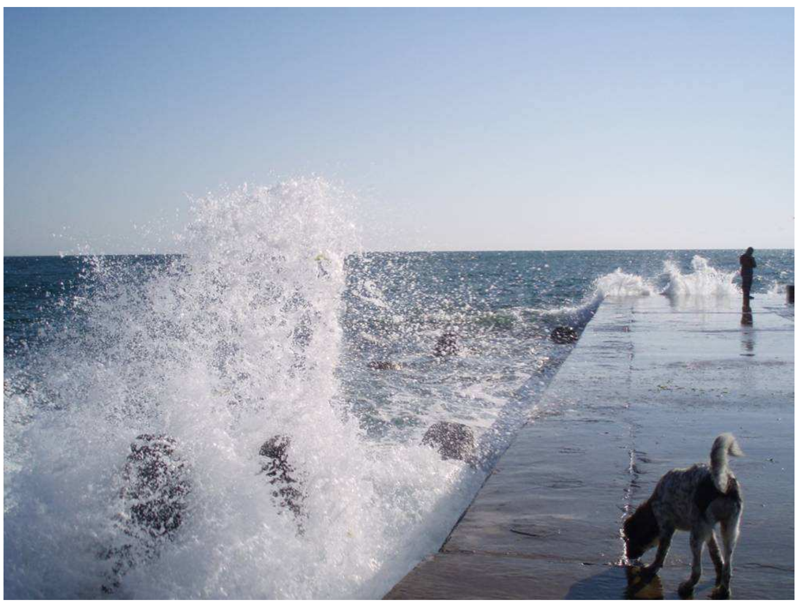


Figure 21 Impression of wave attack along the coast

At first visual wave observations were done to get insight into the wave heights and periods. The results can be seen in Paragraph 3.2. To compare this data, pressure measurements were done and translated to wave heights in Paragraph 3.3. Paragraph 3.4 shows visual results from both the visual observations and pressure measurements.

The significant wave data used in this report are originated from application of a SWAN model (Paragraph 3.5) SWAN is a computer model to calculate short wave action in coastal regions. This model is used to calculate the transition from deep water waves to shallow water waves close to the coast. Information about the deep water wave height has been taken from the Argoss website (www.argoss.nl). After validation of the model, it is possible to calculate the significant wave height, which is a requirement in order to come to a proper design.

3.2 Visual observation

Visual observation of waves, although difficult to confirm, may provide an indication of wave height, period, direction and frequency of occurrence. Instrumentation has been developed for recording wave height and period at a certain point like digital video recordings and image processing techniques. Instrumentation for recording wave direction is presently in development stage, this direction data should be obtained from visual observations.

The visual measurements were carried out by means of a self-made scale and a theodolite (see paragraph 4.5.1 and 4.5.2 for an explanation of this instrument and its use) that is placed at a certain distance. The scale, with its top above the highest crest and its tail beneath the lowest wave trough, is attached to the side of the jetty and the position of the theodolite is perpendicular to that scale (see Figure 22). The location of the scale should be at a place where the waves are as little as possible disturbed by the bottom (shoaling and breaking) and objects in the surroundings (diffraction). Therefore waves outside the surf zone were measured. Otherwise, the statistical properties of the waves are disturbed and the properties that are expected are less pronounced.

Not only the wave heights, but also the wave periods are unknown. Therefore a second visual observation was performed. To obtain the wave periods, the time period of twenty waves are measured with a stopwatch and then the mean value can be calculated. Both measurements were repeated several times to enhance the statistical accuracy.

Figure 22 Position of the pressure meter, scale, and theodolite

With the use of a theodolite, the accuracy of these measurements is higher than with only the naked eye. But even with a theodolite it proved difficult to measure the waves. Because of the irregular wave pattern, crests of other waves came in front of the troughs of the waves that had to be measured. This made it sometimes impossible to read the scale. It was at best possible to estimate the height in the order of a decimetre. Additionally the waves were quite high at the day of the measurements. This further enhanced the accuracy since it meant that the height differences were larger and thus the relative error decreased. Several sets of hundred waves for the wave heights and several sets of twenty waves for the wave period were measured in order to ensure that representative values for both parameters will be used.

Figure 23 Theodolite wave height measurements

A total of 826 waves were measured in this way (see Figure 23). The measurements were taken in windy conditions and a maximum wave height of 1,20 m was observed.

3.3 Pressure measurements

The second method of wave measurements is done by the use of a pressure sensor. This sensor measures the water pressure at a certain depth and compares it to a reference level, in this case the atmospheric air pressure. The pressure sensor was attached to a pole, lowered into the water, mounted on a jetty and connected to a computer laptop. The pressure data were immediately stored into a computer file. Measuring the depth proved to be somewhat difficult since there were no appropriate instruments. This was eventually done by lowering a heavy object via a rope onto the bottom and measuring the length of the rope from the object to the bottom of the jetty. Then the same procedure was repeated for the mean water level. The difference is then the water depth. The depth of the sensor was measured from the pole at which it was attached.

The water particles in a wave describe an orbital motion. Because of the wave motion the pressure at the crest and the trough differ (see Figure 24). From linear wave theory the relation between the water pressure under a wave, as function of the depth, and the wave height is known. For this theory it is required that the waves are in deep water, where the wave height / depth ratio is very small. This is obviously not the case for our measurements but it is assumed that the influences do not yet dominate the results too much. The fact that the waves were quite high when the measurements were carried out does not benefit this assumption since the wave height / depth ratio is then larger.

The pressure data obtained every 0,1 s for half an hour, has been stored in a laptop computer.

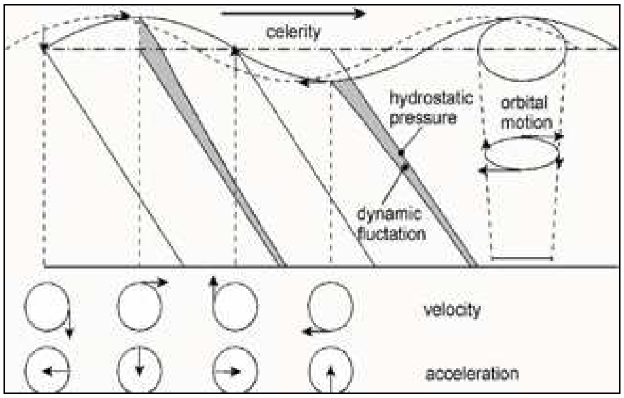


Figure 24 Orbital motion

Afterwards the number of waves and the wave heights can be calculated from the data using the formula of the linear wave theory:

$$p = -\rho g h + \rho g a \frac{\cosh k(h+z)}{\cosh kh} \sin(\omega t - kx) \tag{3.1}$$

in which:

- p = pressure [kPa]
- ρ = Mass density of water [kg/m³]
- g = gravitational acceleration [m/s²]
- h = water depth [m]
- a = amplitude [m]
- k = wave number [m^{-1}]
- z = measuring depth [m]
- ω = wave celerity [s^{-1}]

To rule out the hydrostatic pressure, because only the pressure due to the waves is required, the measuring depth z has to be calculated. To do this, the varying second term of the formula must be zero (this occurs at t = 0 s and x = 0 m).

$$p_{gem} = -\rho g z \quad \text{and} \quad z = \frac{p_{gem}}{-\rho g} \tag{3.2}$$

It is assumed that the pressure measurements are much more accurate than the measurements obtained from the visual observations. This is because of the use of reliable pressure software in comparison with measurements by human hand. However, the accuracy of the pressure measurements depends on the sensitivity of the meter, the sample frequency of the device, and the accuracy of the software. Furthermore, the assumption has been made that the linear wave theory is valid. The applicability of this assumption still needs to be verified with the use of the Rayleigh distribution.

3.4 Preliminary data results

Ten sets of twenty waves were timed in order to get an average wave period of 5,72 s. Furthermore, there were in total 826 waves measured visually and 259 waves measured through a pressure meter. In Figure 25 a time frame is shown of the pressure meter.

There are several aspects to be declared from this water level variation before the data can be processed into the respective frequency distributions (see Figure 26). Firstly, there is a high frequency of wave heights from 0 to 0,10 m. Since the data accuracy of the visual data is in the order of 0,1 m, this wave height range cannot be included in the proceeding analysis.

Second of all, the sensitivity of the pressure meter increases with 0,07 m intervals. Since the wave height classes of the histogram are chosen according to the sensitivity of the visual data, there is an overlap in the pressure data classes. This is the reason why there are some outliers in the histogram.

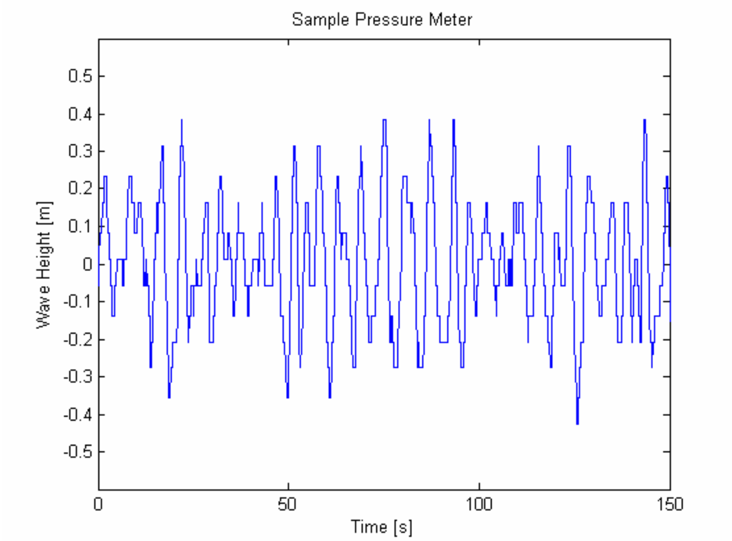


Figure 25 Sample pressure meter

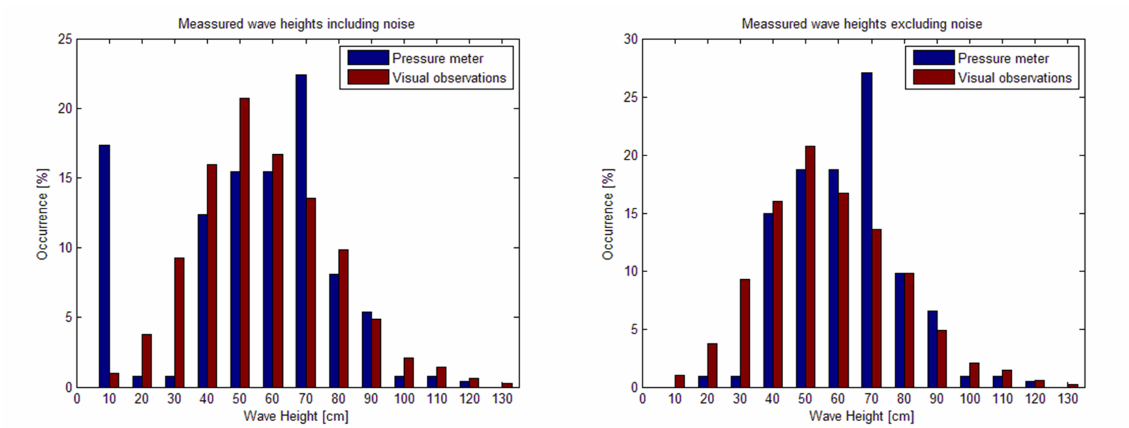


Figure 26 Measured wave height

From the frequency distribution of the visual wave heights, the wave probabilities can be determined. This is done by dividing the frequency of a specific height class with the total number of waves. Finally, the cumulative distribution of respectively the visual and pressure meter waves can be found by adding up probabilities of the wave height classes. This cumulative distribution can be compared with the expected theoretical Rayleigh cumulative distribution, where H_s represents the significant wave height.

$$P[\underline{H} < H] = 1 - e^{-2\left(\frac{H}{H_s}\right)^2} \quad , \quad H/H_s \geq 0 \qquad (3.3)$$

The Rayleigh distribution is used for modelling the maxima of continuous stochastic processes, especially where the frequency spectrum is narrow and shows a single or few peaks. It is thus commonly used to describe the distribution of wave heights in deep water.

In order to visualize the cumulative Rayleigh distribution, the H_s of respectively the visual data and the data found from the pressure meter is needed. This can easily be found by sorting the wave heights from the largest to the smallest value. The average value of the largest 1/3rd of the wave heights corresponds with H_s, where j is the rank number of the wave, with j=1 as the highest wave and N is the total number of wave heights measured.

$$H_s = H_{1/3} = \frac{1}{N/3}\sum_{j=1}^{N/3} H_j \tag{3.4}$$

The comparison of the measured data with the corresponding theoretical Rayleigh distributions has been plotted in two different ways (see Figure 27).

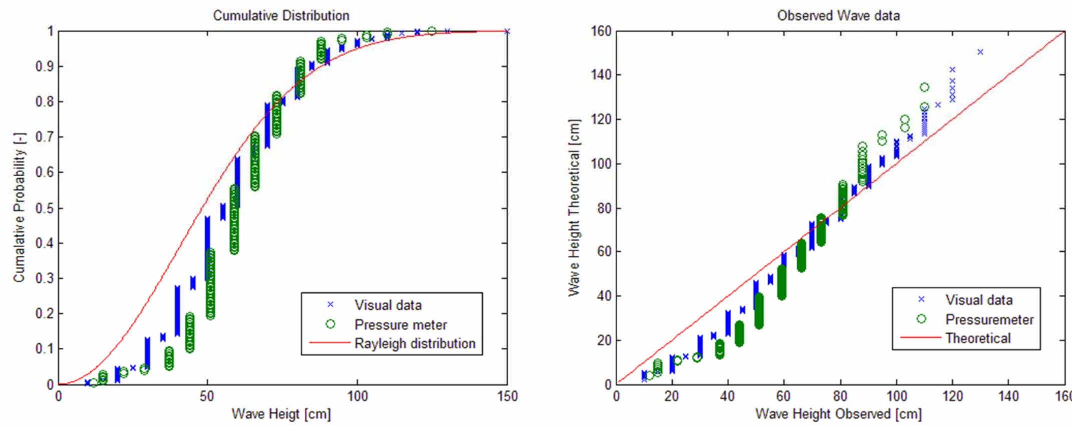


Figure 27 Cumulative distribution of observed wave data

Both the wave data obtained from the visual measurements as from the pressure meter data correspond well to its respective Rayleigh distribution (see Figure 27).

The cumulative distribution of the lowest waves from the pressure meter lies lower than the cumulative Rayleigh distribution; the cumulative distribution of the highest waves on the other hand, lies above the Rayleigh distribution. This implies that there are too few low wave heights being measured with the pressure meter while at the same time more high waves than what would have been expected are measured. The conclusion deriving from this observation is that the range of the height of the waves is quite narrow. This means that if the Rayleigh distribution is taken as a base, lower waves are overestimated while higher waves are underestimated. This can be quite dangerous, thus special care shall be taken concerning the excess number of high waves.

The cumulative distribution of the lowest waves from the visual data lies lower than from the cumulative Rayleigh distribution. This shows again, that the lowest waves were not measured visually, which reinforces the fact that the accuracy for the visual data is not sufficient if one needs the wave height data in the lowest range. Visual observations are more accurate for the larger wave heights. Also, the more visual observations made, the higher the accuracy of the overall wave data will be. What can be concluded from this comparison is that both data sets comply with the theoretical Rayleigh distribution so that the linear wave theory would be applicable for the preliminary design process.

3.5 Swan

When a wave approaches the shore, refraction and shoaling will occur until it finally breaks. To obtain realistic estimates of random short-crested waves, the numerical wave model SWAN (Simulation WAves Nearshore) can be used. This program requires a given bottom topography, wind field, water level, and current field. With the obtained wave and bathymetry data from the fieldwork, a 1D SWAN model will be set up and calibrated. The actual deep wave field data is obtained by the website of the Turkish State Meteorological

Service. With the adequate measurements, the program SWAN is also suitable for use as a wave hind cast model for the specific day.

If the validation is successful, the model can be used for the probabilistic design. The deep water wave data will be used from the Argoss database, where the occurrence of significant wave heights has been recorded. Furthermore, the return period of several normative wave heights is available so that a full probabilistic analysis can be made. A probabilistic design calculation of the highest wave with a specific chance of exceeding will be further explained in section 3.5.2.

3.5.1 Validation

Boundary conditions need to be specified. To calibrate the model, the data from the Turkish State Meteorological Service from the same day will be used. This includes the deep water wave height, the peak wave period and the wind velocity. Furthermore, in the Black Sea the tidal window is very small so that the tidal currents can be neglected.

The most important input parameter is the bathymetry. When a wave approaches the shore, the decreasing water depth induces shoaling. When the angle of the coastline with respect to the North is known, it is possible to calculate the refraction that will occur. With the use of maps, a coastline angle of 19° and a ray angle of 20° at the measuring point were defined.

With the use of external data, the following input measurements have been defined:

Parameter	
H_0	1,15 m
T_p	5,8 s
v_{wind}	7,7 m/s
θ_{wind}	30 °
L_{visual} = point 3	130 m
$L_{pressure}$ = point 4	80 m
Wave setup	yes

Table 8 Input measurements for the validation of the SWAN model

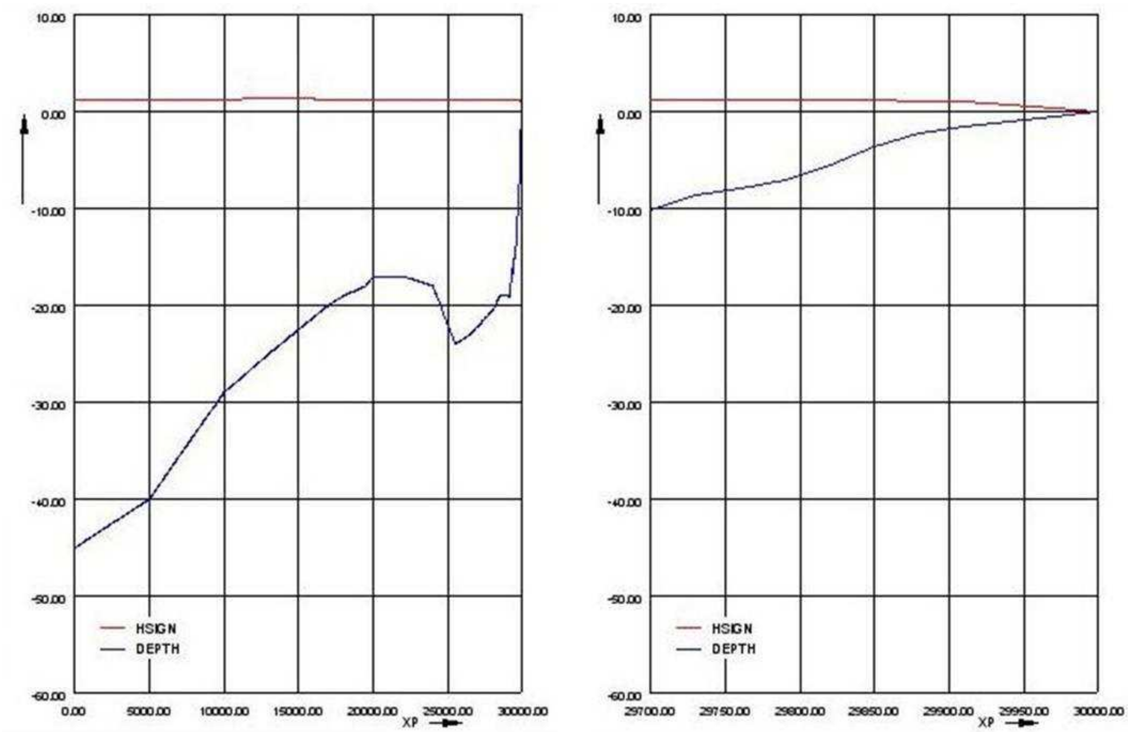


Figure 28 Validation output (left: 30 km / right: 300 m from the coast)

From the visual and pressure measurements, an H_s of respectively 0,82 m and 0,78 m was found. With the SWAN program, an H_s of respectively 1,01 m and 1,00 m was found. This is a difference of 20%, which results in an error of the SWAN calculations in the order of magnitude of 20%.

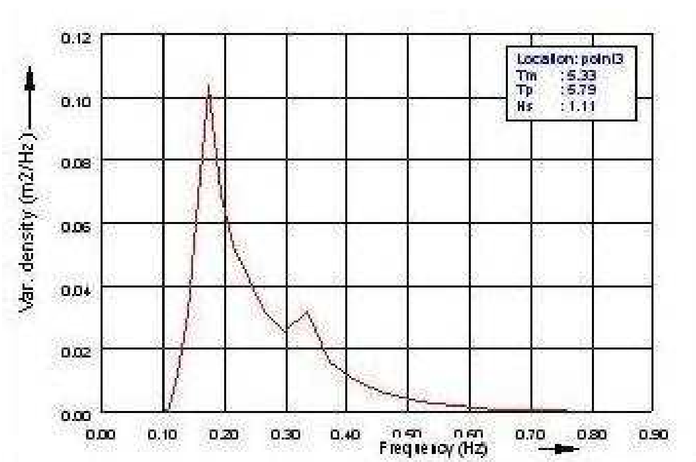


Figure 29 Frequency spectrum

The frequency spectrum that SWAN generates has a plausible shape. This further supports the fact that SWAN is properly calibrated. For the probabilistic calculations, the software program SWAN will be used. The program gives a good indication of the wave height to be expected when the deep-water wave is known. One needs to keep in mind that the error is in the order of approximately 20%.

3.5.2 Probabilistic design calculation

To design a revetment near shore, a significant wave height is required. The calculation is made with SWAN in which for both the bathymetry and wave angle the same values are assumed as in the validation. Argoss provides the period, wind speed and wave heights at deep water as well as the correlation between these parameters.

The correlation between wind speed and significant wave height can be seen with a scatter table (see Figure 30). For SWAN it is required to have a fixed wind speed per significant wave height in order to decrease the number of parameters in the calculation. To obtain a fixed wind speed the correlation between the average wind speed and the wave height has been extrapolated to the values that are required.

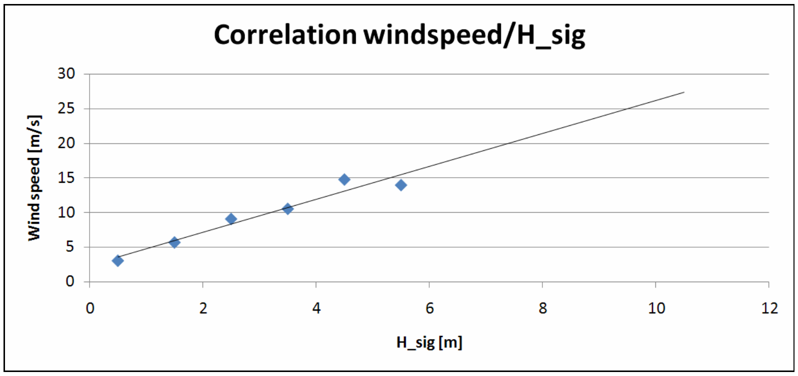


Figure 30 Correlation wind speed and significant wave height

An important remark for this figure is that the extrapolation of wind speed has been assumed linear, even though theoretically it would be a parabolic line. It should also be noted that this could lead to an underestimation of the wind speed since the average value and not the maximum value is taken into account.

For the wave peak period a value of 6,5 s is assumed because of the absence of swell. The Black Sea is relatively small which results in a small fetch. Some data on the mean wave period in relation to the significant wave height is provided, but this data shows little correlation and is therefore not useful.

Argoss also provides the return periods for a range of wave heights (Table 9).

Return period [year]	Deep water (Argoss) Signicant wave height [m]	Wind speed (Argoss) Corresponding wih Hsig [m/s]	5000m Offshore (SWAN) Signicant wave height [m]	1000m Offshore (SWAN) Signicant wave height [m]	500m Offshore (SWAN) Signicant wave height [m]
1/12	3.9	11.7	4.17	3.97	3.80
1	5.4	15.3	4.40	4.24	4.10
2	5.9	16.4	4.51	4.33	4.20
5	6.4	17.6	4.53	4.36	4.24
10	6.9	18.8	4.69	4.56	4.40
25	7.4	20.0	4.78	4.68	4.52
50	7.9	21.2	4.93	4.74	4.56
100	8.3	22.2	4.91	4.76	4.56
1000	9.7	25.5	5.42	5.28	5.05

Table 9 Argoss data

In this table the given deep water significant heights and the respective calculated wind speeds result in a calculated significant wave height near the shore. This can also be plotted on logarithmic paper (Figure 31).

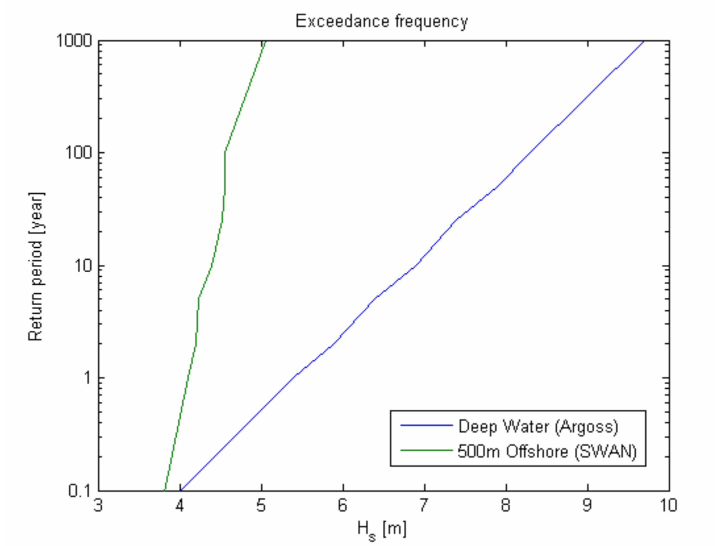


Figure 31 Return period

4 Morphological aspects

4.1 Introduction

With the sand and rock characteristics determined in Chapter 3 and the significant wave height determined in Chapter 4 an estimate of the impact of (the construction of) the artificial island can be determined. During the fieldwork several morphological aspects of the area have been studied. Paragraph 4.2 describes the bathymetric survey that has been carried out and compares the results obtained in this year's fieldwork to those results from the same area obtained in previous years. Paragraph 4.3 gives a general overview of the morphological features in the area that have been observed during the fieldwork, as well as some observations made from satellite images. In paragraph 4.4 the results of the measurements that have been made of the groyne are presented. Measurements of cross sections of the beaches around the groyne have also been done. The results of these measurements are presented in paragraph 4.5.

4.2 Bathymetry

Invisible for our eyes, but of major importance for hydraulic engineering is the topography of the sea bottom, the bathymetry. All kinds of features and characteristics such as ridges, rock formations, slopes and dunes give information about the behaviour of the sediment near the coast and around structures. The bed features interact with waves and currents and are therefore required for this kind of computations. From sediment volume calculations of a stretch of beach at different times, conclusions can be drawn about local sediment gain or loss. Additionally it gives information about the amount of material that is needed for construction to elevate it above the water table.

To construct an artificial island, extensive knowledge about the local seabed is valuable. To obtain this information, a bathymetric survey is carried out. This bathymetric survey consists in the case of this fieldwork of a bottom survey with the use of an echo sounder linked with a GPS device.

4.2.1 Method

To measure the depth of the bottom a GPS device and an echo sounder were put in a boat. A Global Positioning System (GPS) device manufactured by GARMIN was used. The GPS system consists of 21 geostationary (NAVSTAR) satellites that transmit very low power radio signals. A handheld device, such as the one from GARMIN that was used, combines these signals to determine its location. At least four of these signals are needed to get a reading, but the accuracy of this system is rather low. Even while standing still, the device calculates a movement in the order of a few meters. Combining this system with a control station on earth (a DGPS system) enhances the accuracy, but this was not done because of the limited time and the lack of availability of a control station. Nevertheless the system was performing well enough for our purposes.

When one is walking with the device switched on, the apparatus automatically records its position and stores this in the memory. One can thus obtain a track from its displacement. If one walks along the shoreline, the track represents its location. Additionally the location of points along this track can be stored in the devices memory. This was done to locate special positions such as the tip of the groyne or the location of an object. Afterward the data is downloaded as plain ASCII text that can be interpreted and represented with the help of specialized software.

A GPS device can be combined with an echo sounder. This apparatus determines the depth of the water through sending and recording an acoustic signal. From the time lapse between sending and receiving, the reflection length, and thus the depth, can be calculated. The speed of sound varies with the temperature and salinity of the water. But the error that is introduced through this is relatively small (up to a few percent) and can be neglected. The GPS automatically combines these values with the position data stored in the memory. This data consists of the locations, the height and the depth of the measured track. It is possible to store even other data, but only the location coordinates and the depth were needed.

The trouble with using data from this type of devices is that it is sometime rather elaborate to relate it to other coordinate systems. It stores the locations in terms of longitudes and latitudes, which correspond with a curved surface. But with maps and in computer models, flat surfaces are represented. There is software available to transform the data into, for instance, UMT coordinates. In this fieldwork UMT coordinates are used.

A rubber inflatable motorboat (shown in Figure 32) was used to sail in the area of interest. At first a survey in the area of the building site of the artificial island was planned, but due to heavy weather this was not possible. To get acquainted with the measurement method the bathymetry of a marina near Varna was measured. Several tracks were sailed, of which some parallel to the coast and some perpendicular, up to a water depth of about 15 m. The sailing pattern was not very regular, but the track record on the GPS device showed what places were measured, and in the end the entire marina was more or less covered. During the same survey, a GPS-measuring of the coastline was done in this area. The depth-data from this measurement have later been changed to zero to create a system boundary for the bathymetry interpolation.

Figure 32 Depth measurements

Later on during the fieldwork period, the weather at St. Konstantin I Elena got calmer so a bathymetric survey at this site was possible. During previous years the same area had been surveyed, but at that time there no measurements were made up to relatively deep water. For wave modelling however the transition between deep water and shallow water is fairly important concerning the effects of refraction and shoaling for example.

Due to lack of time and failing equipment, there was only time to make three tracks perpendicular to the coast, up to a depth of about 20 m. Again the position of the coastline at this site was measured and also the piers and groyne were mapped. During the processing of the data, the data-points on the piers have been excluded from the creation of the bathymetry map. This is due to the fact that the piers were no hard structures, which would enforce a 0-waterline and corresponding seabed-shape. The groyne however was included.

The results obtained with this survey are compared to those of previous years to see if there are any large deviations, possibly due to morphology of the seabed, or whether the data can be combined to make a more accurate and larger bathymetry map.

The algorithm used for the interpolation of the bathymetry maps is the Inverse Distance to a Power method, which takes several sample points and uses those to determine the depth at an intermittent location. The weight of a sample point reduces exponentially with increasing distance to the output location. The reason for the use of this method is that it produces a smooth surface and gives no serious problems when extrapolating outside the area of source-data.

4.2.2 Accuracy

Several factors considerably influence the measurements. Waves negatively affect the accuracy of the measurements. Several possible errors are schematised and explained below.

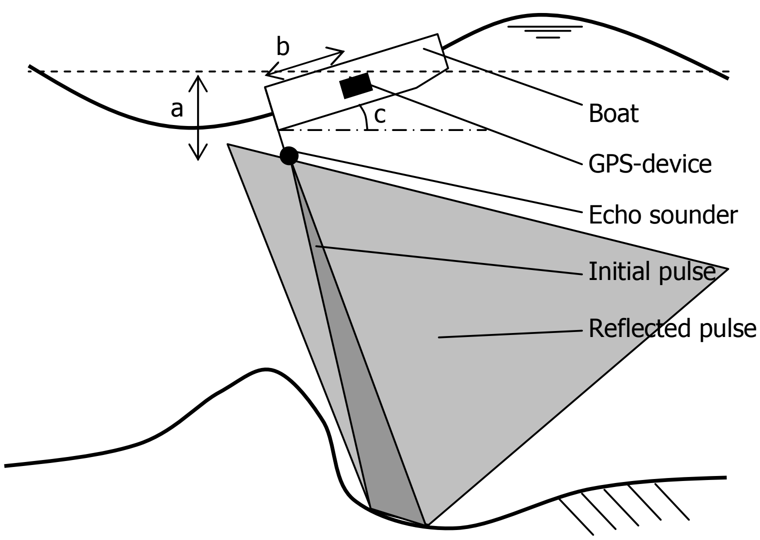


Figure 33 Schematisation of measurement errors using an echo sounder and GPS

a) The deviation between the height of the echo sounder and mean water level affect the accuracy. This is partly due to the fact that the echo sounder is installed underneath the boat. This can be easily compensated for, by measuring the distance between echo sounder and still water level and subsequently adding this distance to all depth measurements. But in addition, the deviation is partly due to squat as a result of the movement of the boat and due to wave elevation and depression. Therefore the boat should sail slowly during measurements.
b) The distance between echo sounder and GPS-device affects the measurements. The GPS-device should be installed as close to the echo sounder as possible. It should be noted that this distance may seem insignificant, but the effect is doubled when the boat sails perpendicular to the coast. Sailing towards the coast a deeper measurement is taken, while sailing away from it a shallower measurement is obtained than should have been in general.
c) The angle between the horizontal plane and the longitudinal axis (or transverse axis: this gives the same negative effects) of the boat is not always the same. This is caused by either waves, irregular loading of the boat, or too high sailing speed of the boat and generally results in too deep depth measurements. The sound pulses travel a longer distance before they reach the bottom. Also, a different area is measured

than what should have been measured, which may cause a spatial shift of features of the seabed.

4.2.3 Results

In this paragraph also the results of the bathymetric survey at the marina near Varna are discussed.

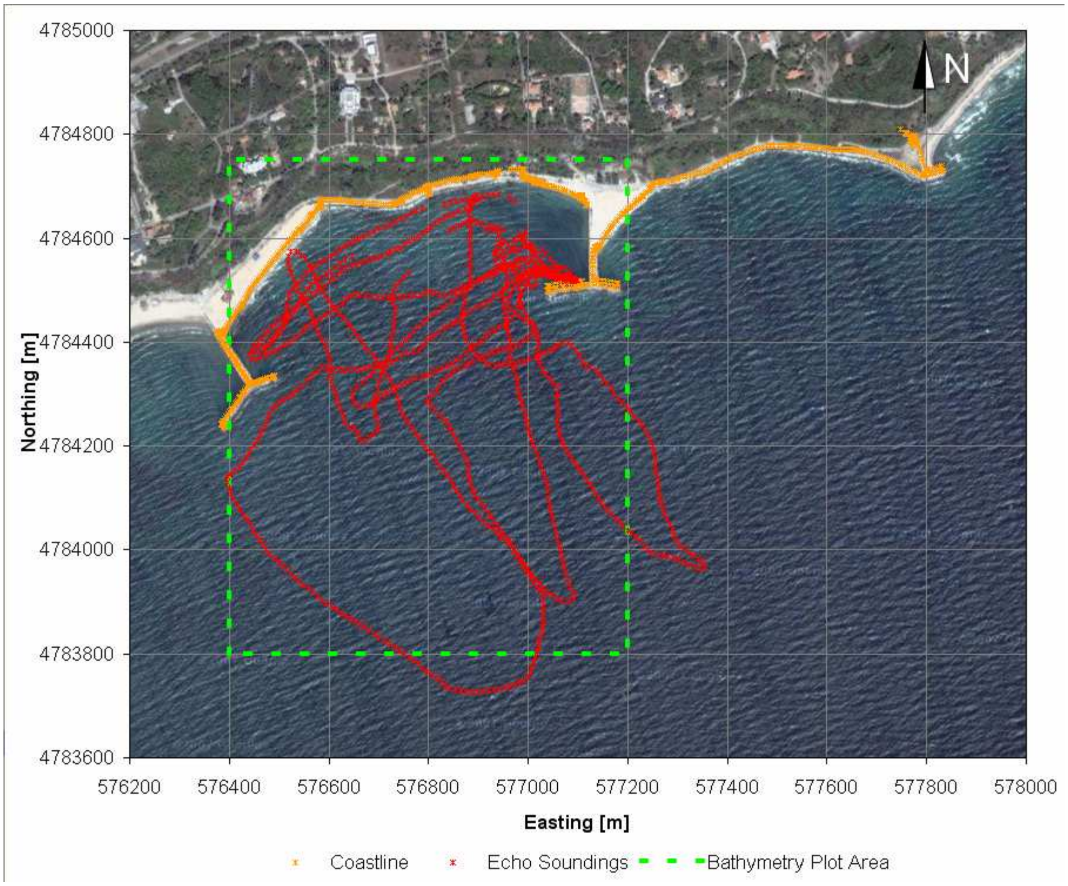


Figure 34 GPS-tracks, survey of the marina near Varna

A bathymetry map was produced which represents the elevation of the seabed in the area corresponding to the green box in Figure 34. The results are shown in the following figure:

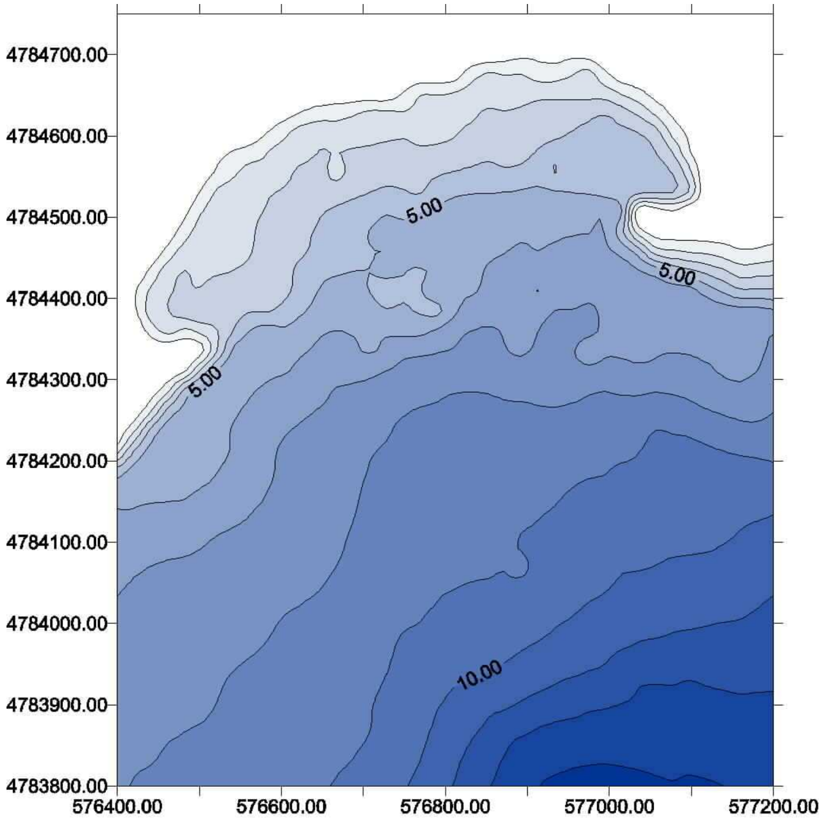


Figure 35 Bathymetry map interpolated for the marina near Varna

From this figure it can clearly be seen that right next to the breakwaters, the slope is very steep and the water depth increases rapidly. Next to the beach however, the slope is fairly gentle (approximately 1:40). Also there seems to be a shallow in the centre of the area, between the two breakwaters.

The results from the bathymetric survey near St. Konstantin I Elena are represented in Figure 36. In this figure also the data-points from the 2003-, 2004- and 2007-fieldwork surveys are shown, as well as the coastline measured in 2007. The boxes mark special areas, which are examined more into detail later on in this chapter.

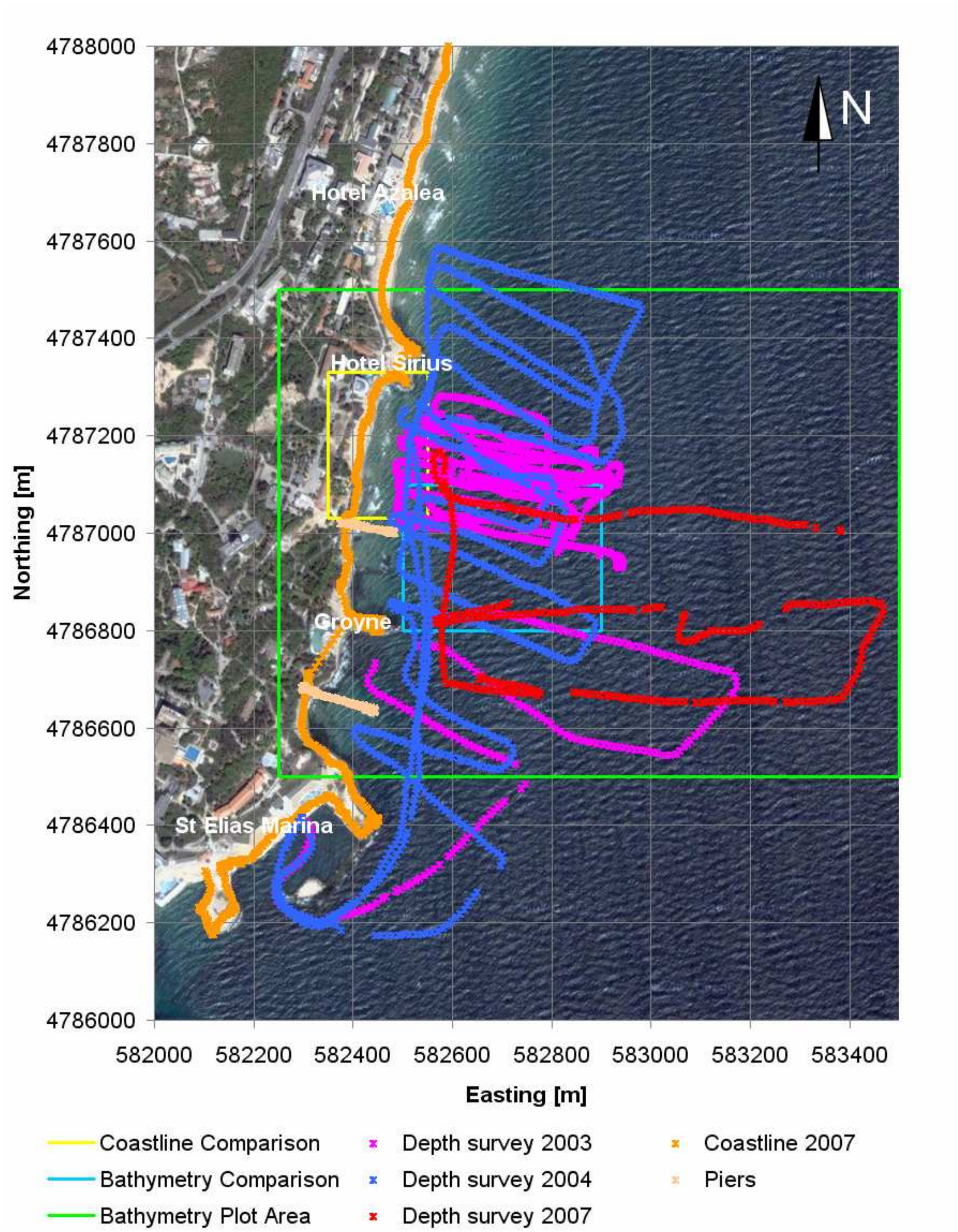


Figure 36 GPS-tracks, survey of St. Konstantin I Elena coastal zone

To determine whether the bathymetry has changed significantly over the past four years, the bathymetries of the different years can be compared. However, as can be seen above, not exactly the same areas have been surveyed and the measurements do not have the same data-density. For this reason, an area has been selected which includes as much possible data from all years.

The results of the bathymetry-interpolation for the designated area in different years results in the following figures, combined in Figure 37.

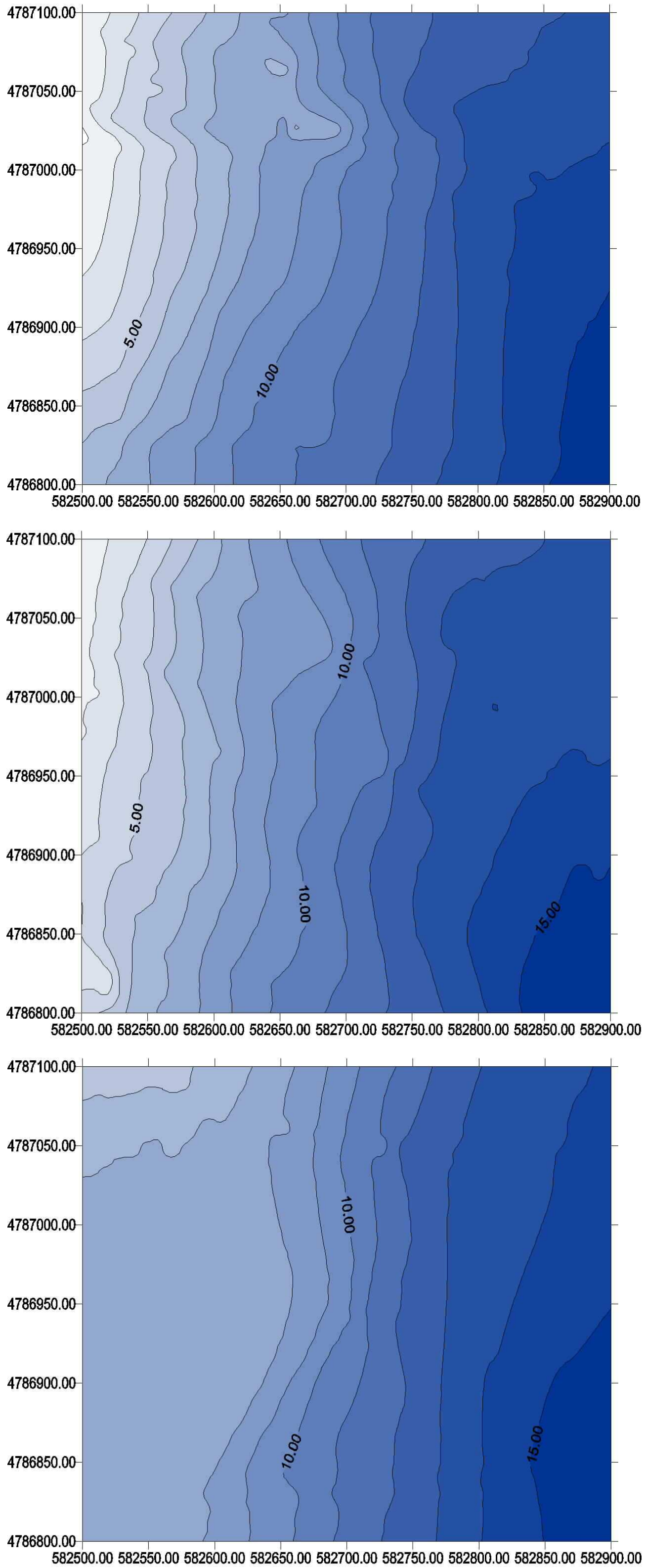


Figure 37 Comparison of bathymetric surveys (top: 2003, middle: 2004, bottom: 2007)

Some considerable differences may be noted at first sight, especially for the 2007-map. However, when checking for large changes in the bathymetry, and recalling the figure which shows the locations of the data-points during different years, it can be seen that in most cases the changes are due to lack of sufficient data-points. The 2007-map for example does not have any data-points along its western boundary. This may be the cause for the sudden change. For this reason it cannot be concluded from this comparison that there are large shifts in the seabed. In general the bathymetry maps even seem to match pretty well, especially in areas where all three years provide data-points. It can be said that the considered area is morphological stable over these years. With the purpose of creating a large detailed bathymetry map the data of these years are therefore be combined. This results in Figure 38, of which the morphological features can be studied in more detail.

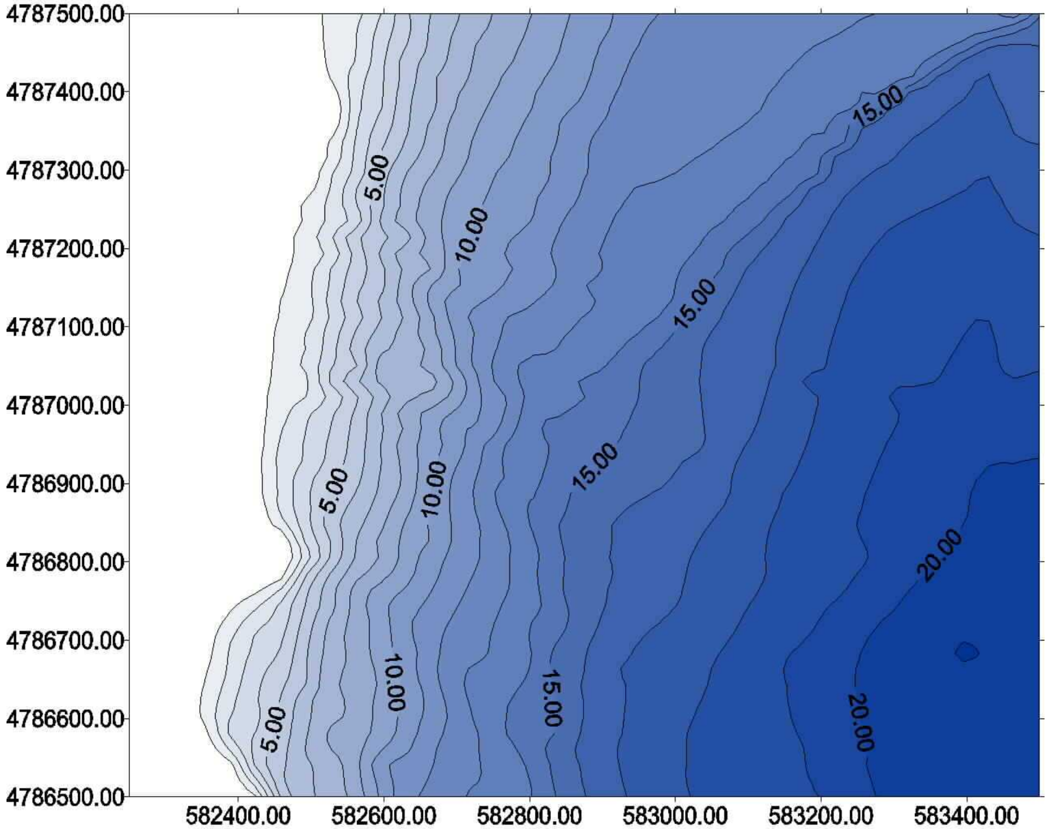


Figure 38 Bathymetry map of the coastal zone of St. Konstantin I Elena

There seems to be a steep slope in the north-eastern quadrant of the area. Again this turns out to be an extrapolation-artefact as a result of lacking data-points. Other uncertainties of this map are the shallow areas along the coast, which seem to be too large, especially around the groyne. In Figure 36 it can be seen that there is a zone between sea and coast where there are no data-points (probably because it was too shallow over there to navigate the boat). A drawback of the applied interpolation method is that it uses a limited amount of sample points. So if the, for example 10, closest data-points have elevation 0, the output point also gets elevation 0.

With this map and the fact that no (large) difference occurred in the area it could be concluded that the bathymetry is relatively stable. But for a better indication the effects of a longer time period have to taken into account. To see whether the construction of the hotel influences the area the morphology is studied in the next chapter.

4.3 Morphology

In order to make a good design for a new hotel in front of the beach, it is important to study the consequences that the construction of this hotel will have on the existing coastline. Using software packages like Unibest and Genesis it is possible to make a fairly accurate prediction of the coastline evolution that can be expected after the construction of the island. However, the aim of this fieldwork is only to collect the data required to make such a study. The actual morphological modelling is considered to be outside the scope of this report.

This chapter will evaluate several observations made during the fieldwork as well as observations from satellite photographs of the area. Based on these observations some general predictions about the expected evolution of the coastline are made.

4.3.1 Building site

Figure 39 shows an aerial photograph of the area around the location of the new island. Some important features are marked in the figure. On the right side of the figure Hotel Sirius is marked as a reference point for the orientation of the reader.

Figure 39 Aerial photograph of the area around the location of the new island

The features that have been marked on the photograph are the following:

A. An eroding beach bordered by a marina on the southern side.
B. A cliff between the beaches A and C, there is no beach present here.
C. A beach in front of the hot spa and bordering the groyne where the new island will be constructed.
D. The building location for the island of the new hotel.
E. A beach bordering the groyne where the new island will be built.
F. 'Sirius beach', the beach in front of the Hotel Sirius.

In the next paragraphs the most important aspects for these features will be discussed.

4.3.2 Morphological aspects beaches

Beach A

The beach marked Figure 39 as A was observed during the fieldwork. It became clear during the observation that this beach has been subject to erosion for an extended period of time. Figure 40 shows a photograph that is taken on this beach during the fieldwork. Two lines are drawn in Figure 40, which show the approximate height of the bottom of the wall that was once built at the bottom of the stairs. The photograph also shows the two sets of three steps of stairs that have been added to the stairs at a later time to compensate for the falling beach level. The second line shows the approximate height of the pier, which is at roughly the same height as the bottom of the wall.

Both the pier and the wall were built at the same height as the beach approximately 20 years ago. It is clear that the beach level has dropped significantly over the last 20 years. To further indicate the scale of the erosion a person is standing close to the wall, which shows that the beach level at that point is nearly 2 meters lower than it was at the time the wall was built.

Figure 40 Examining the erosion at beach A

An interesting question at this point is where the eroding sand from this beach went. If this sand had disappeared in a northern direction, it could be expected that significant accretion would have occurred at the groyne at beach C. No such accretion is apparent from the photograph (or from the field observations) and it is therefore thought that the sand has disappeared in southward direction around the marina. This is in line with morphological features that can be observed further south on the coast, which suggest a small net longshore current in southward direction.

Beaches bordering the groyne (C and E)

The beaches C and E are of interest as they border the groyne where the artificial island will be situated. It can be seen from the aerial photograph in Figure 39 that fairly little accretion has occurred at the groyne. This has also been observed during the fieldwork. The amount of accretion can be considered small in comparison to the amount of time the groyne has existed, namely about 25 years. From this observation it can be concluded that the net longshore transport along this coast is very small. It does not, however, give any decisive information in the amount of longshore transport that occurs during various periods throughout the year.

At the northern side of the beach E is a concrete walkway along the side of the cliffs that exists between the beaches E and F. At the southern side of this walkway some damage can be observed that may have been caused by erosion, this can be seen from Figure 41. In any case the erosion is not nearly as severe as at beach A, discussed in the previous paragraph. A shifting beach due to the construction of the groyne possibly caused this 'erosion'.

Figure 41 The concrete walkway at beach E as viewed from the groyne

Some measurements were conducted to investigate the dynamics of the groyne. The analysis of these measurements can be found in paragraph 4.4.

Beach F

During the fieldwork the coastline position of the beach at F has been recorded using a portable GPS device. For the beach line, the same GPS is used as with the bathymetry measurements (paragraph 4.2.1), though without the echo sounder. These measurements have also been carried out during the fieldwork in previous years and therefore the evolution of the coastline at this beach over several years can be compared. One could obtain information about the general progression or retreat of the coast over years or the behaviour in different wave climates. These results are shown in Figure 42.

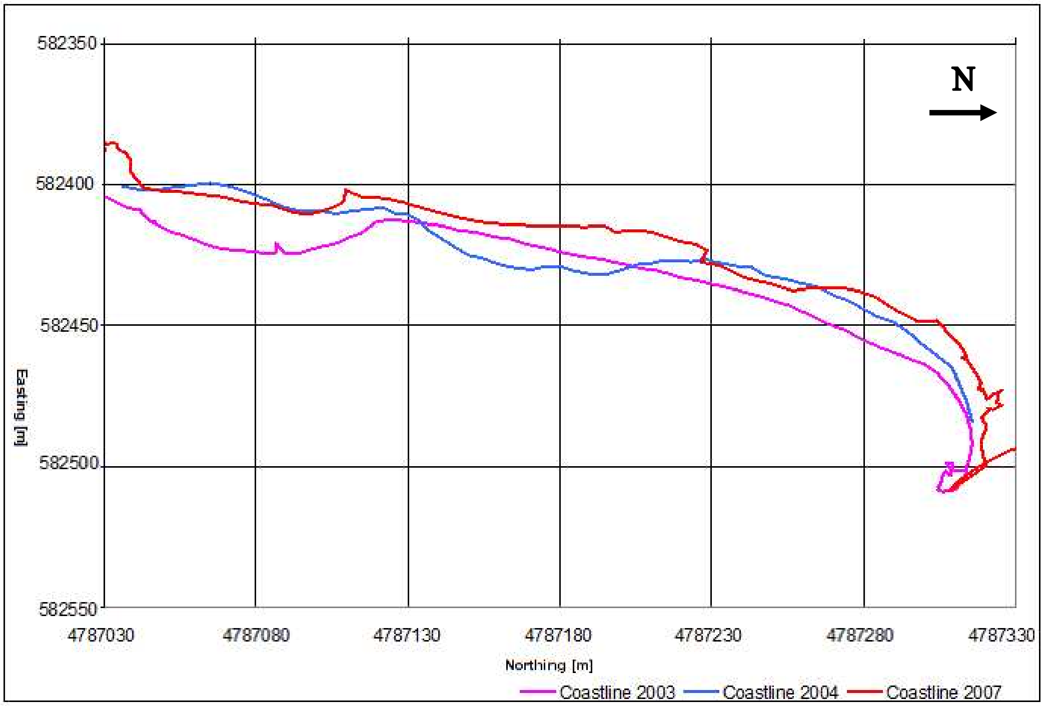


Figure 42 Evolution of the coastline at beach F over several years.

From Figure 42 it can be seen that in the last four years the coastline has retreated quite a lot. Again one may wonder to where this sand has disappeared. If there is indeed a net longshore current directed towards the south, it seems logical that the eroded sand would have accreted at the groyne. As stated earlier, however, very little accretion can be noticed at the groyne.

Another possibility is that the slope of the beach has become milder over the years. Unfortunately there is not sufficient information available to justify such a statement at this time. To get a better insight in the morphology of this coast it is recommended to direct more research into this matter.

4.3.3 Expected consequences of the new island

Since no accurate data on the longshore sediment transport is available, it is difficult to give precise predictions on the consequences of the construction of the new island. In this paragraph an impression of these expected consequences is given based on the earlier discussed data.

Figure 43 contains a picture of one of the preliminary designs made for the island. This is not a definitive design for the island; the image is used here only to indicate the relative size of the new island. The beaches A, C and E have also been marked on this image.

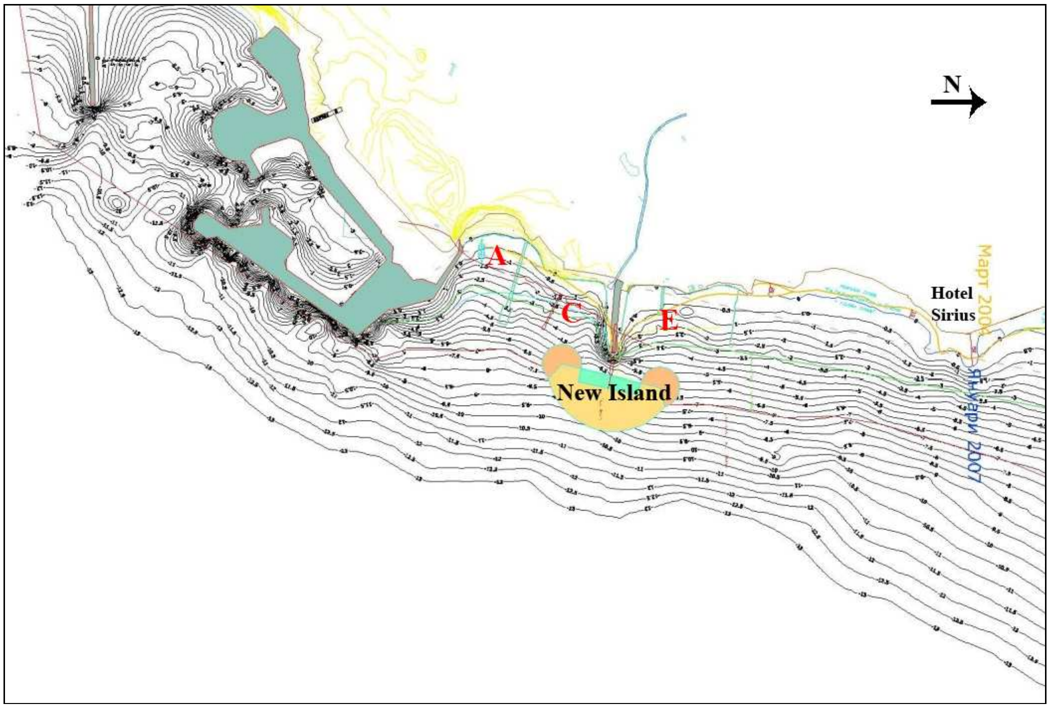


Figure 43 Possible design for the island

Judging from this image it can be expected that the beaches A and C will become more sheltered than they are nowadays. Recalling that the dominant wave direction is from the northeast it can be expected that both beaches will be less influenced by such waves. Very likely this will be beneficial to the ongoing erosion that is currently taking place at beach A as the erosion rate at that beach will decrease.

The beach at E is still subject to direct wave attack coming from a north-eastern direction. Due to the new island however the beach will be more sheltered from more southerly waves. As a result it is likely that after the construction of the island there will be a net sediment transport towards beach E and accretion will occur there. The source of this accretion will be the beaches further northward, especially beach F, where consequently an increased erosion rate will result. Such erosion may quickly become a hazard to buildings close to the shoreline, most notably the Hotel Sirius and may have to be combated by applying beach nourishment.

4.3.4 Recommendations

As mentioned before, it is possible to use the data collected during this fieldwork to create a morphological model using software packages like Unibest and Genesis. These packages can be used to quantify the expected rates of erosion and accretion along the coast. This information can in turn be used to determine whether beach nourishments are required and what the volume of such nourishments should be.

However, to create a reliable model more data, especially concerning waves is required. The wave climate can vary strongly from year to year and therefore it is recommended to collect wave statistics for a period of at least five years. A cheaper and relatively easy method of obtaining insight into the morphological situation of this coast is to monitor the evolution of the beaches for an extended period of time. By regularly measuring the position of the coastline as well as the beach profiles much insight in the morphological processes can be obtained.
Such measurements have also been done in previous years of the fieldwork. Unfortunately these measurements have been done in a fairly inconsistent manner and it is difficult to combine the data from the different years.

4.4 Groyne measurements

To obtain insight in the behaviour and effects of hydraulic structures in the concerned area, an existing groyne was measured. Measuring a groyne aids in understanding whether it fulfils its purpose or not. If a groyne's shape changes during the years it may be that it was not well designed. Waves may have damaged the armour protection and changed its position in the course of time. Additionally the soil under the construction may be affected by its weight and cause additional variation. Measurements of the same groyne were also done in the past.

Figure 44 Measurements groyne

The groyne considered in this chapter is a barrier-type structure that extends from the backshore into the surf zone. The basic purposes of a groyne are to interrupt the longshore sand movement, to accumulate sand on the shore, or to retard sand losses. The groyne concerned is located on the south side of St. Konstantin I Elena resort, as it is illustrated in Figure 45. It is observed that the groyne allowed the accumulation of sand on its right side; thus slightly expanding the beach. It is also constructed with a water conduit in the middle, of which the exact purpose is unknown.

Figure 45 Location of the groyne (indicated with D in the lower picture)

The groyne is a key aspect in the whole artificial island project. It is the link between the coast and the island. Thus it is definitely necessary to research whether the groyne is fulfilling its purpose in the present situation. Furthermore, the present situation will give insight to the capabilities of the groyne for the future. For example, during the construction phase of the artificial island, the hotel, and its facilities, the groyne will be exerted under harsher loads and tougher conditions. The groyne should therefore be scrutinized carefully so as to be able to sustain its state and capabilities.

Measuring a groyne aids in understanding whether it fulfils its purpose or not. If a groyne's shape changes over the years, it may be that it was not well designed. Waves may have damaged the armour protection and changed its position in the course of time. Additionally, the soil under the construction may have been affected by its weight and caused an additional variation of its shape.

The groyne was also measured in the fieldworks of 2002, 2003, and 2004. The intent was to measure and imprint the same cross sections with these previous years, in order to make a comparison of the deformations of the groyne such that conclusions could be drawn about its evolution in time. More specifically, the goal of the measurements was to estimate the changes in volume of the groyne and the displacements of the rocks in the armour layer. Unfortunately, the characteristic specific points, which were used in previous fieldworks, were unrecognisable; therefore an exact comparison could not be made.

4.4.1 Measuring method

To measure the groyne, measurements were executed in two shifts of student groups, each using the same equipment. First of all, a reference location was appointed, which would serve as a fixed point. Along a seaward direction parallel to the length of the groyne, a series of points was marked at intervals of 10 m, which made up the baseline (see Figure 46). Perpendicular to the baseline, the cross section of the groyne would be found by measuring the relative height of the groyne every two meters. Thus, seven independent cross sections, with mutual distances of 10 m, were measured. On the deck of the groyne is the surface flat, so it was not included in the profiles.

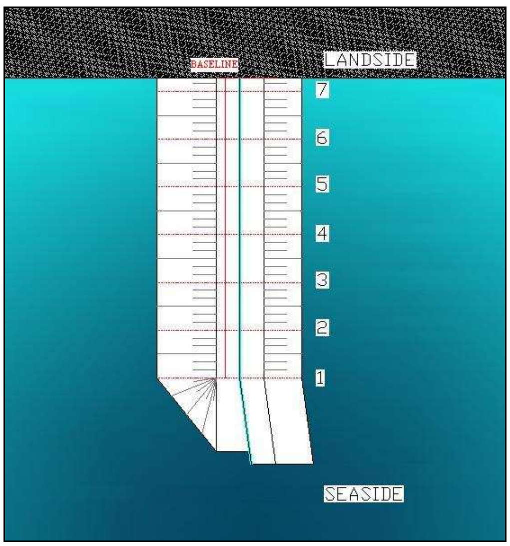


Figure 46 Top view of the groyne

To measure the height, a theodolite (see for detailed description paragraph 4.5.1) was positioned on the highest part of the groyne, from which all other points could be seen. The distance to the baseline was measured with a measuring tape that was pulled tight by two people. A third person would position the scale at the right location. Positioning a scale in between the rocks is difficult and will not give usable information about the shape of the groyne. Placing the scale in a hole gives a very low value but if one would place it a few centimetres further it might be on top of a large rock and give a high value (see Figure 47). To prevent these irregularities, a hemisphere was mounted under the scale.

The hemisphere levels out the influence of an individual rock, preventing the surveyor's scale to be positioned in a gap between adjacent rocks. The result would be a smoothened profile of the groyne, making the measurements more accurate. The accuracy of the method depends a lot on the choice of a correct hemisphere. According to CUR, the size of the hemisphere should have a diameter of 0,5 to 1,0 times the D_{n50} of the armour layer. The armour layer of the groyne consisted of loose stones with a remarkable high gradation. Due to this fact, a determination of the D_{n50} was not performed. Moreover, the number of the available hemispheres was very restricted, so a diameter 0,75m was applied which performed quite well.

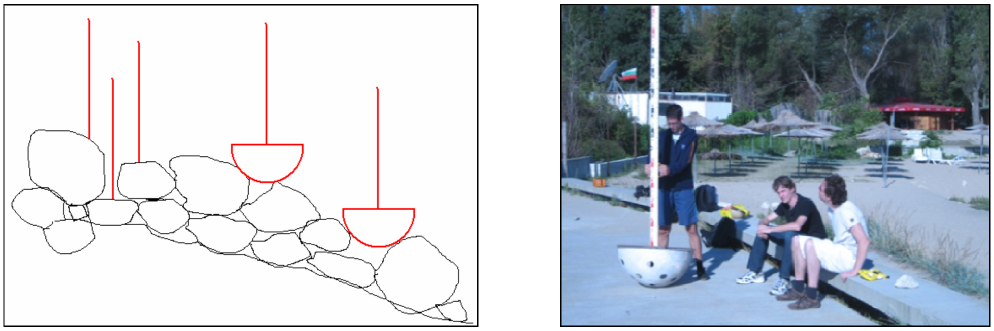
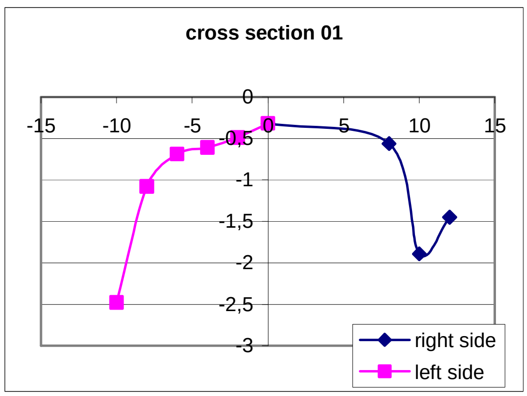
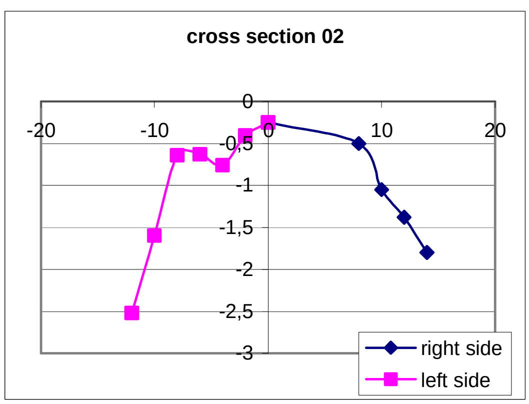


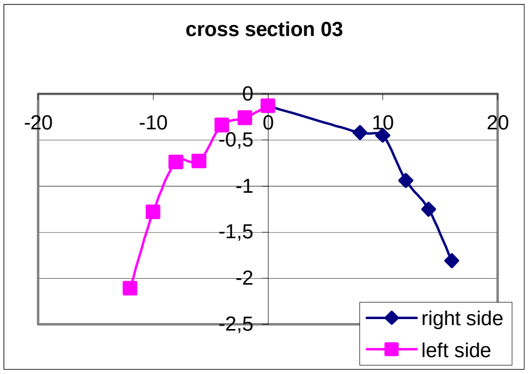
Figure 47 Aid of a hemisphere

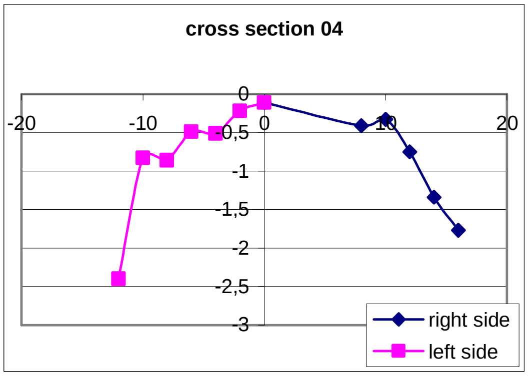
4.4.2 Profile measurements of the groyne

Analytically, the relative heights were determined with respect to a fixed reference point using the spreadsheet programme Microsoft Excel. The groyne was characterised with a base line and its respective cross sections (Figure 46). The measurements were executed on both the right and the left side of the base line, resulting in the profiles shown in Figure 48. One must remember that the centre, horizontal part of the groyne has not been included in the profiles.






cross section 03
right side
left side


cross section 04
right side
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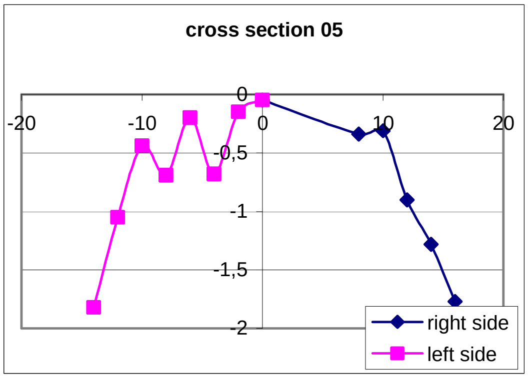
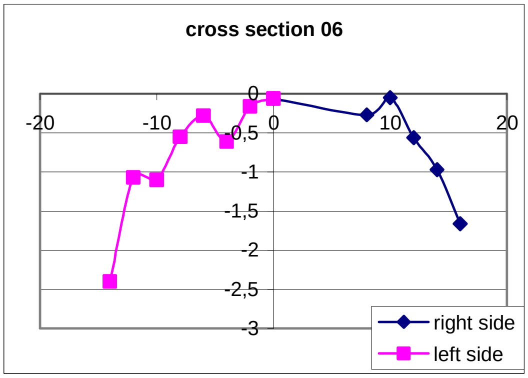

cross section 05
right side
left side


cross section 06
right side
left side

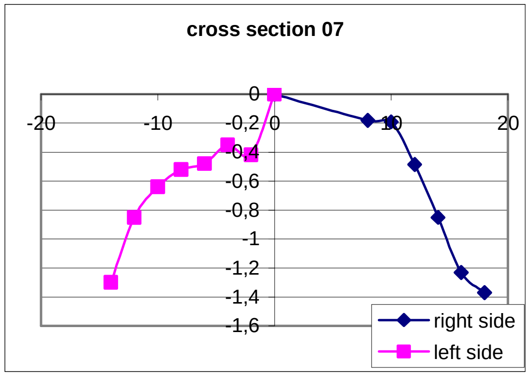


Figure 48 Cross section profiles

One can notice that the results are not sufficiently accurate, since the curve is not fluent. By using a hemisphere with a larger diameter, the curve would have been much smoother. There was another hemisphere of 0,25m diameter, which was available, but this one is still not representative of the D_{n50}, therefore it was not used.

In addition, two extra cross sections were determined. The starting point in the base line is common with that of cross section 1. The location of the supplementary cross sections and the resulted profiles are illustrated in Figure 49 and Figure 50.

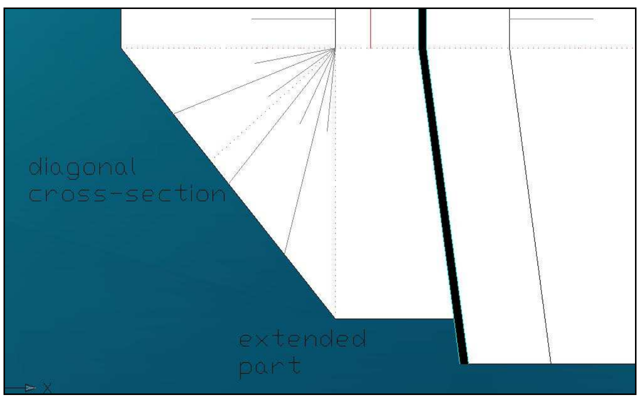


Figure 49 Supplementary cross sections

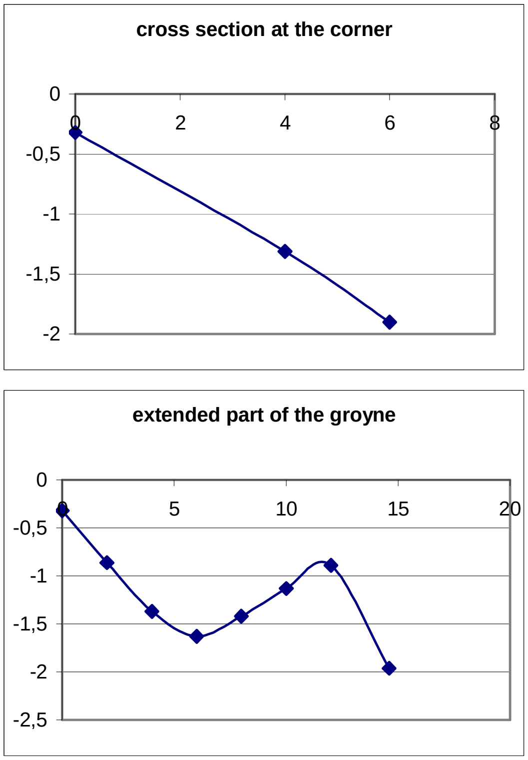
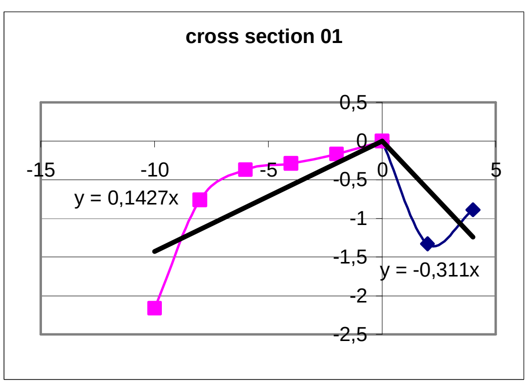


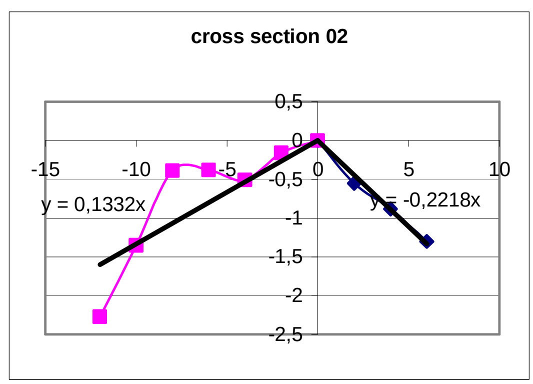
Figure 50 Supplementary cross section profiles

4.4.3 Slope determination

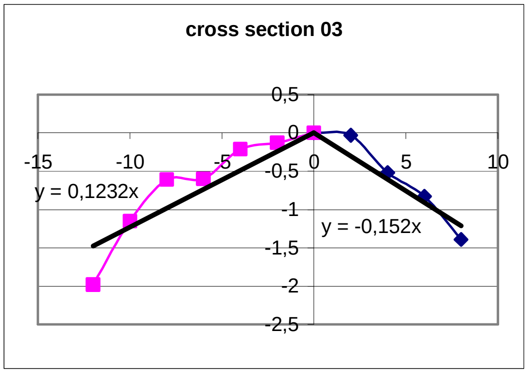
From Figure 48 and Figure 50, the slope of the top layer can be determined. Whilst looking at the results, one must remember that the centre, the horizontal part of the groyne, has not been included. This would explain why the groyne seems to have a sharp 'top'. For instance, the slope of the right side starts from the point located 8 m from the baseline, and not at 0 m as shown in Figure 51, where the estimated slopes are illustrated for each cross section.



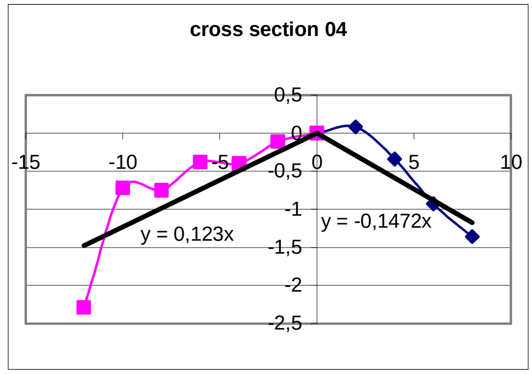
Cross section 01 (slope of the left side: 1/7, slope of the right side: 1/3)



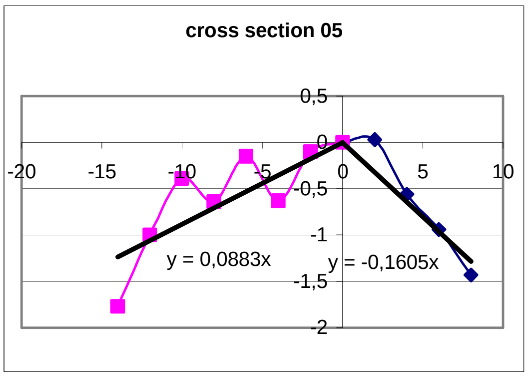
Cross section 02 (slope of the left side: 1/7,5, slope at the right side: 1/4,5)



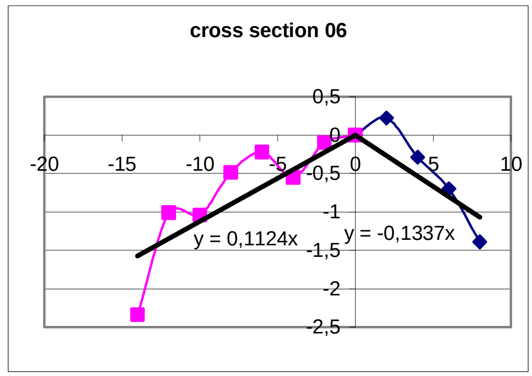
Cross section 03 (slope of the left side: 1/8, slope of the right side: 1/6,5)



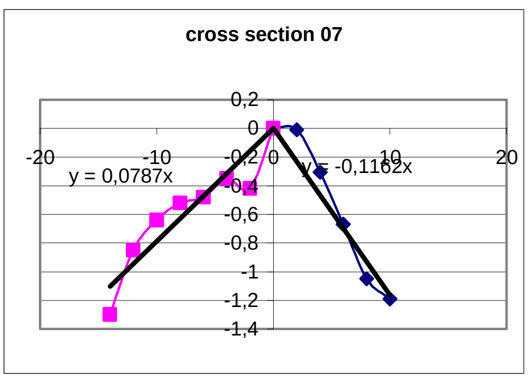
Cross section 04 (slope of the left side: 1/8, slope at the right side: 1/6,8)



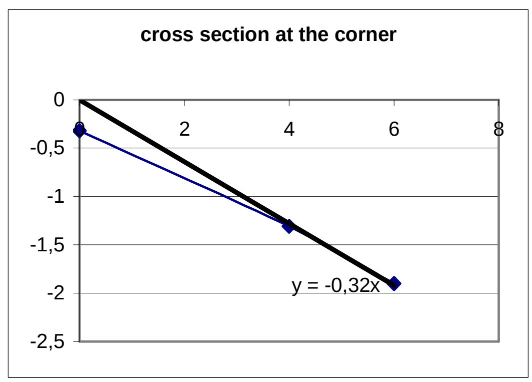
Cross section 05 (slope of the left side: 1/11, slope of the right side: 1/6)



Cross section 06 (slope of the left side: 1/9, slope at the right side: 1/7,5)



Cross section 07 (slope of the left side: 1/13, slope of the right side: 1/8,6)



Cross section at the corner (slope: 1/3)

Figure 51 Estimated slopes for each cross section

Moreover, the cross section of the base line can be plotted, in order to get an impression of the different settlements of the groyne. In Figure 52, the point zero represents the cross section 01, on the sea side.

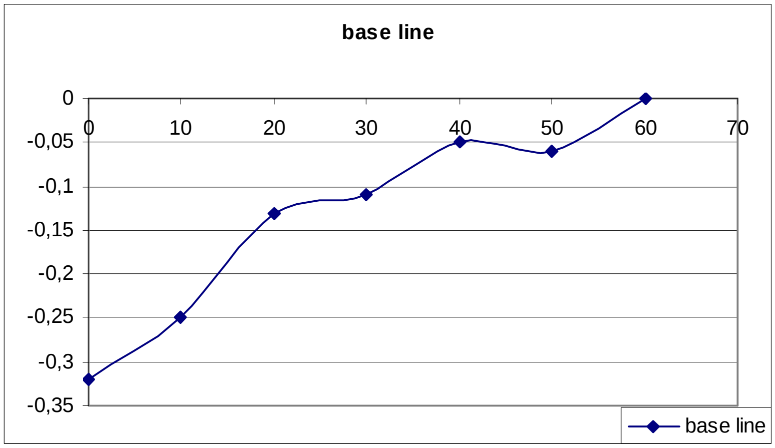


Figure 52 Profile of the base line cross section

4.4.4 Conclusions

For the majority of the cross sections, a flatter area can be distinguished in the upper part of the slope. Taking into account that a normal design slope is in the order of 1:3 to 1:4, it can be concluded that many displacements of rocks have occurred, especially in the upper, central part.

From the cross section along the baseline, it is obvious that many deformations have occurred during the lifetime of the groyne. The reason for such a situation might be the lack of soil improvements during the construction phase. The presence of a bottom protection layer can firstly increase the bearing capacity of the subsoil and at the same time keep the scour hole at such a distance of the structure, minimising the risk of failing. The magnitude of the settlements indicates that bottom protection measurements have not been used during the construction phase of the groyne. One can conclude that the groyne needs to be improved or reconstructed if one wants to use the groyne for the artificial island.

4.5 Beach profiles

The profile of a beach helps to understand morphological behaviour of a stretch of coast. Erosion or accretion and seasonal variations can be observed and related to the sediment characteristics, wave climate and currents that affect the sediment around the beach. Repetition of measurements can give insight in the processes that play a role on the long-term, such as local accretion or erosion, response to sea level rise and the effects of hydraulic structures and measures.

In order to have an idea of the evolution of the beach near the groyne, a small survey at the northern beach was carried out. Several profiles of the beach were measured perpendicular to a certain baseline. These measurements show an inclination of the beach as well as an inclination of the bottom of the sea near the shore. Measurements from previous years were used in order to realize the development of the beach profiles in time. Although the measurements with the GPS were really useful for this objective, some measurements had to be made in the sea, something that did not allow the use of the GPS. The echo soundings were also quite accurate but because the boat could not reach very shallow waters, so the only left alternative was manual measurements.

4.5.1 Equipment

Clever equipment is used for measuring a beach profile. Distances can be measured with general accuracy relatively easily by means of a measuring tape with a length up to 50 m or with a rope with knots. These knots are positioned at regular intervals (in case of the fieldwork at every meter). To measure heights and distances visual instruments such as a theodolite (Figure 53) can be used.

Figure 53 Theodolite and scale

A theodolite (see Figure 53) is usually placed on a tripod frame. Combined with a scale the height relative to the position of the theodolite can be determined. This scale is a board with markings at regular intervals. On a stable floor and levelled accurately, the markings on a scale can be read very accurately. When looking through the glass of the theodolite, one can see three markings above each other. The middle marking indicates the level of the theodolite. Its position on a scale gives the difference in height between the scale and the looking glass is. Measuring vertical angles can also be used for determining heights. The other markings of the looking glass indicate a height difference on the scale.

To assure that every measured beach profile was perpendicular to base line along the coast a pentagon-prism was used. When looking through this device, one can see in three directions at once; straight ahead, perpendicular to the right and to the left. Two jalons are placed at the original line and standing on this line an observer makes sure that both jalons are aligned in the prism. The perpendicular line is then straight ahead.

The sand of the beach was not the ideal soil for this kind of measurements, because the position of the theodolite could be very easily changed by accidence. Finally in order to be accurate in measuring the distances, a modern type of band chain was used. The temperature could not affect the length of this band chain because of its material. Therefore there was no danger of unwanted dilatation or shrinkage.

4.5.2 Method

The procedure of measuring the beach profiles is relatively simple. Every measurement is a height measurement at a certain location. Once a location is determined, a pole or scale can be placed to obtain the height of the beach. To establish a convenient series of locations, a common routine is to set up a base line and measure along rays that are perpendicular to this line. A baseline is a fixed line from which distances can be measured. The requirements for the baseline are that

- it covers the area of interest
- it is straight
- it is horizontal
- it is fixed in space
- it is fixed in time (to redo measurements)
- it is parallel to the waterline

Additionally it is convenient that it is located on dry beach and easily visible from all points at the beach. To define the baseline, two clearly marked points are chosen at fixed objects that are not likely to displace in time. At intervals along the baseline (approximately every 10 meters), perpendicular rays are set out onto the beach and into the sea, along which heights are measured at distinct locations (e.g. the waterline or the escarpment line) and intervals (approximately every 5 meters). Other possibilities to determine locations involve measuring angles (such as triangulation, trilateration and the use of polar coordinates) or the use of GPS equipment. An impression of the method of measurements of the beach profile is indicated in Figure 55. Attention is paid to the set-up of the baseline and the perpendicular cross-sections.

Height differences can be measured with two scales or with optical instruments. In the first case the height is determined putting the first scale at a fixed location and moving the second scale to different locations of interest. An observer looks from the fixed scale to the horizon and reads at what level this "line of sight" cuts the second scale. Optical instruments make the use of the fixed scale unnecessary since they are fixed and are made horizontal themselves. The final beach profiles are acquired by relating the differences in height to each other and to a (local or global) reference level.

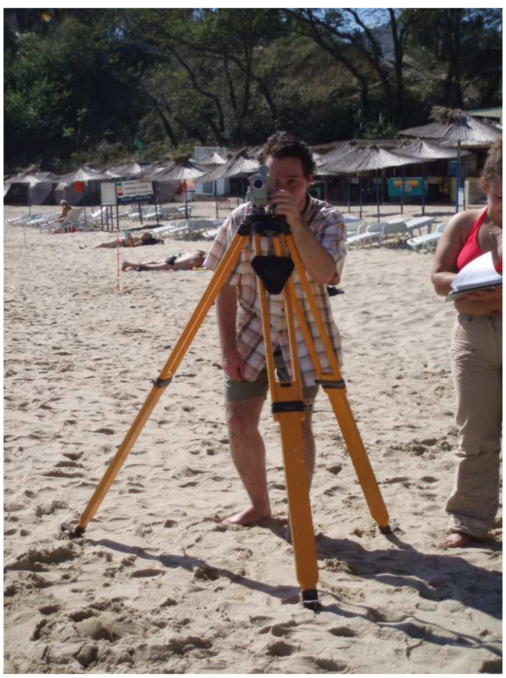


Figure 54 Measurements with a theodolite

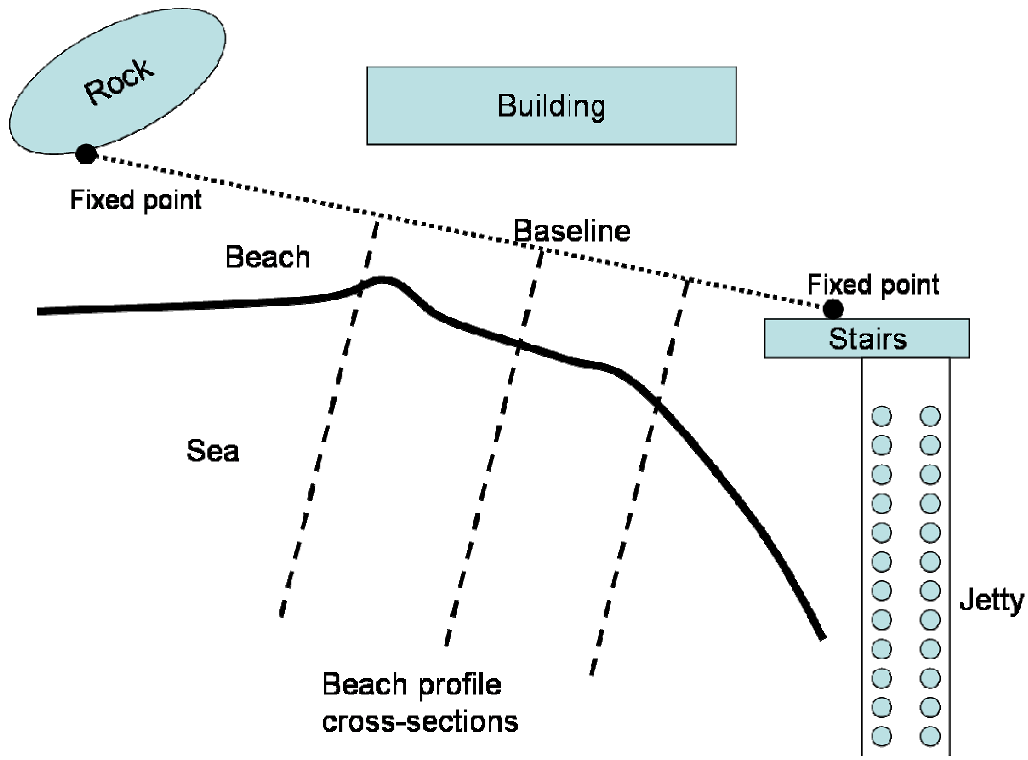


Figure 55 Beach profile measurement using a baseline

The altitude of every point will be converted to the altitude of the reference point as follows:

$$z_i = z_{RP} + (h_{RP} - h_i) + \sum \Delta_i \qquad (4.1)$$

in which:

- z_i = Altitude of measured point number i
- z_{RP} = Altitude of the reference point
- h_{RP} = Number read from the pole at reference point
- h_i = Number read from the pole at the measured point
- $\Sigma\Delta_i$ = Sum of level discrepancies when changing position of levelling instrument
- Δ_i= h_f-h_b
- h_f = The number read on the pole at the same point from the old position and the new position
- h_b = Position with respect to the instrument

4.5.3 Measurement accuracy

Errors in the measurements originate from systematic errors (biasing due to the instruments or the method used, or the environment of the measurement) and random errors (due to statistical variability). The table below gives examples of possible systematic errors for every source.

	Distance measurements	**Height measurements**
Instrument	- Rope: inaccurate, only indicates whole meters - Measuring tape: accurate - Theodolite: accurate	- Two scales: inaccurate, the visibility is very low due to the distance between the scales - Theodolite: very accurate

<table>
<tr><td rowspan="2">Method</td><td>- Rope and tape are not pulled tight and held horizontal</td><td>- The surface of the earth is curved</td></tr>
<tr><td colspan="2">- Reading errors are made easily with the theodolite since markings on the scale are somewhat unclear
- Theodolite is not perfectly levelled
- The scale is not perfectly vertical</td></tr>
<tr><td rowspan="2">Environment</td><td>- Objects and people on the beach prevent the use of some locations for measurements</td><td>- Stones result in a local peak in bottom level
- Walking people disturb the sand and alter the profile
- Wind disturbs the profile during the measurements</td></tr>
<tr><td colspan="2">- Waves and wind hinder the reading results and sway the scale
- The theodolite is not positioned on a stable surface
- The scale penetrates the sand
- People on the beach hinder the visibility of the scales and jalons</td></tr>
</table>

Table 10 Possible systematic errors

The used theodolite is good enough for the purpose of these measurements and gives a relatively small error. The execution accuracy is caused by balancing of the horizontal orientation of the instrument relative to the beach, but also the position of the pole as well as the accuracy in reading from the pole. Acceptable error in this case can be assumed in the order of millimetres. The third part of the accuracy has to do with the beach itself. A sandy beach as well as a moving border between water and land does not fulfil the best requirements for the ideal point under measure. In general the accuracy of the height measurements is estimated to be accurate up to a few cm. The distances are less accurate, but this is of minor importance for the analysis of the results since the horizontal dimensions involved are much larger than the vertical. The accuracy of the measurements is determined by the execution accuracy and is therefore in the order of millimetres. The method is sufficiently accurate to get insight in the beach profiles and morphology since it is used as a first impression.

4.5.4 Location of measurements

The map (see Figure 56) indicates an overview of the project area. Point D is the project area, the groyne that will be used in the construction of the island. In this study this map is referred to many times. The area of interest contains the beaches bordering the existing groyne. Therefore the profiles in the adjacent beach north of the groyne, beach E (see Figure 57 and Figure 58) were determined. Part of the beach to the south (Beach B and beach C) was not very easily accessible and had some hard structures on it that would hinder the survey and make accurate measurements difficult, which would result in not well-founded conclusions. The northern beach on the other hand was ideal for measurements.

Figure 56 Overview of Konstantin I Elena

On the northern beach, the baseline was indicated by a point on the groyne and by a point on the wall. Both were clearly marked with green graffiti. The theodolite was put at the groyne because the concrete made a more solid foundation than the loose sand on the beach would. Perpendicular wave rays were set out with a measuring tape at intervals of 10 metres (see Paragraph 4.5).

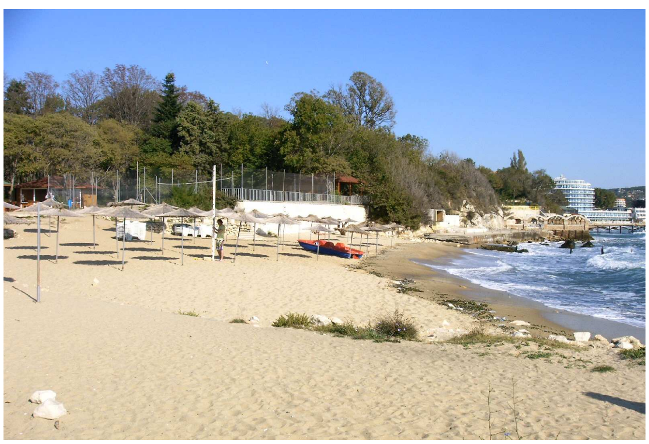


Figure 57 Beach E, north of the groyne

In some profiles accurate measurements could be achieved only until a certain distance from the coastline because of the presence of some rocks on the bottom. Despite these obstacles, adequate measurements were made for those profiles too. In the following picture, the way that measurements were made into the sea can be seen.

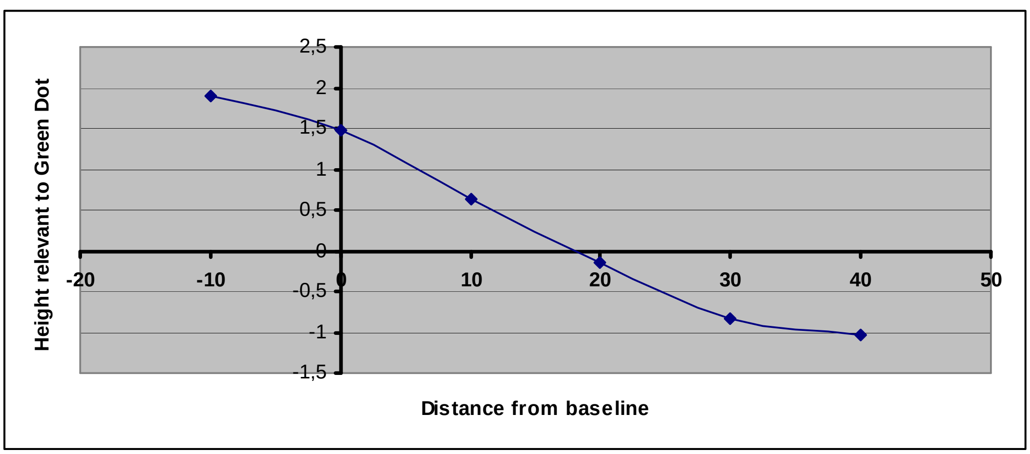
Figure 58 Beach measurement method

Measurements of the same kind were also made at another beach south of the groyne (beach A), which was located south of this groyne, in the vicinity of the jetty (Point A). The exact same procedure was used. There were also some rocks close to sea level, which hindered measurements in the deeper parts of some profiles. The fact that this beach was not exactly near the groyne, does not mean that it is impossible to draw conclusions. Comparisons can be made with the results from the northern beach (beach E), something that will demonstrate whether the beach behaves the same way in a wider area.

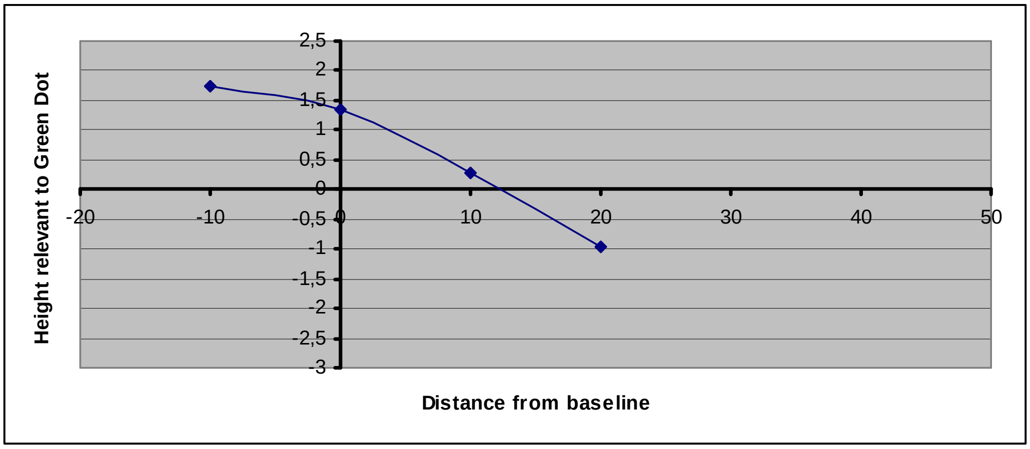
4.5.5 Results

Measurements for Beach E

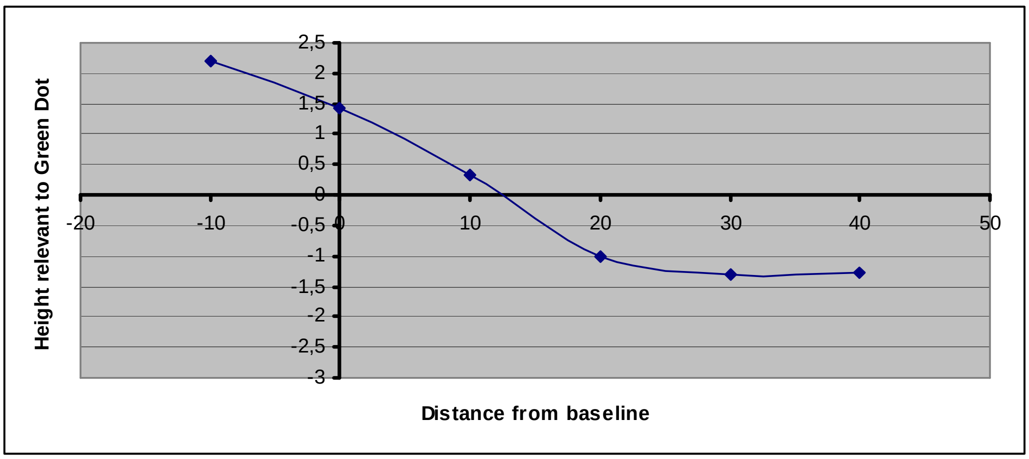
In the following graphs the elevation of the sand in the different profiles can be seen. As it was already mentioned, each profile is measured in different distances due to local obstacles. All heights have been calculated with respect to a reference point (marked with a green dot).



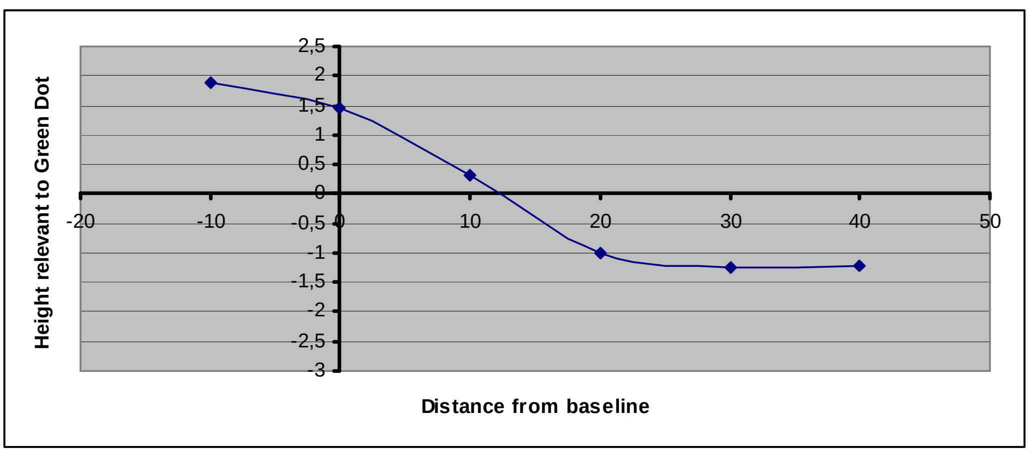
Profile 1



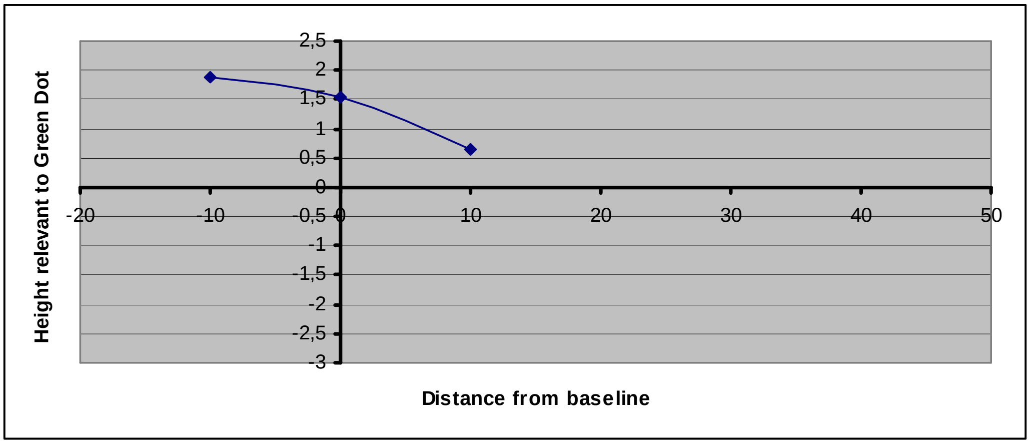
Profile 2



Profile 3

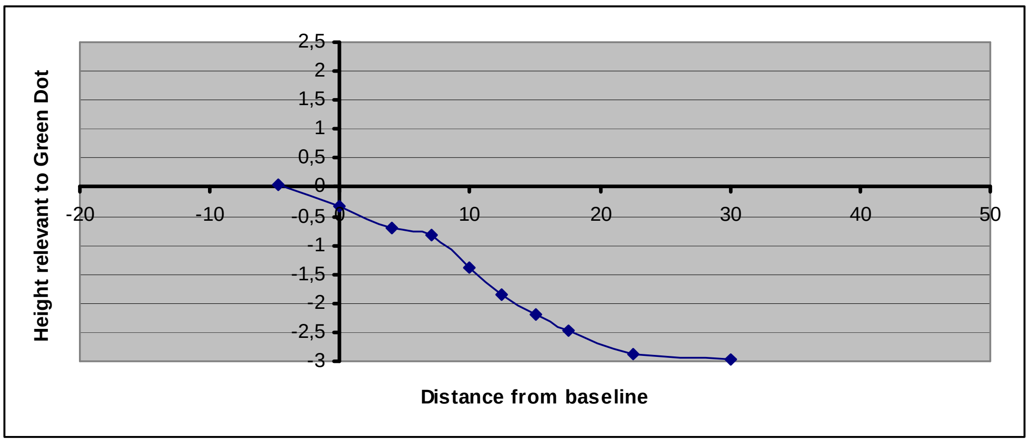


Profile 4

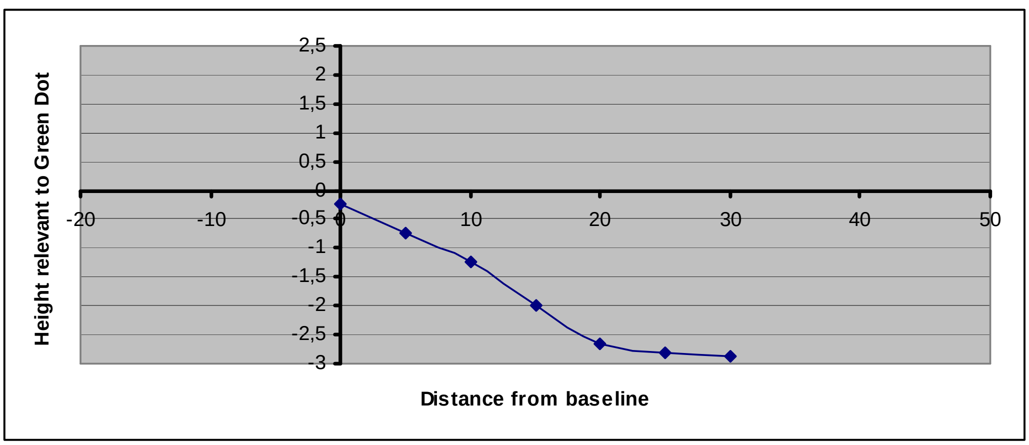


Profile 5

Profile 6 was not included at all in this report because for that profile only one point was available.



Profile 7



Profile 8

Figure 59 elevation of the beach in the different profiles

From the graphs above (Figure 59) it can be said that some quite detailed profiles were found. Except profiles 2 and 5 the rest of the profiles were drawn using adequate number of points.

Profile 6 was not included at all in this report because for that profile only one point was available. Despite the missing information about these three profiles (2, 5 and 6) estimates can be made about what the profile would look like because as it can be clearly seen from the other ones, there is a clear tendency along the beach which does not vary much. This tendency is expressed by a very gentle slope, which starts from the landside, increases a bit in the first twenty to thirty meters from the baseline and than smoothens out again after thirty meters.

The slope is characterized as quite gentle because in a distance of thirty meters there is a height difference of about one meter, which gives us an inclination of approximately 3.3%. In the last two profiles (7 and 8) this inclination is much more because in a distance of 30 meters there is a height difference of three meters, which means an inclination of 10%. This may be explained by the existence of a kind of pier near that profiles that may be interacting with the active profile of the rest of the beach. Piles are always a source of erosion around them. Another reason for this difference could be the presence of the groyne. As mentioned before, the predominant wind and wave direction is north east, which means that there may exist a small accumulation of transported sediment at the northern part of the groyne.

Measurements for Beach A (south of the groyne)

Measurements were made also in beach A, which was located south of the groyne, at a certain distance of approximately 200 meters. Not all of the results will be presented here from those measurements because they do not belong to the area of interest. What can be said though about the state of this beach, is the fact that the erosion is quite visible even without making any measurements. This phenomenon was already observed chapter []. The beach shows an inclination of approximately two meters. A possible explanation for the magnitude of the erosion in this area may again be the groyne. This beach is located down drift from the groyne; as a result erosion takes place because there is a lack of sediment transport due to its accumulation in the up drift beach.

4.5.6 Conclusions and general comments

The main conclusion that can be presented is the constant erosion of the area. This can be especially seen with the visual observation at beach A, as well as with comparisons of both beaches with relevant profiles from previous years. At this point, it can be stressed once more that hard structures are not a panacea; if they are not included in an organized plan with a potential combination of soft measures as well, they may have detrimental effects on the beach.

The measurements with the theodolite proved to be fairly accurate. Considering the dynamic behaviour of the bottom profile that may change even in the range of a couple of hours, a high degree of accuracy is not of much interest. The slope of the bottom of the sea is quite gentle. Especially after the first thirty meters seaward from the beach (the hotel is planned to be constructed more or less in this area), the bottom seems to be even gentler. This is an advantage for the construction of a structure in this area, because it means that the quantities of the materials to be used will not be so large.

Another aspect that is worth mentioning is the difference in the profiles between summer and winter. It is generally known that during winter, because of the storms and generally the more severe weather phenomena, the beach profile gets steeper and a large quantity of sediment is transported more seaward. When the summer season is approaching, these phenomena tend to get milder and the beach profile starts to get a more gentle shape. By the end of the summer season, the sand that has been transported seaward, returns in its previous position.

In case there is larger longshore sediment transport during winter and sand is carried away into nearby beaches. In the area of interest in the coast of Bulgaria, the situation is more or less the same. Severe storms tend to change the morphology of the coast during winter, while during the summer period, the profile returns to its initial form. The magnitude of these phenomena is relatively large. Unfortunately at this time there is no data available in order to make comparisons. With testimonies of the Bulgarian part of our research team and estimate of the changes in the winter could be made. According to these testimonies, the recession of the beach during winter, especially in the area in front of the Azalia hotel, can reach the significant magnitude of five to ten meters. Someone does not have to be a specialist in order to understand that a recession of the beach of this order of magnitude can be catastrophic for potential structures located very close to the sea.

5 Design of the island

5.1 Introduction

Previous chapter focussed on measurements done during the Fieldwork of October 2007. This chapter aims at the design of the artificial island. The first paragraph will elaborate on the design process and the position of the measurements in this design process. In the second paragraph examples are given on how to come to design criteria. In the last paragraph recommendations are given about what should definitely be taken into account during the design process.

5.2 Design process

In Figure 60 is visualized which steps should be taken to fulfil the wish to have a hotel on an artificial island. Logically a project starts with the wish (desire) to have a new building/ road/ island. For our project this was done in chapter 1.2.1. Secondly this desire has to be transformed into the demands for this project (chapter 1.2.3). In the demands, the future owner should formulate his or her wishes to concrete items. Formulating those requirements on before hand reduces the chance that the final design does not fulfil the expectations. The next step is the determination of the boundary conditions that have to be taken into account in the design (chapter 1.2.2). The quality of designs are based the aspects that the contractor finds most important. The criteria for the evaluation of design are only sideways taken into consideration. Low costs, a high level of safety and attractive value were considered. If all the design requirements are formulated, the final design can be made and the construction can start. If the project is finished it is advisable to maintain the structure well, since this can expand the lifespan of the structure.

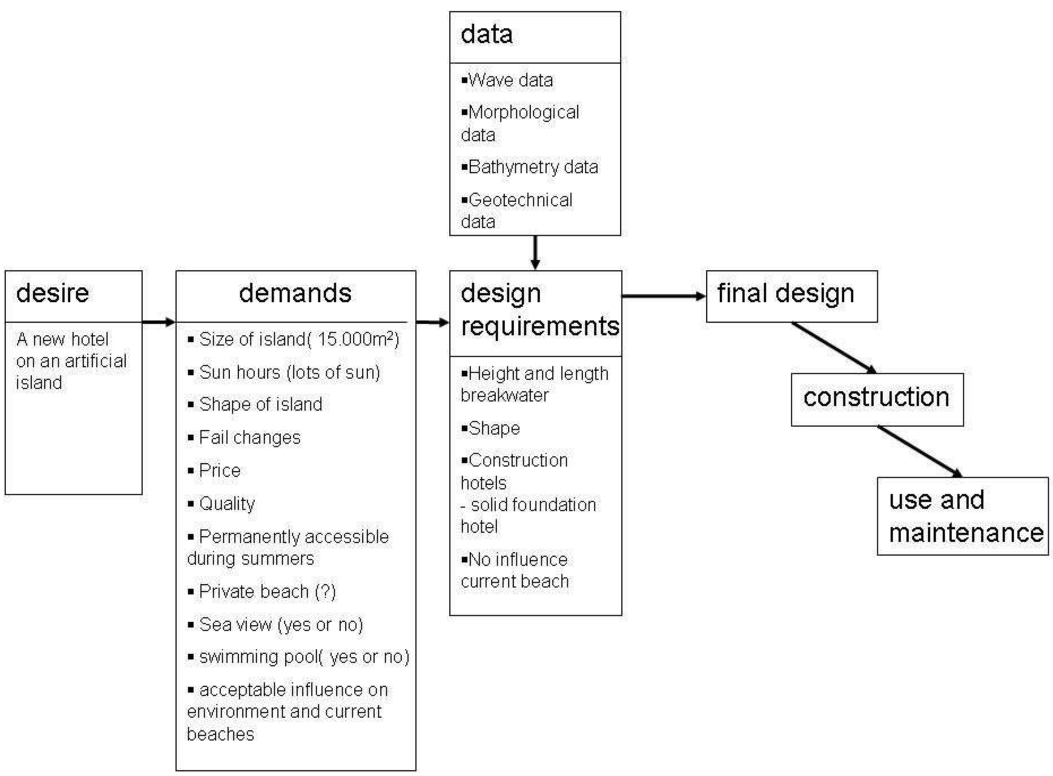


Figure 60 Design process

Figure 60 shows how the measurements done during the Fieldwork in October 2007 fit in the design process. To formulate design criteria that suit the local situation, local data is needed. A part of this data is gathered during the Fieldwork of Delft University of Technology. However to come up with final design criteria more information is needed, this is also discussed in paragraph 6.2. The measurements done during the fieldwork are unfortunately too limited to make a ready for use design.

5.3 Component design

In this paragraph examples are given on how to combine the demands of the island and the boundary conditions into a design. Roughly any artificial island consists of 3 main components:

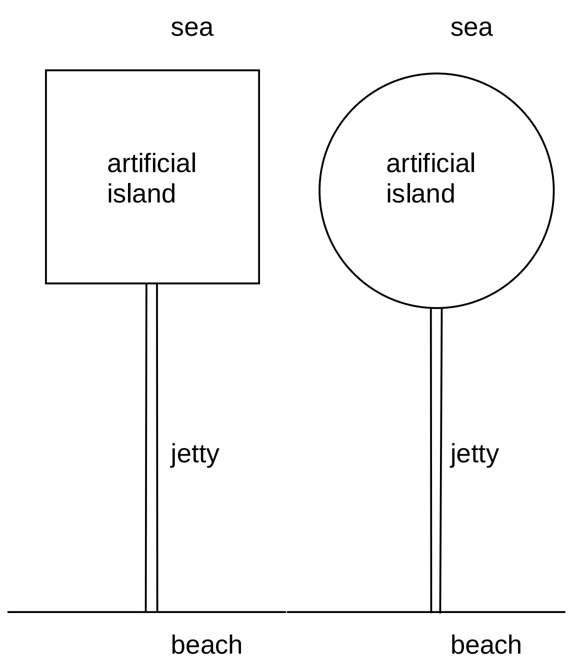
- Island core
- Protection
- Island access

In the next paragraphs a design of the components is roughly made.

5.3.1 Island Core

Shape

In Figure 61 impressions of shapes can be found, of course also other shapes are possible.



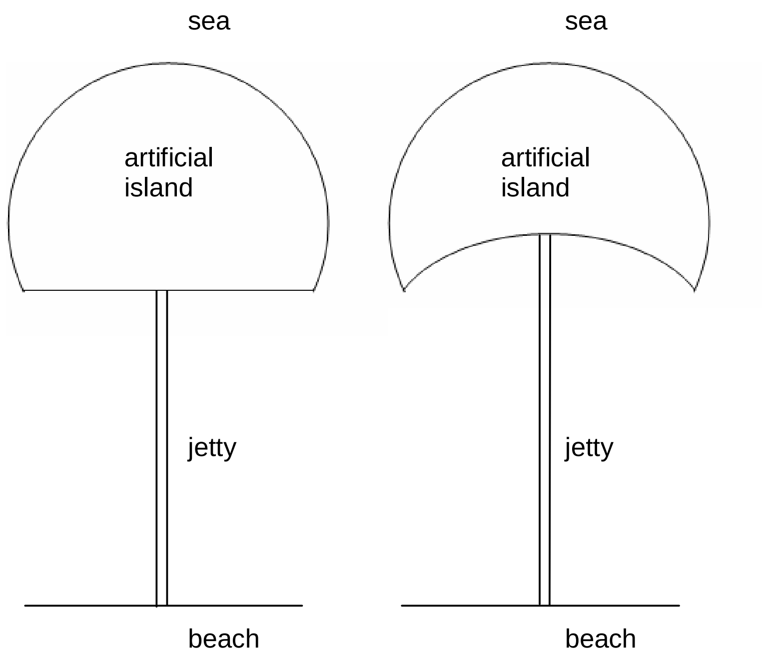


Figure 61 Possible shapes of the island

A round island is most convenient because it has a relatively small perimeter for the required surface, which means that it is less exposed to waves and currents. It is advisable to locate the beaches that are required in the design at the sheltered leeside of the island, so between the island and the coast. The St. Elias marina in the south may provide additional shelter. Unsheltered parts of the perimeter need protection by additional constructions (see Paragraph 5.3.2).

Volume and material

To make an island of the required size, a lot of filling material is required. This can be either sand or rock. The qualities of both are sufficient for use as filling material (see paragraphs 3.1 and 3.2). Sand however is very scarce in the region. It needs to come from very far and is expensive compared to rock. Rock is very easily available due to the many quarries around. Most works that were observed in Bulgaria made use of large quantities of stone. The scarcity of sand and the abundant availability of rock determine a choice for the latter. If rock is used, top-layers of smaller and more solid material has to be applied to make sure that the surface of the island is regular and suited for building and paving.

The required volume of filling material is determined by the surface of the island, the local depth and the height of the island. Detailed values are not yet determined but an order of magnitude computation looks like this:

Volume: 195.000 m^3, which is about 500.000 tons of rock.

- Volume = Surface x (depth + height)

Surface: 15.000 m^2.

Depth: from 5 to 13 m. with an average of 8 m.

- An estimate from bathymetric analysis in paragraph 4.2.3

Height: 5 m.

- An estimate based on wave height with a return period of 500 years in paragraph 3.5.2

5.3.2 Protection

To prevent the island from deterioration by the elements, surrounding breakwaters protects it. They are required at locations where the wave attack on the island is considerable. The breakwater is built on top of the filling material so that it can be constructed with land based equipment which is cheaper and easier than water borne equipment.

Material

Because rock is available in such large quantities and sizes, rock is used for the armour layer of the breakwaters. Observation in the region proved that concrete elements in the area were of poor quality too (paragraph 2.3). Calculate with winter wave height the D_{n50}, the nominal diameter, according to the formula presented in the Rock Manual, which holds for dynamically stable structures, is:

$$D_{n50} = \frac{H_s}{\Delta N_s} \tag{5.1}$$

In which:

- $H_s =$ Significant wave height (m) = 3,00m.
- $\Delta =$ Relative buoyant density (-) = 1,34
- $N_s =$ Stability number (-) = 1,5 for little movement

This means that $D_{n50} = 1{,}49m$ and if rock density is assumed at 2600 kg/m^3 then stones of class 5 to 10 tons are needed.

Fail chance

It is possible to reduce the chance of damage to any construction in sea almost to zero. This can be done with a very high breakwater, but that obviously does not provide a nice panoramic view. It is a very cost inefficient way as well. To determine a reasonable height of the breakwater a probabilistic approach can be used. The basis of the analysis is to find a balance between the efforts that have to be made to reduce the chance of failure and the damage that will occur if a structure fails.

The expected maximum significant wave height during the lifespan is determined with a SWAN calculation, by using the deep water wave climate provided by Argoss. A typical lifespan of a hotel is 50 years. During this period a certain chance should be taken into account of the hotel suffering damage due to wave attack. To give an indication about heights a value for this chance is chosen at 10%, though this is dependant of the amount of damage caused by the wave attack. In case these values are chosen, it will lead to a return period for a once in a 500 year significant wave height, which is 4,8 m. according to the data provided by SWAN.

Height

In the design of many hydraulic structures the crest level is determined by the wave overtopping discharge. To calculate the time-averaged overtopping discharge for smooth slopes, the dimensionless freeboard, $R^*(-)$, and the dimensionless specific discharge, $Q^*(-)$, where defined by Owen (1980), using the mean wave period, $T_m(s)$, and the significant wave height, $H_s(m)$.

$$R^* = \frac{R_c}{T_m\sqrt{gH_s}} = \frac{R_c}{H_s\sqrt{s_{om}/2\pi}} \tag{5.2}$$

$$Q^* = \frac{q}{T_m g H_s} \tag{5.3}$$

In which:

- R_c is the elevation of the crest above SWL (m)
- s_{om} is the fictitious wave steepness based on T_m.
- q is the average specific overtopping discharge (0,05 m^3/s per m)

The relationship between the dimensionless parameters is defined by:

$$Q^* = a\exp\left(-bR^*/\gamma_f\right) \tag{5.4}$$

in which:

- a and b are empirically derived coefficients that depend on the profile (in case slope = 1:2 then $a = 9,39*10^3\left(-\right)$ and $b = 21,6\left(-\right)$)
- γ_f is the correction factor for the influence of the slope roughness. $\gamma_f = 0,55$ for armour stone (two layers on impermeable base)

Filling out the numbers gives for this example a crest height above SWL $R_c = 4,2m$.

There are ways to further reduce the height of the breakwater. It is possible to provide the breakwater with a berm under the mean water level. The advantage is that the height can be reduced significantly, but at a high price. Another way is to create a barrier zone on the island (for instance a swimming pool) where more damage is allowed. The advantage of this solution is that the strong wave attack usually occurs in winter time when fewer guests are in the hotel. The disadvantage is the high maintenance works required.

5.3.3 Island access

For logistic reason it is advisable to pay attention to the connection of the island to the coast. Since the most important purpose of the artificial island will be accommodating a hotel, it is desirable to (re)construct the jetty. The connection must be designed to the load of a truck, since the hotel has to be supplied.

This connection can be a bridge, a tunnel, a jetty or the existing groyne. The current quality of this groyne is such that cars can not drive over it. A tunnel or a bridge does not seem feasible for such a short distance. It is advised to construct an open jetty, which allows water to stream under the structure. The benefits of an open structure are that the water quality will not diminish because water can freely stream around the island. Moreover longshore sediment transport is disrupted at a minimum with an open jetty, although it will always be disturbed by the island.

6 Conclusions and recommendations

6.1 Fieldwork Conclusions

Didactical purposes

The fieldwork aimed at giving students an opportunity to get experience with the practical side of hydraulic engineering. This has been achieved splendidly. Most of the students gained feeling for estimates of materials and processes involved. They can imagine more easily what the actual size of a rock class looks like, how accurate wave parameters are and the effort that is involved in operation in this kind of big projects, for instance. This will help a great deal when they are involved in designing other hydraulic constructions and gave them a renewed enthusiasm for their future profession. Everyone participated enthusiastically and enjoyed working on the project. The beautiful weather helped a great deal in the excitement of course.

Assignment

It was incredibly difficult to just start on an assignment when one lacks experience. Most of the things that are assumed as known, during the education, proved to be less certain in practice. It made the students hesitate a little in the beginning of the analysis. "*Can you assume something like that?*", "*How can we be sure of this*?" were frequently asked questions. After the initial reluctance they got on with the job and got more and more certain of their abilities to give a reliable opinion about the feasibility to build the artificial island. Their education proved to be handy and applicable in practical situations.

6.2 Assignment conclusions

The construction of an island to build a new hotel might very well be feasible from a hydraulic engineering point of view. During the investigation no insolvable problems were discovered. The orders of magnitude of the boundary conditions were of an order of magnitude that is very well feasible and not too extreme to build the island. The calculated dimensions of the different components of the island also were of the right order. The building environment can in short be characterised as rather calm, the building site is a good location and the idea of an island in sea is not impossible.

The detail and accuracy of the investigation was rather low and basic. Few means were at the disposal of the designers and a lot of assumptions had to be drawn. Moreover, the team is not very experienced and not fully educated for these types of assignments. This also led to the neglect of some of the demands of the design. Especially the influence of the island on the surroundings was only determined marginally. Much information that is required for a thorough analysis simply lacked. Also the probabilistic analysis of the failure modes of the construction in total (island, hotel, etc.) is not clear. A lot of aspects of the design remain uncertain.

6.3 Recommendations

During the Fieldwork there were some subjects that drew attention.

- All the measurements presented in this report are preliminary results. It is advisable to do more measurements before starting with the calculation and construction of the island.
- For the final design of the island and the jetty a hydraulic engineer has to be consulted, who can calculate the dimensions of the island. This hydraulic engineer can combine the demand of the future owner and the data to the design criteria.
- An architect must be consulted for the design of the hotel and the swimming pool. This architect can also pay attention to the sun conditions.
- Many boundary conditions depend on the chosen safety value; therefore it is important to choose a safety value. The accompanying design conditions can be determined with a probabilistic analysis.
- It is important to do measurements during the winter season, since those are needed to make a reliable analysis of the variations in wave characteristics throughout the year. The winter conditions differ pretty from the conditions in summer. Most of the calculations in this report are based on the measurement done during fieldworks in October; those conditions can be characterized as end of the summer measurements.
- It is advisable to continually (few time a year) measure the beach profiles. This will give insight in the changes of the beach.
- It is important to take notice of possible effects on nature, and to mitigate them.
- Special attention needs to be given to the water quality behind the island. It must be guaranteed that it is not polluted.
- The morphological effects of the island on the current beach are not yet investigated. Before the island is constructed it has to be calculated whether lee-side erosion will occur due to the island.
- Near the current jetty a small river flows into the sea, this river and the fresh water out flow of the river has to be taken into account during the design of the island. The outflow of fresh water might increase water quality problems.
- It is advisable to check the economic feasibility of the construction of the island.

Appendices

APPENDIX I SIEVE ANALYSIS

ON BEACH 1

Mesh size (mm)	Mass (g)	Cummulative mass (g)	Cummaltive (p-value)	Passing (p-value)	Gauss value
0,850	4,590	4,590	0,149	0,851	1,042
0,600	7,960	12,550	0,407	0,593	0,236
0,425	10,200	22,750	0,737	0,263	-0,635
0,300	5,890	28,640	0,928	0,072	-1,464
0,212	1,640	30,280	0,982	0,018	-2,086
0,150	0,290	30,570	0,991	0,009	-2,362
rest	0,280	30,850	1,000	0,000	

SURFZONE BEACH 1

Mesh size (mm)	Mass (g)	Cummulative mass (g)	Cummaltive (p-value)	Passing (p-value)	Gauss value
0,850	7,276	7,276	0,196	0,804	0,857
0,600	12,24	19,516	0,525	0,475	-0,062
0,425	11,25	30,766	0,827	0,173	-0,943
0,300	5,22	35,986	0,967	0,033	-1,845
0,212	1,11	37,096	0,997	0,003	-2,784
0,150	0,07	37,166	0,999	0,001	-3,154
rest	0,03	37,196	1,000	0,000	

OFFSHORE BEACH 1

Mesh size (mm)	Mass (g)	Cummulative mass (g)	Cummaltive (p-value)	Passing (p-value)	Gauss value
0,850	3,01	3,010	0,080	0,920	1,403
0,600	11,18	14,190	0,379	0,621	0,309
0,425	18,33	32,520	0,868	0,132	-1,118
0,300	4,23	36,750	0,981	0,019	-2,076
0,212	0,48	37,230	0,994	0,006	-2,504
0,150	0,16	37,390	0,998	0,002	-2,900
rest	0,07	37,460	1,000	0,000	

ON BEACH 2

Mesh size (mm)	Mass (g)	Cummulative mass (g)	Cummaltive (p-value)	Passing (p-value)	Gauss value
0,850	3,274	3,274	0,109	0,891	1,232
0,600	7,130	10,404	0,347	0,653	0,394
0,425	7,700	18,104	0,603	0,397	-0,262
0,300	7,430	25,534	0,851	0,149	-1,040
0,212	3,820	29,354	0,978	0,022	-2,014
0,150	0,520	29,874	0,995	0,005	-2,600
rest	0,140	30,014	1,000	0,000	

SURFZONE BEACH 2

Mesh size (mm)	Mass (g)	Cummulative mass (g)	Cummaltive (p-value)	Passing (p-value)	Gauss value
0,850	0,300	0,300	0,007	0,993	2,468
0,600	0,790	1,090	0,025	0,975	1,965
0,425	5,450	6,540	0,148	0,852	1,044
0,300	18,540	25,080	0,568	0,432	-0,172
0,212	16,050	41,130	0,932	0,068	-1,493
0,150	2,780	43,910	0,995	0,005	-2,593
rest	0,210	44,120	1,000	0,000	

OFFSHORE BEACH 2

Mesh size (mm)	Mass (g)	Cummulative mass (g)	Cummaltive (p-value)	Passing (p-value)	Gauss value
0,850	0,77	0,770	0,014	0,986	2,184
0,600	0,86	1,630	0,031	0,969	1,871
0,425	2,73	4,360	0,082	0,918	1,392
0,300	10,38	14,740	0,277	0,723	0,591
0,212	24,69	39,430	0,742	0,258	-0,648
0,150	11,73	51,160	0,962	0,038	-1,777
rest	2,01	53,170	1,000	0,000	

Appendix II

Fieldwork hotel in sea

Студентска практика хотел в морето

Sv. Konstantin I Elena

CT5318 Fieldwork

October 6th 2007

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Contents

- Problem description
- *Описание на проблема*
- Present situation
- *Настояща ситуация*
- Consequences
- *Последствия*
- Design
- *Проект*
- Conclusion
- *Заключения*
- Fieldwork
- *Учебна практика*

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Problem description
Описание на проблема

- Artificial island in sea
- *Изкуствен остров в морето*

- Preliminary investigation for feasibility
- *Предварителни проучвания за ефективност*

- Rough estimates
- *Приблизителна оценка*

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Present situation
Настояща ситуация

- Map area
- *Карта на района*
- Low maintenance
- *Ниски разходи за поддръжка*
- Erosion/accretion
- *Брегова ерозия/акумулация*
- Structures influence
- *Влияние на конструкцията*

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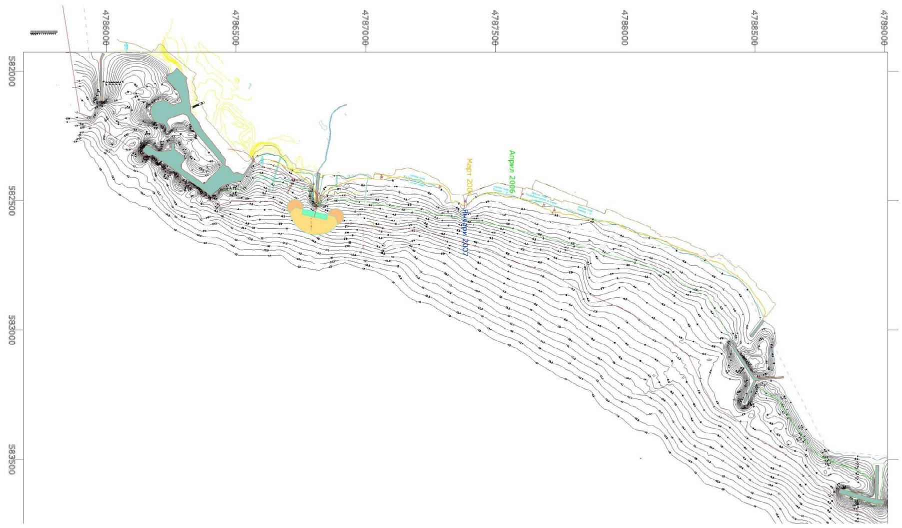

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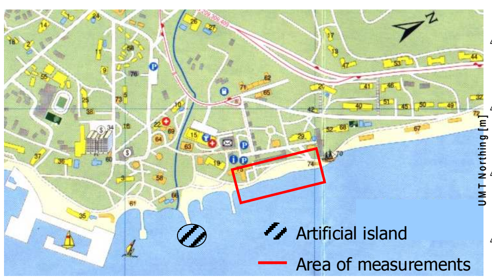

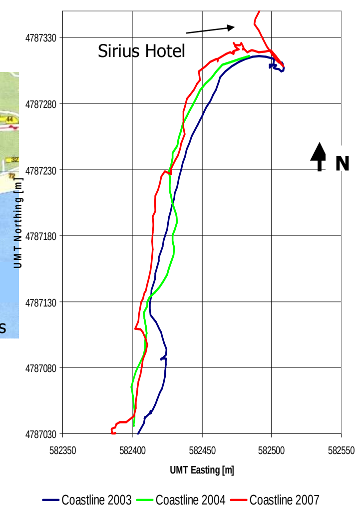

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Consequences
Последствия

- Morphology
- *Морфология (конфигурация на брега и плажа)*

- Less erosion → repetitive nourishment
- *По-малко брегова ерозия → подхранване с пясък*

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Consequences
Последствия

- Water quality → Adjustment river
- *качество на водата → заустване на дерето*
- Connective groyne → Pier/jetty
- *Свързваща буна → естакада (пирс)*

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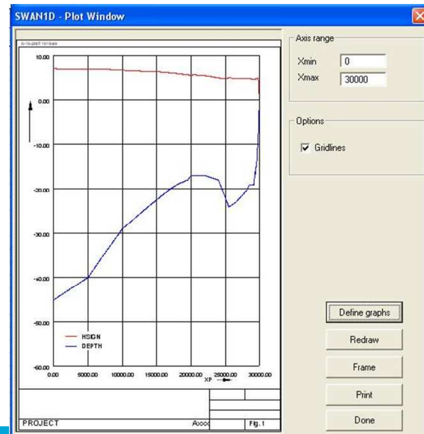
Wave impact
Вълново въздействие

- Allowable damage
- *Допустимо ниво на разрушение*
- Height island
- *Височина на острова*
- Costs versus risk
- *Стойност отнесена към риска*



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Designs
Проектни решения

- 4.75 meter significant wave height (SWAN)
- *Височина на проектната вълна 4.75 метра (анализ, извършен със СУОН)*
- Surface island 15000 m^2
- *Площ на острова 15 000 м2*

• No damage		
height 7.5 m	volume 230,000 m^3	price 5.8 mln Leva
• Damage		
height 3 m	volume 165,000 m^3	price 4.1 mln Leva
• multilevel		
height 7.5 & 3 m	volume 200,000 m^3	price 5.0 mln Leva
		(prices only rock material)

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Designs
Проектни решения

Height reduction

Намаляване на височината

- Berm and (submerged) breakwaters
- *Берма и (потопен) вълнолом*

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Conclusion
Заключение

- Enough information of hydraulics
- *Достатъчна информация за хидродинамиката*
- More data processing needed
- *Необходимо е да се извърши допълнителна обработка на данни*
- Allowable risks determine the price
- *Допустимото ниво на риска определя цената*

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Recommendations
Препоръки

- Geotechnical and environmental data should be acquired
- *Геотехнически данни и данни за околната среда са необходими*
- Design life hotel and failure probability should be determined
- *Експлоатационен период за хотела и вероятността от разрушения следва да бъдат определени*
- Permanent monitoring between Sunny Day Marina and Cape St. George
- *Необходим е непрекъснат мониторинг между нос Кавакар и нос Св. Георги*

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Fieldwork
Учебна практика

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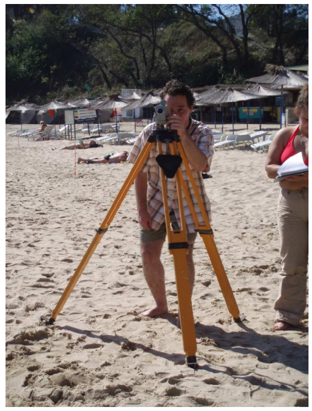

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