FIELDWORK COASTAL ENGINEERING

Varna, Bulgaria

LIST OF PARTICIPANTS

Gijs Bosman
Oscar Dijkstra
Carl Gilding
Ties van der Hoeven
Jeroen Langedijk
Hai Trung Le
Willen-Frederik Louwersheimer
Bob Maaskant
Maartje van der Sande
Robert-Jan van de Waal
Arnoud de Wit
Sander Zweers

PREFACE

Studying Civil Engineering at Delft University of Technology (DUT) students mainly learn theoretical courses. There are only a few opportunities to explore the practical side as well. One of those is the fifth year course "fieldwork coastal engineering (ct 5318)" which focuses on analyzing coastal structures and processes. For this course a trip is made to Varna, Bulgaria, where hydraulic measurements on the beach and the coastal structures are executed by the students.
This report describes the measured data, the used methods and the technical interpretation of the results. All the data was processed in Varna and analysed once returned in the Netherlands.
Every year this fieldtrip is organised with great enthusiasm by Ir. Henk Jan Verhagen. In Varna he is assisted by ir. Boyan Savov and prof. Kristjo Daskalov. Thanks to them it was once again an unforgettable experience for all of us. We would also like to thank the 'Van Oord' company for their financial support.

This coastal engineering fieldwork is organised every year with a main goal to expose student to the problems, which concern all the aspects of a field survey. The group stayed the whole week in St. Constantine, where is a village situated at the Black Sea coast just north of Varna in Bulgaria. St. Constantine is a booming tourist place and a lot of luxurious hotels were recently built in the surrounding of the beach. Some of them are actually build on the beach. To protect the beautiful beaches and keep them as wide as possible for the tourists some hydraulic structures are built.

There were beach measurements executed on the beach of St. Constantine and on a beach just North of Varna. The beach of St. Constantine was also investigated last year but the beach just North of Varna was investigated for the first time in a fieldwork. This was done because a Dutch contractor is interested in the possibilities for sand nourishment at this beach.

During the week two excursions were made. On one day an oil field in the North of Bulgaria was visited and the plans to construct a marina in an old quarry were explained. The other day, two quarries were visited and some measurements on the quarry stones were done. In the quarry rock samples were taken to investigate at home.

The Bulgarian students will write a report about the measurements and the samples from the quarries and about the possibilities of a marina in the North of Bulgaria.

Delft, December 23rd 2005.

TABLE OF CONTENTS

1) RECOMMENDATIONS TO VAN OORD

1.1) Definition of the problem

The erosion problem of the beach of Varna, already exist for a long time. Along the beach are a couple of bars and restaurants, and during the summer season it's a flourishing tourist boulevard. The last couple of years the erosion problem is getting more and more problematic. Presently during substantial sea conditions the foundations of the bars are already taking direct damage by wave attack.

Fig. 1.1 A bar at the Varna beach, that is taking direct damage by wave attack every day.

The bar owners rent the beach from the local government. The rental contracts already exist for a long time and the price of these contracts is based on the amount of surface area of the beach. The problem is that these prices are still based on the amount of square meters of the beach what it used to be during the formulation of these contracts. This is why the local government is not eager to undertake any action to solve the erosion problem.

1.2) Local solution

The owners of the bars have been desperate now for a couple of years, so they started looking themselves for a solution. A couple of bars are owned by one investment group. This investment group also owns a big stone quarry, 60 km inland of Varna. Five years ago this investment group had the idea of using the leftovers from the stone quarry for an execution of beach nourishment. The leftovers of the stone quarry exist of real fine gravel (all most as fine as sand); this is a by-product when producing stones at the quarry. They had a few million cubic meters stocked up at the quarry. This by-product was pointless and there wasn't a market where they could sell it. So their idea was to use the pointless leftovers to protect other properties of their own investment group.
The execution of this project had some bottlenecks that were difficult to overcome. The biggest problem was the transport the fine gravel to the beach. The only way of transporting it from the stone quarry to the beach was by truck. The amount of truckloads would be tremendous and the only way of reaching the beach by truck, was driving through the city centre of Varna. Another problem was the material it self, because the fine gravel was a by-project of the fabrication of rocks, the gravel had very sharp edges. Therefore it wasn't the most suitable material to use for beach nourishment at a tourist beach. Besides all this a change of situation occurred. In the last years the investments in the tourist sector in Bulgaria explosively increased. At the coast of the Black Sea a lot of new hotels and apartment buildings were being constructed. These investments also had its spin off at the economy of Bulgaria.

The construction sector needed a great amount of concrete to be able to construct al the new projects. This meant that the cement industry needed a lot of sand to satisfy the demand of concrete. A part of the sand needed for the production of concrete is provided by the stone quarry of the investment group and so they finally found a market where they could make a good profit of there leftovers. So after a couple of years of brainstorming for a solution with the sand of the stone quarry, a new solution had to be found for the Varna beach. This is when the option of dredging came into sight again.

1.3) Dredging

The advantage of dredging is that the problem of accessibility of the beach is solved. One of the problems that now occur is the remote location of Varna. If an international operating dredging company would carry out this project, they have to sail a great distance with their dredging vessel to arrive in the Black Sea. The amount of cubic meters of sand necessary to complete the beach nourishment at Varna beach is estimated at 3 million cubic meters. To make this project more feasible, it would be good if there were other projects near Varna. An example of a possible other project is the 'Sirius beach' located 10 km north of Varna. At the edge of the beach a big Hotel named 'Sirius' is been constructed.

Fig. 1.2 The Sirius hotel at the time that the erosion problem wasn't that problematic jet.

A few years after the completion of the hotel the erosion of the beach also occurred here and was becoming a serious problem. They decided to invest in the construction of a groyne to protect the beach in front of the hotel for wave attack. Still that didn't stop the erosion and at this time there are only a couple of meters of beach separating the hotel from the breaking waves. The advantage of this possible project is the magnitude of investments at this beach. The amount of money invested in the Sirius beach is much bigger then all the small investment together of Varna beach.

Another advantage here is that there is only one problem owner this makes the realization of the project much easier. The amount of cubic meters of sand necessary is smaller than the Varna project, but a bit further north of the 'Sirius beach' there is a much bigger beach. Also here the erosion problem occurs. Along this beach five big luxurious hotels are constructed, and the foundations of a couple of hotels are already taking direct damage by wave attack.

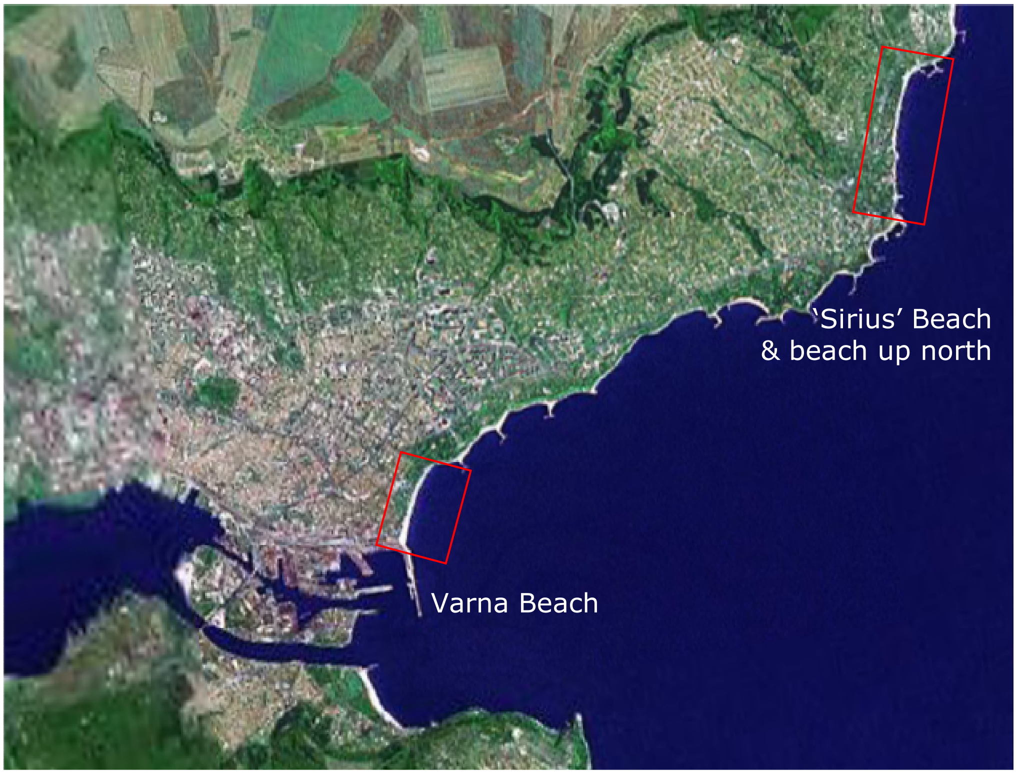


Fig. 1.3 Locations of possible projects near by Varna

1.4) Conclusion

To save the flourishing tourist boulevard of Varna, beach nourishment is necessary to protect the buildings from collapsing due to beach erosion. Local solutions are not available at this moment. One of the problems is that when you want to reach the beach by road you have to go through the city centre. This is why dredging would be a nice solution. The beach is very good accessible by water, because of the shipping lane in front of it. The actual amount of cubic meters of sand necessary to complete the beach nourishment is estimated at 3 million. The start cost of the project will be very high because of the remote location of Varna. So our suggestion is to look for more projects near Varna. For example, the 'Sirius Hotel' beach and the beach a bit further up north. Because of the high density of investments on these beaches, they seem even more interesting for possible projects. When all these projects are joint together, the feasibility will increase a lot.

2) INTRODUCTION

2.1) Bulgaria

Geography
The Republic of Bulgaria is situated in South Eastern Europe and is bordered by Turkey, Greece, the Former Yugoslav Republic of Macedonia, Serbia and Montenegro, Romania and the Black Sea. Sofia is the capital city of Bulgaria. Other important cities are Plovdiv, Varna, Bourgas, Rousse, Stara Zagora, Pleven, Dobrich, Sliven and Shumen.

Environment
Bulgaria is mountainous with over four thousand mapped caves. Thirty-eight percent of Bulgaria consists of forests and woodlands; there are many rivers, waterfalls, lakes and mineral springs. The climate is temperate with cold snowy winters and hot summers.

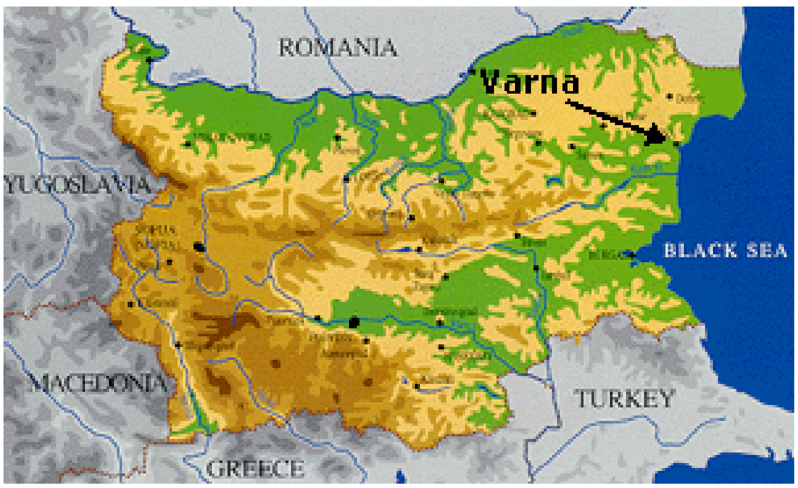


Fig. 2.1 Map of Bulgaria

Population
Bulgaria's population was estimated at 7.450.000 in 2005.

Languages
Bulgarian is the official language.

Religion
The main religion in Bulgaria is Bulgarian Orthodox. Thirteen percent of the population is Muslim. Minority religions include Roman Catholic, Protestant and Jewish.

Economy
Since the political changes at the end of the 1980s and the beginning of the 1990s, Bulgaria has worked towards the privatisation of business. Bulgaria aims to join the EU although it was not ready for the wave of new memberships in 2004.

The agricultural sector accounts for just over a quarter of the labour force. Agricultural products include fruit, vegetables, wheat, barley, sugar beet, sunflowers and roses (attar of roses is used in perfume). Cattle, sheep and pigs are kept. Other primary products are fish and timber.

Just under one third of the labour force works in industry. Main industries are nuclear fuel, electricity, gas, coke, refined petroleum, chemicals, fertilisers, metals, construction, machinery and equipment, food, drinks (including red and white wine) and tobacco.

The service sector accounts for employment of just over forty percent of the labour force. Tourism is a major source of employment with eight million visitors a year. The Black Sea resorts and the mountains are both popular destinations for tourists. Spa tourism is also an important part of Bulgaria's tourist industry.

The purchasing power parity is estimated in 2004 around $7,600.

Holidays
New Year, Christmas and Easter are holidays. Other days celebrated are National Day (3 March), International Labour Day (1 May), Day of the Slavonic Script and Bulgarian Culture (24 May), Unification Day (6 September) and Independence Day (22 September).

Varna
Varna is an administrative, economic and cultural centre, the biggest seaport and a well-known international seaside resort. It is the third largest city in Bulgaria with a population of about 330.000 people. It is widely called the Seaside Capital of Bulgaria as it is for sure the biggest city along the Bulgarian coast, some 470 km away from Sofia eastwards. Varna is nestled in a deep valley between two plateaus and its structure follows the curves of the Bay of Varna. It sprang up in the 6th century BC as a Greek colony called Odessos, meaning “town upon water”. Over the next years Odessos was ruled by the Persians, Thracians, Romans and Slavs. The town was renamed Varna by the latter in the 7th century. At the end of the 8th century the town was a part of the Bulgarian Kingdom and was an important fortress and seaport until 1386 when Varna was conquered by the Ottomans. In 1921 it was proclaimed a resort.

Below is a table of the average weather conditions in Varna;

Month	Average Sunlight (hours)	Temperature Average		Record		Discomfort from heat and humidity	Relative humidity		Average Precipitation (mm)	Wet Days (+0.25 mm)
		Min	Max	Min	Max		am	pm		
Jan	2	-1	6	-16	20	-	89	80	28	8
Feb	3	-1	6	-13	21	-	86	75	30	9
March	4	2	11	-8	24	-	86	70	26	7
April	6	7	16	-2	30	-	83	68	37	8
May	8	12	22	2	34	-	83	69	26	8
June	9	16	26	9	35	Medium	78	67	64	9
July	11	19	30	10	39	High	75	61	45	6
Aug	10	18	29	11	36	Medium	79	60	37	6
Sept	8	14	26	3	34	Medium	83	62	27	5
Oct	6	11	21	1	32	-	88	68	58	8
Nov	3	6	13	-6	24	-	87	72	35	9
Dec	2	1	7	-14	21	-	88	79	63	11

Table 2.1 Average weather conditions, Varna, Bulgaria

2.2) Descriptions of locations

2.2.1) Varna beach

The Varna beach is situated to the west of the city Varna. The beach is well used for recreation threw out of the year. The busied time is during the summer months. When many people come down to spend a day. The road next to the beach is where a lot of bars, restaurants and amusement parks situated. Some of these buildings are also located on the beach. To the north of the beach there is a Y-groyne. Along the beach there are a couple of small jetties for recreational use. To the south of the beach there is a large breakwater that protects the harbour.

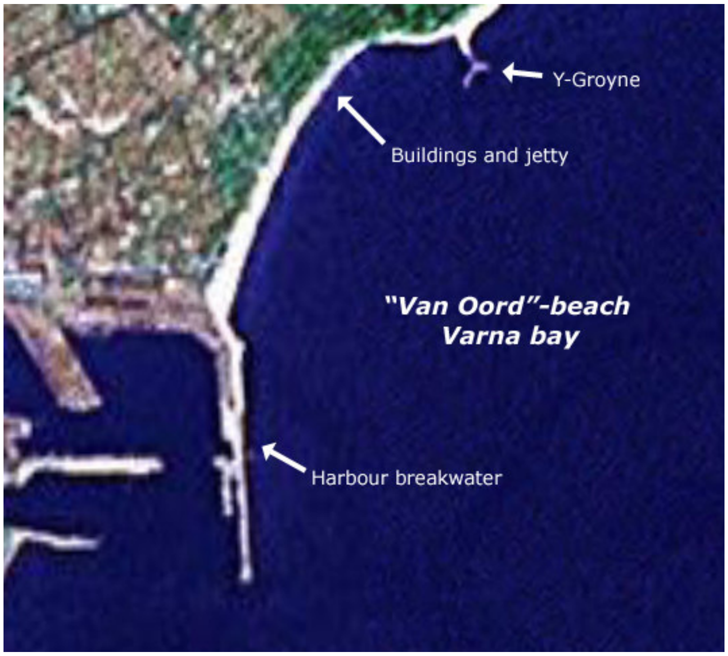


Fig. 2.2 Overview of Varna beach

Because of the erosion of the beach several buildings are being threatened by the sea. The erosion has been taking place the last couple of years. The situation is getting critical. As can be seen in Fig. 2.3

Fig. 2.3 Erosion

The owners of these buildings have complained about the problem. Some owners have already taken the matter in to there own hands by dumping sand in front of there buildings. But this measure is of no influence for the complete problem. Along the beach there is a large erosion problem what has to be solved.

The Y-groyne
The Y-groyne is a groyne in a shape Y what goes out in to the sea for about 500 meters.
The main function of the groyne is retaining the long shore sand transportation. The groyne is open for the public. On the shallow sides of the groyne there is a docking facility for very small boats. The body of the groyne is regularly used by local fishermen.
The Y-groyne is build with large concrete blocks, which show some wear and tear. Damage to the top layer is severe, showing the concrete reinforcement steel. On the sea side of the Y-groyne Tetrapods have been placed for wave energy dissipation. Quite a couple of the tetra-pods have been damaged by the wave climate. These must been replaced.
On the body of the Y- groyne rubble mount as been dumped. See the measurements (chapter 9) for the specification.

Fig. 2.4 Y-groyne

Harbour breakwater
On the south end of the beach there is a big breakwater. This breakwater is to protect the port from the wave climate and to provide a smooth passage. The breakwater is build up with rubble mount which has been dumped. The rubble mound is lime stone, so not the best type of stone for wave protection.

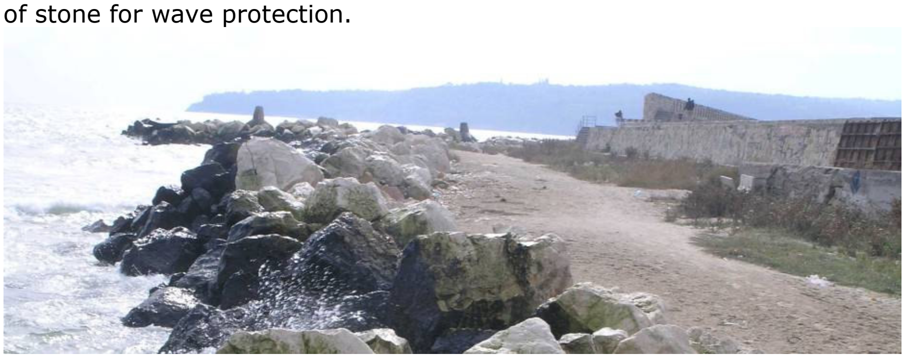


Fig. 2.5 Harbour breakwater

Jetties
A long the beach there a two small jetties for mooring of small recreational boats. The jetties are falling to bits and the only thing standing are the steel structure. The jetties have already been closed for public access.

2.2.2) Sirius beach

The Sirius beach, located to the east of St. Constantine, is a sandy beach with a width of approximately 20 meters. In the recent years lots of hotels are built along the beach for the large amount of recreation which visits St. Constantine during the summer. Most of the hotels and other recreation facilities are built on the beach, very close to the sea; as a consequence erosion has become a problem for some parts of the coast. Some buildings are only a few meters away from the water line.

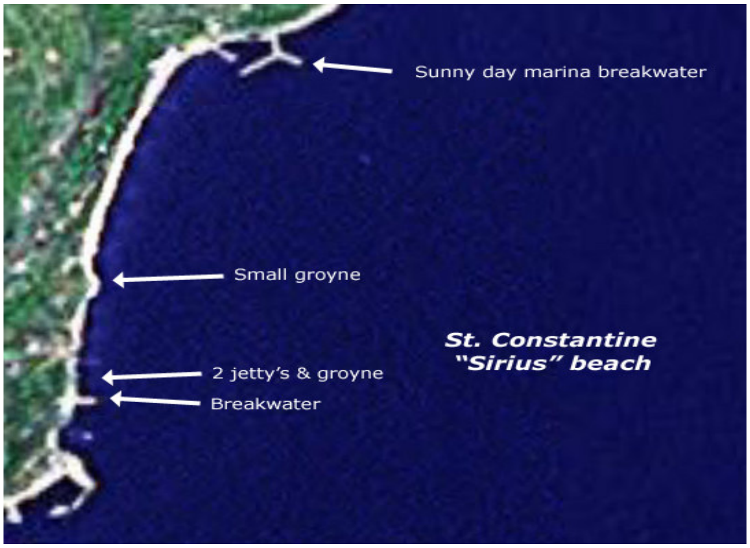


Fig. 2.6 Overview Sirius beach

Remarkable features at the south side are the two jetties which are built in the past for the mooring of small recreation vessels. The quality is in such a bad state that use is impossible, the construction is mostly all corroded and large parts of the concrete have been damaged. In Fig. 2.7 you can see that the steel which must be within the concrete is now fully exposed to the seawater.

Fig. 2.7 Jetty 2, damage of construction.

Between there jetty's a groyne has been build in an effort to activate accretion to the south. At this moment there is no sandy beach for several doznes of meters. If you look closely to jetty 2 (Fig. 2.7) you can see that at the north side only rocks. The quality is good; no severe damage can be seen with the eye.

Fig. 2.8 Overview of jetty's

Also at the south side of the beach there is a rather peculiar breakwater (Fig. 2.9). It isn't a neatly build breakwater, but consists of three different types of material; concrete blocks, natural rocks and Tetrapods. The placement of the different materials looks messy but although there is some displacement of rock, big damage is not present.

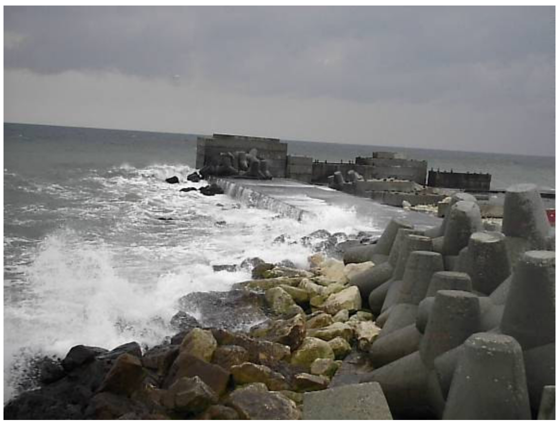


Fig. 2.9 Breakwater made of concrete blocks, natural rocks, and Tetrapods.

More to the north a small groyne has been built in front of the Sirius hotel (Fig. 2.10) which must prevent the beach to erode any further. The smaller rocks applied for the construction can be found spread out over a small area, from this it is possible to conclude that the size of the rocks or the filter construction has not entirely been applied properly, but for the working of the groyne it isn't big problem because the damage stays small.
When comparing the erosion of the beach over the last couple years you can see that there is still erosion taking place.

Fig. 2.10 Groyne in front of Sirius Hotel

At the far most northern point there has a marina been build which is protected by a Y-shaped breakwater (Fig. 2.11). It is made from large concrete caissons with placed Tetrapods to protect it from wave impact. Some damage can be seen on the Tetrapods, these are mostly located at the north-east part of the breakwater, and this is also the side from which the waves come in. Judging on the small amount of broken Tetrapods, the construction date (1984) and the way they are broken, that errors were made during the construction of the Tetrapods. It can be said the construction is built strong enough for the ruling weather conditions.

Fig. 2.11 Y-breakwater

3) WAVE MEASUREMENTS

3.1) Introduction

Wave data is essential for coastal engineering designs and to know what kind of wave climate can be expected, wave data must be analysed. However, there is no wave buoy data available for our location. Two methods are used to determine the local wave height: visual observation and the use of water pressures. In chapters 3.2 and 3.3 these used methods and their results are explained and the obtained data is compared to linear wave theory. A corresponding wave height at deeper water is calculated in chapter 3.4.

It is also possible to determine some extreme wave heights that have occurred by examining the damage to some Tetrapods that are located at a marina in the area. Several theories are available to obtain a wave height that corresponds with this damage. This is done in chapter 3.5.

3.2) Visual measurements

3.2.1) Introduction

To obtain wave heights visually, non-breaking waves are required. Therefore waves outside the surf zone are used. To measure waves outside the surf zone reliably, they are in this case compared to the height of a jetty. At a location parallel to the jetty looking perpendicular to the jetty (Fig. 3.1), the waves are measured. During fixed time intervals the waves are counted and measured in height.

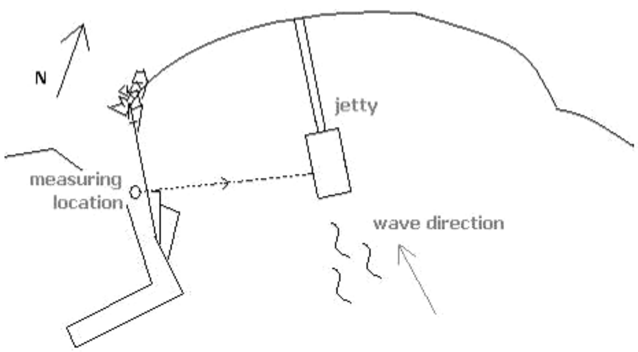


Fig. 3.1 Measuring location looking perpendicular to the jetty

A total of 367 waves were observed and their wave heights were divided into 6 categories to be able to compare different measurements. The measurement was taken at stormy weather and waves were observed up to 3 meters in height. In Fig. 3.2 an example of the occurring waves is shown.

The equipment, the used method and the accuracy of these two is treated in the following chapter. Also the results and a conclusion of the results can be found.

Fig. 3.2 Waves at the day of measurement (10 October 2005)

<u>3.2.2) Equipment</u>

To measure waves a theodolite can be used. This allows you to determine the wave height accurately and at a fixed point. During the measurement, the attempt to use the scale of a theodolite nevertheless failed because the waves were too high. The waves simply didn't fit into the sight of the instrument. The only alternative was to choose one point of the jetty as reference point and to determine the wave heights with the naked eye.

<u>3.2.3) Method</u>

After measuring the waves relative to the jetty (Fig. 3.3), the dimensions of the jetty were determined as a reference for the wave heights. The wave troughs appeared to be at a rather constant level, after which the wave heights where categorised into six categories. These six categories were translated into meters again.

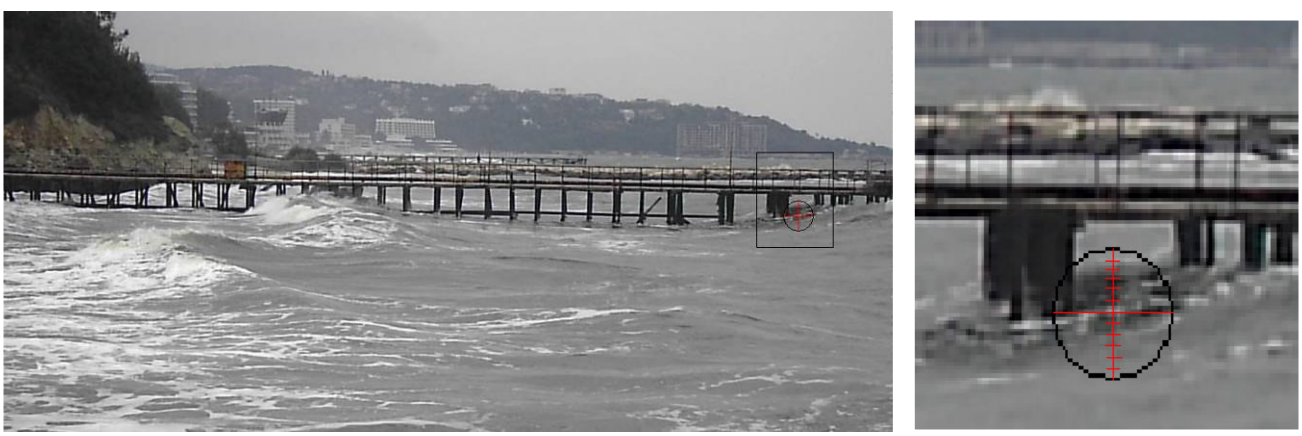


Fig. 3.3 Reference point at the jetty used to visually measure the wave heights with detail

<u>3.2.4) Measurement Accuracy</u>

By determination of the wave heights with the naked eye, the accuracy of the measurement is much less than when the theodolite can be used. It proved rather difficult to accurately measure the wave height relative to the jetty from that distance away and with waves of that magnitude. The error therefore will be in the order of 20-30 cm.

3.2.5) Results

During the measurement we divided the waves into 6 categories, ranging from 0,5 to 3 meters in height. The measured waves are shown in Fig. 3.4.

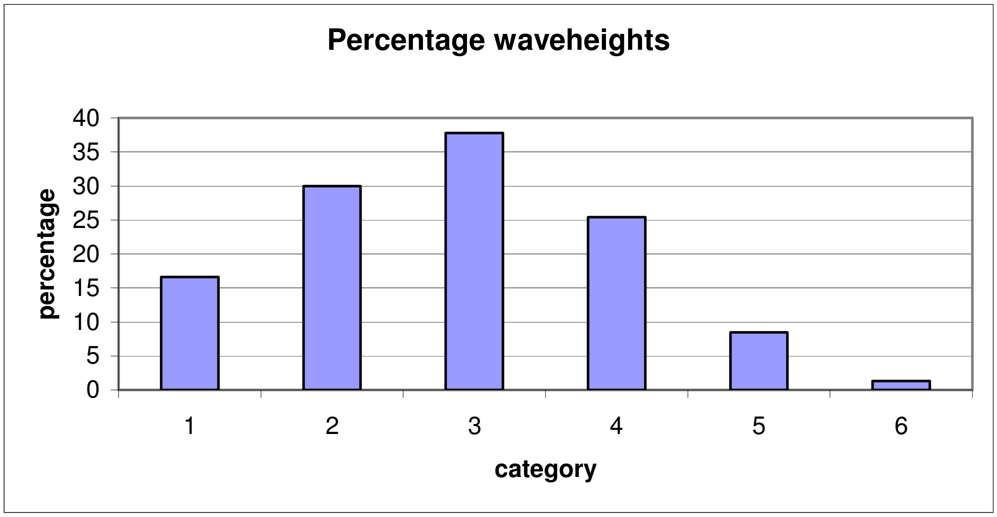


Fig. 3.4 Categories and their percentage of the total number of waves

To correspond with the theoretical wave heights, the waves should have a Rayleigh distribution. A Rayleigh distribution is given by

$$P(H < H) = 1 - e^{-(2H/H_s)^2}$$

with H = wave height

H_s = significant wave height

And the significant wave height of a record with N waves is given by

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

where j is the rank number of the wave based on the wave height.
(i.e. $j = 1$ is the largest wave, $j = 2$ the second-largest wave, etc.)

The significant wave height in the visual observations is equal to the averaged height of (in this case) the 122 highest waves, which is 2,08 meters.

To determine the cumulative probability of an occurring wave height we use

$$P(H < H) = i\left(\frac{1}{N}\right)$$

with i = number of waves with $H < H$

N = total number of waves

Now we can plot the distribution of the observed wave heights against the Rayleigh distribution as is done in Fig 3.5.

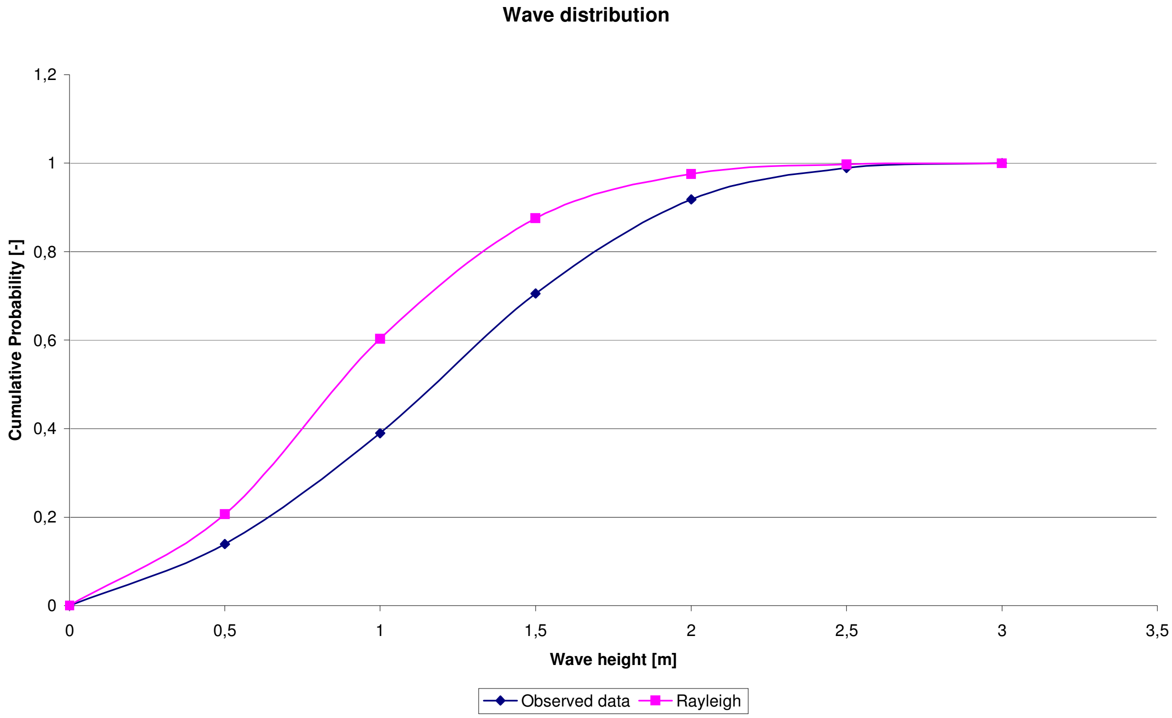


Fig. 3.5 Comparison between the observed and theoretical distribution of wave heights

The wave period is determined by dividing a total record time through the total number of waves in that record, in our case this yields

$$T = \frac{T_{total}}{N} = \frac{26 \text{ min}}{263} \approx 6 \text{ sec}$$

The estimated wave angle (estimated by hand) is 30°.

3.2.6) Conclusion

The observed wave heights show some similarity with the expected Rayleigh distribution but the waves seem to be a little overestimated. This is probably caused by the fact that a visual measurement without measuring instruments is not really accurate, as is stated in the previous chapter about the accuracy.

3.3) Pressure measurements

3.3.1) Introduction

To determine the wave heights at a certain measure point, a pressure sensor can be used. This sensor measures the water pressure and compares this to a reference pressure, mostly the air-pressure. The sensor measures the pressure every 0,2 seconds and with simple computer software like MS Excel this data can be processed to determine the wave properties. Seven measurements were taken, with all comparable results. One measurement is chosen to be the best data to be representative for the pressure measurements and is treated here in this chapter. Again, the equipment, method, and their accuracy, will be dealt with, as well as the results and possible conclusions.

3.3.2) Equipment

A simple sensor called the 'Honeywell 24PCBFA6D pressure sensor' is used to measure the water pressure and compare this to the air pressure. A general laptop computer can be used to store and analyze the obtained data.

3.3.3) Method

If the pressure data is obtained, one can calculate the wave height by using linear wave theory, according to:

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

in which:

$p =$ pressure [kPa]

$\rho =$ Mass density of water [kg/m^3]

$g =$ gravitational acceleration [m/s^2]

$h =$ water depth [m]

$a =$ amplitude [m]

$k =$ wave number [m^{-1}]

$z =$ measuring depth [m]

$\omega =$ wave celerity [s^{-1}]

The average pressure at the measuring point with height z is the undisturbed, hydrostatic pressure. The hydrostatic pressure occurs where the varying part of the equation (dependent of the wave) is 0, so when t=0 (x is assumed equal to 0). From our measurements we can then calculate the exact height z of the instrument. In our case:

$$p_{gem} = -\rho g z$$

$$z = \frac{p_{gem}}{-\rho g} = \frac{13{,}1887 \text{ kPa}}{\left(-1017 \text{ kg/m}^3\right)\left(9{,}81 \text{ m/s}^2\right)} = -1{,}32 \text{ m}$$

So the depth of the pressure sensor is 1,32 m.

Now we know the contribution of the hydrostatic pressure to the pressure data we can determine which part of the pressure is caused by the waves and determine their wave height. This is done for the measurement of 2005, resulting in the graphs in the chapter 'results'.

To be able to convert these elevations to wave heights, we follow the definition of a wave in a time record with upward zero-crossings. The actual wave height of a wave is then the difference between the trough and the 'following' crest and the total number of waves is the total number of zero-crossings.

Out of the pressure data it's now possible to obtain the wave heights, the wave period (determined by the same way as the visual observations, so the total record time divided by the total number of waves) and the distribution of waves.

3.3.4) Measurement accuracy

The inaccuracy of this pressure measurement is minimized because there is no human interference and a reliable pressure sensor and computer software is used. The accuracy of the founded wave heights is a little bit less, because of the assumption that linear wave theory is applicable. These assumptions will nevertheless give reasonable results which do give a realistic view of the wave climate at the time of the measurement.

3.3.5) Results

The pressure measurement in kPa is converted to water elevations using the previous described methods and equations. When we process this data with MS Excel we are able to plot these results, for instance the water elevation at a given time in the time record. The obtained graph of elevations is shown in Fig. 3.6.

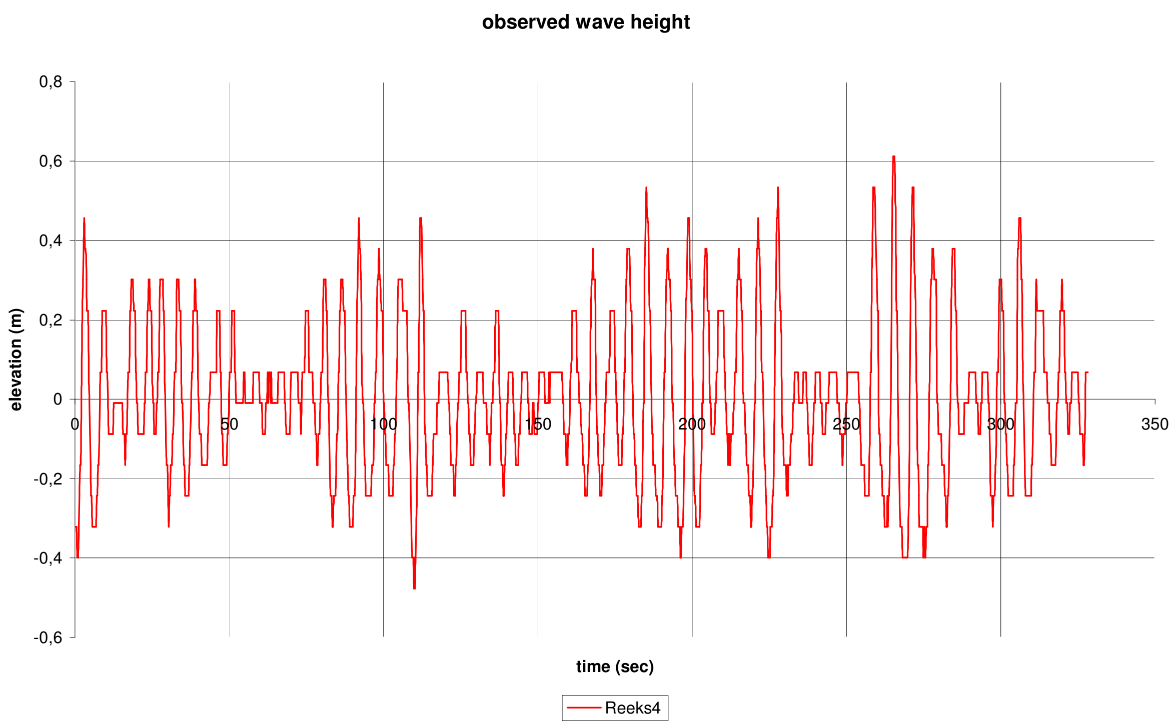


Fig. 3.6 Elevations in a chosen time record

As was stated in the explanation of the method, we can determine the wave heights in this time record with the chosen definition of a wave. For the elevations from Fig. 3.6 this results in the following graph of the number of the wave in the sequence (58 in total) and their corresponding wave heights.

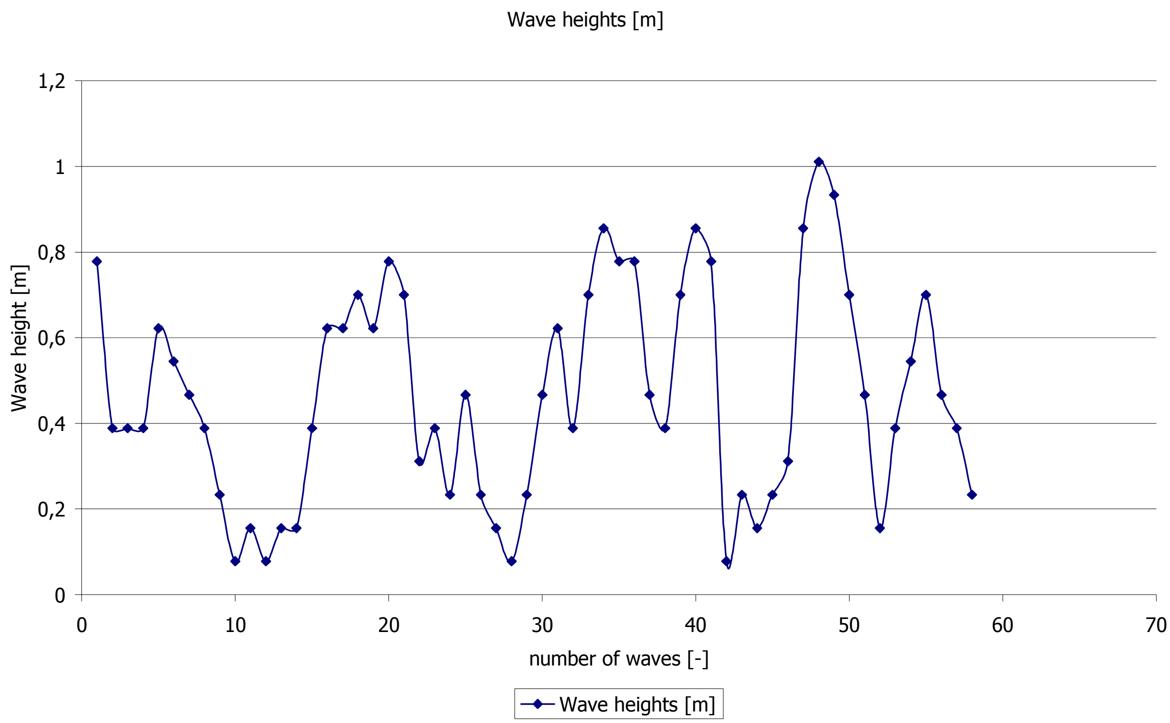


Fig. 3.7 Number of waves and their corresponding wave heights

We can compare this distribution with the theoretical Rayleigh distribution. To do so, we need the significant wave height, which is defined in ´visual observations´ as the mean of the 1/3 highest waves in the wave record of 'N' waves:

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

where j is the rank number of the wave based on the wave height.
(i.e. $j=1$ is the largest wave, $j=2$ the second-largest wave, etc.)

The significant wave height in our time record is $H_s = 0,7736 \text{ m}$.

It's possible to rank the waves and calculate the cumulative probability for a specific wave height in the same way as was done with the visual observations.

$$P(H < H) = i\left(\frac{1}{N}\right)$$

with $i =$ number of waves with $H < H$
$N =$ total number of waves

With these parameters we can plot our cumulative probability against the theoretical distribution as is done in Fig. 3.8.

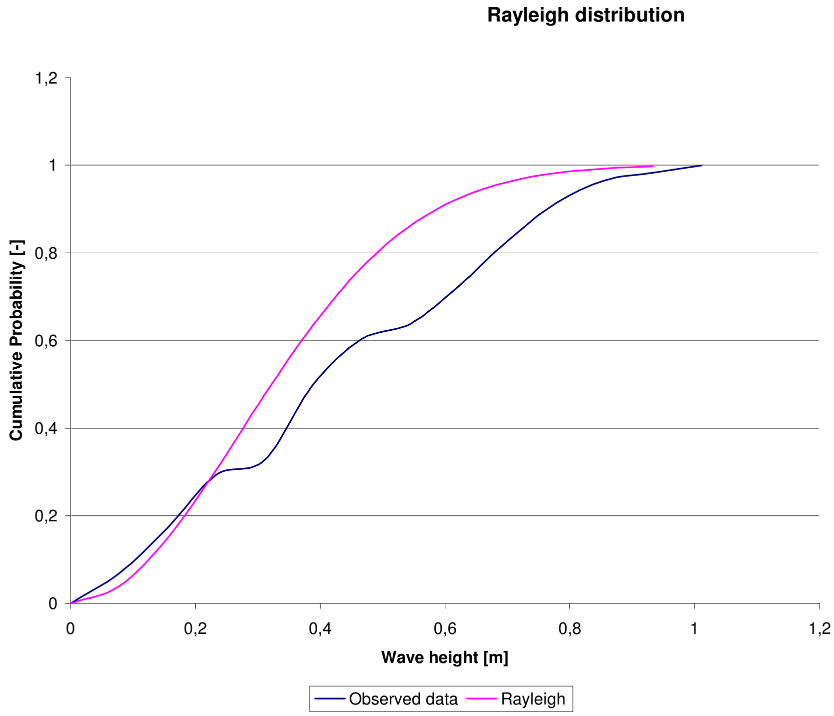


Fig. 3.8 The observed data and a Rayleigh distribution

The observed wave period is given by 328,2 sec divided by 58 waves. This means that the observed wave period is 5,66 seconds.

3.3.6) Conclusion

It can be seen that the observed data somewhat follows the same pattern as the Rayleigh distribution, but there are some differences. There is a higher number of large wave heights measured then the theoretical expected number of large wave heights predicts. An explanation of this can be that the significant wave height is underestimated due to this (relatively) small number of waves.

The theory with the Rayleigh distribution is based on the assumption that the waves come from a random phase/amplitude model which generates a stationary, Gaussian process. A wave record at sea, where the conditions are never really stationary, should be approximately stationary for the duration of that wave record. At the time this measurement was taken, the weather was changing from stormy weather to calm weather. It is therefore also possible that other frequencies still play a role and influence the distribution of the wave heights.

3.4) Deep water wave height

For the parameters of the visual observations we will determine the wave height at deep water. This wave height can at a later stage be compared to the wave height at deep water that is needed to guarantee a stability conditions for the beach slopes. The deep water wave height can be determined by the following equation:

$$H_0 = \frac{H_1}{K_s K_r}$$

$H_x =$ wave height at location x

$K_s =$ shoaling factor

$K_r =$ refraction coefficient

The wave height at point 1 is the significant wave height of the visual observations. This significant wave height is calculated as 2,08 meters. The shoaling factor is given by

$$K_s = \frac{1}{\frac{1+2kh}{\sinh(2kh)}\tanh kh}$$

$k = \frac{2\pi}{L} =$ the wave number [m^{-1}]

$h =$ water depth [m]

This factor can be found by using a table in which K_s is given when h/L_0 is known.

$$L_0 = \frac{gT_p^{\,2}}{2\pi}\text{, with } L_0 = \frac{gT_p^{\,2}}{2\pi}$$

With a depth of 3,55 meters at the point where the waves were observed h/L_0 becomes 0,040. The table gives us then an K_s of 1,064.

For the refraction coefficient K_r the following equation is used

$K_r = \sqrt{\frac{\cos\theta_0}{\cos\theta_1}}$, with an estimated angle of 30° at deep water and an angle of 0° at the measuring point this becomes 0,931.

$$H_0 = \frac{H_1}{K_s K_r} = \frac{2{,}08\text{ m}}{(1{,}064)(0{,}931)} = 2{,}1\text{ m}$$

4) TETRAPODS

4.1) Introduction

At the 'Sunny Day' marina complex in St. Constantine, a breakwater has been constructed. This breakwater is constructed out of a solid body, protected by 2 different sizes of Tetrapods. Two maps with the location of this breakwater are shown in Fig. 4.1.

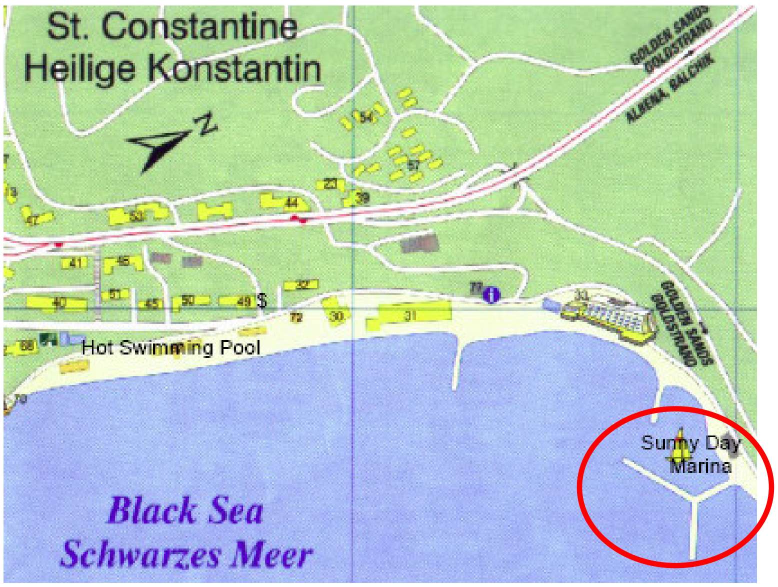


Fig. 4.1 Local maps of situation at the 'Sunny Day' marina complex

4.2) Measurements

When measuring of the Tetrapods started, several different sizes of blocks were measured.

The reason for these different sizes of blocks is probably caused by the way construction of these blocks is executed. This can be caused by the way the moulds are constructed. The exact sizes of the moulds might not be the same. Another important factor is the quality of the concrete. The concrete itself has to contain the right mixture of water, cement and aggregates. Pouring of the blocks is the last factor in the fabricating process, after pouring the concrete into the mould, the packing of the concrete has to be tightened. This is needed to make sure that the whole mould is filled with concrete (so no air is entrapped). After pouring the concrete, the blocks have to harden, during hardening quite some heat develops. Since fabricating moulds for these blocks is costly, these moulds should be removed from the blocks as soon as possible. So after some time after pouring (often 24 hours), the mould is taken from the block and the developing heat (concentrated in the middle of the block) can not easily be cooled. This temperature gradient will cause some internal fractures in the fresh concrete. These fractures will decrease the tensile strength of the block. A dry and temperature varying area will increase the number of fractures.

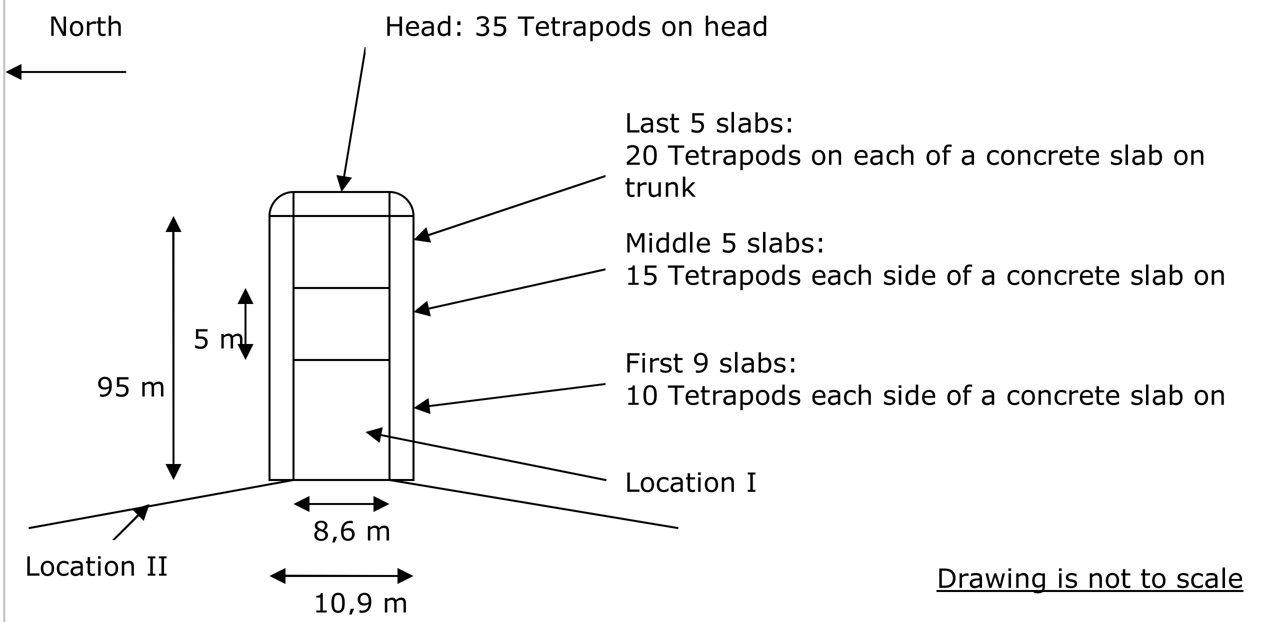


Fig. 4.2 Situation description of breakwater St. Constantine

Dimensions of breakwater

Length of crest:	95 m
Width of crest:	8,60 m
Length of concrete slab:	5 m
Height of crest above still water line:	1,70 m
Slope of Tetrapods above still water line:	1.5:1

In Fig. 4.3 the seaward direction of the breakwater is shown. On the other picture (Fig. 4.4), the top structure of the side legs of the breakwater is shown. This structure is an in-situ constructed concrete top-structure on top of the parapet structure. The reason it is constructed is probably for aesthetic reasons, however this structure is not connected to the breakwater very well. A consequence of this is that there is some space in the joint between these structures. Due to the splashing water (from the Tetrapods) water can get into this gap. The splashing water will build up a very big pressure between these parts and finally (in this case after 2005 – 1984 = 20 years) broke the ‘connection’. This concrete failure is shown in Fig. 4.4.
Another remarkable thing of this breakwater is the use of reinforcement steel. On several places (Fig. 4.3; floor, Fig. 4.4; vertical wall) reinforcement steel can be seen. The most probable explanation is that the required concrete coverage (in The Netherlands about 5 cm) is not used constructing this breakwater.

Fig. 4.3 Seaward direction breakwater St. Constantine, with Tetrapods on the right side of the breakwater

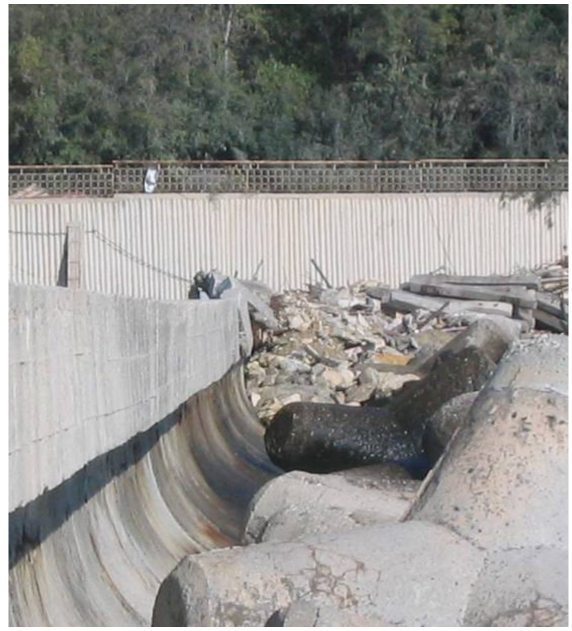
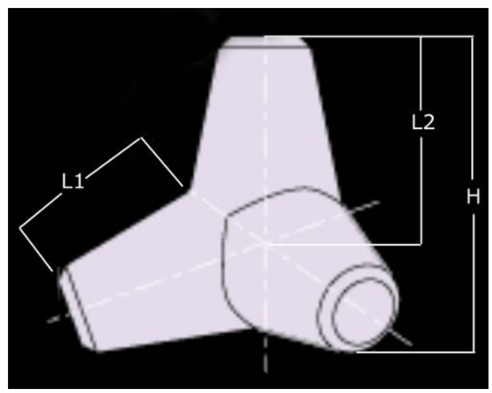


Fig. 4.4 Broken cap on top of breakwater

4.3) Characteristics

Several different sizes of blocks were measured; the blocks are divided in two distinctive groups, the blocks at the head and at the trunk of the breakwater.
The measuring results are given in two tables. At every location five Tetrapods were measured. It proved not to be possible to measure every leg of the blocks with all blocks. Measurements were done with an accuracy of five centimetres, since measuring was not easy at all locations. The computation (Table 4.1 and Table 4.2) is done with an accuracy of centimetres, so is the final calculated height of the two Tetrapod sizes.



Tetrapod n	$C_{n,1}$ [cm]	$C_{n,2}$ [cm]	$C_{n,3}$ [cm]	$C_{n,4}$ [cm]	no C_n	C_n averaged [cm]
A	130	125	125	110	4	123
B	135	135	125	-	3	132
C	135	130	120	-	3	128
D	140	120	120	-	3	127
E	135	125	-	-	2	130
Average leg length, C_{head}:						128
Average height of Tetrapod at head of breakwater [m]:						2,68

Table 4.1 Calculated average height of Tetrapods at head of breakwater

Tetrapod n	$C_{n,1}$ [cm]	$C_{n,2}$ [cm]	$C_{n,3}$ [cm]	$C_{n,4}$ [cm]	no. C_n	C_n averaged [cm]
A	125	115	110	110	4	115
B	125	120	115	115	4	119
C	110	110	105	-	3	108
D	120	120	115	-	3	118
E	120	105	110	-	3	112
Average leg length, C_{trunk}:						114
Average height of Tetrapod at head of breakwater [m]:						2,40

Table 4.2 Calculated average height of Tetrapods at trunk of breakwater

This results in the following general data about the Tetrapods:

Characteristic \ Location of Tetrapods	Tetrapods at head	Tetrapods at trunk
Total number of units	35	45
More or less undamaged units	9	30
Minor cracks units	4	11
Major cracks units	7	5
Broken units	3, and 1 split	-
Height – using H = 2,096 * $C_{Tetrapod}$ [m]	2,68	2,40
D_n – using D_n = 0,65 * H [m]	1,74	1,56
Volume of unit – using 0,280 * H^3 [m^3]	5,39	3,87
Mass of unit – using 2,4 * Volume [tons]	12,9	9,29

Table 4.3 Characteristics of Tetrapods used in breakwater

An order of magnitude of the wave regime in the last years can be determined from the fact that the breakwater, with its measured characteristics, is still standing at this location more or less in one whole.

From visual observation, not all Tetrapods can be included. Therefore, the still water level until the crest of the breakwater will be used in the formulas.

One other thing needed mentioning is, the slope of the Tetrapods is 1.5 vertical to 1 horizontal. The tangent of the angle (alfa) is then 1,5 / 1. So alfa is equal to cotangent 1,5. This is an extremely steep slope. All empirical data found on Tetrapod stability is based on a slope of 1:1.5. This empirical data (1:1.5) is used to determine the height of the waves; since no other data was available. Therefore the wave height that is going to be calculated is probably higher than the wave height in reality, since the stability of the real breakwater is lower than the used characteristics in the calculations.

The local wave climate will be calculated with the formulas of Hudson, Van der Meer and Hanzawa.

The relative density is used in all the formulas:

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w} = \frac{2400 - 1030}{1030} = 1,33\ [-]$$

4.4) Calculation of local wave climate

4.4.1) Hudson

The Hudson approach is based on curve fitting of data acquired with experiments. This results in the following formula:

$$\frac{H_{10\%}}{\Delta D} = \sqrt[3]{K_D \cot \alpha}$$

For the K_D values, 6 and 8 are chosen, since these are the constants for non breaking waves, as should be used in these circumstances.

This leads to the following wave heights for Tetrapods at the head of the breakwater:

$$H_{10\%} = 1,33 \bullet 1,74 \bullet \sqrt[3]{6 \bullet \cot\left(\cot\left(1,5/1\right)\right)} = 3,87m$$

And for Tetrapods at the trunk: $H_{10\%}$ = 3,47m.

The given wave height, $H_{10\%}$, stands for the wave height that is the average of the highest 10% of al waves. This value is used in the Shore Protection Manual of 1984.

The generally used (therefore in this report as well) indication for wave heights is H_s, the significant wave height. The calculated wave heights can be transformed to H_s by using: $H_s = H_{10\%} / 1,27$. This leads to H_s = 3,04 at the head and H_s = 2,73 m at the trunk of the breakwater.

However, the Hudson formula is known (according to CEM, 2004) for not being able to give a reliable result for steep slopes, therefore these calculated values will not be used from now on.

4.4.2) Van der Meer

The Hudson approach is based on regular waves. These are waves that have the same characteristics during a certain period. This can be during a storm, during a week, or for years on end. In reality, waves are not regular. They can (and will) vary along a year, a week and even during one single storm. This results in a different approach of the stability of the breakwater.
The approach on stability for irregular waves is given by Van der Meer. This formula uses a number of waves (N_z), since a more damaging wave is more likely to occur in a storm with a longer duration. An often, in this calculation as well, used value of N_z is 3.000.

The general Van der Meer formula, to be used for non-depth-limited waves is:

$$\frac{H_s}{\Delta D_n} = \left(3.75 \frac{N_{od}^{0.5}}{N^{0.25}} + 0.85\right) s_{om}^{-0.2}$$

However, a formula for depth-limited waves (by d'Angremond, Van der Meer and Nes, 1994) has to be used; therefore the following formula is to be found in the CEM, 2004:

$$N_s = \frac{H_{2\%}}{\Delta D_n} = 1.4\left(3.75 \frac{N_{od}^{0.5}}{N_z^{0.25}} + 0.85\right) s_{om}^{-0.2}$$

This formula is valid for two-layer armed, non-overtopping, slopes with Tetrapods on 1:1.5 slopes.

For Tetrapods the mechanical strength of the blocks plays a role. Therefore two factors are being introduced here, Nod and Nor. These numbers stand for: damage due to actually displaced units and damage due to blocks that might break because they are rocking against each other. The total number of moving units is equal to the sum of them, expressed in N_{omov}.
A value for Nod needs to be determined; this value needs to be determined by the allowable damage. It is safe to chose a value of 0,5. For damage in this category no repair is needed. The Tetrapods at the actual breakwater are damaged a bit, but there is no (urgent) need for repairs.

The wave steepness is used in the surf similarity parameter (or Iribarren parameter). The most severe attack on the slope occurs with a Iribarren parameter of 3.

Wave steepness: $$s_{om} = \frac{H_s}{L_{om}} \text{ and: } \xi = \frac{\tan\alpha}{\sqrt{s_{om}}}$$

Maximization of the wave steepness leads to: $$s_{om} = \left(\frac{\tan\alpha}{\xi_{\text{om-minimaal}}}\right)^2 = \left(\frac{1,5:1}{3}\right)^2 = 0,25$$

However this wave steepness can not occur in real life. This parameter (s_{op}) is seldom higher than 5 to 5,5%. As described in 'Breakwaters and closure dams, K. d'Angremond and F.C. van Roode, 2001

The final formula, the wave height overtopped by 2% of the waves at the head reads:

$$N_s = \frac{H_{2\%}}{1,33*1,74} = 1.4\left(3.75\frac{0,5^{0,5}}{3.000^{0.25}} + 0.85\right)0,055^{-0,2} \rightarrow H_{2\%} = 6,99m$$

Tetrapods at the trunk: $H_{2\%}$ = 6,27.

For deep water this 2% overtopped wave height can be expressed in a significant wave with: $H_{2\%}$ / H_s = 1,4. In local, shallow, water conditions, this factor is assumed at 1,2. Therefore H_s head = 5,83 m and H_s = 5,22 m at the trunk of the breakwater.

However, during our stay in Varna, there was a week (about 5 days) of serous wave attack on the beach and the breakwater. This sort of storm happens a few times per year (according to local people). Therefore it can be noted that the number of waves (now 3.000) is probably not high enough. However, when calculating with for example waves this leads to a significantly lower wave height.

$$N_z = \frac{5*24*3.600}{6} = 72.000$$

The reason for this is that more waves of, distributed, wave conditions lead to a lower significant wave height. The wave heights ($H_{2\%}$) then are 5,9 and 5,2 meters.
This is considered to be too low; therefore the previously calculated values will be applied in this report.

4.4.3) Hanzawa

Another approach of the stability of the Tetrapods in a breakwater is developed by Hanzawa in 1996, this method can be used for caisson type breakwaters. This is like the breakwater at St. Constantine. His formula reads:

$$\frac{H_S}{\Delta D_n} = 2,32\left(\frac{N_{od}}{N_z^{0,5}}\right)^{0,2} + 1,33$$

Resulting in:

$$H_S = 1,33 \bullet 1,76 \bullet 2,32\left(\frac{0,5}{3.000^{0,5}}\right)^{0,2} + 1,33 = 3,45m$$

for Tetrapods at the head of the breakwater, and for the Tetrapods at the trunk: $H_s = 3,21m.$

4.4.4) Conclusion

The different, calculated, wave heights are shown in the following table:

Calculation method:	H_s at the head [m]:	H_s at the trunk [m]:
Hudson	3,87	3,47
Van der Meer	5,83	5,22
Hanzawa	3,45	3,21

Table 4.4 Calculated wave heights with use of several calculation methods

There is quite some scatter between the results from the different formulas. When comparing Hanzawa with Van der Meer, the only parametrical difference in the formulas is the wave steepness (breakwater slope / Iribarren-parameter: 0,055-0,2), this has serous consequences, since results vary roughly 2 metres. When calculating with the factor $H_{2\%}$ / H_s = 1,4 (so for deep water), results are a bit closer to the other values. However, still not really close.
The results between Hudson and Van der Meer differ a bit less. But reliability of the Hudson formula in case of steep slopes is doubted by the Coastal Engineering Manual.
The results obtained with the Hudson formula will not be used from now on, because of the remark in the CEM. In the next parts of this chapter, the significant wave height of Van der Meer is used, since the irregular wave approach is the most probable schematisation of this situation.

4.5) Maximum depth-limited wave

The maximum depth-limited wave can be determined using the Miche breaking criterion:

$$H_b = 0,142L\tanh\left(\frac{2\pi}{L}h\right)$$

For shallow water, this criterion is limited by the local water depth. Corresponding to the fact that waves break when they are larger than 1,5 – 2 H_s, this criterion can be rewritten as: $H_s/h \approx 0,4 – 0,5$ for shallow water.

The depth in front of the breakwater is assumed at 8 m, this is including set-up (since the estimation was done during days where possible set-up was present). This leads to a Hs of 0,5 * 8 = 4 m.

This is less than the calculated value by the Van der Meer equation. This can either mean that the breakwater is over dimensioned, that the depth estimation in front of the breakwater is wrong or that after constructing the breakwater a lot of sand was transported to the toe of the breakwater.
The most probable explanation is the over dimensioning of the breakwater. Therefore the most probable value of the significant wave height is used, the one which is limited by the local water depth, therefore: H_s = 4 meters.

4.6) Wave transmission

4.6.1) Introduction

Wave transmission through the Tetrapods in front of a breakwater consists of two parts, the transmission through the blocks and the overtopping over the Tetrapods respectively. The total of these two can be calculated with the wave transmission formulas by Goda (1969) and Takahashi (1996).

4.6.2) Goda

This formula is developed for regular, head-on waves. However, when using Hs for H, it can be applied for irregular waves. The calculation will be done for the blocks at the head of the breakwater. The formula applicable for this depth to wave height relation (R_c/H) is:

$$C_t = \left(0,25\left(1 - \sin\left(\frac{\pi}{2\alpha}\right)\left(\frac{R_c}{H}+\beta\right)\right)^2 + \ 0,01\left(1 - \frac{h_c}{h_s}\right)^2 \right)^{0,5} \text{, for: } \beta-\alpha<\frac{R_c}{H}<\alpha-\beta$$

Using the following variables:

C_t = transmission coefficient

R_c = height from crest of breakwater to SWL = 1,70 m

$d = h_c$ = height of breakwater itself = 8 m

h_s = scour depth in front of breakwater = 10 m

$H = H_{1/3} = H_s$ = significant wave height = 4 m

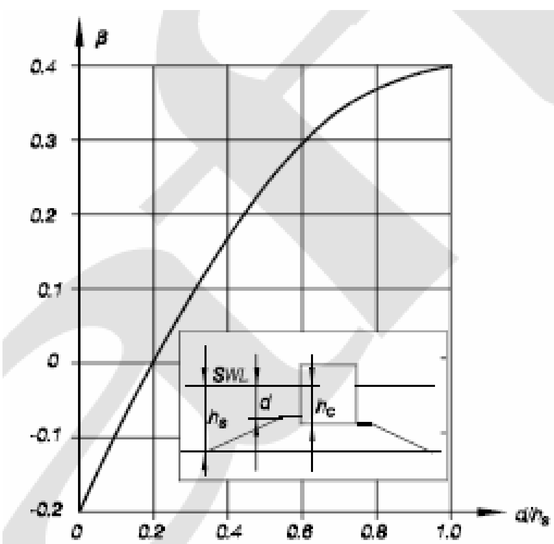


Figure 4.5 Determination of beta value

The given condition for this formula:

$$\beta - \alpha < \frac{R_c}{H} < \alpha - \beta$$

$$\alpha = 2,2 \text{ (constant)}$$

$$\beta = 0{,}37 \text{ since } d/h_s = 8/10 = 0,8, \text{ see figure on the right}$$

$$\frac{R_c}{H_s} = \frac{1,70}{4} = 0,425$$

$$-1,83 < 0,425 < 1,83$$

The final formula reads:

$$C_t = \left(0,25 \left(1 - \sin\left(\frac{\pi}{2\alpha}\right)\left(\frac{R_c}{H} + \beta\right)\right)^2 + \ 0,01\left(1 - \frac{h_c}{h_s}\right)^2 \right)^{0,5} = 0,24$$

This is the wave transmission through the Tetrapods at the head of the breakwater. The transmitted wave height is therefore 0,24 * 4 = 0,96 m.

<u>4.6.3) Takahashi</u>

This formula is valid for irregular, head-on and oblique long-crested waves. The formula reads:

$$C_t = \left[0,25 \left[\left(1 - \sin\frac{\pi}{4,4}\right)\left(\frac{R_c}{H_{1/3}} + \beta + \beta_s\right)\right] + 0,01\left(1 - \frac{h_c}{h_s}\right)^2 \right]^{0,5}$$

$$\text{valid for: } \beta + \beta_s - 2,2 < \frac{R_c}{H_{1/3}} < 2,2 - \beta - \beta_s$$

Where:

$$\beta_s = -0,3\left[\left(R_c - 2d_c\right)/\left(H_{1/3}\tan\theta\right)\right]^{0,5}$$

The angle of incidence of the waves is used in this condition as well. In the local situation any angle of incidence between 0 and 45 degrees is possible. The calculation is made for these two values (0 and 45).

Calculation in case the angle of wave incidence, theta, is 0 degrees:

$$\beta_s = 0$$

$$\beta = 0{,}37 \text{ since } d/h_s = 8/10 = 0,8$$

$$-1,83 < \frac{R_c}{H_{1/3}} = \frac{1,7}{4} = 0,425 < 1,83$$

This results into: C_t = 0,44

Calculation in case the angle is 45 degrees:

$$\beta_s = -0,3\left[\left(R_c - 2d_c\right)/\left(H_{1/3}\tan\theta\right)\right]^{0,5} = -0,3\left[\left(1,70\right)/\left(4\bullet\tan 45°\right)\right]^{0,5} = -0,20$$

$$\beta = 0,37 \text{ since } d/h_s = 8/10 = 0,8$$

$$-2,03 < \frac{R_c}{H_{1/3}} = 0,425 < 2,03$$

This leads to: C_t = 0,50

These transmission coefficients lead to a transmitted wave height of 1,76 and 2 meters at the head of the breakwater. The oblique incident waves are transmitted better through the Tetrapods.

4.7) Expected breakage

Burcharth derived a formula to determine the relative breakage of dolosse and Tetrapod blocks. This formula reads:

$$B = C_0 M^{C1} f_T^{C_2} H_S^{C_3}$$

Using:

M_I = Armor unit mass in ton, Tetrapod I = $2,4\bullet1,76^3$ = 13,1 ton.

M_{II} = Armor unit mass in ton, Tetrapod II = $2,4\bullet1,56^3$ = 9,11 ton

f_T = Concrete static tensile strenght in MPa (B35) = 1,5 MPa

H_s = Significant wave heigth in meters = 4 m

The fitting parameters are: C_0 = 0,00393; C_1 = -0,79; C_2 = -2,73; C_3 = 3,84.

For Tetrapods at the head of the breakwater, this leads to:

$$B = C_0 M^{C1} f_T^{C_2} H_S^{C_3} = 0,00393\bullet13,1^{-0,79}\bullet1,5^{-2,73}\bullet4^{3,84} = 0,035 \rightarrow 3,5\%$$

Given the actual breakage of Tetrapods at the head is equal to: 4/35 = 0,114 -> 11%.
When applying the wave height calculated with the Van der Meer equation (5,8m) the relative breakage becomes 15%. This is closer to the number of broken blocks, however still quite inaccurate. Two explanations can be given, either the Tetrapods are that poorly constructed that more than 3 times as much blocks break than calculated. Or the used significant wave height (derived from the maximum depth limited wave height, 4m) is too small and the real wave height at the breakwater is about 5,8 meters. This (5,8m) significant wave height would result in a breakage of 15%. The most probable explanation is of course the poor quality of the blocks.

At the trunk of the breakwater the expected (according to Burcharth) breakage is equal to 4,6%. However, no blocks are actually broken. The calculated breakage percentage is higher in this case, because the breakage is tested with the full wave height (4m) and smaller Tetrapods. The actual wave height in this area (the trunk of the breakwater) will however be less than the wave height at the head of the breakwater. Therefore less actual breakage can be expected.

5) BEACH MEASUREMENTS

5.1) Introduction

In order to be able to give an advice about any beach adjustment for the future, several beach measurements have been done. In this we looked at the two location described at the beginning of this report: the Sirius Hotel beach and the beach close to Varna. In this chapter the methods and the results are given of the different measurements. GPS and a theodolite are used on both beaches. The Sirius Hotel beach has been measured in previous years and can therefore probably be compared to this previous data. If so an estimation can be done about the change of the beach. The beach close to Varna will be measured for the first time. By these measurements a boat was also used. Together with an echo sounder connected to the GPS a depth coordinated was measured. With this data a 3D view of the see bottom could be generated.
In the first part of this chapter the data collected with the GPS and the Echo Sounder will be discussed. Later on the beach profiles generated with the theodolite will be described.

Fig. 5.1 Overview Varna beach

5.2) GPS & ECHOSOUNDING

5.2.1) Introduction

The beach west of Varna has to be extended to protect the buildings that are threatened by the serious erosion that has taken place. A couple of measurements have to be done to get in impression of the current beach situation.
The collected data provides us the information we need to estimate the amount of sand that has to be nourished to extent the beach.

5.2.2) Equipments

For this survey we used a zodiac, a GPS and an echo-sounder. The GPS and the echo-sounder were connected to each other and mounted on the back of the zodiac.
The GPS determines the horizontal position of the zodiac and the echo-sounder determines the water depth.

- GPS
  A GPS determines the horizontal position by using several satellites. The GPS that was used in during the survey was able to show on its screen the route that was covered. This was very useful in the case the GPS was connected to the Echo Sounder because it made it easier to sail perpendicular to the coast in straight parallel lines.

- Echo sounder
  The echo sounder was linked to the GPS and at a fixed time interval of 5 seconds the GPS would store the X,Y coordinates and the Z coordinate provided by the Echo Sounder, thus producing a series of points recording the sailed route and its water depth.


Fig. 5.2 measuring equipment

5.2.3) Methods

For getting the contour lines of the beach, the GPS was used. A group walked over the beach while the GPS was logging the path that was walked. Different paths were saved, the border between the beach and the waterline, the line where the beach ends and the inland starts. Also the positions of buildings and special waypoints were marked; those can later on be used as reference points in the coming years.
This was done for both beaches. For the Varna beach also a boat was available. Together with the echo sounder depth measurements could be done.
In order to get a reliable bathymetry along the beach, the boat has to sail in straight lines on top of imaginable cross sections perpendicular to the coastline. This was done visually, because of the lack of a DGPS.
The boat positioning then was linked to the measurement of the echo-sounder. This is possible as the time of the both devices were adjusted to each other. Consequently the water depth at an exact position is known.
Afterwards the results can be linked to the beach measurements in a way that the total sediment volume in the coastal zone can be calculated.
The boundary definition of the area is based on the principle of looking at a sediment cell in the coastal zone. By setting the boundaries at two intersections between which you want to quantify sediment volume changes, you can investigate the sediment flux in/out the area of interest. As we are looking at the "Sirius" beach this area is given by a groyne in front of the hotel and by a jetty southward. One usually takes the so called closure depth as the lower limit of the coastal profile. Depth changes seaward of these changes are not directly related to the shoreline dynamics. The closure depth is often the outer edge of the transport zone corresponding to the highest wave that may occur.

Fig. 5.3 Measuring vessel

5.2.4) Measurement accuracy

- **GPS**
The amount of satellites connected to the handheld GPS influence the accuracy of the data. The more satellites the better accuracy you will get. Therefore it is always useful when you start measuring with your GPS, that your GPS is turned on long before you start your measurement. This extra time uses the handheld to find enough satellites. According to the manual of the handheld, the GPS device has a horizontal accuracy of typically 3-5 meter. The vertical accuracy is not taken into account because for vertical positions an Echo Sounder was used.
There is also a human error. When a man walks a path he will never walk precisely the path that was decided in advance. For example: you will never walk exactly along the waterline if you don't want wet feet.

- **Echo Sounder**
The temperature and the density of the water influence the speed of the sound pulse generated by the Echo Sounder device unit. The echo Sounder is calibrated with a certain speed of sound in the water. If the speed in the water during the measurements is different you will get an error.

In case the temperature is different, an example:
If the temperature is for example 15°C instead of 20°C, the change in speed of sound is about 20 m/s. If you know the depth is 10m (and the instrument was calibrated for a water temperature of 20°C). You will measure a depth of 10.13m in case the water temperature is 15°C. That is a error of 1.4%. Even if the instrument is calibrated on a temperature of 25°C and the ocean will suddenly be frozen… The error at a depth of 10 meter is only 70cm and therefore 7.0%.

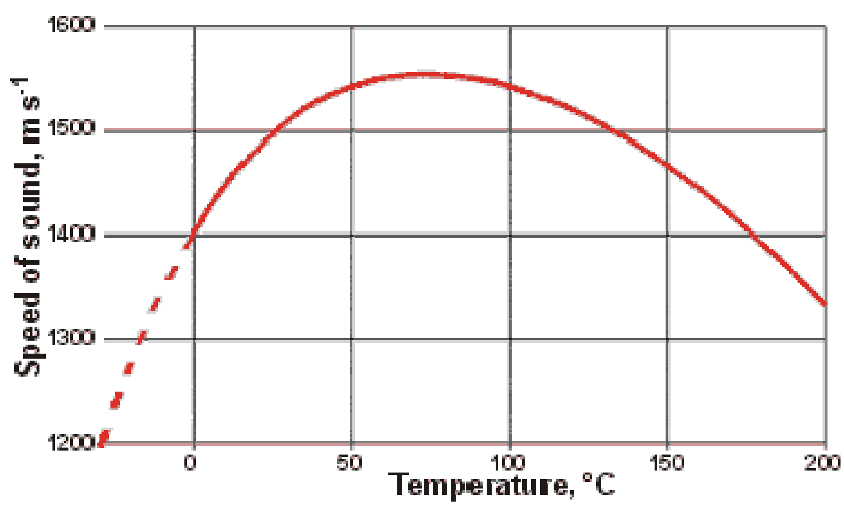


Fig. 5.4 Graph about Speed of sound in, and temperature of, water

In the graph below you can see the influences on the speed of sound in water by different salinities and different water temperature.
The following formula has been used:
$v = 1449.2 + 4.6t - 0.055t^2 + 0.00029t^3 + (1.34 - 0.01t)\cdot(s-35) + 0.016d$

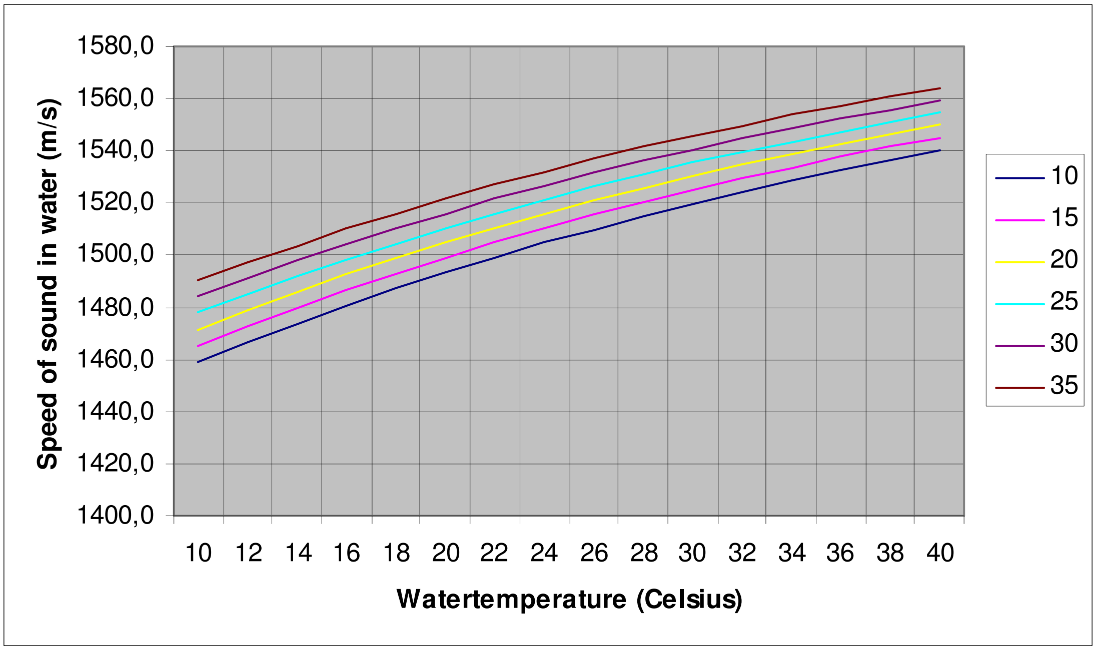


Fig. 5.5 Speed of sound against the water temp. by different salinities in case the water depth is 10 m.

In case the salinity is different, an example:
The instrument is calibrated with a salinity of 30‰ (regular sea water). If the measurement will be done in water with a salinity of 15‰ what will be difference in water depth. We take a temperature of 15°C. The difference in speed of sound between the two salinities is (according to the graph) 1502-1483 = 19 m/s. The difference will only be 10.13 – 10 = 0.13m (1.3%).

Another example in case salinity and temperature are different:
If the instrument is calibrated with 25°C and a salinity of 30‰ and the depth is 10 meter, speed of sound is about 1530 m/s. Survey is for example done by 15°C and a salinity of 15‰ then the speed of sound is 1483 m/s. Th depth you will measure is in this case 10.32 meter. The error is now 3.2%.

- **The Zodiac boat**
  The Boat moves during the measurements because of the waves and human influences. During the measurements there were very little waves.

  An example in case the boat has a pitch or roll of 10°;

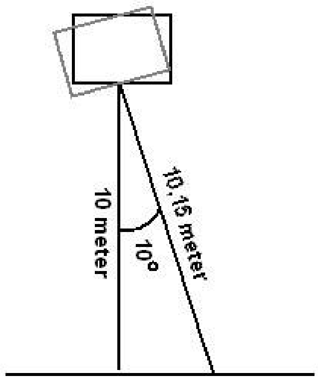
  

  Fig. 5.6 Pitch example

  The picture on the left shows the difference in measuring when there is a pitch or a roll of 10°. In case the boat has a pitch and a roll on the same time of 10°, at a depth of 10 meter, the measured difference will even be twice as much: 30cm.

- **Positioning GPS and Echo Sounder on board**
  The error can be neglected because both instruments were situated very close to each other.

- **Variation sea level**
  The variation in sea level has an influence at the measured depth. For example wind setup can create a water level rising. This will not give an error in your data itself. In other words the difference in depth 50 meter off shore and 100 meter off shore will be the same. You only have to consider this variation when compare your data to the mean Black Sea level.

- **Conclusion**
  All the different instruments and methods do not have a big error themselves. But when we combine all these errors a significant error will occur. For example when the temperature of the water has a big difference compared to the calibrated one together with a difference in salinity and the boat has a big pitch and roll at the same time, the measured data can have error of up to 7%. That is quite a considerable amount that cannot be neglected.

5.3) Varna beach

5.3.1) Results GPS

The program OziExplorer was used to plot the GPS data into a map. In Fig. 5.7 the sailing pattern is shown. The measurement started at the Y-groyne (see the blue dot at the end of the Y-groyne) and from this point we sailed southwards in the direction of the harbor.

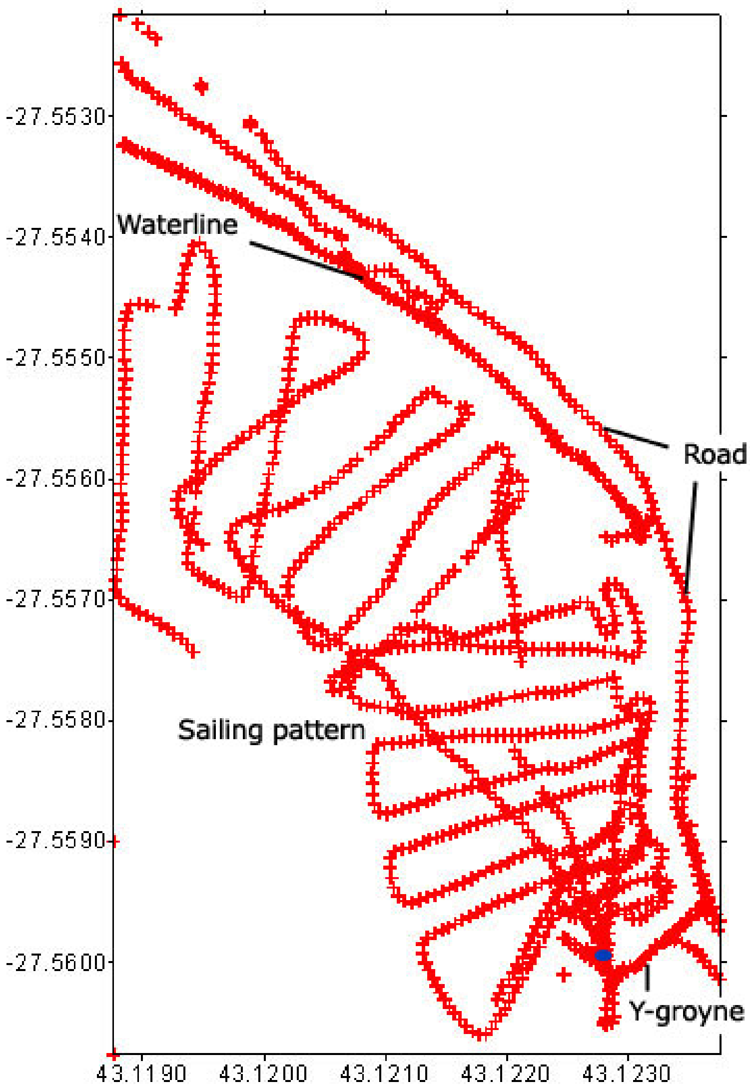


Fig. 5.7 Sail and walk patterns GPS

The zigzag path is the sailing pattern as indicated in figure 5.7. The road and the waterline are also shown. Where these two lines come together the beach ends. From that point up to the Y-groyne a rock revetment separates the road from the waterline. The road is situated +2.5 m. above the waterline.

5.3.2) Results GPS & Echo sounder

To combine the horizontal and vertical measurements made with the GPS and the echo-sounder the program surfer32 was used. This program interpolates and extrapolates the data to generate a 3D surface map.
In Fig. 5.8 you see the map of the Varna beach with depth contour lines.

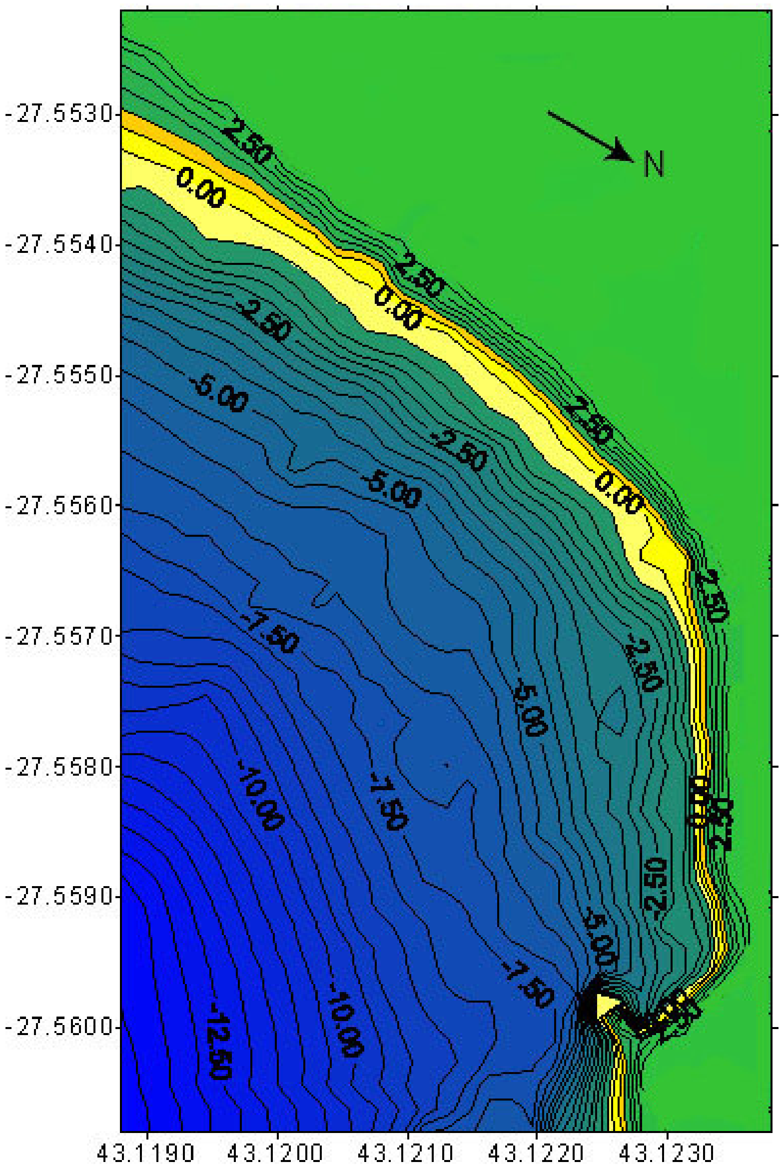


Fig. 5.8 Depth contour line map Varna beach

The solid green area is the area behind the beach. This area was not measured, so no conclusions can be drawn from that part of the map. The +2.50 meter contour line indicates the road behind the beach (see also Fig. 5.7).
Keep in mind that only the south part of the Y-groyne is shown on the map. Also the contour lines directly north-east to the Y-groyne are not correct. In fact there is a greater depth over there.

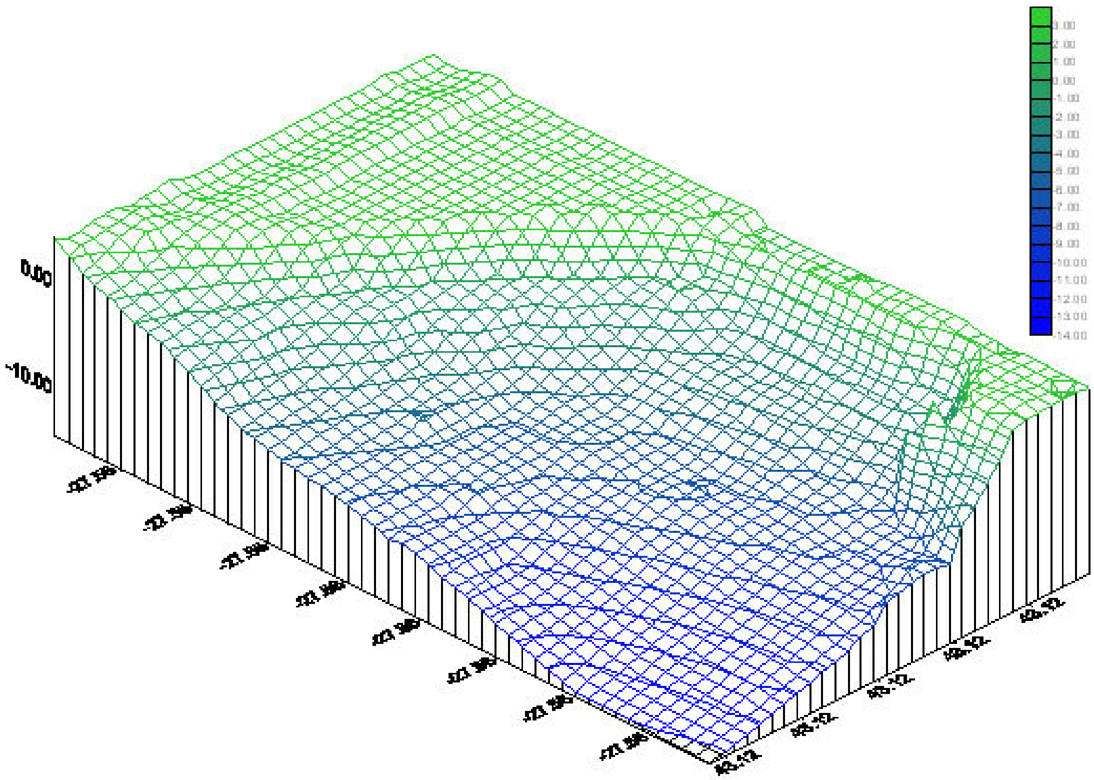
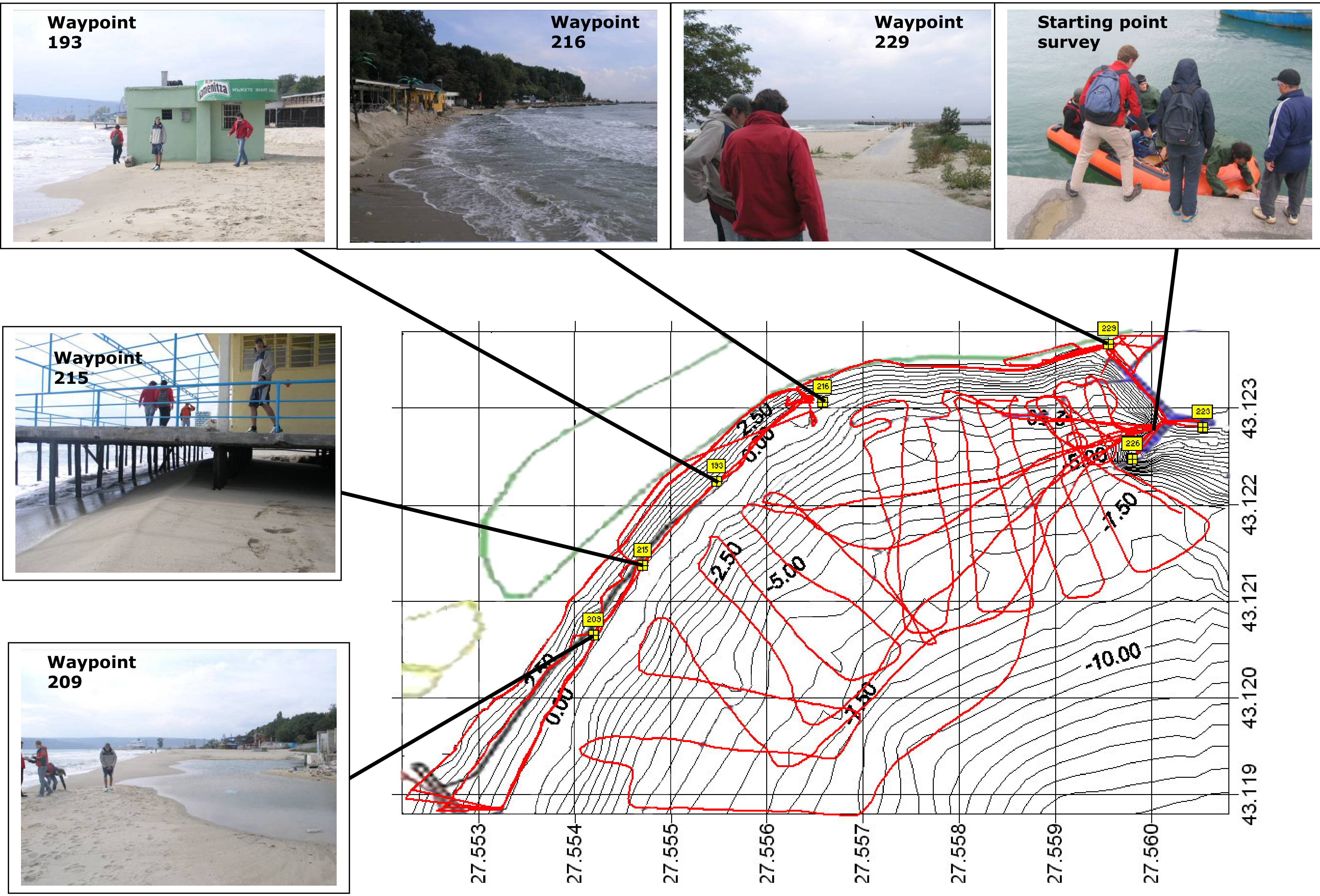


Fig. 5.9 3D-map of the survey area at Varna beach

The figure above (Fig. 5.9) shows a 3D view of the map with the contour lines created with Surfer32.



Waypoint 193
Waypoint 216
Waypoint 229
Starting point survey
Waypoint 215
Waypoint 209
229
216
193
215
209
226
223
2.50
0.00
-2.50
-5.00
-7.50
-10.00
27.553
27.554
27.555
27.556
27.557
27.558
27.559
27.560
43.119
43.120
43.121
43.122
43.123

5.4) Sirius beach

5.4.1) Introduction

In order to get more understanding of the Sirius-beach area there is some GPS-data collected. The data is collected on two different days and on these days the beach was under different wave attack. The first day was Monday the 10th of October 2005. The wave attack was heavy. During the week the wave attack became smaller and on Saturday the 15th of October 2005 there were hardly any waves left. On that day another GPS-dataset of the shoreline was collected.

5.4.2) Measurements

A big difference in the shoreline occurred between the two days. The difference is shown in Fig. 5.10. The map is made with Ozi-explorer. The blue line on the right indicates the shoreline during heavy wave attack and seems to be rather straight. The red line on the right side gives the shoreline at the end of the week, when the wave attack was very low. One can see that the shoreline isn't straight anymore. the shoreline is looking rather wavy. Three 'crests' and four 'troughs' can be seen.

The resolution of the map is not very good and other software is needed to make a good estimation of the order shoreline change. In other words, how dynamic is this beach?

Therefore the datasets are put in MS Excel. Fig. 5.11 gives the scatter of the two datasets. We know that the distance between the two reference points is about 200 meter. With this we could estimate the movement of the shoreline between both days. It is shown in Fig. 5.11 that the beach extends up to 5 meter and retreats in this case about 2 meter in-between. In Fig. 5.12 a picture is shown of the shoreline made on the 16th of November. In Fig. 5.11 the orientation of the picture is seen.

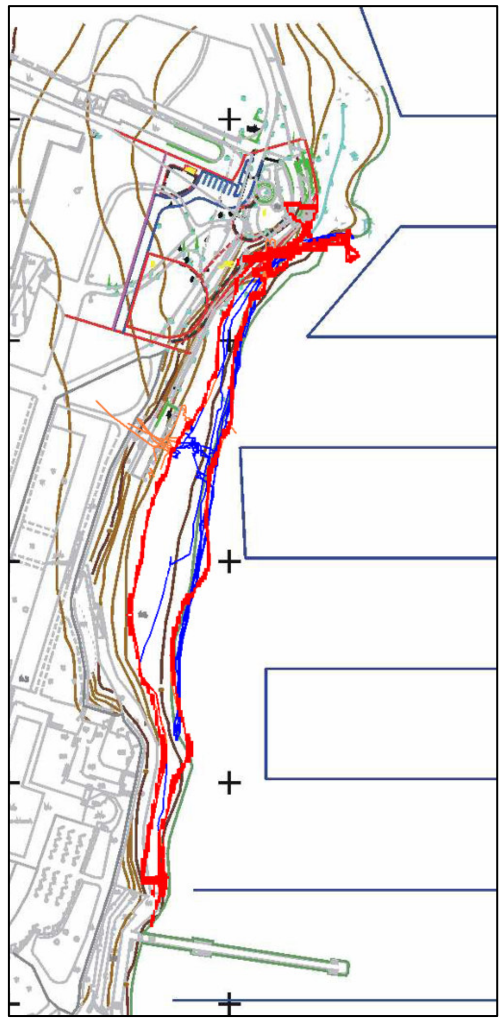


Fig. 5.10 Map of the Sirius beach

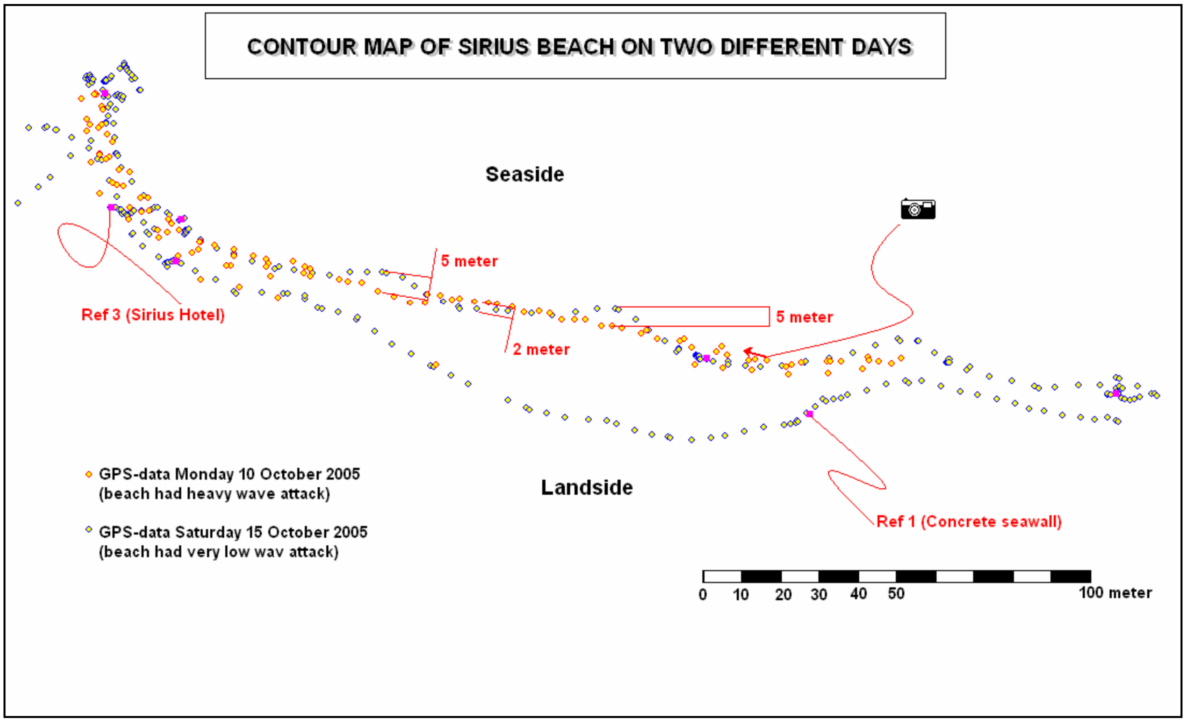


Fig. 5.11 Scatter of two datasets of the surface area of the Sirius beach

Fig. 5.12 Picture of Sirius beach on 15-10-'05

5.4.3) Conclusions

In previous years measuring of the Sirius beach was also done. It would have been very interesting to compare the results in order to know something about a change in the beach profile over the years. Unfortunately the maps in the report of last year had no reference points included. So it is not possible to plot them correctly in one map.
However, they stored their collected GPS data, so we were able to try to plot them all in one map via Ozi-Explorer. The problem that then occurred is that the data collected in 2004 is near the Caspian Sea and the data of 2003 was even beyond Iceland. Even after trying to convert their data to another coordinate system it did not work out.
So no comparisons could be made with previous years. This year clear reference points are included in the maps to make it easier for the coming years.

6) BEACH PROFILE

6.1) Introduction

The beach profile is measured and this data is collected for several years. Based on the data, the situation is compared to other years and it can be determined how the beach changes through time. Erosion and accretion is estimated, and development tendency is predicted for future. The stability of the structures located in the area is therefore possibly estimated and calculated.

6.2) Equipment

In this measurement, we did use a basic instrument a so called theodolite. The theodolite means to establish a horizontal line, for ascertaining the differences of level between different points of the earth surface.

6.3) Method

Measurement is normally carried out with the simple theodolite in order to draw cross sections of the beach, and then an average beach slope can be calculated.
First, one reference point with known altitude is chosen, and the (X, Y) coordinates are determined with GPS for instance. We use the theodolite to read the number on the pole at the reference point. Then read the number on the pole at every point needs to be measured. The altitude of every point will be converted to the altitude of the reference point as in the following equation:

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

In which:

z_i	Altitude of measured point number i	(m)
z_{RP}	Altitude of the reference point	(m)
h_{RP}	Number read from the pole at reference point	(m)
h_i	Number read from the pole at the measured point	(m)
$\Sigma\Delta$	Sum of level discrepancies when changing position of leveling instrument $\Delta_i = h_f - h_b$	(m)
h_f, h_b	The number read on the pole at the same point from the old position and new position respectively of the instrument	(m)

Fig. 6.1 Explanation of symbols

6.4) Measurement accuracy

The measurement accuracy consists of three components which are instrument accuracy, execution accuracy and the object is measured itself. Theodolite with its technical characters is good enough for this kind of measurement.
Execution is how the balance of instrument on the beach, the position of the pole and accuracy of reading from the pole. Acceptable error for those of thing is in order of millimetres.
The third part of accuracy that is predominant in this measurement is the beach itself. In whatever kind of measurement the object which is measured distributes an important contribution in accuracy of the result.
Material of the object: metal or earth, its shape: flat or curved, its regime: stable or active, all this affects the accuracy of the result. Beach is mainly built by sand, a non-cohesive material, and beach is exposed to wave attack, wind attack and possibly human attack. It means that beach is an object of always being dynamic; it changes in both time and space. When doing the measurement at one point on the beach, the pole only moves on the surface some centimetres, as the beach surface is not completely flat, and there is usually the ripple thus the read number from the pole can change strongly. Error of decimetres indeed can be expected from the beach itself.

6.5) Varna beach

6.5.1) Location of measurements

At the Varna beach not only the beach under the waterline was measured but also the beach profile above the waterline. To obtain some insight in the beach profile five measurements are done with a theodolite.
The five measurements were done near the 'buildings and jetty' in the figure below.

Fig. 6.2 Overview of Varna beach

Directly south of the jetty the first profile was measured. The theodolite was placed at the beach and not moved for the first three profiles.
To measure the mean Black Sea Elevation (BSE) the pole was placed at the water level and the scale was read. After that the height of all the points were read compared to BSE.

Fig. 6.3 Jetty at Varna beach

To measure the second and third beach profile the theodolite was not moved and the height of the different points could be read from the scale in meters above BSE.
The location of the other beach profiles can be seen in figure 6.3.

Fig. 6.4 Location of beach profiles at Varna beach

After measuring profile three, the theodolite had to be moved because of the buildings at the beach.
After moving the theodolite profile 4 and 5 could be measured.

<u>6.5.2) Results</u>

All the beach profiles are drawn below. The height is in meters above BSE and the distance between the measuring points is also given in meters. The distance to the waterline was not measured, only the 'dry' beach profile was taken into account.
For the first profile measuring points in sea were taken into account because the pole could be placed into the water from the jetty.
After replacing the theodolite the height difference between the two locations was not correctly measured so the measured heights of profile 4 and 5 could not be converted in height above BSE. A course assumption has been made for the BSE so the profiles 4 and 5 could be drawn.

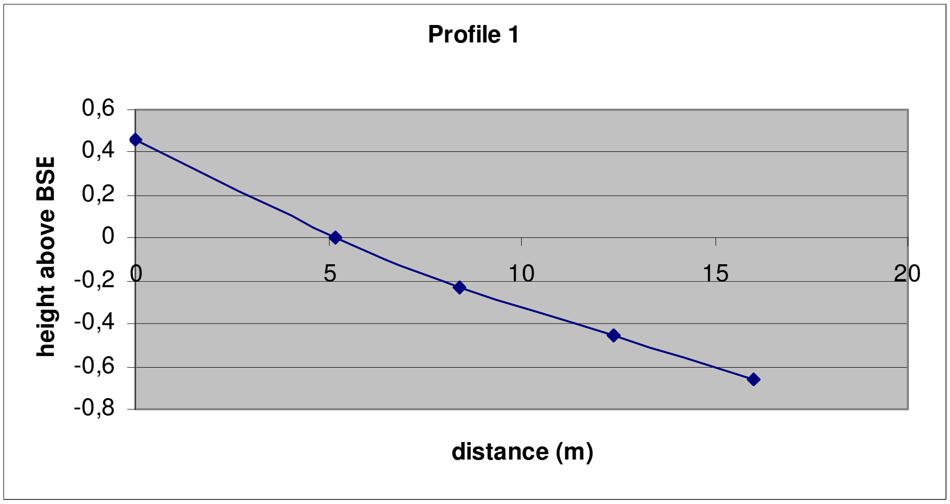


Fig. 6.5 Beach profile 1, measured from jetty

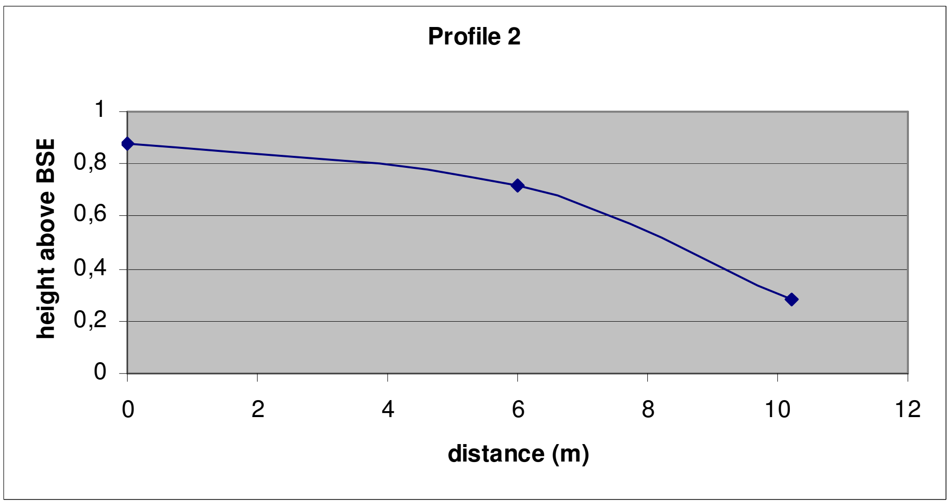


Fig. 6.6 Beach profile 2

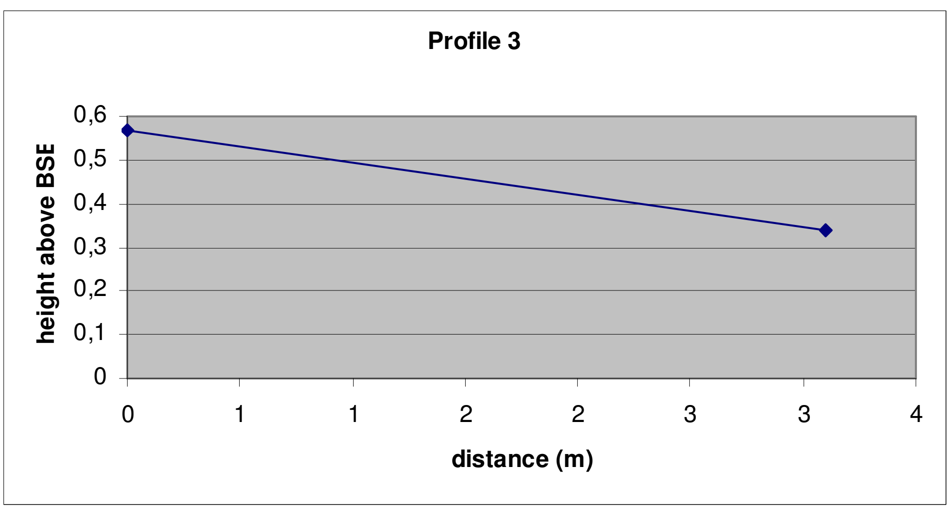


Fig. 6.7 Beach profile 3

Fig. 6.8 Beach profile 4

Fig. 6.9 Beach profile 5

<u>6.5.3) Conclusions</u>

To measure the 'dry' beach profile with a theodolite can obtain good results. The theodolite is very accurate which is not really necessary for measuring a beach profile. Due to wind, waves and people the height of the beach can vary with centimetres easily so measured the height in millimetres does not make any sense.
The first three profiles are rather accurate although the level of the mean Black Sea Elevation can vary with a few centimetres. This was measured by placing the pole at the water surface but due to waves this was not very easy.
Because the height difference between the two locations of the theodolite is not known an assumption had to be made for the level of the BSE according to the new location of the theodolite. So there will be some errors in the exact height of the measuring points in profile 4 and 5.

6.6) Sirius beach

6.6.1) Introduction

Sirius beach is in the St. Constantine resort, located 8 km northward from Varna. The hotel and restaurant density in this area is relatively high, and these concrete buildings tend to stand so close to the coastline. Therefore the change of the beach is considered important to the stability of local properties. Measurement of the beach might be interesting to investors, authorities, and coastal engineers.

6.6.2) Results

On the Sirius beach, 2 reference points RP1, RP3 were chosen; a straight line connects the PR1 and RP3. Every 25m from the RP3, a profile perpendicular to the (RP1; RP3) line, was measured.
RP1 is one point on the concrete base of the blue hotel, RP3 is assumed to be constant +2.705m above the MSL = 0m. Black Sea has a more or less constant water level, and the hotel seems to be relatively stable, so this assumption is safe and reasonable.
RP1 is located on the base of a concrete seawall about 200m Northward from the RP3. PR1 is expected stable as well.

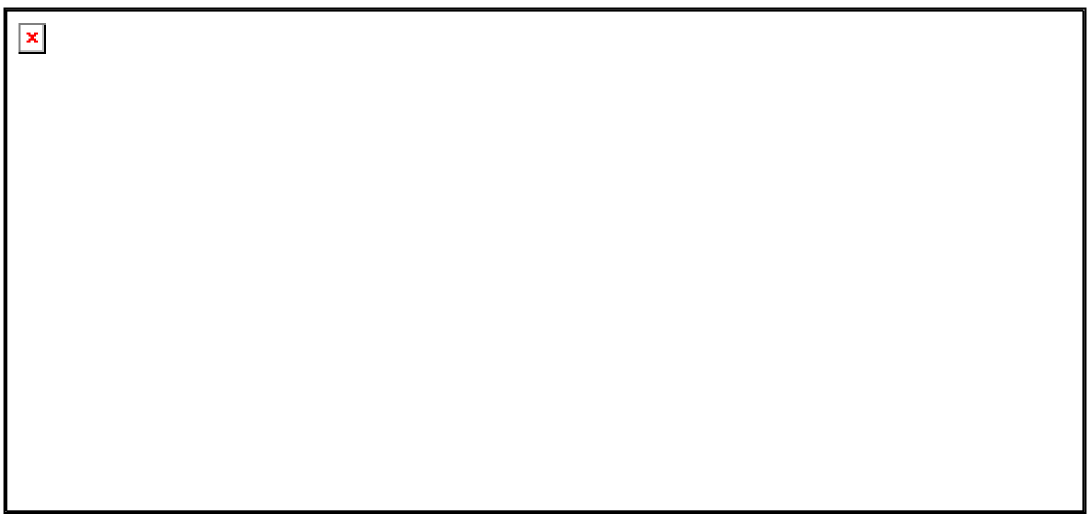


Fig. 6.10 Overview of profiles

The altitude of RP1 in fact is not as same in the morning data as in the afternoon data. The discrepancy is about 40cm that is really big and unacceptable as the measurement area is not large (about $6000m^2$), and there was not any recognizable movement of RP1 or RP3.
Mistake can be caused by some main sources:

- Mistake in reading the pole
- Mistake in writing data
- The pole was not always vertically standing
- The instrument moved without recognition
- The instrument is not precise

To assess the error, the data has to be compared to old data. If the altitude of RP1 is so far different from the old data, the new data is wrong, of course old data is believed correct and reliable. But there is no altitude of RP1 available in previous years' data, so the assessment got stuck.
In the 2003 and 2004 report, altitude of RP3 is +0.11 and not available respectively. While this year, RP3's altitude is assumed +2.705m above the MSL (=0m) that is even far different from old data. There is no uniform in reference coordinate so error assessment is impossible.

As mentioned before, in 'Measurement accuracy' part, error is even mainly from the beach itself as beach is very dynamic and especially in Black Sea. The error of 40cm is assumed due to the beach, measurement execution and considered acceptable. Now, comparison between morning data and afternoon data is made with the assumption that the afternoon data is correct. The morning data is converted to the same reference with the afternoon data as follow: minus all morning data by Δh = 0.425m. Where Δh = 0.425m is the altitude discrepancy between RP1 in morning and afternoon data.
The error correction is illustrated by 5 graphs, in each graph two lines are drawn expressing morning data and afternoon data for the same profile.
As can be seen from the five graphs, the shape of morning line and afternoon line quite agree each other but there is a big step between them with the exception of Profile IV, 100m far away from RP1. The general altitude difference between every couple of lines is impressively 40 – 50cm.

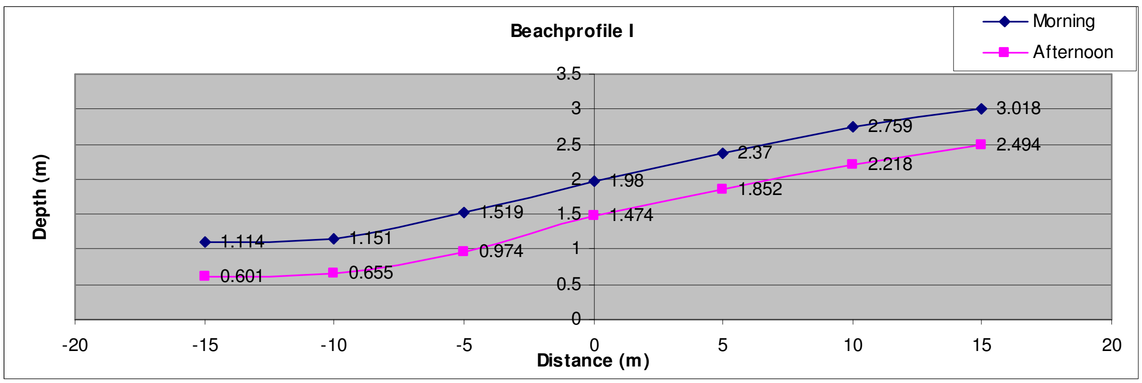


Fig. 6.11 Beach profile I - 25m far away from the RP1.

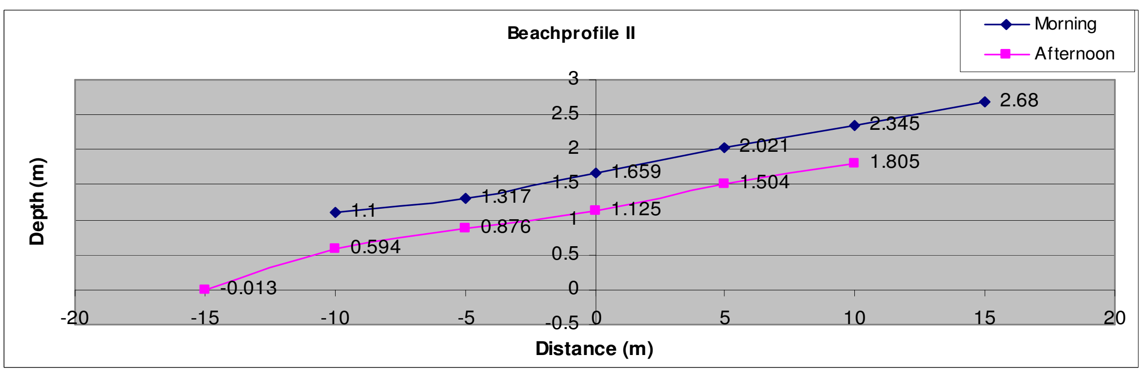


Fig. 6.12 Beach profile II - 50m far away from the RP1.

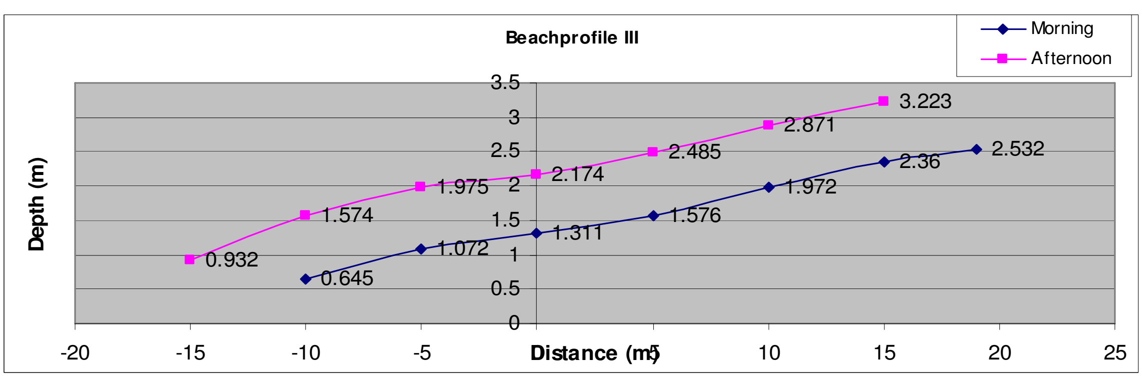


Fig. 6.13 Beach profile III - 75m far away from the RP1.

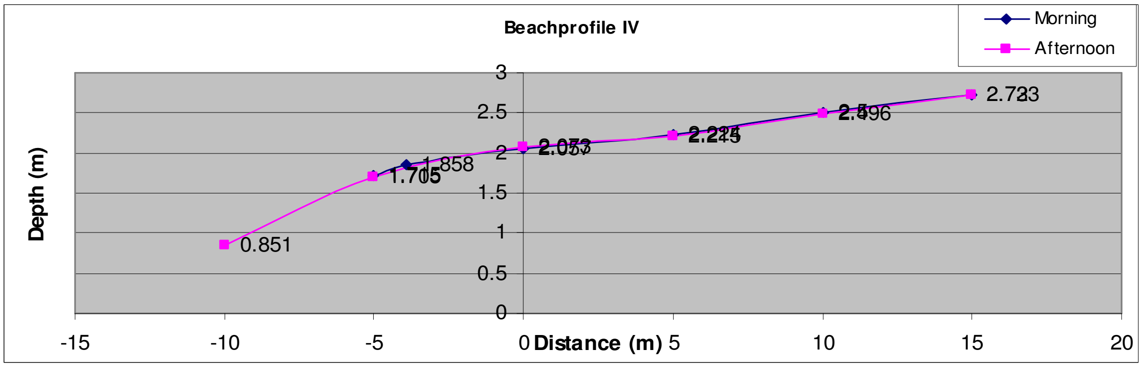


Fig. 6.14 Beach profile IV - 100m far away from the RP1.

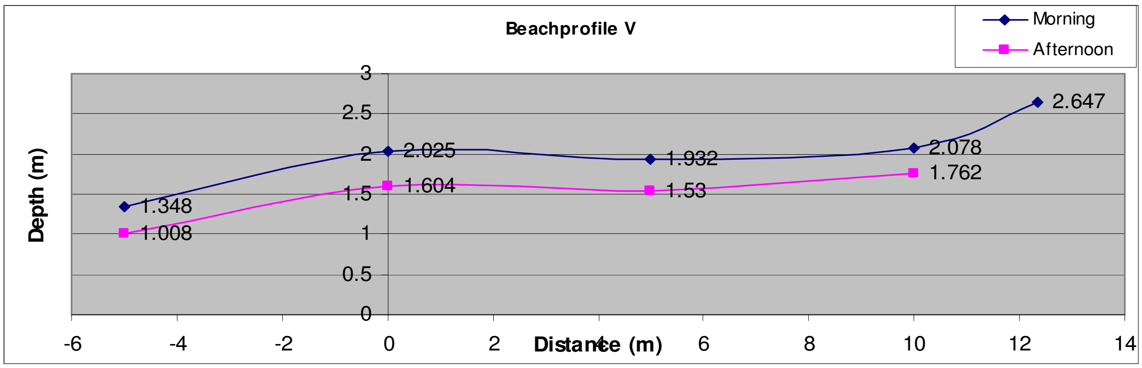


Fig. 6.15 Beach profile V - 125m far away from the RP1.

The measured part of the Sirius beach is a continuous one, there is no hard structure dividing the beach, the coming wave direction is assumed normal to the coastline. If there is erosion or accretion it should be more or less the same tendency for the whole part. But with looking at the above figures, it is found not the case as profile number 1, 2, 3, and 5 suffer dramatic erosion, in the meanwhile nothing happens to profile 4. Data and assumption do not logically unify so it is hardly to conclude about the situation of the beach. Effort to overcome and compensate errors has failed.

7) SAND VOLUME

7.1) Introduction

To have an estimation of the amount of cubic meter sand involved, in case of beach nourishment, a calculation has been done. To run this calculation a computer program called 'surfer' has been used.

7.2) Method

For a good calculation another surface in surfer should be added to the surface that is deducted from the data of the fieldwork. This surface should describe the slope that is preferred for a stable beach. However, we are only interested in an estimation of the amount of sand and than this method would cost too much time, especially when you take the movement of the beach because of wave attack into account. The 3D map generated from the survey data is just a snapshot in time and will be totally different during another kind of wave attack. That was clearly shown earlier in the report when GPS measurements of the Sirius beach was discussed.
The following method has been used:
A slice is taken from the bathymetric survey data, as indicated in the top view on the left in Fig. 7.1. This slice is about 400m x 130m.

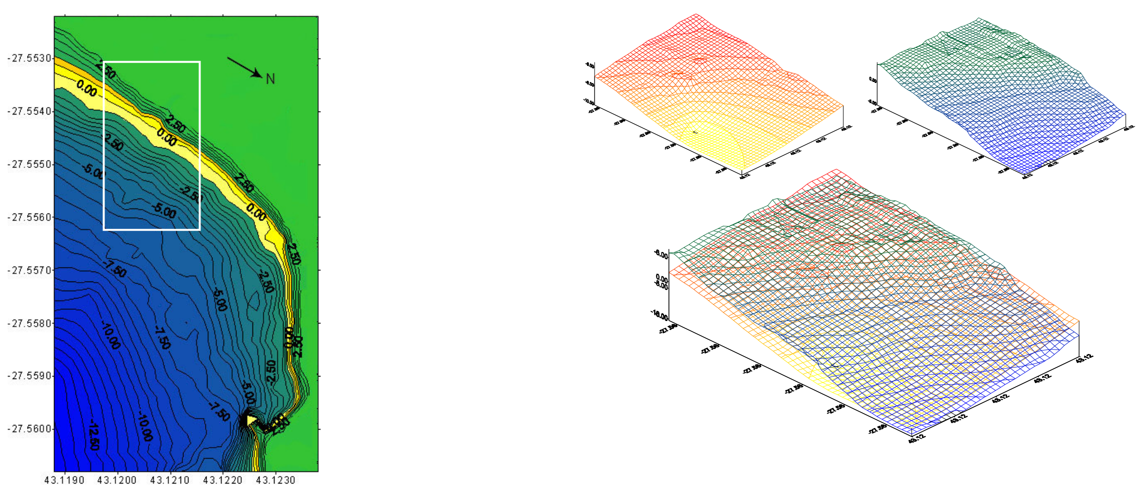


Fig. 7.1 Slice of 3D surface of the Varna beach used for volume calculation

Fig. 7.2 shows what is done with the data of the slice from Fig. 7.1. A value of 50 meter has been chosen for a beach extension in seawards direction. At the coordinates of one side a value has been added to move the area in eastern direction for about this 50 meter. At both ends the data is deleted to let the different data fit to each other. The difference between the two volumes below sea level is an estimation for the necessary amount of sand. This calculation is done with surfer32.

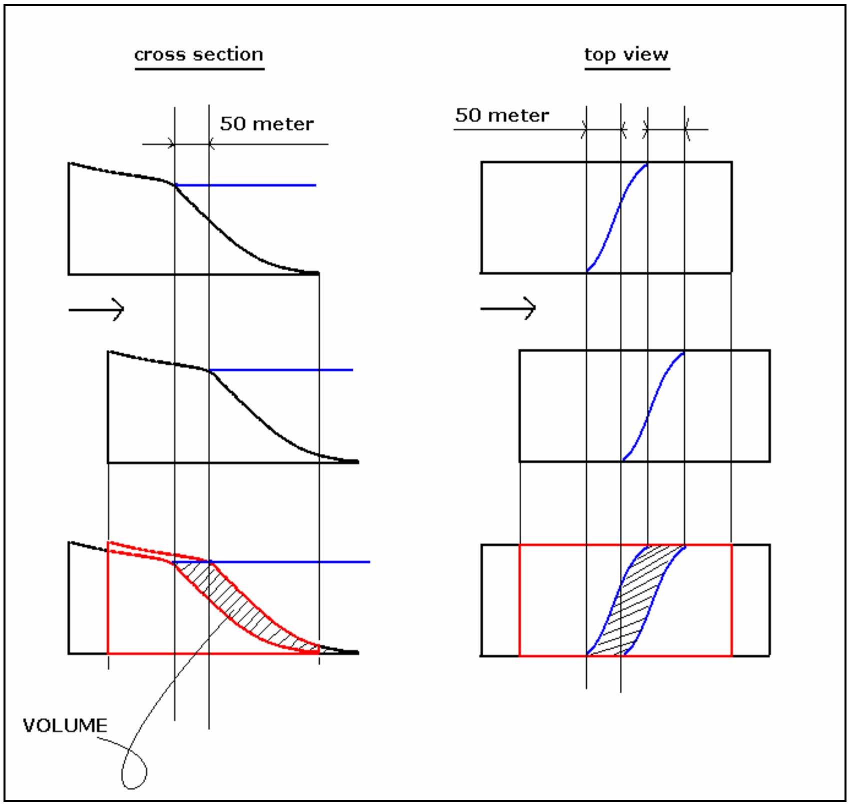


Fig. 7.2 Cross section and top view of displacement of data

Positive characteristics of this method

- Relatively simple
- Quick for a rough estimation

Negative characteristics of this method

- A very rough approach for the determination of the slope.
- The less data there is the less reliable the outcome. In this case there is worked with data of 164 points (x,y,z) while the original data contained 1948 points.
- The beach extension of 50 meter in seaward direction may not be realistic.
- With converting meters into GPS coordinates and the other way around is in the long run not very accurate.

7.3) Results

VOLUME COMPUTATIONS UPPER SURFACE Level Surface defined by Z = 0 LOWER SURFACE Grid File: F:/CIVIELE TECHNIEK/FIELD-WORK/VOLUME/REDUCED.GRD Grid size as read: 35 cols by 50 rows Delta X: 5.88235E-005 Delta Y: 5.91837E-005 X-Range: 43.119 to 43.121 Y-Range: -27.5588 to -27.5559 Z-Range: -10.0707 to -5.43023 VOLUMES Approximated Volume by Trapezoidal Rule: 4.56369E-005 Simpson's Rule: 4.56392E-005 Simpson's 3/8 Rule: 4.56408E-005 AREAS Positive Planar Area (Upper above Lower): 5.8E-006 Negative Planar Area (Lower above Upper): 0 Blanked Planar Area: 0 Total Planar Area: 5.8E-006	VOLUME COMPUTATIONS UPPER SURFACE Level Surface defined by Z = 0 LOWER SURFACE Grid File: F:/CIVIELE TECHNIEK/FIELDWORK /VOLUME/REDUCED-OPGESCHOVEN.GRD Grid size as read: 35 cols by 50 rows Delta X: 5.88235E-005 Delta Y: 5.91837E-005 X-Range: 43.119 to 43.121 Y-Range: -27.5588 to -27.5559 Z-Range: -5.11301 to 4.40048 VOLUMES Approximated Volume by Trapezoidal Rule: -3.78593E-006 Simpson's Rule: -3.78134E-006 Simpson's 3/8 Rule: -3.78053E-006 AREAS Positive Planar Area (Upper above Lower): 2.5518E-006 Negative Planar Area (Lower above Upper): 3.2482E-006 Blanked Planar Area: 0 Total Planar Area: 5.8E-006

Fig. 7.3 Results from Surfer32

Volume is $4.56 \cdot 10^{-5} - 3.78 \cdot 10^{-6} = 4.18 \cdot 10^{-5}$.

Gives $Volume = Volume * \cdot \Delta X \cdot \Delta Y = \dfrac{4.18 \cdot 10^{-5}}{1.34 \cdot 10^{5} \cdot 6.15 \cdot 10^{5}} = 350.000 m^3$ per 123 meter.

About 300.000 m^3/100m of sand is needed for beach nourishment according to this method.

7.4) Conclusion

A rough estimation gives that for the complete Varna beach, with a length of 1 kilometre about 3 million m^3 of sand is needed. The calculation is not very reliable but it gives a good rough estimation for the amount of sand needed.

8) SAND CHARACTERISTICS

8.1) Introduction

During the measurements on Varna beach and Sirius beach several sand samples were collected. The samples have been sieved to determine the grain size distribution of the sand. These sand characteristics are needed to make morphological computations regarding the beach profile of Sirius beach and the intended beach nourishment on Varna beach. In general the size (and colour) characteristics of the nourishment sand should be more or less similar to those of the natural beach.

8.2) Collecting of samples

8.2.1) Varna beach

Varna beach comprises several distinctive sections that vary in orientation, slope, length, width and the presence of stones and/or a stretch of sandy beach. In each section with a stretch of sandy beach a sand sample was collected. These were taken on the beach within 0-2 m from the currrent waterline. Every minute or so these spots were washed over by the higher waves. Because of quite rough weather (Fig. 8.1) and a considerable swell, the waterline at the time of the measurements lay a few meters landward of the MSL in the Black Sea. This means the collected sand may be somewhat coarser than the sand near the MSL, as the coarser grains are generally found higher up the beach, where they are deposited during storms. No samples from the surf zone or further landward from the waterline have been taken.

The sand samples were picked up a few centimetres below the surface to avoid collecting shells or fine wind-transported sand from the top layer. In each case about a handful of sand was taken and stored in a plastic bag (Fig. 8.2). These were brought to Delft for the sieving.

Fig. 8.1 Varna beach during the measurements.

Fig. 8.2 Collecting a sand sample on Varna beach.

8.2.2) Sirius beach

Six sand samples were collected on Sirius beach. Four of those were taken in one cross-section (5 m apart from each other) halfway along the beach to gain insight into the grain size distribution with regard to the distance from the waterline. The other two samples were collected on both ends of the beach (north and south side). The six samples provide an overview of the grain size distribution across the beach.
Again the sea was not very calm (Fig. 8.3), so the waterline at the time of the measurements lay a little landwards of the Black Sea's MSL.

Like on Varna beach, each time about a handful of sand was collected and brought to Delft, where the sand has been sieved.

Fig. 8.3 Sirius beach during the measurements.

8.3) Processing

8.3.1) Introduction

In total 12 sand samples were taken to Delft to be sieved in the Fluid Mechanics Laboratory. Prior to sieving, the samples were dried by means of heating them up and contaminants such as shelves were removed. The sieving was carried out according to a standardized procedure. First the sieves to be used in the sieving instrument, which can contain up to 8 different sieves, were chosen from a set of 12 sieves (ranging in mesh size from 125 µm to 850 µm). This was done based on a visual assessment of the sample's grain size.

Next a small amount of sand was taken from the sample and scattered over the top sieve in the sieving instrument. Then the sieving instrument was switched on for 16 minutes, after which the amount of sand on each sieve was weighted. This procedure was repeated for every sample. With the results of the sieving, the grain size distributions have been plotted on a Gauss-log scale, to analyze the gradation.

8.3.2) Varna beach

Six samples were taken on the Varna beach, one of them north of the northern breakwater. To avoid confusion, this sample is plotted separately. Fig. 8.4 and Fig. 8.5 show the sieving curves of the samples.

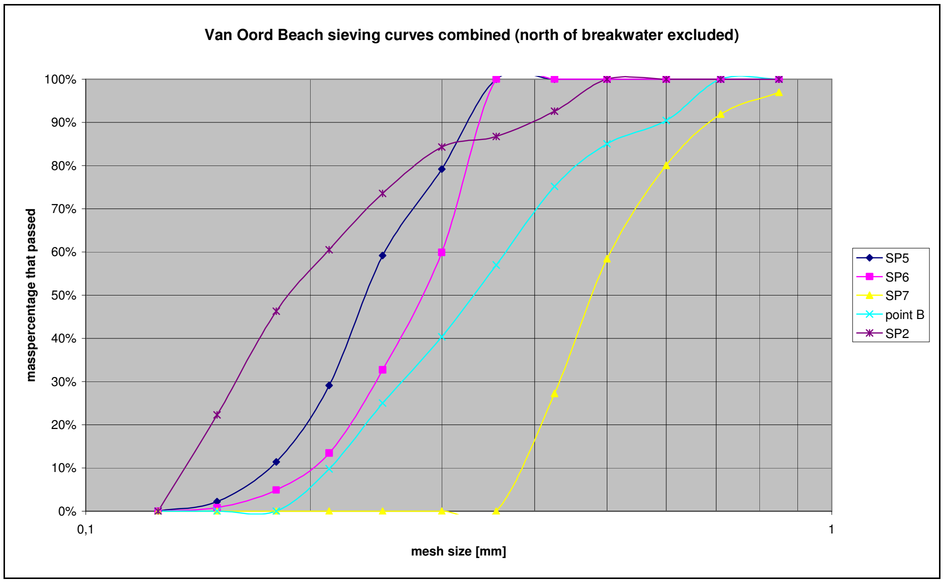


Fig. 8.4 Sieving curves of the Varna beach

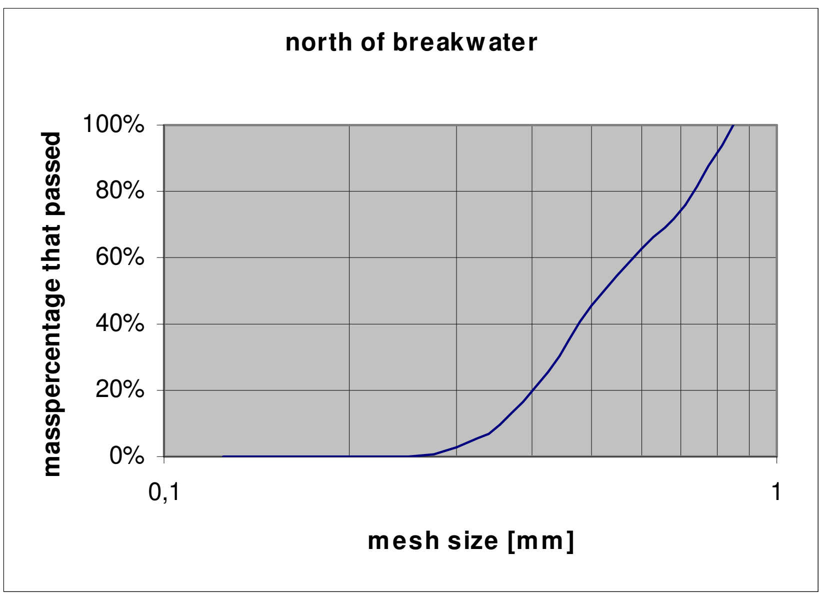


Fig. 8.5 Sample North of the breakwater

Most attention goes to the five samples in the first figure, it shows that there is considerable variation in the sieving curves. The individual grain sizes (D15, D50 and D85) were taken from the graphs. These values are shown in Table 8.1.

Location	D15 [mm]	D50 [mm]	D85 [mm]
SP5	0,18	0,24	0,31
SP6	0,21	0,28	0,33
SP7	0,39	0,47	0,65
Point B	0,21	0,31	0,5
SP2	0,14	0,19	0,34
North of breakwater	0,31	0,51	0,76

Table 8.1 Grain sizes

For the average grain sizes on the beach the sample north of the breakwater is ignored, the values are: D15=0.27mm; D50=0.30mm; D85=0.43mm.

To see if the samples were well graded one should plot the result on a different scale, namely on a Gauss-log scale. It is also possible to look at the S-curves to check the gradation, but the downside to this method is that this is hard to give an objective opinion to whether it is a nice S-shape or not. The Gauss-log scale, if the sample well graded, will result as a straight line in the graph.

The figures below give the gauss-log plots of the results.

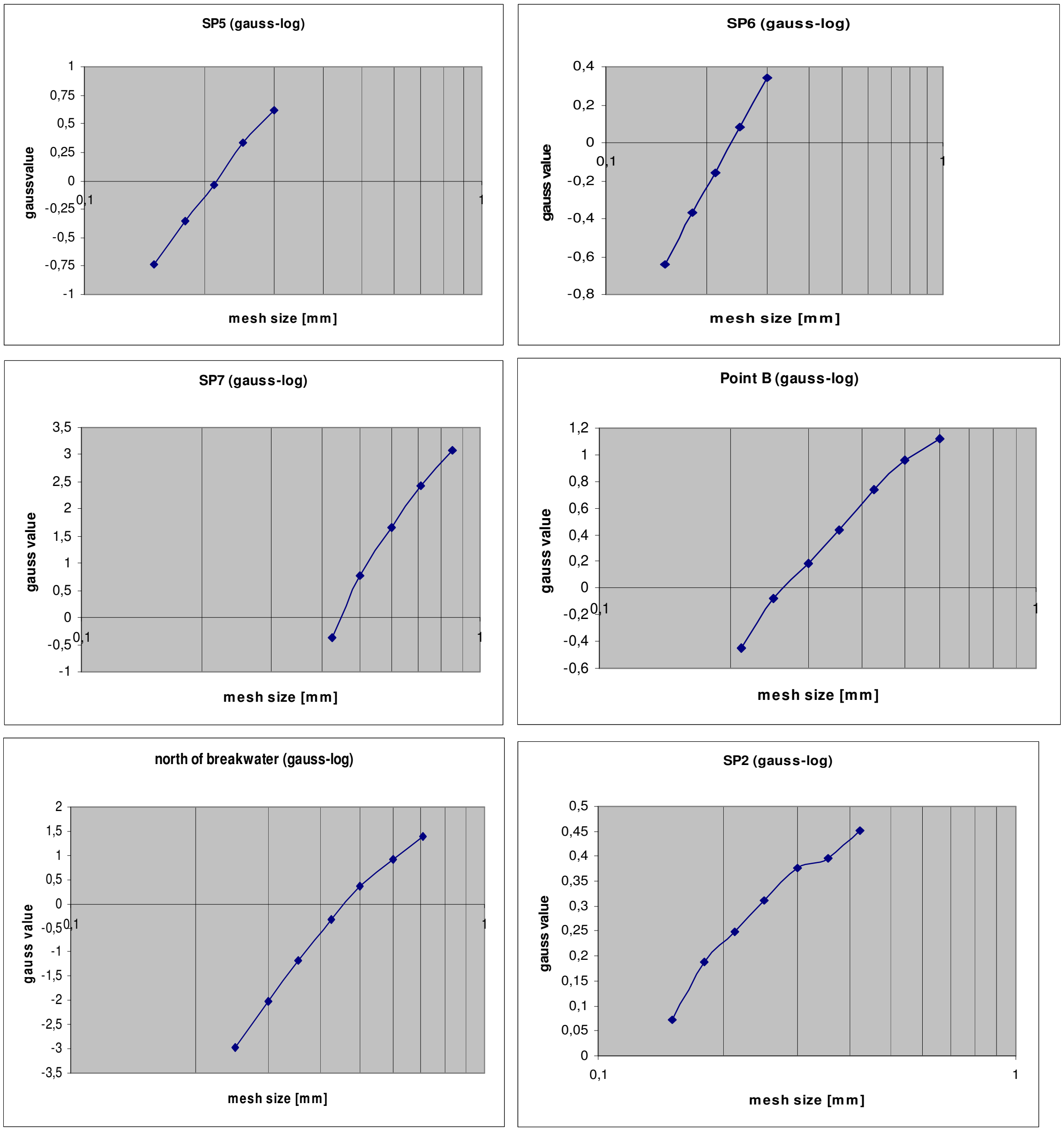


Fig. 8.6 Gauss-log plots

It can be seen that for some samples the line is quite straight (SP5, SP6, Point B and North of the breakwater) so these samples are well graded. Sample SP2 is not straight, so this either means that the sample is not well graded, or that something went wrong during the sieving.

8.3.3) Sirius beach

Same as the Varna beach, six samples were taken. The figure below shows the results.

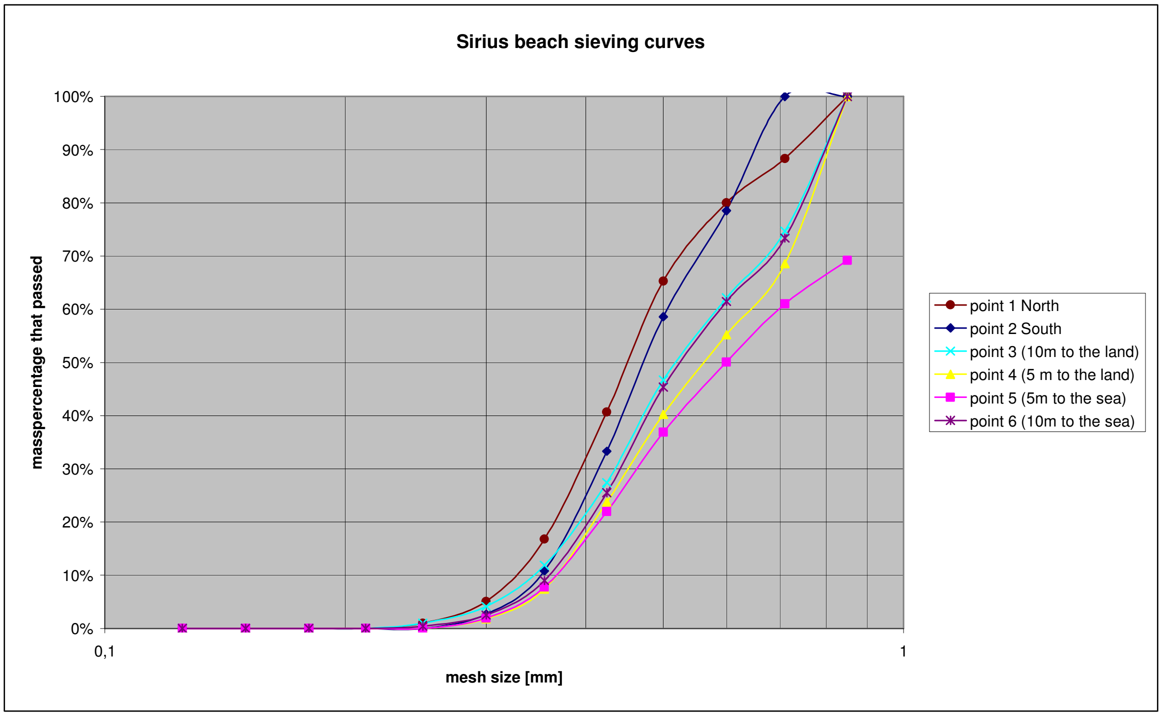


Fig. 8.7 Sirius beach sieving curves

These curves are quite similar to each other; this means the sand is about the same over the complete cross section of the beach. The individual grain sizes (D15, D50 and D85) were taken from the graphs. These values are shown in Table 8.2.

Location	D15 [mm]	D50 [mm]	D85 [mm]
point 1	0,33	0,42	0,65
point 2	0,37	0,47	0,61
point 3	0,37	0,51	0,76
point 4	0,39	0,55	0,78
point 5	0,39	0,6	n.a.
point 6	0,38	0,51	0,76

Table 8.2 Grain sizes Sirius beach

The average values are: D15=0.37mm; D50=0.51mm; D85=0.71mm.

The figures below show the gauss-log curves of the samples taken from the Sirius beach.

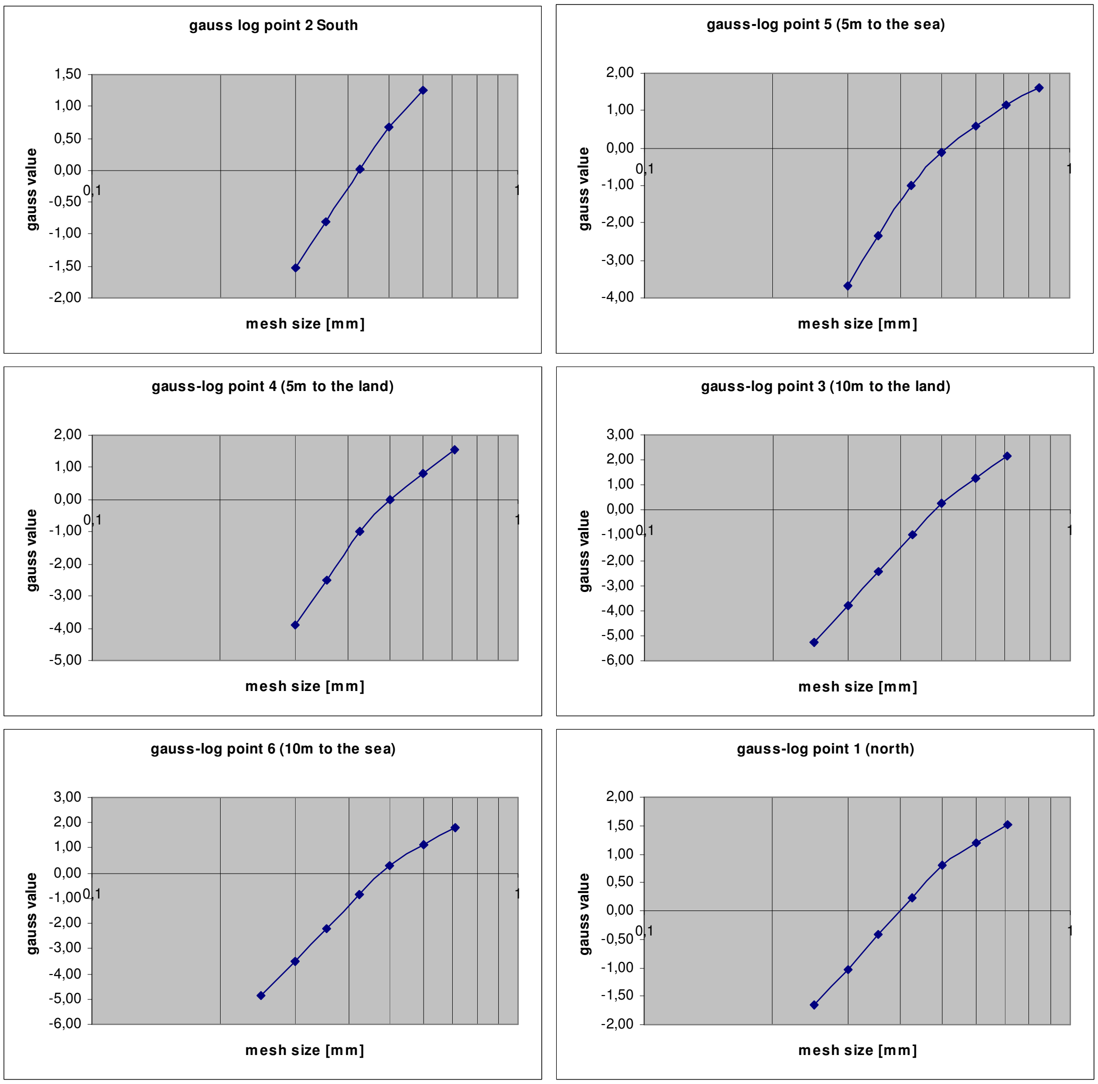


Fig. 8.8 Gauss-log curves for the Sirius beach

These curves are all more or less a straight line. It can be concluded that the samples from the Sirius beach are well graded.

<u>8.3.4) Conclusions</u>

The sand characteristics of the two beaches have been determined and it turns out that they are quite different from each other. The values of the grain sizes on the Sirius beach are less spread than those of the Varna beach. The gauss-log curves also gives more satisfying results, i.e. the lines are straighter. The biggest differences are the characteristics themselves; the D50 of the Sirius beach is about 1.7 times larger as that of the Varna beach This may be explained with the effect that these two beaches are not part of the same beach. They lie eight kilometres apart and this part of the coast has lots of rocky outcrops that interrupt the beaches. This is in contradiction, for example, with central Holland, where the coast is a long straight line that is largely uninterrupted. It is remarkable that the sand of the Varna beach is finer than that of the Sirius beach although it is located nearer to the river mouth (the Varna harbour). One would expect the opposite.
The samples of the Sirius beach have sieving curves that are quite equal to each other, in contradiction to the Varna beach, where the sieving curves are quite scattered. This difference could be the result of the fact that the Sirius beach is a stretch of undisturbed coast with no

building or piers for instance. Here the forces of nature (wind and waves) are unhindered, resulting in a rather homogenous type of beach.

The Varna beach on the other hand has a lot of buildings and piers built on or adjacent to the beach. This hinders the wind and wave forces at places resulting in a beach where the size of the grains is dependant on the location. This is also proved by the fact that the Varna beach comprises several distinct sections that vary in slope, orientation, presence of stones, etc.
Despite the rather homogenous sand found on Sirius beach, the variation in grain sizes found in one cross-section (points 3 to 6) cannot be ignored. The results however do not show a particular pattern; they seem to be at random with the smallest grain sizes found farthest from the waterline (point 3) and closest to it (point 6). Usually one would find the largest grain sizes most far from the water, where they are deposited during storms. The 2004 group indeed found such a pattern. It is likely that the deviation from this pattern that was found this year is caused by the stormy weather that prevailed at the time of the fieldwork, redistributing the sand over the cross-section.
The storms may also explain why the D50 values found on Sirius beach this year (between 420 and 600 μm) are considerably larger than last year's values (between 320 and 410 μm), despite being collected at more or less the same spots. Apparently the rough sea conditions have brought the coarser grains into suspension and deposited them on the beach.
Both beaches have one sieving curve that doesn't reach 100%, for the Varna beach this is the curve of SP7 and for the Sirius beach this is the curve of point 5. This is due to the fact that we haven't used the right sieves. We should have used sieves with larger mesh sizes for these two samples. This mistake can be blamed on the fact that the choice of the sieves was based on a visual assessment of the sample's grain sizes.

8.4) Determination stable slope Varna beach

The slope of the beach depends on the grain size of the beach. The type of sand is defined by the D_{50}, which can be obtained with sieving, described in above.

Dean [1983] suggested a formula that is used to determine the slope of the beach;

$$h = Ay^m$$

h	= water depth at a distance y from the shoreline	[m]
A	= local scale parameter	[$m^{1/3}$]
m	= coefficient, mostly in the order of 2/3	[-]

The local scale parameter (A) is dependent on the sediment fall velocity (w), which is dependent on the sediment size (D_{50}) itself. This is shown in Fig. 8.9;

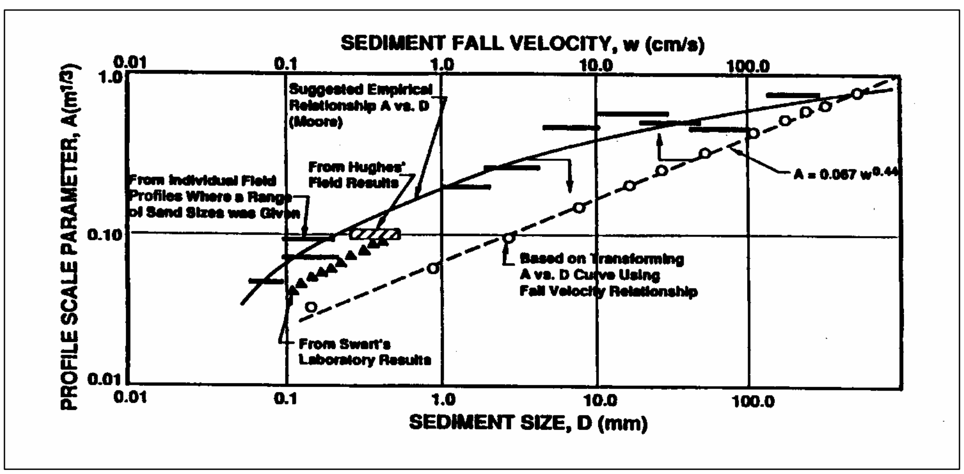


Fig. 1.9 Variation of beach scale parameter A [Dean 1987]

In Table 8.3 the needed parameters are given.

Waypoint	Sample number	D_{50} [mm]	A [$m^{1/3}$]
008	SP5	0.24	0.1286
010	SP6	0.28	0.1406
014	SP7	0.47	0.1977
	Point B	0.31	0.1496
001	SP2	0.19	0.1135

Table 8.3 Sieve Data

y [m]	D50 [mm]	A [m1/3]	20	40	60	80	100	120	140	160	180	200
h [m] SP 5	0,24	0,13	0,95	1,50	1,97	2,39	2,77	3,13	3,47	3,79	4,10	4,40
h [m] SP 6	0,28	0,14	1,04	1,64	2,15	2,61	3,03	3,42	3,79	4,14	4,48	4,81
h [m] SP 7	0,47	0,20	1,46	2,31	3,03	3,67	4,26	4,81	5,33	5,83	6,30	6,76
h [m] point B	0,31	0,15	1,10	1,75	2,29	2,78	3,22	3,64	4,03	4,41	4,77	5,12
h [m] SP 2	0,19	0,11	0,84	1,33	1,74	2,11	2,45	2,76	3,06	3,35	3,62	3,88

Table 1.4 Slopes

With the table of the slopes (Table 8.4), each profile can be determined and plotted. This has been done in the next figures;

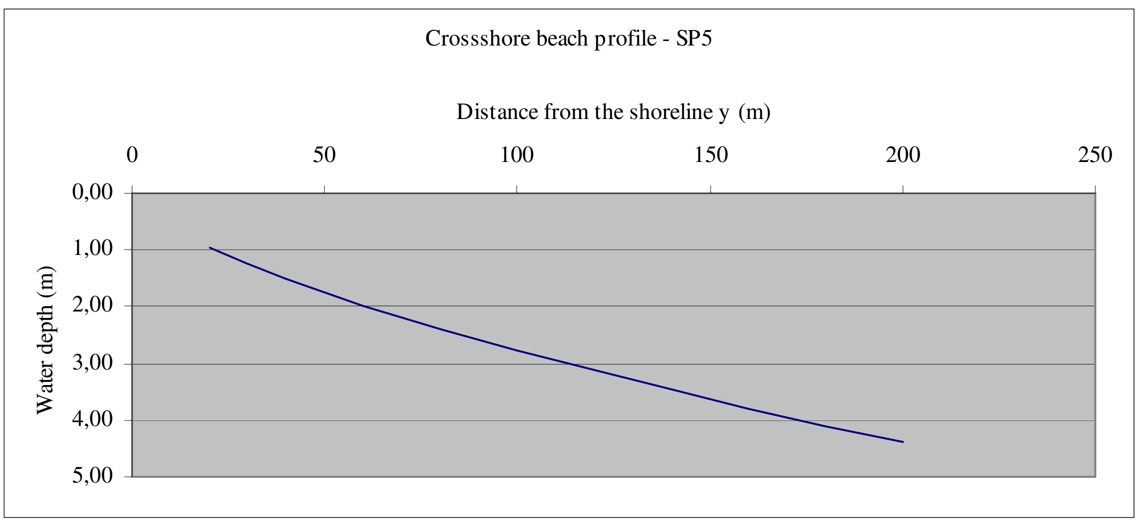


Fig. 8.10 Slope at SP5

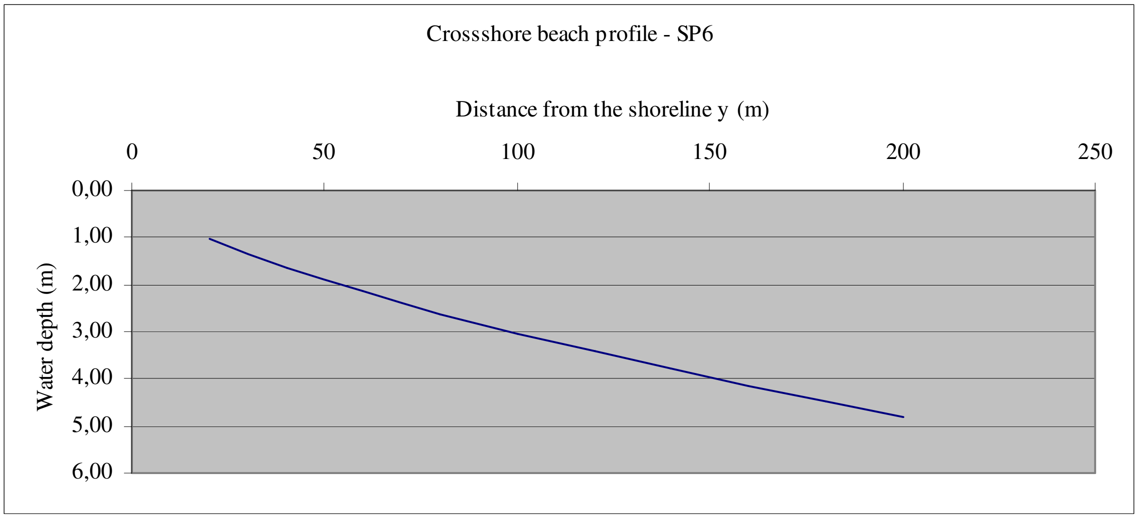


Fig. 8.11 Slope at SP6

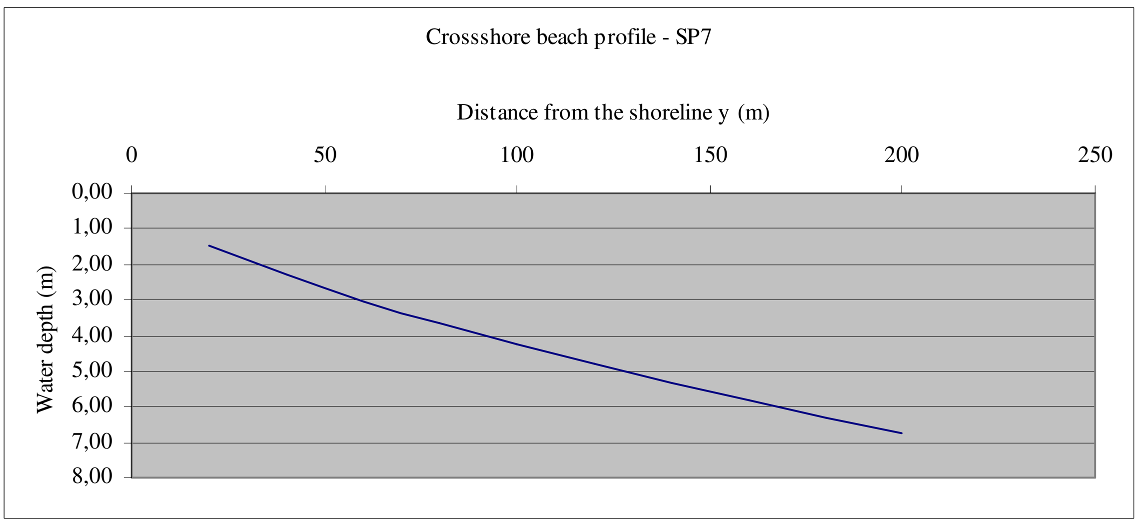


Fig. 8.12 Slope at SP7

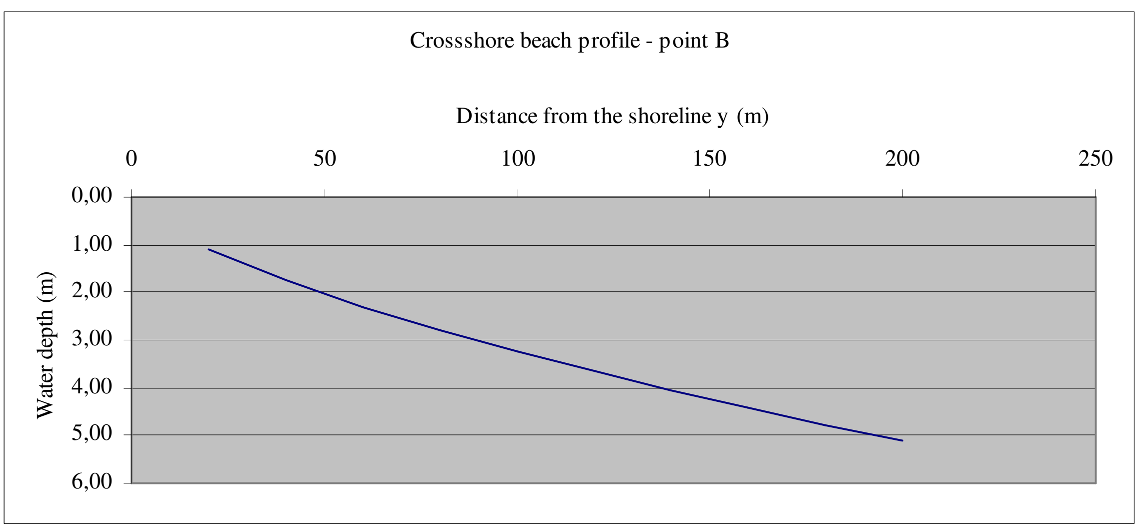


Fig. 8.13 Slope at point B

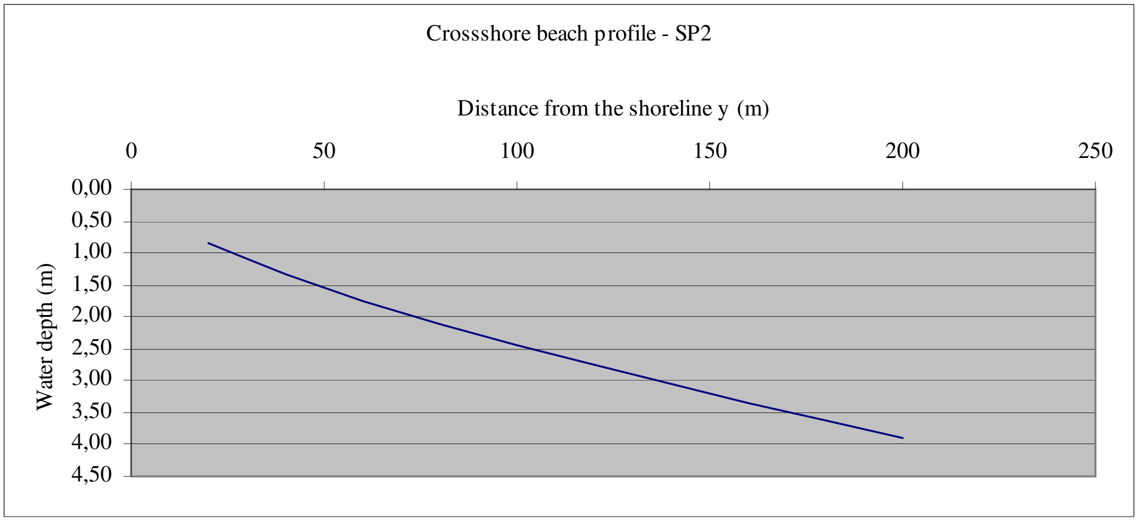


Fig. 8.14 Slope at SP2

9) GROYNE MEASUREMENTS

9.1) Introduction

On the north side of Varna Bay a Y-shaped groyne is located. This groyne is located here with the thought to protect the beach to the north from eroding. A groyne is a structure that can trap the littoral drift along the shore.

To get a first idea whether the groyne fulfils the design guidelines some measurements are done. The purpose of measuring the groyne is to get a first measurement which can be compared with measurements in the future. These measurements will show the capability of the structure to cope with the local wave climate. By comparing the results of different years, changes can be observed which indicates damage of the groyne. Damage is in the sense of moving rocks or degrading of the rock. This will show whether the block sizes where chosen large enough, it doesn't show anything about its influence on the littoral drift.

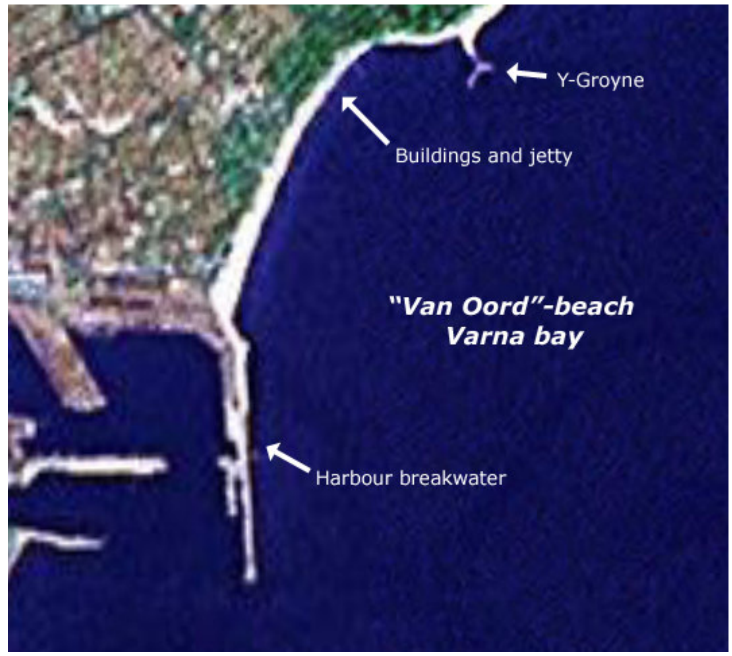


Fig 9.1 location of the Y-groyne close to Varna beach

9.2) Equipment and method

The measurements are done using a hemisphere fixed to the end of scaled rod. Two cross sections perpendicular to the axis of the groyne are determined. This is done by checking the height at every meter distance from the reference line. With the use of a levelling instrument, a theodolite, the height is then determined. The reference line is chosen by using two steel poles on the groyne, a black pole and a yellow pole. They are well marked using a red waterproof marker.

Fig. 9.2 measuring the profile with the levelling instrument (left) and the hemisphere (right)

The hemisphere that is used is in the ideal case a representation of the D_{50} of the rock used in the revetment of the groyne. The diameter of the hemisphere should be half the size of D_{50}, a hemisphere is used to decrease the influence of the individual blocks on the results.

9.3) Measurement accuracy

The measured height in theory has high order of accuracy by using the levelling instrument, which was placed on a stable location. However the use of the incorrect size of hemisphere will likely not give satisfying results. At the time of the measurements no better hemisphere was available than a Ø750 mm hemisphere. It is clear from the photo in figure 9.2 that this hemisphere is not half the D_{50}. The measured distance from the reference line on the groyne was done with a measuring tape with a accuracy of about 1.0 cm.

9.4) Results

This is the first in a series of measurements. Subsequently the result can't be compared yet with the results of other measurements. The attempt was made to measure till the waterline, however due to rough weather conditions and wave action this was not always possible.

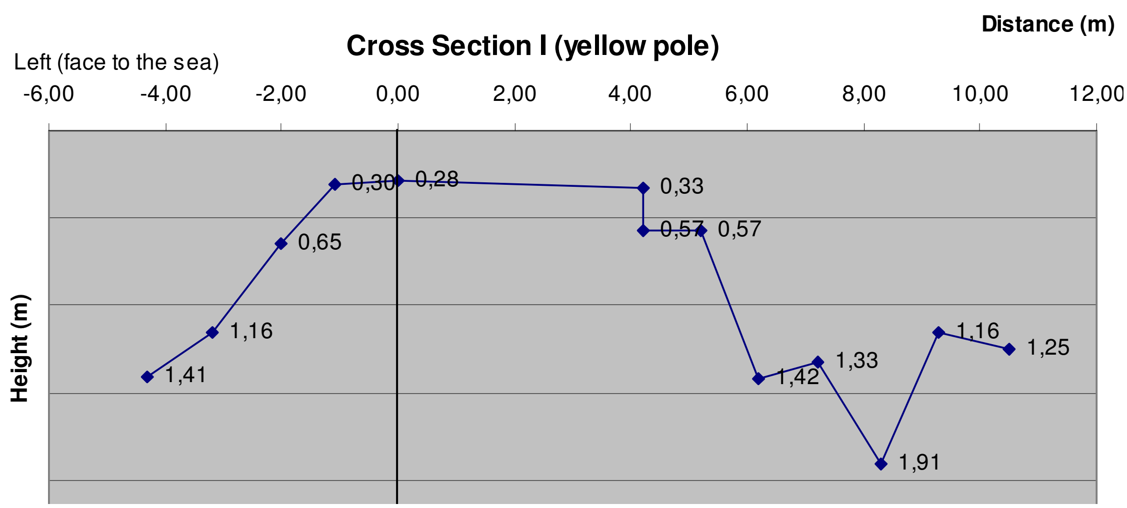


Figure 9.3 Cross Section I at yellow pole.

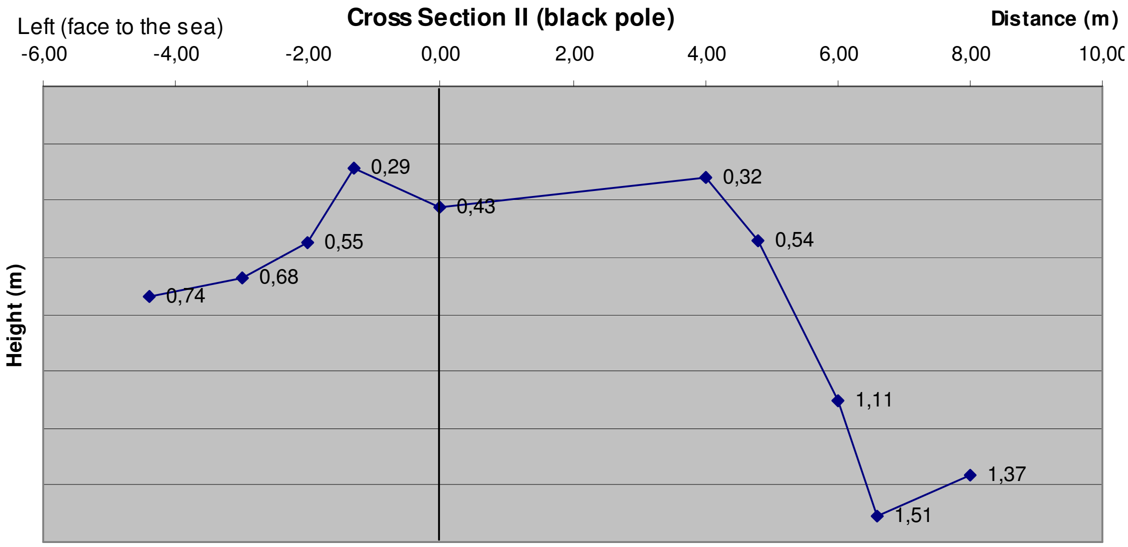


Figure 9.4 Cross Section I at black pole.

The top of the groyne is horizontal with a width of about 5 metres. Here a concrete road has been constructed. From the side of this concrete the blocks roughly follow a slope of 1:4.

9.5) Conclusions

The hemisphere Ø750 mm has a too large diameter to get a good result. This is visible in the non-fluent curve in the profile of the groyne. With a smaller diameter the curve would have been much smoother. It is however not always possible to get the best equipment.