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Fieldwork
Hydraulic Engineering
Designing Cape Sirius

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Preface

This report is written for the course 'Fieldwork Hydraulic Engineering' held between the TU Delft and Sofia University. The course consisted of 19 participants who carried out measurements in and around the small village St Konstantin, near the Bulgarian city Varna, from the 29th of September till 6th of October. The report describes the results and analysis of the fieldwork undertaken in Bulgaria.

We sincerely would like to thank Mr. Boyan Savov of the Black Sea Coastal Engineering Association, for his assistance during the fieldwork, and Boyan Savov Jr. We also would like to thank the University of Sofia for providing the measuring instruments, with special thanks to Prof. Kristjo Daskalov for his assistance during the measurements. Finally, we would like to thank Mr. Henk Jan Verhagen, who organized the fieldwork.

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Executive Summary

The hydraulic fieldwork of 2008 took place from 29 September until 6 October in and around the small village of St. Konstantin near the Bulgarian city Varna. The primary goal of the fieldtrip was to provide students with an understanding and experience in practical aspects of hydraulic engineering and site work. Students were required to undertake suitable measurements which enable improvement designs to the immediate beach front of Hotel Sirius. Hence, with very simple means the hydraulic conditions that influence the design needed to be determined. In this way the students trained a multitude of practical abilities that are of importance for practicing hydraulic engineers. These skills include the estimation of sizes, dimensions, characteristics and values of parameters, communication with other (foreign) engineers and non-engineers about hydraulic engineering topics, analysing uncertain data and managing incidents.

The assignment

The assignment involved the development of an outline improvement plan for the existing hotel beach, the investigation of a possible relocation of a vessel shaped restaurant to a prominent beach position and the outline design of a small leisure boat launching facility for Hotel Sirius.

Measurements

Local hydraulic conditions needed to be established to enable an analysis and the development of an outline design. A series of relatively simple measurements were carried out, an overview of the measurements and results is presented below:

Wave characteristics

Key wave characteristics, significant wave height and average wave period, were determined in the vicinity of the Hotel site based on visual observations and continuous measurements from a wave pressure meter. The measurements were taken on a redundant degraded pier structure approximately 25m from the shore.

The recorded data was analysed and a wave distribution was fitted to the data to enable extrapolation. The significant wave height at the point of interest, near a proposed groyne extension was determined from the data.

At the location of the groyne extension the significant wave height for typical wave conditions is 0.54 m and 0.34m for the visual observation and pressure sensor reading respectively. It should be noted that there is a high degree of uncertainty in the accuracy of the found magnitudes due to the measuring and analysis method.

Bathymetry and morphology

Measurements of the bathymetry and the beach profiles were carried out to establish an understanding of the coastal system and the relative importance of longshore/offshore transport. This was done by comparing this year's measurements with measurements from previous years where available. It was found that there has been a shift of the 2m depth contour right in front of Sirius beach. In 2004 the 1m, 2m and 3m depth contour are relatively parallel. However, in 2008 the 2m depth contour has shifted towards the hotel

indicating erosion. In addition, approximately 50m south of the hotel beach a large shoal is visible. This indicates that a general southward sediment transport trend is present.

A simple analysis of the morphology was made and it was found that the beaches are eroding at some places and accreting at other places. Typically, the effects of extreme storm events on the narrow hotel beach were significant in terms of redistribution onshore/offshore with some sediment being transported to a shoal region. The longshore transport element appears relatively weak. In the longterm it is believed that the overall magnitude of an offshore loss is likely to be low to medium as no significant sudden bathymetric ‘sand trapping features’ appear present. However the limited width of the beach and the relative proximity of the hotel to the water are of concern. Hence, any measures that increase the beach width and allow for a longer time period and ‘buffer zone’ in redistributing the offshore/onshore transport are considered advantageous. Therefore, any beach nourishment increasing the hotels beach width would result in a better risk management and improve beach quality.

The magnitude of the coastal processes is very uncertain and requires monitoring and further measurements in the future.

Two pictures of the Varna beach walk were compared with the pictures made in 2005, from which could be concluded that significant changes in coastline position and erosion processes have occurred in the last three years.

Groyne measurement

The groyne south of the hotel Sirius was surveyed. The stability of the groyne and in particular the stability of the armour units was reviewed by comparing the results of the survey with measurements undertaken in 2002 and 2003. No significant changes were found from the investigation in 2002 and 2003. The volume has remained more or less constant in the last six years.

Quarry measurements

Two local quarries were visited during the fieldtrip to determine the suitability of the rock for a possible groyne extension. Both quarries contained relatively soft rock which are probably not likely to meet the design standard of EN 13833. However the higher quality, stronger rock may be suitable if maintenance expenditure or a shorter design life are accepted. The quarry did have ‘oversized rock’ in stock from blasts which could be cherry picked to make a grading that is suitable for the proposed groyne extension.

Sand characteristics

During the fieldtrip a series of sand samples has been obtained which has been subsequently sieve tested at the TU Delft . A grain size distribution has been developed based on the sieves results to provide characteristics of the beach. The differences in the characteristics of sand at various locations gave insight in the forces at these locations, larger grains are located just a couple of meters off shore and the smaller sand particles are found on higher grounds. This is the opposite of the observations from 2004. Between 2004 and 2008 a beach nourishment was carried out about 500 meters north of Sirius hotel. It is obvious that this has an effect on the beach at the compared cross section.

Conclusions and recommendations

The placement of the vessel shaped restaurant on a groyne extension is a possible solution to relocate problem.

Material for constructing a groyne extension is available at a local quarry. This material may not meet the strict requirements of EN13833, however it is likely to fulfil a marginally lower design standard with higher associated maintenance cost and shorter design life. An initial outline size of a rubble mound type groyne has been determined. Further investigations, such as ground investigations and long term extreme wave analysis are required to develop the scheme further. Furthermore, any beach nourishment which is proposed in conjunction with the groyne extension needs to be assessed on a cost-benefit basis.

Concerning the morphological evolution it is difficult to draw up hard conclusions from the results. The results indicate an offshore/onshore transport with some possible longshore transport in southward direction. The topo- and hydro-graphic measurements have been obtained at multiple locations with various measurement techniques resulting in a high uncertainty in the data and data analysis results. Ideally, long term measurements taken at the same reference points should be undertaken to enable a future more detailed assessment.

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1 Introduction

Each year a fieldwork is planned by the section Hydraulic Engineering of the faculty Civil Engineering and Geosciences of the TU Delft. Master students with a special interest in coastal engineering can participate in this fieldwork and will experience how to collect and interpret different kinds of data related to coastal engineering. The fieldwork is done in the neighborhood of Varna, a Bulgarian city at the coast of the Black Sea.

In this chapter an introduction of the whole fieldwork will be presented. In the first section the project and its immediate surroundings will be introduced. Thereafter the key two objectives and the approach on how to achieve the said objectives will be presented.

1.1 Project area

1.1.1 Bulgaria

Bulgaria is situated in the south-eastern part of Europe, see Figure 1-1. Bulgaria has been marked in red in the figure, the Netherlands is encircled with a green line for reference.

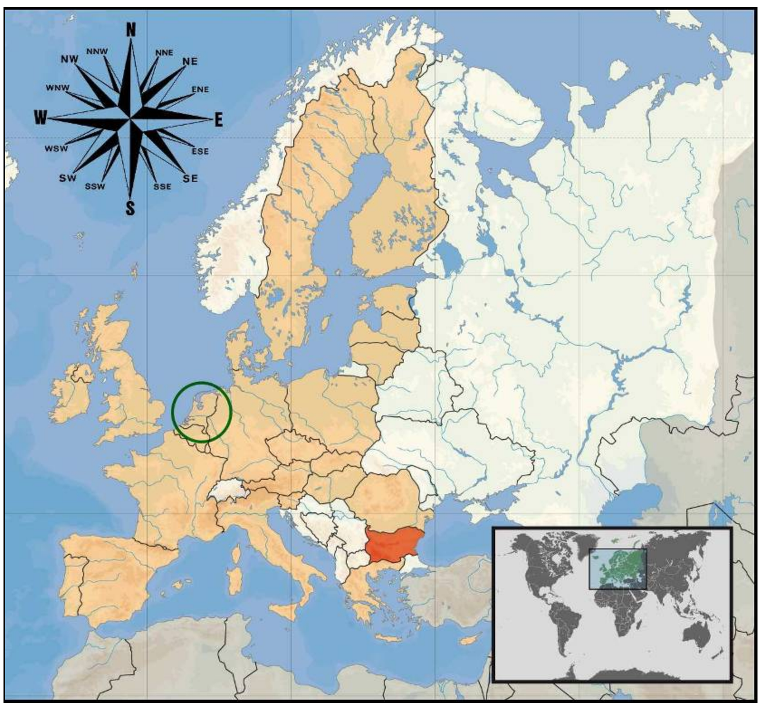


Figure 1-1 Map of Europe with the location of Bulgaria (marked in red) referred to the Netherlands (encircled with the green line)

The country has approximately 7.5 million inhabitants and covers an area of 110,912 km². Sofia is the capital and biggest city, situated in the western part (see Figure 1-2) with 1.2 million inhabitants. Other important cities in the country are Burgas and Varna, both situated along the coast of the Black Sea, and inland Plovdiv and Roese (Ruse).

Figure 1-2 Map of Bulgaria

1.1.2 Varna

Varna is located on the Black Sea coast, see Figure 1-2. It is the largest city along the coast and is commonly referred to as the marine capital of Bulgaria. Varna is a major tourist destination, accommodating a university centre and the headquarters of the Bulgarian Navy. Recently Varna was designated a seat in the Black Sea Euro-Region by the Council of Europe The Black Sea Euro-Region encourages greater awareness and careful use of the Black Sea resources as well as sustainable management. The city of Varna served as the destination of the flight to Bulgaria.

1.1.3 St. Konstantin & Elena

St. Konstantin & Elena is the region where the Hotel Sirius is located and where the main part of the fieldwork at the beach was executed. It is a rapidly growing tourist area with a large number of hotels. The tourists arrive seasonally, and are mainly present during summer time. A map of St. Konstantin & Elena is presented in Figure 1-3. The Hotel Sirius, is indicated with the black arrow in the figure. The coastline of the beach which was subjected to this year's measurements is marked with a red line.

Figure 1-3 Map of St. Constantine & Elena

1.2 Objectives

For this year's fieldwork two objectives are formulated. The first objective is a common objective for each year's fieldwork.

1. Obtain information of hydraulic boundary conditions to be able to evaluate possible changes in morphology.

The second objective concerns the elaboration of an assignment. This year's assignment is to propose a design of the replacement of the ship-shaped restaurant that belongs to the Sirius hotel.

2. Propose a preliminary design for the replacement of the restaurant and for a slope for boat launching.

The restaurant is in the form of a ship and the owner wants to replace the ship to a more prominent location in order make it more like a landmark. Besides this a slope for the launching of boats from trailers, called a slipway, needs to be designed while the public springs and beach bathing facility north of the hotel needs to be sustained. The proposed layout as presented in the assignment is shown in Figure 1-4.

Figure 1-4 Illustration of the replacement of the ship and the design of the launching platform

1.3 Approach

To fulfill the two above mentioned objectives it is important to collect information about hydraulic boundary conditions. These will be obtained by undertaking measurements in and around the area of Sirius beach. The measurements are carried out to acquire information about:

- Wave characteristics
- Beach profiles
- Bathymetry
- Sediment characteristics
- Rock characteristics from quarry
- Characteristics of nearby constructions (groynes, visual inspections)

The wave characteristics are based both on visual observations and measurements from a wave pressure meter. The data has been analyzed and a wave distribution created. With this distribution the wave climate has been evaluated and a governing design wave height computed for the design of the relocation of the ship-shaped restaurant.

Measurements of the bathymetry and the beach profiles were used to develop an understanding of the coastal processes affecting the beach. In the past similar measurements have been carried out. This years results were compared with measurements from previous years to see if significant changes had taken place.

A chapter is devoted to a series of observations made during a 'Varna beach walk'; in the fieldwork of 2005 a similar walk was undertaken. In both years pictures were taken of the most remarkable features concerning possible erosion problems along the coastline of the city of Varna. Pictures of the different years were compared to see if any significant changes in coastline position and erosion processes have occurred within last 3 years.

The groyne south of the hotel Sirius has been surveyed and the results compared with the data from 2002 and 2003 in order to investigate the stability of the groyne and in particular the stability of the armour units.

Two quarries were visited during the fieldtrip and measurements were taken to determine whether the size of the rocks available in the quarry complies with the requirements for the extension of the groyne.

Next the series of sand samples taken during the fieldtrip are discussed. The samples have been subjected to a sieve analysis. With the results of this sieve analysis a grain size distribution can be made. These distributions will provide more information of the characteristics of the beach. Grain sizes present at specific locations of the beach can give information of possible coastal processes that took place in the past.

The report will be finished with the elaboration of this year's assignment of the fieldtrip.

A design of the new location of the ship restaurant will be presented as well as the design of the slipway for boat launching and a groyne for coastal protection. Also a rough design of a beach nourishment is presented in order to widen the beach in front of the hotel to create more area for recreational purposes.

2 Wave measurement

2.1 Introduction

Wave climate is the most important criterion in the design of coastal structures, and influences early decisions on the type and construction methods of a structure. The wave climate data may be obtained via in situ techniques (wave buoys, wave poles, pressure meters and echo sounders), remote sensing techniques (radars), image processing techniques and in many cases through visual observations. In the present study, we obtained the data through visual observations and wave pressure meters and finally processed the results with computer models.

2.2 Wave measurement techniques

2.2.1 Visual observations

Visual observations are often the only source of wave information available to engineers. Sometimes measurements made with instruments are available, but when not, visual observations are usually a promising alternative. Before we can objectively define a wave height or period we need to define precisely what a wave is. In a time record, the surface elevation is the instantaneous elevation of the sea surface (i.e., at any one moment in time) relative to some reference level. In such a record, a wave is the profile of the surface elevation between two successive downward zero-crossing of the elevation (zero means mean surface elevation). In visual estimates, the height of the crest relative to the preceding trough is normally considered to be the wave height.

Figure 2-1 Left side the pole and the attached measuring rod, right side installation of the pressure meter and measuring rod

2.2.1.1 How to collect the data

The visual measurements were carried out by means of a self-made measuring rod and a theodolite that is placed at a distance to have a proper view of the waves in order to distinguish the incoming waves. The measuring rod, with the top above the highest crest and the bottom beneath the lowest wave trough, was attached to the side of the jetty. The position of the theodolite was perpendicular to this rod. The location of the scale should be at a place where the waves are as little as possible disturbed by the bottom (shoaling and breaking) and objects in the surroundings (diffraction). Otherwise, the statistical properties of the waves are disturbed and the properties that are expected are less pronounced. A number of records of 2 minutes were taken to read the measuring rod. Not only the wave heights, but also the wave periods are unknown. Therefore, whilst reading the wave heights someone was responsible for reading the stopwatch at every wave height.

2.2.1.2 Elaboration of the Collected Data

Having the raw data the first task was to find the significant wave height $H_{1/3}$ (mean of the highest one-third of the record), and the average wave period.

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

$$H_{1/3} = 0.54m$$

$$T = 7.6s$$

The accuracy of the observations was in the order of 10cm. Therefore we only have some specific numbers of wave heights. By weighting every specific wave height and counting them, we can find the governing distribution of the wave heights. Figure 2-2 and Figure 2-3 illustrate a good agreement of the analytical Rayleigh distribution and the actual distribution. The theoretical Rayleigh probability density function is:

$$p(H) = \frac{H}{4m_o}\exp\left(-\frac{H^2}{8m_o}\right)$$

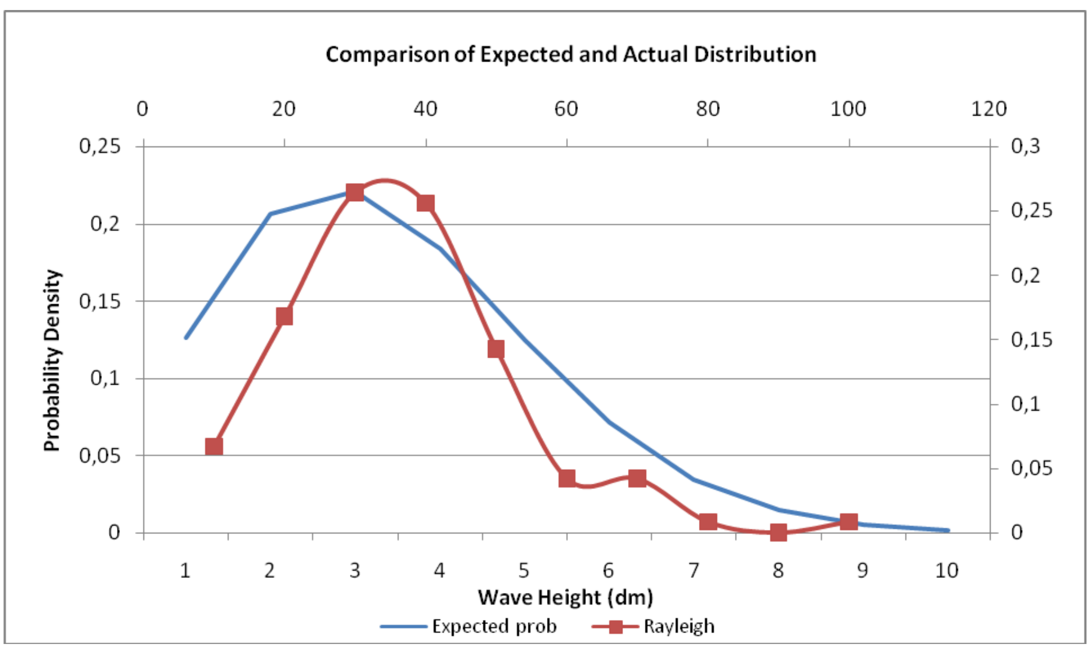


Figure 2-2 Comparison of Rayleigh distribution (red line) and measured wave height distribution (blue line).

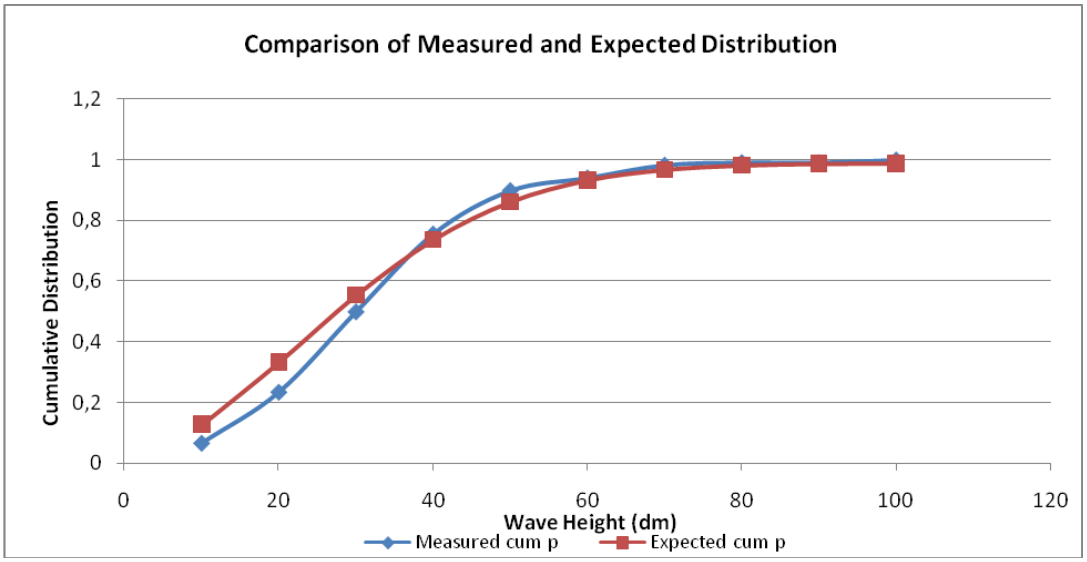


Figure 2-3 The cumulative Rayleigh distribution (red line) and the measured cumulative distribution (blue line) of the obtained wave height.

Further, it can be seen that the probability of having smaller waves according to measured data is slightly smaller than the expected distribution. This might go with the the nature of visual observations; the lower waves are mismeasured and more attention is paid to the higher waves. The rest of the distribution is reasonably close to the expected Rayleigh distribution. This might be a consequence of having moderate weather during measurements (not really high waves).

2.2.2 Wave induced pressure meters

The second method that was used to describe the wave characteristics is by calculating the wave induced pressure at a specific depth using a pressure sensor attached to a pole. All the data were obtained at the pier of St. Constantine south of Hotel Sirius. The concept of this technique is to measure the pressure variations comparing with a reference level, the sea surface, where the pressure is assumed to be atmospheric. At this site the application of Linear Wave Theory is valid, as the ratio of wave height-depth is not large ($\frac{H}{d} < 0.78$) and the waves were not steep ($\frac{H}{L} < 0.14$).

The total wave pressure is $p_{wave} = -\rho g z + \hat{p}_{wave} \sin(\omega t - kx)$ [2.2.1]

with $\hat{p}_{wave} = \rho g a \frac{\cosh[k(d+z)]}{\cosh(kd)}$ [2.2.2]

- p_{wave} = total pressure (KPa)
- $\hat{p}_{wave}$ = wave induced pressure (KPa)
- ω = wave celerity (sec^{-1})
- k = wave number (m^{-1})

- ρ = water density (kg/m^3)
- g = gravitational acceleration (m/sec^2)
- α = wave amplitude (m)
- d = depth (m)
- z = distance from the surface (m)

The first term is the hydrostatic pressure, which is independent of the wave presence while the second term is the wave induced pressure. In deep water the equation [2.2.2] reduces to:

$$\hat{p}_{wave} = \rho g a e^{kz} \quad [2.2.3]$$

The data were obtained and recorded every 0.1 sec. After the determination of the waves and the elaboration of the data (as described with the previous technique), it is apparent from Figure 2-4 that the wave height distribution is approaching the Rayleigh distribution. The accuracy of the data for low amplitude waves is small due to mechanical malfunction. As a result, the significant wave height is equal to $H_s = 0.34m$.

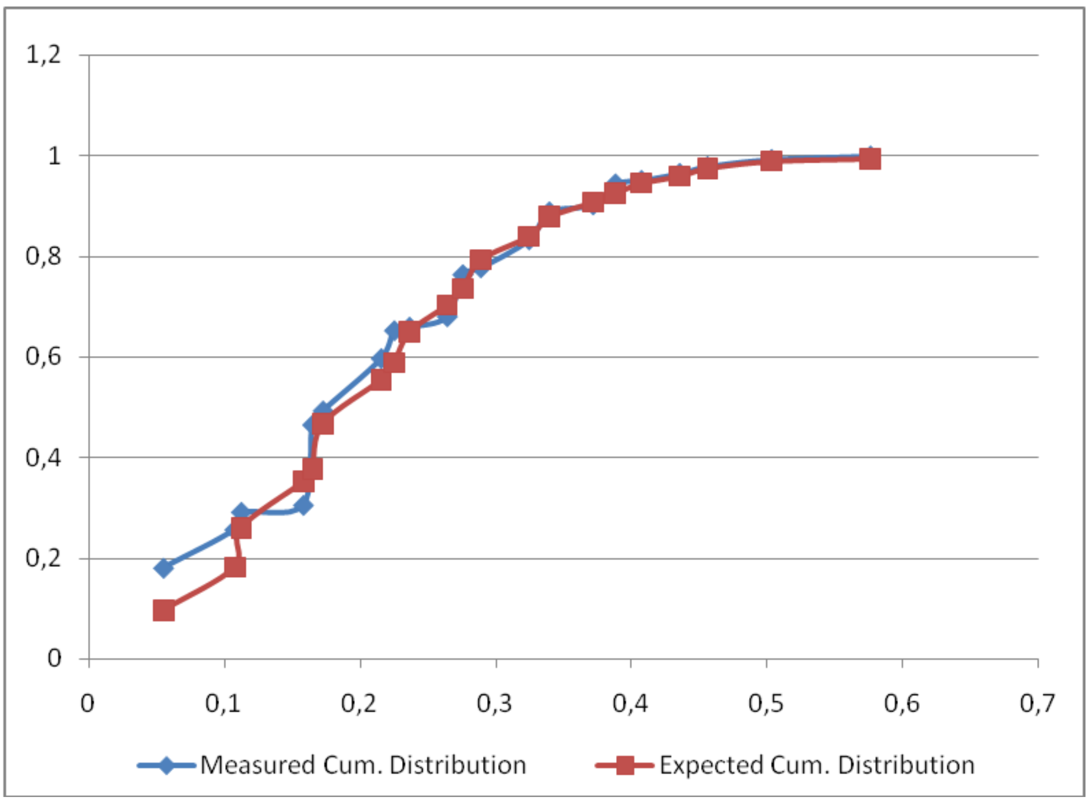


Figure 2-4 The measured wave height distribution is comparative with the Rayleigh distribution.

2.3 Computational results using SWAN model

SWAN is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters, and it is being widely used for engineering and scientific purposes. SWAN is supported by Office of Naval Research (USA) and Rijkswaterstaat (as part of the Ministry of Transport, Public Works and Water Management, The Netherlands).

When ocean waves enter coastal waters, the amplitude and direction will be affected by the limited water depth. This results in different phenomena such as shoaling, refraction, wave-induced breaking, diffraction and reflection. All of these phenomena are modeled using SWAN.

As input, we have the offshore extreme wave height of 6m, with wave period of 12s. In addition, the bottom profile has been obtained from the survey and the resulting bathymetry. Waves in deep water have an angle of 30^o normal to the coast, and while approaching the coast, as a result of refraction, they turn towards the normal to the coast (as can be visually observed).

The results of this computation are essential for the design of the groyne, and the boundary condition of any other coastal structure. Running SWAN for the above mentioned offshore boundary conditions, resulted in a 2m wave height at the toe of the structure.

3 Morphology

3.1 Introduction

In this chapter the coastal morphology around Hotel Sirius will be described and analyzed. The beach, the position of the shoreline and the bathymetry have been surveyed in 2003, 2004, 2007 and 2008. For these three features the method and results of the survey of 2008 will be presented. The results of the four years will be compared as well to give an indication of the morphological evolution of this particular stretch of coast.

3.2 Bathymetry

For a coastal engineering project good bathymetric data is very important. Bathymetric data are measurements of the coordinates and depth of the sea bottom. A bathymetry map can be used to determine the amount of sediment in the profile at the moment of measuring. If there is bathymetric data from several years of the same area, one can evaluate bathymetry changes and possibly predict its evolution in the near future. For engineering purposes near shore wave heights, wave direction and breaker angles need to be computed. In deep water a simple nautical map can be used as bathymetry. In transitional and shallow waters, where waves interact with the sea bed, these maps are often not as accurate as one would want. Therefore one has to survey the area of interest to obtain better bathymetric data. With this data wave propagation and transformation can be computed. This chapter deals with collection and processing of bathymetric data.

3.2.1 Collection of bathymetric data

In order to measure the sea bed near Sirius beach a small inflatable rubber boat (Figure 3-1) has been used. The boat is equipped with a Garmin handheld GPS and an echo sounder were mounted on the boat. In this way the position of the boat could be determined quite accurately with the GPS and at the same time the depth will be measured with the echo sounder.

Before setting out to sea and just start measuring it is wise to make a plan considering:

-the purpose of the data that has to be obtained

-the area of interest

-defining a sailing pattern with so called way points[1] to orientate oneself at sea.

Figure 3-1 Image of the used rubber boat with the measuring equipment on board

[1] Specified x,y-coordinates loaded into the GPS, for instance begin/end point.

3.2.1.1 Purposes

The bathymetric survey serves three purposes. The first is to design the groyne extension in front of Hotel Sirius. The second is the nourishment of Sirius beach. The last is to compare the yearly bathymetries to analyze morphological changes.

3.2.1.2 Area of interest

The area of interest is shown in Figure 3-2. The area just north of Hotel Sirius is suspected to have ridges perpendicular to the beach.

Figure 3-2 Turning points of ridges perpendicular to the beach

To investigate this, this area has been included. The area in front of the Hotel is of direct importance for computing wave heights as well as for determining the amount of material needed for the extension of the groyne. The area south of the Hotel is mainly included for the comparison of the bathymetry of the other years. Moreover, the beach directly in front of the hotel is very narrow. For a nourishment on this part of the beach, this data is indispensable.

3.2.1.3 Sailing pattern

With the determined area of interest completed, the sailing pattern must now be defined. Because beaches and the near shore show, in general, more variation normal to the beach than parallel to it, it is best to sail perpendicular to the shoreline, then 20 to 50m parallel to the shoreline and then sailing out to sea again. In this way the cross shore variations are measured very accurately. Figure 3-2 shows the waypoints that have been determined for the survey. The two lines are basically the begin points (right line) and end points (left line) of the tracks to be sailed and surveyed. When arriving at the first point, one sails in the direction of the landward way point. When it gets too shallow for the boat (d<0.5m) one turns parallel to the coast looking for the next way point and sailing towards it. It does nt matter that the landward line is actually on land, because it merely serves as a target and not as a point that has to be surveyed.

Other interesting features have been measured as well. An example of this is the shoal in front of the southern beach that was quite evident during wave breaking. It almost looked like a rock bottom break, because during two days of waves the location where the waves started to break (the peak) did not change. Moreover, it was the only location where waves were breaking, besides next to the rocky outcrop. During calmer conditions the contour and the summit of the shoal have been mapped with the handheld GPS.

3.2.1.4 Accuracy

Several factors can influence the accuracy of measurements of the echo sounder. Therefore one should be careful while using the echo sounder and take the following aspects into account:

Measured depth versus real depth

The echo sounder is placed underneath the boat, not at still water level. To calculate the real depth, one should add the distance between echo sounder and still water level to all depth measurements.

Inaccuracy of GPS

The accuracy of a GPS depends on conditions which affect the satellite signals. Therefore, you always have to reckon with an inaccuracy of about 5 meters.

Waves

Waves have a negative influence on the accuracy of the echo sounder measurements. When the boat is on a crest the measured depth will be too high, in a trough it will be too low. Furthermore, amongst others waves cause differences in the angle between the horizontal plane and the longitudinal axis of the boat, which generally results in too deep depth measurements, see Figure 3-3. The sound pulses travel a longer distance before they reach the bottom. Also, a different area is measured than what should have been measured, which may cause a spatial shift of features of the seabed.

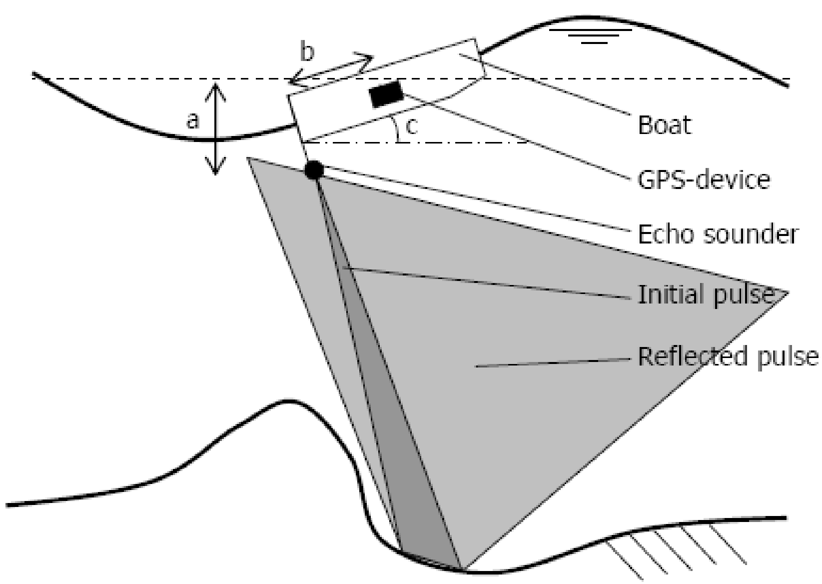


Figure 3-3 Schematization of measurement during big waves

To eliminate the negative effects of waves on the accuracy of the measurement, it is important to measure on a day with as little waves as possible.

Sailing speed

The echo sounder needs some time to measure the depth. If the boat is sailing too fast, it is impossible to measure. Next to that, the sailing speed affects the angle of the boat as well. Therefore the sailing speed should not be too high, say less than 5 km/h.

3.2.2 Processing of bathymetric data

The data obtained during the survey has to be processed to be usable. The raw data consists of a lot of information, but for now only the x, y and depth (z) values are important.

Figure 3-4 Path that has been sailed to measure the bathymetry

Figure 3-4 shows the path that was sailed during the survey. After some editing all these sample points have an x, y, z-value. This file serves as the basis for interpolation in any interpolating software program. In this fieldwork Delft3D-RGFGRID/QUICKIN and Surfer have been used to visualize the sample points. Surfer is used make an interpolation and to compare the bathymetric data of 2008 with the data of other years.

3.2.3 Comparison

In 2003, 2004 and 2008 the bathymetry in front of Hotel Sirius has been surveyed in a way that a good comparison is possible. The data of 2007 is very limited; however, the shoreline measurement of 2007 is useful. With this information a comparison of the wet portion can be made. The area within the white box is chosen as the area to be compared with the other years.

Figure 3-5 Paths that have been sailed for measuring the bathymetry over different years, including area of interest enclosed in the white rectangle

To leave as little room for interpolation differences as possible, the datasets of the bathymetry of previous years have been interpolated with the same grid as used this year.

Based on the bathymetry maps (see Figure 3-6, Figure 3-7, Figure 3-8) it can be concluded that beyond the 4m depth contour there are no significant changes in the bathymetry. The most important change in the shallower part appears to be the shift of the 2m depth contour immediately in front of Sirius beach. In 2004 the 1m, 2m and 3m depth contour are relatively parallel. But in 2008 the 2m depth contour has shifted towards the hotel. Approximately 50m more south a large shoal is visible. This indicates sediment transport to the south. Why this shoal is so pronounced is not yet clear. A strong recommendation for the following years is to monitor this shoal closely. Another observation is the protuberance at (582550, 4787250) in the 3m depth contour in the bathymetry of 2004, that seems to have disappeared in 2008.

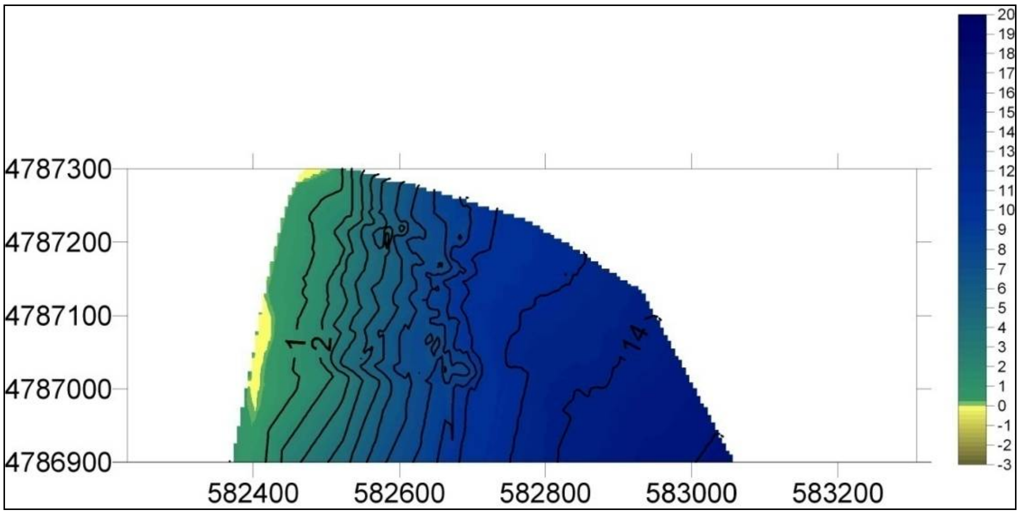


Figure 3-6 Schematized bathymetry of 2003

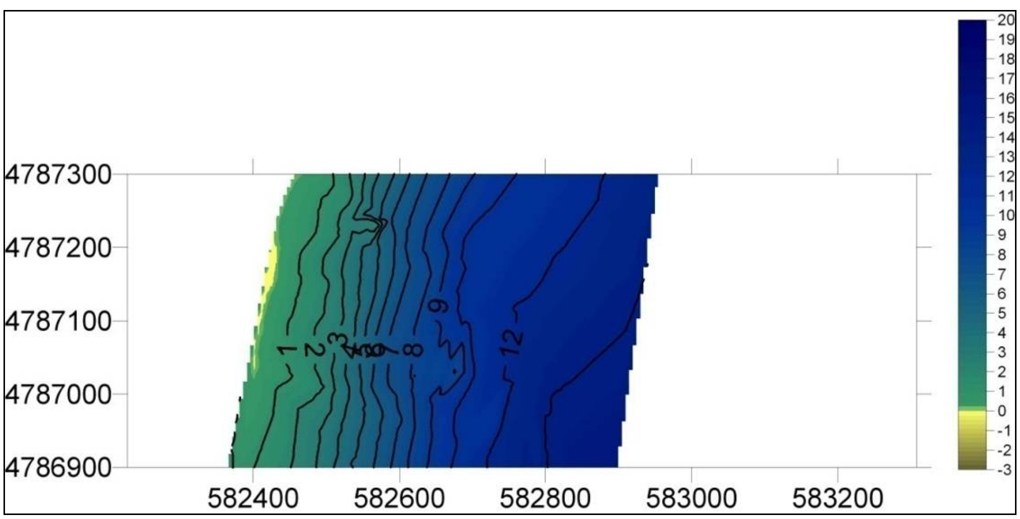


Figure 3-7 Schematized bathymetry of 2004

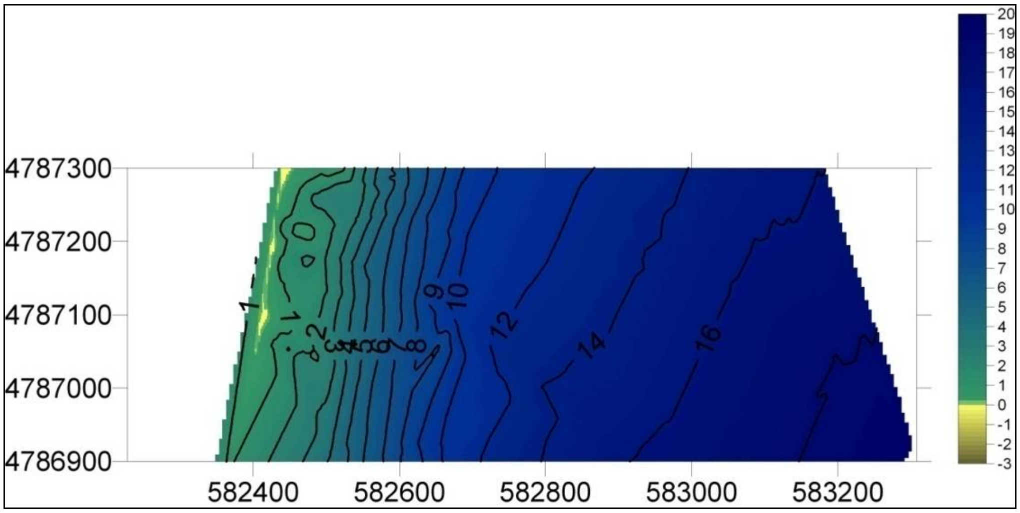


Figure 3-8 Schematized bathymetry of 2008

3.3 Shoreline

The position of the shoreline has been measured by walking along the waterline with a GPS recorder. When compared to measurements of previous years and in combination with the beach profiles, it provides an insight into the long-term local coastal evolution.

Figure 3-9 shows the beach extension North and South of Hotel Sirius, with Cape Sirius being the rocky outcrop in the middle. It also includes the position of a large sand shoal at mid-beach. The landwards limit of the beach is very irregular because of the presence of many obstacles, including buildings.

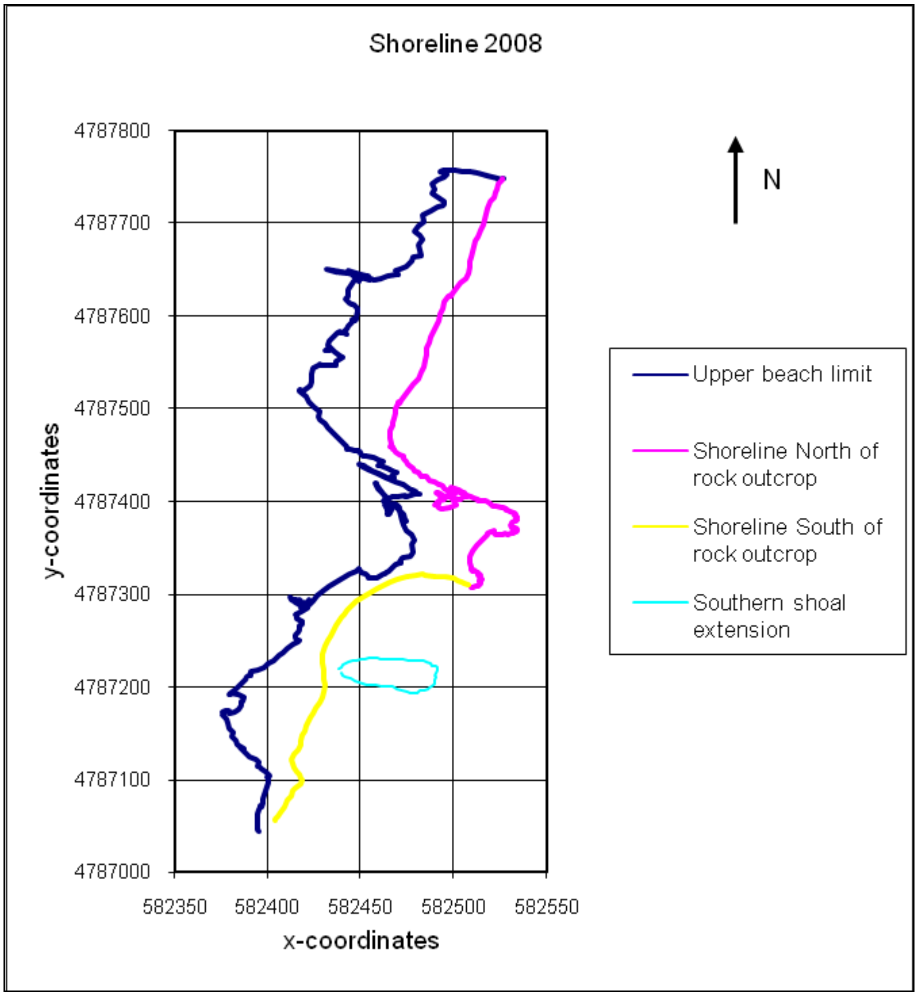


Figure 3-9 Schematization of the beach adjacent to the Sirius hotel

3.3.1 Comparison

For the South beach, measurements of the shoreline are available from previous years. They have been compared in Figure 3-10. The shoreline seems to be fairly stable; maybe slightly eroding immediately in front of Hotel Sirius, but the marked protuberance on the 2003 shoreline indicates a slight southward long shore sediment transport. This is the result of a beach nourishment earlier that year in front of Hotel Sirius, where the sand added migrated to the south under wave action. The rocky outcrop Cape Sirius acts as a natural groyne, with expected slight accretion on its Northern side and erosion on its Southern side. Therefore, in the actual stable beach configuration, beach nourishment alone appears to be an ineffective long-term measure.

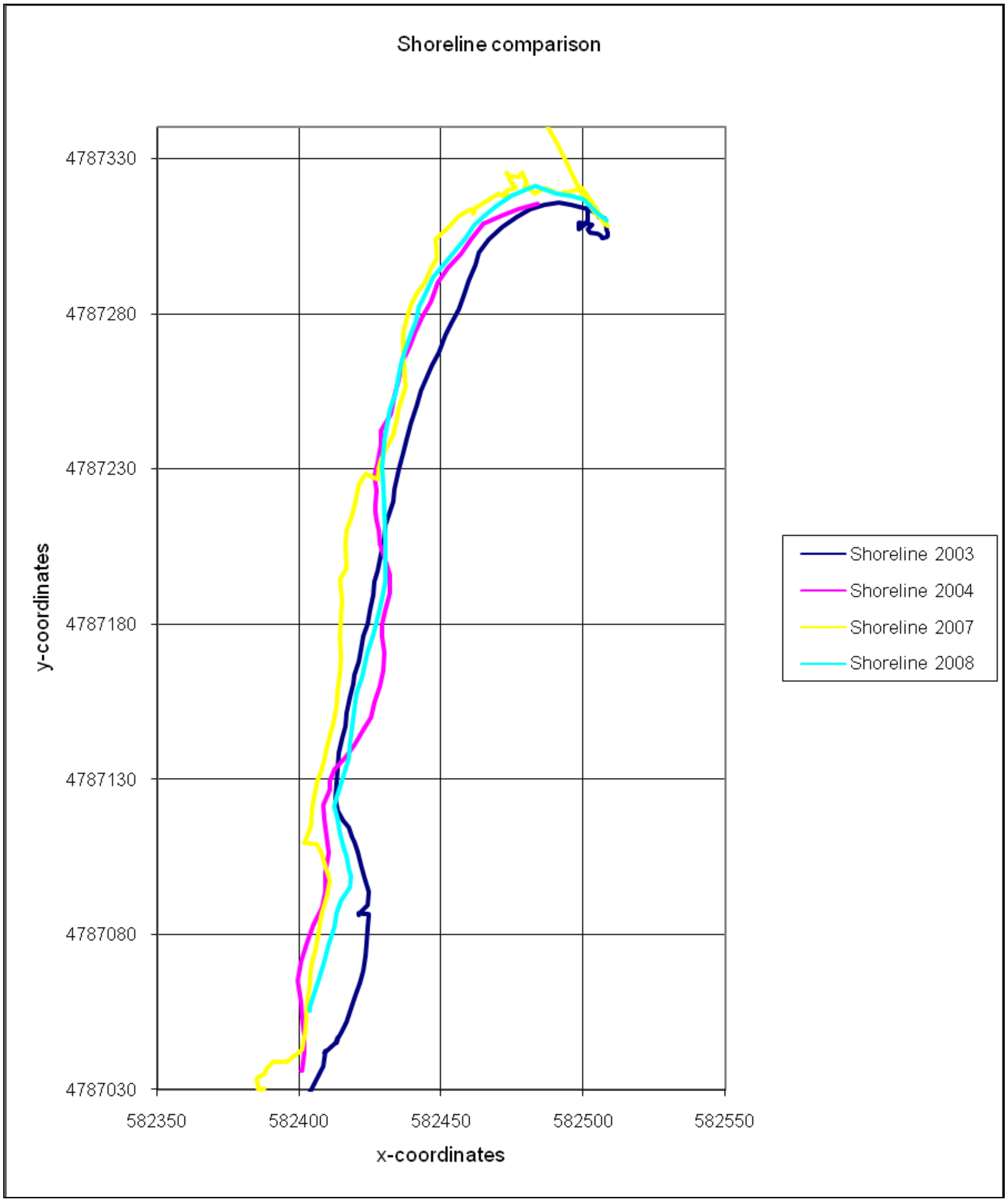


Figure 3-10 Presentation of the position of the shorelines over different years

3.3.2 Accuracy

The shoreline measurements were done with the GPS. The hand held GPS devices used are not accurate surveying instruments. They are able to measure the relative distance well but the exact location on earth has an inaccuracy in the order of meters. In order to measure the exact location of the reference points, the GPS was left on the reference point for a long time (0.5-1 hour). In this period the GPS connects to different satellites and in this way a track path around the reference point is created. By averaging these coordinates relatively accurate coordinates of the reference points can be obtained. The measured shoreline should than be shifted by the difference in coordinates of the averaged reference point and the reference point measured in the same time as the shoreline.

A second measurement of the south beach shoreline has been made at the end of the fieldwork, four days later. Substantial changes can be seen on Figure 3-11, especially in front of Hotel Sirius, where sand ridges and strong erosion were visible. The shoreline retreated by about 10 m in average between the two measurements.

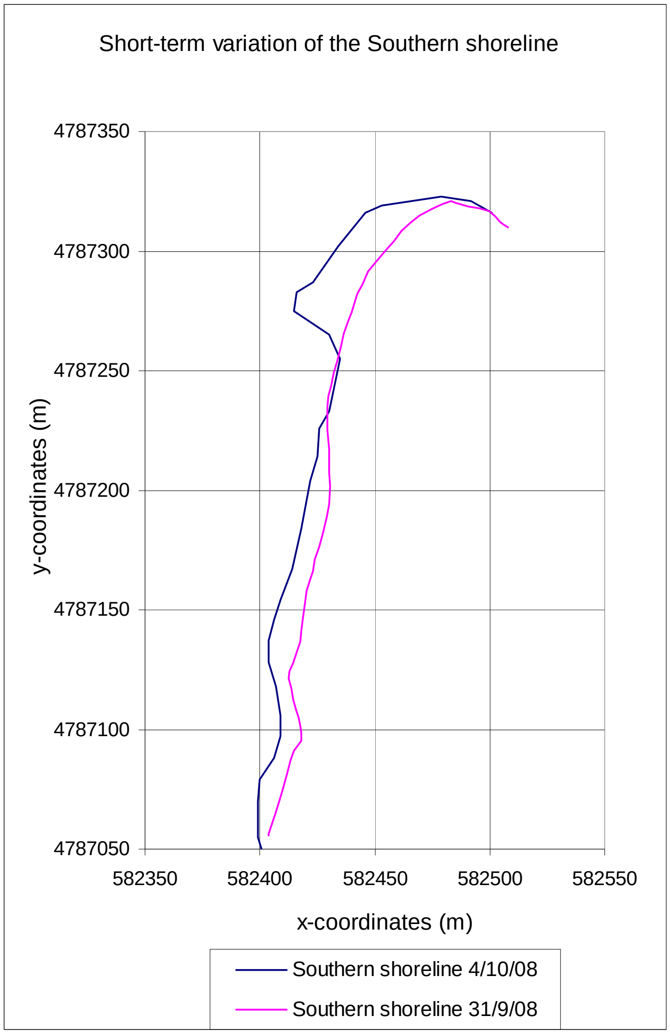


Figure 3-11 Short-term variation of the southern shoreline

This shows the limited accuracy of one single shoreline measurement. The shoreline is dynamic, influenced by tide (negligible in the Black Sea) and wave-induced set-up, an increase in water level near the coast proportional to wave height. Indeed, the first measurement has been done under quiet wave conditions, whereas during the second waves were significantly higher. Finally, the accuracy of the GPS device used is of a few meters, no time-averaging has been done. For a reasonable comparison, shorelines should be measured under comparable wave conditions.

3.4 Beach Measurements

In order to be able to make an analysis of the stability of the coast and the variations in sand locations the bathymetry around the Sirius Beach Hotel is measured. In Figure 3-12 the area of interest is given. The measurements of the beach were split in the measurements of the north side and of the south side of the Sirius Beach hotel.

In section 3.4.1 a description of the method and equipment used is given, followed by a description of the location of the measurements and the reference points used. In section 3.5 and 3.4.1.3 of respectively the cross shore profiles and the shorelines the measured profiles are given, a comparison with previous years is made and the conclusions drawn from that are discussed.

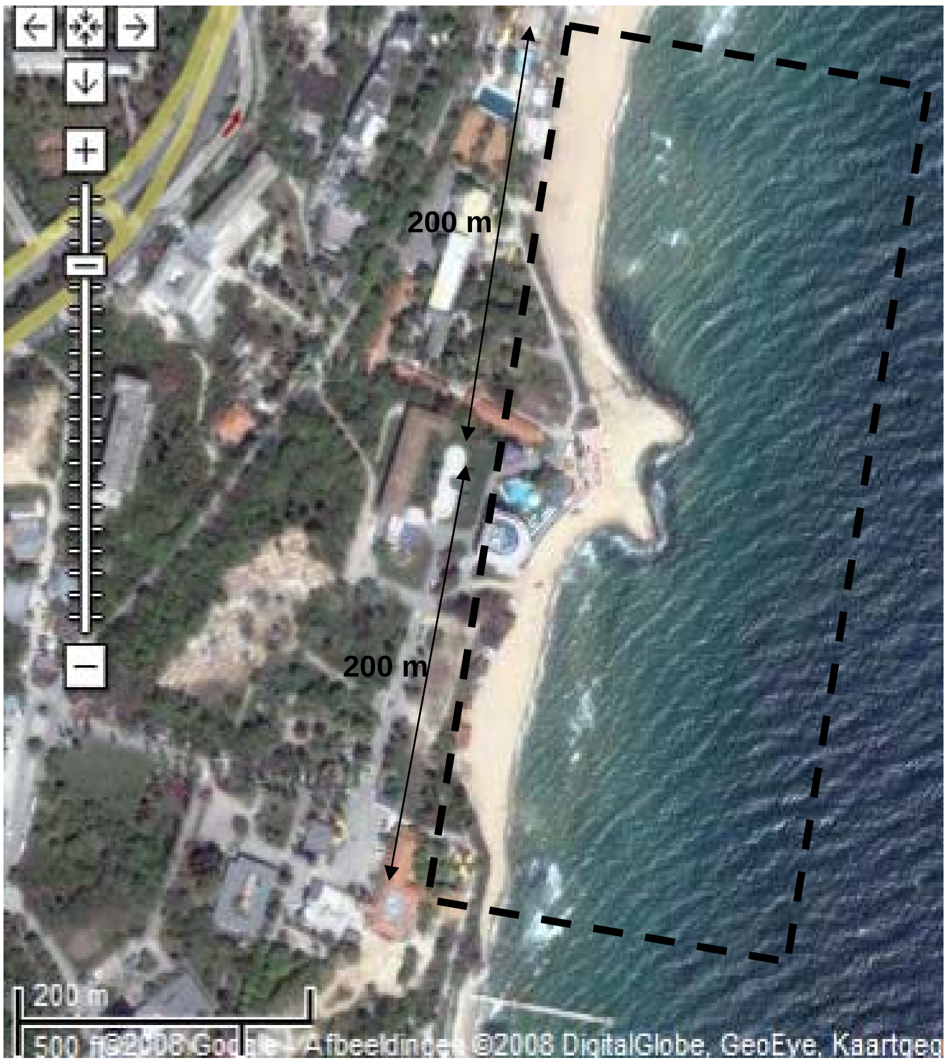


Figure 3-12 Area of interest

3.4.1 Method

In order to measure the on and near shore profiles of the beach one can use different types of equipment. A theodolite is a very easy to use measurement tool. If no equipment is available at the measurement location it is relatively easy to do measurements with only locally available materials. With two poles it is already possible to make a first approximation of the beach profile. If one looks over one pole along the horizon (which is a horizontal line) one can visually measure the height of the second pole relative to the first pole.

3.4.1.1 Equipment

For the beach measurements theodolites were used to measure the on and near shore bathymetry. A theodolite is an instrument that is used for measuring angles. In our case the theodolite is installed horizontally and used to read a value on a vertically placed scale. The first measurement is used to measure the height difference with the reference point. After this one can start measuring depths on the cross-section. We have measured the beach profile at locations with a large change in gradient. In this way we hoped to give a better indication of the profile than by using a standard difference in distance.

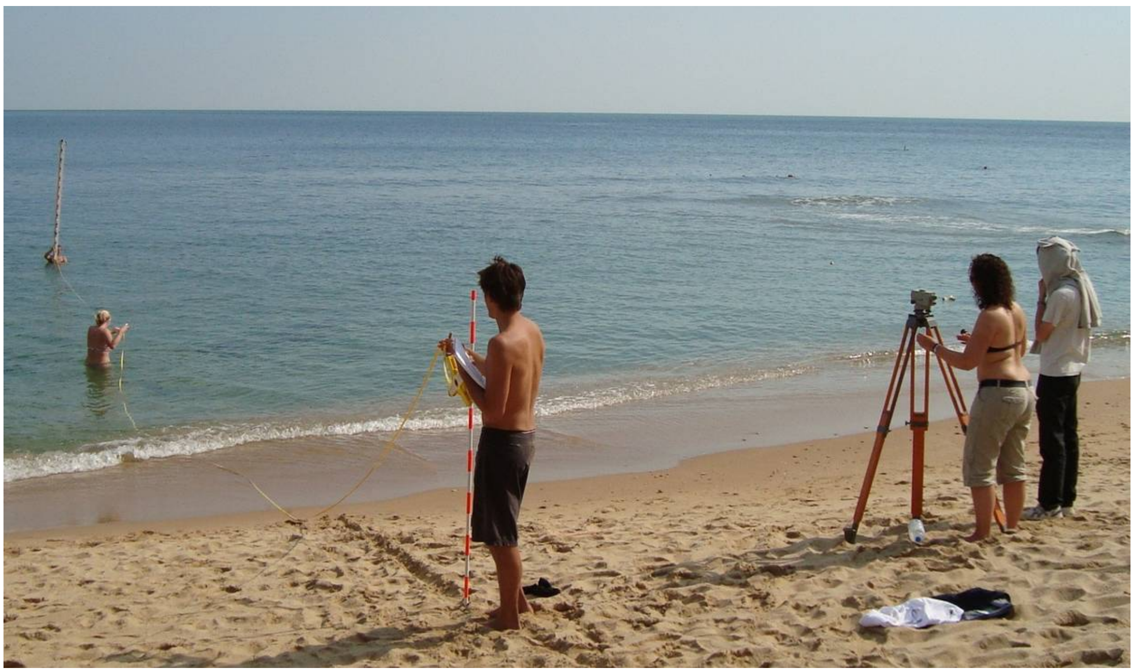


Figure 3-13 Measurements with a theodolite

To measure the near shore profile along the jetty a sounding lead was used. On the rope of the sounding lead every half-meter was indicated. In this way the depth relative to the water line could be measured. Along the jetty approximately every 5m a depth was measured. This was because we were not able to see large differences in gradients from our position on the jetty.

3.4.1.2 Accuracy

The theodolite beach measurements are relatively accurate. The scale was in cm so we were able to read the scale up to centimetres. Nevertheless it should be noted that it was very difficult to keep the scale straight up in the water. The locations of the measurement were located with a measuring tape and the baseline and the line perpendicular were created visually with the aid of a prism. It is to say that the most loss of accuracy in these measurements occur in the location of the measurement more than in the measurement itself. For the purpose of the measurement the accuracy is certainly sufficient.

The measurements with the sounding lead have an accuracy in the order of decimetres. The rope has half-meter indications and it is read visually. The measurements will be distorted because the scale is read under an angle. In addition the measurements were done when there were waves. So it should be noted that there was probably some wind and wave set-up.

3.4.1.3 Location

To make sure that the measurements in every year would be comparable to each other a couple of years ago several reference points were chosen. These referents points were used to construct a baseline which is more or less perpendicular to the coastline. In this way the cross-shore profiles can be taken perpendicular to the baseline. Reference point 1 (rp1) was chosen near the hotel, to the side of the concrete staircase that leads to the beach from the seaside of the hotel. The height of the measurements is measured with respect to the top of the concrete wall at the left side of this staircase; see the left photo in Figure 3-14. Reference point 3 (rp3) was chosen at the end of Sirius Beach. Just to the left of a concrete staircase where the straight wall turns into a curved wall, see the right photo in Figure 3-14.

Figure 3-14 Left: Reference point 1. Right: Reference point 3.

In Figure 3-15 the two reference points used are indicated. In previous years also a reference point called reference point 2 was used, this is somewhere around the location of the text r4 in Figure 3-15. We have not indicated this in the picture because we made no use of this reference point. Our measurements started at rp1. We have measured cross-section rays every 25 m towards rp3. Ray 1 (r1) was located 5.4 m from rp1 because it would measure mostly above water due to the curvature of the beach around here. For this reason we have chosen to measure an extra ray parallel to the baseline. This ray is located on baseline 2 which is constructed perpendicular to baseline 1 and goes through rp1.

At a distance of 150 m from rp1 we have not measured a cross-shore profile because many parasols and beds were present and the profile (above water) does not differ significantly from r5. R7 is taken on rp3 which is slightly further than 200m from rp1.

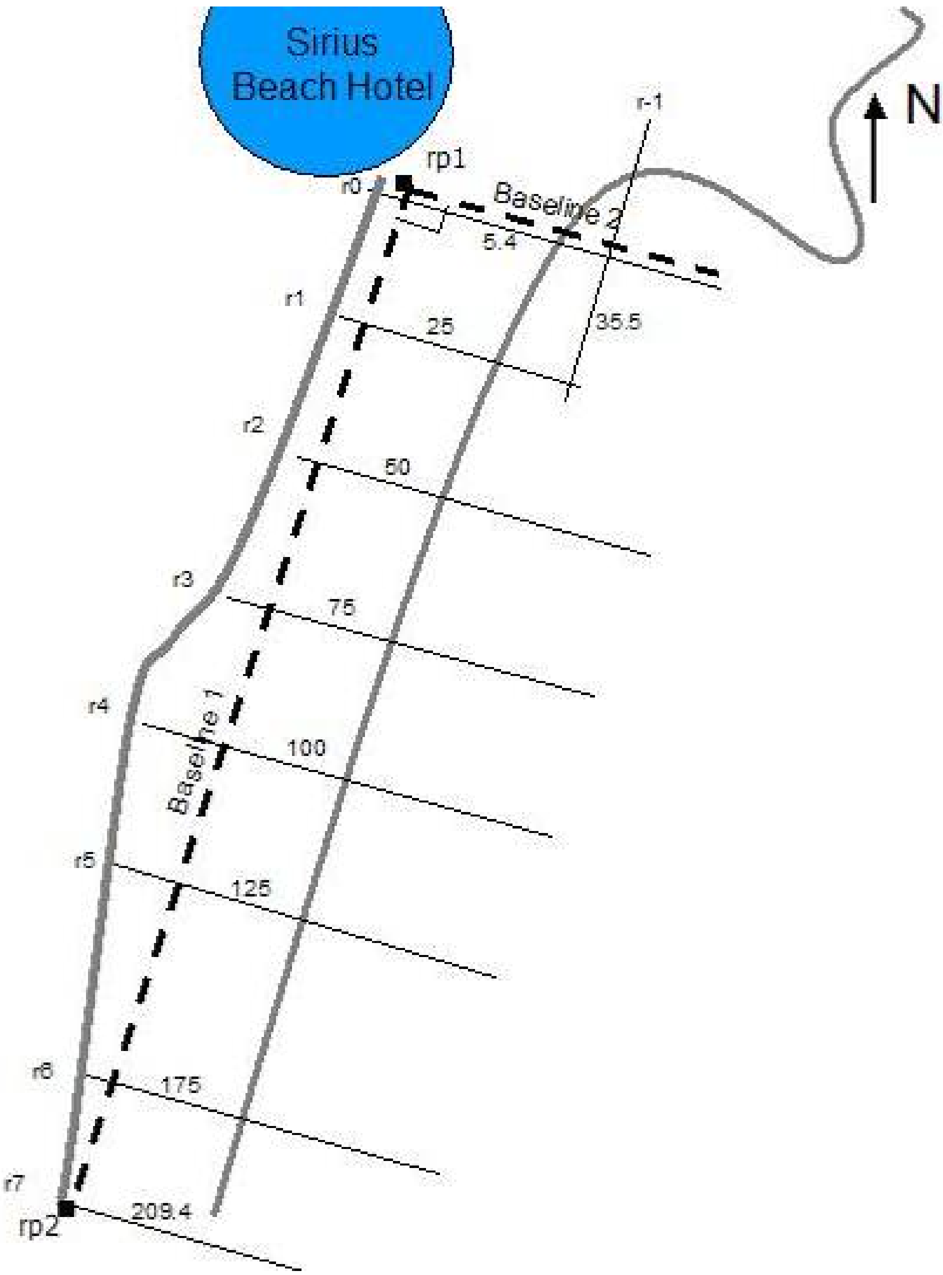


Figure 3-15 Ray Allocation South Beach

3.5 Cross section measurements

3.5.1 North of Sirius Beach Hotel

The Northern beach profiles have been determined using the same method as for the southern beach, however the intermediate base points are not exactly on the baseline. They were chosen along it, at particular landmarks (usually rocks) and their GPS coordinates have been recorded. The profiles are still perpendicular to the baseline, not to the shoreline. They can be seen on Figure 3-16. For following years it would be best to choose cross-sections at fixed distances like for the South beach.

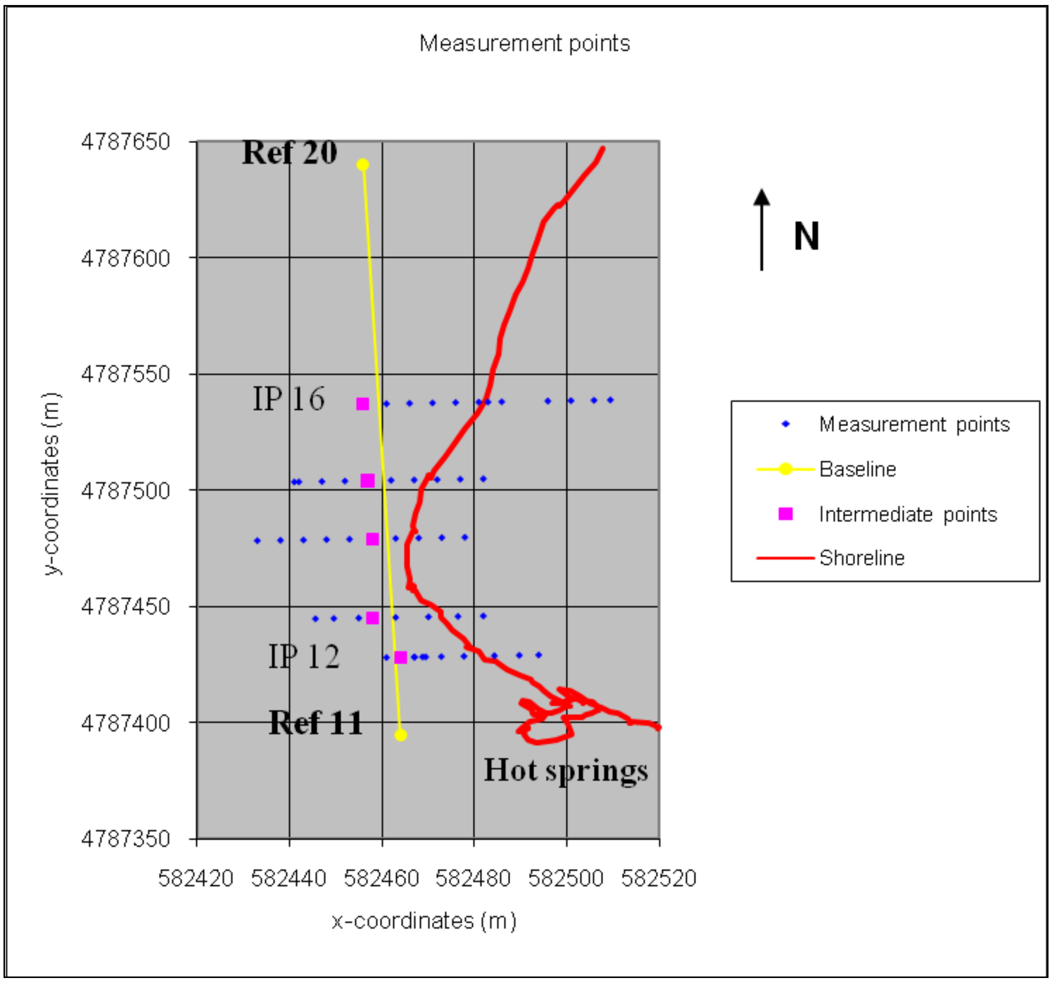


Figure 3-16 Ray Allocation North Beach

Reference points 11 and 20 have been used to determine the baseline. Reference point 11 has been used as the height reference, 284 cm above Black Sea level. Their exact position as well as their averaged GPS coordinates can be seen on Figure 3-16 below. Intermediate points 12 to 16 have the following GPS coordinates:

IP 12: 0582464, 4787428

IP 13: 0582458, 4787445

IP 14: 0582458, 4787479

IP 15: 0582457, 4787504

IP 16: 0582456, 4787537

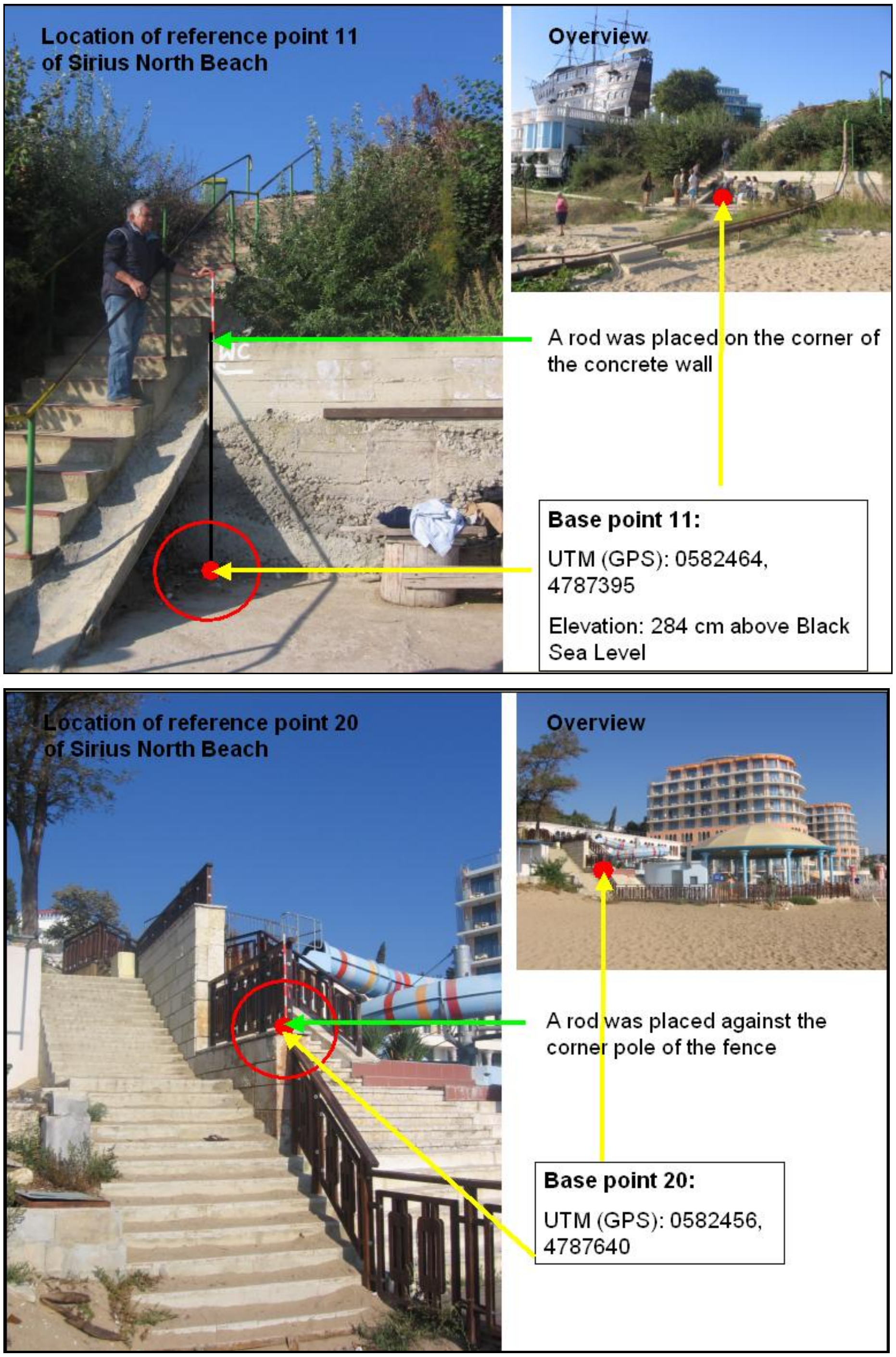
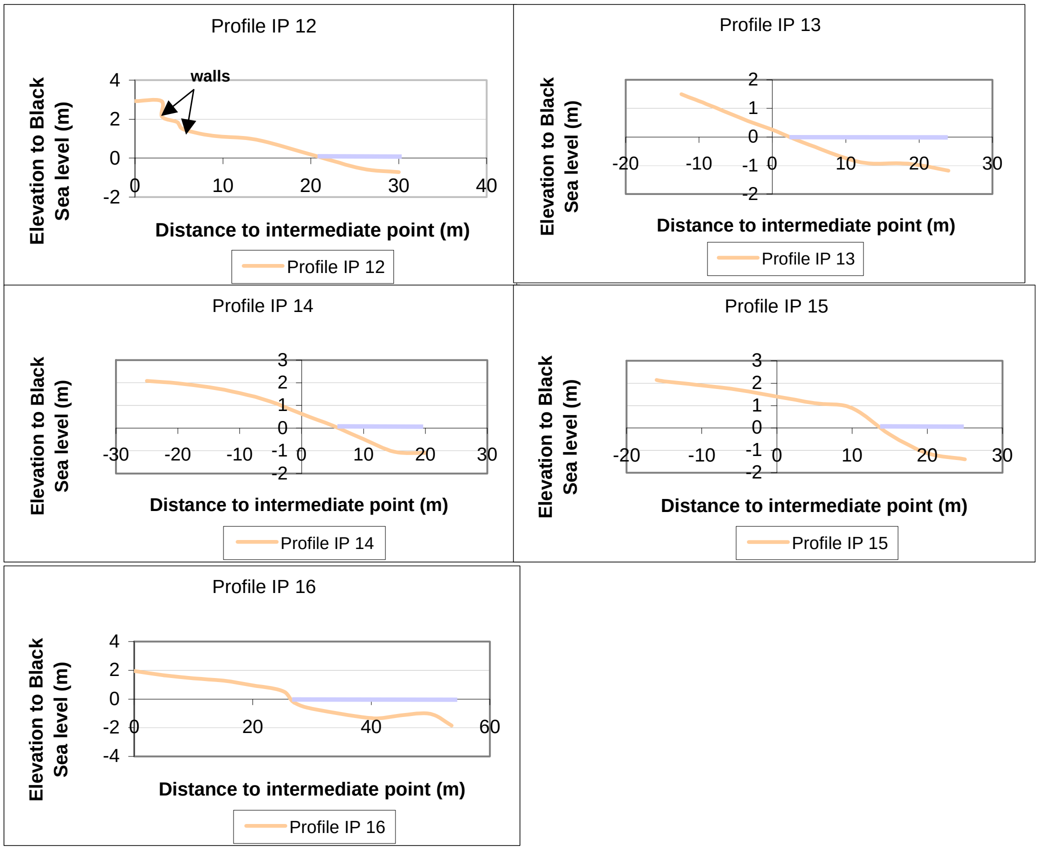


Figure 3-17 Top: reference point 11. Bottom: reference point 20

Figure 3-18 North Beach profiles



These measurements yield the beach profiles above:

These profiles are used in combination with the bathymetric survey to construct contour lines for the elevation map of the area which is then used for shallow water wave conditions. This can be found in the chapter on bathymetry. It is the first time measurements are done on the beach north of Hotel Sirius, hence no comparison can be done with regards to previous years.

3.5.2 South of Sirius Beach Hotel

In the following section the results of our measurements of the beach south of the Sirius Hotel are presented. In the same figures, results from previous years are plotted if there was relevant data to compare it with.

It is difficult to compare results from different years. We measured the whole length of the baseline of the south beach. In the year 2003 they started at our 4th basepoint and worked back to the hotel. They only measured five rays, compared to the ten rays we measured. These rays do coincide, except for ray 0, we measured it with an offset of 5.4 meters from the basepoint.

In 2004 the south beach was measured, but no results were left for us to compare it with. An estimation for ray 2 has been made using the figure printed in their report, which represents this cross-section.

Comparing the values of 2005 and 2008 is not at exactly the same ray. In 2005 they started measuring at RP3 + 25 meters and went back to the hotel. Their first basepoint is on RP3 which is our ray 7, but after that there is a difference of 9.4 meters. This is due to the fact that we started measuring at the Sirius hotel, and the distance between RP1 and RP3 is 209.4 meters, not exactly 200 meters.

The data says they started at RP3 and measured from that location on; however, in the report it says in the caption that they started to measure from RP1. Looking at the data we concluded that the test results should be correct starting at RP3, due to the fact the there is no beach to measure behind basepoint 1.

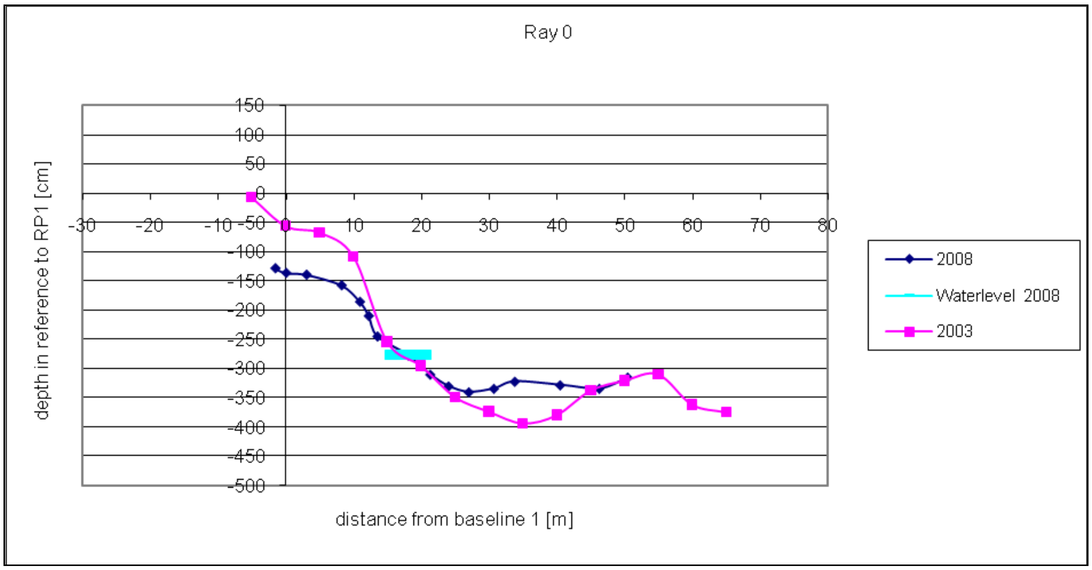


Figure 3-21 Cross-section Ray 0

In Figure 3-21 the cross-section of ray 0 is given. The results represent two different cross shore profiles. The offset is 5.4 meters between the results of 2003 and 2008. The basepoint is located just in front of the concrete wall near the hotel. The beach has been nourished in 2003 which is visible here. Part of this sand moved to the foreshore in a couple of years.

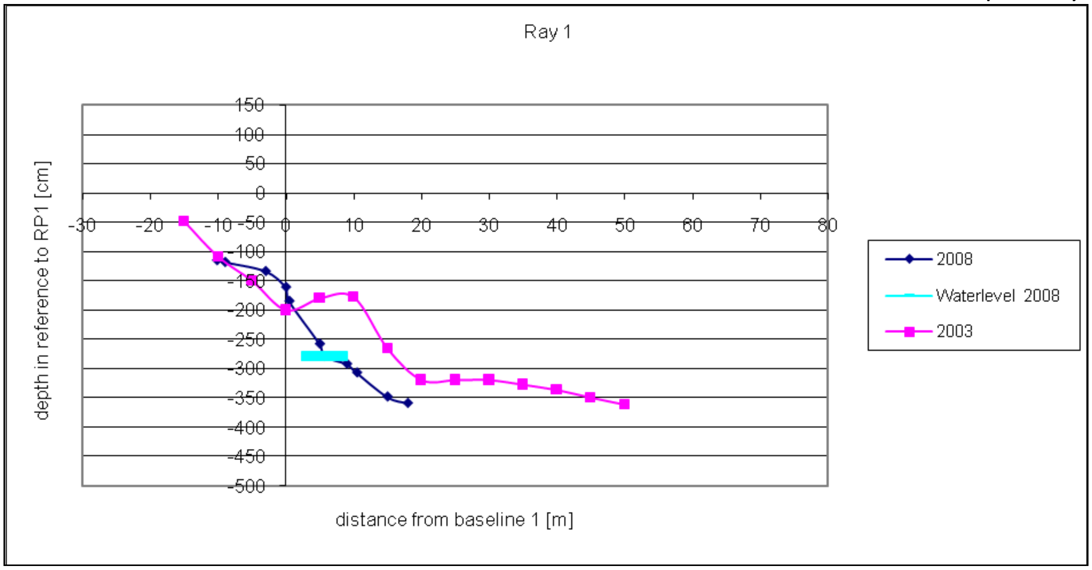


Figure 3-22 Cross-section Ray 1

In Figure 3-22 the cross-section of ray 1 is plotted. The beach is a lot wider in 2003 which is peculiar, because the last measurement performed at this ray and all the other rays was against the concrete wall or where the beach ends. This wall did not move in a couple of years. The nourishment is visible in 2003. By 2008 most of this nourished sand left this section of the beach.

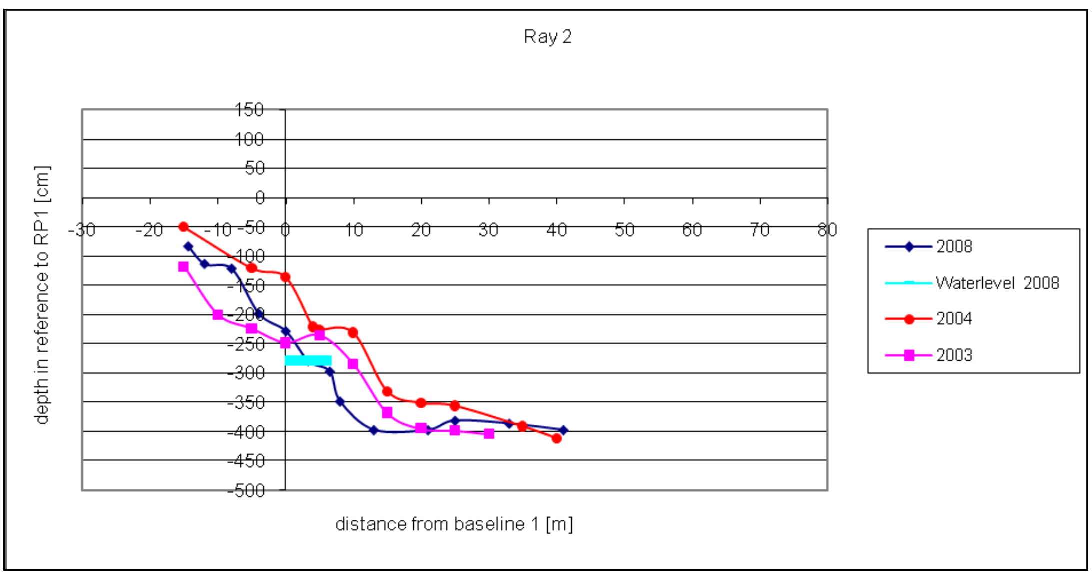


Figure 3-23 Cross-section Ray 2

In Figure 3-23 the cross-section of ray 2 is printed. The data from 2004 results in a higher beach profile than measured in 2003 and 2008. Some of the nourishment could have been moved downstream by wind and current resulting in a higher profile, but the difference between 2003 and 2004 is quite large so this probably did not occur. The profiles of 2003 and 2008 are similar, with a maximum difference of 60 cm.

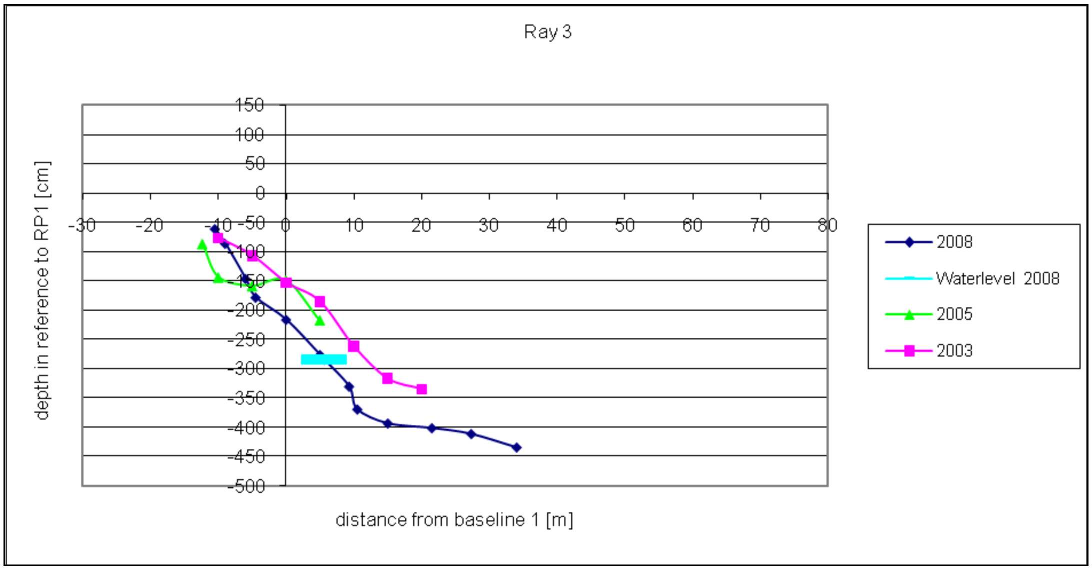


Figure 3-24 Cross-section Ray 3

In Figure 3-24 the cross-section of ray 3 is plotted. In 2005 only the dry profile was measured due to bad weather. So no comparison between the wet cross-sections can be done, just from the dry beach profile. Also taking into account that there is a difference of 9.4 meters in the cross-shore profiles, it appears that quite a lot of sand left the beach in the period 2003-2008.

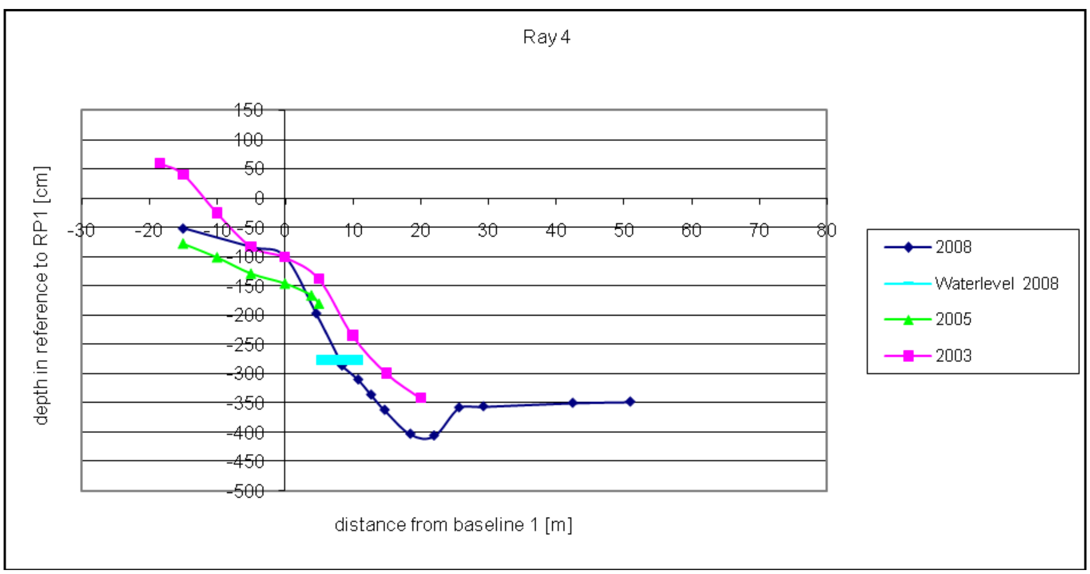


Figure 3-25 Cross-section Ray 4

In Figure 3-25 the cross-section of ray 4 is printed. In 2003 there appears to be a large volume of sand located at the end of the beach which was not there anymore in 2005 and 2008. The lower dry profile comparing 2005 and 2008 could be a cause of the bad weather which moves the sand off shore and with calm weather this sand will be moved back. This cross shore transport is also visible in the Figure 3-26 and Figure 3-27, which represent the cross-sections of ray 5 and 6. Ray 4 and 5 depict the shoal of sand just offshore the beach.

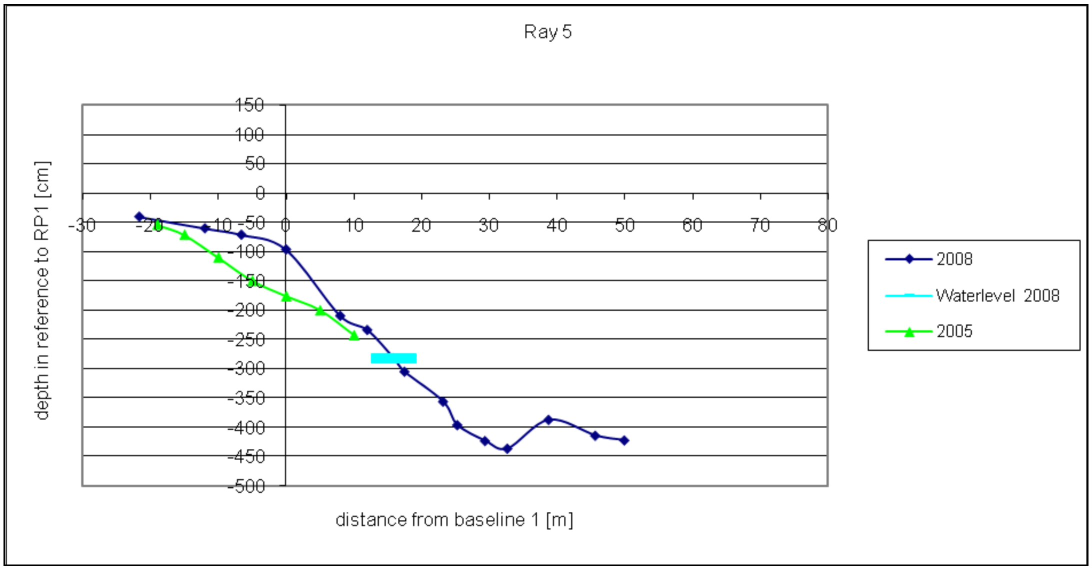


Figure 3-26 Cross-section Ray 5

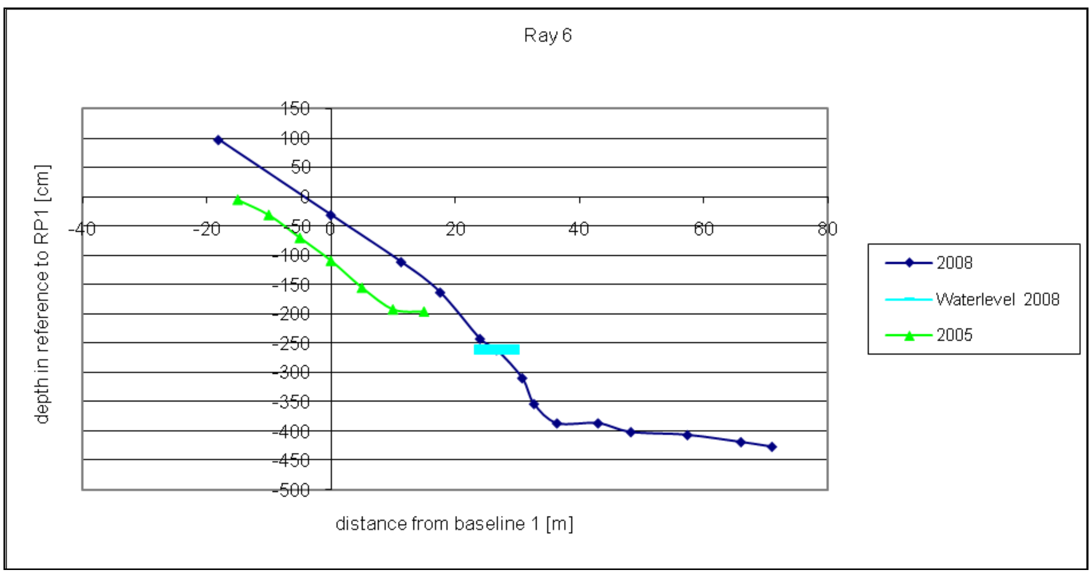


Figure 3-27 Cross-section Ray 6

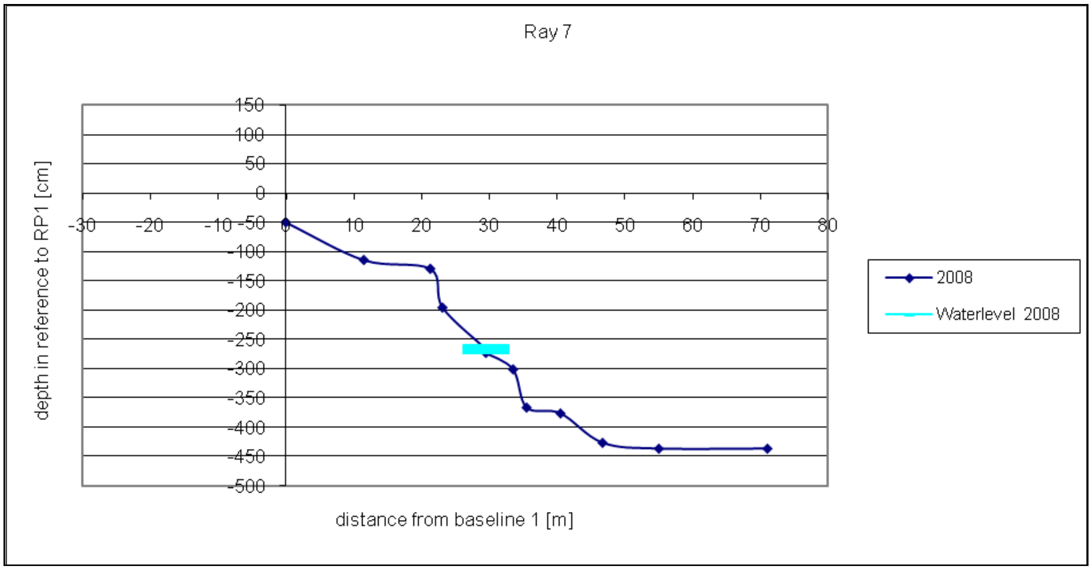


Figure 3-28 Cross-section Ray 7

InFigure 3-28 the cross section of ray 7 is plotted. At a length of 20 meters from the baseline a scarp is visible. The sand has been washed away at this location. Along the beach at some locations scarps were visible. The height difference sometimes went almost up to one meter.

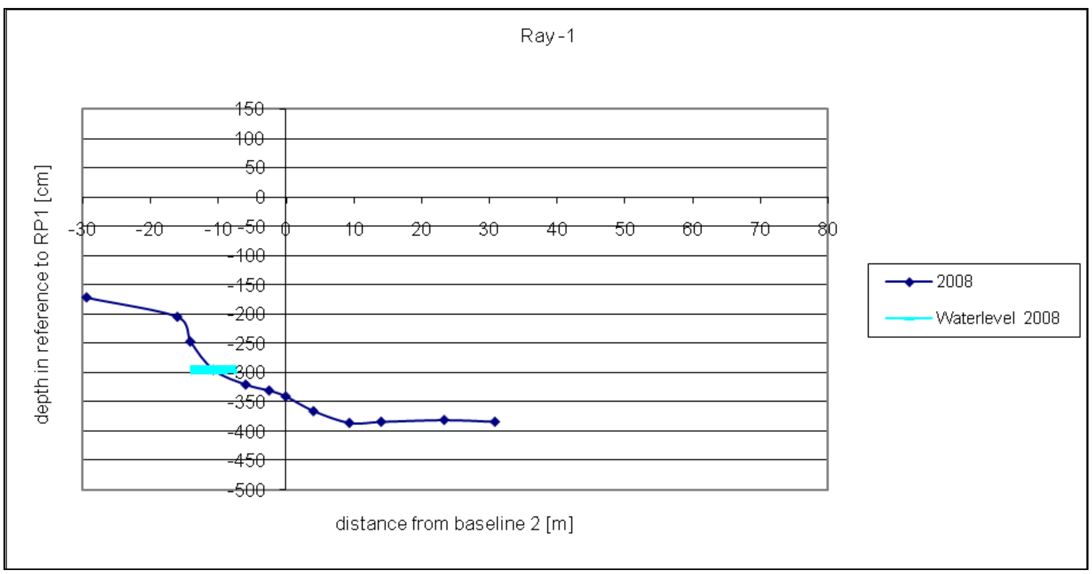


Figure 3-29 Cross-section Ray -1

In Figure 3-29 ray -1 is printed. Ray -1 is the ray parallel to the baseline and almost parallel to the shore. The gradient underwater is not as steep as the other profiles. The depth contours seem parallel to the shoreline.

3.5.3 Jetty

The cross shore profile along the jetty was measured. The profile is printed in Figure 3-30. There are no records from previous years so a comparison cannot be done regarding this profile.

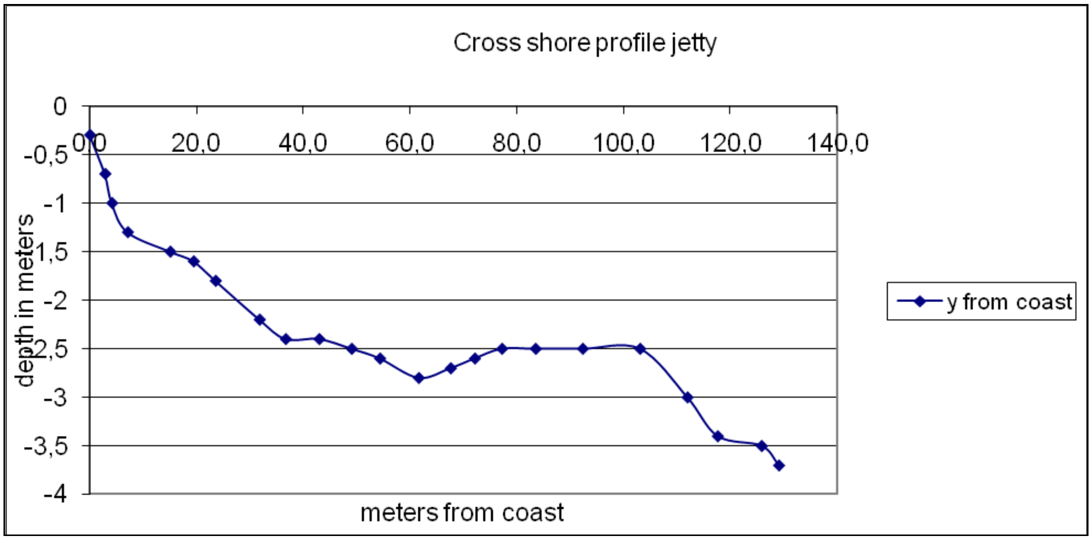


Figure 3-30 Depth profile along the jetty

3.6 Conclusion

Measurements have been done in previous years, but not always in the same way. Which results in data what is not really comparable and so a morphological development is hard to determine. For the cross-sections south of the Sirius Hotel measurements have been done for a couple of years but a development is difficult to determine. The nourishment in 2003 is visible near the hotel but where the sand moved to is still unknown.

4 Varna beach walk

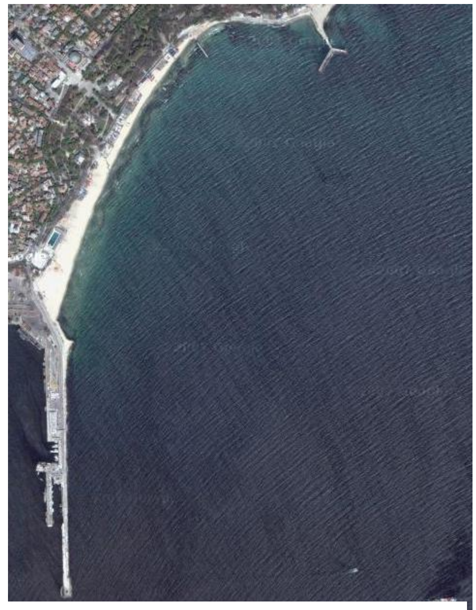


Figure 4-1 Varna beach with the breakwater (south) and Y-groyne (north).

In 2005 Varna beach has been measured by another group of TU Delft students participating in the fieldwork course of that year. They have surveyed the near shore as well as the actual beach. Moreover they took some pictures of this beach at locations where the shoreline had come very near to buildings on the beach. In this section the pictures of 2005 will, where possible, be compared to the pictures taken during the 2008 fieldwork. The rest of the pictures taken in 2008 will be presented as well to clarify some observations made regarding to erosion problems.

The start of the walk was at the Tetrapod breakwater of the harbour of Varna and the end of the walk was at the Y-groyne North of Varna, see Figure 4-1.

4.1 The beach walk

The first thing that became clear was that at the base of the breakwater accretion took place. According to the professors this was the result of nearly 100 years of longshore sediment transport. This was the first observations that longshore transport in this area is very small.

Walking to the north the beach gets narrower, until approximately 500m south of the Y-groyne where no beach is left. Rock and rubble is visible in Figure 4-2.

Figure 4-2 Stones and rubble at northern end of Varna beach, 500m south of Y groyne.

There are no pictures taken at the same locations as in 2005. However, at the base of the Y-groyne almost the same picture has been taken in 2005 and 2008 (resp. Figure 4-3, Figure 4-4).

Figure 4-3 Y-groyne 2005

Figure 4-4 Y-groyne 2008

Not a lot can be said about the beach width or stability of the groyne. It looks like the stones on the right side of the groyne have not been moved by storms except for two big stones visible in Figure 4-4 which are not in Figure 4-3. To show the accretion on the north side of this groyne in 2005 clearer, Figure 4-5 has been added.

Figure 4-5 Accretion on northside of the Y-groyne 2005

Now that the southern and northern end of the beach walk have been presented, an attempt will be made to compare the rest of the beach. Since the pictures are not taken on the same locations and in the last 3 years several buildings have been demolished or rebuilt, it is difficult to find reference points or views that can be compared. The first comparison of the beach views can be made using Figure 4-6 and Figure 4-7.

Figure 4-6 view in 2005 of Varna beach looking south. Object of comparison is the green building and balcony into the sea.

Figure 4-7 view in 2008 of Varna beach looking south. Object of comparison is the green building (not there anymore) and balcony into the sea (shortened)

The green building visible in Figure 4-6 is not present anymore in 2008 (Figure 4-7). Furthermore the balcony on the yellow/white building has shortened. In 2005 there were two rows of columns, shown in Figure 4-6 and Figure 4-8.

Figure 4-8 Balcony in 2005. Two rows of columns beyond the last wall of the building.

Now the balcony has significantly shortened (Figure 4-9).

Figure 4-9 Shortened balcony

Figure 4-10 already shows the degradation of the structure in 2005.

Figure 4-10 Damaged balcony and substructure in 2005

Another picture that can be compared between the years 2005 and 2008 is taken at the northern end of the beach, looking north (Figure 4-11)

Figure 4-11 North end of Varna beach. Erosion. 2005

Figure 4-12 North end of Varna beach 2008

This is the last stretch of beach at the northern end. The artificial palms are already rooted in the sea and will, just like the building behind them, eventually end up in the sea. This is confirmed with a picture taken in 2008 showing the same stretch of beach (Figure 4-12).

The buildings that were there in 2005 are no longer there. A completely new building has been built in the mean while. This building is suffering from the erosion as well. It seems; however, that in the design of this building, the erosion problems have been taken into account. It looks like the new building has been built slightly higher up and without a row of columns in the sea. The presence of rubble in the sand indicates that there has been a small 'nourishment' of the beach to build on. Figure 4-13 shows that there is no beach left, whereas in Figure 4-14 there is somewhat more of a beach.

Figure 4-13 shows the existence of a jetty that used to be attached to a boardwalk.

Figure 4-13 Looking south in 2005 at the northern end of the beach. Remains of a jetty, not connected to the boardwalk anymore. Yellow restaurant suffering from erosion problems.

In the foreground the artificial palms and coloured buildings in 2005 are shown. Looking at this same stretch of beach in 2008 there is no sign at all of a jetty (Figure 4-14). The yellow restaurant shown in Figure 4-13 has been replaced by the building shown in the figure below. Also the beach between the two yellow buildings seems to have been 'nourished' or artificially widened.

Figure 4-14 Left: looking south at new building (no jetty). Right: Looking north at new building (no jetty)

Figure 4-15 Looking north at northern end of Varna beach. Top: 2005, bottom: 2008.

Looking north to this stretch of beach it is clear that the boardwalk is still there (Figure 4-15). These last few figures indicate very clearly, that between 2005 and 2008 some nourishment or sand dumping by (private) owners of these buildings has been carried out.

The next two figures (Figure 4-16, Figure 4-17) show how the new buildings are built knowing that they are too close to the sea. Instead of protecting them with big rocks, they are built on big beams and girders, allowing waves to roll underneath the building.

Figure 4-16 New building at northern end of the beach. Picture taken from the boardwalk, that used to be connected to a jetty.

Figure 4-17 Picture taken from underneath the new building looking north.

4.2 Other observations

Another remarkable observation is the outlet of a drainage system right on the beach. After rainfall, these kinds of discharge systems can cause serious damage to the beach. Big scarps of approximately 80cm are visible in Figure 4-18.

Figure 4-18 Damage to beach by discharge of drainage system.

A general feature at Varna beach is shown in Figure 4-19 indicating erosion problems. The connections of the wood-steel columns are not supposed to be visible and should ideally be covered with sand.

Figure 4-19 Signs of erosion

Furthermore it seems to be no problem at all in Bulgaria to leave debris, truck tires and old construction materials (like steel profiles) lying at the beach. Dangerously damaged structures and run-down buildings do not contribute to a safe and attractive beach. This is visible in the pictures taken in 2005 as well as 2008. Therefore it is not just an observation of this moment, but a structural problem (see Figure 4-21 - Figure 4-24**Error! Reference source not found.**).

Figure 4-21 Damaged building left on the beach.(2005)

Figure 4-20 Damaged building left on the beach.(2005)

Figure 4-23 Damaged building left on the beach.(2008)

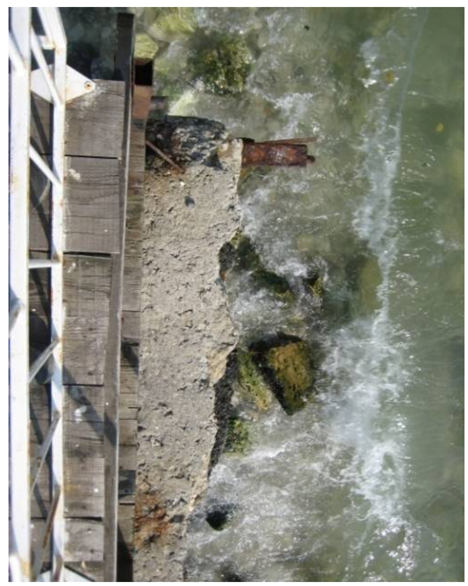


Figure 4-22 Old connection of boardwalk with the collapsed jetty

Figure 4-24 Construction material sticking out of the beach (2008)

5 Analysis of Tetrapods on the Varna breakwater and Y-groyne

5.1 Location

The construction and layout of the Varna breakwater, which provides a sheltered area in the harbour behind the breakwater, is changed several times. The current construction is showed in Figure 5-1. The Tetrapods in front of this breakwater are measured during a field visit.

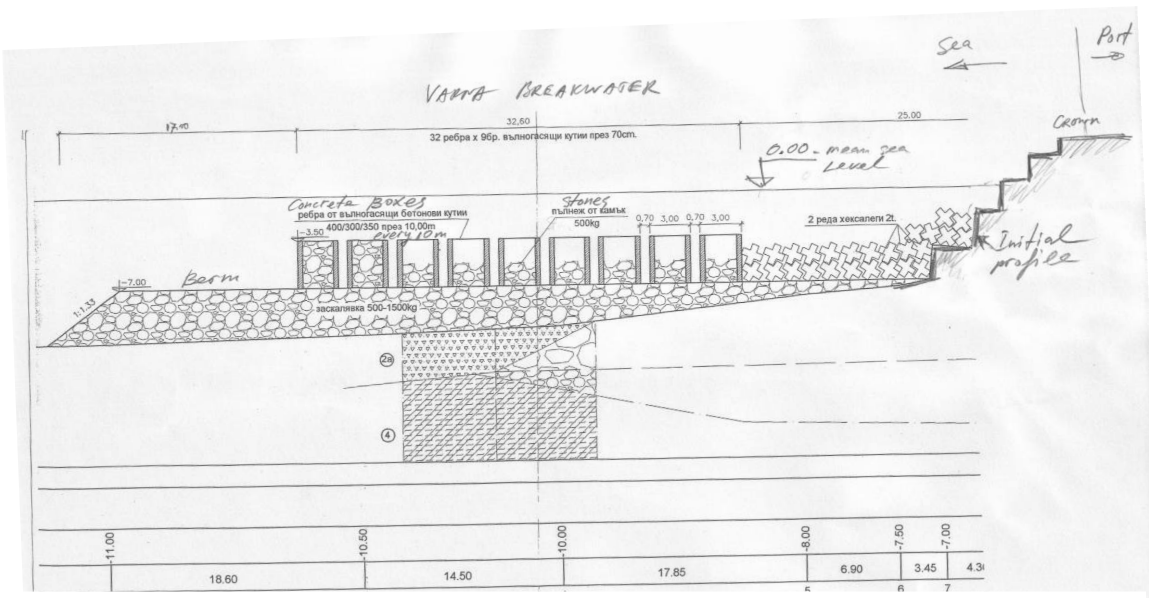


Figure 5-1 Varna breakwater (2008 condition)

The Y-groyne of the "Sunny Day" complex is composed as a caisson type breakwater with Tetrapods in front of the caisson. The breakwater was built in 1984, according to reports of previous years, and has been exposed to storm waves for many years since. Damage due to the storms is visible and this gives questions about the quality of the Tetrapods.

In Figure 5-2 the measurement locations are indicated. With the measured size of several Tetrapods an estimation of their weight is made.

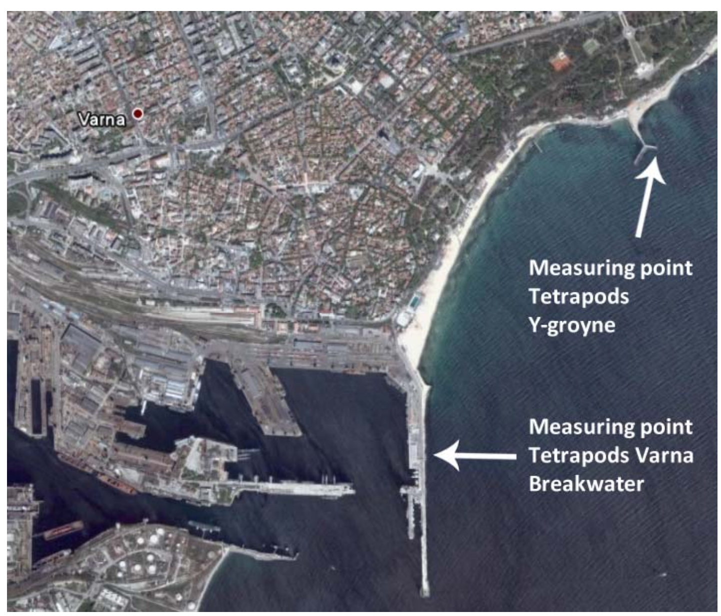


Figure 5-2 Location measuring points [Google earth]

Mass of the Tetrapods

The mass of the Tetrapods is determined based on the measured leg length and the following formulas from the Shore Protection Manual of 1984.

$C = 0.477\ H$ (in which C is the leg length)

$V = 0.280\ H^3$

Different sizes are present at the location of measurement. A clear reason why this is done is not known. It seems like the sizes are randomly distributed over the groyne and breakwater. The mass is determined assuming ρ is 2400 kg/m^3.

Tetrapods on Varna breakwater	C (m)	H(m)	V (m^3)	M (tonne)
Tetrapod 1	0,79	1,65	1,25	3,0
Tetrapod 2	1,25	2,62	5,04	12,1
Tetrapod 3	1,24	2,59	4,86	11,7
Tetrapods on Y-groyne				
Tetrapod 1	0,87	1,82	1,70	4,1
Tetrapod 2	1,11	2,32	3,48	8,4
Tetrapod 3	0,81	1,70	1,37	3,3
Tetrapod 4	1,26	2,64	5,16	12,4
Tetrapod 5	1,30	2,73	5,67	13,6
Tetrapod 6	1,12	2,35	3,62	8,7
Tetrapod 7	0,87	1,82	1,70	4,1
Tetrapod 8	0,87	1,82	1,70	4,1

Table 5-1 Tetrapod masses

5.2 Calculation of the design wave

The design wave is determined with the help of the equations of Hudson, Van der Meer and Hanzawa. The size of the Tetrapods is assumed to be 2.5 meter which is a representative value for the largest Tetrapods.

5.2.1 Hudson

Several values are given for the Hudson formula in Table 5-2 (next page). Apart from these values, the slope of the breakwater cot(α), relative density Δ and d, the equivalent diameter of a cube with the same volume of a Tetrapod are given below. The standard value for the slope of a breakwater is assumed to be 1.5.

$$\Delta = \left(\frac{\rho_s}{\rho_w}\right) - 1 = \left(\frac{2400}{1025}\right) - 1 = 1.34$$

$$d = 0.65 * H = 0.65 * 2.5 = 1.625(m)$$

$$\cot\alpha = 1.5$$

The Hudson formula is simple, but has therefore also a few shortcomings. Primarily, the wave period is not in the formula. Secondly, Hudson assumes permeable breakwaters. A method that does account for these important parameters is the Van der Meer method, which will be further elaborated in the next paragraph. Since the breakwater and the Y-groyne have an impermeable core of caissons, a K_D value of 5 is taken.

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

Table 5-2 Values Hudson formula

Height Tetrapod 2,5 (m)

		K_D	$\cot\alpha = 1{,}5$	Δ	d	H
Head	Breaking waves Tetrapod 2,5 (m)	5	1,5	1,34	1,6250	4,262312
Head	Breaking waves Tetrapod 1,65 (m)	5	1,5	1,34	1,0725	2,813126
Head	Breaking waves Tetrapod 2,73 (m)	5	1,5	1,34	1,7745	4,654445

Table 5-3 Overview design wave according Hudson formula

5.2.2 Van der Meer

The Van der Meer formula takes the breaker index into account. Based on the standard wave steepness of 0.05 and same value for the angle α, this results in a breaker index very close to 3, which is the transition zone between a plunging breaker and a surging breaker. Because of this, the calculations will be made for both plunging and surging waves, for the three Tetrapod sizes 1.65, 2.5 and 2.73 (m) given above.

$$\xi = \frac{\tan\alpha}{\sqrt{s_m}} = 2.98 \text{ with } s_m = 0.05 \text{(wave steepness for standard wave at shallow water)}$$

$$Plunging\ waves: \frac{H_s}{\Delta d} = \left(8.6\left(\frac{N_{od}}{\sqrt{N}}\right)^{0.5} + 3.94\right) s_m^{0.2}$$

$$Surging\ waves: \frac{H_s}{\Delta d} = \left(3.75\left(\frac{N_{od}}{\sqrt{N}}\right)^{0.5} + 0.85\right) s_m^{-0.2}$$

$$D_n = 0.65 * H_{tetrapod}$$

As representative value for the damage level N_{od}=0.4 is chosen, because the smaller ones were sometimes broken. And N is 6000, so a 10 hour storm with a period of 6 seconds.

Plunging Waves					
$H_{tetrapod}$	D_{n50}	N_{od}	N	s	H_{sc}
2,5	1,625	0,2	6000	0,05	5,235138
1,65	1,0725	0,4	6000	0,05	3,598079
2,73	1,7745	0,2	6000	0,05	5,716771
Surging Waves					
$H_{tetrapod}$	D_{n50}	N_{od}	N	s	H_{sc}
2,5	1,625	0,2	6000	0,05	4,125029
1,65	1,0725	0,4	6000	0,05	2,929029
2,73	1,7745	0,2	6000	0,05	4,504532

Table 5-4 Results Van der Meer

5.2.3 Hanzawa

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

$$\frac{H_s}{\Delta d} = 2,32\left(\frac{N_{od}}{\sqrt{N}}\right)^{0,2} + 1,33$$

$H_{tetrapod}$	D_{n50}	N_{od}	N	H_{sc}
2,5	1,625	0,2	6000	4,430116
1,65	1,0725	0,4	6000	3,074429
2,73	1,7745	0,2	6000	4,837687

Table 5-5 Results Hanzawa

5.3 Conclusions

The lowest value is normative for the design wave height. For the larger category Tetrapods, with an average height of about 2.5 meters, this results in a design wave height of 4.13 meter. The difference in the chosen damage factor between the larger Tetrapods and smaller ones is an explanation for fact that the Hudson method is normative for the smaller Tetrapods.

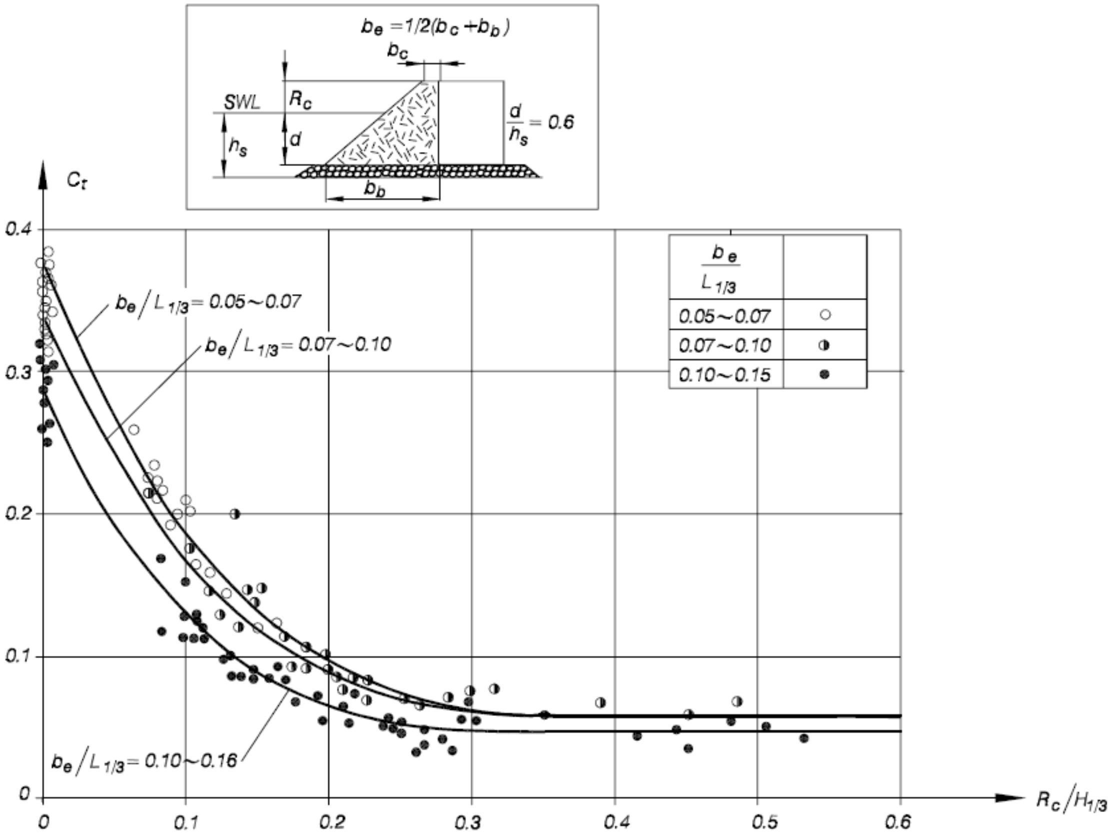
	Hudson	Van der Meer		Hanzawa
Htetrapod		Plunging	Surging	
2,5	4,262312	5,235138	4,125029	4,430116
1,65	2,813126	3,598079	2,929029	3,074429
2,73	4,654445	5,716771	4,504532	4,837687

Table 5-6 Overview design wave height different methods

5.4 Maximum depth-limited wave for this location

No charts are available at the moment, therefore the depth at these locations is assumed to be in the order of 10 meter. The maximum depth-limited wave can be determined by H=0.5*h. The depth limited wave becomes then 5 meters. In storm conditions set-up can occur and the depth limited wave can increase. If the depth is smaller than the estimated 10 meter, the depth limited wave will decrease.

5.5 Wave transmission



$B = C_o * M^{C1} * f^{C2} * H_s^{C3}$

B=relative breakage

M=armour unit mass in:10.5 tonnes

f_t =concrete static tensile strength in MPa, very low quality 2(Mpa)

$C_0 = 0,00393$

$C_1 = -0,79$

$C_2 = -2,73$

$C_3 = 3,84$

This gives a breakage B of 2,13%

This value lies above the graph and therefore a C_t value of 0.5 is applicable in this situation. This results in a transmission wave of 0.05*4.125=0.21m. The transmission wave is minimal for these breakwaters.

5.6 Expected breakage and counted number of Tetrapods

The breakage formula of Burcharth, 2000 gives an estimated percentage of the number of Tetrapods that are broken.

$B = C_o * M^{C1} * f^{C2} * H_s^{C3}$

B=relative breakage

M=armour unit mass in:10.5 tonnes

f_t =concrete static tensile strength in MPa, very low quality 2(Mpa)

$C_0 = 0,00393$

$C_1 = -0,79$

$C_2 = -2,73$

$C_3 = 3,84$

This gives a breakage B of 2,13%

During the field visit a small number of damaged large Tetrapods were detected, so this is in line with the observation at the site.

5.7 General analysis

The Y-groyne is constructed with rather over dimensioned Tetrapods. The Tetrapods that are located in the sheltered area will not be damaged during their lifetime. The smaller ones seem to have been damaged by the storm conditions. The bad quality of the Tetrapods results in legs that break off because of low quality concrete or a poor construction method.

In the northern section of the breakwater a parapet-structure with prefabricated elements is used. The reinforcement of the concrete is situated too close to the surface of the concrete elements. Especially in an environment like this, the concrete cap needs a larger cover. Bad construction and communication between the designer and the constructor lead to these problems.

6 Groyne measurements

6.1 Introduction

To prevent littoral sediment transport, a groyne can be built, which will trap sediment. Many groynes have been built along the Black Sea coast, for example to create wider beaches for tourists. During this year's fieldwork the groyne south of hotel Sirius is measured. This has already been done in previous years. Data of 2002 and 2003 will be used for comparison of the profiles. The stability of the groyne and the armour blocks in particular can be investigated. By plotting the profiles of 2002, 2003 and 2008 the changes in the profiles can be found over a period of 6 years. In other years either other groynes around Varna or cross sections at other locations along this particular groyne were measured. Therefore these data cannot be used for comparison.

6.2 Location

The location of the groyne is indicated in Figure 6-1 and Figure 6-2 below. A detailed drawing of the groyne is also given. The green base point is used as the centre of the coordinate system during measurements. The coordinate system is sketched in Figure 6-3. The green base point was defined in 2002 and can still be found on the groyne as can be seen in Figure 6-2. This point lies on top of a concrete slab which is assumed to have a constant absolute height and location over the years. From this point a base line is drawn towards the coast over the crest of the groyne. The width of the crest of the groyne is 9.5 m, the baseline lies 1.5 m from the southern edge in y-direction.

Figure 6-1 Location groyne **Figure 6-2 Groyne seen from the Sirius Beach Hotel**

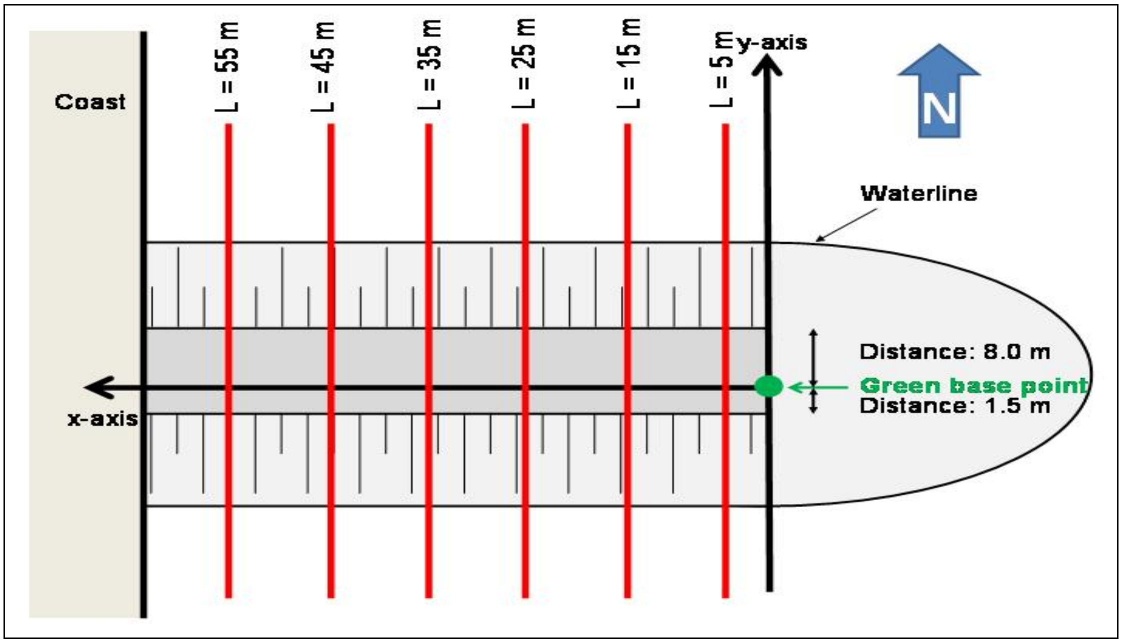


Figure 6-3 Coordinate system on the groyne

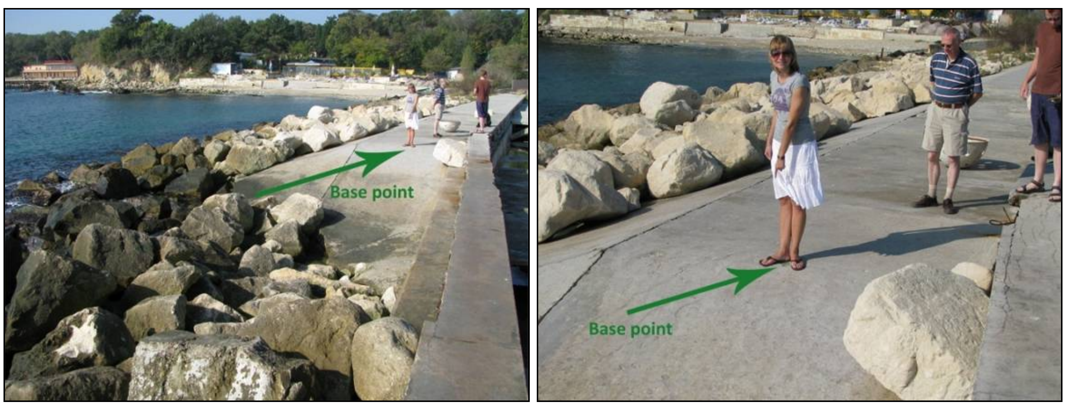


Figure 6-4 Location of the base point

6.1 Setup of the measurements

Along the baseline 6 cross sections were measured, starting at x = 5 m. These cross sections were also measured in 2002 and 2003, and therefore also in 2008 to make a comparison possible. After the cross section at x = 5 m, every 10 m a cross-profile was measured perpendicular to the base line, ending at L = 55 m. The profiles at L = 45 m and L = 55 m were not measured in previous years, so they can not be compared.

At the northern side less profiles were measured because the profile at L=55 m on that side is no groyne but beach.

The crest height is measured at every profile at the edge of the concrete slab. There was about 20 cm difference in height between the seaward side and the landward side of the groyne. The height increased towards the landside. This height difference is negligible, since it will have no impact on the functioning of the groyne. The same height difference was also noticed in 2002 and 2003. Since all measurements were conducted with regard to the base point, the results are comparable. The results are presented in the next paragraphs.

6.2 Estimation of the D_{n50}

The diameters of the rock used were visually estimated on both sides of the groyne. Most of the D_{n50}s at the southern side were found to be between 70 and 110 centimetres, leading an estimate of $D_{n50} \approx 90$ cm. The rocks on the northern side appeared smaller and most of the D_{n50}'s were estimated between 30 and 60 centimetres, leading to $D_{n50} \approx 45$ cm. It also appeared that there were fewer stones on the northern than on the southern side of the groyne.

Figure 6-5 shows pictures of the groyne which support the statements above. The sides are indicated in the pictures and it can be seen that the south side is in better shape: the stones are bigger and the crest of the groyne lies higher.

Figure 6-5 Pictures of both sides of the groyne

In the chapter of the quarry measurements the required stone size for this groyne is calculated. A calculation shows that the currently placed stones are too small for the Black Sea wave conditions. Also the same rock size is normally used at both sides of a groyne. Since heavy storms at this location come from the north it is likely that rocks have broken at the north side. Originally the rock of the entire groyne could very well have had the same D_{n50} of 90 cm.

6.3 Comparison of profiles

In the following graphs the cross sections of the various profiles are plotted. The baseline is located at x = 0. The negative values along the x-axis represent the southern side of the groyne and the positive values represent the northern side. Using these values the concrete slab of 9.5 meters wide is positioned between x = -1.5 m and x = + 8.0 m.

The positive values along the y-axis are depths below the base point. Negative values indicate points were the rocks have a larger elevation than the base point.

At cross sections L = 5 m north side only in 2008 measurements were conducted. For cross sections L = 45 m and L = 55 m this regards both sides.

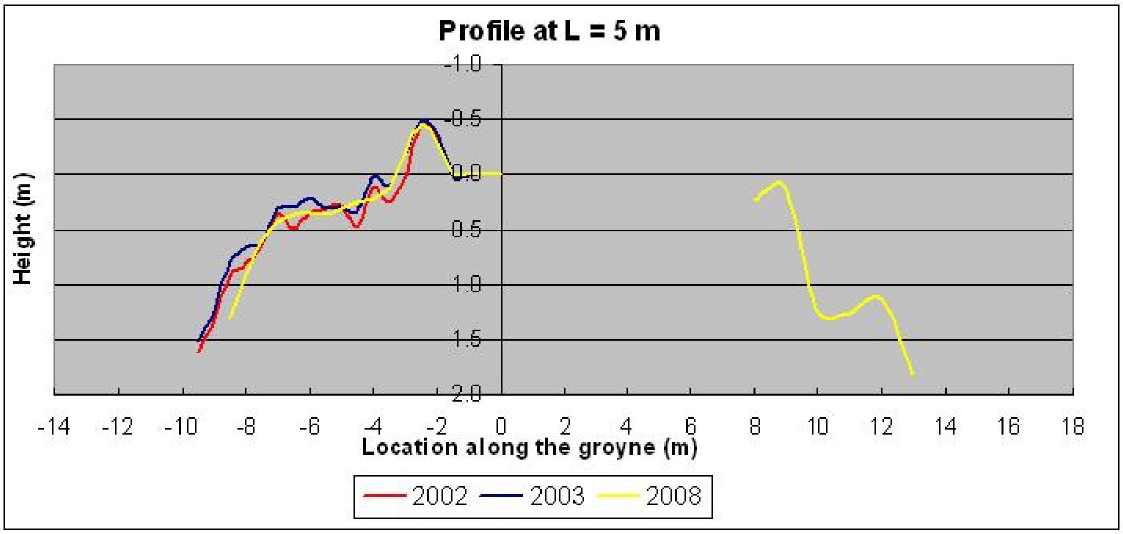


Figure 6-6 Profile at L = 5 m

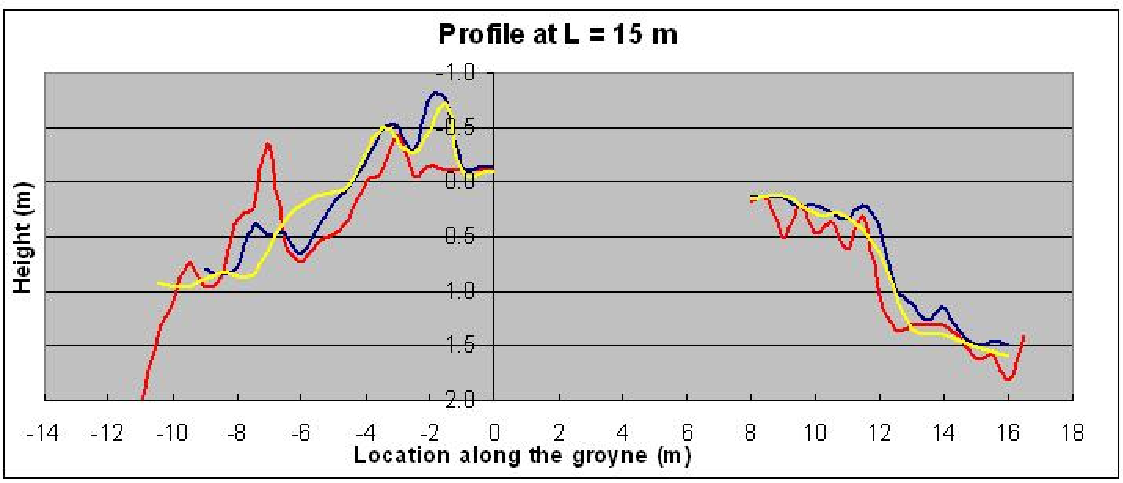


Figure 6-7 Profile at L = 15 m

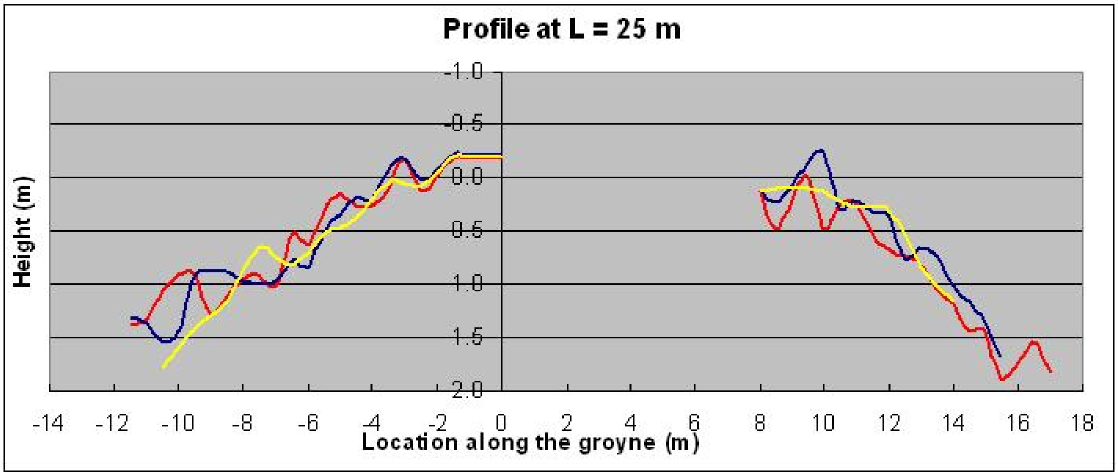


Figure 6-8 Profile at L = 25 m

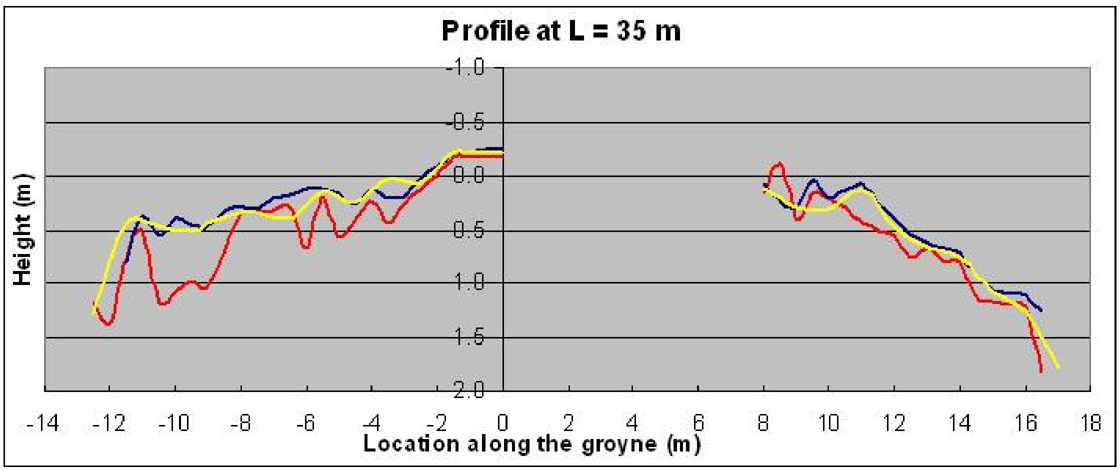


Figure 6-9 Profile at L = 35 m

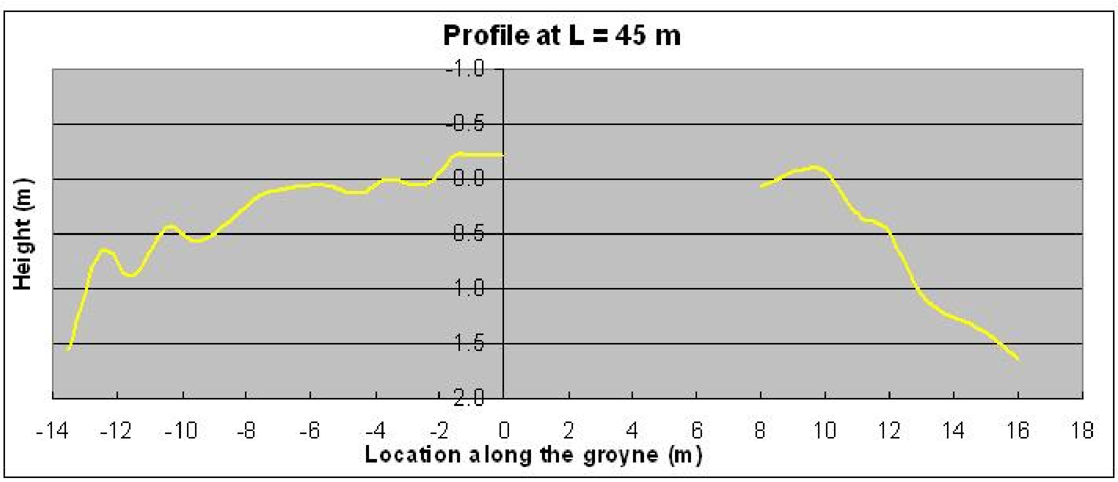


Figure 6-10 Profile at L = 45 m

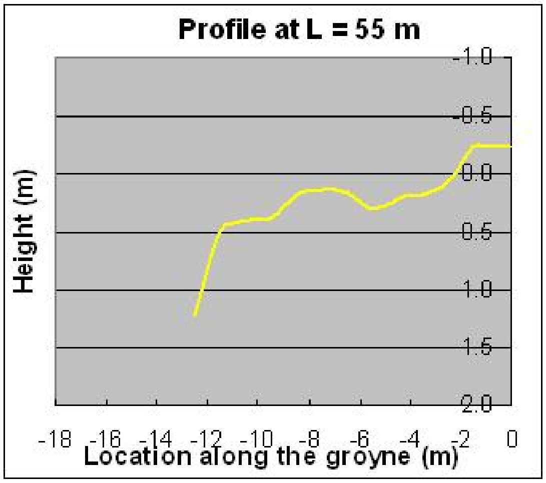


Figure 6-11 Profile at L = 55 m

The difference in profiles remain within a few decimetres, almost all profiles are identical when considering the accuracy of the measurements. This lies within 20 cm in x- and y-direction due to the measuring device.

Only at L = 15 m, x = -7.0 m a spike is shown in 2002, so a large rock has probably moved before the next measurement. At L = 35 m a wide gap is visible around x = -10.0 m in 2002. The next year this has been filled up.

Overall the profiles have changed very little over the past 6 years. This either means that the rocks in combination with the current slope are sufficient or that there has not been a major storm in the period 2002 until 2008 to further damage the groyne. At least the rocks withstood the storms in the past 6 years.

The small changes in profile of 2002 on the one hand and of 2003 and 2008 on the other hand suggest a fairly large storm took place between the summers of 2002 and 2003.

6.4 Volume calculation

6.4.1 Method

The volume of rocks on top of the concrete slope above the waterline is calculated. The waterline is situated 1.65 m below the green base point. The width of every profile is 10 meters, as indicated in Figure 6-12.

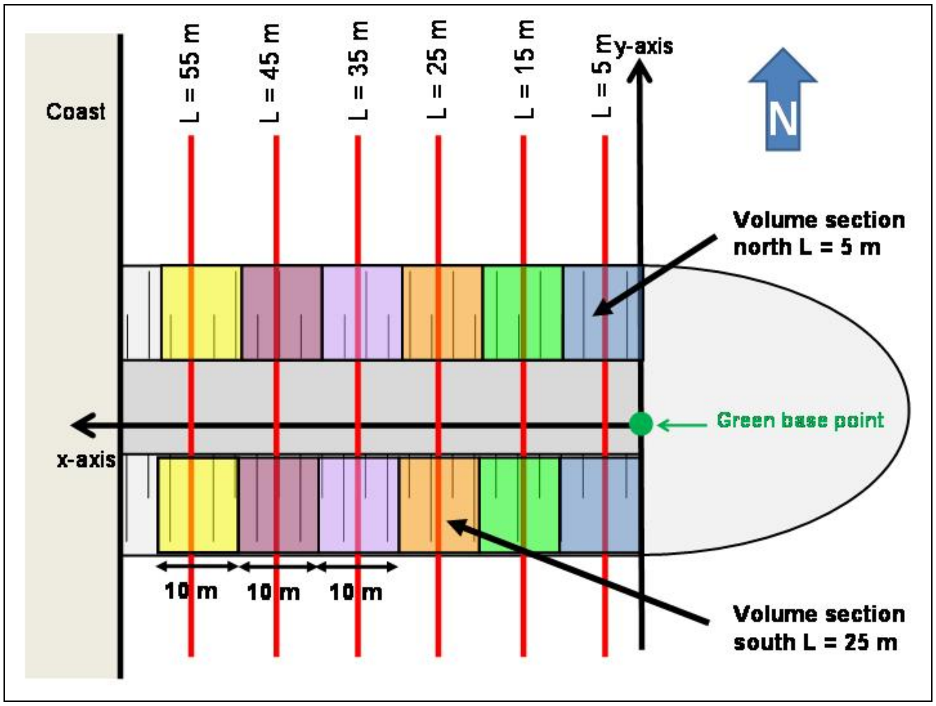


Figure 6-12 Sections for volume calculations

Since it is not clear what level previous years have used to calculate their volumes, no comparison with the volumes mentioned in previous reports could be conducted. Therefore the calculations of 2002 and 2003 are redone using the waterline measured in 2008, enabling a comparison in this report.

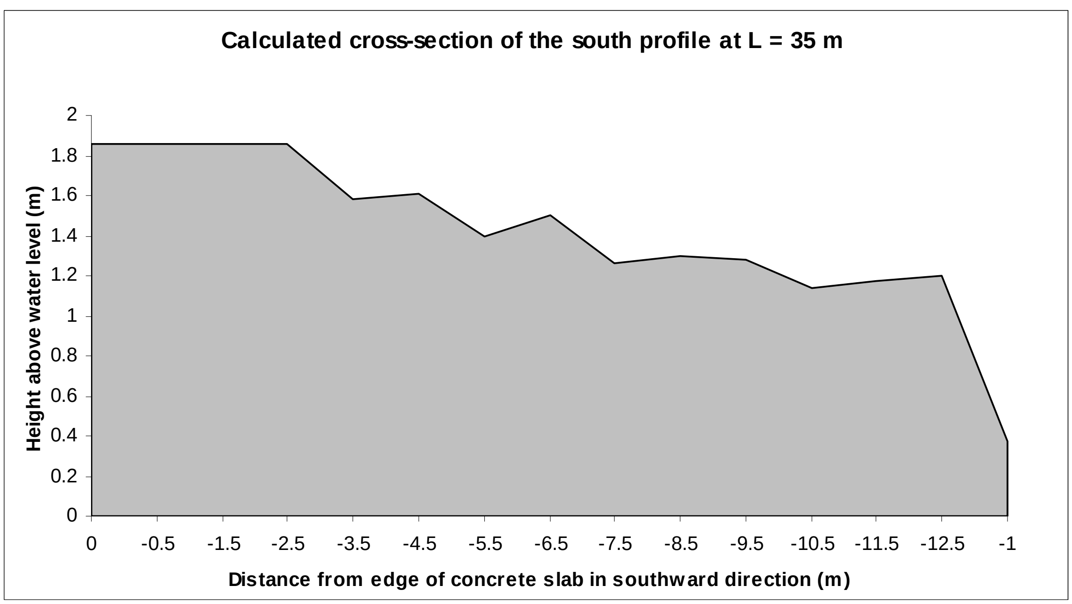


Figure 6-13 Example of volume calculation of a cross section

6.4.2 Comparison of the volume of the groyne cross sections

Every single profile is compared over the three measured years.

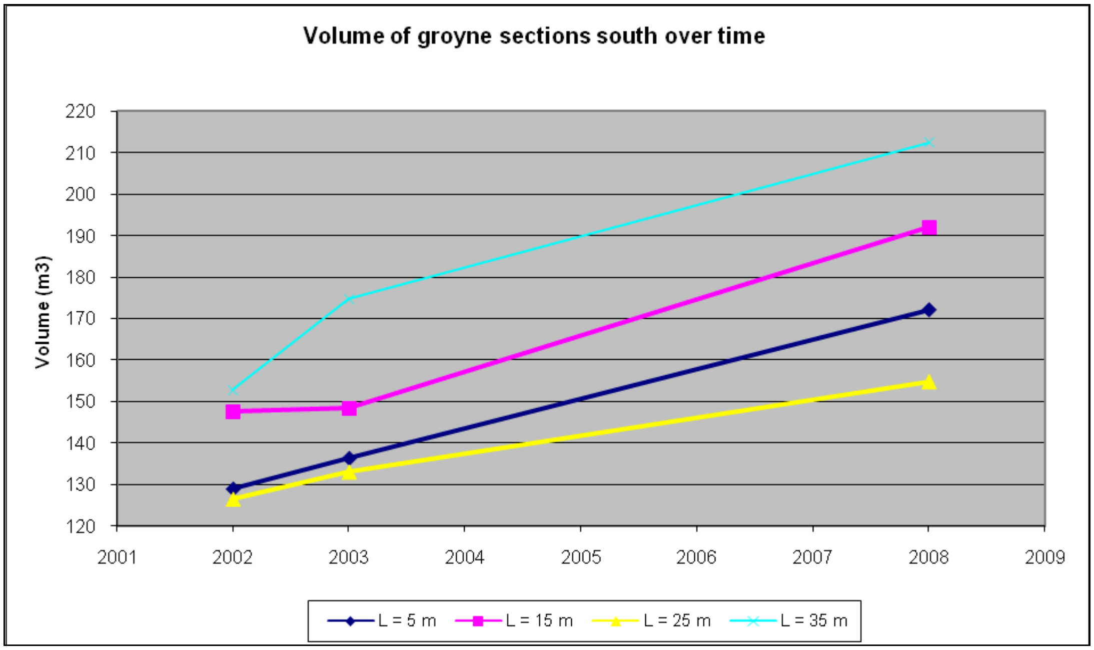


Figure 6-14 Development of southern groyne volume over time

There is an increase of volume over time in all cross-sections at the south side. It is possible that stones from the head were moved to other sections. No cross section was measured at the head of the groyne, but visual observations led to the conclusion that many stones were missing there. It might also be possible that after a heavy storm large stones broke and have been transported towards the coast.

Another trend visible is the increase in volume towards the landward side of the groyne. The only exception is the larger volume at section L = 5 m compared to the section L = 15 m.

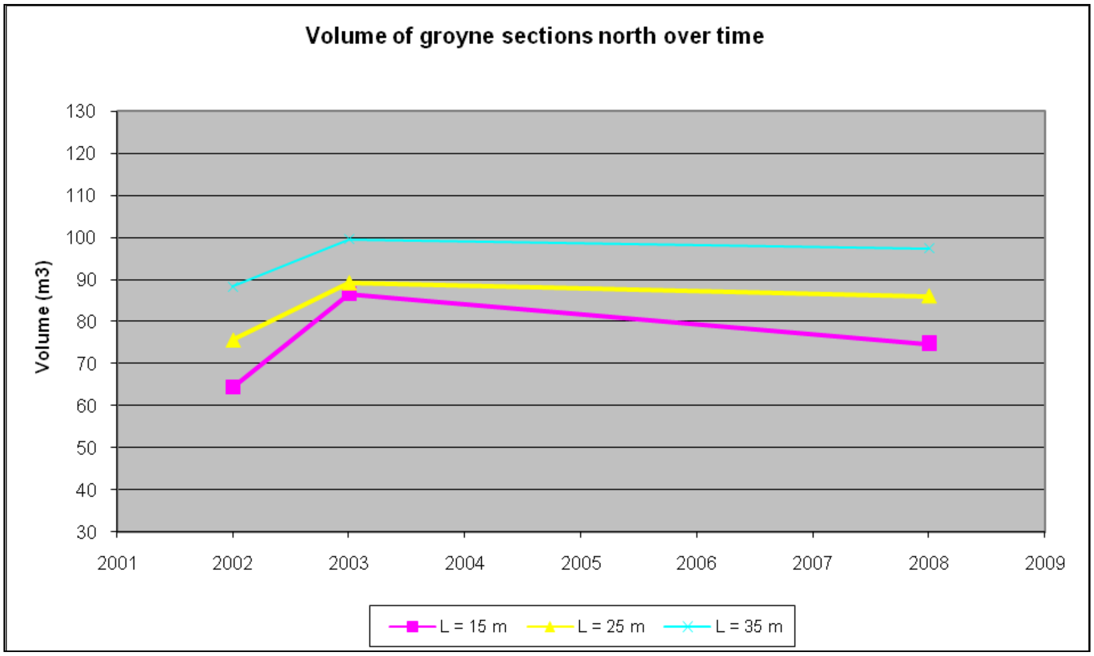


Figure 6-15 Development of northern groyne volume over time

There is an increase of about 15 % in volume between 2002 and 2003. A fairly large storm could have moved stones from the tip of the groyne to the sides. Then the volume slightly decreased between 2003 and 2008. Overall the volumes remained more or less the same, thus the groyne is stable at the north side.

Similar to measurements at the south side, the volume per section increases towards the landside.

6.4.3 Comparison of the volume along the base line

The volumes of the groyne sections along the base line on both sides are plotted in the following two graphs.

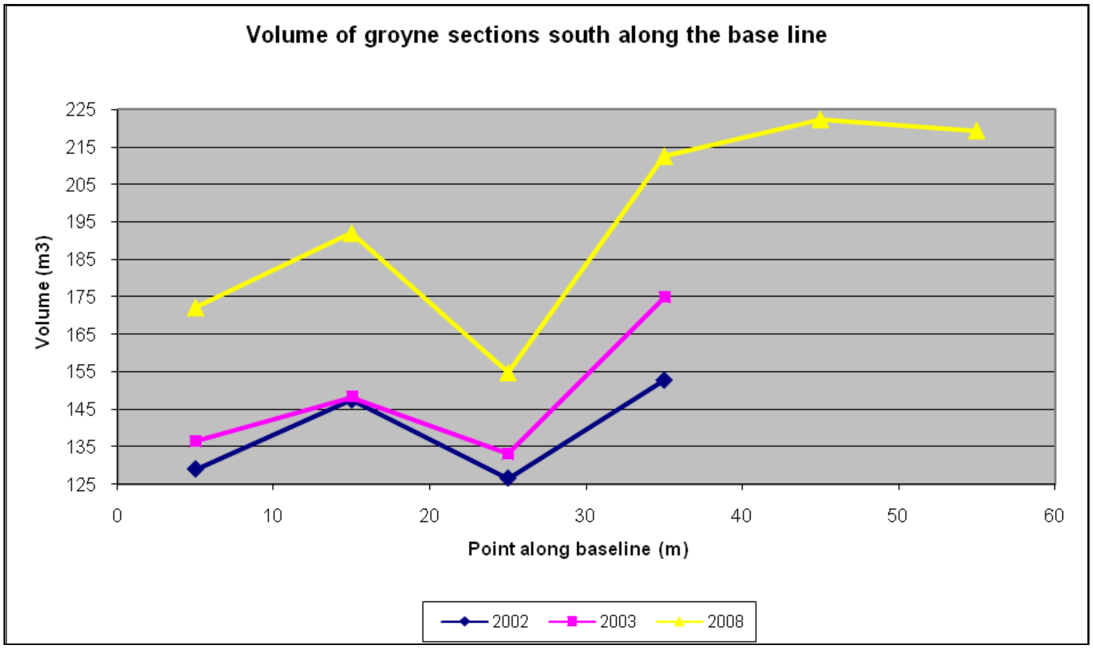


Figure 6-16 Volume of groyne sections south along the baseline

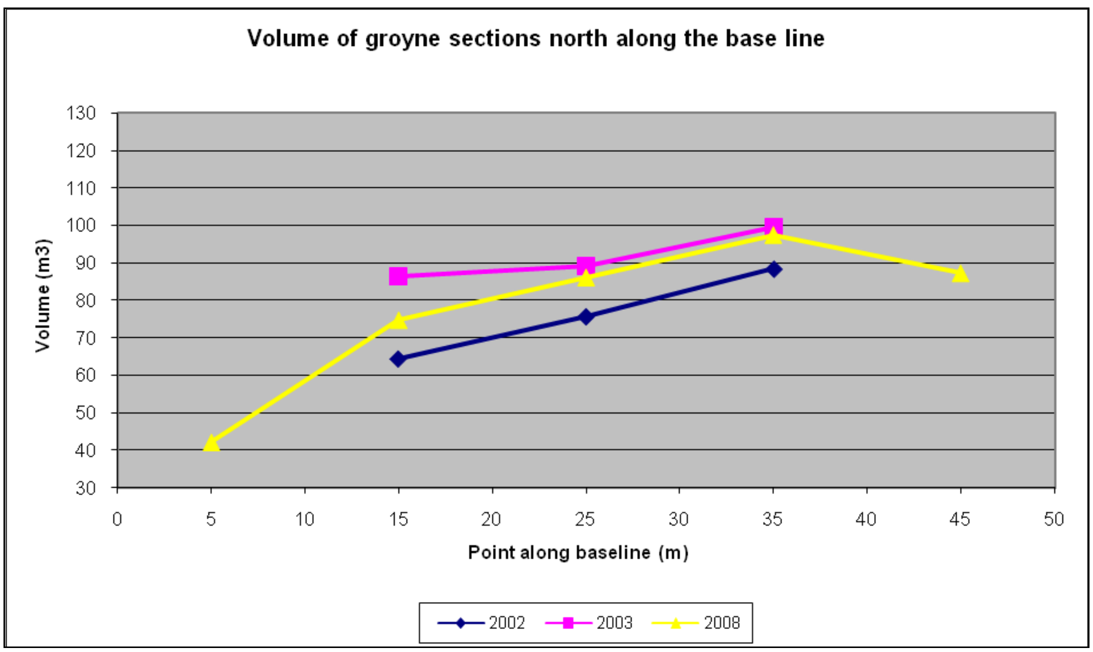


Figure 6-17 Volume of groyne sections north along the base line

The volume along the groyne has increased over time at both sides as already concluded before. What is apparent from these two graphs is that the distribution of the stones per profile has remained constant over the years. On both sides the lines of every year show the same trend.

The volume at the northern side is larger in 2003 than in 2008, as previously found.

6.4.4 Calculated volumes

Table 6-1 shows that the volumes at the north side are almost half of the volumes at the south side. This difference is found for all years.

Year	Volume of south side (m^3)	Volume of north side (m^3)	Total groyne volume (m^3)
2002	427	228	784
2003	456	275	868
2008	559	258	990

Table 6-1 Calculated volumes of the groyne for cross sections L = 15 m until L = 35 m

The volume of the groyne of cross sections L = 5 m until L = 45 m is 1169 m^3 in 2008.

6.5 Conclusions

The conclusion that can be drawn from measurements at the southern side of the groyne will be treated apart from the conclusions for the measurements at the northern side. This is done because of the difference in governing hydraulic conditions for the north and south side. Most waves come from the south, but the most severe storms in this area of the Black Sea come from the north. This leads to different wave loads and therefore to different results in the cross-sections along the groyne.

6.5.1 Conclusions for the south side of the groyne

At the south side of the groyne the stones are larger than on the north side. There are also more stones present. This was visually observed and supported by the profile measurements and all the volume calculations. From the profile measurements it appears that some rocks were displaced between the summers of 2002 and 2003, but the profiles seem stable overall. However, the volume analysis indicates that volumes have increased during the years. This data seems contradicting, but could be explained by a small displacement of the rocks. Because the profiles have not changed much, it is not likely that rocks have been moved from the tip of the groyne to the side of the groyne.

A small displacement of the rocks means that the rocks are too small for the occurring wave load. A slightly bigger rock would prevent displacement. In case the profile changes as seen between the measurements of 2002 and 2003 is the most damage a storm from the south can do, it is not necessary to strengthen the groyne on this side. It must however be taken into account that if larger storms from the south occur, repair might be desirable.

6.5.2 Conclusions for the north side of the groyne

On the north side of the groyne, smaller and fewer stones are present. This visual observation is supported by both the volume calculations and the cross sections. The table with volumes shows this as well and with clear numbers.

Taking into account that the largest storms are from the north and the fact that the groyne was probably dimensioned with the same size of rocks at either side, rocks have disappeared and have broken. This is a plausible conclusion since smaller waves already displaced rocks at the south side. The rocks, or parts of it, have been displaced towards shallower areas below the waterline. Since there is no significant volume change over the years it is probable that this displacement of rocks has taken place before the measurements of 2002. Since then no severe storm has occurred, that changed the profile. Ever since 2002 the concrete slab is an active part of the groyne, dissipating part of the wave energy by overtopping.

It is remarkable that also at the north side the volume increases towards the landside of the groyne, just as on the south side. But again no difference in cross section can be seen during the years. Therefore these displacements probably have also taken place before 2002. Another possible explanation for this increase in rocks towards the land is the displacement of rocks from above the waterline to under the waterline. Since it is physically almost impossible to measure below the waterline with the tools available, there is no information to check this possible explanation.

A possible way to check the conclusions so far is to analyse the wave data of the past ten years. With this information it is possible to see whether a large storm, capable of displacing and cracking stones, has occurred. Since the calculations further on in this report show that the D_{n50} of 90 cm on the south side is not sufficient to withstand the anticipated storm waves, the above conclusions are plausible.

6.5.3 Recommendations

Monitoring of the entire groyne is necessary. Although not much has changed in the last 6 years, it is plausible that big profile changes might occur after severe storm events. The damage can probably be repaired before the groyne collapses.

Measuring the groyne profile below the water level might confirm the ideas of rock displacement.

Also it might be a good idea to investigate the function of this groyne. The groyne is located between a weathered jetty and a small, protected harbour. The beaches on both sides of the groyne are not particularly attractive or well-maintained. Furthermore, the longshore transport along this part of the Black Sea coast is very limited, whereas groynes are usually built to prevent this type of transport. Finding out the purpose of this groyne will help decide whether it should be redesigned, maintained or even removed.

7 Quarry measurements

To investigate the available rock in the surroundings of St. Konstantin, two quarries were visited. In this chapter different characteristics are investigated. From both quarries the specific weight of the rock is determined. At the closest quarry, the Marciana quarry, tests were performed and the available rock sizes were defined. For the tests 26 stones, which could be carried by one person, were selected from a pile of rocks. This number is assumed to be large enough to get reasonable results and small enough to perform the necessary tests at the quarry within the time available.

Figure 7-1: Marciana quarry

7.1 Determination of the specific weight

In this paragraph the densities of different rocks will be presented. From both quarries some samples were brought to Delft to find out the specific weight. From the quarry of Marciana two samples were taken. These rocks looked white and a bit dusty. From Sini Vir more samples were taken, because two types of stones were noticed: yellow stones and gray stones. Observations without instruments result in the presumption that the density of the rocks of Sini Vir is larger.

In NEN 5186 it described how to determine the density of rocks. The density of the rocks can be found using the following formula:

$$\rho_s = \frac{m_3 \cdot \rho_w}{m_2 - m_1}$$

In which

ρ_s	=	the density of the rock [kg/m^3]
ρ_w	=	the density [g/ml] of the water, at test temperature
m_1	=	apparent weight of the stone submerged (g)
m_2	=	weight of the wet stone (g)
m_3	=	weight of the dry stone (g)

Results for all the stones can be found in Table 7-1.

		Marciana		
	m_3 (g)	m_1 (g)	m_2 (g)	Density [kg/m^3]
	142,65	83,60	144,13	2356,68
	180,83	103,70	181,20	2333,29
Averaged				*2344,99*
	Sini Vir, yellow stones			
	m_3 (g)	m_1 (g)	m_2 (g)	Density [kg/m^3]
	164,07	99,90	164,78	2528,82
	119,10	72,40	120,25	2489,03
Averaged				*2508,93*
	Sini Vir, gray stones			
	m_3 (g)	m_1 (g)	m_2 (g)	Density [kg/m^3]
	129,40	80,10	130,60	2562,38
	177,30	109,70	178,30	2584,55
Averaged				*2573,46*

Table 7-1 Measurements and result densities

The density that was found for Marciana (2345 kg/m^3) can be compared with results from previous years, see Table 7-2. This number will be used for further calculations, regarding rocks from this quarry. For the rock from Sini Vir two densities were found (yellow stones: 2509 kg/m^3, gray stones 2573 kg/m^3).

Results previous years	
Year	Density [kg/m^3]
2003	2349
2004	2352
2006	2400
2007	2405

Table 7-2 Results for density Marciana rocks in previous years

It can be concluded that the density that was found for the Marciana rocks is in the same range as the results from previous years and somewhat smaller than the density of the rocks from Sini Vir. For the Sini Vir quarry, measurements were taken in 2002 and 2003, but it is not clear if densities were measured from yellow or gray stones. The difference in density between the two colors is not that remarkable, though the density of the gray stones is slightly greater. It is recommended to take more samples if a more accurate density has to be determined.

7.2 Determination of the D_{n50}

For rocks from the quarry of Marciana the D_{n50} is determined. The selected stones were weighted on a standard scale used in households to weigh persons. The stones are depicted in Figure 7-2. In order to calculate the D_{n50}, the specific weight from the previous paragraph is used.

Figure 7-2 Selected stones

Sorted rock weight (kg)	Volume (m^3)	D_{n50} (m)	D_{n50} (mm)	Exceedance frequency (%)
8.0	0.003	0.151	151	3.8
11.5	0.005	0.170	170	7.7
17.0	0.007	0.194	194	11.5
18.0	0.008	0.197	197	15.4
18.0	0.008	0.197	197	19.2
19.0	0.008	0.201	201	23.1
21.0	0.009	0.208	208	26.9
21.0	0.009	0.208	208	30.8
23.0	0.010	0.214	214	34.6
24.0	0.010	0.217	217	38.5
25.5	0.011	0.222	222	42.3
27.0	0.012	0.226	226	46.2
27.5	0.012	0.227	227	50.0
28.0	0.012	0.229	229	53.8
29.0	0.012	0.231	231	57.7
29.0	0.012	0.231	231	61.5
29.5	0.013	0.233	233	65.4
30.0	0.013	0.234	234	69.2
32.0	0.014	0.239	239	73.1
33.0	0.014	0.241	241	76.9
33.0	0.014	0.241	241	80.8
46.0	0.020	0.270	270	84.6
49.0	0.021	0.275	275	88.5
56.0	0.024	0.288	288	92.3
60.0	0.026	0.295	295	96.2
87.0	0.037	0.334	334	100.0

Table 7-3 Determination of the D_{n50}

Even without plotting the data, it can be concluded that the D_{n50} of the measured sample is 22,7 cm.

7.2.1 D_n-distribution

The D_n-distribution is presented in Figure 7-3 and Figure 7-4.

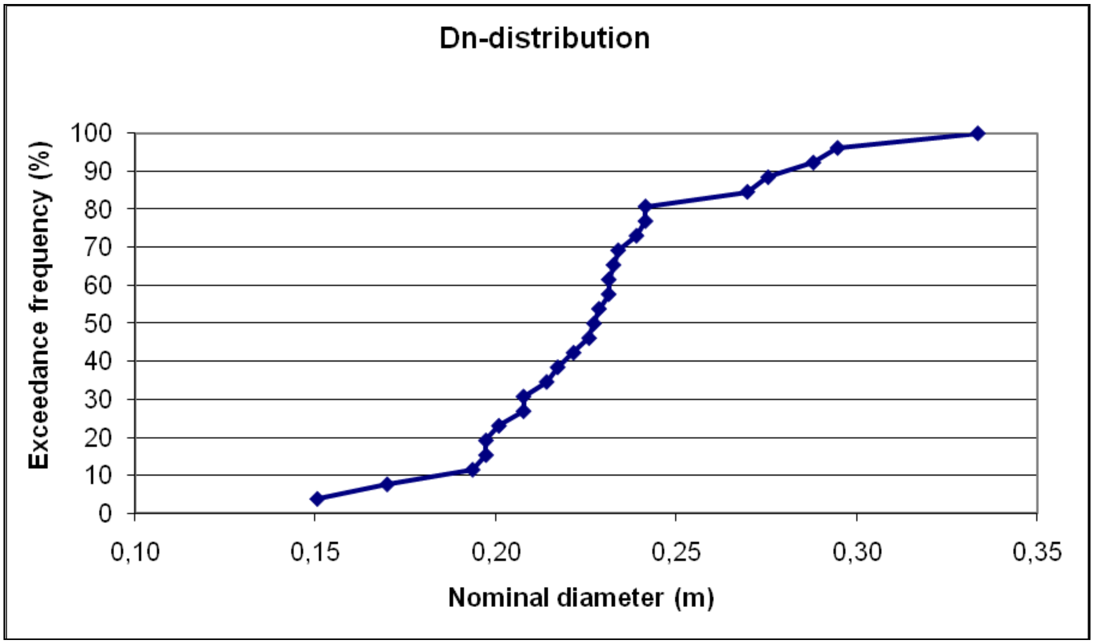


Figure 7-3: D_n-distribution on a regular scale

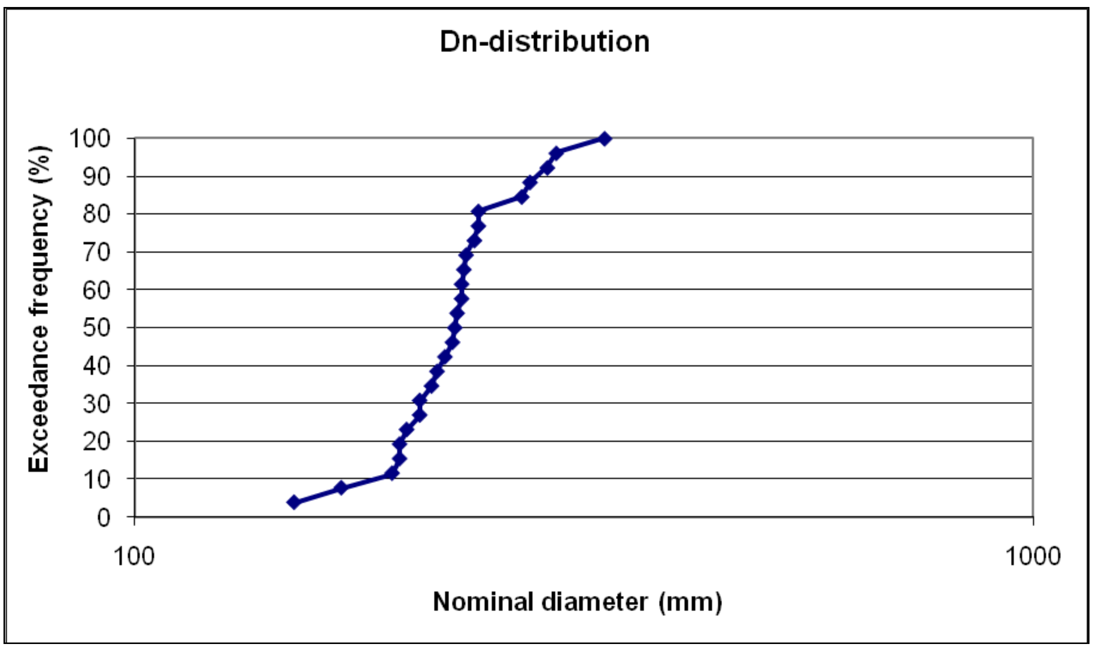


Figure 7-4: D_n-distribution on a logarithmic scale

7.2.2 Grading of the sample

To create a good layer with these stones, the D_{85}/D_{15}-ratio has to be limited. The ratio for this sample is:

$$\frac{D_{85}}{D_{15}} = \frac{270mm}{197mm} = 1.37 \leq 1.5$$

Thus the gradation of the sample is narrow.

7.3 Determination of C_{pl} and C_{sur}

In order to determine the plunging and surging coefficients, which are standard taken as respectively 6.2 and 1.0 in the Van der Meer equations, the blockiness and the elongation have to be determined.

7.3.1 Determination of the blockiness

The blockiness is defined as

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

In which X, Y and Z are the sides of the enclosing cube of the stone as shown in Figure 7-5.

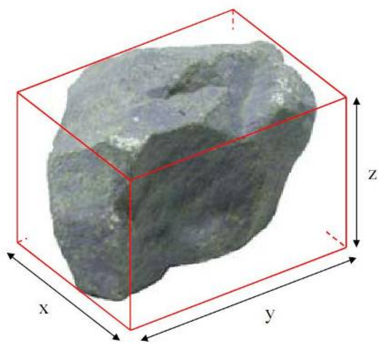


Figure 7-5: Enclosing cube of the stone

For the selected stones from the Marciana quarry this results in the values for the blockiness shown in Table 7-4.

Volume box= X·Y·Z (m3)	**Volume stone (m3)**	Blockiness (-)
0.06	0.004	0.08
0.03	0.011	0.44
0.03	0.010	0.40
0.04	0.003	0.09
0.03	0.008	0.31
0.02	0.012	0.56
0.10	0.023	0.27
0.02	0.013	0.66
0.02	0.009	0.54
0.03	0.007	0.22
0.02	0.022	1.02
0.02	0.007	0.31
0.04	0.011	0.28
0.03	0.013	0.52

0.02	0.012	0.60
0.06	0.007	0.14
0.02	0.018	1.02
0.01	0.009	0.66
0.03	0.007	0.30
0.06	0.033	0.60
0.03	0.011	0.39
0.03	0.011	0.42
0.01	0.010	1.45
0.02	0.008	0.41
0.02	0.011	0.62
0.01	0.019	3.18
	Mean BLc_m	**0.60**
	St. dev. σ(BLc)	0.61

Table 7-4 Blockiness of the selected rocks

7.3.2 Determination of the elongation

The elongation is defined as:

$$\frac{l}{d} = \frac{\text{longest axial length}}{\text{shortest axial length}}$$

For the selected stones from the Marciana quarry this results in the values for the elongation shown in Table 7-5.

Longest axial length (m)	**Shortest axial length (m)**	Elongation (m)
52	27	1.93
50	22	2.27
42	18	2.33
38	23	1.65
40	13	3.08
51	20	2.55
58	27	2.15
37	15	2.47
43	9	4.78
45	14	3.21
40	19	2.11
47	19	2.47
56	20	2.80
36	26	1.38
38	17	2.24
58	14	4.14
41	18	2.28
35	18	1.94
44	19	2.32
47	35	1.34
42	23	1.83

47	23	2.04
24	18	1.33
44	25	1.76
44	19	2.32
29	13	2.23
	Mean l/d_m	**2.34**

Table 7-5 Elongation of the selected rocks

7.3.3 C_{pl} and C_{sur}

C_{pl} and C_{sur} can be determined with the help of Table 7-6 Adjustment table Cpl and Csur.

BLc-range	l/d range	Armour Porosity (%)	Placement method	"6.2"	"1.0"
40%-50%	1.3 - 3.0	38.7	standard	7.09	-
40%-50%	1.3 - 3.0	36.1	dense	6.68	1.67
50%-60%	1.3 - 3.0	37.1	standard	6.44	1.51
50%-60%	1.3 - 3.0	35.2	dense	7.12	2.08
60%-70%	1.3 - 3.0	35.5	standard	7.71	2.63
60%-70%	1.3 - 3.0	34.4	dense	10.85	-
50%-60%	1.0 - 2.0	36.1	standard	8.50	1.45
50%-60%	1.0 - 2.0	34.6	dense	8.80	-

Table 7-6 Adjustment table C_{pl} and C_{sur}

With BLc_m = 59.55 and l/d_m = 2.34 and by using a standard placement method, the result is:

C_{pl} = 6.44

C_{sur} = 1.51

7.4 Determination of the porosity and the layer thickness

In order to be able to redesign the groyne at St. Konstantin and for the design of the groyne extension of the Sirius Beach Hotel the single layer and double layer porosity and the single layer thickness need to be calculated. This can be done with the following formulas:

$$n_v = A + B \cdot BLc_m + C \cdot l / d_m + D\sigma(BLc)$$
$$k_t = A + B \cdot BLc_m + C \cdot l / d_m + D\sigma(BLc)$$

The coefficients for different slopes and the values for the different parameters are given in Table 7-7.

Parameter	Slope	A	B	C	D	Parameter
Single layer porosity n_v	1:1.5	42.38	-0.2177	3.695	-0.4128	50.66
	1:2	42.9	-0.2204	3.74	-0.4179	51.28
	1:3	43.46	-0.2233	3.789	-0.4233	51.95

Single layer thickness k_t	1:1.5	1.1375	-0.0026	-0.1588	-0.0003	0.76
	1:2	1.0736	-0.0024	-0.1499	-0.0003	0.72
	1:3	1.1038	-0.0025	-0.1541	-0.0003	0.74
Double layer porosity n_v	1:1.5	34.53	-0.2137	3.446	0.1852	42.59
	1:2	35.94	-0.2224	3.586	0.1928	44.33
	1:3	36.2	-0.224	3.613	0.1942	44.65

Table 7-7 Porosity and layer thickness

7.5 Estimation of the available stone sizes from the Marciana quarry

To determine the available stone size at the Marciana quarry the stones of a random blast were inspected. Fur our purpose stones of categories smaller than a ton are of no interest. With a simple calculation the D_{n50} of the different categories could be estimated. We made use of the fact that a visual estimation of a diameter is easier than of a volume/weight. With this calculation we assumed the density of the stones to be approximately 2500 kg/m_3 (we took this as a safe estimate but back in Holland we found that they where 2345 kg/m^3).

Stone category	D_{n50}
1-3 ton	0.72 - 1.04 m
3 ton and larger	1.04 m and larger

Table 7-8 D_{n50} of different stone classes

An area of about 20 by 20 m was surveyed. With 7 persons we walked systematically trough the area. Every person would start at one side with 5 meters in between and walk to the other side of the surveyed square. Along the way stones of classes 1-3 and 3-6 tons were counted. This way an area of 400 m^2 was covered to obtain a fair indication of the stones sizes available from the quarry. In Table 7-9 the number of rocks counted and the percentage 1-3 tons of the total amount of stones larger than 1 ton. In Figure 7-6 the stone counting system is shown.

Sample line	Number of stones 1-3 tons	Number of stones 3-6 tons
1	15	12
2	25	16
3	20	40
4	6	16
5	29	14
6	52	20
7	40	15
Total	187	133
% of total	58	42

Table 7-9 Visual estimation of number of rocks in different classes

Figure 7-6 Stone counting system

7.6 Design wave height and period of the St. Konstantin groyne

7.6.1 Required data

The measured groyne in St. Konstantin will be redesigned with stones from the Marciana quarry. With the stone density and D_{n50}, the design wave height for this groyne can be found. Since no stones from this groyne have been taken to the laboratory in Delft, the stone density has to be estimated. Based on results from previous years and information from Professor Daskalov, the stone density is assumed to be $2.6 \cdot 10^3$ kg/m^3. The D_{n50} of both sides of the groyne was estimated.

The stone size on the north and south side differed, since at the north side $D_{n50} \approx 45$ cm and at the south side $D_{n50} \approx 90$ cm. It is known that storms in winter come from the north, so this side is most heavily attacked. The stones at the north side could therefore have been broken. At the north side also much less stones were visible than at the south side. When assuming the groyne was designed with the same stone size at both sides, the D_{n50} to be used should be 90 cm.

7.6.2 Design wave height

The Hudson-formula will be used:

$$\frac{H_s}{\Delta D_{n50}} = \sqrt[3]{K_D \cdot \cot \alpha}$$

The slope of the groyne is about 1:3, so cot α = 3. For Hudson 1.5 ≤ cot α ≤ 4, so the formula can be used. $K_D = 3.5$, since the used stone is rough angular stone assumed in a breaking wave and placed in two layers. For the density of the water of the Red Sea Professor Daskalov was consulted.

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w} = \frac{2600 - 1018}{1018} = 1.55$$

Therefore:

$$H_s = \Delta D_{n50} \cdot \sqrt[3]{K_D \cdot \cot\alpha} = 1.55 \cdot 0.90 \cdot \sqrt[3]{3.5 \cdot 3} = 3.06m$$

The calculated value of H_s = 3.06 m will be used for the redesign of the groyne of St. Konstantin. This value is close to the value found in 2007, which was 3.10 m.

7.6.3 Design wave period

The design wave period of the groyne is not known, so an estimate has to be made. The extension of the Sirius Beach Hotel will be designed based on a period of 8 s. The visually observed wave period at the jetty close to the groyne was 7 s. It is therefore a safe estimate to take a design wave period of 8 s.

7.7 Redesign of the St. Konstantin Groyne

7.7.1 Van der Meer

The Hudson formula is a very simplified formula which does not included the wave period, the permeability, number of waves and damage level. The redesign of the groyne will be done using the Van der Meer formula, since this formula includes these parameters.

Van der Meer has two formulas, one for surging waves and one for plunging waves, so the wave type has to be determined first.

$$\xi = \frac{\tan\alpha}{\sqrt{H / L_0}} \text{ with } L_0 = \frac{gT^2}{2\pi}$$

The Iribarren number depends on the slope. The groyne was designed with a 1:3 slope. It is also possible to make a slope of 1:2. A steeper slope is not recommended, since it requires a very careful construction. For both slopes a design will be made.

The transition from plunging to surging waves is calculated using a ξ_{cr}:

$$\xi_{cr} = \left[C_{pl} P^{0.31} \sqrt{\tan\alpha} \right]^{1/(P+0.5)}$$ with $C_{pl} = 6.44$ as previously calculated for the Marciana rocks

$\xi_{1:3\ slope}$ = 1,90 < 2,71 = ξ_{cr}

$\xi_{1:2\ slope}$ = 2,86 < 3,81 = ξ_{cr}

For $\xi < \xi_{cr}$, the waves are plunging, so the following Van der Meer formula has to be used for both slopes:

$$\frac{H_s}{\Delta D_{n50}} = C_{pl} P^{0.18} \left(\frac{S_d}{\sqrt{N}} \right)^{0.2} \xi^{-0.5}$$

A groyne has to trap sediment, so the core will have to be impermeable. Therefore P = 0.10 has to be used. For the number of waves N = 7500 is chosen. The damage level S will be varied to optimize the design.

7.7.2 Required D_{n50} and stone weight depending on the damage level

A damage level of S = 2 means hardly any damage and S = 10 means failure. S = 6 means moderate repair is required after a heavy storm. Table 7-10 gives the required D_{n50} depending on the accepted damage level and slope and Table 7-11 gives the corresponding stone weight.

Damage level	**S = 2**	**S = 3**	**S = 4**	**S = 5**	**S = 6**	**S = 7**	**S = 8**	**S = 9**	**S = 10**
$D_{n50,1:3\ slope}$ (m)	1.36	1.25	1.18	1.13	1.09	1.06	1.03	1.00	0.98
$D_{n50,1:2\ slope}$ (m)	1.88	1.53	1.45	1.38	1.33	1.29	1.26	1.23	1.20

Table 7-10 Required D_{n50} depending on the damage level and slope

Damage level	**S = 2**	**S = 3**	**S = 4**	**S = 5**	**S = 6**	**S = 7**	**S = 8**	**S = 9**	**S = 10**
$W_{50,1:3\ slope}$ (kg)	6500	5100	4300	3750	3350	3050	2850	2650	2450
$W_{50,1:2\ slope}$ (kg)	11900	9350	7900	6900	6200	5650	5200	4850	4550

Table 7-11 Required stone weight depending on the damage level and slope

7.7.3 Evaluation of the currently used D_{n50}

The currently used D_{n50} was estimated to be 0.90 m. The slope of the groyne is 1:3. When comparing this to Table 7-10, the groyne should have failed after a major storm and was not designed properly.

This conclusion may very well be right, since it appeared that the stone size at the north side was much smaller than at the south side. Also fewer stones were found, so this side is heavily damaged when comparing it to the south side. The reason the groyne has not collapsed yet, might be that the core of the current groyne consists of large concrete slabs.

7.7.4 Slope and stone size required for a new groyne

The maximum stone class available in the Marciana quarry is 3 – 6 tonnes. This means that a 1:2 slope is impossible, since larger stones are required for all damage levels except failure.

Based on visual observations it seems like no repair or maintenance has been conducted the last couple of years. The damage level should therefore be chosen as low as possible, depending on the rock size available. The W_{50} of the 3 – 6 tonnes class has to be between 4200 and 4800 kg. With this maximum class the lowest damage level possible is S = 4. After a heavy storm repair can be required, but this has to be accepted. If not, rock cannot be used for the design. Tetrapods can be an alternative.

When accepting a damage level of S = 4, the required W_{50} is 4300 kg. The Marciana quarry should be able to deliver this. The corresponding D_{n50} is 1.18 m.

7.7.5 Summary of the design

The design parameters are summarized in Table 7-12.

Design wave height H_s	3.06	m
Design wave period T	8	s
Specific weight of the stones	$2.6 \cdot 10^3$	kg/m^3

D_{n50} of tested sample	22	cm
Mean elongation l/d_m of tested sample	2.34	
Mean blockiness BLc_m of tested sample	53.71	
C_{pl} based on tested sample	6.44	
Permeability P	0.10	
Number of waves N	7500	
Damage level S	4	
Required slope for St. Konstantin groyne	1:3	
Required stone class for St. Konstantin groyne	3 – 6	tonnes
Required W_{50} for St. Konstantin groyne	4300	kg
Required D_{n50} for St. Konstantin groyne	1.18	m

Table 7-12 Summary of the design

8 Sand sample analysis

In order to get insight in the morphological evolution for the Sirius North and South beaches, the type of beach sand has to be known. By taking samples from the location of interest and sieving them, it is possible to create a distribution of grain sizes which provides more information about the type of beach.

8.1 Sand samples

During the fieldwork a total of 15 sand samples were taken from both Sirius South and North beach (see Figure 8-1), as well as a sample from the new location of the Sirius ship in front of the hotel (sample H). For several cross-sections a sample was taken at a few meters into the sea and one or two samples at some distance (10 and 20 m) from the waterline, since normally the sediment size close to the shoreline is coarser than the sediment size present further away from the shoreline on the beach. This is caused by the wave breaking process close to the shoreline, which washes away the finer particles. This way a representative distribution of the sediment size can be created for the entire profile. A sieve analysis was carried out in the concrete laboratory of the Faculty of Civil Engineering and Geosciences.

Figure 8-1 Locations of the sample points

8.2 Sieve analysis

The sample sizes vary between 60 and 120 grams and were brought to Delft, where the sieve analysis was carried out in the concrete laboratory of the Faculty of Civil Engineering and Geosciences. In order to get an idea of the D_{50} of the sand, a sieving analysis was carried out for each of the taken samples. For the analysis we used 7 sieves with mesh sizes varying from 0.063 mm to 4 mm. In contrast to previous years the range of the mesh sizes was chosen larger because the samples taken from the surf zone had a significant amount of course material.

8.3 Sieving method

Prior to the sieving process, the samples were dried in an oven long enough that they were completely dry. This is to make sure that only the bulk weight is measured. The different mesh sizes used are:

0,063 mm / 0,125 mm / 0,250 mm / 0,500 mm / 1 mm / 2 mm /4 mm

The sieves were placed in a stack with an increasingly larger mesh size starting from 0.063 mm as the bottom one. A sample is placed in the top sieve and the stack is placed in the vibration machine.

Figure 1 Vibration machine

After a couple of minutes vibrating and shaking, the sand particles are distributed over the different sieves. The coarsest material remains on the top sieve (obviously larger than 4 mm) and the finest material falls down towards the bottom sieve.

8.4 Results

For each of the samples a sieving-curve could be made by setting out the passing value (percentage passed) against the mesh sizes of the sieve. Table 8-1 shows the results from the analyzed samples.

Meshsize	Sample A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
0,063	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,00	0,07	0,00	0,00	0,43	0,00	0,00	0,26
0,125	1,03	6,03	0,88	7,37	10,55	0,98	6,11	4,79	0,81	13,11	5,11	5,65	6,01	3,35	4,34	5,66
0,25	6,71	45,76	6,15	62,65	73,77	5,86	53,26	38,81	2,15	92,40	15,52	51,19	56,12	16,79	34,72	48,25
0,5	22,93	90,96	48,04	93,37	99,54	41,32	94,85	77,58	10,98	99,79	57,26	98,87	96,53	80,46	92,56	92,70
1	76,21	99,72	98,20	99,51	100,00	90,14	99,77	96,74	61,25	100,00	94,09	100,00	99,89	99,22	99,78	99,74
2	95,48	100,00	100,00	100,00	100,00	99,90	100,00	99,00	89,55	100,00	97,67	100,00	100,00	100,00	100,00	100,00
4	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00

Table 8-1 Sieving results per sample

Only the distribution curve of sample A is presented in Figure 8-2, this is just to give an impression.

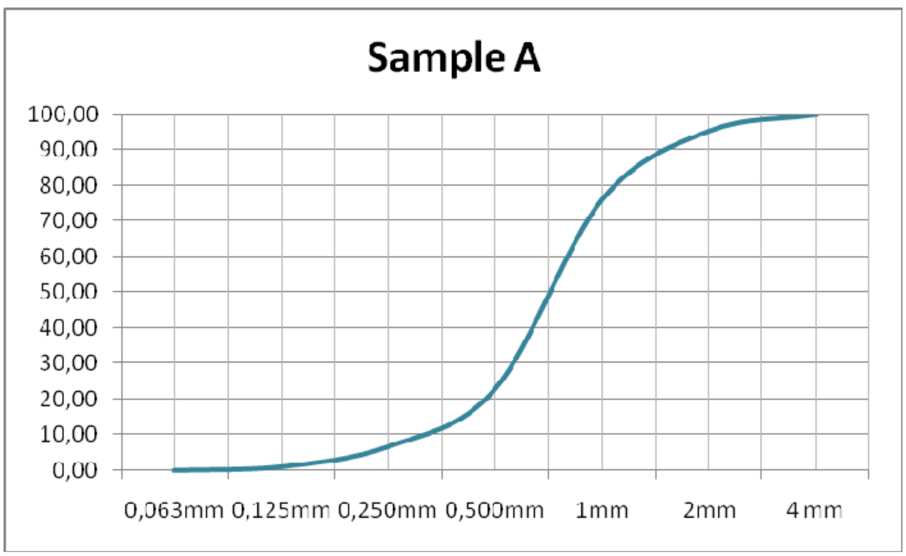


Figure 8-2 Sieving curve from sample A

From this distribution (not all sample distributions are included in the report), some characteristic values of the sand (D10, D50 and D60) can be read out. These values represent the diameter of the grain that is undercut by, respectively 10, 50 or 60 mass percent of the sample.
Because it is interesting to know how the sand is graded at different distances from the waterline, the samples are grouped. Group I is the average of the samples taken from a few meters into the sea, II is from 10 meters from the waterline and III 20 meters from the sea.

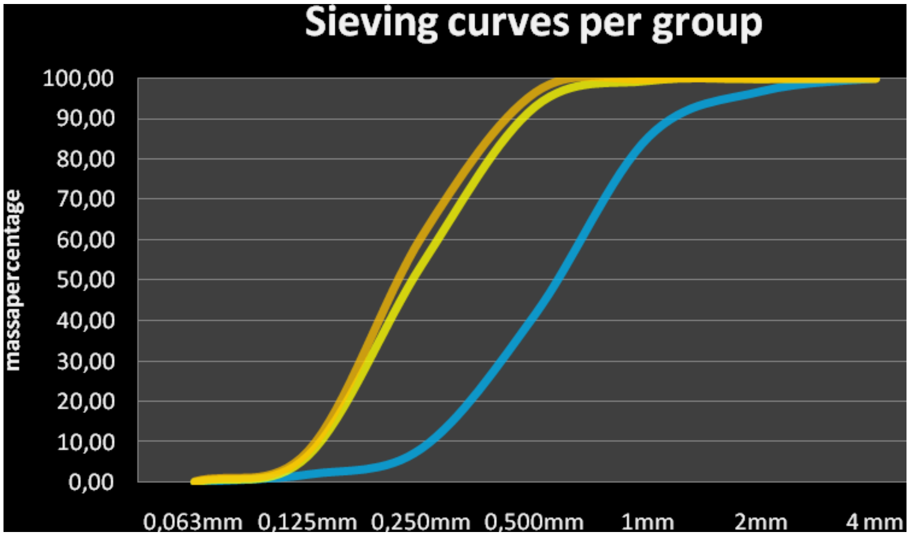


Figure 8-3 Average distributions

In the D_{10}, D_{50}, D_{60} and the D_{60}/D_{10} ratio for each of the groups. As well as from the graph it can easily be observed that the grain size decreases with increasing distance from the sea. In the surf zone, the median grain size is more than twice that of the sand on the beach. Also, the width of the gradation is larger expressed by a larger value of D_{60}/D_{10}.

	I	II	III
D_{10} [µm]	262	134	130
D_{50} [µm]	596	240	224
D_{60} [µm]	709	289	247
D_{60}/D_{10}	2.71	2.16	1.90

Table 8-2 D_{10}, D_{50} and D_{60} of averaged distributions

8.5 Comparison with results of previous years

In order to get an idea of how the beach changes over the years, we now compare the D_{50} of three locations in the same cross section as calculated in 2004 with the results of the samples taken in 2008. The values for D_{50} of the 2004 samples were taken from the fieldwork 2004 report. The location of these sample points correspond more or less with the locations of the sample point of this year's fieldwork (points C, D and E as indicated in Figure 8-1).

	C	**D**	**E**
D_{50} in 2004 [µm]	320	365	395
D_{50} in 2008 [µm]	519	221	203

Table 8-3 Comparison of D_{50} of the years 2004 and 2008

8.6 Conclusions

As can be observed, a lot has changed in 4 years. Now, the larger grains are located just a couple of meters off shore and the smaller sand particles are found on higher grounds. This is the opposite of the observations from 2004. This can only be explained by human intervention as the natural sediment transport mechanisms have not changed that much over this short period.

In the period between 2004 and 2008, a beach nourishment was carried out about 500 meters north of Sirius hotel. It is obvious that this has an effect on the beach at the compared cross section. To further investigate this process, it is advised that in the following years samples are taken from these same locations.

9 Groyne Extension

9.1 Introduction

It is apparent from observations that the current beach is unacceptable and modifications must be made to the structures surrounding the beach. In order to ensure adequate beach area is available in front of Sirius Hotel three options are possible: construct a new groyne south of the hotel (Figure 9-1), slightly extend the existing groyne and construct small groyne south of the hotel (Figure 9-2), or only extend the existing groyne (Figure 9-3).

Figure 9-1 Location of a new groyne south of the hotel, indicated by 'a'

Figure 9-2 Extension of existing groyne and location of a new groyne south of the hotel, both indicated by 'b'

Figure 9-3 Extension of existing groyne, indicated by 'c'

9.2 Design Possibilities

In this section three possibilities of groyne construction will be discussed. Then the most feasible choice will be selected and the basic design elements of the groyne will be computed.

9.2.1 Creation of a new groyne (a)

Constructing a new groyne to the south of the hotel has questionable effectiveness. Some accretion of sand may occur near the new construction; however, a similar erosion profile will exist and the beach will not become significantly wider. Therefore this option is not a viable solution.

9.2.2 Combination extension existing groyne and new groyne (b)

Out of the three possible options, constructing two groynes is the most expensive solution. Also, due to the limited effectiveness of the new groyne "a" this option will not be evaluated.

9.2.3 Extension of existing groyne (c)

Extending the existing groyne will allow for a greater length of underwater slope that is protected from erosion. The beach profile has been consistent for several years which means the slope in front of the beach is stable. Therefore extending the groyne will increase the beach width by approximately the same length.

Additionally, extending the existing groyne allows for the ship restaurant to be placed much more "over water" than on the current groyne. The extended portion can be easily constructed out of new materials and at a chosen elevation to allow high waves to reach the ship.

9.3 Design of extended groyne

Three important design specifications exist for the extension of the groyne.

The groyne should guarantee Sirius beach is stable and allow the beach to become larger with the aid of beach nourishment. This specification limits the length of the groyne.

During stormy conditions a breaking wave at the bow of the ship is preferred while ensuring safe access at all times. This specification limits the height of the groyne.

Also, the material selected for the groyne is important to ensure a stable structure during storm conditions.

9.3.1 Length of groyne

The most important aspect of stabilizing the beach is to ensure a stable slope exists underwater. Through bathymetric profiles obtained during the fieldwork a stable underwater slope for local sand was found to be 14%. Also, the water depth at the location of the extended groyne was measured to be approximately 2.5m. Therefore it can be calculated that the required length of additional protection is 18m. This value has been rounded to 20m for additional buffer of the beach nourishment and sand profile.

$$\frac{2.5}{0.14} \approx 18 \rightarrow 20\text{m}$$

This 20m of additional groyne will allow for 18m of 14% sloped sea bottom to stabilize. This will therefore create a beach in front of the hotel with the same coastline, but beginning at the end of the existing groyne.

Figure 9-4 – Impact of extended groyne on coastline and beach width

9.3.2 Height of groyne

To ensure some waves reach the ship on the groyne, the height is determined using the run-up equation for irregular waves:

$$\frac{R_{u2\%}}{H_{m0}} = \min\left\{A\gamma_b\gamma_r\gamma_\beta\xi_0, \gamma_r\gamma_\beta\left(B - \frac{C}{\sqrt{\xi_0}}\right)\right\}$$

where:

$R_{u2\%} =$ run-up level exceeded by 2% of waves

$H_{m0} = H_s = 2\text{m}$

$A = A_{design} = 1.75$

$\gamma_b = 1$ (berm correction factor)

$\gamma_r = 0.7$ (single layer riprap reduction factor)

$\gamma_\beta = 1$ (angle of attack correction factor)

$\xi_0 = 7$ (Iribarren number)

$B = B_{design} = 4.3$

$C = C_{design} = 1.6$

Therefore:

$R_{u2\%} = \min\{17.15, 5.17\}$

$R_{u2\%} = 5.17\text{m} \rightarrow 5.2\text{m}$

Using the run-up equation it has been calculated that 2% of waves will run-up to an elevation of 5.2m BSL (Black Sea Level). This is a safe level of protection for the restaurant and its customers and employees.

In order to increase the spectacle of waves reaching the ship, the rocks at the bow of the ship can be placed lower depending on the strength of the ship's foundation and structure. For example, this elevation can be set at 4m BSL. This must still be determined based on the loading capacity of the new ship.

It is suggested to ensure the stern and sides of the ship (where customer access will likely occur) is protected by the 5.2m elevation to ensure the safety of the customers and employees. Also, a concrete wall should exist between pedestrian walkways and the rock to maximize customer safety and usable space and to prevent water traveling between the rocks from flooding the location.

Figure 9-5 shows a profile of the proposed groyne.

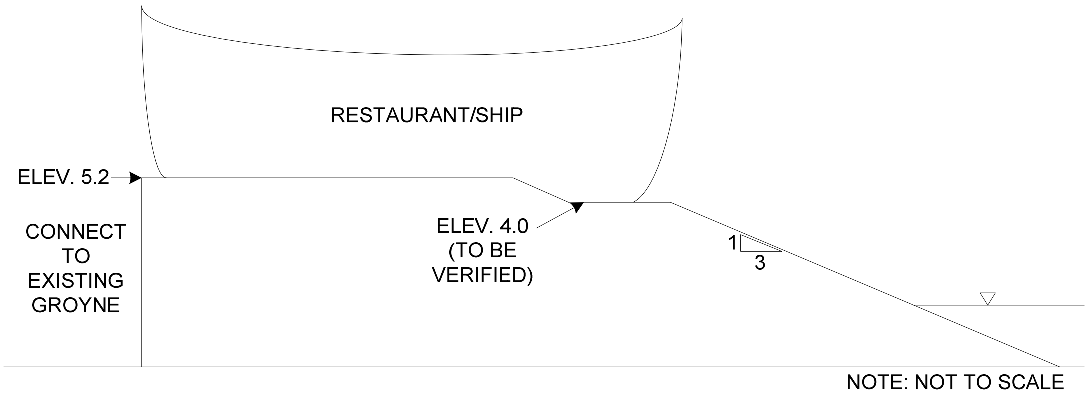


Figure 9-5 – Profile of extended groyne

9.3.3 Groyne material

To ensure the long term survivability of the structure it is suggested to construct the slopes of the groyne using rocks of a similar d_{n50} as existing coastal structures in the area. As discussed in section 7.2 the D_{n50} of these rocks is approximately 1.18m. Rocks can be made available from local quarries.

The remaining material for the foundation of the ship can be composed of more fine material such as gravel or quarry run and is readily available from local quarries. In order to ensure no outwash of this material occurs a concrete wall is proposed and will also help avoid waves flooding the pedestrian walkways.

An example cross section of the groyne can be seen in Figure 9-6.

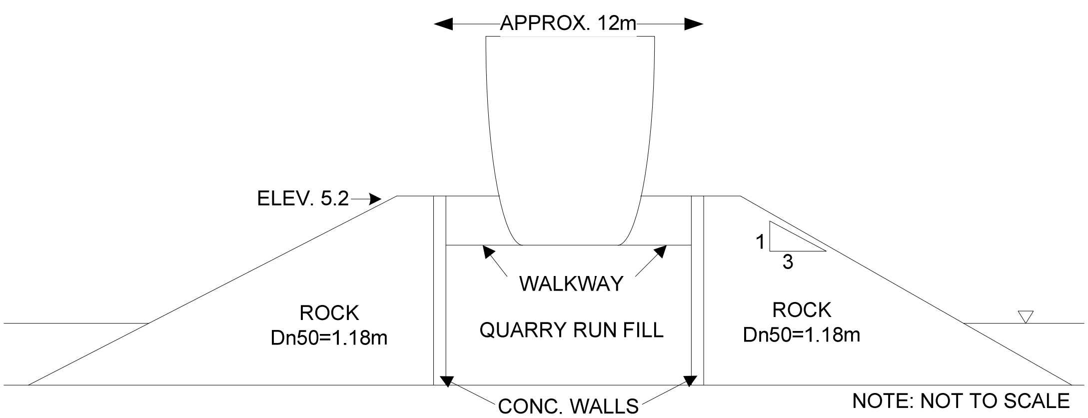


Figure 9-6 – Cross section of extended groyne; looking out to sea

The slopes of the groyne have been chosen to be 1:3. Calculations to verify this can be found in section 7.7.

The width between the concrete walls has been estimated to be approximately 12m. This will ensure space for the ship as well as walkways on either one or both sides.

9.4 Conclusion

Out of the available options, choosing to extend the existing groyne at Cape Sirius is the most feasible solution to the lack of beach located in front of Sirius Hotel. Constructing the extended groyne in conjunction with beach nourishment will provide approximately 20m additional beach width.

Additional calculations must be performed for the concrete walls as well as the structure and the foundation to the restaurant/ship. Also, the connection between the existing and new portion of the groyne must be investigated.

10 Slipway

10.1 Introduction

The hotel owners noted the requirement of a slipway for small craft to be launched near the hotel. In this chapter a possible site with an outline design is provided.

10.2 Site selection

It is a desirable feature that the slipway is accessible by car to enable easy vehicular boat delivery and pick up. Further, the slipway should be reasonably well sheltered to prevent excessive wave forces on the boat and trailer with associated instabilities and possible damage. An access from the existing hotel car park down to the beach with a slipway in between two rock rubble structures is favoured as it makes use of existing infrastructure where possible and utilises shelter created by the rock.

10.3 Orientation

The slipway is likely to be used mostly during summer with occasional use in late spring and early autumn. In summer the predominant wind and wave direction is easterly (ref http://www.nrlmry.navy.mil/~cannon/medports/Varna/). Hence, the slipway should be orientated towards the east to ensure that waves are faced by launching boats head on to reduce rolling and increase stability.

Figure 10-1 Location slipway

10.4 Outline Design

Acceptable gradients and keel clearance are key determining design factors. The proposed site of the slipway is surrounded by rocks and an accurate measurement of the seabed slope was not possible due to the risk of grounding the measuring vessel. Based on measurements a sea bed slope of 1 in 50 was estimated by averaging the slope to a depth of -10m MSL in the vicinity of the site. For vehicular traffic with trailers a slope of 1 in 8 is acceptable and 1 in 12 is desirable. The area behind the hotel, near the carpark is on higher ground which may necessitate a steeper local gradient. Care should be taken when using two different gradients to prevent catching of the trailer at the junction of the gradients.

The slipway should allow the launching of pleasure craft with a typical draft of say 1.5m. A keel clearance of 0.5m is typically recommended and an allowance for wave motion of 0.5m for summer usage has been made. Overall this would result in a slipway with a typical length of approximately 25m with an approach road of approximately 80m length from the car park.

It is likely that the slipway is constructed using quick setting underwater concrete poured into shutters in situ. An A393 mesh or similar should be placed with a 40mm cover below the runway to provide a durable surface which can sustain heavy wheel loads. Dowel bars (T12) which are drilled and socketed into position may be used to fix the mesh into position. However the sockets must be thoroughly grouted to prevent water ingress and later spalling. During curing, a brush stroke finish or similar should be applied with some grooves to enable a better grip. No reinforcement or other metal element should protrude the concrete or have a cover of less than 40mm to prevent spalling. Rocks should be placed on a suitable geotextile or similar to the sides of the slipway typically in a 1:3 tapered slope to prevent direct wave attack which may result in scouring and undermining of the slipway. Excess rock from the ship groyne construction may be used for this purpose.

11 Design of nourishment

11.1 Introduction

The current beach width near hotel Sirius is only sufficient to accommodate a small amount of guests from the hotel. Creating sufficient beach area for all guests would lead to a enormous beach width, since the length of the beach is bounded by a rocky groyne in front of the hotel and beach bar "Cachaça" in the south. It is obvious that accommodating all guests when the hotel is fully booked is not possible here. It would not even be necessary, since it will never occur that all the guests want to enjoy the beach at the same time and most of the times the hotel is not fully booked. It is however clear that the current width is too small, therefore a nourishment will be designed.

The current beach width is 15-20m near hotel Sirius. The beach becomes wider towards the south, and reaches a final width of about 30m. The increase in width is bounded by the length of the extended groyne. Placing sand further into the sea would results in loss of sediment. Therefore the added beach width is 20m at maximum. If a wider beach is desired, the groyne needs to be extended further seawards.

11.2 Volume calculations

The nourishment is not intended to interfere in severe ongoing erosion, but to widen the beach to create more width for recreation. The volume of sand to be placed will be calculated graphically using the most recent profile measurements. An amount of sand will be added to the existing profiles in order to create a beach width which fulfils the moon shape feature presented in Figure 11-1.

Figure 11-1 New layout of the area around hotel Sirius, including the proposed beach nourishment

The volume will be calculated by schematizing the new beach by a trapezoidal cross-section and a triangular plane. The triangle is shown in Figure 11-1 and the trapezium is shown in

Figure 11-2. Making the beach platform wider, until the end of the extended groyne, would undo the intention of making the ship a landmark again. The ship will be surrounded by beaches which is considered as being not the right place for a ship; a ship should be located in the water.

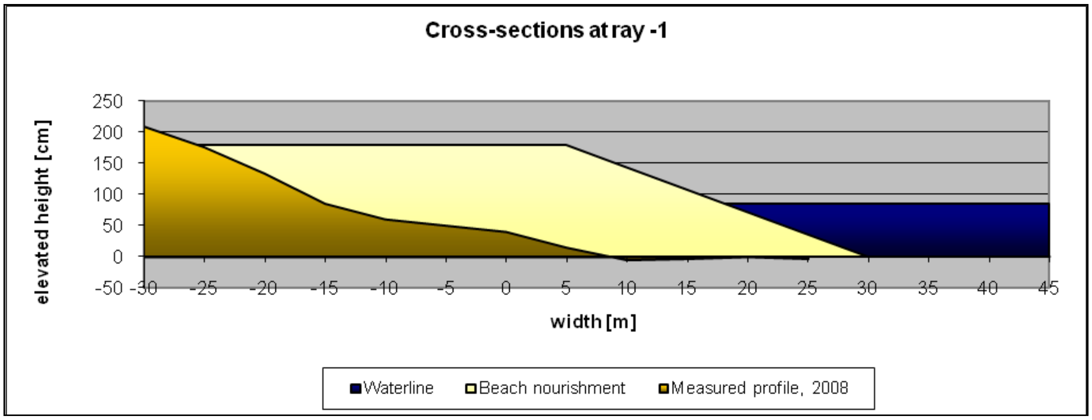


Figure 11-2 Measured and nourished cross-sections at ray -1

The base length of the beach plane is 20m, the current groyne length. The length of the beach plane is roughly 70m. The height of the amount of sediment that is to placed will be based on the present height of the berm and the depth from where the profile remains more or less constant in vertical direction. The difference of these values is determined of the profiles which are included by the nourishment area. This results in the height of the amount of sand that is to be placed. An average value of the different profiles is taken for the whole length of the design. These values are presented in Table 11-1, it follows that the height will be 3m.

Ray	Berm height [cm]	Constant depth [cm]	Height difference [cm]
-1	-200	-380	180
0	-150	-340	190
1	-120	-350	230
2	-120	-400	280
3	-50	-420	370
4	-90	-350	260
5	-70	-410	340
6	100	-410	510
7	-110	-430	320
		Average	298

Table 11-1 Height of the added amount of sediment

With three known dimensions (length, width and height) the volume of sand to be placed can be calculated.

This leads to a volume of $V = \frac{1}{2} \times b \times h \times l = \frac{1}{2} \times 20 \times 70 \times 3 = 2100 m^3$

The source of the sand is not yet known. A study should be performed to investigate the soil condition in the offshore area. If coarser sediment will be applied compared to the size of the native sediment, the beach slope will steepen. If the nourished sand is finer, a milder beach and for the fact that the sediment compatibility is not yet known, an extra 20% will be added. This leads to a nourish volume of 2500m^3.

11.3 Necessity of the beach nourishment

The question remains if the beach nourishment is necessary. If the nourishment is executed in the current situation no more sand will be added compared with the designed situation with the extension of the groyne. The sand will be less trapped and might be transported along the groyne. It was however assessed earlier on that the longshore current is close to none. The necessity of the nourishment is therefore equal for the current as for the designed situation.

Since the beach plane would double in width, a significant larger area will be created for recreational purposes. This will lead to an increase of profit for the hotel, since more guests will stay at Sirius beach instead of visiting another beach or visiting a natural spring. On top of this, using compatible or finer sands, a flatter beach slope could be realised, which would increase the comfort of the swimmers.

The nourishment will however only be profitable when there is a nearby landbased sand source, since only large scale beach nourishment project are profitable when executed from sea. Another way to limit the costs is to combine the nourishment with the extension of the groyne. Constructing the extension will also call for the use of trucks. These trucks can then be used for the nourishment.

The nourishment is desirable for the current situation as well as after constructing Cape Sirius. It will however be better affordable when the nourishment is combined with the extension of the groyne.

11.4 Further investigations

This design is just preliminary. For a detailed design several things should be investigated further.

First possible sand sources should be sought and investigated. Coarse sand will lead to steeper slopes and thus cause increased reflection of waves. This sand could also be uncomfortable for the beach visitors. Sand finer than the native sand will lead to a flat and wide beach, which is ideal for the guests. This implicates however the use of more sand and might cause an increase of erosion. The nourished beach might wash away faster. Sediment sizes compatible with or finer than the native sand is preferred.

Probably the best sand source is the Black Sea, since it is close and will add no pollution. Another source might be the Varna lake or the Varna river. Pollution is expected when using this sand due to the location of Varna harbour. But as said before, dredging will increase the project costs considerably. It is therefore recommended to search for applicable sand in the Varna area. This sand can than transported by trucks. The difficulty of this approach is finding compatible sand. Sand more landinwards will probably be too coarse. Further investigation of possible sources is necessary.

Further more the costs of this part of the project should be investigated. Of course this depends on the sand source.

12 Conclusion and recommendation

12.1 Conclusions

The report introduced this year's hydraulic fieldtrip and assignment which consisted primarily in determining a possible new location and providing an outline design for a ship-shaped restaurant, next to hotel Sirius, in a more prominent location. In addition, the requirement for a slipway for small leisure boat launching has been addressed. At the same time a proposal which improves the beach quality in front of hotel Sirius has been formulated.

It is concluded that an extension of the existing groyne in front of hotel Sirius is the preferred option. This option addresses the relatively narrow beach and the challenge to relocate the ship-shaped restaurant to a more prominent location. The beach southward of the groyne in front of the hotel is narrow but appears to be relatively stable over the past few years. The proposed extension of the existing groyne in combination with a beach nourishment is likely to result in a wider relatively stable beach. Moreover, the extension of the groyne seawards creates space which may be used for the relocation of the ship-shaped restaurant. The top of the groyne will be visually unobstructed and the low surroundings, the sea and the beach, will enable long sweeping vistas. This would provide the relocated ship-shaped restaurant a prominent appearance in close vicinity to the hotel.

Several measurements in the surrounding have been executed to help determine the required stone size for the proposed groyne extension near hotel Sirius and the redesign of the St. Konstantin Groyne.

The first observation was that the St. Konstantin groyne consists of stones with a D_{n50} of 90cm at the south side and stones with a D_{n50} of 45cm at the north side. Furthermore, fewer stones were found at the north side of the groyne, compared to the south side. These observations indicate that the north side is significantly affected by some major storms and that some stones may have become loosened and washed away from the groyne.

It is considered most likely that both sides of the groyne have been designed to the same standard and with the same rock sizing. Hence, probably the groyne has been designed with a D_{n50} of 90cm and some rocks have been moved and displaced resulting in underlayer type rock being exposed at the surface. The Hudson stability formula confirms that a D_{n50} of 90cm is insufficient considering the local wave climate and is likely to fail after one severe storm event for the given rock size.

This theoretical result correlates well with the visual observations and measurements of stone size distribution.

Further, an outline design using the Hudson formula with a very low accepted damage level for the proposed groyne extension near Hotel Sirius would result in a required D_{n50} of 1.18cm.

Visits to two local quarries resulted in finding already blasted rocks in Marciana Quarry which may be used. These rocks are likely to fall short of the stringent requirements indicated in EN13833. However, the rock is likely to be suitable considering a higher maintenance allowance and a lower design life of the structure. It appears that locally quarried rock tends to be softer and less hard with a higher porosity than ideal. However, the cost of importing higher quality rock complying with EN13833 is likely to be prohibitive and significantly exceeding the maintenance cost of using locally quarried rock. Rock of various sizes including 1-3t and 3-6t class rocks are present within the quarry and no additional blasting time would be required in a programme. Hence, it will be probable that sufficient material can be cherry picked according to a suitable grading.

The coastal processes and morphological evolution of the beach at Hotel Sirius have been reviewed. A bathymetric survey as well as a topographic survey of the beach has been undertaken. The topographic survey consisted of beach profiles as well as a walkover survey of the position of the coastline, for the beaches north and south of the hotel.

The north side of the hotel has been surveyed for the first time this year so no data comparison indicating evolution with regard to previous years is available. The survey of the south beach has been compared with results of previous years. These indicate that beyond the 4m depth contour no significant changes have occurred during the last 5 years. In the shallower part a shift of the 2m depth contour is noticeable right in front of the hotel. Furthermore the appearance of a shoal 50m southward is noticeable. Both these features indicate longshore sediment transport in southward direction, however on a small scale. Observations elsewhere on the coast indicate an onshore/offshore transport during storm event. The bathymetry does not indicate any sand trapping type features such as deep sudden valleys and hence it is assumed that any onshore/offshore movements are likely to be balanced out presenting seasonal or annual variations only.

The coastline measurements show a minimal transgression of the coastline in front of the hotel compared to the other years, indicating southward directed sediment transport as well. However, the coastline measurements have been repeated several time during the fieldwork of this year which resulted in a significant different position of the coastline in the order of magnitude of 10 to 20m. This is probably partly caused by the inaccuracy of the GPS meter and partly caused by the difference of conditions while measuring the coastline. Therefore it is difficult to develop a representative coastline that can be compared to the coastlines of previous years. The same applies to the beach profile measurements that have been undertaken. The profiles are difficult to compare with previous years since the measurements locations are different.

12.2 Recommendations

An outline design has been completed for the proposed groyne extension. Further work will need to be carried out prior to commencement of construction and assumption will need to be verified. Further an environmental impact assessment of the project with a consultation of key stakeholders is recommended. A detailed structural and geotechnical analysis and investigation will be required to ensure structural integrity and adequate foundation of the ship restaurant. It is advised to seek professional advice for the final design.

A beach nourishment is considered an essential part of the preferred option as this improves the beach quality, width and hence reduces the risk of damage to the hotel due to flooding or spray. The cost benefit of a beach nourishment scheme needs to be assessed as the small scale may result in higher cubic metre costs than usually anticipated for marine works in that region. It is likely that a landbased nourishment with trucks, diggers and spreaders is most cost efficient. Sea based dredging operations are likely to be costly due to the high mobilisation cost element for such a small overall scheme. Further, it is considered likely that the number of marine contractors in the area is limited compared to landbased contractors reducing competition and raising costs. Further, the concurrent construction of the groyne extension could lead to equipment savings as trucks may be used to import rocks from the nearby quarry.

It is recommended to undertake monitoring of the beach and shoal that is located approximately 50m southward of the hotel. The evolution of the beach and shoal will help develop a better insight into the coastal processes at hand.

Further, it is recommended to record wave statistics nearby the site. Longterm wave statistics would provide a more reliable value of the design wave height, which is necessary for the design of the slipway and the groyne extension. Ideally the order of magnitude of such a record should be several years. Should this is not possible then consideration should be given to record waves over the period of at least one winter for the groyne extension. This data may then be extrapolated using statistical tools and standard extreme value distribution functions. It should be noted that the errors associated with this are likely to be significant.

Reliable survey data to the same reference level and measuring the same locations i.e. beach profiles and bathymetry is vital in analysing the coastal processes and designing a proposed solution.

The bathymetric data is used to transform an offshore wave climate to a nearshore climate. Hence any errors in the bathymetry will lead to errors in the predicted inshore wave climate resulting in possible under/overdesign of the structure.

Further, reliable survey data to a fixed reference level undertaken at the same locations enables comparison year on year. Analysis of reliable data will result is a better identification of the key coastal processes and their relative magnitude. It is therefore recommended that the same route should be followed by the boat year after year. This may only be achieved when using suitable software on the boat indicating the required 'sweep path' to be taken in conjunction with a local positioning system such as GPS.

Further, it is recommended to use more accurate measuring equipment (such as Lidar in conjunction with GPS) to optimise the quality of the measurements taken and to facilitate an easy analysis of data in 3D software packages such as AutoCad Land.

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