Fieldwork Hydraulic Engineering

Asparuhovo Beach

TU Delft Bulgarian Fieldwork 2021

Final Report
Varna, Bulgaria
CIE5318

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TU Delft

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by

Maikel Berg
Sanne van Dijk
Floris de Koning
Stefanus Kurniawan
Marjolijn Mascini
Auke Molenkamp
Roald van der Ven
Thijs Verhoeven

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Fieldwork staff:	Dr. Ing. M. Z. Voorendt,	TU Delft, supervisor
	B. Savov,	Field Team Leader
	T. Marin,	Field Team Assistant

TU Delft

Preface

This report is the final product of the Hydraulic Engineering Master course CIE5318 'Fieldwork Hydraulic Engineering' of the Delft University of Technology. The objective of the course is for students to learn to plan and execute a measuring campaign needed to solve problems in the field of hydraulic engineering. This report is made for educational purposes and made understandable for the target audience of MSc level students with an engineering background.

As a part of the course, 8 students of Delft University of Technology have performed hydraulic fieldwork in Varna, Bulgaria. The students received the opportunity to visit a real project site and to work on an actual hydraulic engineering problem. The second most important part of the course is to process and analyse the data collected during the fieldwork.

The fieldwork was performed from the 23rd to the 30th of September 2021. During this week, the planned measuring campaign was performed to obtain data to assess the proposed problem. Various measurements were performed at Asparuhovo beach itself, but also some other site locations were visited, like two nearby quarries and other relevant beaches and breakwaters. After the fieldwork, the gathered data was analysed to allow the students to draw some preliminary conclusions to the proposed problem.

We would like to thank Mark Voorendt for organising and supervising the course and the fieldwork. Also, we are grateful to Boyan Savov and Traian Marin for sharing their expertise, facilitating the transport, local connections, measuring equipment and all other help during the fieldwork.

Delft,
November 11, 2021

Maikel Berg
Sanne van Dijk
Floris de Koning
Stefanus Kurniawan
Marjolijn Mascini
Auke Molenkamp
Roald van der Ven
Thijs Verhoeven

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The Fieldwork Hydraulic Engineering course, as well as this report, is of a purely educational nature. The main goal is to teach the students about the practical applications of their hydraulic engineering studies by letting them experience a real-life problem first-hand. This report should therefore be read as an educational project for the students. It does not reflect the opinion of the Delft University of Technology in any way.

Курсът по хидротехническо строителство на терен, както и настоящият доклад, са с чисто образователен характер. Основната цел е студентите да научат за практическите приложения на обучението си по хидроинженерство, като им се даде възможност да се запознаят с реален проблем от първа ръка. Ето защо настоящият доклад следва да се разглежда като образователен проект за студентите. Той не отразява по никакъв начин мнението на Техническия университет в Делфт.

Summary

'Fieldwork Hydraulic Engineering' is a course given at Delft University of Technology for the MSc Hydraulic Engineering. In collaboration with local experts Boyan Savov and Traian Marin, a team of 8 students guided by Mark Voorendt was sent to investigate the local conditions at Asparuhovo beach in Varna, Bulgaria, for purely educational purposes. Before 2019, Asparuhovo beach used to have a stable coastline with some seasonal variations. However in 2019, the Karantinata port was constructed and disturbed the equilibrium state of the beach. Rapid sedimentation occurred near the port and the port entrance. Due to this excessive sedimentation near the port entrance, the fishing port has lost almost all of its intended functionality, as minimum water depths in the port entrance approach 0.3m. The port was originally designed for larger fishing boats, which are currently not able to enter and making the port lose functionality. It is yet unknown how this sedimentation trend is formed with the construction of the fishing port.

The main objective of the research was to examine the current sedimentation near Karantinata port by executing a measuring campaign during the Hydraulic Fieldwork and by setting up a 5 year monitoring program for the marine environment. By doing so, the processes which lead to sedimentation can be understood and a model can be made. With this model, adjustments to the port layout can be examined which are potentially needed for the port to operate at full functionality. To tackle these problems, the students performed the fieldwork. With 2 days of beach and foreshore measurements the research question was assessed. With the acquired data of the system, supported by additional lab sieving analysis, data processing and modelling in Delft, the students formed theories on the origin of the sedimentation problem. With these insights, recommendations for the area can be suggested.

The measurements are performed on multiple locations and at each location multiple variables were researched. For Asparuhovo beach and foreshore these are the bathymetry, waterline position, wave climate, beach profile, sediment characteristics and ecology. At the fishing port Karantinata these are the port characteristics such as functions, planning and infrastructure, port entrance, bathymetry and breakwater design. At the Asparuhovo breakwater it is the top protection layer, damage assessment and measures of improvement. At Veteran beach this is the soil samples for grain size distribution. At Martsiana quarry the length to thickness ratio, blockiness were researched, as well as the diameter to check if potentially suitable for breakwater material. With this information, a preliminary model in Delft3D has been set up with the land boundaries, grid and bathymetry file.

With knowledge of the coastal processes and the processed data, potential causes of sedimentation are speculated on. It is unlikely that such large amounts of sediment are coming from outside of Asparuhovo beach system, as there are no sediment rich rivers nearby, the sedimentation occurred in a very short period of two years and the sediment would mostly not be able to cross the deep navigation channel as it would settle due to lower flow velocities. It is expected that large parts of the settled sediment near the port entrance is from the beach itself. This is also more likely due to the two closed boundaries of the beach, the Asparuhovo breakwater and the Karantinata port. This was checked by analyzing the grain size diameter compared to other locations at the beach and looking at the waterline developments. It was found that the grain size at the middle of the beach was 1.8 mm and at the port entrance between 0.2 and 0.3 mm. It was suspected that the fine sediments of the middle of the beach are eroded and deposited at the port entrance as the sediment can settle at the Southeastern part behind the port breakwater due to sheltered conditions. The mechanisms that could have induced this are: rip currents, longshore currents and the different wave patterns.

To examine and validate these findings, a monitoring plan for the coming 5 years is proposed. This is very important to create an understanding of the systems parameters and behaviour. Without monitoring, adjustments to the port cannot be tested in a correctly calibrated model. The parameters which need continuous measurement are the wave parameters, sea level measurements and visual beach observations. Biannual measurements are needed for currents, hydrographic works, visual observations with a drone, bathymetry and sediment parameters. Before the port is fully operational again, the port entrance needs dredging. This can be done in this time span of 5 years to ensure the passage of fishing boats. After dredging a short survey of the area needs to be performed to incorporate the changes into the model. These are the bathymetric survey, visual observations and sediment samples all around the dredging area.

There are three potential solutions incorporated in the report, which can be modelled with the findings of the monitoring plan. The first potential solution to make the port fully operational again is relocating the port entrance with a curved breakwater stretching into the sea. The second solution is a combination of the entrance relocation and water flow through the port. The third is a blocking groyne stretching from Asparuhovo beach into the sea, blocking the sedimentation going into the port entrance. For all these potential solutions, dredging works are needed to re-ensure the required water depth for the vessel draught. The least costly and most promising is the relocation of the port entrance design. It can be noted that continuous dredging is not a sustainable solution as the sedimentation keeps occurring near the port entrance as the hydrodynamic conditions will not change.

It is recommended to first find the source of the settled sediment by comparing control volumes of sediment on the beach over the years. Then a model should be set up of the Asparuhovo beach and foreshore and Karantinata port to give insights in the processes. This model needs to be validated and calibrated with input from a monitoring campaign. With a working model, the causes of sedimentation can be found and further research can be done whether the potential solutions are appropriate.

Резюме

”Хидравлично инженерство на терен” е курс, който се провежда в Техническия университет в Делфт в рамките на магистърската програма по хидравлично инженерство. В сътрудничество с местните експерти Боян Савов и Траян Марин екип от 8 студенти, ръководен от Марк Воорендт, беше изпратен да проучи местните условия на плажа Аспарухово във Варна, България, с чисто образователна цел. Преди 2019 г. плажът Аспарухово е имал стабилна брегова линия с известни сезонни колебания. През 2019 г. обаче беше построено пристанище Карантината, което наруши равновесното състояние на плажа. В близост до пристанището и входа на пристанището настъпи бърза седиментация. Поради тази прекомерна седиментация в близост до входа на пристанището, рибарското пристанище е загубило почти цялата си предвидена функционалност, тъй като минималната дълбочина на водата във входа на пристанището се доближава до 0,3 м. Пристанището първоначално е било проектирано за по-големи риболовни кораби, които в момента не могат да влизат в него и това води до загуба на функционалността му. Все още не е известно как тази тенденция на утаяване се е формирала с изграждането на рибарското пристанище.

Основната цел на изследването беше да се проучи настоящата седиментация в близост до пристанище Карантината, като се изпълни измервателна кампания по време на хидравличните полеви работи и се създаде 5-годишна програма за мониторинг на морската среда. По този начин могат да се разберат процесите, които водят до седиментация, и да се състави модел. С помощта на този модел могат да бъдат разгледани корекциите в устройството на пристанището, които са потенциално необходими, за да може то да функционира в пълна степен. За да се справят с тези проблеми, учениците извършиха теренна работа. С двудневни измервания на плажната и крайбрежната ивица беше оценен изследователският въпрос. С получените данни от системата, подкрепени от допълнителен лабораторен ситов анализ, обработка на данните и моделиране в Делфт, студентите формираха теории за произхода на проблема с утайките. С тези прозрения могат да се предложат препоръки за района.

Измерванията са извършени на няколко места и на всяко място са изследвани множество променливи. За плажа и брега на Аспарухово това са батиметрията, положението на водната линия, климатът на вълните, профилът на плажа, характеристиките на седиментите и екологията. За рибарското пристанище Карантината това са характеристиките на пристанището като функции, планиране и инфраструктура, вход на пристанището, батиметрия и дизайн на вълнолома. При вълнолома в Аспарухово това са горният защитен слой, оценката на щетите и мерките за подобряване. На плажа Ветеран това са почвените проби за разпределение на зърнометрията. В кариера ”Марциана” са изследвани съотношението между дължината и дебелината, блокажността, както и диаметърът, за да се провери дали е потенциално подходящ за материал за вълнолом. С тази информация беше създаден предварителен модел в Delft3D с границите на сушата, мрежата и батиметричния файл.

С познаването на процесите в крайбрежието и обработените данни се правят предположения за потенциалните причини за седиментацията. Малко вероятно е такива големи количества седименти да идват извън плажната система на Аспарухово, тъй като наблизо няма богати на седименти реки, утаяването е станало за много кратък период от две години и седиментите най-вече не биха могли да преминат през дълбокия плавателен канал, тъй като биха се утаили поради по-ниските скорости на потока. Очаква се голяма част от утаените седименти в близост до входа на пристанището да са от самия плаж. Това е по-вероятно и поради двете затворени граници на плажа - вълноломът в Аспарухово и пристанището в Карантината. Това беше проверено чрез анализ на диаметъра на зърната в сравнение с други места на плажа и разглеждане на развитието на водната линия. Установено е, че размерът на зърната в средата на плажа е 1,8 mm, а на входа на пристанището - между 0,2 и 0,3 mm. Предполага се, че фините седименти от средата на плажа са ерозирани и се отлагат на входа на пристанището, тъй като седиментите могат да се утаят в югоизточната част зад вълнолома на пристанището поради защитените условия. Механизмите, които биха могли да предизвикат това, са: морските течения, крайбрежните течения и различните модели на вълните.

За да се проучат и потвърдят тези констатации, се предлага план за мониторинг за следващите 5 години. Това е много важно, за да се постигне разбиране на параметрите и поведението на системите. Без мониторинг корекциите на пристанището не могат да бъдат тествани в правилно калибриран модел. Параметрите, които се нуждаят от непрекъснато измерване, са параметрите на вълните, измерванията на морското равнище и визуалните наблюдения на плажа. Двугодишни измервания са необходими за теченията, хидрографските работи, визуалните наблюдения с дрон, батиметрията и параметрите на седиментите. Преди пристанището

отново да започне да функционира пълноценно, входът на пристанището се нуждае от драгиране. Това може да бъде направено в този период от 5 години, за да се осигури преминаването на рибарските лодки. След драгирането трябва да се извърши кратко проучване на района, за да се включат промените в модела. Това са батиметрично изследване, визуални наблюдения и проби от седименти в цялата зона на драгиране.

В доклада са включени три потенциални решения, които могат да бъдат моделирани с резултатите от плана за мониторинг. Първото потенциално решение, което ще направи пристанището отново напълно функциониращо, е преместването на входа на пристанището с извит вълнолом, простиращ се в морето. Второто решение е комбинация от преместването на входа и водния поток през пристанището. Третото решение е блокираща дига, простираща се от плажа на Аспарухово в морето, която да блокира навлизането на утайките във входа на пристанището. За всички тези потенциални решения са необходими драгажни работи, за да се осигури необходимата дълбочина на водата за газене на корабите. Най-евтиното и най-обещаващото е преместването на дизайна на входа на пристанището. Може да се отбележи, че непрекъснатото драгиране не е устойчиво решение, тъй като утайките продължават да се появяват в близост до входа на пристанището, тъй като хидродинамичните условия няма да се променят.

Препоръчва се първо да се намери източникът на утаените седименти, като се сравнят контролните обеми на седиментите на плажа през годините. След това трябва да се създаде модел на плажа и бреговата ивица на Аспарухово и пристанище Карантината, който да даде представа за процесите. Този модел трябва да бъде валидиран и калибриран с данни от мониторингова кампания. С помощта на работещ модел могат да се открият причините за седиментацията и да се направят допълнителни изследвания дали потенциалните решения са подходящи.

Contents

1

Introduction and analysis

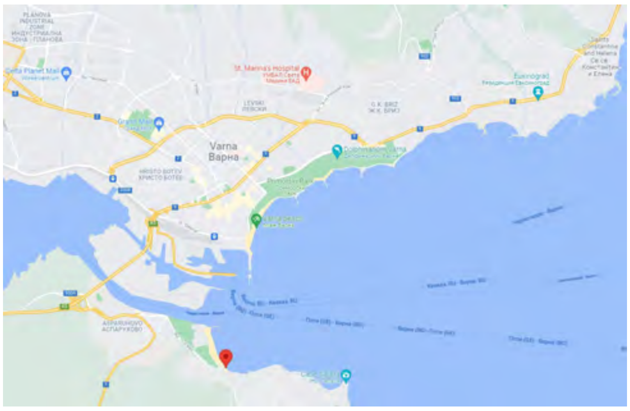
1.1. Motivation

The Fieldwork Hydraulic Engineering course of the Delft University of Technology is a practical course that uses hands-on teaching methods to teach students about measuring campaigns, the origin of construction materials, presentations and all sorts of coastal structures and processes, by letting them experience this themselves. Ever since the first edition, this task has been taken up by Mr Boyan Savov, a coastal engineer and University teacher. The students are sent abroad and in a two-day measuring campaign they learn all about levelling, measuring and all other forms of acquiring necessary data. In some earlier editions the students visited the same Asparuhovo beach, so when the coastline appeared to have changed drastically the University saw enough reason to organise another interesting Fieldwork course on this beach, to try and find out what happened.

1.2. Background information

Constructed in 2019 Karantinata port is a fishing port on the Southeastern end of Asparuhovo beach, which is located to the South of the vibrant and busy port city of Varna in Bulgaria (see Figure 1.1).

(a) The Black Sea, with Varna in the west



(b) Varna, with the Karantinata port in the Southwest

Figure 1.1: An overview of geographical locations around Varna and the Black Sea

The city of Varna is located in the Northern Bulgarian region and is adjacent to the Black Sea. The Bulgarian Black Sea coast is characterised by the absence of major river systems, the closest one to the North being the Danube river at a distance of 270 kilometers as the crow flies. To the south, this is 240 kilometres to the Bosphorus strait. Along the rest of the Black Sea coast Russian rivers Dnieper and Don enter the Black Sea, along with some minor Turkish, Georgian, Ukrainian and Russian rivers.

The area that the Black Sea spans is large for its limited amount of river inflow covering 461000 km^2 including the Sea of Azov. It reaches maximum depth of 2.210 kilometres (Encyclopaedia Britannica, sd). With its only connection to the Atlantic ocean being the Bosphorus strait and all the way to the Gibraltar strait, the tidal differences in the Black Sea are minimal. A typical tidal variation at Varna encompasses around 10 centimetres or less.

Climate information
The climate along the Bulgarian coast is strongly influenced by the proximity of the Black Sea (Velev, 2002). In the western Black Sea the most marked feature of the wind and wave climate is the considerable seasonal variability. The strongest and most continuous winds act during the storm season, which is from October to March (Valchev et al., 2014). During the storm season the average wind speed in Varna is around 5 m/s. In the remaining months of the year the average wind speed is lower than 4 m/s (Spark, sd).

The mean annual air temperature along the Bulgarian Coast is 12 °C, with a mean temperature in January of 0°C and a mean temperature in July of 22 °C. Furthermore, the mean annual water temperature along the coast is 15.9 °C and the annual amount of precipitation is about 450 to 500 mm ((SeaTemperature.re, sd); (Filipova-Marinova et al., 2016)).

Asparuhovo beach and Karantinata port
Asparuhovo beach is one kilometer long and 100 meter wide at some locations, which makes it one of the widest beaches in Varna. As the beach consists of extremely fine sand and the sea is in general shallow and calm, it is one of the favourite beaches of citizens and guests of Varna. At the northern side of the beach, there is a canal connecting the Black Sea with Lake Varna. The canal and Asparuhovo beach are separated by a breakwater, marking the northern end of the beach. Since the construction in 2019, the Karantinata port marks the South-eastern end of the beach (Visit Varna, sd). An overview of Asparuhovo beach can be found in Figure 1.2.

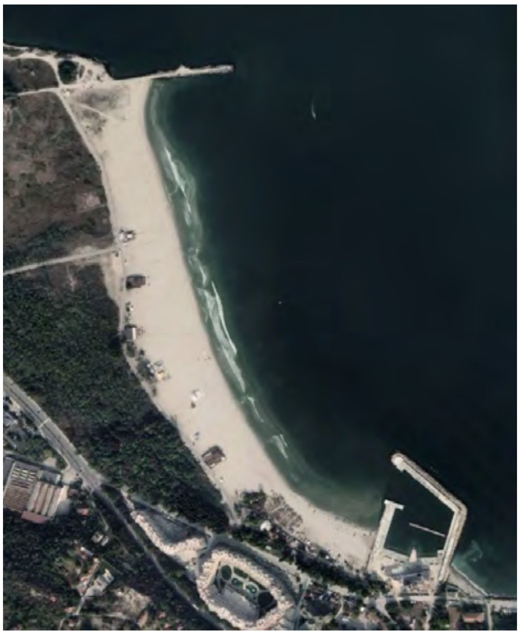


Figure 1.2: Overview of Asparuhovo beach (Google, 2021)

The construction of Karantinata port involved the modernization and reconstruction of an already existing fishing port. In the years before the construction of Karantinata port it was observed that Asparuhovo beach had a stable waterline, indicating no sign of significant sedimentation or erosion. Already during the construction of the port in 2019 a rapid change of the morphology of the adjacent South-eastern end of Asparuhovo beach could be observed. In the two years after port construction, the waterline at the South-eastern part of the beach has shifted significantly in seaward direction and clear sedimentation has occurred in front of the port entrance (see: Figure 1.3).

1.3. Problem statement

Since the construction of Karantinata port in 2019, a strong trend of sedimentation occurred near the port (entrance). In the beginning this did not form a problem, since Asparuhovo beach became just slightly longer and wider at the port side. However, in 2021 the sedimentation process already leads to a partial blocking of the port entrance of Karantinata port, which disturbs port operations. In the current situation, the Karantinata port loses its functionality and the hydraulic processes behind this sedimentation trend are unknown.

Figure 1.3: Aerial picture of the sedimentation in front of the port (24/09/2021)

1.4. Objective

As is mentioned in the problem statement it is unclear which hydraulic processes induce the sedimentation trend at the south side of Asparuhovo beach. Therefore, the main objective is to examine the current sedimentation near Karantinata port by performing measurements during the Hydraulic Fieldwork and by setting up a 5-year monitoring program for the marine environment. The purpose of the monitoring is to collect data over a period of time, carry out analyses and make recommendations for decision-making on the proper operation of the built facilities. Another objective is to examine the lay-out of the Karantinata port and propose solutions for the sedimentation problem in the port entrance.

1.5. Approach

The problem, as described in the problem statement, will be tackled during the course Fieldwork Hydraulic Engineering. This means students did research on the area and a proper measuring campaign before the trip, and then set up a measuring campaign once in Varna. With all the collected data, supported by additional lab tests, data processing and modelling in Delft, the students will try and form theories on the origin of the sedimentation problem. Based on this, they will try to come up with recommendations for the future.

1.6. Theoretical framework

In order to have comprehension of this report, elaboration on the general 'coastal processes' is needed. These processes will be described concise conform the Coastal Dynamics Lecture Notes (Bosboom and Stive, 2015). In the descriptions, the x-direction is the same as the cross shore direction (perpendicular to the coast). The y-direction is the direction along the coast.

1.6.1. Erosion and sedimentation

Erosion is the decrease of the amount of sediment at a certain place. Sedimentation or sedimentation is the increase of amount of sediment in a certain place. Erosion and sedimentation can happen in the cross-shore and alongshore plane.

1.6.2. Shoaling zone and surf zone

In the nearshore, different zones can be distinguished. The shoaling zone is the zone from where the waves start being affected by bottom and start shoaling (see shoaling, second paragraph of Section 1.6.4) until the point where they start breaking. When shallower water waves start to 'feel the bottom' it means that they enter a shallower area in which the shape of the wave is changing, because the friction of the bottom is becoming significant. From the point where the waves start breaking the surf zone (also called breaker zone) begins, which extends all the way to the beach.

1.6.3. Alongshore and cross-shore sediment transport

Sediment can be transported by water in different ways. The two main transport modes are transport as bed-load and transport as suspended load. Bed load transport happens when the bed shear stress is above a critical value. How much sediment is transported is determined mostly by the grain size and the current velocity. The suspended load transport depends on the current and on the concentration of suspended sediment in the water (highest near the bed). The total transportation of sediment has a nonlinear relation with the current. An increase in current velocity results in an even larger increase in sediment transport.

Coastal beaches and foreshores can vary in time due to the movement of sediment from one place to another. These changes are induced by transport gradients. Positive sediment transport gradients, an increase in the transport direction, cause erosion. Negative sediment transport gradients, a decrease in the transport direction, cause sedimentation. When the gradient is 0, it implies that there is no change in the morphology. This does not mean that there is no sediment transport, just that there is no change in morphology. Alongshore transport happens mostly close to the shore. When the waves start being affected by the bottom, they will start to stir up sediment. This is done by an induced bottom friction by the waves and also by the turbulence of breaking waves (in the surf zone). The stirred up sediment will then be transported by currents. These currents can be either in cross shore direction (see for example undertow), or in alongshore direction. In alongshore direction currents are driven predominantly by breaking waves that approach the coast at an angle. Coastal engineering problems are mostly related to alongshore transport gradients when, for example, the alongshore current is interrupted by a breakwater (Bosboom and Stive, 2015).

1.6.4. Wave transformation in the nearshore

When waves start being affected by the bottom or obstacles, they can change in shape and direction. The processes associated with this are called refraction, shoaling and diffraction. The wave direction in the x-direction can change due to refraction. Depth-refraction can occur when a beach is not alongshore uniform and the wave crest can move towards shallower depths at, for instance, headlands. Waves will tend to converge towards the top of a shoal and with this change refraction can lead to the convergence or divergence of wave energy. Simply said, wave crests turn towards a parallel with depth contours tending towards normal incidence. In a way that if a wave comes closer to the beach, the wave angle becomes smaller than the offshore wave angle and this bending effect is called refraction.

When a wave enters shallower parts of the coast and they will start to feel the bottom, the celerity of the wave will increase. Shoaling is the process where wave heights can change in shallower parts of the water due to the change in wave celerity. Outside the breaker zone the energy dissipation is approximately zero. This means that the energy in a control volume should remain constant. Meaning that the wave height will change with the changing water depth.

Diffraction is a process which happens when a wave approaches an obstruction such as a breakwater or a seawall. The wave transforms in the sheltered area behind this obstruction, reducing the wave height (Bosboom and Stive, 2015). This transformed wave propagates at a different angle than the initial wave angle before the obstruction with a curved wave crest.

1.6.5. Undertow

Waves transport momentum (mass times velocity) in the direction of the wave propagation. They carry momentum because of their progressive character and also within the surface roller of the breaking waves (inside the surf-zone). As a result, when the transported water reaches a closed boundary (such as the coast), the water needs to find a way back to the sea (otherwise the water will pile up against the coast). This induces a return current offshore below the wave through level that will compensate for the mass flux.

1.6.6. Scour hole

A scour hole is the local erosion of sediment around a structure. These can present themselves for instance near breakwaters and seawalls. During severe conditions these holes can become deeper, but will form no problem as long as the structure keeps his stability. If the scour hole becomes to deep and the structure becomes unstable, severe and irreversible damage can be done. Often these scour holes will be filled during moderate wave and wind conditions (Bosboom and Stive, 2015).

1.6.7. Winter and Summer profiles

In the Northern Hemisphere, where there are a large number of storms in the winter, a strong seasonality can be observed in cross-shore direction of beach profiles. During the stormy seasons, high and long waves will erode the beaches and transport the sediment offshore. The sediment is deposited in the surf zone. In the summer the same sediment is transported back towards the beach by smaller shorter waves where it is deposited. The seasonality will cause oscillations in the coastline, but the mean position of the coastline will remain constant.

1.6.8. Set-up and set-down

A water level set-up or set-down can be induced by the wind. This set-up or set-down is the response to balance the wind-induced shear stresses. This wind set-up is maximal near the coastline due to the shallow coastal zone and can become dangerously high (storm surge). A set-up difference at the coast can induce a longshore current.

1.6.9. Rip Currents

Differences in wave energy or set-up differences can result in longshore currents (MacMahan et al., 2006). Also, the breaking of waves pushes water to the shoreline. This water and the water that is transported by the longshore currents in the breaker zone will have to return to the sea. In this return a larger depth can sometimes be found as the sand can be (partly) brought more offshore. As a rip current is a strong narrow current directed toward the sea (Bosboom and Stive, 2015).

1.6.10. Sheltered and exposed areas

Sheltered waters are less exposed to wave forcing than exposed waters. This sheltered effect can be induced by breakwaters or structures where waves cannot (partly) penetrate through. The effect of a sheltered area is the increased settling of sediments due to a decrease in turbulence and flow velocities.

1.6.11. Beach state

There are in total six different beach states which can be discerned. These six are subdivided in four intermediate beach states in between the 'Reflective beach state' and the 'Dissipative beach state'. A reflective beach state is characterized by a steep and narrow beach. The sediment is relatively coarse and the Iribarren number is larger than 2. Dissipative beaches have a flat and wide beach with at least one bar. The sediment is fairly fine and the Iribarren number is around 0.2. Dissipative beaches have a high energetic wave climate where mostly spilling and plunging breaker types occur (Bosboom and Stive, 2015).

1.7. Report outline

To assess the problem of the rapid sedimentation near and in the port entrance a fieldwork is performed at Asparuhovo beach. In Chapter 2, the results of the fieldwork campaign are stated and processed in a clear overview. The structure in this chapter is in the macro to meso to micro level form. It starts with the overview of Asparhuovo beach and highlights certain parts in the system. Herein, specific details are stated. In Chapter 3 the potential causes of sedimentation near the Karantinata port are stated. To get more insight into the currently still occurring problem, in Chapter 4 a monitoring plan is proposed for the system to execute. With the outcome of this plan, a model can be properly created and calibrated such that the potential solutions in Chapter 5 can be evaluated. In Chapter 6, the conclusions and recommendations are given based on the collected data.

2
Site survey

This chapter elaborates on the sites that have been visited and studied during the Hydraulic Fieldwork. The outline of the chapter is to get an overall view of the system of Asparuhovo beach and its foreshore first, thereafter the most important subsystems have been analysed individually, like Karantinata port at the South and the breakwater at the Northern end of the beach. Then the influences of the subsystems in the main system have been analysed with an overall Delft3D model. During the Hydraulic Fieldwork, Veteran beach and Martsiana Quarry have been visited as well.

2.1. Asparuhovo beach and foreshore

In this section an overview is given of the Asparhuhovo beach and foreshore. This overview consists of the Bathymetry of the foreshore, the position of the waterline, the wave climate that is present, the profile of the beach and the characteristics of the sediment at the beach and on the foreshore.

Figure 2.1: Sandbank at the Asparuhovo foreshore

2.1.1. Bathymetry

The bathymetry of the Asparuhovo foreshore is shown using ArcGIS Pro. The bathymetry was measured using a sonar device mounted on a boat, an explanation of the full measurement technique is given in Appendix D.3. In this chapter, also an overview is given of all the data-points where depth information was measured. With the interpolation technique: Kriging in ArcGIS the bathymetry was estimated. The estimated bathymetry is shown in Figure 2.2.

This bathymetry is an estimation retrieved by interpolation and the bathymetry shows some flaws. For example, there is a sand bank present close to the waterline, which does not show up properly on the estimated bathymetry. A drone picture that clearly shows the sandbank is presented in Figure 2.1.

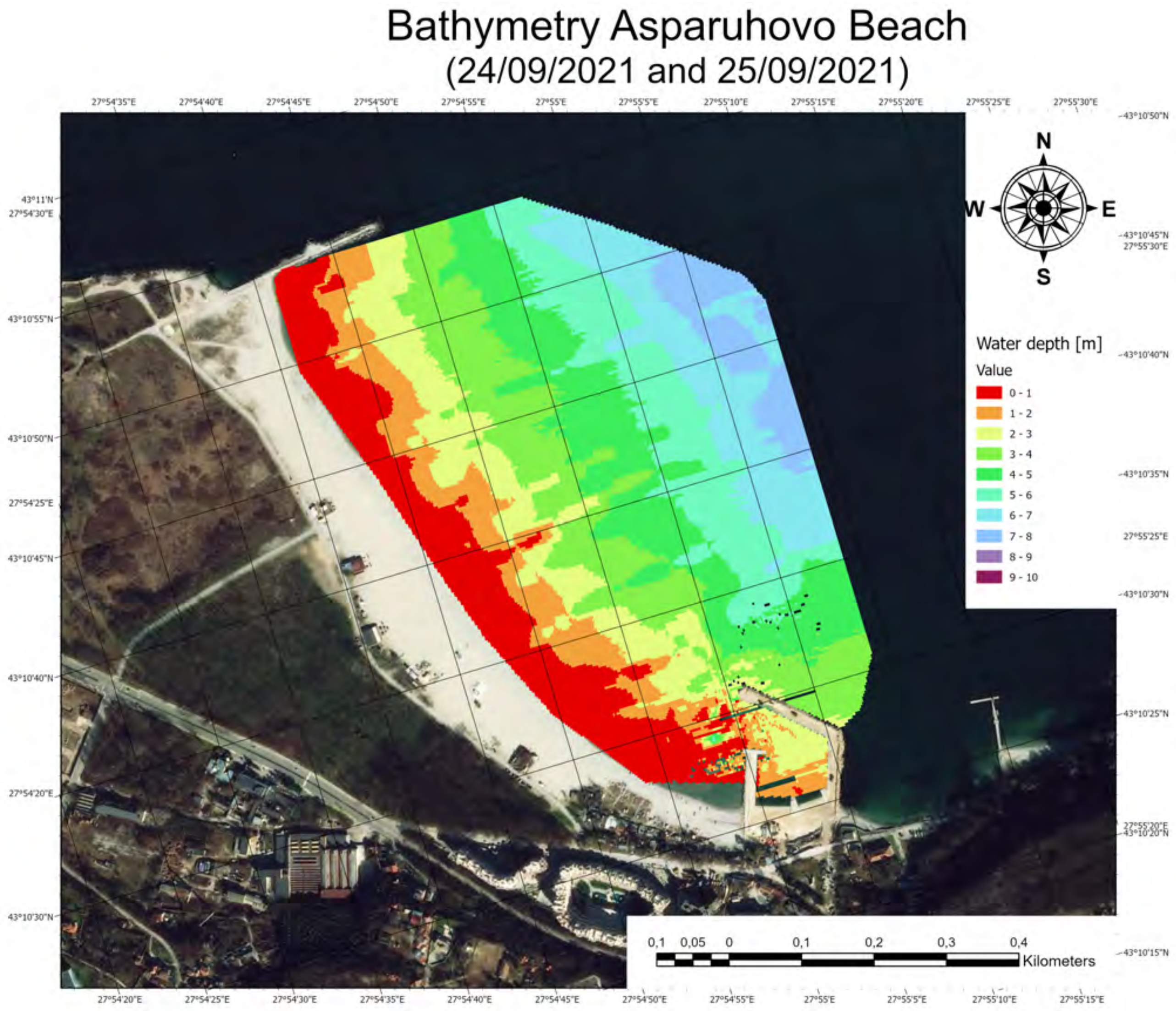


Figure 2.2: Estimated bathymetry Asparuhovo beach

2.1.2. Waterline position

By using GPS measurements and satellite images, the position of the waterline can be evaluated and compared to previous years. The average waterline is determined using 2 devices, which both measured 2 tracks (from South to North and vice versa). The average waterline is then compared to 3 satellite images, shown at Figure 2.3. The measured waterline length is almost 1 km. The first image (19-07-2019) shows the old waterline position before port Karantinata was build. The second image (09-01-2020) was taken just after the port was finished. The third image (27-10-2020) is the most recent satellite image available and represents the current situation.

(a) 19-07-2019 (b) 09-01-2020 (c) 27-10-2020

Figure 2.3: Waterline measurements average compared to satellite images taken on specified dates

The sedimentation at the Western side of the port can clearly be seen, by looking at the waterline advance during the years. This can also be seen at Figure 2.4, where the same shoreline and satellite images can be seen, zoomed in on the port.

(a) 19-07-2019 (b) 09-01-2020 (c) 27-10-2020

Figure 2.4: Zoom of average waterline measurements around port entrance compared to satellite images taken on specified dates

2.1.3. Wave climate

The wave climate near Asparuhovo beach is presented with the use of a wave rose in Figure 2.5. The data for this wave rose is obtained using a wave buoy, which has been deployed since October 2020. The wave conditions of just one year are probably not representative for the entire wave climate, but can be considered representative for the period since the port construction. In the period between port construction and deployment of the wave buoy, one severe storm occurred on April 6th 2020. The measurement methods used to obtain the information about this storm, as well as the measurement method regarding the wave buoy can be found in Appendix D.4.

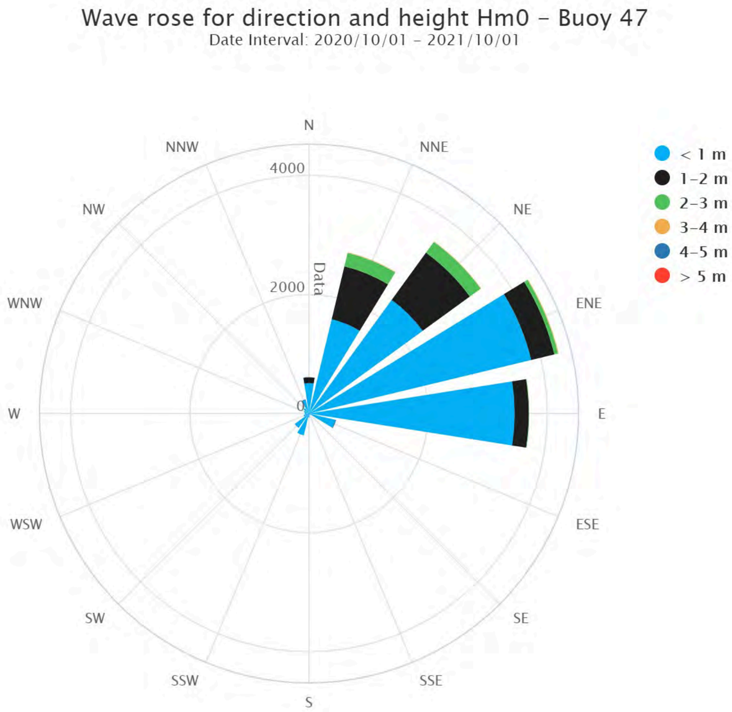
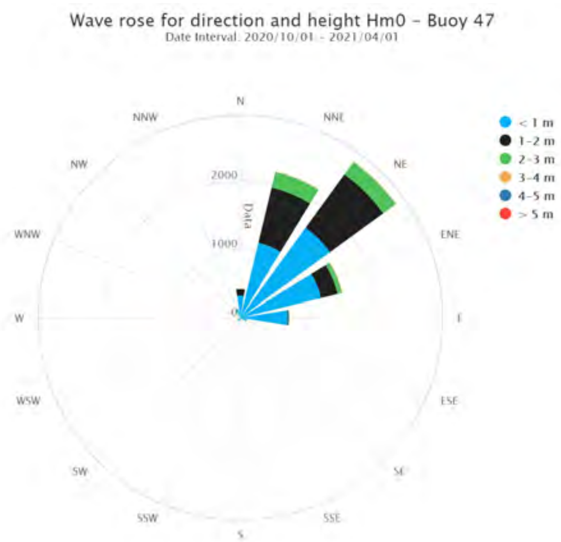
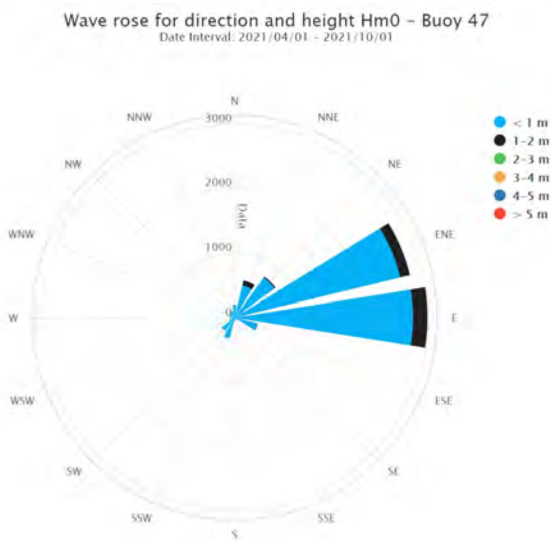


Figure 2.5: Wave rose significant wave height for 1 year

It was found that there is a significant difference in wave height and direction between the summer and winter conditions. During winter conditions, the wave heights are higher and the waves come from a NNE and NE direction. The waves during summer conditions are milder and come mostly from a ENE and E direction. This is illustrated by means of two wave roses in Figure 2.6. More elaborate information on the measured wave conditions, including the storm on the 6th of April 2020, as well as on the seasonal differences can be found in Appendix E.3. Lastly, with the purpose of providing a more visual image of conditions at the beach as compared to the measured wave conditions, the wave conditions have been compared to pictures made by a time lapse camera. The comparison between mild, medium and harsh wave conditions based on pictures of the coast can be found in Appendix E.4.



(a) Winter [01-10-2020 - 01-04-2021]



(b) Summer [01-04-2021 - 01-10-2021]

Figure 2.6: Wave roses with the significant wave height per direction for the winter and summer

2.1.4. Beach profile

To get an understanding regarding the beach profiles of Asparuhovo beach, the elevation along 10 cross sections were measured at with a leveling device. The location of each cross section can be seen in Figure 2.7. A full explanation of the measurement methods is included in Appendix D.1.

Figure 2.7: Map with the 10 transect on Asparuhovo beach (Google, 2021)

From the measurements, the beach profile along the different transects could be observed and compared. The main finding from the 10 different elevation profiles was that the slope of the beach profile near the constructed port was less steep than at other places along the beach. This is as expected since a lot of accretion happened there and a very shallow part was observed. The three transects in the middle of the beach showed a steeper profile than the transects at the port and the transect at the Northern breakwater. In the different figures, the sandbar could be observed. In some cross sections, its presence was more evident than in others. For the full results of the elevation along the 10 transects, a reference is made to Appendix E.1. In the appendix also a comparison is made to the measurement campaigns of previous years. This comparison gives a first insight in the differences, but should not be taken to literally. The result of the comparison was that there is no clear accretion or erosion along the transect. However, the measurements made this year had different locations than previous years, and therefore this could include an error when comparing them.

2.1.5. Soil-sediment characteristics

From the beach and the foreshore, sediment samples were taken to be measured. This was done to get an understanding to where which type of sediment is present. The results of the measurements are explained in Appendix E.2. The results of the measurements were that the average diameter of the sediment varied between 0.2-1.9 mm, depending on the location and the depth. Based on this size, it can be concluded that the type of sediment at Asparuhovo beach is sand. It was also found that the diameter of the sediment at the middle of the beach was larger when compared to the Northern part and the Southern part of Asparuhovo beach.

2.1.6. Ecology assessment

While investigating the beach and foreshore, the ecological situation of the beach was also assessed. This was mainly done visually and by taking pictures of the flora, fauna and waste and anthropogenic activities present at the beach.

Flora

On the beach and near the dune foot some vegetation is present. Different species of grass and plants cover the beach near the dune foot. An advantage of the present vegetation on the beach is that it can reduce erosion of the beach during storms. Near the dunefoot (edge of the beach), the vegetation consists of somewhat rougher and bigger plants and grasses, like buses and trees.

Along the waterline, remains of seagrass and seaweed are found that are washed ashore. This indicates that probably patches of seagrass and seaweed grow on the foreshore. These were not visible from the beach and nearshore, so these grow probably more offshore.

(a) Grass species

(b) Remains seagrass

(c) Another plant species

Figure 2.8: Examples vegetation on Asparuhovo beach

Fauna

During the fieldwork a small variety of fauna was found. On the beach, one species of seagull was found most often (see Figure 2.9). The seagulls are mostly attracted by the activities of fishermen on the beach. Secondly, a lot of stray cats are found living near the northern breakwater of Asparuhovo beach. Further, a lot of shells are found near the waterline. A few species were found in the water as well. Several jellyfish, fish, small (hermit) crabs and water snails were found.

(a) Jellyfish

(b) Stray cats

(c) Seagull with fishing hook

Figure 2.9: Examples fauna on Asparuhovo beach

Waste and anthropogenic activities

The influence of anthropogenic activities was clearly noticeable on the beach. Near the Karantinata port fishermen place their boats on the beach and collect and process their catch. This causes that there remains a lot of waste on the beach, like old fishnets and fishing equipment. Once, even a seagull was spotted with a fishing hook hooked in his body (see Figure 2.9). Also, the fishermen drive their cars to the waterline to collect their catch and to transport equipment.

Some locals have houses on the beach and the state of houses differed, with some newer than others. Also smaller cabins with different purposes were present. These could also be shelter for the fishermen. Around the structures waste was collected, which affects the ecology and aesthetics in a negative way.

There is also a restaurant and remains of an old restaurant present at Asparuhovo beach, which seemed to not be in operating state at the time of visit. The operating restaurants attract people to the beach, but did not seem to create excessive extra waste.

Figure 2.10: Small cabins and litter on Asparuhovo beach

2.2. The Karantinata fishing port

In 2019, the Karantinata fishing port was constructed on the Southeastern edge of Asparuhovo beach. The port is an important part of the system of Asparuhovo beach and is therefore analysed individually. Karantinata port will be analyzed on Port characteristics, Port entrance, Bathymetry and Breakwater.

2.2.1. Port characteristics

Karantinata port is a modernized and reconstructed version of the previous port. Several port characteristics need to be examined to get a better understanding of the port and its function.

Port functions and commodities
A port can have several primary and secondary functions, like traffic and transport functions, industrial, commercial and financial services. The primary function of Karantinata port is focused on connecting land modes with water modes and supporting of cargo flows. As mentioned before, Karantinata is a fishery port, so the main commodity and cargo throughput should consists of fish and fishery equipment. The fishery port is probably separated from the commercial port of Varna for several reasons (Ligteringen, 2017):

- For nautical safety, (local) small-craft fishery boats should be kept away from deep-sea vessels as much as possible.
- Different design criteria.
- Fishing activity depends on the availability and nearness of fish.
- Fishery business are often family owned, so the manner of operation and mentality of the people are often different than in big commercial ports.
- The location was used before by local fisherman for storing boats.

Port planning
The sedimentation trend near the port entrance disturbs the operations of Karantinata port that were meant to happen. Originally, the port was designed for a total capacity of 116 vessels, including 103 boats, 8 berths for 18-24 m long vessels and 5 berths for 24 m long vessels (Bluesprout, 2019). Besides the concrete berths, also a floating pontoon is present. On this are power columns and water supply to dock more vessels. Near the inner port a crane is present to lift the ships in and out the water.

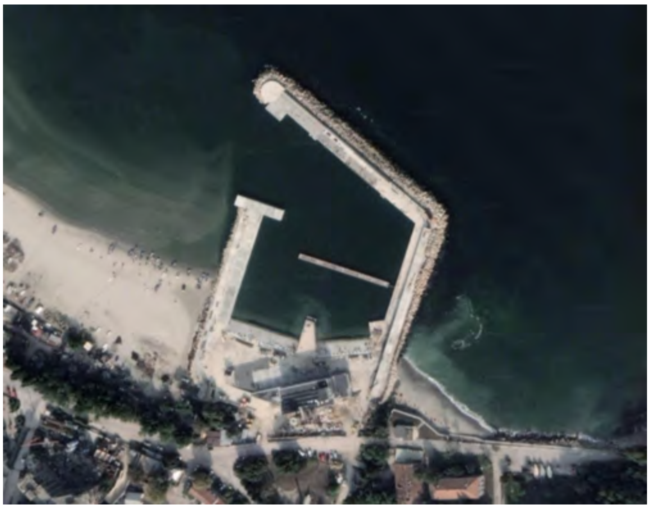


Figure 2.11: Top view of Karantinata port (Google, 2021)

In Section 2.2.3 and in Section 2.2.4, the bathymetry and the breakwater surrounding the port are elaborated on. In Appendix G, an detailed AutoCAD design of the port plan is presented and Figure 2.11 shows satellite view of Karantinata port.

Transport Infrastructure
Several facilities should be present to support the throughput of catch and other cargo flows according to Bluesprout (2019). Two G-shaped cranes are present to lift heavy cargo from ships, those were also spotted during the fieldwork. Bluesprout (2019) mentions that there should be temporary storage and sales facilities for the fishery catch and additional space to repair some small ships. These were actually not sighted during the fieldwork, but that could be because the port is not fully operational right now due to the sedimentation problem. The main building is meant to have multiple functions to facilitate over 30 fishermen, to host meetings and to allow mixed use for public, commercial and service functions.

2.2.2. Port entrance

The port entrance of the Karantinata port is subject to excessive sedimentation. The shoreline of the beach shows accretion and is moving towards the port entrance. Near the entrance the sandbank stretches almost into the port, which is clearly shown in Figure 2.12

Figure 2.12: Karantinata Port entrance with excessive sedimentation

2.2.3. Bathymetry

The bathymetry of the port is shown with a close-up of the total system of Asparuhovo beach as shown in Figure 2.2. The close-up port shows the problematic sedimentation near the port entrance. The bathymetry interpolation is also done with ArcGIS Pro with the interpolation technique known as Kriging. The result is shown in Figure 2.13.

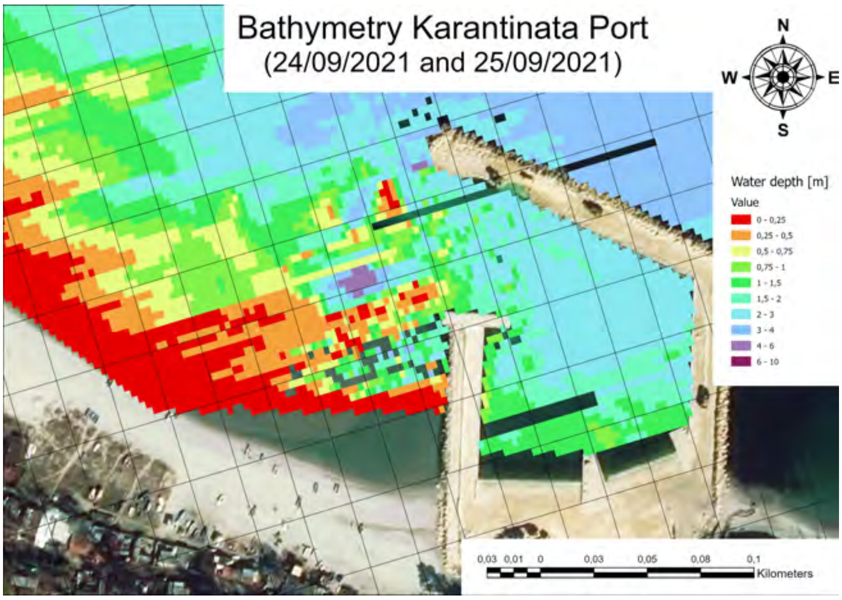


Figure 2.13: Close-up Bathymetry Asparuhovo beach

Note the big hole with depths of 4-6 meter near the port entrance. These were measured with the FishFinder, however not visually observed by the fieldwork group. These measurements are suspected to be false measurements and are deleted in further processing in the Delft3D grid model described in Section 2.4

2.2.4. Breakwater

Karantinata port is protected from the waves by a breakwater. This breakwater consists of a wide concrete path that divides the open part of the breakwater where everyone can enter and the closed part of the port where you have to enter through a secured entrance. This path leads to a round viewpoint of concrete at the head of the breakwater. At the seaside rocks are present to break the incoming waves from hitting the concrete structure behind. In the concrete, a wave recurve return wall is made that returns the incoming water in heavier conditions, which should prevent large overflowing.

Figure 2.14: Breakwater at Karantinata Port

State of the breakwater
The rocks around the entire breakwater have the same structure. The layout has a 2-3 meter wide horizontal plateau. After that the rocks descend with a steep slope towards the bottom. The rocks are placed not very elegantly and show that they have not seen a larger storm before as some seem not very stable in their placement. The rock sizes differ quit a bit which would indicate that a larger spread of the rock is used around the entire breakwater.

Figure 2.15: Head of the breakwater

Figure 2.16: Seaside of the breakwater with plateau and steep slope

2.3. Asparuhovo breakwater

At the Northern side of Asparuhovo beach a breakwater is situated. The breakwater separates Asparuhovo beach from the main channel between the Black Sea, the port of Varna and Lake Varna, laying more inland. The breakwater is approximately 220 meters long and the main protection layers differs in material over the length of the breakwater. The breakwater has two main function: preventing sedimentation in the navigation channel and preventing erosion of Asparuhovo beach.

Figure 2.17: Aerial view breakwater Asparuhovo beach (Google, 2021)

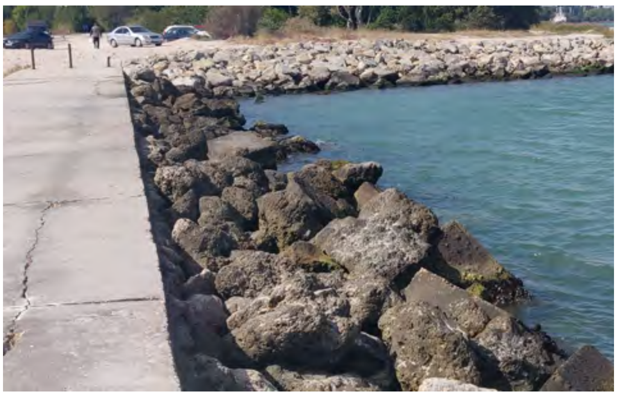
2.3.1. Damage assessment

The state of the breakwater was assessed. To assess the damage of the breakwater, it was divided in three sections by protection layer material. So the most onshore part with natural rocks, the middle part consisting of concrete blocks and the head of the breakwater consisting of Tetrapods.

Most onshore part

The most onshore part of the breakwater is made out of concrete plates that make a path on top of the breakwater with on one side the sand of Asparuhovo beach and on one side natural blackish rock. The size and distribution along the breakwater was irregular. Only a few randomly placed concrete blocks were there. In the concrete along most of this part there was a crack of about 1 cm wide that was located at the channel side and between 30 or 40 cm from the side of the concrete plates, this is also visible in Figure 2.18. It was clearly visible that reparations had taken place in this section of the breakwater. A comparison with earlier assessments showed that the cracks at the beginning had been filled. At the beach side 5 times 4 connected steel poles were located, these were rusty. Also at the start of the concrete plates 3 heavily rusted steel poles were present. The breakwater continued along the channel, but this part was out of the scope of this assessment.

(a) Towards sea



(b) Towards channel

Figure 2.18: Landside of breakwater

Middle part - concrete blocks
The middle part was along the breakwater irregular in profile at the side of the access channel. Two parts were sticking out and were used by local fisherman to catch fish. In these parts there was a larger concrete plate that created a widening of the path from the concrete plates. The part consisted mostly of different sizes concrete blocks with the larger blocks more towards the seaside of the breakwater. However, it was filled up with natural rock as well reaching towards under the concrete plates. For reinforcement different parts of concrete originating from other spots were placed on top of the concrete blocks. Also in this part, the crack at 30-40 cm from the channel side was present.

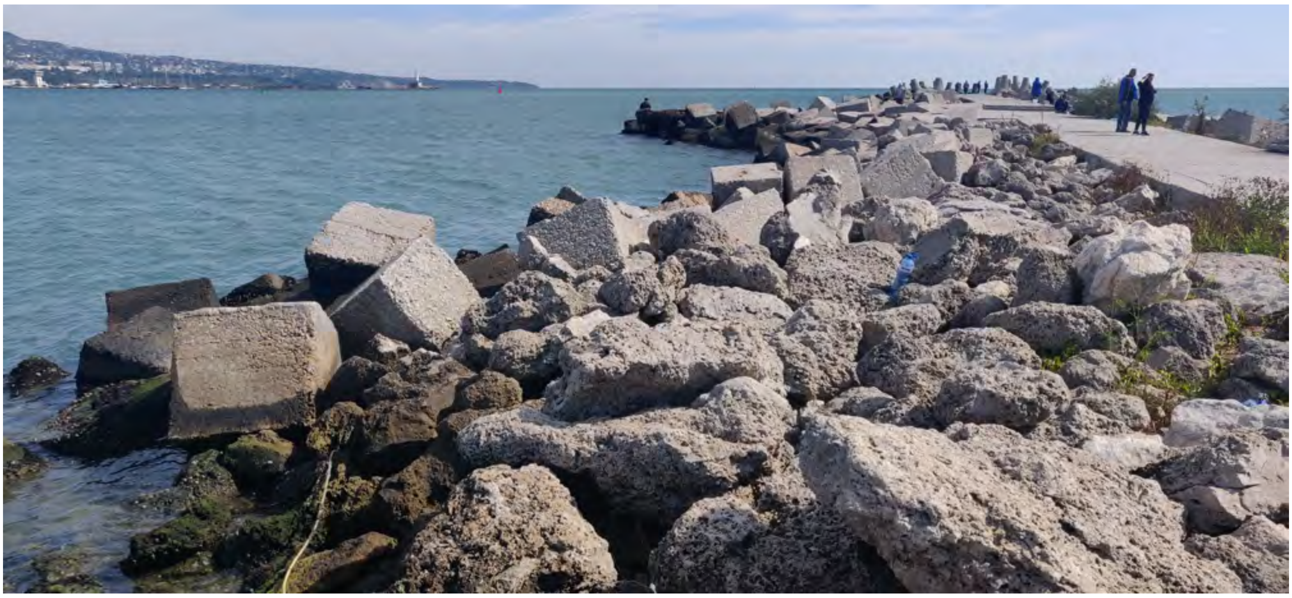


Figure 2.19: Rock and blocks sticking out at two places in the middle part of the breakwater

(a) Concrete reinforcement

(b) Smaller rocks underneath concrete plates

Figure 2.20: Middle part of the breakwater

Breakwater head - Tetrapods
The head of the breakwater consisted of mostly Tetrapods and some concrete blocks. The Tetrapods were not regularly placed and had some distance between them. At the end of the concrete plates there was one larger more round concrete plate were some pieces had broken off at the side of the channel. Also in the concrete that was used for the Tetrapods, cracks were visible that could indicate a decrease in strength of the concrete, shown in Figure 2.22.

(a) Tetrapods and cubes at end of the breakwater (b) Placement of Tetrapods

Figure 2.21: Tetrapod picture 1 and 2

(a) Pieces broke off at the head of the concrete plates (b) Cracks in Tetrapods at head of breakwater

Figure 2.22: Tetrapod picture 3 and 4

2.3.2. Measures of improvement

To improve the quality of the breakwater there are multiple options. The cracks can be filled up to reinstate the quality of the concrete plates. Some erosion at the channel side might have lead to cracking of the concrete plates. Reinforcing under this side of the breakwater with extra rock might help to prevent this. On further notice, it is good to check on the concrete of the Tetrapods at the end of the breakwater. More severe cracks can cause breaking of the Tetrapods in which they will (partly) loose its function. In this case new Tetrapods / extra cubes need to be placed at the head.

2.4. Model in Delft3D

In the system of the 'Asparuhovo beach', the 'Karantinata port' and the 'Asparuhovo breakwater', the influences on each other and the sediment and water in between are interlinked. This can be processed in a computational model. The suggested model for this system is a Delft3D model. Delft3D is a modeling program to give insight into hydrodynamics, sediment transport, morphology and water quality in estuaries and coastal areas. The software consists of a FLOW module, WAVE module and MOR(phology) module created by Deltares (Deltares, sd).

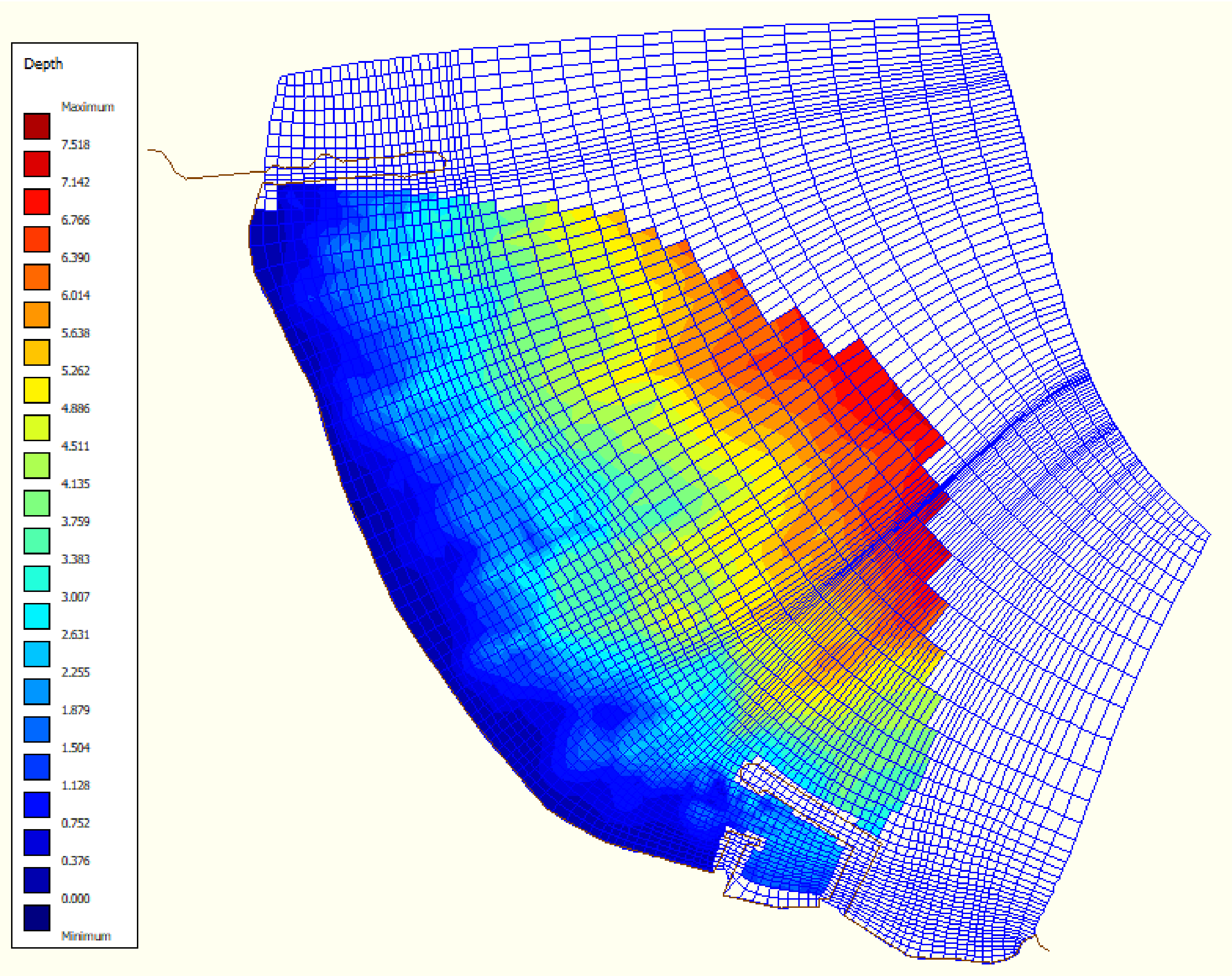


Figure 2.23: Delft3D grid, depth and land boundaries.

This model can be used to provide insight in the sedimentation near the port entrance. To be able to operate this model, the flow and wave files have to be created with the correct input and boundary conditions. This is not done yet, but the available Delft3D grid including the depth and land boundaries give a good basis for upcoming studies to make calculations with the model.

2.5. Veteran beach (South Galata)

Veteran beach is located at the Southern part of Galata. The location of Veteran beach is shown in Figure 2.24. The orientation of Veteran beach is facing to the East. Compared to Asparuhovo beach, Veteran beach is more exposed to the Black Sea, especially to waves coming from the East. The less sheltered position leads to more exposure of waves at the beach. This can also be confirmed by a first visual observation, the wave height at Veteran beach was higher than the wave height at Asparuhovo beach at the same day, so for the same conditions. Also visual observation showed that waves did not fully refract towards the shore. This would imply that in the water the beach is steep. As waves only refract in shallow water this is a good first indication of the morphology surrounding Veteran beach.

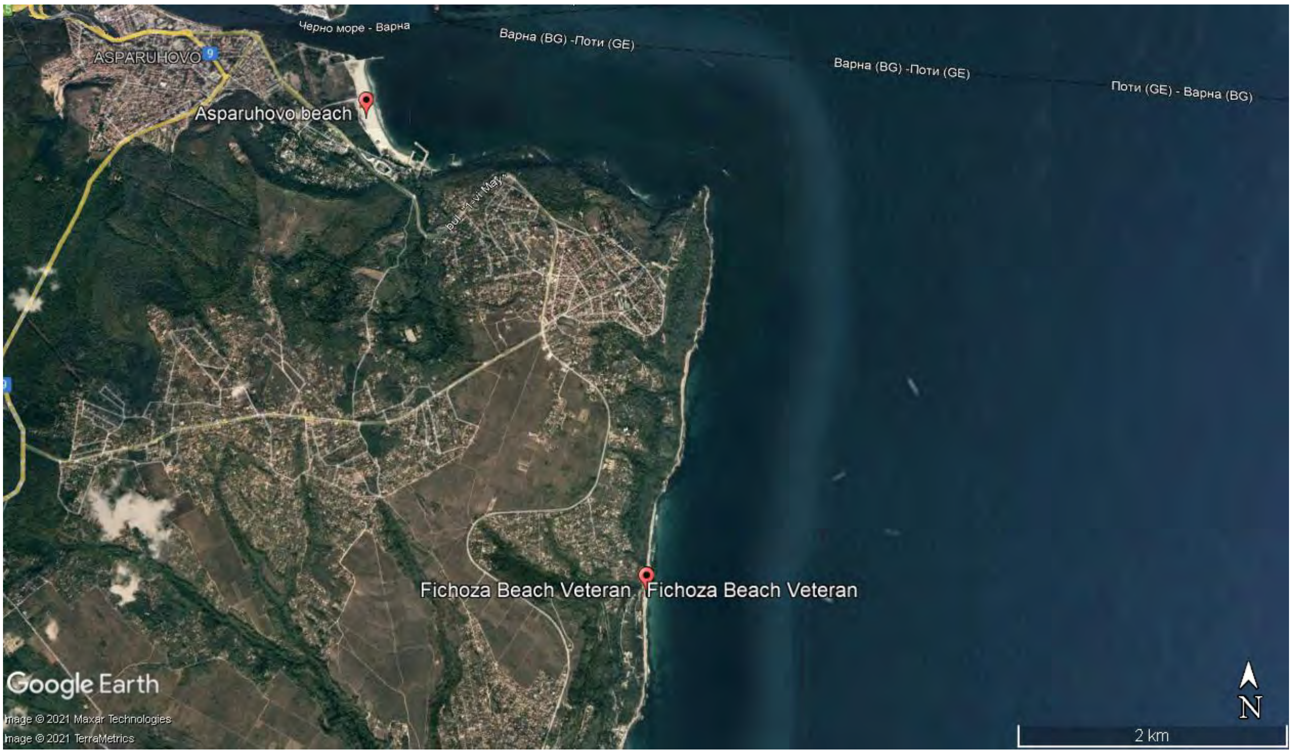


Figure 2.24: Location of Veteran beach (Google, 2021)

Due to more severe hydrodynamic condition, the beach slope is steeper thus it has shorter width. The grain size diameter is also larger compared to Asparuhovo beach. The grain size diameter can be seen in Table 2.1.

Location	Information	Dn50 [mm]
F1	Middle of the beach	1402
F2	Below the waterline	2980
F3	Surface layer ridge 2m from the waterline	3442
F4	At the waterline	1282

Table 2.1: Grain size diameter at Veteran beach

2.6. Martsiana quarry

The Martsiana quarry is located 40 km away from Asparuhovo beach. In this quarry, limestone for coastal application is obtained by using a drilling and blasting technique. Then it is transported and separated in a crushing and sorting plant.

Figure 2.25: The Martsiana quarry

At the quarry different stone sizes were available, from which two different piles were examined and samples were measured. The quality, blockiness, length to thickness ratio and the amount of material available was measured. The goal is to examine how suitable the material from this quarry is for building a breakwater. This could be important for the potential solutions, because it is convenient to know if good material is available close to the Karantinata fishing port.

Pile with small rocks
For 20 small rocks, the length to thickness ratio, the blockiness and the D_n were determined. An explanation of the measurement methods is included in Appendix D.6. The results of the measurements are included in Appendix E.5. From the D_n of the rocks, the $D_{n,50}$ was determined. A $D_{n,50}$ of 0.18 m was found for the sample. Considering the length to thickness ratio of the sample, measurements showed that the armour stone would be suitable for light armour stone, but not for heavy armour stone. The blockiness of a considerable amount of rocks was around or below 50%. This makes the rocks unsuitable to use in an armour layer.

Big rock pile
There was a big pile of rocks available at the edge of the quarry, which could be suitable for building a breakwater because of the large rock diameters (> 0.7 m). The length to thickness ratio was measured, and the blockiness approximated. Besides this, the porosity and height of the pile of blocks was approximated and the area measured, so that an approximation of the total amount of material available could be made. These measurements were made by two groups independently of each other, in this way a more accurate mean result can be used.

The mean porosity of the pile of rock was approximately 44%, the height of the layer was approximately 2.4 m. The area of the rockpile was 5941 m^2, measured by two GPS tracks (see Figure D.13). This gives a total amount of rocks available of 6238 m^3. It depends on the project and how much stone is needed to build the structure (for instance a breakwater), is there is enough stone available.

Suitability for breakwater material
From the material found in the Martsiana quarry, only the big rock pile could be suitable for a breakwater, because of the larger stone diameters. The LT ratio was below 3 for every rock (from 10 samples) and the blockiness is higher than or equal to 50%. These results can be found at Table E.4. Based on the LT ratio and blockiness, the sample of large rocks has good quality to build a breakwater.

However, also a visual assessment was made. These observations showed that a lot of rocks were damaged badly (see Figure E.17 and Figure E.18). The current pile of rocks would therefore not be suitable for construction a breakwater, except if high quality control is applied. The rocks need to be inspected individually to look for any cracks or other weak spots. If a breakwater has to be build, it is therefore recommended to first look at other quarries and see if their rocks are of higher quality.

2.7. Discussion

For the bathymetry data and interpolation (Figure 2.2 and Figure 2.23), there are several points of discussion. First, the measurements were done on two different days. Normally this could influence the measurements, however in our case these days were both during calm conditions. Therefore it is expected that the bathymetry did not undergo significant changes in between these two days. Secondly, the sailing route with the depth measurements is not a perfect route. Some locations have a higher density of measurements than others. Additionally, the sandbank near the entrance is not showed correctly. This is due to the shallow locations where the boat was unable to sail. To measure the sandbank more accuracy, levelling instruments could be used. However it has to be noted that the exact coordinates of these locations need to be noted. Another method is the use of newer techniques, such as using a drone. As can be seen in Figure 1.3, Figure 2.12 and Figure 2.1 a drone can provide clear images of the area. Combining this with new software, the bathymetry can be measured.

Considering the waterline measurements, on the measurement day the wind was blowing in offshore direction, therefore it is possible that a set-down (lower water level) influenced the measurements. However, we expect that this set-down is relatively low, and of low influence compared with the accuracy of the used GPS devices (see Appendix F for accuracy of GPS devices).

The wave rose is generated from data of a wave buoy at a different location than directly in front of Asparuhovo beach. Comparing the data with the time-lapse camera (wave directions and heights) could give some insight in the uncertainties, but this isn't an accurate method to analyse these uncertainties. Besides this, it won't represent the full picture because there is low availability of time-lapse footage during winter storms.

The beach measurement profiles are not very accurate, due to levelling method. Additionally, the measurement technique is time consuming and thus not the most efficient option. Also the comparison with previous years of measuring campaigns is difficult due to differences in transects locations and reference levels. Therefore, the same transects have to be used for future measurements to be able to compare them correctly.

The soil samples were gathered by sampling with a piston sampler. This tool is able to reach into the soil and subtract a sample which is the same as it is divided by layers in the soil. However, not every sample was very smooth as the more saturated samples collapsed while extracting the sediment from the piston. This could have interfered with how the layers were divided per bag and could influence the grain size distribution.

3

Potential causes of sedimentation

Initial speculations on the potential causes of the sedimentation at Karantinata port can be made based on the measurements that were performed during the Hydraulic Fieldwork. As these measurements were performed for a duration of two days only, it is important to note that the speculations presented in this chapter are preliminary. In order to identify the exact causes of the sedimentation, a more extensive monitoring campaign is required. The advised monitoring campaign for the next five years can be found in Chapter 4.

First, speculations are made on the possible sources of the sediment (see Section 3.1). Next, the different sediment transport mechanisms that are playing a role and their combined influence is analysed (see Section 3.2). The chapter ends with a conclusion on the initial speculations (see Section 3.3).

3.1. Sediment Source

To begin with, a closer look is taken at the possible sources of the sediments that have settled at the Southeastern end of Asparuhovo beach. Speculations on these sources can be divided into speculations on sediment coming from outside of the system of Asparuhovo beach and sediments coming from Asparuhovo beach and nearshore itself. These speculations are covered in Sections 3.1.1 and 3.1.2 respectively.

3.1.1. Sediment Coming from Outside of Asparuhovo beach

There is a possibility that the sediment that has settled at the Southeastern end of Asparuhovo beach originates from a different location than the beach itself. By making a comparison of the total volume of sedimentation and the total volume of erosion along the beach, it can be concluded whether this is really the case. For such a comparison, multiple year data on the waterline, cross-shore transects and bathymetry is needed and even more important, this data must be obtained in the exact same manner as before. When performing the measurements in a different way and/or using different transect lines, the comparison between the volumes is no longer valid. Unfortunately, not a fair comparison could be made between the data obtained during the Hydraulic Fieldwork and data from previous years. One of the reasons for this is that in previous years data was obtained along a limited amount of transects. By setting up an extensive monitoring campaign, in which the measurements are performed in the same manner and the exact same transects are followed, more detailed conclusions can be drawn on the possibility of sediments coming from outside of Asparuhovo beach. Moreover this extensive measurement campaign can be found in Chapter 4. For now, solely preliminary speculations on the possibility of sediments coming from outside of the beach can be done. For this purpose, there are several sources that should be considered.

As a start, it is important to realize that the sedimentation occurred in a period of only two years. This implies that the sediments must come from an area in close proximity to the port as sand that is imported from further away usually takes longer. As there are no large rivers nearby that bring in sediment, it can be speculated that the sediments are not a result of river output. Furthermore, through expert judgement it is known that, at depths of 10 meters, the sediment on the top layers of the seabed is very fine material (silt) (Savov, 2021). This finding coincides with the results of a sensitivity mapping and analysis of the Bulgarian Black Sea Coastal zone (Kotsev and Stanchev, 2017). As the offshore material is a lot finer than the material that has settled at the Southeastern end of Asparuhovo beach, it is not likely that the sedimentation originates from offshore. There is, however, a possibility that sediments from the Northern part of Varna bay have been able to reach Asparuhovo beach in the past two years. Sediment transport from the Northern part of Varna bay is likely to only be possible during storms, as the conditions should be harsh enough to bring the sediment in suspension and be transported all the way to Asparuhovo beach. The sediments must therefore cross the navigation channel and bypass the Northern breakwater. As the navigation channel has a depth of 10 to 13 meters, it acts as a sediment trap and it is likely that only finer materials can cross it, considering the conditions are sufficiently harsh (Navionics, sd).

The speculations on the possibility of sediments crossing the navigation channel can be backed by observations during the storm of the 6th of April 2020. In videos made during this storm, areas of increased turbidity, implying sediment in suspension, can be identified. It looks like the sediment is able to pass the Northern breakwater and therefore it might be possible for the finer sediments to reach Asparuhovo beach. It should, however, be noted that the time span of such a storm is relatively short and the frequency of more severe storms is not high either. Based on expert judgement, it is known that storms occur for approximately 50 to 100 hours per year (Savov, 2021). This coincides with the findings in Section 2.1.3, where it was identified that relatively harsh conditions with significant wave heights in the order of 2 to 3 meter only occur for a very limited amount of time per year. Therefore one cannot expect a large volume of sediment to be transported from the Northern part of Varna bay to Asparuhovo beach. As the sedimentation occurred in a period of only two years, it is therefore very likely that part of the sedimentation at the port originates from Asparuhovo beach itself.

3.1.2. Sediment Coming from Asparuhovo beach

Asparuhovo beach is bordered by a breakwater on the Northern side of the beach and by the main breakwater of Karantinata port at the Southeastern end of the beach. The existence of these structures is likely to block the alongshore sediment transport from adjacent coasts, which is why it can be speculated that sediments can only arrive from outside of the system of Asparuhovo beach during harsher conditions. When taking a closer look at the possible sources within the system of Asparuhovo beach, a distinction can be made between the sediment coming from the middle of the beach and the sediment coming from the North of the beach. The possibility of sediments coming from either of these locations can be analysed on the basis of the grain size measurements, of which the results are presented in Appendix E.2.

It was found that the grain size diameter at the top layer at the middle of Asparuhovo beach is 1.8 mm, which is approximately six times as coarse as the grain size diameter that was measured at the Northern and Southern part of the beach. The average grain size at the top layers at these locations was found to be 0.2 to 0.3 mm. As this is a very large difference, it is interesting to compare these results with the results of grain size measurements before the construction of the port. In 2014, the grain size diameter at the same location in the middle of the beach was found to be between 0.11 and 0.53 mm. This is significantly smaller than the grain size diameter of 1.8 mm that was measured during the fieldwork. Furthermore, the grain sizes measured at the Northern and Southern part of the beach are approximately similar.

The significant increase in grain size at the central part of Asparuhovo beach could be evidence that the sediments that have settled in front of the port originate from the middle of the beach. The increase in grain size could be the result of the following process. In the middle of the beach, which is not sheltered from the waves, the waves wash the finer sediments out of the seabed. This is due to the fact that the finer sediments have a smaller weight, and are therefore easier to lift from the seabed. Afterwards, these finer sediments are transported to the Southern part of the beach. As this area is sheltered from the waves, the milder conditions allow the finer sediments to settle. As a result, a layer of sedimentation is formed at the Southern end of the beach and in front of the port. This layer of sedimentation would then consist of the finer sediments that are washed out of the seabed at the middle of the beach. As in the middle of the beach, the finer particles are washed out, the larger particles remain. The absence of finer sediments results in a larger average grain size diameter at the middle of the beach. The measured increase in grain size diameter at the middle of the beach could therefore be explained by this process of fine sediments being washed out of the seabed in the middle of the beach and being transported to the South, where they can settle. For clarification, this process is illustrated in Figure 3.1, where the blue sediments illustrate the sediments originating from the middle of the beach and the orange sediments illustrate the sediments originating from the South of the beach. The larger circles illustrate coarser particles, while the smaller circles illustrate the finer particles. More elaborate speculations on the mechanisms of the sediment transport that could cause the sediment to be transported from the middle to the Southern part of the beach can be found in Section 3.2.

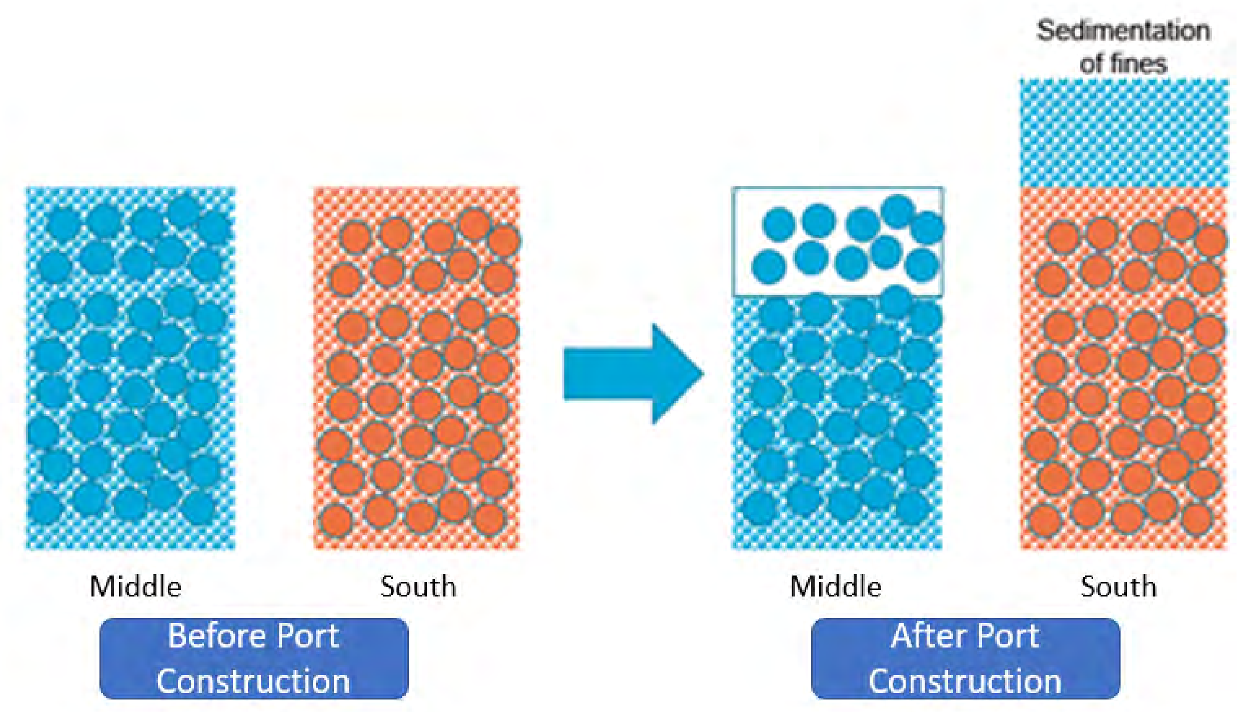


Figure 3.1: Illustration of the process explaining the increasing grain size at the middle of the beach.

3.2. Mechanisms of sediment transport and morphodynamics

When making speculations on the mechanisms of sediment transport and morphodynamics, there are several factors of influence that need to be considered. The factors of influence, that we regard as most influential, are rip currents, longshore current and closure depth. These are first covered separately in Sections 3.2.1 to 3.2.3, respectively. Afterwards, the combined influence of the mechanisms is analysed in Section 3.2.4.

3.2.1. Rip Current

The factor of influence that is considered first, is the occurrence of rip currents. Theoretical background on rip currents can be found in Section 1.6.9. By analyzing pictures taken with a time-lapse camera, a rip current is identified in the middle section of the beach. Moreover the identification of the rip current can be found in Appendix E.4.2. The formation of the identified rip current, during summer conditions, can be explained as followed. The waves approach the Northern breakwater under a certain angle, which leads to a current along the structure in onshore direction. At the same time, waves approach the main breakwater of Karantinata port and diffract around the breakwater, creating an onshore directed current. When both currents reach the waterline, they gradually tend to go alongshore towards the middle of the beach. The two currents are opposite of each-other and at the point where they meet, a compensation current is created in offshore direction. This current is called a rip current.

It should be noted that the process described above is for summer conditions, when the waves are coming from a ENE and E direction. During winter conditions, the wave direction is slightly more from the North and therefore is is likely that the waves do not diffract around the Southern breakwater, but around the Northern breakwater. This would, however, result in the same currents and therefore a similar rip current is also expected during winter conditions. The rip current causes a sediment transport in offshore direction, where its velocity rapidly drops down. At the depth where the rip current disappears, a longshore current takes place. Moreover the longshore current can be found in Section 3.2.2.

3.2.2. Longshore current

A breakwater or a similar structure could provide shelter from waves for the area behind the structure. In this sheltered area, the wave height will be lower than in the exposed area(s) next to it. Such a difference in wave height can cause a difference in wave set-up, which is covered in more detail in Section 1.6.8. In this case, the wave height will be lower in the sheltered area, resulting in a lower wave set-up as well. This difference in wave set-up between the sheltered and exposed area leads to a difference in water surface elevation, inducing a longshore current towards the sheltered area.

Regarding the case of Asparuhovo beach, in summer conditions, the waves come from an East-Northeast and Easterly direction. The breakwater of Karantinata port creates a sheltered area behind it, where the wave height is smaller. As a result, the wave set-up in the sheltered area will be lower than at the exposed areas at the middle and North of the beach. This leads to an alongshore difference in water surface elevation. The water surface elevation difference creates a longshore current in the direction of Karantinata port. The different levels of wave set-up and the direction of the longshore current during summer conditions are displayed in Figure 3.2. The longshore current takes place at the depth where the rip current disappears and transports sediment from the middle of the beach towards Karantinata port. At the sheltered area, in front of the port, the hydrodynamic forces are less severe, allowing the sediments to settle and result in sedimentation. This sedimentation results in the formation of a shoal at the port entrance. This shoal is very steep and therefore has an unstable slope. Sand is sliding down the shoal and blocking the port entrance. As there are no natural forces to get the sand out of this sheltered area, this sedimentation will keep continuing.

Figure 3.2: Wave Set-up and Longshore Current on Asparuhovo beach

The speculations about the longshore current from the middle of the beach to the south of the beach during summer conditions is in line with the longshore current expected based on the grain size measurements in Section 3.1.2. As the measurements during the Hydraulic Fieldwork were performed at the end of the summer period, it can be said that the above speculations with regard to the longshore current during summer conditions can be backed by the grain size measurements.

During winter, however, the waves come from a North-Northeast to Northeasterly direction. As result of this different wave direction, the sheltered area during winter is on the Northern side of the beach, protected by the Northern breakwater. Following the same principle, the longshore current is expected to be in Northward direction. However, the sediment transport during winter conditions may also differ from this due to several other factors of influence, like the harsher conditions. As no measurements have yet been performed during winter conditions, no further speculations can be made on the sediment transport during winter.

3.2.3. Closure depth

Lastly, an important factor of influence is the closure depth. The definition of the closure depth can be divided into the inner and the outer depth of closure, of which the definitions are described below:

- The inner depth of closure marks the transition from the upper to the lower shoreface. It corresponds to the most landward depth, seaward of which there is no significant change in bottom elevation during a given time interval.
- The outer depth of closure marks the transition from the lower shoreface to the continental shelf. It corresponds to the depth where the influence of wave action on cross-shore sediment transport is on average insignificant compared to other influences (Kraus et al., 1998).

The closure depth is an indicator of the depth to which the sediment transport is considerable for different magnitudes of waves. It is therefore an important factor of influence when analyzing how the sediment is transported towards the port and how this transport differs for different wave conditions. Elaboration on the detailed implications of the closure depth is outside of the scope of this report. It is, however, important to note that the closure depth is an important factor of influence to take into account when making wave scenarios for modelling the situation at Asparuhovo beach.

3.2.4. Combined influence of the mechanisms

In the sections above, the factors of influence have been discussed separately. In reality, however, these factors act combined, which makes the situation a lot more complicated. Next to the complications regarding combination of the different processes, the sediment transport is also influenced by the type of wave pattern, different directional wave components, different wave periods and more. One may therefore be convinced that a good assessment of the combined influence of all these factors is only possible by applying an adequate morphodynamic model. Furthermore, a thorough quantitative and qualitative verification of this model for the given conditions is required afterwards. This implies that a model should be run with well-known, measured input values for the wind, waves, currents, sediment characteristics and more. Also, a comparison should be made between the model runs and the real-time measurements of the control parameters. With regard to the qualitative assessment, the visual observation of rip currents and longshore currents is also important.

3.3. Conclusion

In conclusion, regarding the source of the sediment, it is speculated that there is a possibility that a small amount of finer sediments are transported from the Northern part of Varna Bay to Asparuhovo beach during storms. Furthermore, it can be said that it is unlikely that the sedimentation in front of the port is a result of sediments coming from river output or offshore. Therefore it is expected that a large part of sediments that have settled at the Southeastern end of Asparuhovo beach originate from the beach itself. A comparison of grain size measurements along the beach and a comparison with previous years allows for speculations that sediments are taken from the middle of Asparuhovo beach to the Southeastern end of the beach. However, in order to make definite conclusions on this a fair comparison between volumes of sedimentation and erosion is required.

With regard to the mechanisms that could induce the transport of the sediment, there are a lot of factors of influence that should be considered. Several important factors are the presence of rip currents, longshore currents and the different wave patterns. It is clear that the combination of these processes result in a significant sediment transport towards the Southeastern part of the beach, where sediment can settle as a result of shelter from larger waves. However, in order to make a good assessment of what is really causing the sedimentation at the entrance of the port, a good morphological model is required. Next to this, a quantitative and qualitative verification is required, which asks for an extensive, well thought-out monitoring campaign. Recommendations on setting up such a monitoring campaign are given in Chapter 4.

4

Proposed monitoring plan

In this chapter a five-year monitoring plan is presented for the under water profile, the hydrodynamic conditions and the coastline near the fishing port. The reason that a monitoring plan is advised is that there are still a lot of uncertainties regarding the cause of the sedimentation. Moreover, it is also not known how the coastal system will react to new changes in the system. In Chapter 5 potential solutions for the problem are presented. However, it is very important to note that before a solution can be implemented, there should be a better understanding about the system and about how it will react to such a change. A coastal model can give insight in such complex coastal systems. For a coastal model to work properly, information should be known about the boundary conditions, initial conditions and the hydrodynamic conditions of the system. Moreover the model should be calibrated to different situations. This can only be obtained by gathering the information with consistent monitoring.

The monitoring campaign should consist of different measurements with varying frequencies. The different parameters to monitor will first briefly be described together with a proposed method to measure them. It should be noted, however, that other measurement techniques could turn out to be more appropriate based on availability of measurement devices and funding. The proposed techniques in this monitoring plan describe the basics required for an effective and efficient monitoring campaign. After this the target parameters are described. A division is made between parameters that have to be monitored continuously and parameters that have to be measured biannually. After a description of the target parameters, the impact of possible dredging is discussed. A plan to limit the impact of dredging on the results of the monitoring campaign is suggested.

4.1. Continuous measurements

The next parameters should be measured continuously and throughout the year.

4.1.1. Wave parameters

The wave parameters should be measured in real-time. The parameters of the waves that should be measured are the significant wave height H_{m0}, the maximum wave height H_{max}, the direction of the waves, the peak period T_P, and the average wave period T_{m01}. The parameters should be measured with a frequency of once every hour and the proposed method to do so is by installing a wave droid. The proposed location of the wave droid is displayed in Figure 4.1.

4.1.2. Sea level measurements

The sea level should also be monitored in real-time. The proposed method to do this is by installing a tidal gauge in the port. By picking a sheltered location from most waves, the signal of the sea level will be disrupted the least. The proposed location is displayed in Figure 4.1.

4.1.3. Visually measure dry part of the beach

The dry part of the beach should be measured to see if the amount in a control volume changes. This can and should be done with different measurement techniques. The first technique is done with the help of a time lapse camera. By installing a time lapse camera that takes a picture of the beach every hour, the changes in the beach can be observed visually. A valuable addition to the pictures would be to make a video using a drone during the measurements twice per year, as this proved to be useful to visually observe the bathymetry and topography.

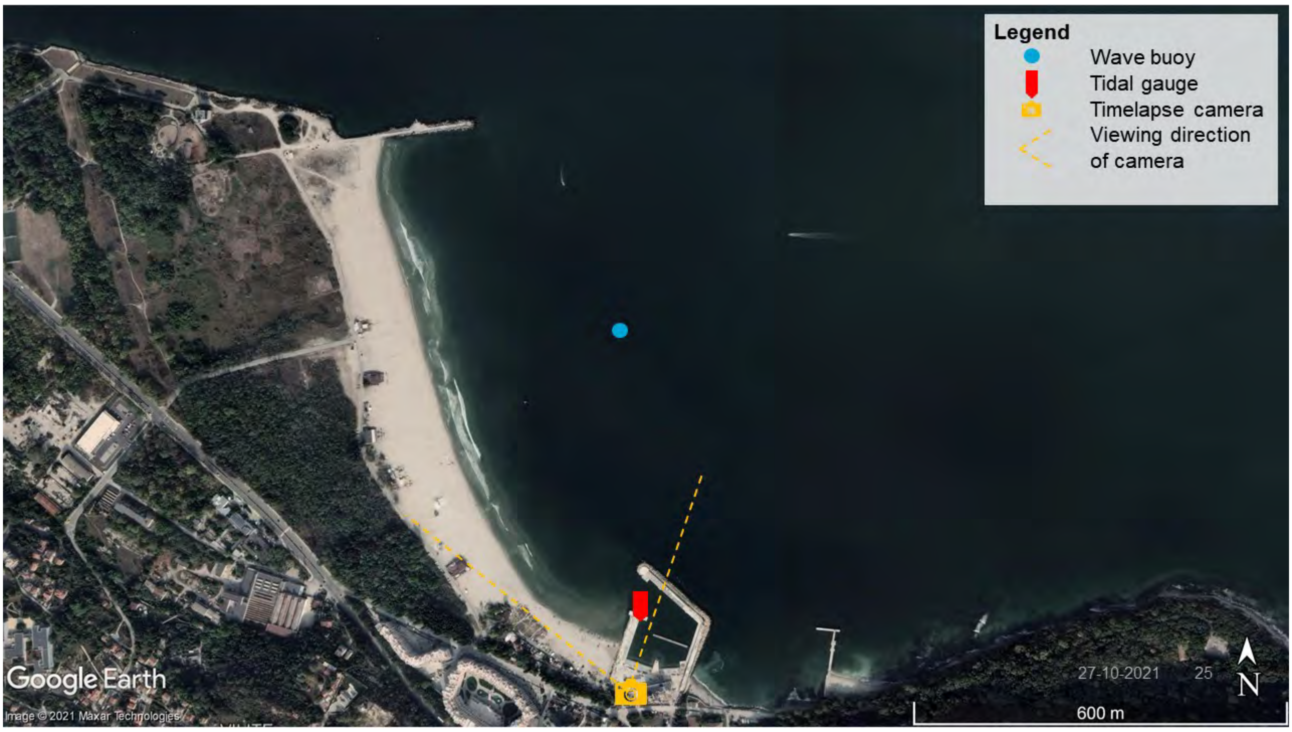


Figure 4.1: Locations of continuous measurement devices

4.2. Biannual measurements

The parameters described below should be measured at least once per half year, preferably after a large storm, and more if more large storms occur. This way, the impact of large storms can be assessed but small and slow processes in quieter times of the year will also not be forgotten.

4.2.1. Currents

The current in the water is one of the most important parameters to understand sediment transport. Therefore, it is important to measure the current of the water at different locations that are of interest. This can be done for example with the help of an Acoustic Doppler Current Profiler. This is a measurement device deployed at the bottom of the sea floor that sends out an acoustic signal and determines the current based on how fast the acoustic signal bounces off the water particles.

4.2.2. Hydrographic works

Hydrographic works are aimed at determining the location of the beach and bed relative to the water. The position of the waterline should be measured twice per year. This can be done by taking GPS measurements of the position of the waterline. Finally, the elevation of the beach should also be measured. There are numerous ways to measure the elevation of the beach. In this research report, a levelling method was used where levelling was done along 10 transects (see Appendix D.1). It is advised to measure along the same transects as proposed in Appendix D.1, so the measurements can be compared to measurements from this year. The GPS measurements were done using a smartphone, and the levelling over the transects was done using analog levelling equipment and a levelling staff. Both are not very accurate, and can easily be improved by setting up a GPS base station. This will improve the accuracy to the order of centimetres for both measurements, and will also allow for continuous measuring along the transects instead of only every five metres. Therefore using a local GPS network with a base station is highly advised.

4.2.3. Visual observations

During the Hydraulic Fieldwork 2021, a drone was used to obtain some aerial footage of the beach and water. This drone footage gives some really useful information on the position of the sedimentation near the port entrance, sand banks and overall bed level near the beach. It is therefore also highly recommended for visual observations like this to be included in the biannual monitoring campaign.

4.2.4. Bathymetry

The bathymetry of the coastal area should be measured for the same reason as that the dry part of the beach should be measured. The proposed method to do this is with a FishFinder under a boat, that registers the depth of the water at the GPS locations it is sailing. The area that should be sailed should be at least the size of the path in Figure D.9.

4.2.5. Sediment parameters

Of the sediment samples, the most important parameter to distinguish is the d_n, the nominal diameter. This can be done by visually estimating samples under a microscope. This is quick, efficient and can even be done whilst the sediment is still wet. For more accuracy, samples of interest can be taken to the lab for a sieve analysis, after which a grain size distribution can be drawn up. This will provide more information on the different components in the sand and is useful, but optional for this research.

Secondly, anything observed visually such as colour, amount of shells, presence of organic material or the smell of the obtained material should be noted down. This will provide valuable information on the origin of the sediment.

4.3. Dredging and Monitoring

Before the final solution or redesign of the port is implemented, more data needs to be gathered. As stated before, this monitoring will need to take place for around five years before the data is accurate enough. It is possible though, that it might be decided to perform dredging operations in the meantime, to maintain the functionality of the port. If this is done, the measuring campaign should be adapted to it as well, to take into account the effects of the dredging operation. If these effects are not taken into account, the results of all other analyses could be disturbed and become invalid.

The effects of dredging can be mapped by doing a short survey around the dredged area. This should be done right after dredging, and should include a new bathymetric survey, visual observations and sediment sampling, all of them around the dredged area, plus any of the other measurements mentioned before that might have been disturbed. This means that if the water line has been moved, a new waterline measurement needs to be done, or perhaps a new transect should be measured. In other words, the monitoring after the dredging operation will have to map the impact of the dredging on all previous measurements done in the dredged area.

5

Potential solutions

In Chapter 3, the potential causes that drive the sedimentation process near Karantinata port have been analysed. Then in the next chapter a monitoring plan to gather more data about this sedimentation process is proposed (see Chapter 4). This chapter contains potential solutions for the sedimentation in the port and is written based on the information stated in the previous chapters. The data from the monitoring plan could eventually be used to solve the sedimentation problem in front of the port entrance. The possible solutions could be described by changing the port layout or performing long term dredging works.

5.1. Preliminary port designs

The preferred potential solution is changing the port layout so the sedimentation is not a threat to port operations anymore. The emphasis lies on using the current port layout as much as possible, building extension on the layout and demolishing the current structure as less as possible. Below, three preliminary designs are proposed, but it must be stressed that these are only initial sketches and ideas. To verify these designs, an extensive design process, more research and modelling have to be performed to examine the influence of the port design on the hydraulic processes, boundaries and whether the design matches the hydraulic loads.

5.1.1. Relocate port entrance

The first idea for a redesign of the port layout is to relocate the port entrance, so sedimentation does not affect the port operation as much anymore (see Figure 5.1). The new location of the port entrance is put more seaward and in deeper water. What used to be the shortest breakwater is elongated and curved around the most seaward breakwater.

Figure 5.1: Relocation of the port entrance

During the modelling phase of the design process, attention must be paid to the direction of the opening and the incoming waves. The head and inner bend of the extended breakwater must be designed such that it can withstand direct wave impact and dissipate diffraction and refraction. A more curved breakwater could possibly positively affect the dissipation of diffraction and refraction. It must be stressed that the wave action in the inner port has to be diminished sufficiently to adhere to the port norms. That is why it is still unsure whether the bend can be used to increase the amount of mooring places of Karantinata port. Also, along the West side of the extended breakwater sedimentation is allowed for now. With morphological modelling for several years it needs to be analysed what the long term effects of the sedimentation could be on the foreshore of the beach.

5.1.2. Combination entrance relocation and water flow

The second preliminary design resembles the first preliminary design in relocating the port entrance by extending the breakwater. This will be performed in the same manner, but in this design there is an additional opening in the Eastern breakwater. The main objective of this opening is to create a flow of water or current through the port. This might decrease the settling rate of the sediment in the port and flush the sediment out of the port. The flow through the port might decrease the length of the enlarged breakwater, the impact however needs to be calculated. The sketch in Figure 5.2 shows that the opening is made by demolishing a part of the present breakwater, but the outlet could also be made in a more subtle manner. For example, a culvert or outlet could be constructed through or underneath the breakwater. Also different positions of the opening can be tested, for example bringing the opening more towards the shore or maybe even have openings at two sides of the port. For this design the flow through the port and the morphological impact should be analysed by extensive numerical modelling.

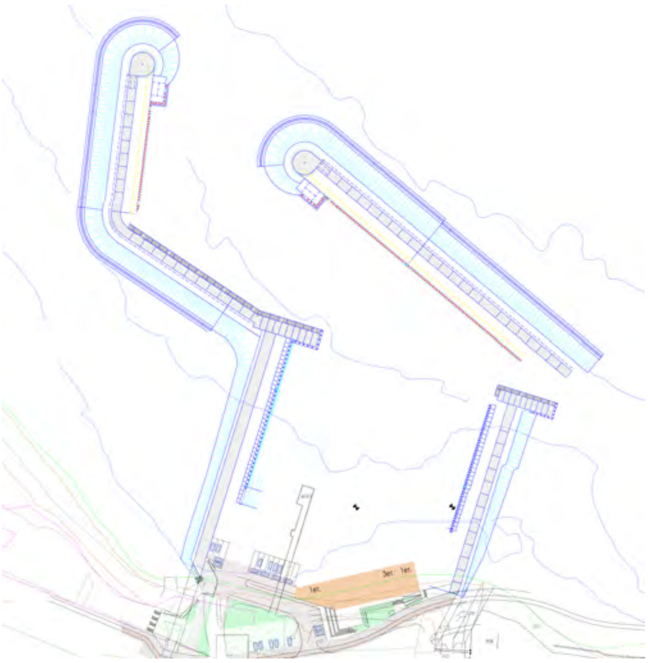


Figure 5.2: Relocation of the port entrance in combination with opening to change water flow

5.1.3. Blocking groyne

The third preliminary design is about blocking the sediment by constructing a groyne at the West side of the port. The objective of the groyne is to shelter the port entrance from the ongoing sedimentation process and the sediment settles at the West side of the groyne. During the design process, it is important to investigate how far the groyne has to reach into sea, to block enough sediment. To reduce these uncertainties, a detailed model study is required to investigate the required design of the groyne.

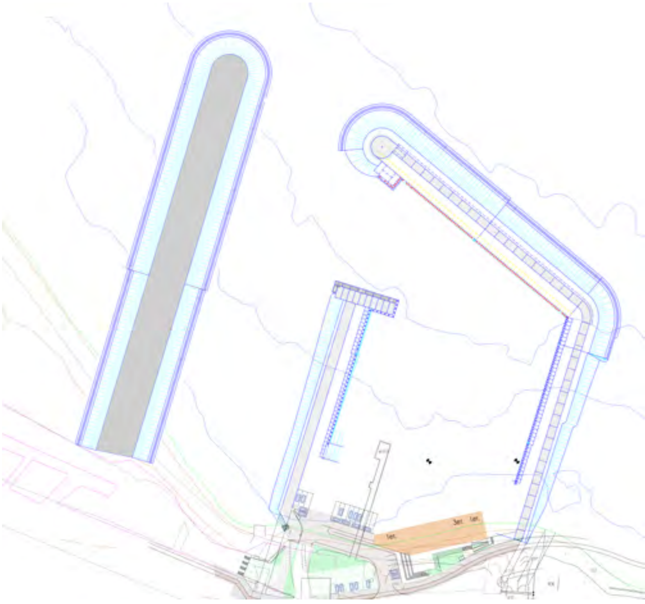


Figure 5.3: Blocking sediment using a groyne

5.1.4. Comparison of costs

Besides the feasibility of the design, the costs are an important factor. Comparing the three preliminary designs, it is expected that the blocking groyne is the least expensive. The relocation of the port entrance is probably more expensive, and the relocation of the port entrance in combination with the opening is most expensive.

Building a blocking groyne would be least expensive, because it does not interfere with the current port layout. One could imagine that demolishing part of the current breakwater to modify or elongate the breakwaters brings additional expenses. To connect the old port and the newly constructed parts, the joint connection needs to be flawless. This brings construction challenges, which also increases the costs. For the blocking groyne this is not a problem, because it does not interfere with the port itself. Taking into account that the required length of the groyne is only a little bit longer than the length of the elongated breakwater at the other designs, this does not add many additional expenses. Therefore it is expected that the blocking groyne is least expensive.

The other two methods both require the relocation of the port entrance, by elongating the Western breakwater. However, one design has additional expenses because of the construction of the opening (culvert or outlet). This brings high additional expenses, because of the demolishing of the current structure and the construction of the new opening. Therefore this is more expensive than the one that only requires the relocation of the port entrance.

5.2. Dredging works

Another solution for the sediment problem at Karantinata port could be to introduce a long term dredging plan. Dredging should deepen the port clearance and free the port entrance. Dredging works can be performed by a high variety of dredging vessels, but for the size of Karantinata port a Backhoe Dredger (BHD) vessels is most suitable (see Figure 5.4). The BHD picks up the sediment using a bucket and fills up another barge that sails to a dumping location.

Figure 5.4: Back Hoe Dredger (Seatools, sd)

The disadvantage of considering dredging as a proper solution is that dredging will not change the hydrodynamic condition, which means the sedimentation will occur again. Because of that, dredging has to be done periodically. Dredging will also bring the system further away from its equilibrium state every time, accelerating the sedimentation process. Due to this and the temporary nature of the dredging effects, dredging is also only a temporary solution. Dredging can be applied as a quick and effective measure to open up the port again, whilst data for a final redesign is collected during a monitoring campaign.

6 Conclusion and recommendations

This chapter proposes the conclusion and recommendations of this report regarding Asparuhovo beach and Karantinata port at Varna, Bulgaria.

6.1. Conclusion

The objective of this research report is to examine the current accretion near Karantinata port and to set up a monitoring campaign for the coming 5 year. Note that the conclusions presented in this chapter are based on preliminary speculations, using measurement results from only two days. To be able to identify the exact sedimentation causes, it is required to perform a more extensive monitoring campaign. During the fieldwork, different measurements were done on and near Asparuhovo beach to obtain information regarding the site and the surroundings.

Based on measurements and observations during the fieldwork, several potential causes for the accretion in the port entrance could be identified. After the analysis, it can be concluded that it is most likely that the sediment in the port entrance is from origin finer sediment (0.2 - 0.3 mm) from the top layer of the middle of Asparuhovo beach where it currently is coarser (1.8 mm). This hypothesis is supported by grain size measurements along the beach from this year and previous years. However, to make a definite conclusion regarding the source of the sediment, a fair comparison between volumes of sedimentation and erosion is required. The sediment is most likely transported by (a combination of) longshore currents, rip currents and varying wave patterns. In order to make a valid assessment about the cause of the sedimentation and the processes responsible, modelling with an appropriate morphological model is required.

Before such a morphological model can work properly, it has to be validated and calibrated. To do this, more information regarding the conditions and the site characteristics is needed. This has to be obtained with a monitoring campaign, some parameters have to be measured continuously and some have to be measured twice per year. The timing of the biannual monitoring is important and should be done preferably after a large storm. The information can than be used to observe if the model represents the impact of such a storm correctly. Moreover, it is important to check that the observed processes such as rip currents and alongshore currents are correctly represented by the model.

After the model works properly, the impact of possible solutions can also be modelled. In Chapter 5, three potential solutions are presented. These are the relocation of the port entrance, a combination of relocation of the port entrance with an additional opening (increased water flow), and the construction of a blocking groyne at the West of the port. The least costly and most promising is the relocation of the port entrance design. However, this is a preliminary design with large uncertainties. To really conclude which potential solution is the most optimal, additional research is required. Before construction of a permanent solution dredging might be done to maintain functionality awaiting the long-term solution.

To summarize, a hypothesis on the cause of the accretion near Karantinata port is formed, including a proposed monitoring campaign. However, this is still a first assessment, further study is needed to test the hypothesis or to find other causes. Therefore the preliminary potential solutions in Chapter 5 are only indicative solutions. Research on the system and the exact cause of sedimentation is needed, before real design solutions can be made.

6.2. Recommendations

Before a solution can be implemented to avoid sedimentation in the port entrance in the future, the true cause of the sedimentation has to be known. To identify the causes of the accretion with certainty, it is recommended to take the following steps:

- First, the **source of the sediment** in the port should be found. This can be done by comparing control volumes of sediment on the beach over the years. To obtain reliable results, it is advised to use the same locations for the cross sections as where was measured this fieldwork campaign in 2021. If there are parts where structural erosion can be observed, that can be the source of the sediment in the port entrance.
- A **hydrodynamic model** should be set-up of the Asparuhovo beach and foreshore and Karantinata port. This model could show insights in the processes of sedimentation/accretion in the area, with different input conditions (stormy or calm conditions). With measurement results from the fieldwork, a Delft3D bathymetry model has already been set up. This model has the potential to work properly with the correct hydrodynamic conditions. A study is needed on the required hydrodynamic conditions as input for the model, for which the wave-buoy data is important. It is recommended to use the current Delft3D model, but other models could also be used.
- Before the model can work, it has to be **validated and calibrated**. This has to be done with the results from the monitoring campaign. During the monitoring campaign the hydrological conditions and the response of the bathymetry is gathered. When applying the same input, the same bathymetry response is desired. If this is indeed the case, the model is probably correctly calibrated.
- With the working model, the causes of the sedimentation can be researched further and the **impact of the potential solutions** on the system can be modelled. Finally, an appropriate solution can be found and implemented in the system.

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Savov, B. (2021). Discussions in real life and over email. Boyan Savov is an experienced freelance consultant with a demonstrated history of working on Port and Coastal Engineering projects. He is skilled in Marine construction, Dredging, Coastal Environment, Modelling and ICZM. As he was a supervisor during the Hydraulic Fieldwork, he was able to provide us with knowledge through his expert judgement.

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A

Participants of the fieldwork

The participants of the TU Delft Fieldwork Hydraulic Engineering (Bulgaria) of 2021.

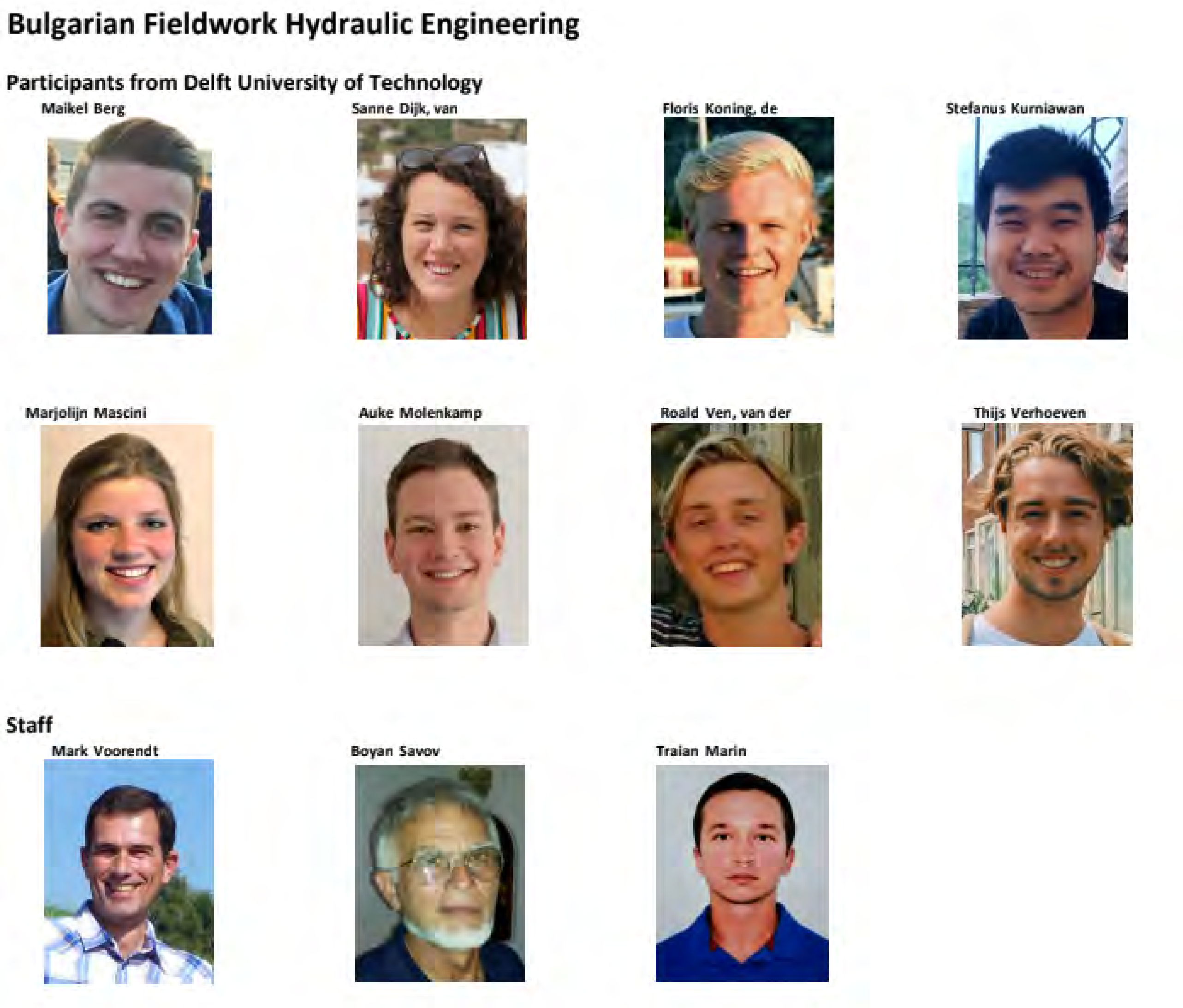


Figure A.1: Participants Fieldwork 2021

B

Safety Plan

The students had to prepare a safety plan before travelling to Bulgaria, to ensure that they were well-informed about the risks of their travels. This safety plan is included in this appendix from the next page onward.

Hydraulic Engineering Fieldwork safety plan

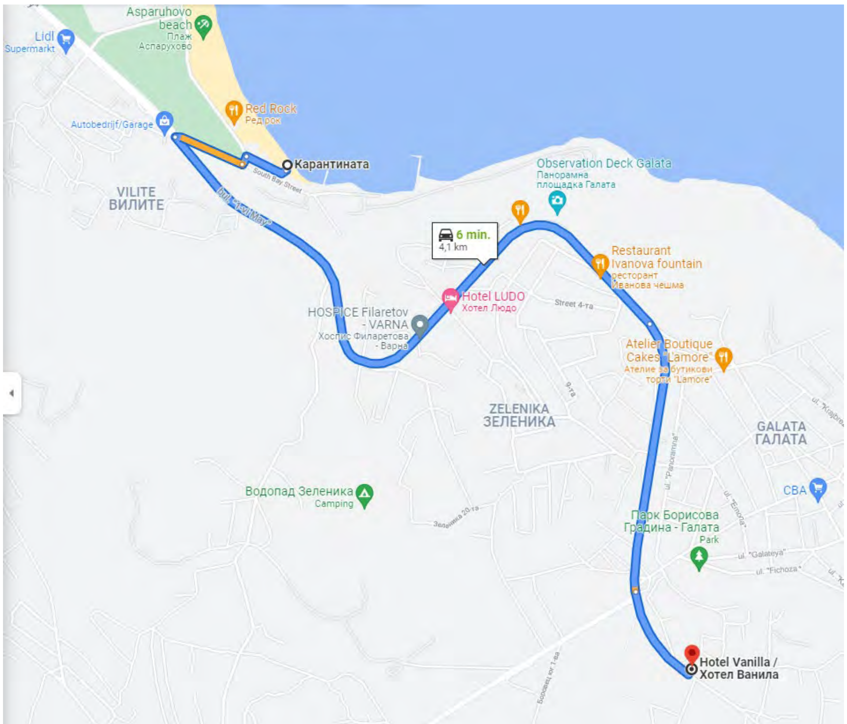
Field Site Location:	*Karantinata/Asparuhovo beach, Varna, Bulgaria*		
Activity Description:	From September 23rd to September 30th, a team (8 students, 1 professor) of the TU Delft wi travel to Bulgaria to conduct a fieldwork. With the help of a Bulgarian and a Romanian supervisor, they will eventually propose a monitoring plan for sedimentation in and near the fishing port at Karantinata/Asparuhovo beach.		
Plan Created for:	*CIE5318 Fieldwork Hydraulic Engineering / Bulgarian group*	**Date of revision:**	*21-09-2021*
Date(s) of Travel:	*23-9-2021 – 30-9-2021*		

A field safety plan serves as a tool to document your hazard assessment, communication plan, emergency procedures, and training. This plan should identify hazards, as well as precautions and actions taken to address and mitigate those hazards. Instructions:

1. **Complete this field safety plan: insert specifics for your site and operations, delete irrelevant sections.**
2. **Complete appropriate training for your site and operations (e.g. first aid, heat illness, task-specific training).**
3. **Obtain immunizations and prophylaxis for your destination, if applicable (schedule 8 weeks in advance).**
4. **Hold a pre-trip meeting with your group and/or supervisor to review your field safety plan, travel logistics, pack list (including first aid kit), personal safety and security concerns, and any remaining training needs.**

Site Information		
Location	Latitude: **43.174102 N**	Longitude: **27.915678 E**
Site Information	The site is located at Karantinata beach in Varna. Karantinata beach is a wide beach with fine, white sand. There is a small port for small (fisherman) boats located at the beach. Normally, there are no high waves at the site and the tidal range is very small (<0.1m). 	

Hydraulic Engineering Fieldwork safety plan

Travel to Site	6 minutes by car, provided by Boyan Savov. Apart from the regular risks associated with road travel, there are no specific safety issues on the way.  	
Site Access	There is a parking area directly behind the beach. Entry to the beach from the parking area is easy; there are no dangerous paths or surroundings present and therefore no specific safety issues are present here.	
	Hazards	**Proposed Mitigation Strategies**
Environmental Hazards	• Strong waves and currents • Strong wind • Weather: lightning- /thunderstorms may occur.	- Avoid swimming/sailing out late afternoon or when it gets dark. - Avoid swimming/sailing in open water during thunderstorms - Check weather forecast before swimming/sailing out - Plan the fieldwork on the beach on the days with the best weather.
Security	We should be aware of local mafia, or other criminal, operations. We should be aware of active thieves and pickpockets in Varna.	We will always travel in groups of at least two and we will avoid confrontation. We will look after the equipment carefully. We will look after our personal belongings.

Hydraulic Engineering Fieldwork safety plan

No-Go Criteria	Activities at the beach should be stopped/canceled when: • The situation is too severe to do any measurement/activity, for example in storm condition. • The temperature is above 40 degrees. COVID-19 measures: • If the travel advice of the Dutch Government changes to Orange (restrictly only necessary travels) the trip probably cannot continue. At the moment the travel advice is yellow. • Reisadvies Bulgarije | Ministerie van Buitenlandse Zaken | Bulgarije | Nederlandwereldwijd.nl | Ministerie van Buitenlandse Zaken We can measure during the entire tidal cycle, since the tidal range is very small (<0.1m). This does not influence the no-go.	
Tidal Cycle	**Low Tide: 11:29 (0.01 m)**	**High Tide: around 17:00 (0.09 m)**
Expected Weather / Sea state	*Expected weather is between 16 and 26 degrees (most days Around 20 °C). Rain is expected in few days (23 & 30 September)* *Expected sea state* September | 23°C | 19.6°C | 26.2°C | warm Sea water temperature in Varna in September	
Drinking Water Availability	☒ Plumbed water available ☐ Water cooler with ice provided ☒ Bottled water provided ☐ Natural source and treatment methods (e.g. filtration, boiling, chemical disinfection): Tap water is drinkable	
High Heat Procedures	Required when temperatures are expected to exceed 30°C: limit strenuous tasks to morning or late afternoon hours. Rest breaks in shade or indoors must be provided at least 10 minutes every 2 hours (or more if needed). Reapply sunscreen and drink water every 2 hours. Bring a hat and some sunglasses with the necessary uv-protection. ☐ Direct supervision ☒ Buddy system ☐ Reliable cell or radio contact ☐ Other:	

Emergency Services and Contact Information

Local Contact	**Lodging location:**	**University Contact**	**Frequency of check ins:** *Only if an emergency happens*
Boyan Savov: +359 888 450 487 Traian Marin: +40 721 261 411	*Hotel Vanilla* *ул. „Прибой-1-ва",* *9021 Fichoza,* *Varna, Bulgaria* *+359 88 855 7730*	Chartis Assistance – 24-hours emergency service **+31 - 10 453 56 56** (60.10.4117)	

Hydraulic Engineering Fieldwork safety plan

<table>
<tr><td>Emergency Medical Services (EMS)</td><td colspan="3">In case of an emergency, Boyan Savov (+359 888 450 487) must always be contacted. As the local contact and the only person in the group able to speak Bulgarian, he will be essential in translating and navigating local services.

Bulgaria:
• European SOS: 112
• Ambulance: 150
• Fire/Rescue: 160
• BULSAR (Bulgarian Black Sea Search & Rescue): 088 161
• Pharmacy on Duty: 178

Ambulance: 112 (Netherlands)</td></tr>
<tr><td>Nearest Emergency Department</td><td colspan="3">St. Marina's Hospital.
bul. "Hristo Smirnenski" 1
9010 Varna
Bulgarije
+359 52 302 851

Link to route:
https://www.google.nl/maps/dir/%D0%9A%D0%B0%D1%80%D0%B0%D0%BD%D1%82%D0%B8%D0%BD%D0%B0%D1%82%D0%B0/St.+Marina+Hospital+varna/@43.2044592,27.8885226,12.94z/data=!4m13!4m12!1m5!1m1!1s0x40a4517c71089a17:0x4c7b5f3a537bcf7!2m2!1d27.9153442!2d43.1739656!1m5!1m1!1s0x40a45438f28ad839:0x744a3bf765d86336!2m2!1d27.9356634!2d43.2271842

Ambulatoriya Za Individualna Praktika Za Parvichna Izvanbolnichna Meditsinska Pomosht
(Outpatient Clinic for Individual Practice for Primary Outpatient Medical Care)

Name: Snejanka Bratoeva

Кабинет 104,
бул. „Народни будители“ 5,
9003 кв. Аспарухово, Varna

+359 88 663 7510

Link to route:
https://www.google.nl/maps/dir/%D0%9A%D0%B0%D1%80%D0%B0%D0%BD%D1%82%D0%B8%D0%BD%D0%B0%D1%82%D0%B0,+Bulgarije/doctor+Varna,+bulgaria/@43.1800937,27.8950236,15z/data=!4m13!4m12!1m5!1m1!1s0x40a4517c71089a17:0x4c7b5f3a537bcf7!2m2!1d27.9153442!2d43.1739656!1m5!1m1!1s0x40a453cf771b5345:0x3659cbdb9b11ed8!2m2!1d27.8959244!2d43.1812182</td></tr>
<tr><td>Cell Phone Coverage</td><td>Primary Number:
Coverage: good-spotty
Nearest location with coverage:</td><td>Satellite phone/device</td><td>Device carried? ☐yes ☒no
Type/number:</td></tr>
</table>

Hydraulic Engineering Fieldwork safety plan

<table>
<tr><td>Nearby Facilities</td><td>Bus services to Varna are available.
Car parking availabilities at ‘Parvi mai’ boulevard.

At the beach:
- 4 Restaurants are located at Asparuhovo Beach. 'Mussel house’, 'Red Rock’, ‘The Barn’ and ‘Tk3c-Bapha'
- A large hotel called ‘Varna South Bay Beach Residence’ is located at the beach.
- At the center of the beach there is a rest area</td></tr>
<tr><td>Side Trips</td><td>• Visit to the northern part of the Bulgarian coast, landslides Balchik, Cape Kaliakra
• Varna breakwater, landslides and Balchik harbour
• Visit two quarries

Activities:
• Go to restaurant for dinner
• Nightlife

See the ‘hazards’ section for related safety measures.</td></tr>
<tr><td colspan="2">Participant Information</td></tr>
<tr><td>Field Team / Participants</td><td>Is anyone working alone? ☐ Yes ☒ No

Primary Field Team Leader: Mark Voorendt +31 6 102 102 22
Secondary Field Team Leader: Boyan Savov +359 888 450 487
Tertiary Field Team Leader: Traian Marin +40 721 261 411
☒ Field Team/Participant list is attached as training documentation
☐ Other attachment</td></tr>
<tr><td>Physical Demands</td><td>All persons joining the trip should be able to walk and swim independently.</td></tr>
<tr><td>Mental Demands</td><td>Possible unsafe feeling in a new environment.
Behaving like a guest in Bulgaria; showing respect to different cultural habits and traditions. Be aware of the different culture and attitude when speaking to locals and authorities.</td></tr>
<tr><td>First Aid Training
& Supplies</td><td>At least one first aid trained person (with current certification) should be present for work at remote sites. CPR also recommended.

Auke Molenkamp: ILS Beach Lifeguard, First Aid, CPR & AED, ER (Dutch: BHV)
Roald van der Ven: ER (Dutch: BHV)
Location and description of group medical/first aid kit:
The first aid kit will be provided by Boyan Savov. It will be taken to the fieldwork location every day.</td></tr>
</table>

Hydraulic Engineering Fieldwork safety plan

Immunizations or Medical Evaluation	*Covid-19:* • **Proof of vaccination**, valid **from 14 days after the second dose**, or from 14 days after the first dose if the vaccine is administered in a single dose (Janssen/Johnson&Johnson) or • **Proof of recovery from COVID-19**, valid **180 days** (at least 11 days after the positive result to a COVID-19 test), or • Negative result to a **COVID-19 test.** **Both PCR and Rapid Antigen tests (RAT)** are accepted. Validity: **72 hours prior to arrival** for PCR tests, **48 hours prior to arrival** for RAT tests For travel-related immunizations or medical advice, contact SGZ Gezondheid & Zorg at http://www.sgz.nl/ 8 weeks prior to your trip.

Hydraulic Engineering Fieldwork safety plan

Equipment and Activities

Research Activities

Monitoring Programme:

1. Measurement of the parameters of waves in real time
2. Measurement of the current profile at specified points of interest
3. Monitoring the change of the dry part of the beach in real time using photo equipment (time-laps camera with high resolution)
4. Real-time sea level measurement with tidal gauge
5. Carrying out hydrographic works: measuring, mapping, and determining the amount of sediment in a control area twice a year to detect seasonal and episodical (due to storm events) fluctuations with magnitude Hs>3.5 m at a depth of 15 m
6. Carrying out an analysis of the local sediments (beach-forming material and its spatial distribution)

Schedule of Tasks

Thursday 23-9	Travel to Bulgaria
Friday 24-9	**Karantinata**: Introduction to the area and main assignment; inspection of the project location, making plans, dividing tasks
Saturday 25-9	**Karantinata:** Beach measurements; hydrographic survey; wave height measurements
Sunday 26-9	**Excursion:** Visit to the northern part of the Bulgarian coast, landslides Balchik, Cape Kaliakra;
Monday 27-9	**Karantinata**: Beach measurements; hydrographic survey; wave height measurements (continued)
Tuesday 28-9	**Visit two quarries** + assignment; **Excursion** Varna breakwater, landslides and Balchik harbour
Wednesday 29-9	**Karantinata:** Beach measurements; hydrographic survey; wave height measurements (continued)
Thursday 30-9	Travel back to the Netherlands

The programme will be adapted to weather and other circumstances!

Field Transportation

Car/bus will be used for travelling from the hotel to the activity location (beach, port, quarry, etc). Local taxis can be used as an alternative transportation.

Local taxis number:

- **Triumf Taxi**: +359 52 644 444; +359 879 644 444; www.triumftaxi.com
- **Omega Trans Taxi**: +359 52 388 888; +359 878 388 888; www.omegataxivarna.com
- **Hippo Taxi**: +359 52 344 444; +359 876 344 444; www.hippotaxi.bg
- **Lasia Taxi**: +359 52 500 000
- **JoyTaxi**: +359 52 30 30 30; +359 52 66 66 66; +359 899 388 388; www.joytaxi.bg
- **Viva Taxi**: +359 52 755 555; +359 878 755 755
- **City Taxi**: +359 878 388 838

Hydraulic Engineering Fieldwork safety plan

Research Tools	Equipment to be used: • Theodolite • Leveling instrument • Tripod • Level staff • Range pole • Prism • Tape line • Measuring tape • GPS-device • Wave height meter • Hemisphere • Soil probe • Van Veen grab • Echo sounder • Transducer • Anemometer • Sand ruler • Wave buoy Preparation for usage of this equipment should include reading the instruction manuals and safety instructions as supplied with the equipment. No prior training is necessary, but caution needs to be advised, especially with waterborne equipment. In this case boats should be operated by qualified drivers. Observers in the water should be made aware of the sea conditions and supervised from the shore. Drone: Knowledge and experience with flying a drone is required. If the drone exceeds a certain weight, a flying license is required Other specific instruments required need good preparation on how to use it. Instruments where you need to be in the water to install them needs extra caution, as mentioned before knowledge on wind, waves, current and temperature information is required before entering the water / installing the equipment. This also applies for the echosound vessel used for the bathymetry survey.

Hydraulic Engineering Fieldwork safety plan

	Hazards	Proposed Mitigation Strategies
	Climbing rocks, breakwaters	Wearing appropriate footwear, not doing this activity if not necessary.
	Taking measurements in sea: currents, waves, underwater obstacles	Be informed about the sea conditions, act carefully. Wear appropriate footwear if necessary.
	Measurements on the beach.	Wear appropriate footwear such as water shoes or flip-flops. Be aware of mosquitoes, wasps or other insects.
	Working outside: rain, thunderstorms and sun	Be informed about the weather predictions. Apply sunscreen regularly, drink enough water. Bring warm and dry clothes for cold weather.
	Visiting quarries and rough terrain	Wear appropriate footwear. Keep at least two meters distance from the edge of cliffs.
	Drone usage	Use a qualified and experienced pilot, be aware of weather conditions such as wind and rain and be informed about obstacles such as trees. Do not fly directly over people.
Personal Protective Equipment	Required (for the quarry visits): Safety shoes/firm hiking shoes, long trousers and safety helmets. Recommended: Hat, sunglasses, sunscreen, insect repellant, water shoes.	
Required Training	Swimming diploma, or sufficient swimming experience.	
Additional Considerations		
Insurance	We have health and travel insurance from the TU Delft. Everyone should register at Osiris.	
COVID-19 Measures	• Stay at the hotel and get tested if anyone has symptoms. • Wear face masks in public places. • Keep a safe distance if it's possible. • Follow the local guidelines and from the website: https://www.tourism.government.bg/en/kategorii/covid-19	
Dutch Embassy / Consulate	Dutch embassy in Sofia Oborishte street 15 1504 Sofia, Bulgaria +35928160300	

Hydraulic Engineering Fieldwork safety plan

Personal Safety & Security During Free Time	Personal safety risks during free time should be considered and discussed in advance, e.g. leaving the group, situational awareness, sexual harassment, or local crime/security concerns. Review expectations and set the tone for a safe, successful trip. During all times, do not leave on your own without telling anyone. If going further away, for instance to Varna city centre, always go with at least 2 people, stay together and inform Mark Voorendt before leaving. Do not use drugs in, or bring drugs to, Bulgaria due to the strictness and harsh punishments of local authorities. Also, do not buy local drugs due to the additional health risks. This applies to both hard and soft drugs. The consumption of alcohol is allowed, if it does not endanger the consumer, people in this group or anyone else. This includes the fact that everyone must stay careful and respectful towards locals and authorities, but also that all participants should be able to partake in the research and activities safely and actively the next day. Purchase alcohol only from authorized resellers, such as official super markets or staff in restaurants. Visits to bars and restaurants should be chosen carefully, and illegal or unofficial bars should be avoided.
Campus Contacts	
University Health Services	+31 (0)15-2121507 (Student Health Care) +31(0)15-2511930 (After-hours huisartsenpost)
CiTG Service Desk	+31 (0)15 27 89802 servicedesk-ceg@tudelft.nl
CiTG Health & Safety Advisor	Bert Meijer +31 (0)15 278 2771 h.h.meijer@tudelft.nl TU-IV@tudelft.nl
Confidential Advisor	Jenny Dankelman J.Dankelman@tudelft.nl Bernard Dam B.Dam@tudelft.nl

Signature of PI / Supervisor:

I acknowledge this safety plan has been prepared for field work under my supervision.

Name	Signature	Date	Phone Number
Dr. Ing. M.Z. (Mark) Voorendt	**************		**************

Field Team / Participant Roster - Training Documentation

I verify that I have read this Field Safety Plan, understand its contents, and agree to comply with its requirements.

List of Participants not included due the privacy reasons.

TUDelft

C

Data and Communication Plan

Similar to the safety plan, the students also had to think about the way they share and communicate their data. Their findings are included on the next page. The email addresses and phone numbers of the participants have been redacted because of privacy reasons.

Data and Communication plan Fieldwork 2021

CIE5318 Fieldwork Hydraulic Engineering

Bulgarian Group

Data storage

To store the data, Microsoft teams will be used. The upsides are that it is easy to share the data, and if Microsoft word documents are used, they can be easily adjusted and synchronized automatically. Another upside is the privacy and data security policies of Microsoft. As a customer of Microsoft word, 365 and teams you own and control your own data.[1] In this way we can be sure that the measured data will always be in our own possession and cannot be used by Microsoft without our permission. With regard to security, Microsoft Teams follows all the security best practises and procedures such as service-level security through defence-in-depth, customer controls within the service, security hardening and operational best practises. More about the security of Teams and how Teams handles common security threats can be found on the website of Microsoft.[2] Furthermore, as we only access the Teams through our TU Delft accounts, two-factor authentication is enabled, which provides additional security.

For the final report, overleaf will be used. The reason behind this are the efficient reporting options and easy real-time collaboration between different users. Overleaf uses Google backup servers to secure the data, but the data is still our own.[3] This means that also overleaf is secure to use without the possible risk to lose our right on the data. The Google Cloud Platform that Overleaf is using for data storage uses Google data centres. These data centres feature a layered security model, including safeguards like custom-designed electronic access cards, alarms, vehicle barriers, perimeter fencing, metal detectors and biometers. It can therefore be said that using Overleaf is secure.[4]

Beside these cloud storage options, we also use local SD-cards and USB-sticks to store the data. These are easy to use, fast, and in combination with the cloud storage we can be sure that all the data is secure. Data stores on a flash disk is safer from the risk of get hacked compared to online storing as long the USB-sticks are only used/plugged into trusted computers. The data will be stored in a structured way. The general working directory is called "Fieldwork HE 2021". The sub directories are divided in instruments and parameters, for instance "instrumentX_wave height". In these subfolders there is a distinction between raw data, meta data and processed data. In each of these respectively the data is subdivided in folders with the dates on it where the actual datafiles are present.

Communication

For the communication, the fieldwork group uses a WhatsApp groupchat 'Fieldwork Bulgaria' for informal and fast communication. WhatsApp uses end-to-end encryption, which makes sure only the sender and recipient can read the messages. Messages are owned by the people in the conversations and stored on the devices, not on servers, which means that neither WhatsApp nor other parties can access information sent through the app.

Besides this, email is used for more formal communication. This poses a slightly larger security risk, as messages are handled by different companies (Microsoft for @tudelft.nl, @hotmail.com and @live.nl email addresses, Google for @gmail.com addresses). Both companies do not view the contents of emails sent through their services, and protected and encrypted when stored on their servers. Accounts are also protected against suspicious logins and unauthorised activities. All of this makes email a reasonably safe medium to send messages, documents and transfer information. However, users should be aware of the risks and caution is advised.

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[1] https://docs.microsoft.com/en-us/microsoftteams/security-compliance-overview
[2] https://docs.microsoft.com/en-us/microsoftteams/teams-security-guide
[3] https://www.overleaf.com/legal
[4] https://www.overleaf.com/legal#Security

In Bulgaria and on the local site internet connection is present, but we will also phone each other when fast communication is needed. A list with names, phone numbers, emails and emergency contacts are available for the fieldwork group and staff, see the attachment on the next page. As also written in the safety plan, *whoever goes anywhere must first inform Mark Voorendt*.

Delft,
21-09-2020

List of contacts

Nickname	Family name	E-mail	Mobile phone number
Maikel	Berg	***************	***************
Sanne	Dijk, van	***************	***************
Floris	Koning, de	***************	***************
Stefanus	Kurniawan	***************	***************
Marjolijn	Mascini	***************	***************
Auke	Molenkamp	***************	***************
Roald	Ven, van der	***************	***************
Thijs	Verhoeven	***************	***************
Mark	Voorendt	***************	***************
Boyan	Savov	***************	***************
Traian	Marin	***************	***************

D

Measurement methods

In this Appendix the method for every measurement is extensively discussed. Also, the equipment that was used for the measurements is shown. This includes the measurements of the beach profile, waterline, bathymetry, waves and soil samples. The locations of all measurements are shown in Figure D.1.

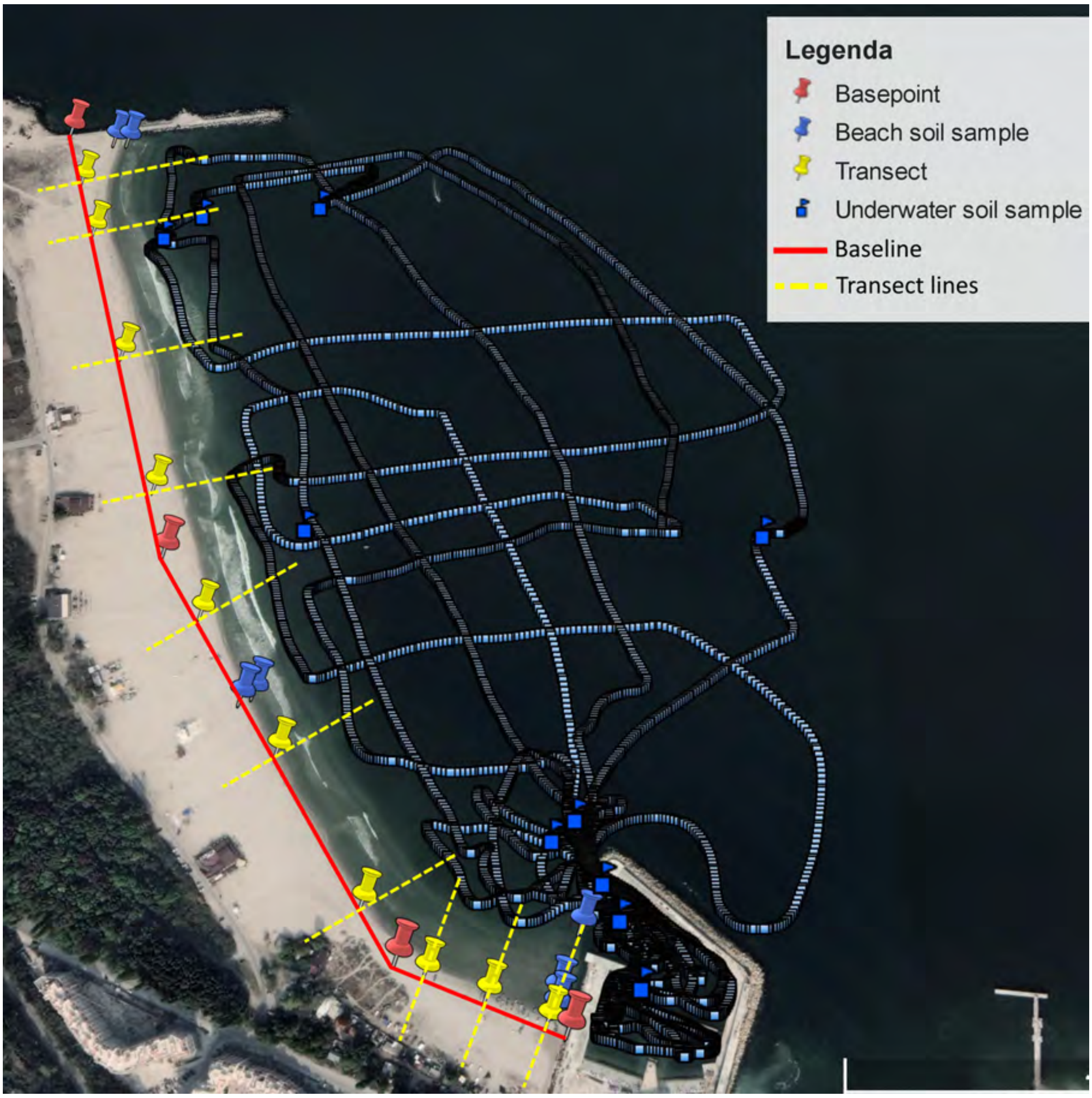


Figure D.1: Full overview of all measurement locations

D.1. Beach profile

The beach profile measurements of Asparuhovo beach were performed to find out if there was a trend in erosion or accretion of the beach. Also, the measurements from this year can be used as comparison to discover future trends. A basic beach observation system was set up with very simple equipment. The system consists of a few steps that were taken to obtain the elevation of the beach along several cross sections:

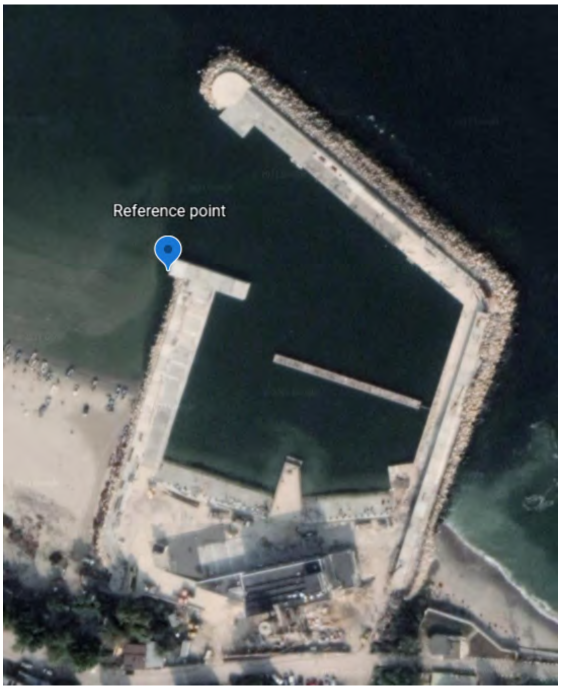
- Define reference point
- Define beach grid and transects
- Actual cross section measurements
- Post data processing

Each step is explained individually down below.

D.1.1. Reference point

Deciding on a useful reference point was the first step in setting up the beach observation system. This step is very important since this is eventually the basis of the survey. The reference point was used to make all profile measurements coherent. It was not possible to do all the cross section measurements on the same location without moving the levelling instrument. However, if the levelling instrument was moved, the instrument level corresponding to the previous measurements was not the same as for the measurements that came after. Therefore, a reference point was used to relate the different levels from different locations and measurements back to one base level.

It is important to choose the reference point wisely. To find a trend in changing morphology, beach profile measurements have to be done frequently, so the reference point had to be easy to find in the future and still be located in exactly the same spot. That is why the reference point was chosen on a permanent structure for which the actual height can be found in reference to MSL. During this fieldwork the reference point was set to the corner of the concrete quay wall south of the port entrance (see Figure D.2). The coordinates of the reference point are: 43.1745211 degrees North and 27.9165299 degrees East. The height of the reference point with respect to MSL is +2.05 m.



(a) The reference point in Google Earth (Google, 2021)

(b) Auke indicating the reference point

Figure D.2: Location of the reference point approx (43,1745211; 27,9165299)

D.1.2. Beach grid

The next step of the beach observation system was to define a beach grid and transects to perform the levelling measurements on. The layout of the beach has to be analysed from a fixed point of view, in order to be able to recreate the measurements in the future. That is why a fixed baseline was set along the coastline. The baseline was chosen such that it was (as good as) parallel to the waterline. This meant that two bends were needed in the baseline indicated with basepoint B and C in Figure D.3. Basepoint A and D represent the beginning and end of the baseline, respectively.

For each section of the baseline, multiple transects were made perpendicular to the baseline. These transects are the location at which the cross section of the beach was measured. For the areas where a lot of change was expected, more transects were put closely together, making a finer grid. It is for this reason that near the Asparuhovo breakwater in the North and near the port entrance in the South the transects are closer together. In Table D.1 the coordinates of the base points and transect points (on the baseline) are shown. Also, the distance between the points are shown in the 'Interval distance' column. These distances indicate the distance between the current point and the previous point. For example, the distance from AB1 to A is 17m and the distance between C and CD1 is 70m.

The main goals of the survey was to measure the elevation of points along the cross sections. For each transect the distance between measuring points from the baseline to more onshore is 20m and from the baseline towards and into the sea is 5m.

Figure D.3: Transect Map of Asparuhovo beach (Google, 2021)

Base/transect Point	Longitude [°]	Latitude [°]	Interval distance [m]
A	43.1739442	27.9163818	-
AB1	43.1740112	27.9161981	17
AB2	43.1741836	27.9156301	50
AB3	43.1743323	27.9150518	50
B	43.1740112	27.9161981	23.8
BC1	43.1748164	27.9144463	50
BC2	43.1759396	27.9135735	150
BC3	43.1770313	27.9122975	150
C	43.1775374	27.9122975	80
CD1	43.1781064	27.9121409	70
CD2	43.1793374	27.9116682	150
CD3	43.1805645	27.9112072	150
CD4	43.1810952	27.9110073	65
D	43.1816324	27.9108095	65

Table D.1: Coordinate and location of Base and Transect Points

D.1.3. Levelling execution at the site

The measurement system was effectively performed by 6 people with different roles. Two portable radios were used to enhance communication among the group members. This paragraph explains the steps that were taken at the site to perform the measurement correctly.

- At first the baseline was set out by two people and indicate the beginning, ending and bends with poles.
- Two people held the levelling staff and walked along the transect, stopping at each indicated distance.
- The last two people read and noted their elevation relative to the levelling staff using the levelling instrument. Once the distance between the levelling staff and instrument became to big, the levelling instrument had to be moved and calibrated to the new height of its own location.
- This process was repeated for the rest of the baseline and transects.

During the execution a few things were noticed that could be improved for future measurements. These things are summed up below, to make sure that future measurements can go even better and more effective:

- It is advised to make a clear measuring plan beforehand and make sure everybody understands their role. This prevents mistakes in communication and a more effective start-up of the measurements.
- It is most effective to set up the next baseline sections while doing the measurements of the previous baseline section. In the beginning, the whole baseline was set, but throughout the day the poles/markers used for indicating the basepoints were taken away/stolen.
- It would have been ideal if there were 3 portable radios, one for every group. It prevents that the group setting out the baseline has to run back and forth over the beach to communicate.

D.1.4. Data processing

After the beach profiles were measured, the only thing left to do was to process the data per transect. Each transect and its corresponding data represents the elevation of the cross shore profile of the beach at that point. Once the data was converted to elevation with respect to MSL, the cross sections could be compared with beach profiles found in the past. This comparison could show whether or not there is an erosion or accretion trend at Asparuhovo beach.

D.1.5. Used equiment

The equipment that was used for measuring the elevation along the cross sections is given below.

- Levelling staff
- Tripod
- Levelling instrument
- Prism
- Tape line
- Portable radios
- Poles or other markers

(a) Levelling instrument (b) Tripod (c) Levelling staff

Figure D.4: Equipment used for beach levelling

In Figure D.4 the three core pieces of the levelling campaign are highlighted. The tripod was used to find a stable spot in the sand. Its three pointy ends can stick into the sand and each one can adjust its height. The goal for the tripod is to give the levelling instrument a stable and horizontal base. The levelling instrument is the device with a lens inside. First the levelling device was setup horizontally. This could be checked by using a spirit level. As the levelling instrument is horizontal it first reads the vertical distance to the reference point. As the levelling instrument is stable and in its vertical position, all later measurements can be retraced back to the level compared to the reference point and if the height of the reference point compared to mean sea level to the mean sea level. The levelling instrument reads other points at which the levelling staff is placed on vertically. As the levelling staff is put directly on the bed and the relative value is measured, all points can be calculated related to mean sea level. High accuracy levelling is accurate for 1-2 mm. However since also measurements were taken in the water where some movement of the levelling staff was present the accuracy is assumed to be 1-2 cm.

Figure D.5: Reading heights on levelling device standing on tripod

D.2. Waterline

The position of the waterline at the beach was measured. This was done to see if there were any significant changes of the position of the waterline (and the beach) when compared to earlier year data and google Earth images. This was done by walking along the waterline with a GPS device and logging the GPS data. The experiment was repeated to increase the accuracy and eliminate weather effects. However, set-up or set-down could not be eliminated this way, and neither could seasonal effects. However, the significant changes over a longer period of time on which the focus lies here will still be recorded this way.

D.2.1. Google earth comparison

The GPS files from earlier years were plotted in Google Earth and compared to the newest one. Also the evolution of the beach line could be researched through older satellite images of Google Earth. Beach line measurements from previous years plotted in Google Earth are displayed in Figures D.6 and D.7.

Figure D.6: Waterline 2018 measurement (Google, 2021)

Figure D.7: Waterline 2021 measurement (Google, 2021)

D.3. Bathymetry

The bathymetry of the bay at Asparuhovo beach was investigated to finalize the profile measurement of the entire area. This bathymetry is of interest to the project, because it shows the underwater morphology that is key to understand how waves will react to entering the bay. Also differences in depth can lead to conclusions about sediment transport. All measurements were done in calm waters at constant speed to avoid any measurement errors in vertical motion of the measuring device.

Figure D.8: Bathymetry measuring

D.3.1. Data gathering

For the data gathering a boat was used with a FishFinder. This was used at the time function, which meant that the slower the boat was sailing the more dense the points would be. First the port was sailed around very slowly to have a good view of the bathymetry inside the port. After that the boat sailed out towards the sea and the Northern breakwater at the access channel to create a boundary for the racks to the sea and back to the beach. The plan for data gathering and the retrieved data points are shown in Figures D.9 and D.10. The retrieved data points differ somewhat from the original plan as at the same time also the sand samples from the bottom were retrieved.

Figure D.9: Plan bathymetry

Figure D.10: Retrieved bathymetry depth samples

D.3.2. Data processing

The files that were retrieved from the FishFinder were processed later. These were converted to specific depth points that could be interpolated to get a full bathymetry of the bay. This can be seen in Figure 2.2.

D.3.3. Used equipment

To measure the bathymetry, a Raymarine hybridtouch was used in combination with a Raymarine sonar transducer (FishFinder). The device uses sonar wave reflections to record the water depth. In combination with the GPS function of the Raymarine hybridtouch the depths of specific points were measured. The GPS has an accuracy of <5 m for 95% of the time (Raymarine, sd). The accuracy of the transducer is dependent on the used frequency.

D.4. Wave measurements

In this section the measurement method of the waves is presented. For the majority of the wave measurements, the wave buoy installed by the Bulgarian National Institute of Hydrology and Meteorology was used. The wave buoy is located in Varna Bay, as displayed in Figure D.11. The green dot represents the wave buoy and Asparuhovo beach is located in the South-West of the bay. The wave buoy measures the significant wave height, maximum wave height, mean wave period, peak wave period, wave direction and water temperature. Data could be retrieved starting from October 2020.

Figure D.11: Location of the wave buoy

Since the wave buoy was deployed in October 2020, not all wave data since the port construction could be retrieved. Additional data on the wave conditions before October 2020 was obtained with the use of a wave droid. The station name of this wave droid is BVS Hermes BG-1 and it was located further away from Asparuhovo beach, as indicated with the yellow mark in Figure D.12. The most severe conditions during this period occurred between 01/04/2020 and 15/04/2020, at which the significant wave height, maximum wave height, mean wave period and peak wave period were measured each 30 minutes.

Figure D.12: Location of the wave droid

D.5. Time lapse camera

A time lapse camera was installed, which was used to understand the consequences of certain wave heights and directions at the coast, as well as identify certain processes. The time lapse camera was installed on a high tower at Karantinata port. It was installed in such a way that the pictures included the entire Asparuhovo beach, as well as the foreshore. During the fieldwork, it was set to take a picture every 5 minutes and afterwards this was changed to a picture every hour.

D.6. Quarry

In this section the measurement methods that were used in Martsiana quarry are presented. The goal of the measurements in the quarry was to evaluate the quality of the rocks from Martsiana quarry. This was done by assessing the quality of a pile of small rocks ($D_{50} < 0.5$m) as well as those of bigger rocks that are commonly used in breakwaters.

D.6.1. Quality check small rocks

To determine the quality of the pile of smaller rocks produced in the quarry, a sample of 20 rocks was taken that was representative for the pile of rocks. For the sample of 20 rocks, the length to thickness ratio was determined as well as the blockiness. Finally, the D_{n50} of the sample was determined. All the measurements were done twice (once by each group of 4). However, one of the groups failed to measure all the parameters needed to calculate the blockiness of the rocks. That is why, for the calculation of the blockiness, only the data of one group was used.

Length to thickness ratio
To determine the length to thickness ratio of the sample, the longest axial length and the shortest axial length of the rocks were measured with a measuring tape. These are the longest and shortest distance between two parallel planes through which the rock just fits. The length to thickness ratio could be determined with Equation (D.1).

$$LT = \frac{longest\ axial\ length}{shortest\ axial\ length} \tag{D.1}$$

Blockiness

The blockiness of a rock is defined as the volume of the stone divided by the volume of the enclosing xyz-orthogonal box with minimum volume (CIRIA et al., 2007). To determine the blockiness, first the mass of the stone was determined by weighting the stone on a scale. The volume of the stone was estimated by using an average density of the stones of 2400 kg/m^3. Next the height, width and depth of the smallest enclosing xyz-orthogonal box were determined by using a measuring tape. The blockiness of each of the stones was calculated with Equation (D.2).

$$BL_x = \frac{V_{rock}}{X_{box} \cdot Y_{box} \cdot Z_{box}} \cdot 100\% \tag{D.2}$$

In this equation, V is the calculated volume of the rock and X_{box}, Y_{box}, and Z_{box} are the measured lengths of the edges of the xyz-orthogonal box. After the length to thickness ratio and the blockiness of all the 20 individual rocks were determined, boxplots were made for the length to thickness ratio and the blockiness. From these boxplots (as shown in Appendix E.5.1) the distribution of the sample could be observed.

Determining D_{n50}

To determine the D_{n50} of the sample, first the D_n of each individual rock were determined. This was done with the calculated volume of the rock, following Equation (D.3)

$$D_n = V^{1/3} \tag{D.3}$$

After the D_n of all of the rocks were determined, they were ordered from small to large. The D_{n50} is then the rock for which half of the sample has a smaller D_n.

D.6.2. Quality check large rocks

In the quarry a large pile of rocks was chosen to do the analysis for the larger rocks. From the pile, 10 large rocks were chosen to be analysed (5 per group). The analysis consisted of determining the length to thickness ratio and the blockiness of the sample. Moreover, a visual quality check of the pile was done by observing individual rocks in the pile. The total volume of rocks in the pile was also estimated.

The length to thickness ratio of the individual rocks was determined in the same manner as for the smaller rocks, described in Equation (D.1). The longest axial length and the shortest axial length of the rocks were measured with measuring tape.

The blockiness of the large rocks could not be determined in the same way (the mass of the rocks was too large to weigh them). Instead, a visual observation was done to estimate the blockiness of the rocks. For each rock, 4 members of a group estimated the blockiness and told their estimates at the same time (to have independent observations). From the estimates, the average was taken to obtain an average blockiness.

The quality check of the rocks in the pile was done by walking around the pile and observing the rocks. The rocks were checked for irregularities and/or damages.

The total volume of rock in the pile was also measured. This was done by measuring the circumference with a GPS device on a phone (see Figure D.13). The average height of the pile and the porosity of the pile were determined visually. The total volume of rock in the pile was determined with Equation (D.4).

$$V_{total} = A_{pile} \cdot h_{average} \cdot (1 - porosity) \tag{D.4}$$

Figure D.13: GPS area measurement of big rock pile at Martsiana quarry

D.6.3. Used equipment

To measure the rocks in the quarry a scale was used to measure the weight of the rocks. Furthermore, a measuring tape and a handheld GPS device were used.

D.7. Sediment sample analysis

To have a better understanding of the beach and the bay, sediment samples were taken at different locations. The goal of taking these samples was to generate an overview of the sand that is present in and around the beach and also to provide a comparison of different parts of the same beach. As sand always is composed of multiple grain sizes, the objective of the sampling was to determine the d_{n50} for each of the samples, as well as the grain size distribution for a few samples of interest. These distributions can give insights on the origin and distribution of the material when they are compared to each other.

Figure D.14: Sample locations at Asparuhovo beach

D.7.1. Soil sampling on the beach

The sand samples at the beach were gathered with a piston. They were taken at different points of interest. Three samples were taken at the new port Karantinata. They were at a straight line perpendicular to the beach. The first was at the edge of the beach itself. The second one was just at the waterline and the third was on the sandbar at the entrance of the port. In the middle of the beach sediment samples were taken as well, one at the waterline and one on the beach. Finally, two samples were taken at the breakwater at the North of the beach. An overview of this can be found in Figure D.14.

D.7.2. Soil sampling in the water

For the samples in deeper water the Van Veen grab was used. A boat sailed out and a sample was taken at various points. The first sample was taken at the seaside. The depth was more or less constant at this point so no major changes were expected when sailing more offshore. Three more samples were taken at the North side of the bay and on a straight line towards the beach. These could be used to compare a cross section of the beach in the water. After that, the middle of the beach in which a deeper part occurred the next sample was taken. 5 more samples were taken in and around the fishing port to have enough data for conclusions about the fishing port. These points are displayed visually in Figure D.14.

D.7.3. Data processing

For the data processing first the microscope was used to determine grain sizes of the sediment samples. Five samples of interest were stored and taken to Delft for a full sieve analysis in the lab.

D.7.4. Used equipment

Piston sampler
The piston sampler is used to take sediment samples to a depth of up to 1.5 meters. The piston is pushed into the ground and the inside is retrieved once out of the ground, producing a clear cylindrical shaped soil sample of which visual observations can already be done.

Figure D.15: Retrieved sediment in piston sampler

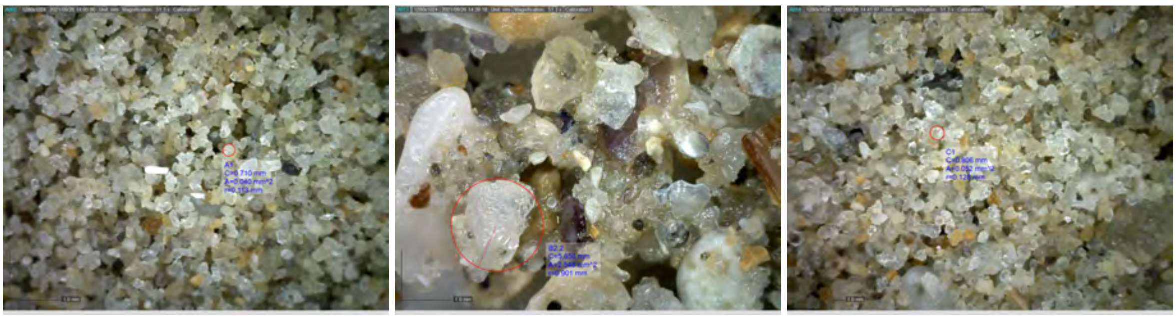
Van Veen Grab
As it is not possible to use the piston sampler at larger water depths the 'Van der Veen grab' was used to retrieve sediment from deeper water. It was used while sailing the boat. When the boat was at a location of interest the grab was prepared and used. The grab was attached to a cable of which the end remained at the boat to retrieve the grab. The grab was opened and sunk into the water. Once the opened grab hit the ground the string that held the grab open was released so that the grab enclosed the sediment at the bottom. This sediment was then retrieved by the cable and stored in designated storage bags.

Figure D.16: Van Veen Grab

Sand ruler
To get a first indication of the size of the sand samples a sand ruler was used. With this the retrieved sediment samples can be compared to standard distributed grain sizes that are on the sand ruler. This is for a first indication only. To get a clear estimation the sediment is first rubbed dry in the hand and then placed in the middle of the sand ruler. By comparing the sand to different grain sizes along the sand ruler, the size of the retrieved sand can be estimated.

Figure D.17: Sand ruler

Portable microscope
Once all the samples were taken and secured, they were analysed by using the Dino-Lite microscope as shown in Figure D.20a. The DinoCapture 2.0 software was then used to calibrate the microscope and measure the d_{50} of every soil sample. Of every measurement a screenshot was taken and stored, such as shown in Figure D.18. The corresponding measurements of the d_{50} can be found in Appendix E.2.

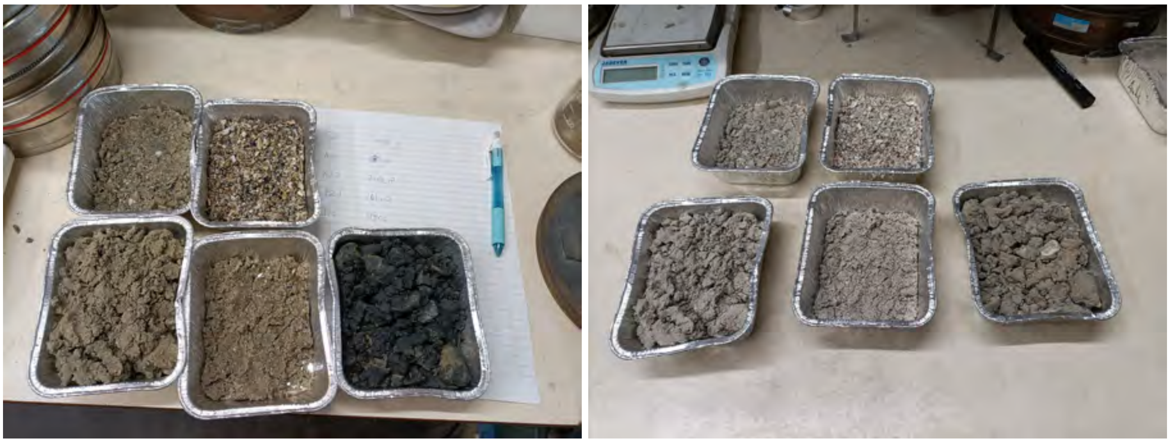


(a) A.1 (b) B.2.2 (c) C.1

Figure D.18: Snapshots of some d_{50} measurements done for different samples with the Dino-Lite microscope

Oven drying and burning

An oven was used to remove organic materials and any water from the soil samples. All samples were placed in allocated aluminium trays and then the trays were put inside the oven. All the samples were heated on 150°C for 24 hours. See Figure D.19 for the trays with samples before and after 24 hours in the oven.



(a) Before (b) After

Figure D.19: Samples A.2.3, B.2.1, B.2.2, Sample 7 and Sample 10 before (left) and after (right) 24 hours of drying and burning of organic material at 150°C.

Sample sieving and weighing

The dried samples were then subjected to a sieve analysis to determine the grain size distribution of each soil sample. The sieves were stacked into a column with the sieve with the biggest opening diameter on top. The opening diameter of each sieve was chosen such that the maximum amount of available sieves was used, in the realistic range that could be expected from the d_{50} measurements with the microscope. This range was decided to be between a maximum sieve opening of 2360mm, and a minimum of 90mm. The sieve sizes that were used are shown in Table D.2. The sieving took place on full power for 10 minutes per sample.

(a) Dino-Lite AM4115T - EDGE universal microscope (b) Sieving machine with sieves (c) Sartorius Research scale

Figure D.20: Equipment used for investigating the soil samples

Sieve	Opening diameter [mm]
1	2360
2	1800
3	1600
4	1400
6	900
7	710
8	250
9	170
10	125
11	90

Table D.2: Opening diameters of the sieves used for sieving

Finally, the remains of every sample in every sieve after sieving were weighed to create a grain size distribution. The results can be found in Appendix E.2.

E

Results per data type

This section presents the data that was acquired during the Hydraulic Fieldwork and by processing data from a wave buoy. The data has been organised per measurement method, as described in Appendix D.

E.1. Beach profile

In this section, the results of the beach profile measurements are presented. As described in the methods (see Appendix D.1), the elevation along 10 cross sections was measured. The elevation along the cross sections are displayed in Figures E.1 and E.2. It should be noted that these figures are not to scale.

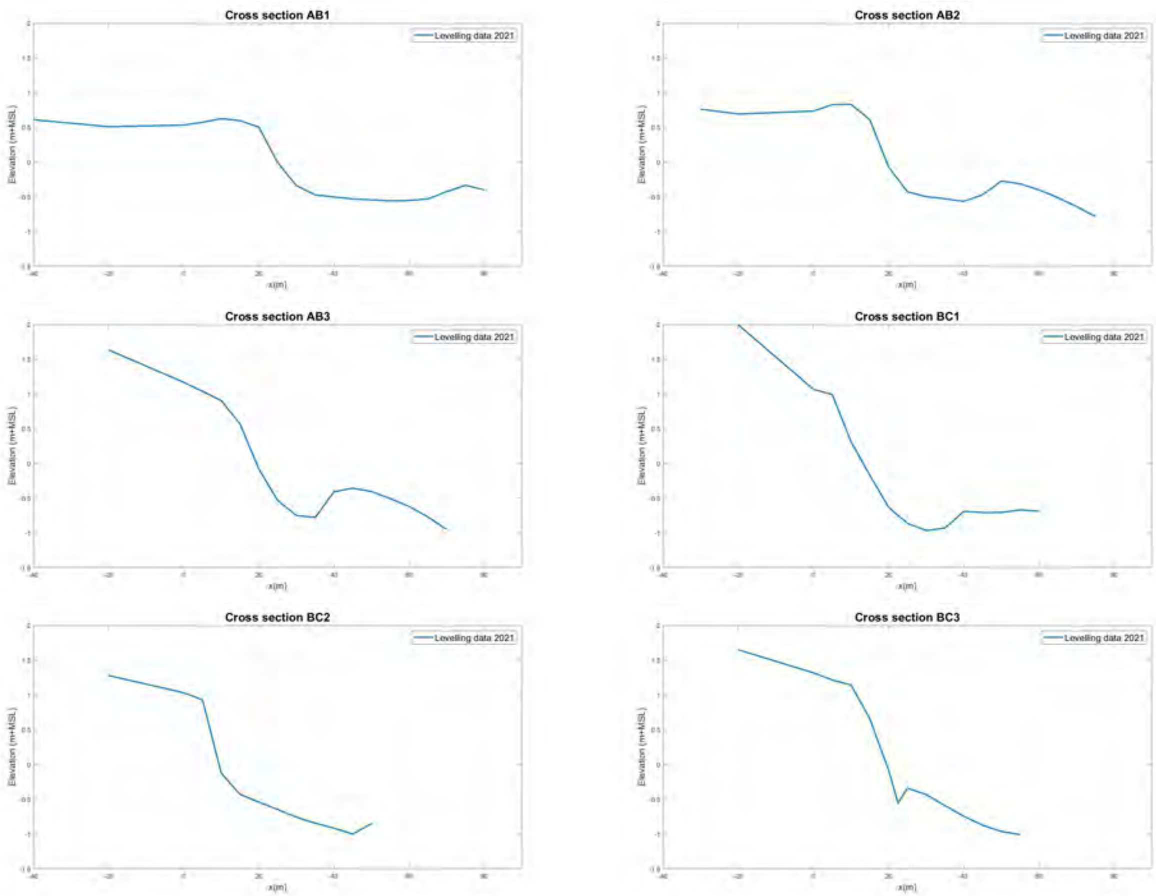


Figure E.1: Cross shore profiles AB and BC

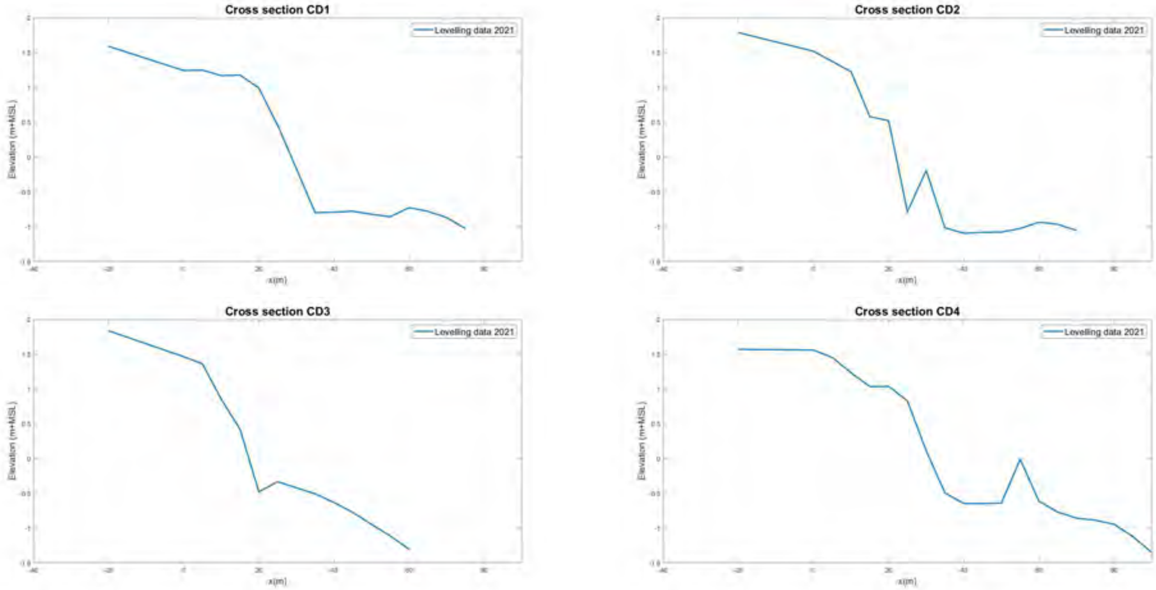


Figure E.2: Cross shore profiles CD

Cross sections AB1-AB3 were close to the port. The sandbar can clearly be observed in these figures. The figures also show that the slope is much steeper around the middle of the beach (cross sections BC1-BC3) than near the port (AB1-AB3). Almost all figures show a deeper part near the waterline and a shallower part behind (the sandbar). When observing cross sections CD1-CD4 (located at the Northern part of the beach, close to the breakwater) it can be observed that the cross-shore location as well as the height of the sandbar differ. This can be explained by the shape of the beach and the position of the waterline at that location (see Figure D.3).

Comparing cross sections to previous years

By comparing the cross sections to measurements from previous years, it is possible to observe how a cross section changed over the years. The locations of the cross sections in 2021 were different from previous years (2010-2014). However, 1 cross sections could still be compared. Cross section CD1 (located in the middle of the beach) was very close in terms of location to cross section measurements done in previous years. However, it should be noted that the location was not exactly the same and also the direction of the cross section was a little different (although the difference is minor). The results should therefore be interpreted with this in mind. Previous years also had a different reference point. The elevations from previous years therefore had to be converted to the reference height of 2021. An explanation of how this was done is included in Appendix D.1.

In Figure E.3, the measured elevations of all years are plotted along the transect CD1.

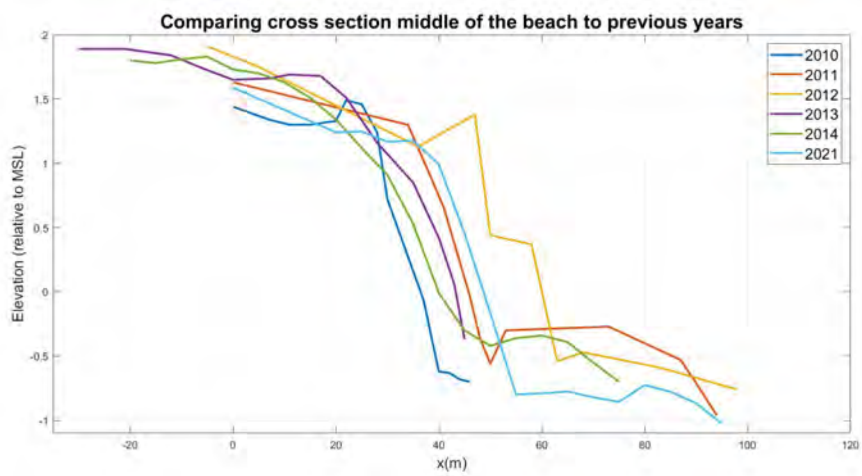


Figure E.3: Comparing cross section CD1 to similar cross section measurements from previous years

From the comparison made, it is clear that there is no exact pattern of erosion or accretion along this particular transect at Asparuhovo beach. However, there is a variation between the measurements of the different years. From the Figure no clear conclusion can be drawn regarding the stability of the transect. There can be multiple explanations for why no clear pattern can be observed when comparing to previous years. First of all, the locations do not match perfectly. A different reference point was used and the conversion of other years to this years was not a very exact method. Secondly, in the levelling method errors can be made when performing the measurements. Finally, an explanation can also be that there is no large change along the transect when compared to previous years. Also seasonal variations can be of an influence here. Nevertheless, the Figure shows how an comparison between years can give insight in the behaviour of a beach over the years. If levelling will be done in coming years, it is advised to use the same transects as in 2021 so a comparison can be made that is the least sensitive to errors.

E.2. Soil sampling

The observed d_{50} of all samples is shown in Table E.1 and Figure E.4.

Location	Sample ID	Radius [mm]	d_{50} [mm]
A - Karantinata port	A.1	0.113	0.226
	A.2.1	0.120	0.240
	A.2.2	0.115	0.230
	A.2.3	0.149	0.298
	A.3.1	0.127	0.254
	A.3.2	0.125	0.250
	A.3.3	0.131	0.262
	A.3.4	0.151	0.302
	A.3.5	0.117	0.234
B - Middle of Asparhuovo beach	B.1.1	0.260	0.520
	B.2.1	0.154	0.308
	B.2.2	0.901	1.802
C - Asparhuovo northern breakwater	C.1	0.128	0.256
	C.2.1	0.130	0.260
	C.2.2	0.142	0.284
F - Veteran beach	F.1	0.701	1.402
	F.2	1.490	2.980
	F.3	1.721	3.442
	F.4	0.641	1.282
Sample - Underwater samples Asparhuovo beach	Sample1	0.104	0.208
	Sample2	0.062	0.124
	Sample3	0.084	0.168
	Sample4	0.136	0.272
	Sample5	0.131	0.262
	Sample7	0.101	0.202
	Sample8	0.091	0.182
	Sample9	0.147	0.294
	Sample10	0.124	0.248

Table E.1: Observed radii and corresponding d_{50} from all soil samples, as measured with the Dino-Lite microscope

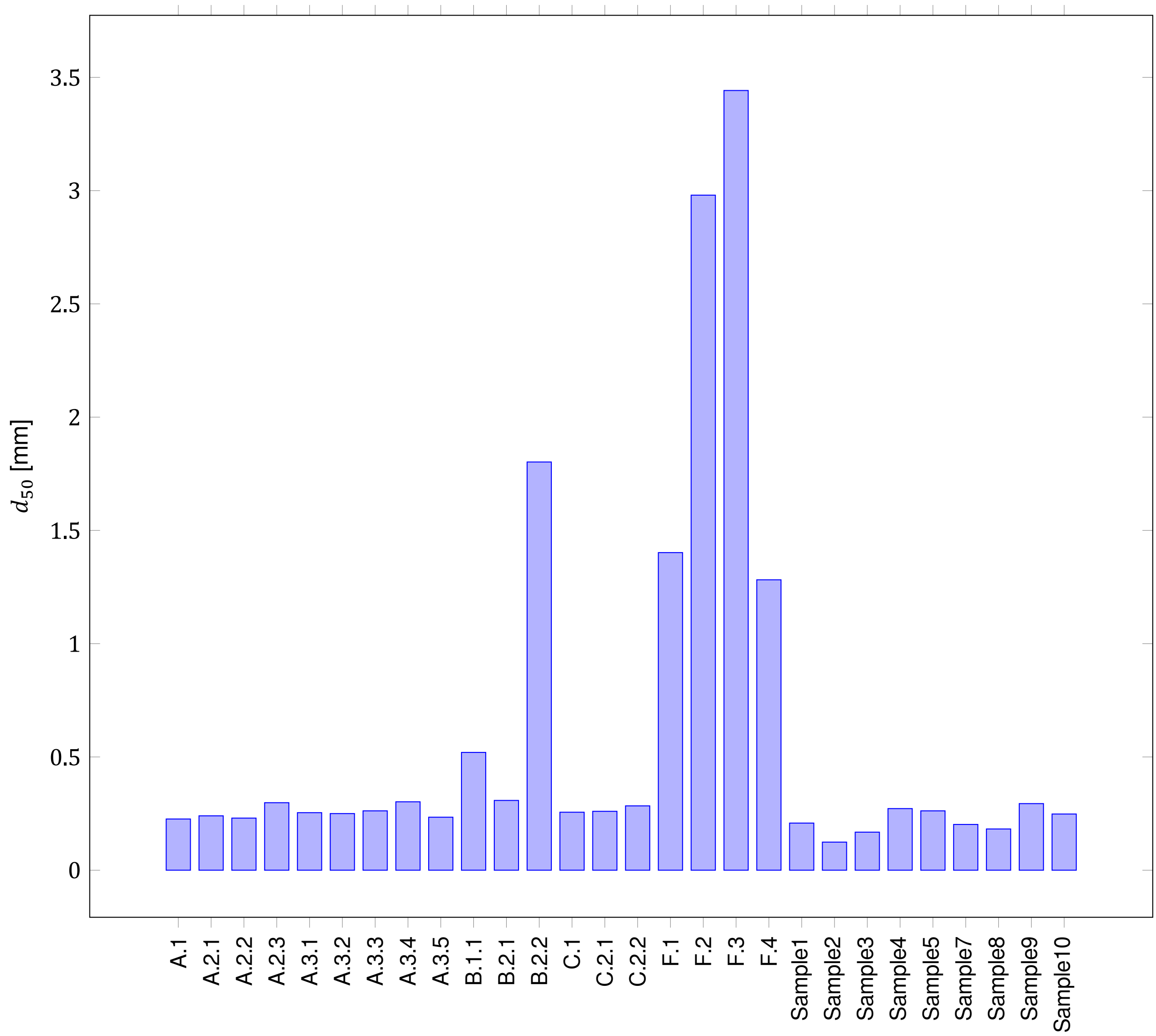


Figure E.4: Visualisation of d_{50} for all samples

Five samples from different locations on Asparuhovo beach (A.2.3, B.2.1, B.2.2, Sample 7 and Sample 10) were then taken to the laboratory in Delft for further analysis. These samples were chosen due to their locations in the sedimentation area, suspected erosion area and control locations on the beach and in the water. Their obtained grain size distributions can be found in Figure E.5.

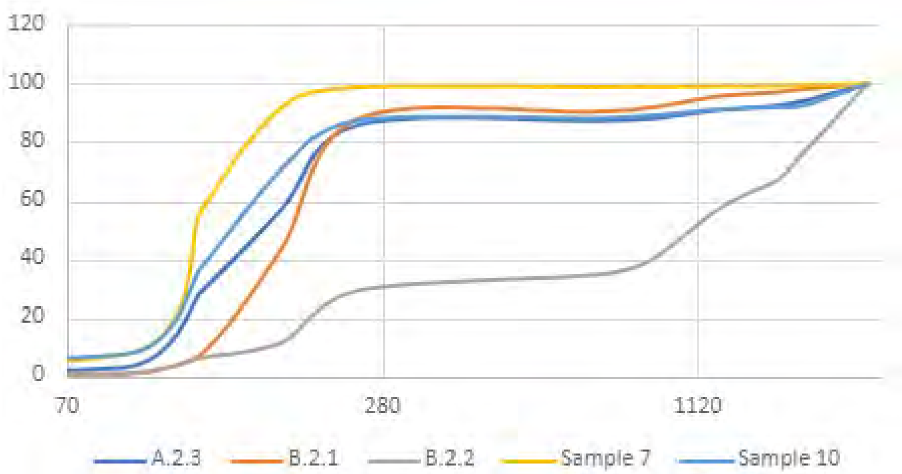


Figure E.5: Grain size distribution for samples A.2.3, B.2.1, B.2.2, Sample7 and Sample10

E.3. Wave measurements

In this section the results of the wave measurements are presented. The wave measurements were mainly performed with the use of a wave buoy. This wave buoy has been deployed at the location in Varna bay since October 2020 and has therefore collected data for about a year. It is important to note that the retrieved data is therefore probably not representative for the entire wave climate. It can, however, be used as a representation of the wave climate since the construction of the port. In the period between port construction and deployment of the buoy in Varna bay (October 2020), there has been one significant storm. With the purpose of representing the wave climate since port construction as accurately as possible, data of this storm was obtained with the use of a wave droid, located further away from the project location. More information about the type of wave buoy and droid, as well as their locations can be found in Appendix D.4.

E.3.1. Wave conditions of the previous year

From the wave buoy, wave data was obtained from previous year (October 1st, 2020 to October 1st, 2021). In Figure E.6 a wave rose is presented with the significant wave heights per direction for this period. The figure shows that almost all waves come from a Northern to Eastern direction and that the highest waves come from the North-East.

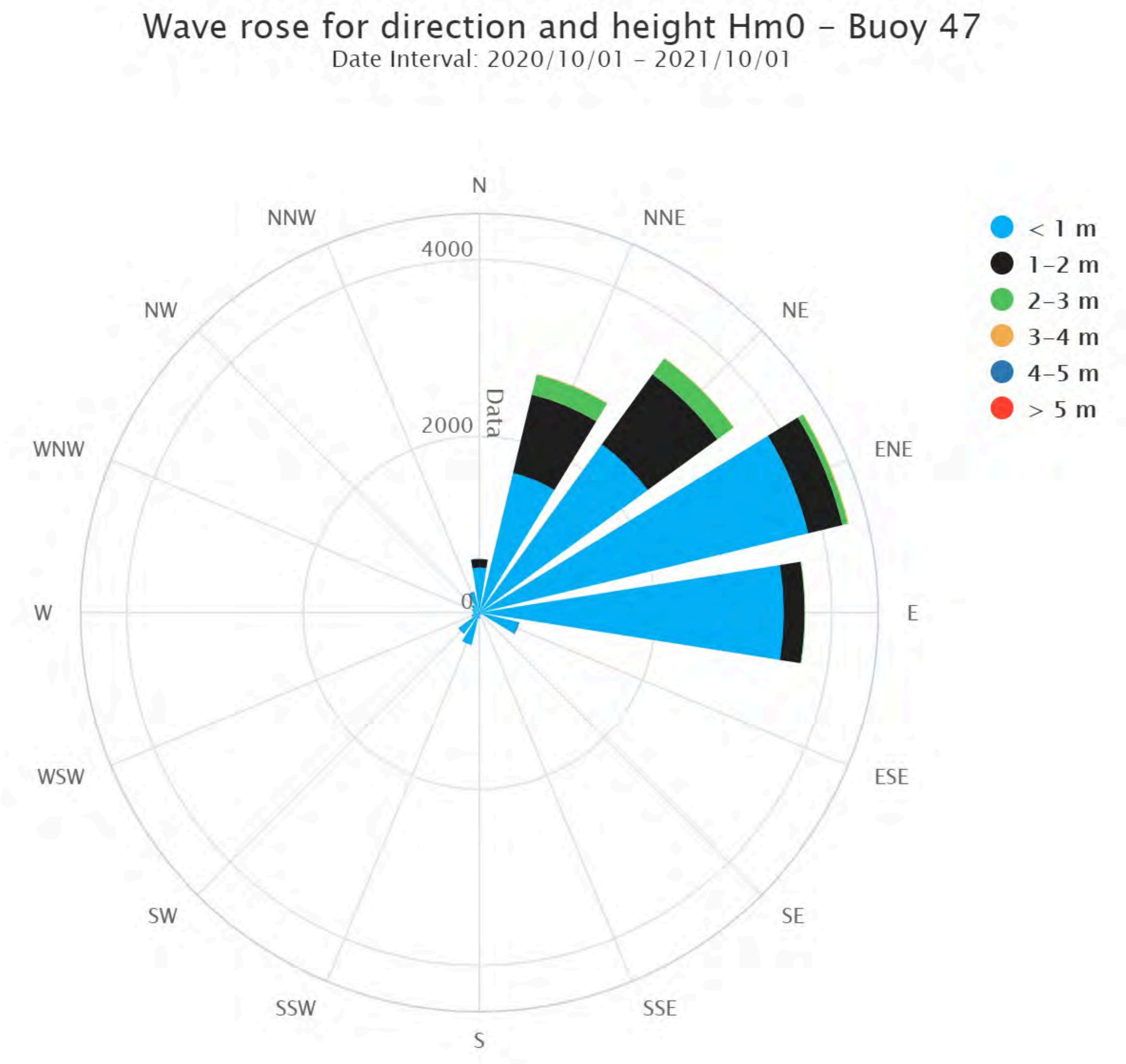
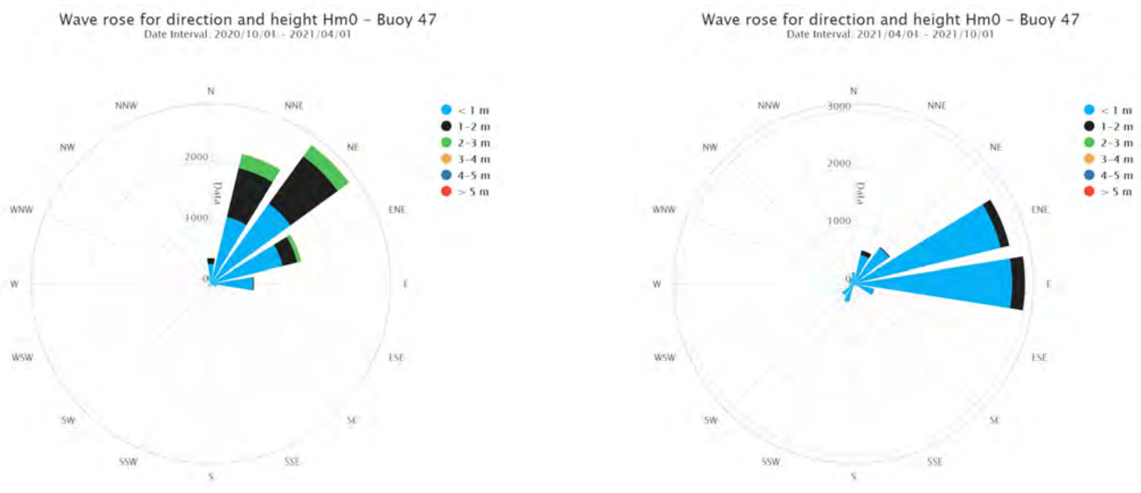


Figure E.6: Wave rose significant wave height for 1 year

To get a better understanding about when the storms happen and from what direction they come, the significant wave height data was split up in 2 time periods: a summer period (from April to September) and a winter period (from October to March). The wave roses for the winter and summer periods are given in Figure E.7.



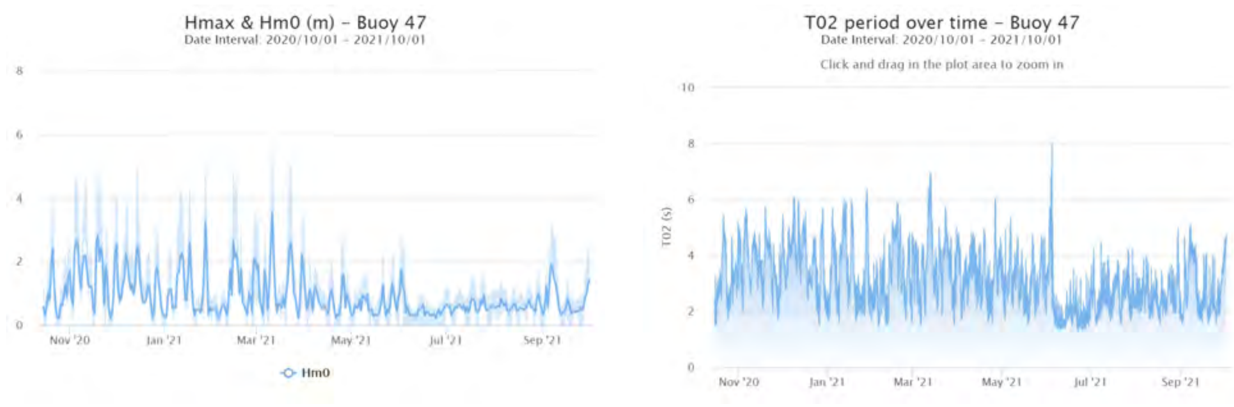
(a) Winter [01-10-2020 - 01-04-2021]

(b) Summer [01-04-2021 - 01-10-2021]

Figure E.7: Wave roses with the significant wave height per direction for the winter and summer

The Figures show that the higher waves came during the winter and that they came from a NNE to NE direction. During summer the waves came mostly from the ENE and E and the waves were milder.

In Appendix E.3.1 the maximum wave height and the significant wave height are given for the period 1 October 2020 to 1 October 2021. They show that the maximum wave height in the winter was up to 6 meters and that the mean period in winter was most of the time around 6 seconds and in summer around 4 seconds.



(a) H_{m0} and H_{max}

(b) Mean zero-upcrossing period T_{02}

E.3.2. Wave conditions during storm of 6th of April 2020

As mentioned, the wave data described in Appendix E.3.1 can be seen as representative for the wave climate under normal conditions in the period since the port construction. There has, however, been one significant storm since the port construction, of which no data was obtained by the wave buoy. This storm occurred on the 6th of April 2020. Data of this storm was obtained with the use of a wave droid. The largest significant wave height during this storm was 2.65 m and corresponding mean wave period was 6.7 seconds. It is, however, important to take into account that the location of this wave droid is different from the location of the wave buoy.

E.3.3. Wave climate during fieldwork

The fieldwork took place in the last week of September. In Figure E.9 the wave rose with the significant wave heights during the fieldwork is presented. It was a relatively calm week with respect to wave heights (most wave heights were below 1 meter) and the dominant wave direction was from the East. Since it was at the end of the summer, this is as expected if compared to the rose in Figure E.7.

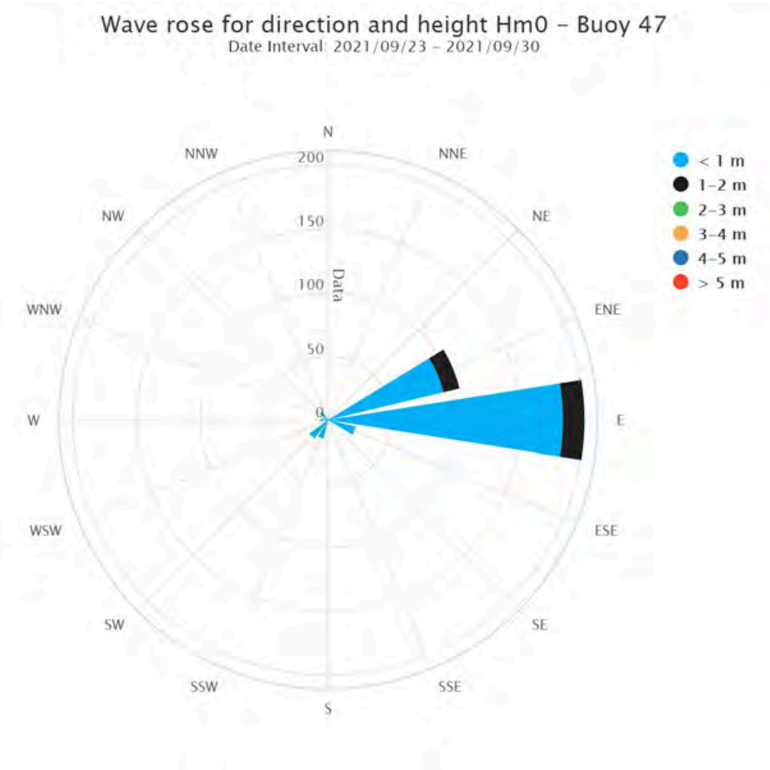


Figure E.9: Wave rose during fieldwork week

E.4. Time lapse camera

In addition to the wave buoy and droid, a time lapse camera was installed. More information regarding the installation of the time lapse camera can be found in Appendix D.5. Where the wave buoy and droid provide data on the wave heights, directions and periods at the location of the buoy (offshore), the time lapse camera can be used to understand the consequences of certain wave heights and directions close to the coast. Next to this, the time lapse camera can be used to identify certain processes happening close to the coast.

E.4.1. Comparison wave conditions and time lapse camera

In order to get a better understanding of the consequences of certain offshore wave conditions, a comparison was made between three situations; a situation with mild wave heights, a situation with medium wave heights and one with large wave heights. On the 27th of September 2021, at 9:00 in the morning, the conditions were relatively mild. The significant wave height at that moment was equal to 0.22 meters and the waves were predominantly coming from South-eastern direction. The picture made at that moment is displayed in Figure E.10. On October 5th at 10:00 a wave height of 0.82m was recorded by the wave buoy. A picture of the conditions at the beach is displayed in Figure E.11. On the 6th of October 2021, at 17:00 the wave heights were relatively high (1.37m) the waves came predominantly from an eastern direction. The picture made at that moment is displayed in Figure E.12.

Comparing the three pictures, it can clearly be seen that in the case of the harsher conditions, the waves are significantly larger and break further from the coast. When the conditions are mild, the waves are very low and the individual waves can not clearly be identified. When comparing the conditions at October 5th and 6th, the individual waves can be identified and it can be observed that the wave lengths on October 6th are larger than on October 5th. This can be explained by the longer duration of the storm.

Figure E.10: Picture of wave conditions 27/09/2021 9:00

Figure E.11: Picture of wave conditions 05/10/2021 10:00

Figure E.12: Picture of wave conditions 06/10/2021 17:00

E.4.2. Identifying processes near the coast

The pictures that were made by the time lapse camera can be used to identify certain processes happening close to the coast. In this subsection, the processes of diffraction and rip currents are identified and analysed. Theoretical knowledge on these processes can be found in Section 1.6.

Firstly, a closer look is taken at the diffraction patterns. Looking at Figure E.10, the zone that is sheltered from the South-Eastern waves can clearly be identified. As the waves in this situation are very small, it is quite hard to recognise the diffraction pattern. When analyzing Figure E.11 and Figure E.12, a clear diffraction pattern can be recognised. The sheltered zone is smaller at these moments than for the milder conditions. This can be explained by the fact that the waves are coming from Eastern direction.

Furthermore, the presence of rip currents is looked at. There are several signs with which a rip current can be identified. The most clear signs are: (1) deeper, dark colored water, (2) fewer breaking waves, (3) rippled surface, surrounded by smooth water and (4) anything that is flowing back to the sea, or colored water flowing back out to sea. Not all rip currents have to show all these signs. Some rips may only show one or two of the signs (Surf Life Saving Australia, 2016).

With the use of this knowledge and the pictures made by the time lapse camera, it can be identified that a rip current is present most of the time. A clear identification of this rip current can be done on the basis of a picture made at 13.00 on the 9th of October 2021 (see Figure E.12). At the location of the rip current, it can clearly be observed that fewer waves are breaking. Furthermore, the surface seems to be slightly more rippled than the surrounding water. Lastly, the color of the water at the location of the rip current is darker than the surrounded water. The identified rip current is indicated with the blue arrows in the picture.

(a) Picture made by time lapse camera

(b) Identification of the rip current

Figure E.13: Identification of rip current on picture made by time lapse camera 09/10/2021

E.5. Quarry

In this section, the results of the measurements performed in the Marsiana quarry are presented.

E.5.1. Results small rocks

Results LT ratio

In Table E.2 below the measurement results for the Length to thickness ratio and the calculated LT ratio are presented. The numbers of the blocks do not match between the two groups. This is however not a problem. To interpret the results, a boxplot was made for the measurements from both groups. The boxplots are given in Figure E.14. The Figure shows some deviation between the results of the two groups. However, the results of both groups show that the LT ratio is below 3 for almost all rocks in the sample. According to the Rock Manual the amount of rocks with a LT ratio of larger or equal to 3:1, should be smaller than 5% (heavy armour stone) and smaller than 20% (light armour stone) of the total amount of rocks (CIRIA et al., 2007). According to the results, the amount of rocks with a LT ratio larger than 3:1 is 5-10%. This means that the armour stone would be suitable to be used as light armour stone, but not as heavy armour stone.

Block Nr	Longest axis [cm]	Thickness [cm]	LT ratio [-]
1	20	8	2.50
2	23	9	2.56
3	23	14	1.64
4	31	17	1.82
5	35	16	2.19
6	34	15	2.27
7	34	16	2.13
8	34	17	2.00
9	30	16	1.88
10	43	16	2.69
11	39	12	3.25
12	37	18	2.06
13	36	19	1.89
14	35	17	2.06
15	39	22	1.77
16	42	24	1.75
17	41	25	1.64
18	49	20	2.45
19	75	16	4.69
20	68	32	2.13

(a) Length to thickness ratio group 1

Block Nr	Longest axis [cm]	Thickness [cm]	LT ratio [-]
1	22	15	1.47
2	25	11	2.27
3	38	17	2.24
4	29	16	1.81
5	32	20	1.60
6	31	18	1.72
7	33	17	1.94
8	28	21	1.33
9	39	15	2.60
10	35	18	1.94
11	29	16	1.81
12	42	15	2.80
13	36	18	2.00
14	35	23	1.52
15	27	26	1.04
16	40	24	1.67
17	44	37	1.19
18	73	18	4.06
19	20	11	1.82
20	65	45	1.44

(b) Length to thickness ratio group 2

Table E.2: Length to thickness ratios for the two different groups

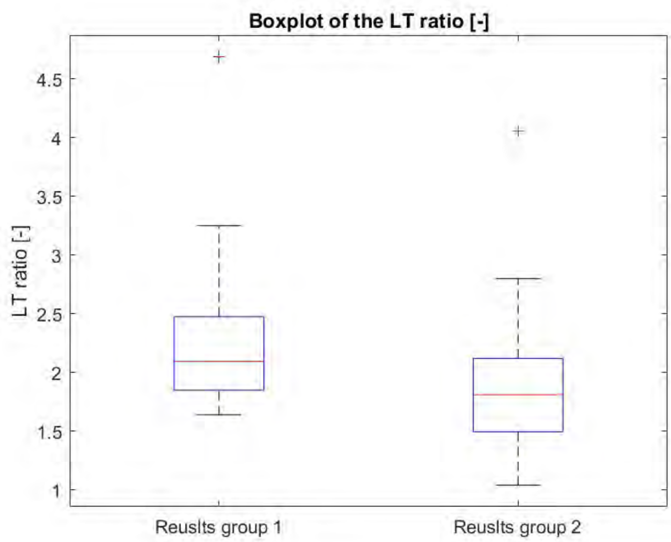


Figure E.14: The results of the LT measurements of the two groups

Results blockiness

The results of the blockiness measurements are summerized in Table E.3. In the Table a blockiness of 148% is given for block number 9. This is probably the result of a measurement error, since a blockiness larger than 100% is per definition not possible. The rock was deleted from the results before making a boxplot of the results. The boxplot is given in Figure E.15. The boxplot shows that the blockiness of most stones is around or just below 50%. According to the Rock Manual, there should be few or no stones with a blockiness below 50% for a good quality of armour (CIRIA et al., 2007). This is not the case for the measured stones. It can therefore be concluded that the quality of the stones regarding the blockiness is not sufficient for them to be used in an armour layer.

Block Nr	Length [cm]	Width [cm]	Height [cm]	Mass [kg]	Volume $[10^{-3}m^3]$	Volume squared $[10^{-3}m^3]$	Blockiness [%]
1	20	13	10	3	1.25	2.60	48.1
2	20	15	9	3.5	1.46	2.70	54.0
3	22	20	14	6.5	2.71	6.16	44.0
4	24	20	18	10.5	4.38	8.64	50.6
5	24	23	16	11	4.58	8.83	51.9
6	28	23	14	11	4.58	9.02	50.8
7	27	16	23	13	5.42	9.94	54.5
8	24	22	15	13	5.42	7.92	68.4
9	29	16	8,5	14	5.83	3.94	147.9
10	41	24	20	14	5.83	19.7	29.6
11	34	26	14	16	6.67	12.4	53.9
12	32	26	20	17	7.08	16.6	42.6
13	33	30	21	17	7.08	20.8	34.1
14	34	27	17	19.5	8.13	15.6	52.1
15	28	22	22	21	8.75	13.6	64.6
16	40	31	24	22	9.17	29.8	30.8
17	43	34	25	33	13.8	36.6	37.6
18	43	25	35	38	15.8	37.6	42.1
19	75	44	17	41	17.1	56.1	30.5
20	58	48	31	79	32.9	86.3	38.1

Table E.3: Results blockiness measurements

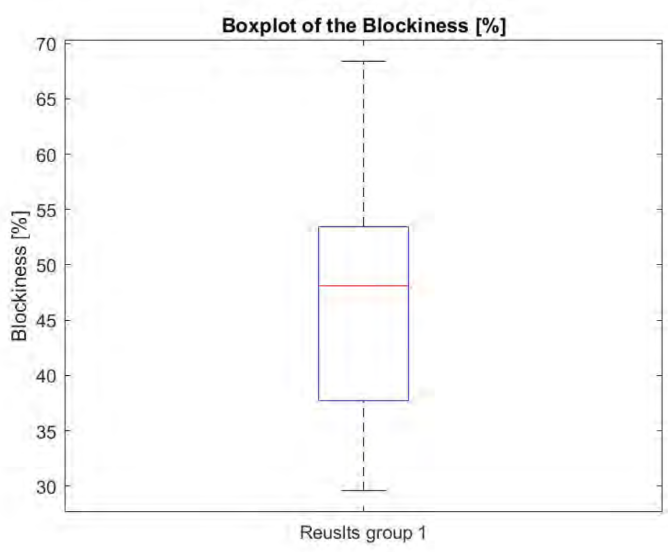
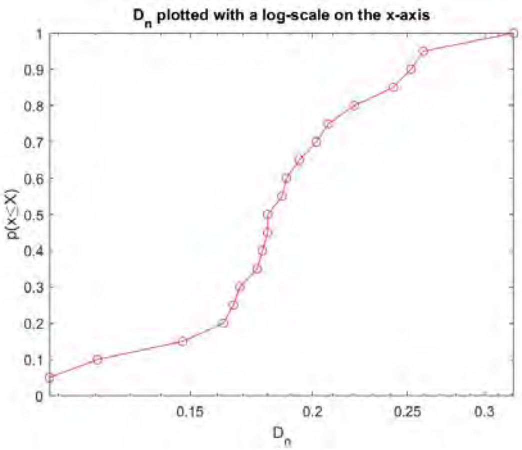


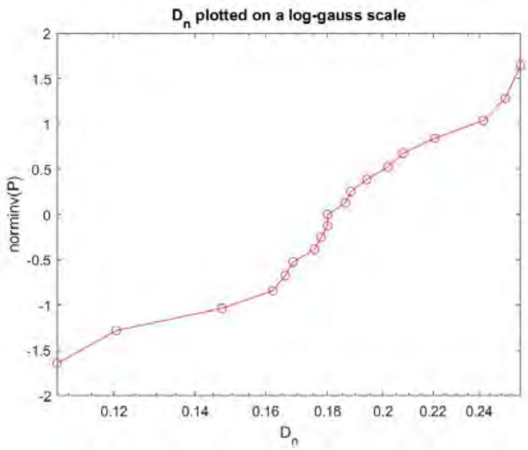
Figure E.15: Boxplot of the Blockiness results

Determining the D_{n50}

The D_n of each individual rock was determined with Equation (D.3) and after that the D_n of the rocks was plotted on a log scale (Figure E.16a) and on a log-gauss scale (Figure E.16b). The Figures show that the D_{n50} of the sample is 0.18 meter.Figure E.16b suggests that there is no evidence that the diameters of the sample follow the normal distribution. If this would have been the case, the samples would have made a straight line.



(a) D_n of the sample plotted on a log-scale



(b) D_n of the sample plotted on a log-gauss-scale

E.5.2. Results large rocks

The results of the LT ratio and blockiness of the 10 large rocks are presented in the Table E.4. The Table shows that for every rock, the LT ratio is below 3 and that the blockiness is higher than or equal to 50%. Based on the blockiness and the LT ratio, this sample of large rocks is of good quality.

Block Nr	Longest axis [cm]	Thickness [cm]	LT ratio [-]	Blockiness [%]
1	140	80	1.8	60
2	140	75	1.9	80
3	135	65	2.1	85
4	150	70	2.1	50
5	230	190	1.2	50
6	257	190	1.4	70
7	262	125	2.1	80
8	217	155	1.4	55
9	160	70	2.3	60
10	343	156	2.2	50

Table E.4: Results LT ratio and Blockiness large rocks

Besides the LT ratio and the blockiness, the pile of large rocks was also checked on quality with a visual assessment of the rocks. From these observations, it turned out that a lot of rocks were damaged. This can also be seen in Figures E.17 and E.18.

Figure E.17: Examples of damages of the large rocks in the pile

Figure E.18: Examples of damages of the large rocks in the pile

F
Data and accuracies

In this appendix Table F.1 provides the data that was collected with frequencies and accuracies during the Bulgarian fieldwork in October 2021.

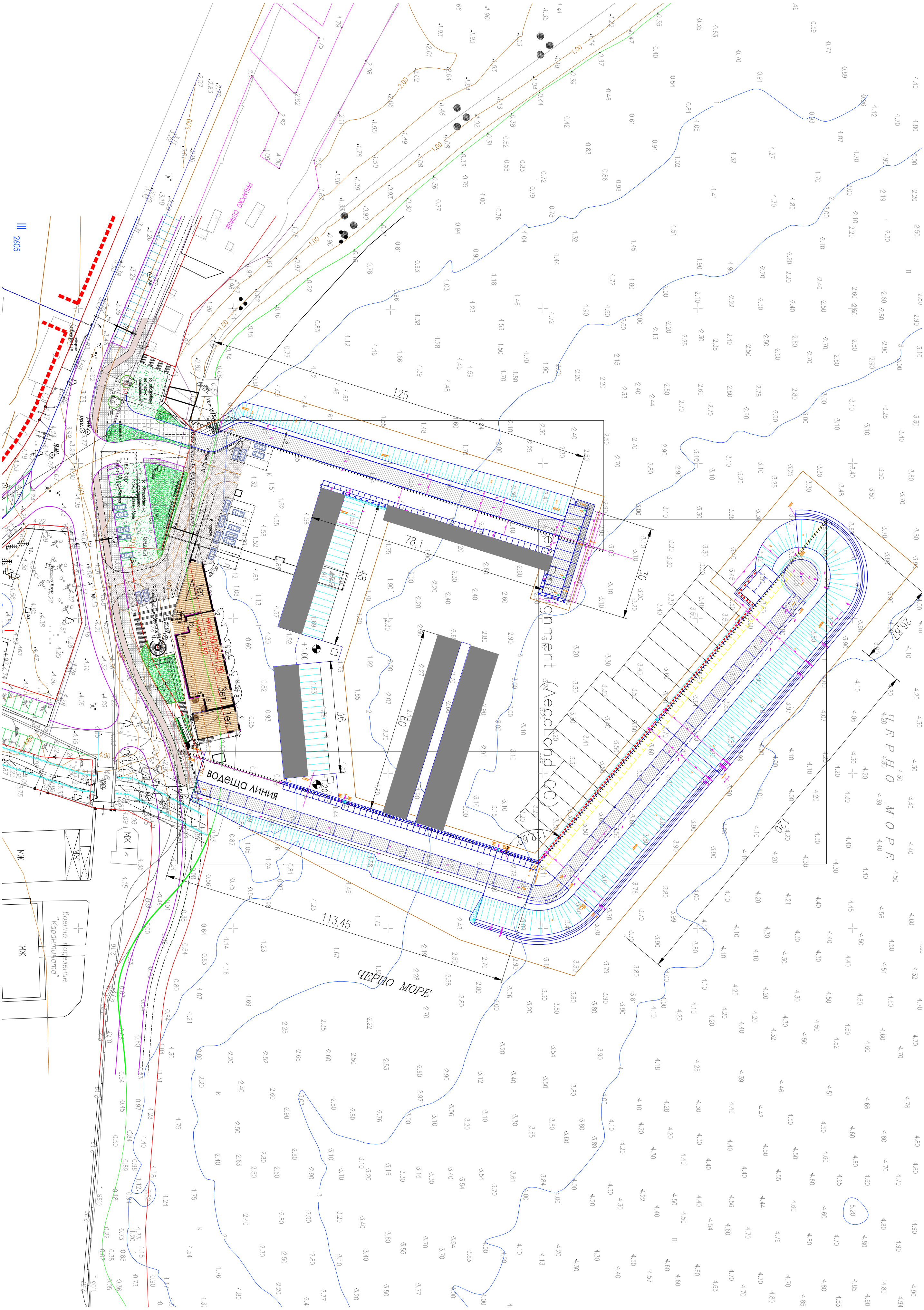
Equipment and/or method used	Type of data	Sample frequency	Variables	Accuracy (+-)	
Wave buoy	Wave properties	Once every 30 minutes	Hs	0.1	m
			Tm	0.5	s
			Dirp	10	°
Anemometer or website	Wind speed	2 days, 3 times per day	Uw	2	m/s
	Wind direction	2 days, 3 times per day	Dir	20	°
GPS on phone	Waterline position	4 times in total, with 2 different devices	GPS coördinates	2	m
Leveling instrument beach profile (elevation)	10 times in total		x,y: 1 z: 0,1	m	
Echo sounder boat	Bathymetry	5m per point		0.1	m
Measuring tape	Distance	Between transects and on transects		0.05	m
Prism square	Perpendicularity (90 degrees)	On every baseline and transect		0.5	m
Piston sampler	Soil sample onshore	6 times in total			-
Van Veen grab	Soil sample offshore	10 times in total			-
Portable microscope	Soil grain diameters	-	D50	0.01	mm
dn50	Block properties	2x20 samples	dn50	0.01	m
L/T ratio	Block properties	2x20 samples	L/T	0.35	[-]
Blockiness	Block properties	1x20 samples	-	10	%
Stockpile quantity	Available material	1 stockpile 2 times determined	-	250	m3

Table F.1: Collected data and their accuracies

G

AutoCAD Design Karantinata Port

This appendix shows the plan of the Karantinata port. This plan was shared by Mr Boyan Savov, one of the supervisors of the project and a retired Bulgarian coastal engineer. In this plan, the conditions are from before the construction of the port, which means that they show the initial depths from before any sedimentation occured.



водеща линия
ЧЕРНО МОРЕ
Военно поделение "Карантината"
рибарско селище
МЖ
ниво ±0,00=+1,50
125
78,1
48
36
60
30
113,45
120
26,87

H

Daily reports

Friday September 24th

The first official day started as a colder morning but after a good breakfast at the hotel we arrived at Asparuoho beach. A morning kick start at the local Red Rock restaurant with a cup of tea and coffee started the week. A division of tasks and an overview of the week was discussed. After that a plan for the day was made. Three people were surveying the ecology and did a damage assessment of the breakwater (Roald, Sanne and floris). Two people measured the waterline level during the calm wind and weather conditions (Marjolijn and Stefanus). The last people measured the bathymetry of the new fishing port from the boat of Bulgarian supervisor Mr Boyan Savov (Auke, Thijs and Maikel). After that the lunch came with a lovely pizza from the hotel. The afternoon came and new groups were formed for the different activities. Three persons measured the rest of the bathymetry in the bay and took sand samples at different interesting points with a Van Veen grab. In this Marjolijn found her new passion in grabbing the sand from the bottom of the seabed. All others were deeply invested in taking samples across the beach into deeper depth. Pistons were hammered into the ground and the samples were undertaken for a first examination. A great day ended where it started to complete the circle of the day. A small meeting was held, covering points of improvements for the next day. Red Rock provided in food and beverages.

Saturday September 25th

The morning started with a short briefing on the concrete wall of the new harbor. Roald and Stefanus went along with the last bathymetry measurements on Boyan's boat. Everyone else was lined up to make a plan for the leveling. After some back and forth, whether or not a good reference point had been chosen et cetera, the first baseline was set up with drawings. After some instructions by Mark, the fixed reference point was measured and the first grid lines could be walked. Auke and Marjolijn always walked at right angles to the baseline. A prism was used for this. Auke with the levelling staff and Marjolijn with a measuring tape for the next measurement. Close to the sedimented harbor the density of lines was greater because this is an interesting place. The beach side of the baseline was also measured every 20 meters and the seaward side deep into the water every five meters. Thijs and Maikel were always one step ahead of the group where they started looking for the next point on the baseline. Floris and Sanne always positioned the leveling instrument between two points and could thus read all heights well. By lunchtime the entire new stretch of beach had been measured. The mood was good after the longer start-up was followed by increasingly faster measurements. After lunch, the rest of the beach was measured. This was eventually complicated by slightly larger waves and more wind that made it difficult to keep the ruler straight. However, Auke and Marjolijn didn't know how to stop and they walked into the water every time. Finally joined by some hydraulic jokes from Roald in the walkie-talkie. Around 6 o'clock the entire profile was measured, a huge achievement! The things were cleaned up and a delicious meal was served at the panorama viewing point of Galata. On to tomorrow where a new beach awaits!

Sunday September 26th

The day started with a nice breakfast and a ride to the beach on the other side of the Galata hill. That it was a different kind of beach became immediately clear to our group of young coastal engineers, not only because of the aggressive dog that was present and chased everyone (especially Floris). Larger grains, less refraction of the waves (they came in at an angle on the beach) were quickly analyzed. Samples were taken for later comparison with those from the hitherto explored 'Asparuhovo beach'. This 'familiar' beach was also the next stop to inspect the condition of the breakwater of the new fishing port. Then lunch was served in the Red Rock. The afternoon was spent in a meeting with a brainstorming session about the problems and a plan for Wednesday's presentation. A game of football and a coffee halfway through led to the last part of the afternoon in which the collected data was converted into usable pieces. After that everyone ended up in the center of Varna by bus and taxi where -of course- they immediately went to the beach and had dinner with their feet in the sand. The evening ended with Heineken beers in a bar with some interesting games for Traian and Stefanus.

Monday September 27th

The quarry or the -kwarrie- was on the program. The safety shoes that had been carried along from the Netherlands were therefore finally allowed to be worn. Long pants, a helmet from Boyan and everyone was ready to hit the field. First an inspection from above on the quarry showing how deep the quarry was executed and an explanation of how the process of digging worked. Vertical drilling up to the desired 22 meters with explosions at the bottom that loosened the stones. The distance between the blasts and the sequence made up for the size of the stones they released. An exercise was then carried out in the quarry in which various stones were measured and an estimate was made of the amount available to see if there was enough for any new plans with the fishing port. After this visit, we drove to the St. Constantin and Helena district where the packed lunches were consumed. After lunch we set off by going past a fence -with Mark leading the way- to view the breakwater and a half-finished harbour. Once again it turned out that Boyan knew about every piece of concrete that could be found in this area, when it was laid and which parts he designed himself, how long it took to build and much more. The last destination was the breakwater in Varna itself. The European sailing championships for the Laser Radial class was in progress and the breakwater turned out to be a source of many stories. Stones that were alternated by Tetrapods, several people who hadn't hired anyone and just poured concrete because "that would solve all the problems", different floors and much more. The day ended in a hip tent with Italian cuisine. The next day we would leave early so we went to bed early.

Tuesday September 28th

A new day with a new plan. The day started early with breakfast and departure by bus at 8.30 am. Fresh in the bus, the first place was visited. A house/hotel along the coast that had sunk several meters down. Boyan said that the 'sliding' of pieces of land along the coast was a bigger problem than just here and that measures were taken wherever there was enough money, in the form of improved drainage or the construction of retaining walls. However, this place had been in this state for 10 years. A leaking tank was the cause for wet ground and the ground started to slide as a result. On the path to the next destination (the second 'kwarrie') Boyan told about all the other parts along the coast where this was a problem and that you could see from the steep rock cliffs that over the centuries large pieces of land have already come down had come and provided the current flatter 'terrace'. The second stop was another quarry. What the youths immediately noticed was that there was much more red in the stone, indicating a greater amount of iron in the stone. A demonstration by the site workers showed the crumbling and separation process. Boyan could tell that even with more porosity, these more colored stones were more reliable than the stones from the day before. The road continued along the coast and lunch was served on a breakwater in the town of Balchik. A plan was also discussed here for tomorrow. After all, the presentation had to be made from scratch in a day and a battle plan would help with that. The road was again continued along the coast to Cape Kaliakra. A promontory into the sea with ancient fortresses and mythical stories about the unconquerable place and 40 women who tied their hair together and jumped into the sea together. A ship had hit the rocks near Cape Kaliakra earlier in the week, so such a temporary coastal attraction could not be missed and after a stop at steep rocks that have provided beautiful pictures, a long walk was taken to visit the ship up close. The front appeared to be fixed and the back was still floating. After the calm weather of earlier in the week and a failed salvage attempt, the ship was now bobbing nicely in the spot, almost in the rocks and with the bow resting on a boulder one meter above the waterline. After this visit we drove back to Galata where we had dinner for the last time in the Red Rock.

Wednesday September 29th

Today it had to happen! At the end of the day a presentation was scheduled where a number of people from the local authorities would be there to listen in on the findings. And so it started early, the plan from the day before was repeated and everyone got to work on their own task. The PowerPoint was made, leveling data was registered, the microscope was used for the sand samples, a monitoring plan was described, a video with images as an asset for the presentation was made, plans were discussed and the theory was discussed. All this led to a fully filled working day with a delicious pizza ready for lunch. At the end of the afternoon some preparations and exercises for the presentation and then it was time. To the harbor and let those people come. The presentation went well and everyone was happy with the result. It was made clear to those present that many more findings would come with our report and that they would definitely be interested in them. That bodes well for the coming months. Afterwards, Boyan took the group to a classic Bulgarian restaurant called Chuchurite. A wonderful closing followed where beautiful last words for this journey were spoken by Mark, Boyan and Roald.