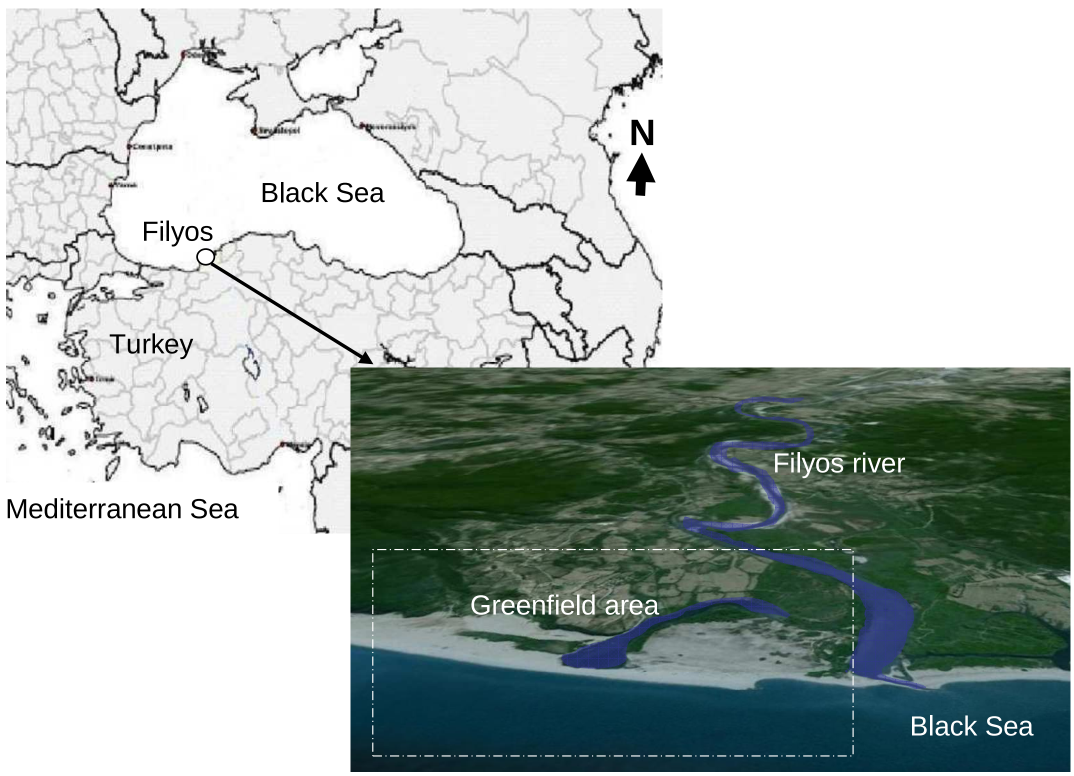
# Layout design for greenfield port Filyos





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June 2010


**Delft University of Technology**
Faculty of Civil Engineering and Geosciences
Section Hydraulic Engineering
Specialisation Ports & Waterways

# Layout design for greenfield port Filyos

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering and Geosciences, section Hydraulic Engineering, specialisation Port & Waterways.

Thesis committee:

| | | |
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Cover images:
Left: Overview of Turkey and bordering coastal waters
Right: Bird eye view delta region Filyos in Turkey (Google Earth, 2009)

# PREFACE

The present report is the result of the project undertaken in order to obtain the degree of Master of Science at Delft University of Technology (DUT). This project comprises the layout design and the modelling of physical site conditions for the greenfield port Filyos in Turkey. In reality it has been carried out by a consortium of four companies. Engineering company Witteveen+Bos is part of this consortium and is responsible for the element of port masterplanning. This company offered me support to work on this thesis at the background of the project for which I'm very grateful.

Many disciplines are involved in port engineering, of which I came more and more aware during the thesis study. It had proven to be very challenging and informative to me, trying to link all disciplines in a transparent way. The variety in the composition of the committee was therefore welcome. I would like to thank the committee members for their feedback on the project; Prof.ir. H. Ligteringen, Ir. P. Quist, Ir. S.J. Ouwerkerk and Ir. F.A.M. Soons.

Furthermore, I would like to thank colleagues at Witteveen+Bos and my room mates at the graduation office of Hydraulic Engineering at DUT. Advisory and support at the university was also given by Ir. D.J.R. Walstra and by Dr.ir. J. van de Graaff, for which I've much appreciation.

And last but not least I would like to thank my family and close friends for their support during my time in Delft.

Loek Donders
Delft, June 2010

# ABSTRACT


*Introduction*

On a national level need has arisen for Turkey to realise a new large capacity gateway port. At the Black Sea coast in the province Zonguldak a flat area is available at the delta of the regional river Filyos. According to a previous feasibility study this location is considered optimal for the port. The extent of the captive area is promising. There is expected cargo transport demand from the metropolitan area of Ankara and of the planned local industry. Furthermore, the site conditions and possibility to connect with the hinterland are favourable at Filyos.

*Objective*

The objective for the thesis study is to develop a port layout that offers capacity for the forecasted throughput at adequate operational conditions. To guarantee that the requirements with respect to operational conditions are met, several engineering solutions are implemented in the design.

The operational conditions for merchant vessels depend to a large extent on the possibility to manoeuvre in the harbour and to load and unload at berth. These conditions are amongst others influenced by the climate of wind, waves and currents. Focus laid in this thesis study is on the wave climate in the harbour and at the berths. A well considered allocation, orientation and shape of the harbour entrance and berths is therefore essential.

The other focus is laid on the dry infrastructure. Sufficient space for storage and through transport of cargo is required. Furthermore, advisory is needed with respect to the superstructures and the use of human resources.

*Analysis*

In order to design the port layout a thorough analysis is carried out in the thesis. The various boundary conditions for the project are analysed and reported. Amongst others, an overview is provided of socio-economic developments, hinterland connections and forecasts of throughput & vessel sizes for various scenarios. Furthermore, physical conditions are analysed, which are primarily based on obtained survey data. Where information about boundary conditions lacked, starting points are used of which a separate overview is provided. For the main requirements of the project an overview is made, which completes the boundary condition analysis.

In order to develop the layouts, minimum component dimensions are required in combination with an overview of the preferred shape, orientation and location. For this purpose different design guidelines are followed. In order to derive required dimensions in time phasing of the project is chosen.

*Layout development and evaluation*

Three significantly different alternatives are considered in the project including phasing for the medium term (until 2020) and long term (until 2030). These layouts are evaluated on the basis of the following requirements: nautical accessibility and safety, loading and unloading ability at berth, through transport and storage ability, robustness and coast morphological impact. The best layout is selected for further refinement on basis of a qualitative Multi-Criteria Evaluation (MCE) and on an analysis of capital costs. Costs have turned out to be decisive in the selection of the best alternative.

*Refinement of layouts*

The most promising alternative of the previous step is refined with respect to the inner harbour configuration. Different terminal and berth positions and orientations are considered, resulting in two variants of the layout alternative. The layouts are given a quantitative value with the use of an MCE, which are based on model simulations and engineering judgement. A coast morphological model (UNIBEST CL+) and a wave model (SWAN) have been setup for this purpose. Both the resulting values and estimated capital costs of the different layout variants turned out to be close to each other. The layout with the highest ratio of value over cost is selected as best.

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# ABBREVIATIONS & DEFINITIONS

| | |
|---|---|
| B | Beam |
| CD | Chart datum |
| CFS | Container Freight Station |
| CPT | Cone Penetration Test |
| D | Draft |
| DWT | Dead Weight Tonnage |
| FEU | Forty feet Equivalent Unit container |
| GDP | Gross Domestic Product |
| HAT | Highest astronomical tide |
| ITRF 96 | International Terrestrial Reference Frame 1996 |
| IWT | Inland Water Transport |
| LAT | Lowest astronomical tide |
| LOA / L | Length Over All (m) |
| LBP | Length Between Perpendiculars (m) |
| LOLO | Lift-on / Lift-off container vessels |
| MCE | Multi-Criteria Evaluation |
| MHW | Mean tidal high-water level |
| MLW | Mean tidal low-water level |
| MW | Mean water level |
| TEU | Twenty feet Equivalent Unit container |
| WGS 84 | World Geodetic System 1984 |

| | |
|---|---|
| Berth | A space for a ship to dock or anchor. |
| Diffraction of waves | Bending of waves around the edge of an obstacle. |
| Fetch | Length of water surface over which the wind blows in generating waves. Together with wind velocity and duration, this determines wave height. |
| Harbour | Protected water area to provide safe and suitable accommodation for ships for loading and unloading of cargo. |
| Hindcasts | Simulation of the past wave climate on basis of corresponding wind data. |
| Port | Next to the harbour for transfer of cargo, it includes the approach channel and anchorage place. |
| Refraction of waves | The process by which the direction of incoming waves in shallow water is altered due to the contours of the seabed. |
| Superstructures | Port structures above the foundation, except from equipment. It comprises amongst others buildings, sheds and silos. |

# LIST OF SYMBOLS

**Port capacity**

| Symbol | Definition | Expression | *Unity (SI)* |
|---|---|---|---|
| **Queuing theory** | | | |
| $E_k$ | Erlang k distribution | - | - |
| M | Negative exponential distribution | - | - |
| u or ρ | Occupancy ratio, λ/μ | - | - |
| V | Contents of 1 TEU [i] container | $m^3$ | *$m^3$* |
| λ | Inter-arrival rate of ships | - / h | *$s^{-1}$* |
| μ | Service rate of ships | - / h | *$s^{-1}$* |
| **Other parameters** | | | |
| C | Annual throughput that passes the storage area | metric ton [ii] / yr | *kg* |
| $C_b$ | Annual berth productivity | - metric ton / yr<br>- container movements (TEU & FEU) / yr | *$kg * s^{-1}$* |
| $C_i$ | Annual number of TEU container movements that passes the storage area | TEU / yr | *$s^{-1}$* |
| F | Required area per TEU, inclusive equipment travelling lanes | $m^2$ / TEU | *$m^2$* |
| $F_1$ | Proportion gross / net surface, due to internal traffic lanes | - | - |
| $F_2$ | Bulking factor, due to cargo specific requirements | - | - |
| h | Average stacking height of cargo | m | *m* |
| $\bar{t_d}$ | Average dwell time of cargo | days | *s* |
| m | Average rate of occupation | - | - |
| n | Number of berths | - | - |
| O | Required area | $m^2$ | *$m^2$* |
| p | (Un)loading productivity per handling entity | metric ton / h | *$kg * s^{-1}$* |
| r | Average stacking height / nominal stacking height | - | - |
| $t_n$ | Number of operational hours per year | h / yr | - |
| ρ | Commodity density | ton / $m^3$ | *$kg * m^{-3}$* |

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[i] A TEU container has a content volume of 29 $m^3$
The outer dimensions of a TEU container are:
Length * height * width = 6.03 m (= 20 feet) * 2.44 m * 2.44 m = 35.9 $m^3$
An FEU container has the same dimensions, but is twice as long.

[ii] A metric ton is equal to exactly 1000 kg; in contrast to the British long ton and the American short ton.

**Hydraulic parameters**

| Symbol | Definition | Unity (SI) |
| --- | --- | --- |
| $c_w$ | Friction factor | - |
| h | Water depth | m |
| g | Gravitational acceleration constant [iii] | $m * s^{-2}$ |
| F | Fetch length | m |
| $H_{S,\ 1/3,\ m0}$ | Significant wave height (average of one third highest waves), determined from resp. visual observations and the energy spectrum. | m |
| $L_{,0}$ | Wave length, subscript: deep water | s |
| k | Wave number (= 2π / L) | $m^{-1}$ |
| $T_p$ | Peak wave period, from visual observations | s |
| $T_{1/3}$ | Peak wave period, from wave spectrum | s |
| $u_{10}$ | Wind velocity, measured 10 m above water surface | $m * s^{-1}$ |
| $\gamma_{br}$ | Breaker index, ratio of corresponding significant wave height over depth | - |
| φ | Approach angle to the coast, expressed in degrees (°) | rad |
| ρ | Density | $kg * m^{-3}$ |

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[iii] The gravitational constant is equal to 9.81 $m * s^{-2}$

# 1 INTRODUCTION

This chapter describes the background of the project initiative and the resulting objective for this thesis study. Subsequently, it provides a description of the typical time horizons for port planning. Furthermore an overview of the master planning process is given, which is followed to carry out the project; see § 1.3.4.

## 1.1 Background

In the preceding years the growth of maritime transport in relation to the Turkish Republic has risen. The traffic demand has therefore exceeded the capacity of many ports. In this paragraph a description is given of the current problems with corresponding arising opportunities. The resulting project initiative is presented at the end.

### *1.1.1 Current situation*

In this sub-paragraph the relevant problems are described that are currently met with transport of cargo.

**Congestion at Istanbul**

At the moment Istanbul serves as a gateway for a large part of the maritime freight for Central Anatolia, including the industrial regions close to Ankara (Figure 1-1). This contributes to a large extent to port and hinterland congestion at Istanbul. Expansion of the existing port facilities and improvement of hinterland connection to the Central Anatolian Region appears however hard to realise according to NEA (2009).


*Figure 1-1 Map of Turkey with referred locations*

**Inefficient transport route**

A lot of cargo originated from and destined to Central Anatolia via Istanbul is related to countries bordering the Black Sea. Mainly Russia and Ukraine are important trade partners. At the moment the cargo flow between Russia and Central Anatolia takes place via Istanbul to Ankara with a road and railway connection, serving a distance of 430 km.

**Congestion at Bosporus Strait**

Next to congestion problems at Istanbul, the Bosporus Strait (Figure 1-1) also faces difficulties with maritime traffic. This traffic is induced by trade to and from the Mediterranean Sea in relation with countries bordering the Black Sea.

### *1.1.2 Opportunities*

From the above described situation opportunities arise, which are presented in this sub-paragraph.

**New gateway**

Because of the described problems with congestion and the inefficient transport route, the realisation of a new gateway port eastward of Istanbul, is preferred. The province Zonguldak plans to have a lot of new industrial developments - amongst others power generation activities - and provides a strategic location. The red circle in Figure 1-2 indicates this province. With a new facility at this region the main cargo flow will result as indicated in the figure.

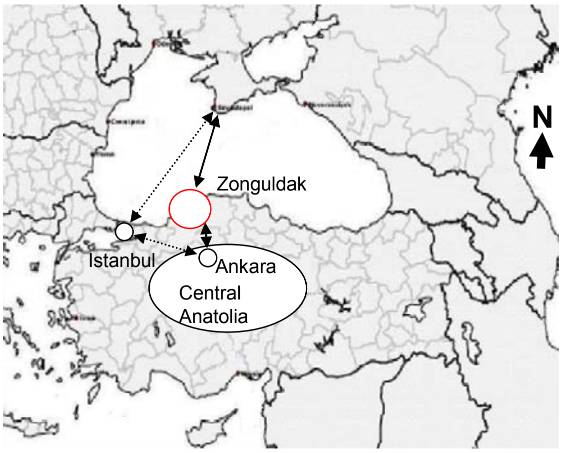



*Figure 1-2 New gateway*

**Land bridge**

The increasing congestion at the Bosporus Strait is also an incentive to search for new opportunities. A land bridge function with the northern coast seems attractive. At least, under the condition that short transit times are possible. At the south-east of Turkey the port Mersin is situated, that has sufficient capacity to evolve as a hub port in the future. In Figure 1-3 a possible land bridge is indicated with an arrow, from the above mentioned gateway location to Mersin. Especially the traffic with large ships originating from other continents could be alleviated by using a land bridge. For small ships that come from nearby countries at the Mediterranean Sea, it seems more attractive to sail directly to the Black Sea ports.

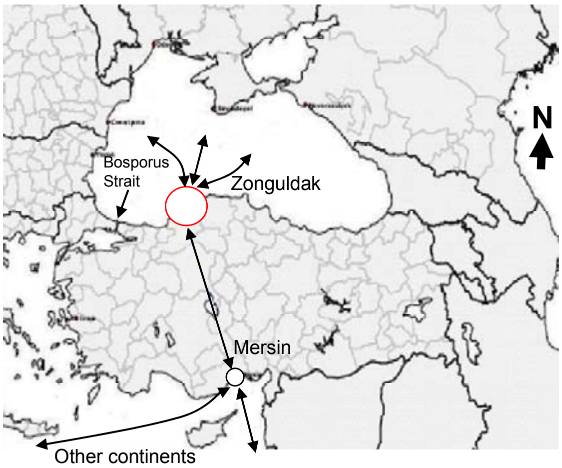



*Figure 1-3 Land bridge*

### 1.1.3 Project initiative

As can be concluded from the previous sub-paragraph, the advantages of creating a new port facility at the province Zonguldak are worthwhile. Therefore the Turkish government decided to carry out a feasibility study for the port in this region.

**Feasibility study**

In the feasibility study several existing ports in the region were examined on expansion possibilities. Furthermore, it was considered to realise a new port at the river delta Filyos, of which more information is presented in the next section.
Usually a river delta is not the most preferred location because of currents, morphological developments and possible flooding. At this area however there is an unlimited coastal area in contradiction to other locations along the Black Sea shore, which are bounded by continuous steep mountains. Due to spatial limitations of the regional ports, Filyos is considered the most attractive location according to the study.

**Filyos region**

An overview of the deltaic environment of Filyos is presented in Figure 1-4. The river Filyos deposited a flat land that is surrounded by mountains in a range of 4 km. At the west side of the river the small fishery port Filyos is situated. Similar to the other regional ports, expansion up to the required project scale is not possible at that location.

With a red rectangle the destination area for the port is roughly indicated in Figure 1-4 and elaborated in the more detailed drawing. Except for the land geometry, the drawing contains the contour lines of the sea bottom, which are obtained from Witteveen+Bos (2009). Close to the indicated project area a deep trough is situated, of which the boundary is indicated in the figure with dash dotted lines. This line corresponds to a depth of 20 m below Lowest Astronomical Tide (LAT). Southerly and easterly boundaries for the port are also indicated. These boundaries are based on a more detailed map which is provided in Figure 4-1.

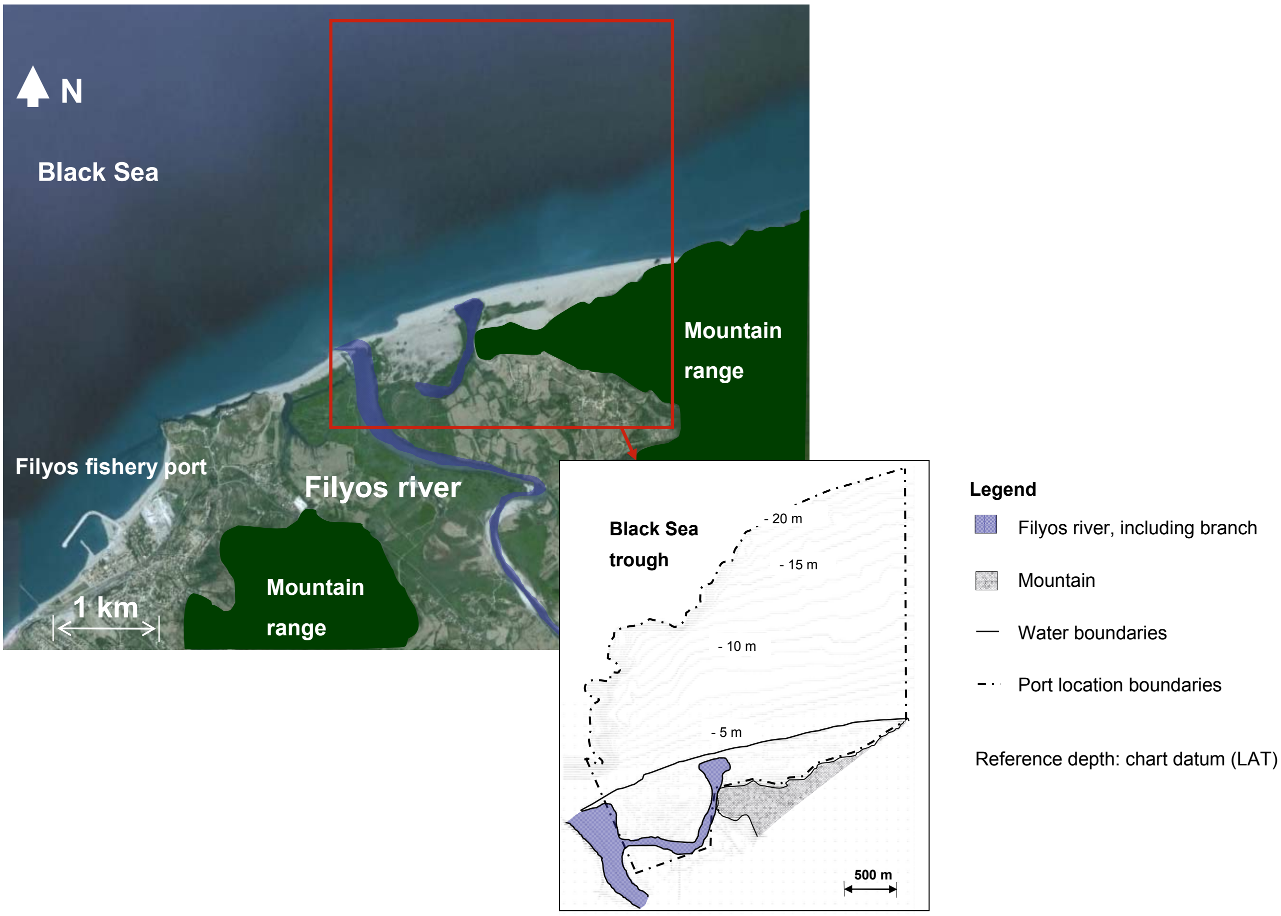



*Figure 1-4 Port location boundaries (Ref. [1])*

## 1.2 Objective

A design of a port layout is needed, which is able to offer capacity for the forecasted cargo throughput and shipping traffic. This is the minimum requirement; in order to provide an attractive service for the clients, adequate conditions are essential.

The offered service depends to a large extent on the efficiency of cargo handling at the terminal. Therefore the wet and dry infrastructure, superstructures, equipment and human resources at the terminal need to be configured well. Focus in this thesis is laid on the infrastructure, offering space for the ships, handling of cargo and for storage. For the equipment and human resources advisement will be done.

The configuration of the wet infrastructure influences the conditions during nautical operations and (un)loading at berth. In these cases there is vulnerability to waves, wind and currents. To improve the circumstances in this respect, there is need to implement effective engineering solutions in the layout of the port.

Summarising, the objective of the thesis study can be stated as follows:
**“Design of a port layout with engineering solutions, that offers capacity for the forecasted cargo throughput and shipping traffic at adequate operational conditions.”**

The referred cargo throughput forecast is presented in § 2.2. In § 2.3 an overview is provided of the waves, wind and currents at Filyos.

## 1.3 Port planning

### *1.3.1 Introduction*

To meet the above formulated objective, a port plan is required with layout development that fulfils the requirements on the short, medium and long term. As previously described, the project implementation on a national and regional scale has already been studied. The local and individual port planning is regarded in this thesis. It forms an essential element for the port authority or operator to be able to anticipate on future developments. It also ascertains that the infrastructure functions well. Furthermore, it forms a necessary document to obtain finance and all legal permits.

In the next sub-paragraph the required components for the port are provided. It is followed by a description of different planning time horizons. To conclude, the planning process for the master plan is provided, which will be followed in this thesis.

### 1.3.2 Layout components

The port layout can be split into different components. A distinction is therefore made between primary and secondary components, which are described below.

The primary components of the port are:

- Wet & dry infrastructure;
- Superstructure;
- Equipment;
- Human resources.

These components can be decomposed into the, more touchable, secondary components. An overview of these components is given in Table 1-1. The sequence is formed by the activities that take place in the port. The first activity starts from arriving and leaving of ships and arriving and leaving of cargo from and to the hinterland. Components that cannot be placed in a specific part of this transport chain are mentioned at the bottom of the table.

*Table 1-1 Primary and secondary layout components*

| Activity | Wet & dry infrastructure | Superstructure | Equipment | Human resources |
|---|---|---|---|---|
| Call at port | | Pilotage buildings | | Pilot / captain |
| Wait | Anchorage area | | | |
| Approach | Approach channel & breakwaters | | Tug boats | Captain |
| Manoeuvre | Harbour basin, including turning circle & berthing area | | ,, | ,, |
| Berth | Berths | | Terminal equipment (various) | Stevedores |
| Loading / unloading & transport | Apron areas, inner lanes & transfer areas | | ,, | ,, |
| Store | Storage areas | Sheds, CFS, warehouse, silos | ,, | ,, |
| Weighing, loading and unloading at hinterland transport module | Train marshalling yard | Container gates | ,, | ,, |
| Transport to the hinterland | Hinterland connections | | | |
| Parking | Parking area | | | |
| Repair & maintenance | | Workshops | | |
| Administration | | Offices | | Administrators |

### 1.3.3 Time horizons

Three different terms of planning are normally considered in port planning; namely short-, medium- and long-term. The corresponding time horizons that are usual for these terms are presented in Table 1-2.

*Table 1-2 Characteristic time horizons of planning*

| Term period | Time horizon (years) | Characteristic |
|---|---|---|
| Long | 20-30 | Master plan |
| Medium | 5-10 | First phase of a master plan |
| Short | 1-2 | Minor layout changes |

The indicated master plan forms a blueprint for future development, reserving space where it may be needed in the future, taking account of the regulatory and environmental requirements and creating efficient and economic port operation.

**Interrelation & update**

In the ideal situation the long-, medium- and short-term plans are interrelated. The master plan provides the framework for the medium-term plan, while this in its turn forms the basis for the short-term projects. An update of the master plan is preferred at intervals of about 5-10 years, during which the actual throughputs are compared with the forecasted. The forecasts will then be adjusted and accordingly the original phasing will be reviewed and updated. The master plan should therefore be flexible to follow fluctuations in economic development and changes in the transport patterns.

### 1.3.4 Master planning process

In this sub-paragraph an overview is provided of the planning steps that are followed in the project. To design the port layout the project is divided into 3 steps. The first step comprises the total project analysis presented in Figure 1-5 on the next page. In the second step different port layout alternatives are generated, which are evaluated to select the most promising. Then, in the third step, refinement of the selected layout takes place. Below a more detailed description of these different steps is provided.

**Step I: Analysis**

The first step consists of collecting and analysing all relevant project information. This has resulted in the list of the boundary conditions, the programme of requirements and starting points of the project. Herewith, the port component dimensions are determined as input for the later step. A description is provided below.

*Boundary conditions (Ch. 2)*

The boundary conditions are presented in chapter 2. Paragraph 1 consists of the socio-economic and infrastructural developments. It provides an own summary of the report on this subject by NEA (2009), which is under development. It describes the current and future situation for Filyos from a national to a regional and urban level. Three different development scenarios are presented of which one is used in the further planning process.

Paragraph 2 provides the cargo throughput and shipping forecast, which result from the analysis of the previous chapter. These forecasts are also carried out by NEA (2009), and are therefore considered as fixed project boundaries. It provides the information to design the wet and dry infrastructure and to plan proper landside operations.

In paragraph 3 the physical conditions of the port location are presented.

*Programme of requirements (Ch. 3)*

Requirements that are fundamental for the design of the port layout are presented in this chapter.

*Starting points (Ch.4)*

In this chapter important starting points are provided, which are required for the design.

*Component dimensions (Ch. 5)*

In Ch. 6 two different building phases for implementation of the project are chosen. For these phases the **minimum** component dimensions (in $m^1$ and $m^2$) are determined of the components (see Table 1-1).

**Step II: Layout development & selection (Ch. 6)**

Three different layout alternatives are developed to come to a good solution. Afterwards these layouts are evaluated with the use of a qualitative Multi-Criteria Evaluation (MCE). Furthermore estimation is done of capital costs of the wet infrastructure, including hydraulic structures, and of the reclamation of land for the terminals. On basis hereof the most promising alternative is selected for further refinement.

The following criteria are taken into account in the MCE:

- Nautical accessibility
- Nautical safety
- Loading & unloading ability at berth
- Through transport and storage ability
- Robustness
- Coast morphological impact

**Step III: Layout refinement & selection (Ch. 6)**

The most promising alternative of the previous step is refined with respect to the harbour basin layout. Different terminal and berth configurations are considered, resulting in three layout variants. A quantitative MCE is carried out in this step, as well as estimation of capital costs. The best layout is selected on basis of the highest value over cost ratio.

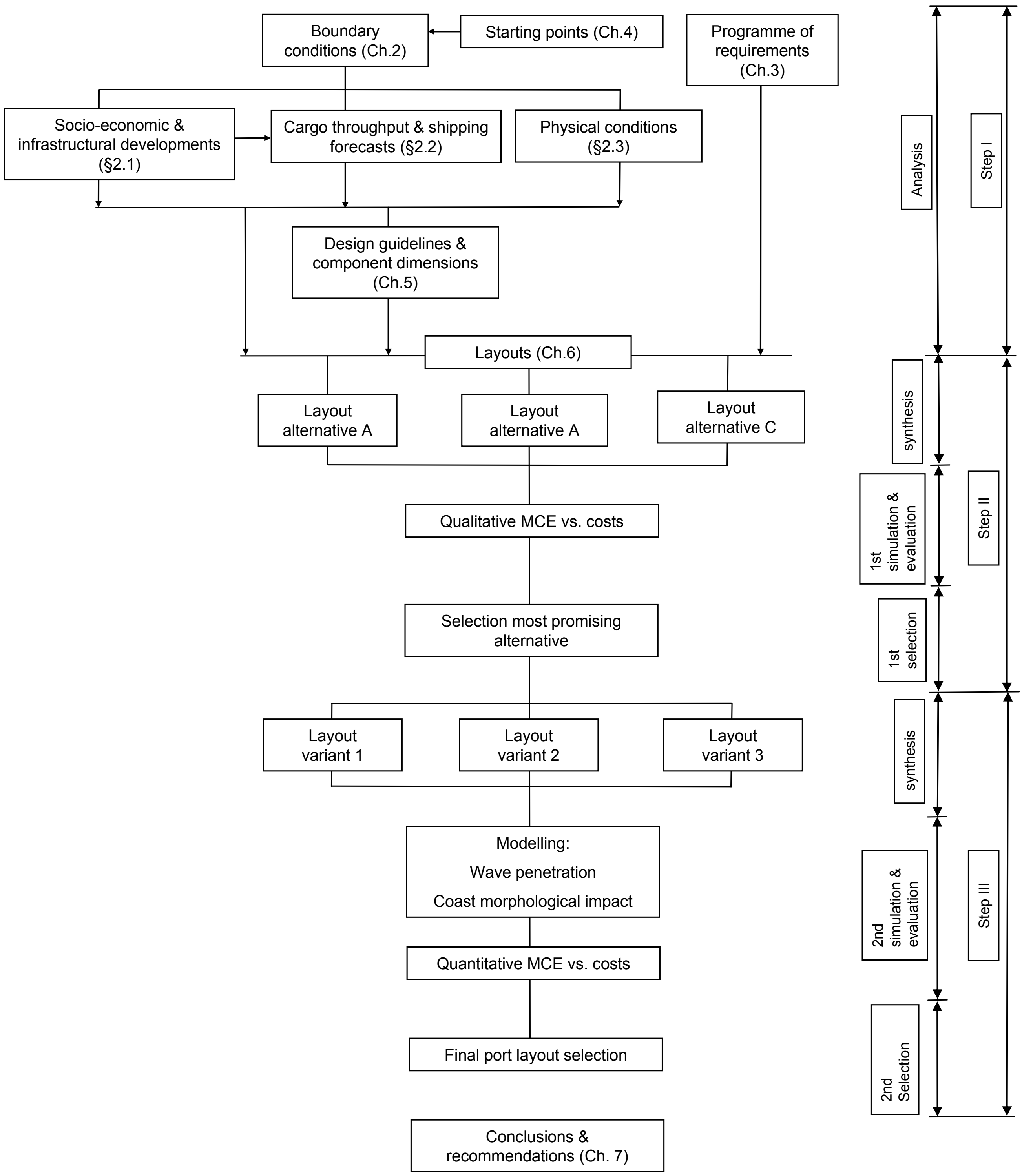



*Figure 1-5 Master planning process & report structure*

# 2 BOUNDARY CONDITIONS

## 2.1 Socio-economic & infrastructural developments

In this paragraph the socio-economic and infrastructural developments are described that effect Filyos. It provides the fundament for the throughput forecast study for Filyos, which is presented in the next paragraph. The information has been derived from an analysis which is carried out by NEA (2009). A description of its study approach is provided in the first sub-paragraph.

### *2.1.1 Approach & scenarios*

The approach of NEA and the considered development scenarios of the forecast study are described below.

*Approach*

The approach in the study is on a strategic level, considering the background changes in Turkish land usage, socio-economic factors and industrial development. With this information a description could be made of the potential evolution of maritime traffic, with respect to the Turkey's Black Sea coast. This information is combined with interviews with stakeholders and supply side market research (transport networks and costs) to identify flows for which Filyos will be competitive.

*Scenarios*

In the study three different scenarios are considered for the case that a port is being realised (see Table 2-1). Distinction is made between low and middle economic development; on a global, national and regional scale. Moreover, investments in the region and in cooperating countries bordering the Black Sea are taken into account. A distinction is therefore made between certain and uncertain investments. Finally, sensitivity parameters are used for the development. For instance the reference scenario (REF) is coupled to a middle economic development, certain investments and high sensitivity.

*Table 2-1 Selected scenario as function of development, investment and sensitivity (NEA, 2009)*

| **Economic development** | Certain investments + middle sensitivity | Certain & uncertain investments + high sensitivity |
|---|---|---|
| Middle | **Reference scenario (REF)** | High scenario (HS) |
| Low | Low scenario (LS) | - |

Selection

For this project the **reference scenario** will be taken into account. This scenario, indicated with a bold font in Table 2-1, is based on the middle economic development in combination with certain investments and middle sensitivity parameters. This scenario is rather conservative in comparison with the high scenario. However, due to the uncertain economic developments - described in the next sub-paragraph - it seems a wise choice.

### 2.1.2 Economic developments

In this section the economic developments are presented that are fundamental for middle and low economic development scenarios. To start, information is given of the historical Gross Domestic Product (GDP) development in Turkey. This is followed by a description of energy availability and the current oil price, which both have an important influence on the economic production rate and demand for maritime transport. Furthermore the prospected national economic developments are presented for the low and normative middle development.

**National economic development & energy resources**

*Historical economic trends in Turkey*

In Table 2-2 the development of the Turkish GDP in the years since 2002 is shown. In the period between 2002 and 2007 an average annual growth of 6.9% is observed. In mid 2008 the consequences of the economic crisis become visible in the development of the Turkish GDP. NEA (2009) did not give information about the results of the last quarter of 2008, because the information was not available yet. According to Ref. [4] this last quarter has shown a GDP decline of 7.1% in comparison with this quarter in 2007. With absolute numbers the total annual growth for 2008 can be calculated. Regarding the percentages, it can be stated that a very low growth of GDP results herewith. For the year 2009 the growth is also expected to be low.

*Table 2-2 Historical GDP development Turkey (NEA, 2009)*

| Year | GDP growth (% annual) |
|---|---|
| 2002 | 7.8 |
| 2003 | 5.9 |
| 2004 | 8.9 |
| 2005 | 7.4 |
| 2006 | 6.9 |
| 2007 | 4.6 |
| 2008 1st Q | 6.7 |
| 2008 2nd Q | 2.3 |
| 2008 3th Q | 0.5 |

*Energy availability and oil price*

In the latest version of the World Energy Outlook of the International Energy Agency (IEA) it is stated that it is likely that in the coming decade there will be a gap occurring between the demand and maximum oil supply (peak oil).

A solution for this problem is to shift to alternative sources of energy. However, this is a very time consuming process requiring enormous investments. Currently the oil prices are relatively low due to a lower demand for oil due to the economic crisis. After an economic revival the prices could go up to levels observed in the first half of 2008 (160 USD). This could imply a limitation of economic growth. At this stage there are however many uncertainties around this issue and no clear predictions can be made on the consequences. Moreover, technological replacements will take place to a certain extent within the forecasting time period. Therefore a mild economic growth limitation is assumed with a higher oil price of 100 USD up to 2015 and rising to 120 USD in 2030.

Influence on Filyos

In case of higher oil prices the alternatives like for instance electricity, and therefore also coal, will become even more important. Therefore this will have a positive effect on Filyos with the foreseen power plants. So even if there is a lower demand for energy because of a potential economic downturn the demand for electricity and coal is not expected to go down. Furthermore, it can be expected that transport will become more expensive and therefore will be organised more efficiently. Container transport by sea is an efficient solution that will have an increasing importance for international transport. Furthermore, it can be expected that the port related transport distance over land will be minimised. This implies that Filyos will have an increasing benefit compared to the ports in the Marmara Sea for transport to the Ankara area.


*Figure 2-1 Position of Marmara Sea with respect to Ankara, compared to Filyos*

*Future economic development*

The future economic situation for Turkey is uncertain. Integration with the EU still needs to be reached. Furthermore, the effects of the current economic crisis, that started mid 2008, are very difficult to predict. Trust in the financial markets and the economy is still declining. After a period of stabilisation it will be easier for experts to come up with more reliable and stable predictions.

General opinions are that a recovery can be expected at the end of 2010. More negative opinions say that this will take up to 2012, which would be in line with recovery periods of previous crises. For instance the economic crisis in Japan. For this reason these two situations are taken as basis in the forecast report, presented as respectively the middle and low economic development scenario.

In the case of middle economic development, relatively high (compared with the lower economic development scenario) levels of economic integration in the Black Sea region are assumed. Moreover, a relatively high increase of economic integration is predicted between the EU and Turkey. In case of low economic development these processes are assumed to take longer.

From the year 2010 an increase of GDP is prospected, growing to a constant rate of 6.0% from 2014 until 2030 for the middle scenario (see Table 2-3). This rate is in line with the previously presented historical growth of GDP. To make a comparison also the low economic development scenario is visible.

*Table 2-3 Scenarios GDP development Turkey 2009 - 2030 (NEA, 2009)*

| Year / GDP development | Middle (%) | Low (%) |
|---|---|---|
| 2009 | **-1.5** | -2.0 |
| 2010 | **0.0** | -2.0 |
| 2011 | **2.0** | 0.0 |
| 2012 | **3.0** | 0.0 |
| 2013 | **4.0** | 2.0 |
| 2014 | **6.0** | 3.0 |
| 2015 | **6.0** | 4.0 |
| 2015 - 2020 | **6.0** | 4.7 |
| 2020 - 2030 | **6.0** | 4.7 |

**Investments that effect Filyos**

This section provides information of investments, which will have an effect on Filyos.

*Current industry & certain investments*

In this sub-section the currently present industry and the certain investments are described. The criterion for a certain investment is that it is officially agreed and clear. These investments are taken into account for the reference scenario.

Power plants

Several different industries are present in the region of Province Zonguldak. The most important are the thermal power generation activities which need import of coal. One power plant is currently present in the region and a second one is under construction at Catalagzi, which place is presented in Figure 2-2.

A third thermal power plant is planned to be located at Filyos at the industrial area according to NEA (2009). Its initial capacity is planned as 300 megawatts, which can be increased to 600 megawatts in 5 years time at least. It depends mainly on imported coal from Ukraine and Russia. The power plant requires 50 hectares of space according to JICA (1991). As a starting point, this amount of space is still required in the future.

Mining

Also coal mining industry and steel factories are present in the region. The firm Kardemir has a huge steel factory positioned in the city Karabük, situated about 65 km southeast of Filyos (see Figure 2-3).

LOLO

Investments in LOLO ships by countries bordering the Black Sea will also have effect on Filyos. A limited expansion of the Black Sea container market is however expected due to shortage of capacity at partner country ports, i.e. at Ukraine and Russia, which are indicated in Figure 1-1. There is strong competition from Marmara Sea ports, and from newly privatised terminals.

*Uncertain investments*

There are some uncertain investments which would have an effect on Filyos. These are **not** taken into account in the reference scenario, but only in the high scenario. For completeness they are however presented in Table 2-4. In contradiction to the stated low container market growth under certain investments, high growth is considered for this case in the report of NEA (2009).

*Table 2-4 Uncertain investments, only taken into account in high scenario (NEA, 2009)*

| | |
|---|---|
| Power plant at city Amasra (Figure 2-2) | Not decided |
| Steel factory near the port | Idea based on planned production growth Turkey |
| Tax free zone near the port | There is an officially defined potential free zone location at the Filyos area. The boundaries of free zone were previously determined and published at the Official Gazette on 20th September 2008 (**see map**). Investments not arranged yet. |
| Coordinated LOLO investments in Black Sea countries | Co-ordinated investments in Turkey, Romania, Ukraine, Russia, and Georgia. Increased terminal capacity, vessel deployment, and changes in market practices. Higher levels of containerised cargo and supporting intermodal transport facilities. Rapid growth in Black Sea container transport, and reduction in RORO market share. Introduction of feeders serving immediate hinterland |

### 2.1.3 Regional ports & infrastructure

**Regional ports**

Currently port activity in the vicinity of Filyos is specialised in heavy industry. Ports situated near Filyos within a coastal stretch of 100 km are indicated in Figure 2-2. Below a short description per port is provided.

*Port of Eregli*

At the west of Filyos, a bulk cargo port is situated at Eregli. The port has two (un)loading docks, of which the newest one has a depth of 20 meters, where vessels of size 200,000 DWT are able to dock. The port has Ro-Ro and ferry train quays in international standards. But the Ro-Ro quay is not used effectively; this type of transport has been shifted to Zonguldak port, which is subsequently described. The port is specialised in handling raw materials and basic manufactured goods, which are related to the steel factory (NEA, 2009) Erdemir. Therefore the port is also referred to as Port of Erdemir.

*Zonguldak*

At the city Zonguldak a RORO & general cargo port is situated. It was established in 1950 in order to facilitate energy supply and demand, such as providing export of locally mined coal to other Turkish destinations. Is also serves for the import of logs for mines.
It is estimated that there are coal reserves in the area for the next 100 years. One of the port's major clients for the import of coal is the iron and steel factory Kardemir at Karabük, which is presented in Figure 2-3. This figure also shows the direct rail connection with Filyos. A disadvantage for the port is the limited space, which makes considerable future expansion not possible.

*Catalagzi / Muslu*

Close to Catalagzi the small region Muslu is situated, where currently a port is under construction. This port will serve the second thermal power plant at Catalagzi, which is being built in the region. This dedicated port will have 3 deep water berths for the import of coal, which will take place from Ukraine and Russia. Vessels with a size of 170,000 DWT will be able to dock (NEA, 2009).

*Bartin*

Bartin is a new port which yearly facilitates approximately 500-600 ships, handling 1 million tons of commodities. The capacity can reach up to 3 million tons (NEA, 2009). The port is however constrained by limited ship draught. Moreover, it does not have a railway connection yet. It can be stated, that most of the cargo handled in the region moves relatively short distances inland. Due to the direct rail connection that the Filyos port will have with amongst others Kardemir, it is likely that the current shipping of iron ore via Bartin Port will be shifted to Filyos Port.

*Amasra*

As described in the sub-section on uncertain investments, a fourth thermal power plant is considered at the city Amasra. A private company has initiated this idea. There already exists a created harbour for tourist boats, which could be extended. The region however has a touristic character at the moment; therefore there is considerable objection to this idea.

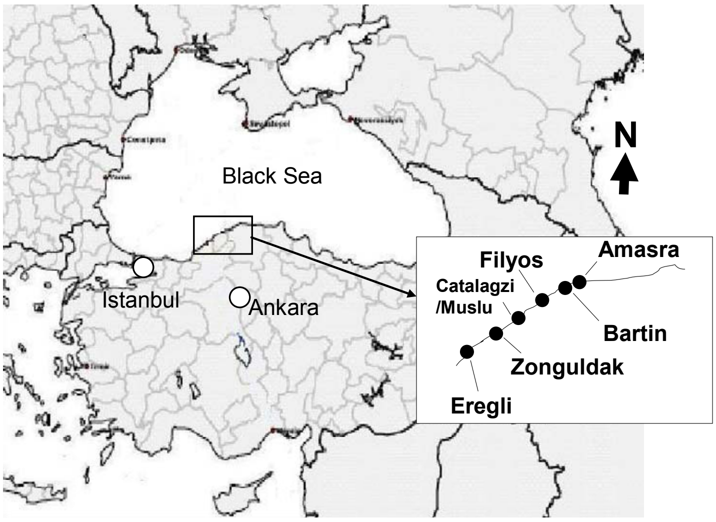



*Figure 2-2 Described regional ports*

**Hinterland connections**

Connections to the hinterland and especially the region of Ankara will be very important for the port of Filyos. The large stretch of flat land at the project location provides opportunities for good infrastructure and economic activities. At this moment there is no decent connection to the basic infrastructure net. According to NEA (2009) connection is possible for both rail and road, at a distance of about 2 km south of the greenfield area and at the east side of the river Filyos. The connection possibilities that follow from this point are described below.

*Rail*

Once connected to the network, there will be a connection to the railway line, which is presented in Figure 2-3. This map is made in 1991 and in the mean time no considerable adjustments to the alignment of the rail are made. The connection to Irmak, situated at an approximate distance of 60 km east of Ankara, is 415 km long. From Irmak there is a connection to Ankara and the rest of Turkey. The indicated city Karabük is important because of the present steel factory, which imports dry bulk via Filyos (see § 2.2.2).

In the other direction there is a connection to the city Zonguldak (Figure 2-3). The current capacity of the rail line between Zonguldak and Irmak is about 15 to 20 trains per day. The average speed of the line is about 30 km/h according to NEA (2009).

Planned upgrading

Upgrading will be carried out with respect to electrification. The speed and capacity of the rail will however not be upgraded. Therefore it is expected that, even in the future, no hinterland transport of general cargo and containers will take place via rail. For dry bulk this option will however be used for transportation of hard coal, steel products and iron ore to and from the steel factory Kardemir at Karabük, which is indicated in Figure 2-3.


*Figure 2-3 Regional railway connection to Ankara and the rest of Turkey (JICA, 1991)*

*Road*

Filyos has a road way connection to Zonguldak and Ankara. It takes about 3.5 hours to reach Ankara by road. The direct coastal road between Filyos and Zonguldak is very poor and maximum speeds are 30 km/h.

*Waterway*

The nearby river Filyos is meandering heavily. Due to narrow profiles and rapids at the curvatures navigation is difficult. Therefore it is not suitable for ship traffic at the moment. Canalisation of the river is being considered but will however be a costly operation (NEA, 2009) Furthermore, there are clear plans to regulate the river by hydroelectric dams, which will hinder the waterway function. More information about the Filyos River is presented in § 2.3.4.

## 2.2 Cargo throughput & shipping forecasts

This paragraph provides the results of the preliminary forecast of cargo throughput which is made by NEA (2009). It is based on the developments that are described in the previous paragraph.
Also future capacities of ships are forecasted, which are based on the existing fleet. With this information different phases for the project realisation are selected.

### *2.2.1 Cargo throughput*

The study presents forecasts until the year 2030 for the three previously described scenarios. This provides a solid basis to develop a master plan, which needs to have a scope of 20 years at minimum for western country standards.
In the first section a summary is provided of different scenarios that result from the expected corresponding developments. In the second section the resulting forecasts are presented.

**Quantified scenario elements Filyos**

The influences of the described developments in the previous paragraph are included in scenario elements that are relevant for Filyos. The share of these elements is presented in Table 2-5. A description of the elements is provided afterwards. The forecast study does not present an indication yet of the low scenario for the considered regional economic development and land bridge function.

*Table 2-5 Filyos scenario elements by forecast year (NEA, 2009)*

| | **2015** | **2020** | **2025** | **2030** |
|---|---|---|---|---|
| Containerised general cargo / LOLO * | | | | |
| LS | 10% | 17% | 30% | 50% |
| REF | **10%** | **17%** | **30%** | **50%** |
| HS | 20% | 35% | 50% | 50% |
| Regional economic development due to Filyos * | | | | |
| REF | **0%** | **3%** | **8%** | **10%** |
| HS | 0% | 5% | 12% | 20% |
| Land bridge function ** | | | | |
| REF | **0%** | **2%** | **5%** | **5%** |
| HS | 0% | 4% | 7% | 10% |

* percentage with respect to throughput tonnages

** percentage with respect to captive Black Sea flows

*Containerisation*

The containerisation relates to the certain and uncertain investments presented in § 2.1.1. In the **reference scenario** the normal investments on LOLO are assumed in the region. In the high scenario, the high coordinated LOLO investments are made by the Black Sea countries. In the latter case the containerisation is assumed to be catching up faster due to global tendencies. Also the starting level at opening of the port is assumed to be higher.

*Regional economic development*

The economic development in the region is not assumed to be influenced by the port immediately in the beginning. Different levels of additional growth due to industries are assumed for the subsequent periods.

*Land bridge*

Also for the land bridge function it is assumed in the report that it will not immediately start at the opening of the port. A gradual evolvement of the port is expected. Focussed is on the captive countries in the Black Sea and the percentage of shipping lines that wants Mersin as hub port.

**Throughput results**

In this section the results for all three scenarios are presented. An overview is provided of the tonnages per cargo type and per commodity until 2030. It must be realised that this forecast is rough on the long term. Especially in the container market port development is very rapid and shipping lines may shift large volumes from one port to another.
It needs to be stated that liquid bulk has been excluded from the potential, since other ports on the Black Sea coast can also fulfil this function. And because more benefit can be achieved from other types of cargo in Filyos.

*Throughput per cargo type*

Three different cargo types are expected to be handled at the port, namely: dry bulk, general cargo and containers. In Table 2-6 the throughput results are presented per cargo type until 2030. The amounts represent both import and export. The visible containerisation of general cargo corresponds to the percentages as previously provided in Table 2-5.

*Table 2-6 Forecast of annual throughput per cargo type by forecast year (x 1,000 metric tons) by NEA (2009)*

| **Cargo type** | **2015** | **2020** | **2025** | **2030** |
|---|---|---|---|---|
| Dry bulk | | | | |
| LS | 3,841 | 3,988 | 4,330 | 4,648 |
| REF | 3,912 | 4,167 | 4,635 | 5,101 |
| HS | 3,912 | 6,289 | 6,813 | 7,397 |
| General cargo, **incl.** containers | | | | |
| LS | 1,598 | 2,334 | 4,200 | 5,201 |
| REF | 1,747 | 2,685 | 4,737 | 6,010 |
| HS | 1,747 | 4,851 | 7,134 | 10,102 |
| Containerised general cargo | | | | |
| LS | 160 | 397 | 1,260 | 2,601 |
| REF | 175 | 456 | 1,421 | 3,005 |
| HS | 349 | 1,698 | 3,567 | 5,051 |
| Total | | | | |
| LS | 5,439 | 6,322 | 8,530 | 9,849 |
| REF | 5,659 | 6,852 | 9,372 | 11,110 |
| HS | 5,659 | 11,140 | 13,947 | 17,499 |

To give a better overview, the annual total volumes per forecast scenario are presented in Figure 2-4.

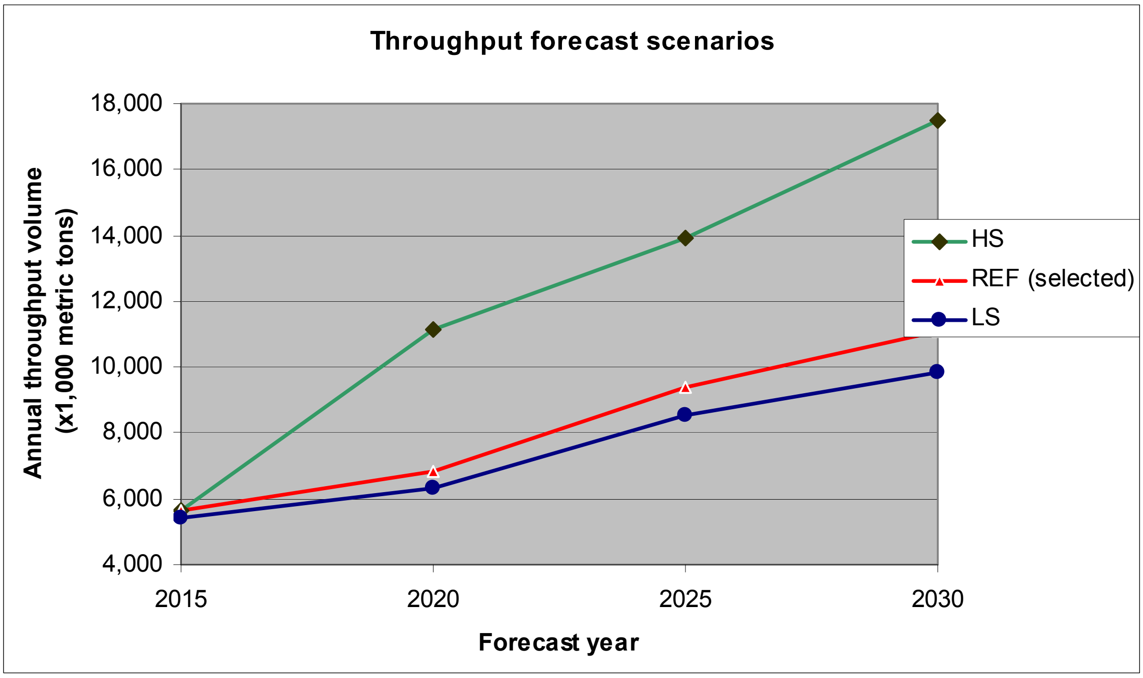



*Figure 2-4 Throughput forecast scenarios until the year 2030*

Notes

As visible from the table a slow start is expected just after opening of the port, except for the scenario HS. General cargo volumes will grow fast after 2020 or all scenarios. Beginning at about half the volume of dry bulk, the share of general cargo volume will rise above dry bulk.

Containers

The above presented table leads to the total number of handled TEU containers as provided in Table 2-7. In these amounts also empty containers are included. Therefore the tonnages per moved TEU are considerably low; for 2015 and 2030 respectively: 6.7 ton / TEU and 8.1 ton / TEU.

*Table 2-7 Reference scenario forecast of annual container throughput by forecast year by NEA (2009)* ***(x 1,000 TEU's)***

| Cargo type | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Containers | 26 | 62 | 176 | 369 |

Furthermore, FEU containers are being handled which are included in the presented amounts. One FEU is equal to 2 TEU. According to the report, the expected ratio of FEU:TEU amounts to 2:1.

*Throughput per commodity for reference scenario*

In Table 2-8 the cargo throughput per commodity and the corresponding amount of import and export are specified. The overview is provided for the years 2020 and 2030. As appears in the selected phasing (see § 5.1), the throughput demand for these years is selected for dimensioning the port.

*Table 2-8 Reference scenario forecast of annual throughput per commodity by forecast year* ***(x 1,000 metric tons)*** *by NEA (2009)*

| Cargo type | Commodity | 2020 import | 2020 export | 2030 import | 2030 export |
|---|---|---|---|---|---|
| Dry bulk | Iron ore | 60 | 0 | 60 | 0 |
| | Coal | 3,144 | 0 | 3,144 | 0 |
| | Sand & gravel | 114 | 421 | 213 | 935 |
| | Fertilizers | 425 | 3 | 742 | 6 |
| **Subtotal** | | **3,744** | **424** | **4,159** | **941** |
| General cargo / Containers | Metal products | 162 | 98 | 162 | 98 |
| *2020: 83% / 17 %* | Agricultural products | 137 | 46 | 240 | 88 |
| *2030: 50% / 50 %* | Food products | 95 | 11 | 170 | 23 |
| | Chemicals | 266 | 173 | 834 | 535 |
| | Machinery & other | 990 | 707 | 1,911 | 1,948 |
| **Subtotal** | | **1,650** | **1,034** | **3,318** | **2,692** |
| **Total import & export** | | **5,394** | **1,458** | **7,477** | **3,633** |
| **Total in 2020 & 2030** | | | **6,852** | | **11,110** |

Notes:

- Cargo tonnages transported in containers are presented under general cargo. An exact forecast of the tonnages per commodity handled in containers cannot be given at the moment. As a starting point, an even distribution of the commodities in containers is assumed.
- In the forecasts of all 4 years (see Table 2-6), of which 2 are presented above, a significant increase of export is visible from the beginning in 2015 until 2030; respectively 15% and

33% of total throughput. This tendency is however still visible in the table, with a percentage of 21% in 2020.

- Dry bulk cargo mainly consists of the commodity coal, which will be transported to the dedicated power plant. There will also be hard coal incoming in Filyos which has the steel factory of Kardemir (Karabük) as destination.
- Of general cargo the main product is machinery & other manufacturing.
- As previously described, the land bridge possibility does not form a huge share in this throughput scenario. This is visible in the type of commodities handled (for example no electronic devices) and in the low number of containers. The proportion of land bridge throughput is however assumed to rise from 0% in 2015 to 21.5% in 2030.

To give a visual overview of the commodity volumes handled in the reference scenario, Figure 2-5 is provided.

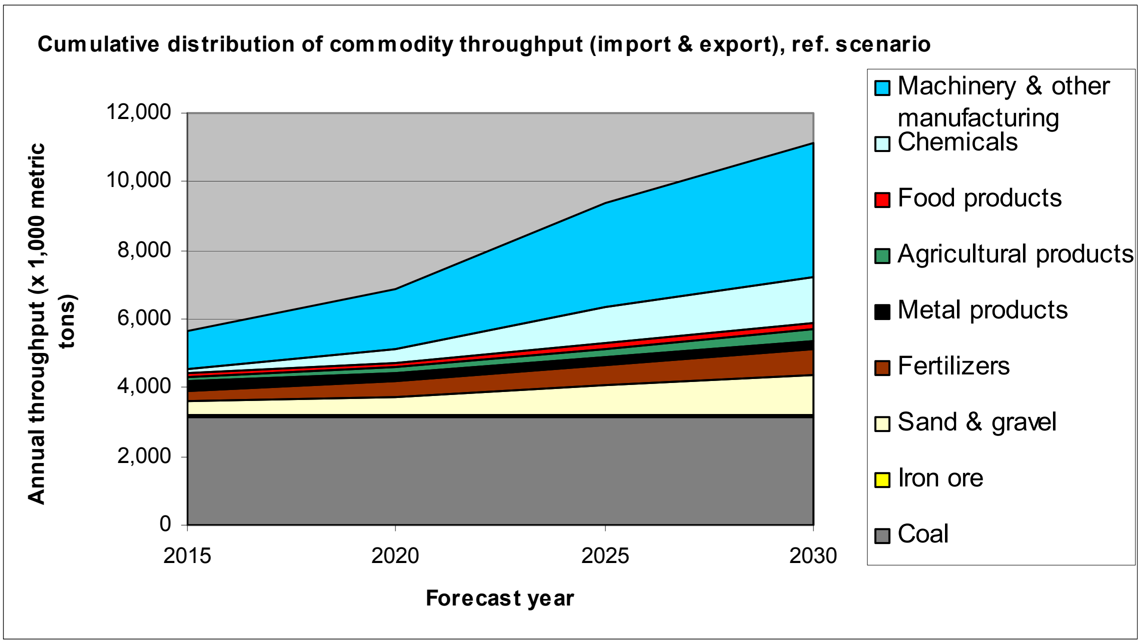



*Figure 2-5 Cumulative distribution of commodity throughput*

### 2.2.2 Overview of cargo flow

Of the information from the previous sub-paragraph an overview of the cargo flow to and from the port terminal area can be made. This information is needed to determine the required throughput per modality and the terminal handling and storage capacity.

*Sea-to-sea & land-to-land*

Because of the location it is not expected that the port Filyos will be attractive for direct sea-sea transhipment. It is assumed that this will not take place. Also no cargo will be transported via land to the port for adding value (for assembling, packaging etc.) and subsequently leaving the port via land. This means that all previously indicated import and export volumes will pass the terminal.

*Hinterland modalities*

To determine the required hinterland capacity an overview is required of the percentages of cargo flow, which will use the different modalities. As previously stated in § 2.1.3, the river Filyos will not be used as a hinterland connection. Therefore, hinterland transport will take place via road and rail. As stated before, transport by rail will only be carried out for hard coal, steel products and iron ore to and from the steel factory Kardemir at Karabük.

Rail

A more detailed prognosis of the commodities incoming and outgoing to Kardemir is carried out by NEA (2009) for the year 2015, see Table 2-9.

*Table 2-9 Prognosed throughput tonnage to and from Kardemir in 2015 (Reference scenario; NEA, 2009)*

| **Commodity** | **Incoming** | **Outgoing** |
|---|---|---|
| Hard coal | 200,000 | |
| Steel materials | 162,000 | 70,000 |
| Iron ore | 60,000 | |
| **Subtotal** | 422,000 | 70,000 |

The total flow is therefore equal to **492,000 tons**, which is expected to be transported by rail. Since no change of overall throughput volumes is expected for these commodities, this total flow to and from Karabük is considered constant in the period 2020-2030. As considered in § B.6, the current rail line will provide sufficient capacity for this purpose.

Conveyor belt

According to NEA (2009) 2.4 million ton of coal per year will be transported to the future power plant at Filyos. Another 600,000 ton is prospected to flow to the steel factory at Filyos. It is assumed that both will be supplied by a conveyor belt system, resulting in a total annual transport of **3.0 ton**.

Road

The residual traffic of cargo will be transported via road. This results in traffic of 3.4 million and 7.6 million ton respectively for the year 2020 and 2030. In § B.6 the required road capacity is consulted.

Overview

In Figure 2-6 an overview is provided of the modalities with corresponding estimated transport tonnages for the years 2020 and 2030.

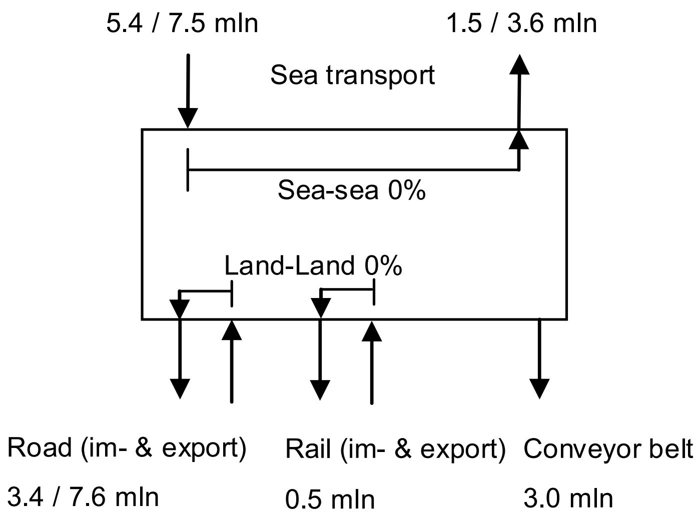



*Figure 2-6 Cargo flow with estimated cargo tonnages for resp. 2020 and 2030*

### 2.2.3 Ship characteristics

Based on the existing fleet, a preliminary forecast is made of the future fleet capacities by NEA (2009). This results in an overview of leading ship capacities per commodity type.

**Capacity & dimensions**

The capacities of ships differ per commodity handled. In Table 2-11 these different capacities are presented. Until the year 2030 a constant capacity is assumed for the dry bulk and general cargo ships. For containers two different ship types are assumed to enter from the year 2020.
Because ships have multiple destinations (mostly general cargo and container ships) the call sizes vary. Therefore, as a starting point, ships use on average half of their capacity for loading and unloading.
With the use of graphs according to Ligteringen (2009) the ship dimensions are determined, based on the capacity.

**Loading & unloading equipment**

Most of the ships will not have self-unloading equipment according to NEA (2009). In further berth calculations, the productivity of landside equipment is therefore considered leading.

**Traffic**

Based on the forecasted total throughput and call sizes, the yearly amount of traffic is determined. This traffic is important for the consideration of a, possibly needed, one- or two-way approach channel. Also it is important for determining the required quay lengths. Furthermore, it forms one of the input parameters to determine the chance of congestion in the port.

With respect to the container ships no forecast is given of the share in the total cargo throughput. Two different ship capacities are expected, of which the high capacity ship (type II) is forecasted to arrive after the year 2020. To derive the yearly traffic, the following **assumptions** are made with respect to the proportion of transport with respect to the total throughput.

*Table 2-10 Percentages of total container throughput transported per ship type*

| Forecast year | Container ship I (%) | Container ship II (%) |
|---|---|---|
| 2020 | 80 | 20 |
| 2025 | 65 | 35 |
| 2030 | 50 | 50 |

In Table 2-11 the derived characteristics are presented.

*Table 2-11 Ship dimensions & traffic, derived from capacities provided by NEA (2009)*

| Type | Commodity | Capacity DWT / TEU | $L_{OA}$ (m) | Draught (m) | Beam (m) | Yearly traffic 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| Dry bulk I | Iron ore | 60,000 | 215 | 13 | 32.0 | 2 | 2 | 2 | 2 |
| Dry bulk II | Coal, sand & gravel and fertilizers | 25,000 | 170 | 10 | 23.0 | 308 | 329 | 366 | 403 |
| General cargo I | Metal products | 25,000 | 165 | 11 | 23.5 | 21 | 21 | 21 | 21 |
| General cargo II | Agricultural & food products, chemicals, machinery & other | 15,000 | 140 | 9 | 21.5 | 198 | 323 | 597 | 767 |
| Container I | | 1,000 | 200 | 9 | 27.0 | 26 | 99 | 229 | 369 |
| Container II | | 5,000 | 300 | 12 | 40.5 | n.a. | 5 | 25 | 74 |
| | **Total yearly traffic** | | | | | **555** | **779** | **1,239** | **1,635** |

## 2.3 Physical conditions

In this paragraph the physical conditions are presented that form boundaries for the design of the port layout. For most conditions first information is given on a scale of the Black Sea. This approach is chosen to give a good understanding of the important local conditions, which is reported later on. Most of the information is based on recent and old measurements. For the cases where data was lacking, literature is consulted and calculations are carried out. The latter can be found in Appendix A, of which the results are provided in this paragraph.

### *2.3.1 Bathymetry*

In this sub-paragraph the bathymetry of the Black Sea and at Filyos are described.

**Black Sea**

The seabed of the Black Sea can be divided into a shelf, a continental slope and a deep-sea depression. The bathymetry is presented in Figure 2-7. The deepest part is situated at the centre of the sea and reaches a depth of MW - 2,200 m (Ref. [5]). The shelf occupies a large area in the northwestern part of the Black Sea, where it is over 200 km wide and has a depth ranging from 0 to 160 m. In other parts of the sea it has a depth of less than 100 m and a width of 2.2 to 15 km. At the Anatolian coast, where Filyos is situated, the shelf is only a narrow intermittent strip.

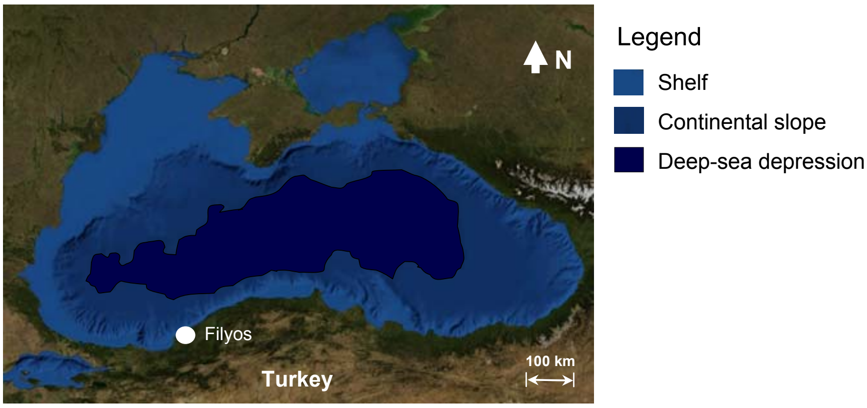



*Figure 2-7 Bathymetry of Black Sea (Ref. [2])*

**Filyos**

A bathymetric survey of the Filyos coast has been carried out by echo sounding in 1991. In 2009 new soundings have been made of a more narrow area, which represents the potential area to build the port. To give a good overview of the total area, both maps are combined. In Figure 2-8 the resulting projection of the old onto the new map is presented. It is visible that close to the river mouth, at a distance of about 200 m, a trough is situated. Furthermore, it is visible that little of the trough border shape and position has changed during the past 20 years. Therefore it is assumed that this combined bathymetry reflects the current situation. The local bathymetry is an essential input for the nearshore modelling of waves, which will be carried out later on in the project.

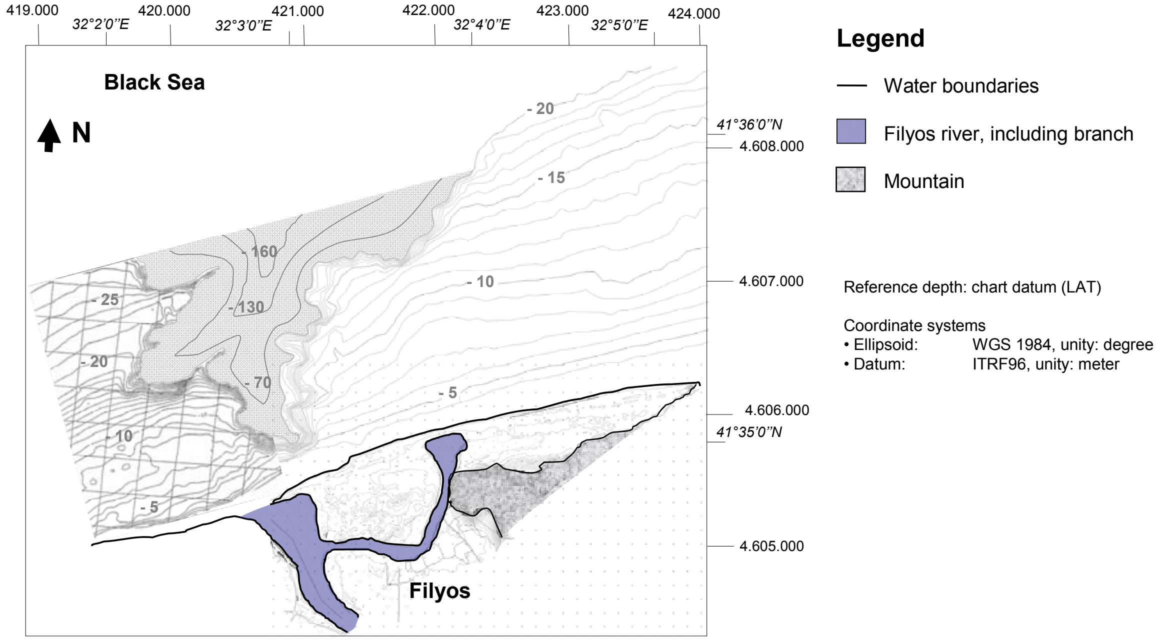



*Figure 2-8 Local bathymetry with combined old and new survey (Witteveen+Bos, 2009; JICA, 1991)*

The coastal shelf is steep near the coast until the bottom contour line of LAT -5 m. From that point onwards to the sea a normal steepness of about 1:100 is present until a depth of LAT -20 m. The trough is steep; between the distances from 200 m to 1,600 m offshore, the depth ranges from respectively LAT -5 m to -160 m.

It can be remarked that at the river mouth the bottom contours are parallel to the coastline. The influence of the Filyos river discharge on the bathymetry therefore seems negligible. This indicates that the trough is induced by the developed mountains in the Filyos delta instead of the river Filyos.

### 2.3.2 Soil conditions

In this sub-paragraph the soil conditions at Filyos are described.

**Geology**

The river induced erosion of the bedrock and layers of river deposits cover the same bedrock (Su / Yapi, 2001). As visible from Figure 2-9, the alluvial deposits consist of sand and silt. Along the river also gravel, peat and clay are present. Near the coastline the mountain consists of basaltic rock.

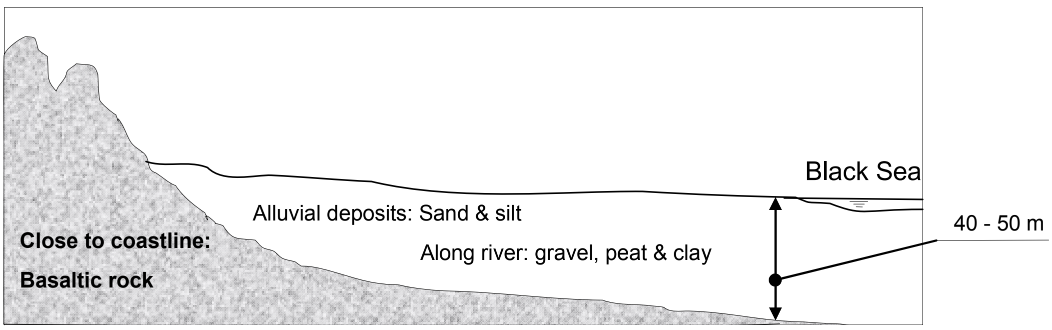



*Figure 2-9 Geological cross-section of mountain and alluvial deposits (Witteveen+Bos, 2009)*

Towards the coastline the thickness of these deposits increases. According to seismic measurements described in JICA (1991), this deposit layer is 40-50 m thick.

**Offshore borings**

Of several locations offshore borings are made of the soil layers. The area at the east side of coordinate 422.100 (ITRF 96) several offshore borings were made in an early stage of the project. In Figure A-1 an overview is made of the resulting offshore cross-sections. It is visible that the silt layer east from coordinate 423.400 is small compared to the west side. Approximate layer thicknesses are respectively 5 and 20 m.

At the west side only a single boring is made at the moment, which is presented in Figure A-2. The conditions indicated by this boring show a very bad bearing capacity. Up to a sub-bottom depth of 30 m the soil mainly consists of clay, with a bearing capacity below 5 MPa. In a later stage of the project, new borings came available which show that this boring is rather representative for the area west from the coordinate 422.100.

**On-shore borings**

Most of the on-shore borings have been carried out outside of the relevant project area. From the borings made, a clear distinction is visible between the area west and east from the old river branch (see Figure 4-1). As visible in the figure, a border is selected at coordinate 422.000. East from this coordinate layers of sand are present. West from this coordinate the sand layers are mixed with silt (and partly clay).

### 2.3.3 Seismology

Seismic activity is of course an unfavourable phenomenon for the port structures. Filyos is situated north of the North Anatolian Fault, which is the major active fault in Turkey. Current practise in the design of structures is the use of the seismic hazard map from the Ministry of Reconstruction and Settlement (1996). It divides Turkey into five subclasses of seismic zones. As visible in Figure 2-10, Filyos is situated at the border of zone 1 and 2. Zone 1 corresponds to the highest seismic activity. An assigned peak ground acceleration (pga) between 0.4 and 0.3 g holds respectively for zone 1 and 2, according to Kayabali *et al.* (2002).

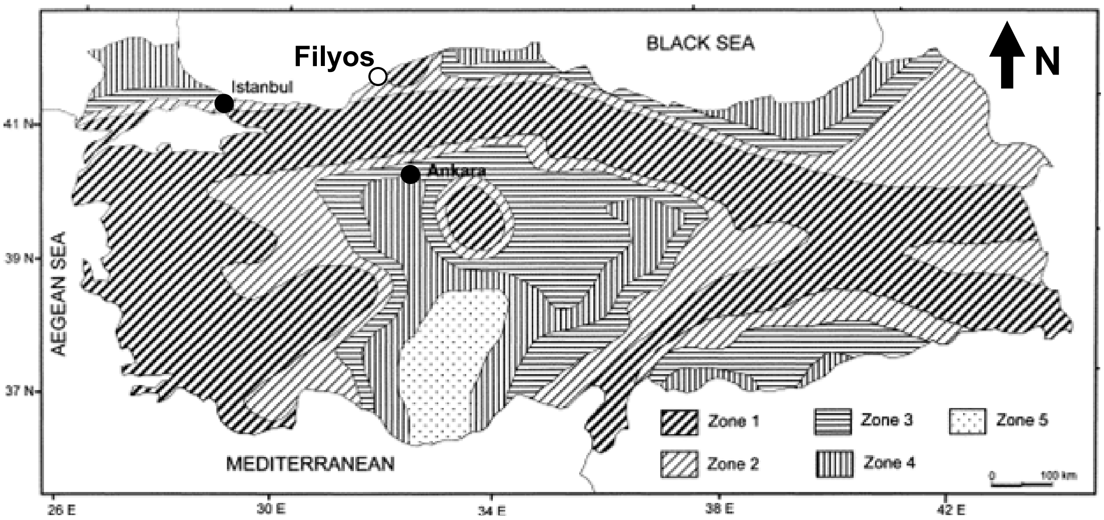



*Figure 2-10 Seismic activity in Turkey, divided in 5 zones of hazard (Kayabali et al., 2002)*

### 2.3.4 Filyos river

This sub-paragraph describes the characteristics of the river Filyos, which is situated next to the project location (see Figure 1-4). The discharge of water and resulting sediment flow will have effect on the port operations. A plan is however made to prevent flooding, which will have several favourable consequences for the port.

**Characteristics**

In this section the characteristics of the river are described.

*Discharge and catchment area*

The size of the river catchment area is 13,300 $km^2$, situated in the West Black Sea Region (JICA, 1991). And the annual average discharge amounts 3.085 * $10^9$ $m^3$, corresponding with an average discharge of 100 $m^3$ / s. As visible in Figure 2-11 the river is meandering heavily. Considering the narrow width of the river mouth and along other parts, this satellite photo is taken at the dry season. The width of the river varies between about 50 to 200 m. With an estimated depth of 3 m, this results in an average flow velocity of about 0.5 m/s.
The discharge is very irregular and the maximum discharge that was measured in 1975 was 2,780 $m^3$ / s. Since the opening is rather narrow, destructive floods have occurred frequently in the past.

*Sediment transport*

The delta river Filyos carries along sediment to the coast. The annual sediment transport amounts about 233 $m^3$ / (yr * $km^2$) according to JICA (1991). About 90% of this amount is in suspension according to the same report. Combined with the catchment area, this results into the following transport rate: 13,300 $km^2$ * 233 $m^3$ / (yr * $km^2$) * 0.9 (-) = **2.8 * $10^6$ $m^3$ / yr**.

The above presented rate can be validated by comparison with characteristics of other rivers, which are presented by Jansen (1979). The river Tiber (Italy), which has a slightly larger catchment area and higher discharge, gives a comparable yearly transport rate. Differences up to a factor 2 are however possible, due to deviations in bottom soil characteristics, vegetation and river steepness.


*Figure 2-11 The meandering river Filyos with zoom of local narrow widths during dry season (Ref. [1]).*

**Flood protection plan**

This section contains information about the plan to protect the area of Filyos against flooding.

*Levees and dams*

To prevent future flooding, a plan is made to create levees and dams. This can be combined with the generation of hydroelectric power and with irrigation facilities. In total 7 dams, 8 flood retarding dams, 6 hydroelectric power plants and irrigation systems, covering an area of 20,895 ha, will be build (Su / Yapi Engineering, 2001).

*Embankment*

The river mouth shape will be fixated by the use of guiding embankment structures. This will prevent the river from creating new branches near the project location. As a starting point, the guidance structures will be extended until the trough to force the sediment to settle at this location. The length of the required pier structures is about 300 m.

**Consequences**

Except from flood protection, the measures will have other effects. Firstly, the regular discharge will be lowered. This will result in less hindrance by currents for ships near the river mouth. It is therefore assumed that future port operations are hardly influenced by the river discharge. Secondly, morphological hindrance by the river will be lower. The lower discharges will force the river to a new bottom equilibrium situation. Also part of the sediment will be caught by the dams. Therefore a reduction of sediment supply at the river mouth is expected. Moreover, the presence of guided embankment will interfere in the longshore transport from western direction.

### 2.3.5 Wind

This sub-paragraph provides information about the **offshore** wind conditions. This data will be used as input for the wave generation model SWAN (Simulating WAves Nearshore).

**Data characteristics**

Surface wind recordings of the Black Sea are available over the period 09-Jan-1992 to 31-Dec-1999. The surface wind speeds, 10 meter above sea level ($u_{10}$), and corresponding directions originate from the global numerical weather prediction model of ECMWF (2008), which stands for European Centre for Medium Range Weather Forecasting. The spatial resolution is 0.25° (~ 28 km) and the time step is 3 hours.

**Adjustments**

*Witteveen+Bos*

The data is corrected and validated at each grid point, using wind measurements by satellite wind scatterometer and radar altimeter. The wind speed was gathered from all satellite radar altimeter and wind scatterometer missions to date, and calibrated and quality checked by ARGOSS. Sampling by satellite is determined by the orbits of the various satellites and is therefore nor regular nor complete. The quality of the data is generally high (Witteveen + Bos, 2008).

Originally, the ECMWF wind fields were on a 0.5° by 0.5° (~ 56 $km^2$) resolution grid with a temporal resolution of 6 hours; they were transferred to the 0.25° by 0.25° regional wave model grid and 3 hour time step by interpolation.

*Calibration*

The available data of the period 1995-1996 has a maximum velocity ($u_{10}$) of 14 m/s, resulting in an $H_S$ at shallow water of about 2.8 m. This height is too low according to the buoy recordings during the same period. Since the wind is originally recorded 6 hourly, the velocities are lower. Comparison with wind data from a local weather station at Filyos from Bergøe (2009) for the same period indeed shows a significant difference. It provides one hourly recorded wind velocities consisting of maxima up to 22 m/s.

Correction with a factor is therefore required as basis for hindcasts. In Appendix E a simulation with the model SWAN is carried out to simulate the wave climate at the buoy on basis of the offshore wind. A correction factor for the wave height results from the comparison with the buoy recordings.

**Extreme conditions**

In Table A-1 the long term extreme wind velocities are presented, which are approximated with the use of the Generalised Pareto distribution. For more information is referred to § A.2.

*Table 2-12 Approximated maximum long term wind velocities*

| Return period | $U_{10}$ (m/s) |
|---|---|
| 10 yr | 23.4 |
| 25 yr | 25.7 |
| 50 yr | 27.9 |
| 100 yr | 30.4 |
| 200 yr | 33.2 |
| 225 yr | 33.8 |

### *2.3.6 Water levels*

To determine the required dredging depth and to design port structures, information is needed about the water levels. Extreme water levels are important for the structures of breakwaters and quays.

Next to the tide, which is described first, many other phenomena have effect on the water level. The extreme water levels resulting from the phenomena, which are described and elaborated in Appendix A, are presented below.

**Tide**

The water level of the Black Sea is hardly affected by the tide. This is caused by the fact that Mediterranean tidal waves extinguish in the Bosporus channel. The average spring range is only 8 cm in the western part according to Eisma *et al.* (1998). The chart datum for harbour works is generally the Lowest Astronomical Tide (LAT). For the berth structures itself and for land installations, the chart datum is usually referred to with the mean water level. In Table 2-13 the tidal water levels are presented, determined with interpolation. MW is considered as chart datum (CD) in this overview.

*Table 2-13 Approximated tidal levels of Black Sea*

| Abbreviation | MW (= CD) +/- |
|---|---|
| HAT | + 0.04 m |
| MHW | + 0.02 m |
| MW | 0.00 m |
| MLW | - 0.02 m |
| LAT | - 0.04 m |

**Extreme water levels at Filyos**

As stated in the introduction above, of main interest are the extreme water levels at Filyos. In Appendix A an approximation is carried out for the long term. The following phenomena are here fore taken into account:

- Atmospheric under and over pressure;
- Wind set-up and draw-down;
- Variation due to river discharge;
- Sea level rise.

In Table 2-14 the results of the analysis are provided.

*Table 2-14 Approximated water level maxima and minima at Filyos coast*

| Return period | Maxima (MW +) | Minima (MW-) |
|---|---|---|
| 10 yr | 0.9 m | 0.6 m |
| 50 yr | 1.3 m | 0.8 m |
| 100 yr | 1.7 m | 0.9 m |

*Notes*

For approximation of the minimum water level it is assumed that no future rise of the sea level rise will occur. Furthermore, the water level variation due to river discharge is set to zero for the minimum level.
For the design of structures and required dredging also information about the subsidence of land is needed. No information in this respect for this Turkish area is however available. Known is that seismic activities take place in the area (see § 2.3.3). Furthermore, the 50 m thick soil layer above the hard rock layer is considerably soft, see Figure 2-9. Annual subsidence should therefore be researched.

### 2.3.7 Waves

Information about the local waves is of crucial importance for the design of the port layout. It determines the need for one or more breakwaters, the accompanied orientation of the entrance and the orientation of the approach channel.
In the first section the data is provided from a buoy. Extreme conditions, which are approximated with the model SWAN, are provided in the second section.

**Buoy data**

Wave conditions were recorded by a buoy during the period 21-Dec-1994 until 26-Dec-1996 at Filyos, on a 2 hourly basis. These measurements are obtained from Bergøe (2009). The buoy was situated close to the shore at Filyos at a depth of MW -13 m. With this information the buoy location may vary along a stretch of about 3 km, which is indicated in Figure A-6.

*Annual average conditions*

In this sub-section the annual average conditions are presented as obtained from the buoy.

Wave heights

In Table 2-15 the distribution of significant wave heights is provided of the buoy recordings. The heights are put into bins of 0.5 m height and in 8 directions. About 80% of the year significant wave heights of less than 1.0 m are measured. Waves can however be relatively high, with an $H_S$ reaching 5.0 m in these recorded years. The prevailing wave direction is N-NNE in autumn and winter and WNW-NW in spring and summer.

*Table 2-15 Directional distribution of $H_{1/3}$ for 1995-1996 (%)*

| $H_{1/3}$ / direction | N | NE | E | SE | S | SW | W | NW | Total |
|---|---|---|---|---|---|---|---|---|---|
| **0.0 - 0.5** | 18.3% | 11.8% | 2.1% | 0.0% | 0.0% | 0.0% | 5.0% | 13.8% | 50.9% |
| **0.5 - 1.0** | 7.7% | 5.4% | 1.0% | 0.0% | 0.0% | 0.0% | 3.1% | 9.6% | 26.7% |
| **1.0 - 1.5** | 3.7% | 1.0% | 0.3% | 0.0% | 0.0% | 0.0% | 2.5% | 4.2% | 11.7% |
| **1.5 - 2.0** | 1.9% | 0.4% | 0.2% | 0.0% | 0.0% | 0.0% | 1.3% | 2.2% | 6.0% |
| **2.0 - 2.5** | 0.5% | 0.4% | 0.1% | 0.0% | 0.0% | 0.0% | 0.7% | 0.7% | 2.4% |
| **2.5 - 3.0** | 0.3% | 0.2% | 0.1% | 0.0% | 0.0% | 0.0% | 0.4% | 0.4% | 1.4% |
| **3.0 - 4.0** | 0.3% | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.5% |
| **4.0 - 5.0** | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.3% |
| **Total** | **33.1%** | **19.2%** | 3.8% | 0.0% | 0.0% | 0.0% | **13.0%** | **30.9%** | 100.0% |

To give a visual impression of the wave heights and direction, a wave rose is provided for 16 directions in Figure 2-12.

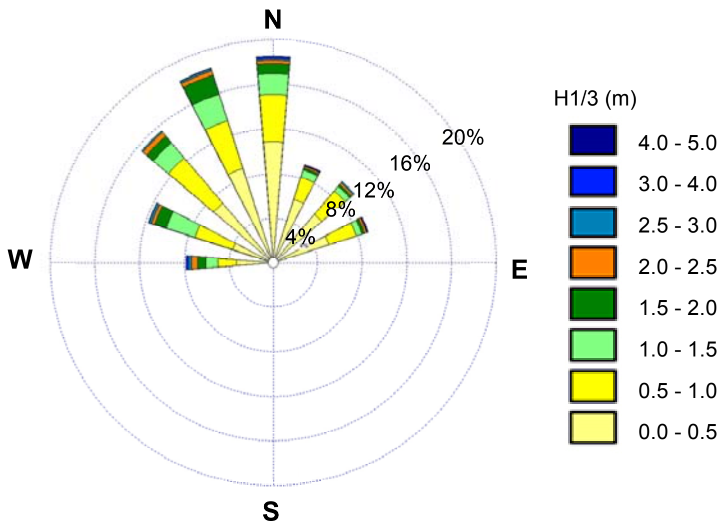



*Figure 2-12 Directional distribution of $H_{1/3}$ for 1995-1996 (m)*

Wave periods

In Figure 2-13 the corresponding distribution of peak wave periods is plotted.

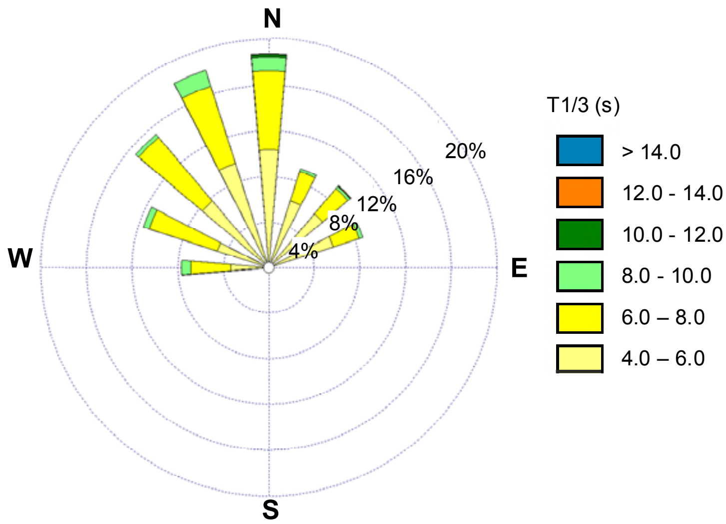



*Figure 2-13 Directional distribution of $T_{1/3}$ for 1995-1996 (s)*

Wave height vs. period

In Table 2-16 the yearly distribution of wave height ($H_{1/3}$) versus the wave period ($T_{1/3}$) is provided. Herewith the wave steepness can be determined. It shows that the waves are predominantly locally generated under the influence of wind.

*Table 2-16 Yearly distribution of wave height (H1/3) and period (T1/3) combinations during 1995-1996*

| $H_{1/3}$ / $T_{1/3}$ | 4.0 – 6.0 s | 6.0 - 8.0 s | 8.0 - 10.0 s | 10.0 -14.0 s | Total |
|---|---|---|---|---|---|
| 0.0 - 1.0 m | 49.0% | 8.0% | 0.0% | 0.0% | 57.0% |
| 1.0 - 3.0 m | 6.0% | 29.0% | 4.0% | 0.0% | 39.0% |
| 3.0 - 5.0 m | 0.0% | 0.0% | 3.5% | 0.5% | 4.0% |
| **Total** | **55.0%** | **37.0%** | **7.5%** | **0.5%** | **100.0%** |

**Extreme conditions**

From the extreme wind conditions (determined in § 2.3.5), the nearshore wave heights are approximated using the program Cress. This program offers the use of the formula of Bretschneider (1958; CUR, 2007). These conditions are put in the wave simulation model SWAN for 5 output locations along the breakwaters, see Figure A-5 in § A.3. The results are provided in Table 2-17.

*Table 2-17 Extreme wave conditions along breakwater structure (1/225 yr)*

| Output # | Hs | Tp |
|---|---|---|
| 1 | 3.7 | 12.1 |
| 2 | 5.8 | 12.2 |
| 3 | 6.9 | 12.4 |
| 4 | 5.6 | 9.9 |
| 5 | 4.0 | 12.2 |

### 2.3.8 Currents

Information about the local currents is important for the design of the approach channel. In this sub-paragraph the conditions of currents measured at Filyos are described. To give a better understanding of the local conditions, a description of the current pattern of the Black Sea is provided in § A.6.

**Filyos**

At the same location range and time period as described in § 2.3.7, currents are recorded, originating from Bergøe (2009). The distribution of the measured current velocities during the period 1995-1996 is plotted in Figure 2-14.

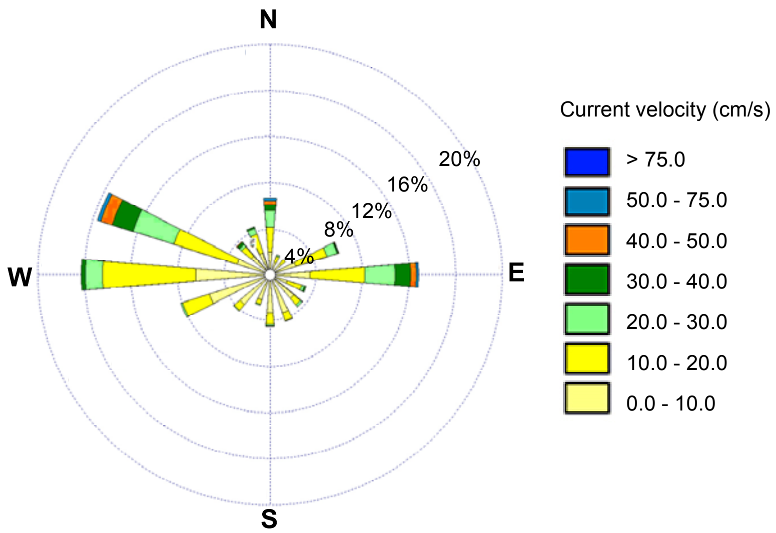



*Figure 2-14 Directional distribution of measured current velocities for 1995-1996 (cm/s) at Filyos; currents presented with direction of origin*

It is visible that the prevailing directions of the currents are long shore. The buoy location is situated at a depth outside of the breaker zone; therefore the measured currents are not wave driven. It is visible that on average a velocity in the order of 20 cm/s is measured. This corresponds to the indicated velocity range of the Black Sea region (see § A.6). The maximum current velocity in the recording period was 71 cm/s.

*Note*

It is important to notice, that adjustments needed to be made with respect to the reference orientation of the obtained data. Unlike for wind and waves, the currents were registered according to the Cartesian Convention. According to Belnap *et al.* (2005) it defines the direction where the vector points, measured counter clockwise from the positive x-axis of the system (in degrees). In the figure above the direction where the currents come from are presented.

### 2.3.9 Longshore sediment transport

The construction of a port will interfere with the longshore transport of sediment. To decide if and what measures are needed, an indication of the yearly transport is necessary.

In Appendix A.7 an approximation is carried out with the use of the model UNIBEST LT for three different transport formulae. A verification of the bulk energy formula CERC is done by hand calculation.

The results of the Bijker and Van Rijn formula in the UNIBEST module show a high similarity. The formula Van Rijn has the highest physical meaning of the mentioned formulae. The results with the use of the **Van Rijn** theory are:

**$S_{x,}$ eastward: 266,000 $m^3$/year**
**$S_{x,}$ westward: 213,000 $m^3$/year**

These results are used as input for the coast morphological impact analysis in Appendix D.

**Note**

Of the eastward transport at the trough location it is more difficult to make an estimation. Sediment will partly be trapped in the trough (see Figure 1-4). Because of the planned river guidance embankment, the longshore transport in this direction will however be completely interfered at this location.

# 3 PROGRAMME OF REQUIREMENTS

Requirements that have to be taken into account in the planning of the port are presented in this chapter. As stated in the objective, focus is on the offered service level for the clients. In the first paragraph the required functions are presented, which are important for the port performance. In the second paragraph the requirements with respect to the performance are given. In the third and fourth paragraph the environmental and technical requirements are provided.

## 3.1 Functional requirements

Nautical accessibility, loading and unloading ability at berth and through transport & storage ability comprise the primary functions of the port. Below these functions are discussed, in combination with nautical safety and robustness.

**Nautical accessibility**

While navigating into and out from the port, ships need possibility to manoeuvre. Therefore hindrance by wind, waves and currents needs to be minimised. Moreover, sufficient space is required at both sides and underneath of the ship.

**Loading & unloading ability at berth**

To function properly, the conditions to load and unload at berth are very important. Downtime of these operations needs to be minimised to acceptable values. In Table 3-3 the criteria for the total allowable downtime percentages per year are presented.

**Through transport and storage ability**

To guarantee an adequate service level, efficient handling of cargo is required on the terminal and to and from the hinterland. Except from sufficient space, a well considered allocation and shape of the terminal areas is necessary.

**Nautical safety**

Safety must be aimed during all operations in the port. Of main interest is the safety of ships from the moment of navigating into the harbour until loading and unloading at berths and vice versa, the nautical safety. Account therefore needs to be taken of sufficient space to manoeuvre and of tranquil climate conditions (wind, waves and currents).

Various calamities may occur because of inattentiveness of the captain or stevedore or because of malfunctioning of the equipment. Additional measures are therefore required. Next to strict port regulations, guidance/interference by experienced safety guards is required on the terminal and in the harbour (tug boat assistance).

The following needs to be taken into account in the wet infrastructure:

- It is not allowed to place berths or hard structures in the stopping line of the vessels. Instead a natural slope is preferred at the end of the stopping line;
- Sufficient length for the ship’s stopping procedure.

**Robustness**

The port needs possibility to develop in the future. Account therefore needs to be taken of possible expansion at the inner or outer boundaries of the port. Also flexibility is required with respect to re-allocation of port components. Both are especially important with respect to the berth structures, terminals and the harbour manoeuvring areas.

## 3.2 Performance requirements

To provide good service for the clients, adequate conditions must be guaranteed. Therefore **own determined** requirements with respect to the overall port performance are set. Because Turkey has undergone rapid economic development in the past decade, it is assumed that a high service level is required. The service characteristics presented are based on this assumption.

**Maximum service characteristics**

In line with the mentioned service level, maximum values are selected that represent the provided service (see Table 3-1). The accepted maximum average waiting time is provided as proportion of average service time. Waiting time comprises the time from arriving at the anchorage area until being guided into the berth area. Consequently, the service time consists of the total time in the berth area: mooring, loading/unloading and unmooring. The total turnaround time consists of the waiting time plus service time and time for leaving the harbour.

*Table 3-1 Assumed maximum service characteristics*

| Cargo type | Average waiting time / service time (%) | Turnaround time (days) |
|---|---|---|
| Dry bulk | 20 | 3 |
| General cargo | 20 | 3 |
| Containers | 10 | 1 |

**Maximum occupancy**

In addition to the previous section another approach is from the offered service as function of the berth occupancy. Even if average waiting times are low, the chance that ships have to wait can be too high. Based on experience, a berth occupancy ratio until 40% is still efficient, in case of one berth. In case of multiple berths a higher occupancy is possible. UNCTAD (1985) recommends for general cargo a maximum berth occupancy as function of number of berths, as provided in Table 3-2. These numbers are based on a ratio of ship cost to berth cost of 4:1.

*Table 3-2 Recommended maximum berth occupancy for general cargo (%; UNCTAD, 1985)*

| Number of berths in the group | Recommended maximum berth occupancy (%) |
|---|---|
| 1 | 40 |
| 2 | 50 |
| 3 | 55 |
| 4 | 60 |
| 5 | 65 |
| 6-10 | 70 |

**Maximum downtime of port operations**

The port is preferably year-round operational. For the port operator it is possible to make high revenue then. The client on its turn wants to have a guaranteed service time; otherwise a nearby port will be selected. There are however various unfavourable phenomena that can cause downtime of operations in a port. In Table E-1 the normative wave conditions for operations at berth are presented.

From experience allowable maximum percentages of downtime can be obtained. In accordance with the above assumed high service level, the yearly percentages per cargo type are set as presented in Table 3-3.

*Table 3-3 Assumed allowable downtime of port operations* [iv]

| **Cargo type** | **Max. total yearly downtime percentage** |
|---|---|
| Dry bulk | 10% |
| General cargo | 10% |
| Container | 5% |

xliv

[iv] These percentages are provided by Prof.ir. H. Ligteringen

## 3.3 Environmental requirements

Measures need to be taken to minimise nuisance with respect to the environment of the port. One of the unwanted affects is high morphological change to the coastline. Below also an enumeration is provided of other unwanted influences on the environment.

**Coast morphological impact**

Morphological change of the Filyos coastline needs to be avoided as much as possible. It needs to be investigated to which extent the impact on the coastline, in terms of erosion and accretion, is allowed.

**Mountain**

Blasting of the basaltic rocky mountain near the shore is very difficult and unfriendly to the environment. According to Witteveen+Bos this is not allowed.

**Regulations**

With respect to influence on the environment also attention is needed for the general port regulations. There are restrictions about amongst others:

- Contamination (e.g. toxic substances & gasses, dust, odour, vibrations) of:
  - Air
  - Soil
  - Water
  - Sediment
- Waste generation
- Energy consumption
- Habitat management

## 3.4 Technical requirements

In this paragraph the main technical requirements for the port and its structures are provided.

**Lifetime & maintenance**

It is assumed that the port and port structures must have a minimum lifetime of 50 years. This is in the range as recommended by Simm *et al.* (2003). Strength, stability and stiffness requirements have to be guaranteed during this time period. To fulfil this and to achieve a good service, a high maintenance level of the structures is assumed.

**Specific requirements**

*Conveyor belt system*

Clogging of conveyor belts should be avoided as much as possible. Here fore the length of the conveyor belt must be kept as short as possible. Angles in the conveyor belts are not wanted either for the same reason.

# 4 STARTING POINTS

For determining the planning process and component dimensions for some conditions starting points are required. This chapter contains information that was needed for the spatial planning. Moreover, for dimensioning of the approach channel, berths and terminals.
Some starting points are provided by the project managers that are currently working on the project by Witteveen+Bos. However, mostly own starting points are set; derived from variables based on empirics, obtained from literature.

## 4.1 Spatial planning

In Ch. 2 boundary conditions were presented with respect to planned activities at Filyos. This paragraph contains additional starting points to derive the available space for planning of the port. Below an enumeration is provided with indicated reference. In Figure 4-1 an overview is given of the planned facilities at Filyos.

Witteveen+Bos [v]:

- Permits are granted for realisation of the port east of the river Filyos;
- An industrial area will be located south of the old river branch and east of the river Filyos.

NEA (2009)

- The power plant will be located near the port, so transport by a conveyor belt is possible.

Own starting points:

- No industry is planned at the terminal area.
- The power plant requires 50 hectares of space according to JICA (1991)
  → As a starting point, this amount of space is still required in the future.
- The power plant will be combined with the industrial area.



[v] Obtained from Filyos port planner Ir. S. Meijer

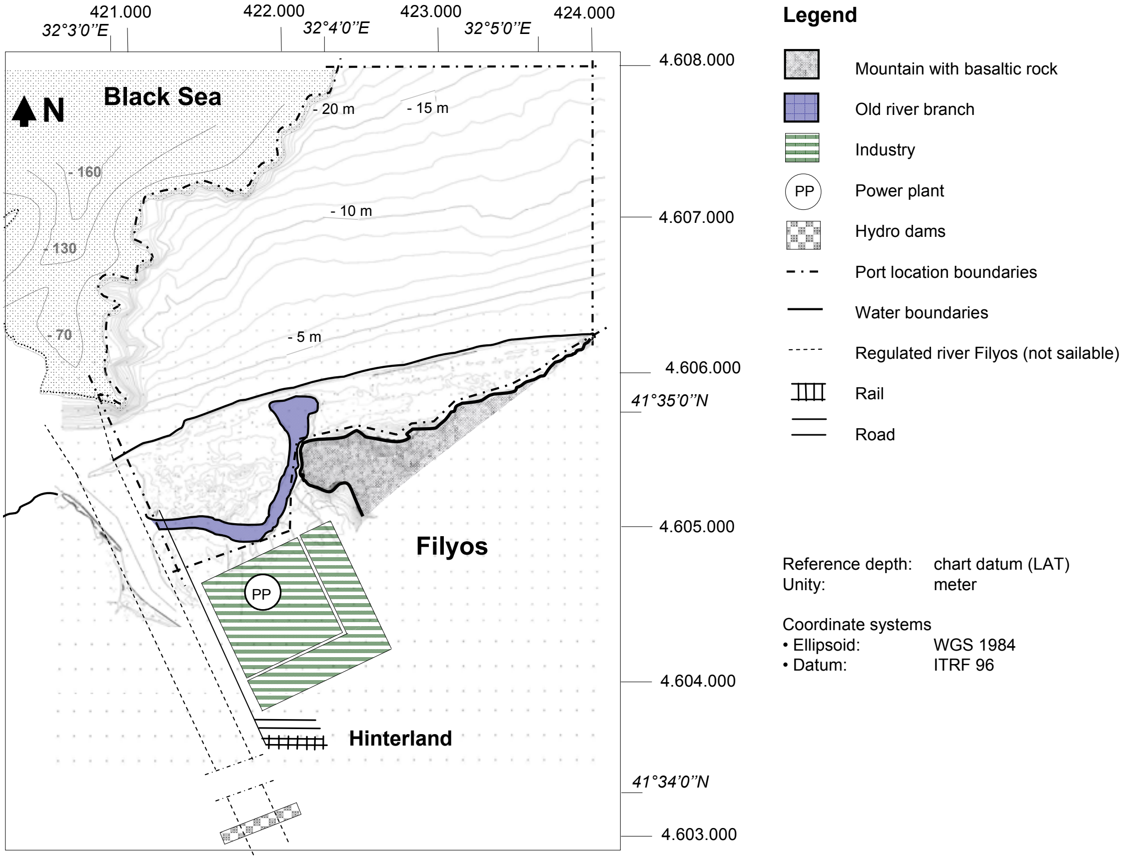



*Figure 4-1 Map indicating the planned facilities at Filyos*

## 4.2 Approach channel

The following characteristics are used for the calculation of the approach channel dimensions:

- Ship manoeuvrability
  - Container ships (normative): Moderate to poor
  - Rudder angle: 20°
- Ship speed at approach channel: Moderate
- Embankment
  - outer channel: Sloping channel edges and shoals
  - inner channel: Steep and hard embankments
- Aid to navigation: Tug assistance until berthing area; no use of a Vessel Traffic System.

Because the number of annual Dry bulk I vessel passages is very low, the draft of container II vessels is taken normative. Solely at tranquil climate conditions Dry bulk I vessels are allowed to enter the port.

All ships are assumed to stay at the anchorage place, outside the port, for waves with an $H_S$ of above 2.0 m.

## 4.3 Berths

This paragraph provides the starting points which are required for the calculation of the amount of berths and cranes.

**All cargo types**

The following starting points are used in the queuing theory and resulting dimension calculations for all cargo types:

- Load as percentage of ship capacity: 50 %;
- At maximum one crane at the quay can be applied per 50 m ship length;
- Ships do not use self-unloading equipment and / or do not have higher capacity rates for loading and unloading;
- The port has 8,400 operational hours / yr (= +/- 350 days * 24 h);
- Inter-arrival and service time distribution: E2 / E2 / n (see Appendix B.4.2);
- The queue-discipline is: first come first served;
- Mooring and unmooring time: 2 * 2 h;
- The average LOA is 80% of the maximum LOA.

**Loading & unloading equipment**

Based on the selected cranes at the landside of the berths in Appendix B, the effective crane productivities are taken into account as presented in Table 4-1.

*Table 4-1 Selected crane type and effective loading & unloading productivities*

| Cargo type | Crane type | Effective productivity / (h * crane) |
|---|---|---|
| Dry bulk | Overhead trolley unloading grabbing crane | 1,500 metric ton |
| General cargo | Mobile crane | 144 metric ton |
| Containers | Gantry crane | 25 movements |

## 4.4 Terminals

In this paragraph starting points with respect to storage areas, equipment and parameters used for storage formulas are provided. For determining the total required area an overall **factor of 1.5** times the storage area is used.

**Storage area**

Starting points that are important for determining the area required are presented in this section per cargo type.

*All cargo types*

No transhipment (sea to sea transport) and land to land transport will take place. Therefore all transported cargo will need storage, according to an average dwell time.

*Dry bulk*

Imported coal will directly be transported to the power plant by a conveyor belt system. No dedicated storage yard is required. To prevent malfunctioning of the conveyor belt an advanced system is however necessary. Otherwise an intermediate storage area for coal is essential in case of a transport calamity. Therefore account is taken of an extra storage area, situated relatively close to the dry bulk berth for coal.

*General cargo & containers*

The reference forecast includes expected total proportions of general cargo / containers (see Table 2-8). A specification per commodity is however not given. As a starting point the same proportions holds per commodity; for 2020 and 2030 respectively: 83% / 17% and 50% / 50%.

Furthermore, it is assumed that the proportions of export / import for containers are the same as for general cargo; for 2020 and 2030 respectively: 15.4% / 84.6% and 32.7% / 67.3%.

Of the total container amount handled 25% is expected to be empty. The following own starting points are made with respect to the rate of empties per import & export containers:

- 40% empty containers: import
- 60% empty containers: export

The following ratios are considered reasonable to go through the CFS:

- 30% of imported full containers
- 10% of exported full containers

**Handling equipment**

The choice of equipment is an important input for determining the required storage areas. Based on the required service level and availability of space, the following equipment is chosen for further calculations:

| | |
|---|---|
| Dry bulk: | Conveyor belt systems and shovels |
| General cargo: | Forklift trucks and terminal tractors |
| Containers: | Straddle carriers and trailers |

**Storage parameters**

In Table 4-2 the parameters are presented that are selected to determine the storage areas required. For dry bulk and containers a different formula is used than for containers.

*Table 4-2 Selected storage parameters*

| Storage parameter | Definition and unity | Dry bulk | General cargo | Containers | CFS |
|---|---|---|---|---|---|
| $f_1$ | Proportion gross/net surface in connection with traffic lanes (-) | 1.3 | 1.5 | | 1.4 |
| $f_2$ | Bulking factor due to cargo specific requirements (-) | 1 | 1.2 | | 1.1 |
| $\bar{t}_d$ | Average dwell time (days) | Iron ore: 30<br>Other dry bulk: 20 | 15 | Import: 6<br>Export: 5<br>Empties: 12 | All: 3 |
| ρ | Commodity density (metric ton / $m^3$), see Table A-1 | | | | |
| h | Average stacking height (m) | All dry bulk: 4 | Metal products, chemicals & machinery: 2<br><br>Agricultural products & food: 4 | | 2 |
| m | Average rate of occupation (-) | 0.7 | 0.7 | Import: 0.7<br>Export: 0.7<br>Empties: 0.8 | 0.65 |
| F | Required area ($m^2$) / TEU, inclusive travelling lanes (see proposed equipment) | | | 15 | |
| r | Average stacking height / nominal stacking height (-) | | | Import: 0.6<br>Export: 0.8<br>Empties: 0.9 | |

In Table 4-3 the densities of the commodities handled are presented. A part of the values is provided by Ligteringen (2009). Other values are estimated on the combination of weight and expected gross volume.

*Table 4-3 Cargo densities*

| Commodity | Bulk density, ρ (metric ton / $m^3$) |
|---|---|
| **Dry bulk** | |
| Iron ore | 2.5 |
| Coal | 0.8 |
| Sand & gravel | 1.6 |
| Fertilizers | 0.8 |
| **General cargo** | |
| Metal products | 3.0 |
| Agricultural products | 0.6 |
| Food products | 0.8 |
| Chemicals | 1.0 |
| Machinery & other manufacturing | 2.5 |

# 5 DESIGN GUIDELINES & COMPONENT DIMENSIONS

This chapter provides information about the component dimensions and corresponding guidelines. Two phases are selected for dimensioning the port, which is described in the first paragraph. In the second paragraph the dimensions of the components are provided.

## 5.1 Phasing

Based on the cargo throughput and shipping forecast (see § 2.2), phasing for the project is chosen. A description is provided below.

**Throughput forecasts**

Regarding the throughput forecasts, a slow growth of cargo throughput is expected from the year 2015 until 2020. From this year until 2030 a rapid throughput growth is foreseen.

**Shipping forecasts**

For dry bulk and general cargo commodities the expected ship sizes between 2015 and 2030 are constant. For container ships a variation is foreseen. From 2015 to 2020 solely ships of type I will arrive. After this time period a slow introduction of type II is expected. This ship has considerable larger dimensions.

**Conclusion**

It can be concluded that there are two periods visible with different development in throughput and ship size, namely 2015-2020 and 2020-2030. It is therefore attractive to implement 2 corresponding project phases for the layouts. The time horizon of planning for 2020 can be interpreted as medium term, according to the definitions of § 1.3.3. In this planning requirements (e.g. flexibility) for the short term must be taken into account.

In Figure 5-1 the 2 selected project phases are indicated. A time period range for realisation of the phases is provided as well.

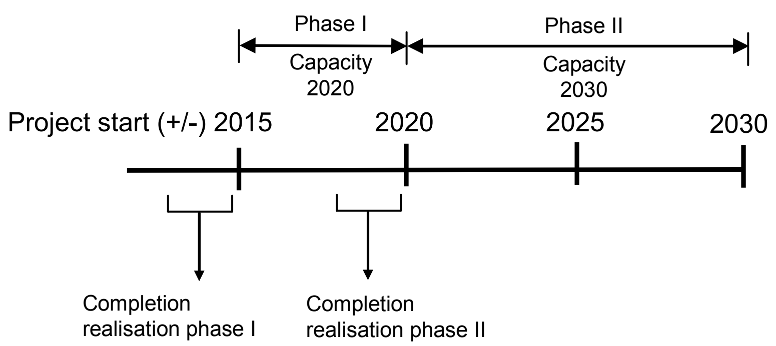



*Figure 5-1 Chosen project phasing*

## 5.2 Guidelines & component dimensions

This paragraph provides an overview of the minimum component dimensions (expressed in $m^1$ and $m^2$), which are determined in **Appendix B** for both phases. This appendix also presents an extensive overview of guidelines that hold for the preferred location, shape and orientation of the components. Important notions made are briefly described in this paragraph.

It needs to be stated, that for the breakwaters and berths different structure types are optional. An enumeration of possibilities hereof is provided in the respective sub-paragraphs.

### *5.2.1 Approach channel*

For the dimensioning of the approach channel the guidelines of PIANC and IAPH (1997) have been used. Based on the relatively low traffic volumes, a one-way channel is considered sufficient for the period between 2015 and 2030. This is based on a forecasted average daily passage amount of 4.6 ships in 2020 and 9.3 ships in 2030, see § B.1.3.

In Figure 5-2 a schematisation is presented of the harbour entrance and approach channel. The sinusoidal movement of the ship during navigation is indicated. This movement takes place to maintain ship control during hindrance from wind, waves and currents. Extra width of the approach channel is therefore required. In the figure also the determined minimum length for the stopping procedure of ships is indicated.

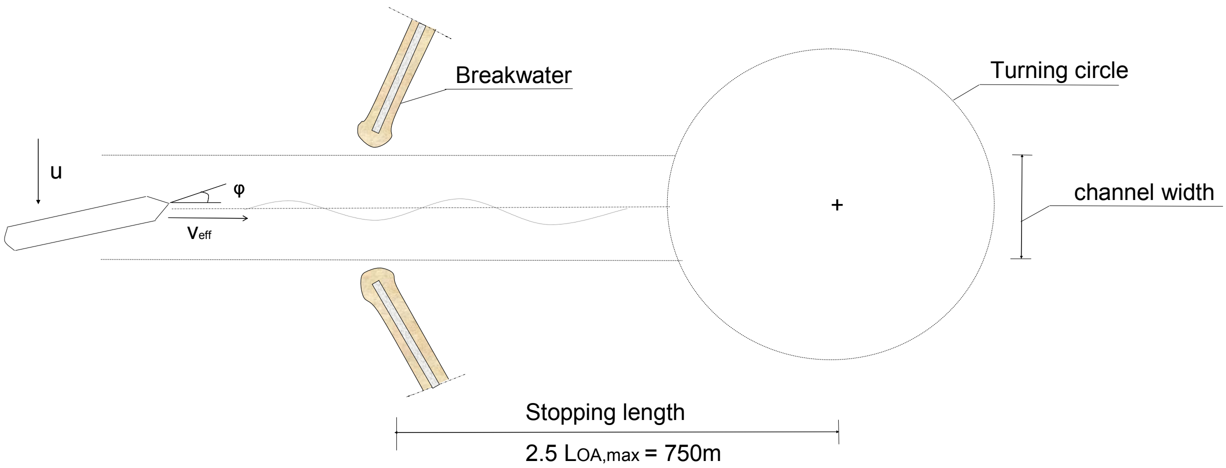



*Figure 5-2 Schematisation of approach channel with indicated stopping length*

The required width for the one way channel consists of a basic manoeuvring space and a bank clearance, as presented in Figure 5-3.

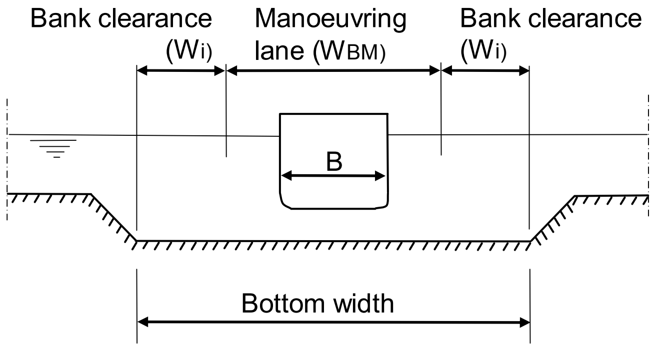



*Figure 5-3 Bottom width of approach channel*

The determined approach channel dimensions are provided in Table 5-1. Considered are the dimensions for a NW orientation, which is the most preferred orientation with respect to nautical conditions. The predominant directions of wind, waves and currents are hereby in line with the axis of the ship. It also has the advantage, that the channel can be combined with the natural depth of the trough, which makes a shorter channel length possible.

*Table 5-1 One-way approach channel dimensions for both project phases, orientation NW (m)*

| **Variable** | **Dimension (m)**<br>**Phase I + II** |
|---|---|
| Guaranteed/nominal depth | 14.2 |
| Initial total depth (incl. tolerances) | 15.2 |
| Straight section | |
| Minimum length inner channel | 750 |
| *from entrance until centre of turning circle* | |
| Bottom width | 205 |

*Notes*

- Because over a distance of about 2.5 $L_{OA}$ (= 750 m) allowance of lateral movement is required in the harbour, the channel width outside and inside the harbour are equal;
- For alternative orientations a wider bottom width is required for manoeuvring;
- Because of smaller container ships arriving before 2020, it is planned to start with a reduced bottom width of 162 m during the period 2015-2020;
- At the entrance the embankment is hard. Therefore an extra width of 2 * 0.5 B must be taken into account, resulting in a total of 245.5 m;
- In case a bend is applied in the channel alignment, a width of 156 m and a radius of 2,040 m are required.

### 5.2.2 Breakwaters

In this sub-paragraph the essence of building breakwaters and the corresponding configuration are discussed. Moreover, different structure types are considered.

**Breakwater essence & configuration**

Regarding the wide range and frequency of high incoming waves, protection by breakwaters is important. In § B.2 a description is provided of the motivation per wave direction. It can be concluded that penetration of waves originating especially from west and north are unfavourable, above all from the range N-NW. Also protection from easterly waves is preferred. A breakwater at the east side will have the advantage of preventing siltation of the approach channel. It should therefore be lengthened until the end of the breaker zone, situated at about MW - 8.9 m. In Figure 5-4 a schematisation is provided of the possible main configurations.

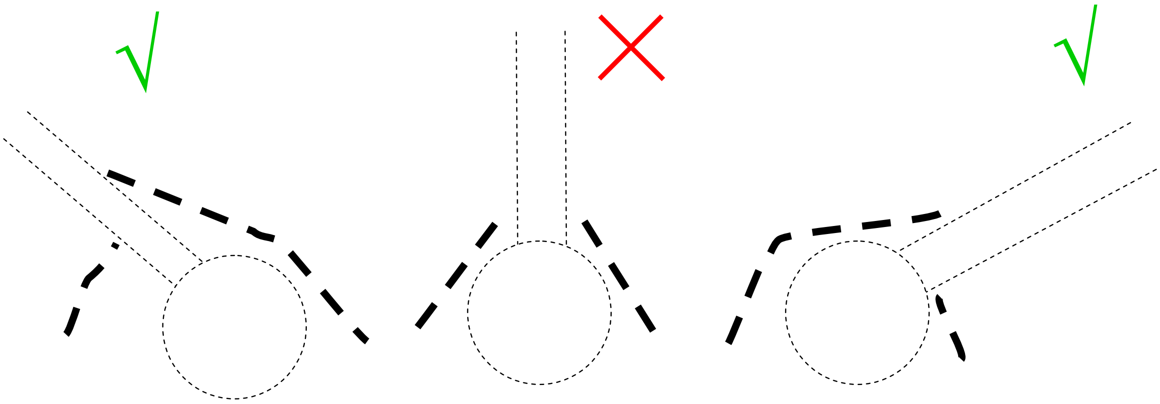


*Figure 5-4 Schematisation of possible configurations of approach channel, turning circle and breakwaters*

Thorough optimisation of the configuration is of course needed. Except from accessibility, care should be taken of the required stopping length of 750 m, sufficient space in the harbour basin and the implementation of the berths with corresponding lengths.

**Structure type**

Choice for a breakwater structure type has to be made on basis of costs, building method, availability of material & equipment, and on experience of local labour. The breakwater will reach a maximum depth up to about MW - 15 m. Several construction types are available, of which a rubble mound breakwater and a caisson type are most realistic. A combination in the form of a composite breakwater is also an option. A floating breakwater is not an option because it is not effective against the long waves approaching Filyos. Because of the depth and the availability of rock in Turkey a rubble mount breakwater seems most attractive.

### *5.2.3 Harbour basin*

The wet area within the breakwaters forms the harbour basin. Inside this basin a possibility to turn is required for further navigation to the berths, which are usually accommodated in a berthing area. Below the calculated minimum dimensions are presented. More information can be found in § B.3.

**Turning circle**

Thoresen (2003) recommends a minimum of 2 * LOA in case tug boats are available. This corresponds to a diameter of **600 m**. The required depth is set to LAT **-13.7 m** (see Table 5-2).

**Berthing area**

In case berthing structures are used parallel to each other, a berthing area is formed (see Figure 5-5). As a guideline, a width for such an area is needed of 4 to 5 * B + 100 m for **general cargo and container ships** (Ligteringen, 2009). Because of intermediate wind conditions a factor 4.5 is considered sufficient. E.g. for a container II ship this results in **283 m**.

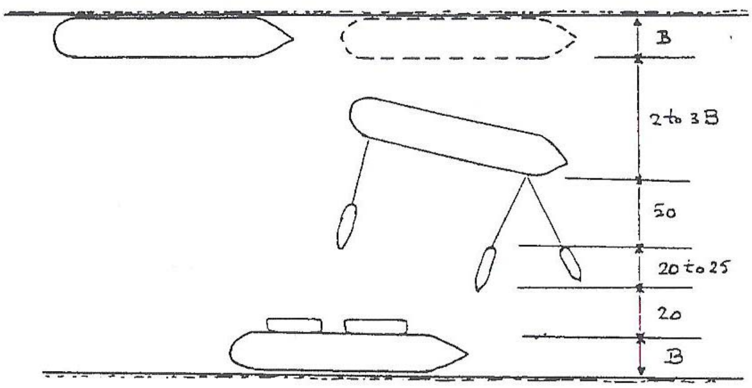



*Figure 5-5 Berthing area width (Ligteringen, 2009)*

### *5.2.4 Berths*

In this sub-paragraph the number of berths and corresponding dimensions are provided. Furthermore, an overview of possible structure types is given. More detailed information about the berth calculations can be found in § B.4.

**Dimensions**

The required number of berths is calculated using the queuing theory, provided by Groenveld (2002). Subsequently, the total berth lengths per cargo type are derived with the use of theory from UNCTAD (1985). For the bottom depth an extra margin is determined above the maximum ship draft, of which results are presented in Table 5-2.

*Table 5-2 Berth amount and dimensions per cargo type and project phase*

| Cargo type | # Berths | Total berth length (m) | Bottom depth (meter below LAT) |
|---|---|---|---|
| **Phase I** | | | |
| Dry bulk:<br>Iron ore & coal | 1 | 245 | 13.7 |
| Dry bulk:<br>Sand, gravel & fertilizers | 1 | 200 | 11.7 |
| General cargo | 2 | 335 | 12.7 |
| Container | 1 | 230 | 10.7 |
| **Total** | **5** | **1,110** | |
| | | | |
| **Phase II** | | | |
| Dry bulk:<br>Iron ore & coal | 1 | 245 | 13.7 |
| Dry bulk:<br>Sand, gravel & fertilizers | 1 | 200 | 11.7 |
| General cargo | 3 | 490 | 12.7 |
| Container | 2 | 570 | 13.7 |
| **Total** | **7** | **1,505** | |

The ships need assistance by 2 tugboats, as determined in § B.1.1. Considering the approximate length of 50 m, a total berthing length of **150 m** is here fore taken into account.

Due to their limited size tug boats are vulnerable for short waves, which are easily able to penetrate into the harbour basin. Therefore it is better to place the berths further inwards into the harbour basin. In order to provide service to the ships at the anchorage area, the distance to the harbour entrance should however not be too long.

**Structure types**

The following types of berths are optional:

- Quay, marginal or over entire ship length;
- Jetty, nearshore or offshore (in combination with trestle);
- Dolphin berth;
- Deep sea unloading berth.

**Preferred location**

The location of the berths is preferably in the shadow zone of the breakwaters. This will reduce the wave heights at berth, resulting in higher operation ability for loading and unloading. In Table E-1 the limiting wave height criteria for operations are provided. Handling of container cargo is most vulnerable for incident waves, causing downtime in case $H_S$ exceeds 0.5 m. An $H_S$ exceeding 1.0 m is not allowed for any berth operation.

In Table E-1 a distinction is made between waves approaching parallel (0°) to the berth and with an incident angle varying 45-90° with the axis of the ship. In Figure 5-6 an overview is presented of the preferred berth orientation with respect to waves. The same preference holds for incoming waves and currents. Although, the latter will be reduced significantly because of the presence of breakwaters. The criteria according to OCIMF (1997, op.cit. Ligteringen, 2009) for allowable current velocities, of 3.0 and 0.75 knots for respectively parallel and perpendicular orientation, will be met.

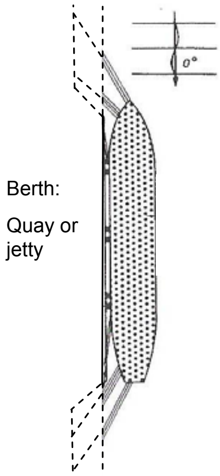



*Figure 5-6 Minimisation of incident wave, wind and current angle at berth*

### 5.2.5 Terminal areas

The port requires a terminal area for bulk and general cargo of which 17% is put in containers in 2020. Therefore also a small container area is required from the start of operations. From then onwards, an increase of containerised general cargo is expected up to 50% in 2030. The calculations for the required terminal storage areas can be found in § B.5. An important input in the calculations is the choice of handling equipment, of which an overview is provided in § 4.4.

**Storage & total areas**

Based on the yearly throughput and cargo properties the needed storage areas are determined according to Ligteringen (2009). In Table 5-3 the total areas required for storage are presented. Also account must be taken for the apron area, inner lanes, transfer areas and buildings. A **factor of 1.5** is used to take this extra surface into account. A specification of the storage areas per commodity is provided in the next section.

*Table 5-3 Storage and total area required per cargo type (ha)*

| Cargo type | 2020 Storage | 2020 Total | 2030 Storage | 2030 Total |
|---|---|---|---|---|
| Dry bulk | 2.3 | 3.5 | 3.3 | 5.0 |
| General cargo | 6.7 | 10.1 | 9.0 | 13.5 |
| Container | 3.1 | 4.7 | 18.3 | 27.5 |
| **Total** | **12.1** | **18.2** | **30.6** | **46.0** |

**Specification of storage areas**

*Dry bulk*

The results of the gross storage areas required for the dry bulk commodities are provided in Table 5-4.

*Table 5-4 Minimum storage areas dry bulk in 2020 and 2030 (ha)*

| Storage area | Iron ore | Sand & gravel | Fertilizers | *Coal (intermediate area)* | Total |
|---|---|---|---|---|---|
| $O_{2020}$ import | 0.09 | 0.18 | 1.35 | *5.00* | 1.62 / *6.62* |
| $O_{2020}$ export | 0.00 | 0.67 | 0.01 | *0.00* | 0.68 |
| **Total 2020** | *0.09* | *0.85* | *1.36* | *5.00* | **2.3 / 7.3** |
| $O_{2030}$ import | 0.09 | 0.34 | 1.36 | *5.00* | 1.79 / *6.79* |
| $O_{2030}$ export | 0.00 | 1.49 | 0.02 | *0.00* | 1.51 |
| **Total 2030** | *0.09* | *1.83* | *1.38* | *5.00* | **3.3 / 8.3** |

Note

The required area for the dry bulk terminal is small, because the main commodity coal will directly be transported to the power plant. An enhanced conveyor belt system is needed to guarantee continuous transportation over the long distance to the power plant. In case this cannot be fulfilled an intermediate storage area of **5** hectares is required in case of calamity. Therefore this amount of space is reserved in the layouts.

*General cargo*

The results of the gross storage areas required for the general cargo commodities are provided in Table 5-5.

*Table 5-5 Minimum storage areas for general cargo in 2020 and 2030 (ha)*

| | Metal | Agricultural | Food | Chemicals | Machinery & other | Total |
|---|---|---|---|---|---|---|
| $O_{2020}$ import | 0.26 | 0.54 | 0.28 | 1.26 | 1.88 | 4.22 |
| $O_{2020}$ export | 0.15 | 0.18 | 0.03 | 0.82 | 1.34 | 2.52 |
| ***Total 2020*** | *0.41* | *0.72* | *0.31* | *2.08* | *3.22* | **6.74** |
| $O_{2030}$ import | 0.15 | 0.53 | 0.27 | 2.21 | 2.02 | 5.18 |
| $O_{2030}$ export | 0.09 | 0.20 | 0.04 | 1.41 | 2.06 | 3.80 |
| ***Total 2030*** | *0.24* | *0.73* | *0.31* | *3.62* | *4.08* | **8.98** |

*Containers*

The results of the gross storage areas required for the containers are provided in Table 5-6.

*Table 5-6 Required gross container storage areas per stack type for 2020 and 2030 (ha)*

| Stack type | 2020 | 2030 |
|---|---|---|
| Import | 1.75 | 8.67 |
| Export | 0.13 | 2.17 |
| Empties | 1.06 | 6.32 |
| CFS | 0.15 | 1.15 |
| **Total (ha)** | 3.09 | 18.31 |

### 5.2.6 Rail, road and landside port access

In § B.6 the rail and road traffic and required capacity are estimated. The drawn conclusions are provided below.

**Rail**

About 10 trains per day on average will enter and leave Filyos. It is concluded that the rail line to Karabük, which will be electrified, will provide sufficient capacity for the forecasted throughput of coal, steel and iron ore products. Moreover, at the dry bulk terminal one railway line will fulfil the transport demand. There will be a marshalling yard at the dry bulk terminal.

**Road**

For the road to and from Filyos an average traffic density of about 1,150 trucks per day is expected. The hourly peak traffic may be significantly higher. One road with two lanes is considered sufficient for the traffic.
At the gates it is estimated that about 4 lanes are required for trucks. Because of the separate general cargo and container terminal, no congestion is expected at the terminal roads and truck marshalling yards.

**Miscellaneous**

Next from the required areas for the terminals, **4** hectares are reserved for the port authority, parking area, technical services and the entrance building.

# 6 LAYOUTS

This chapter comprises the design of the port layouts. In the first paragraph layouts are developed based on the analysis provided in the previous chapters. A selection of the most promising alternative is refined in the subsequent paragraph to derive the best layout.

## 6.1 Layout development

### *6.1.1 Introduction*

Based on the previous analysis different layouts are made. Evaluation is done based on the functional requirements. Furthermore, the coast morphological impact and capital costs are important criteria. To be complete, the criteria are enumerated below:

- Nautical accessibility
- Nautical safety
- Loading & unloading ability at berth
- Through transport and storage ability
- Robustness
- Coast morphological impact
- Capital costs

Capital costs are an important factor and can be influenced most in the first design step. The wet infrastructure, consisting of the approach channel, breakwaters, and harbour basin, constitute a major part of the overall investment. Costs for dredging and reclaiming of land are namely high, considering the soil volumes. Therefore an attractive balance needs to be found between the material quantities dredged and reclaimed. For these quantities is referred to Figure A-1. For the available space for the port location and facilities in the area is referred to Figure 4-1.

On basis of the described analysis and criteria, different sketches are made. In the next sub-paragraph the best layouts that resulted here from are discussed.

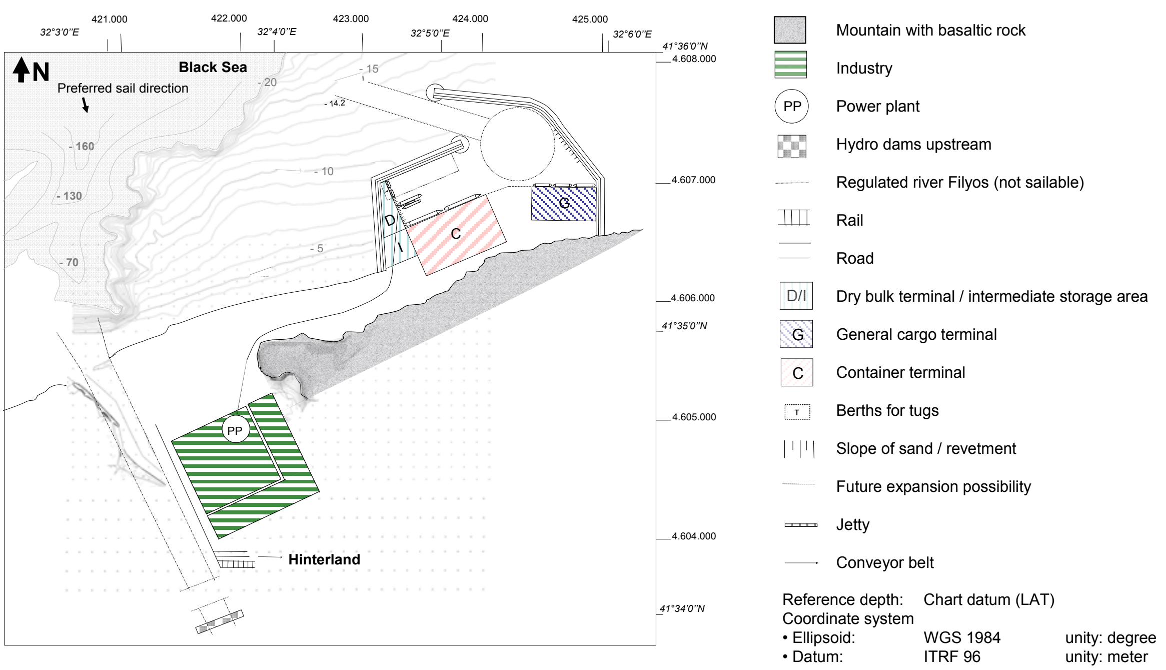
### *6.1.2 Layout alternatives*

From the sketch phase three best layouts resulted which are presented in Table 6-1. The layouts are significantly different, which makes a good comparison possible. The layouts are based on the required capacity for 2030 (phase II). For the layout drawings on A3 format is referred to Appendix C.

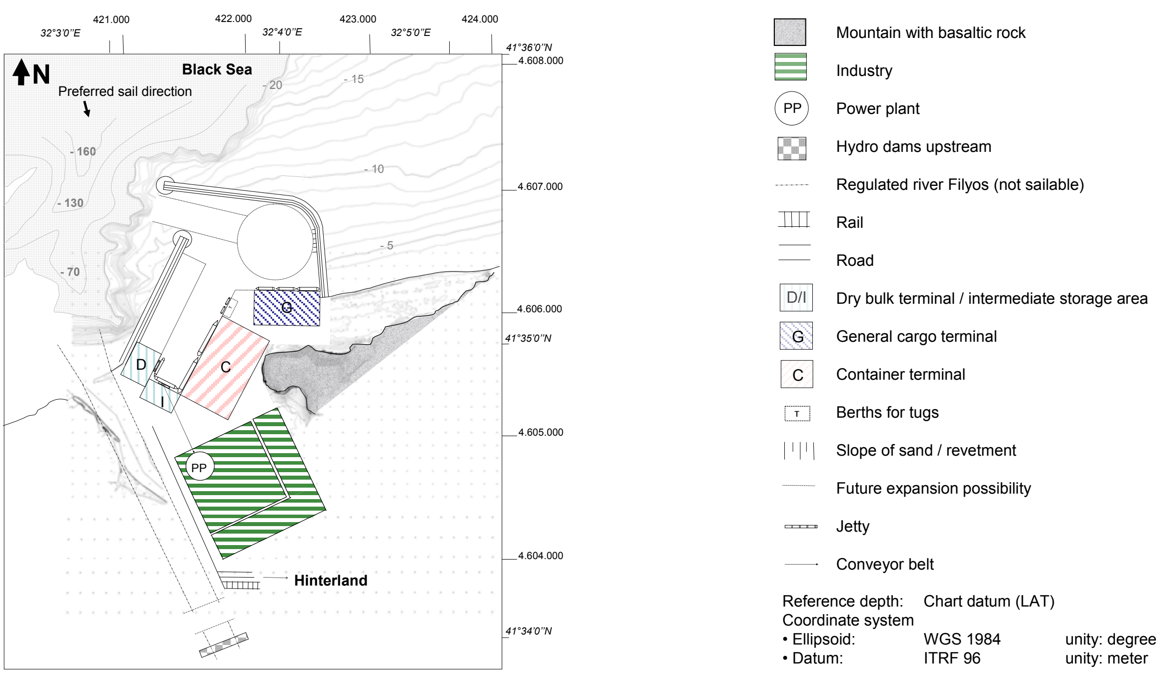
In the next sub-paragraph the properties of these layouts are evaluated, followed by a selection.

*Table 6-1 Port layout alternatives A-C, phase II (2030)*

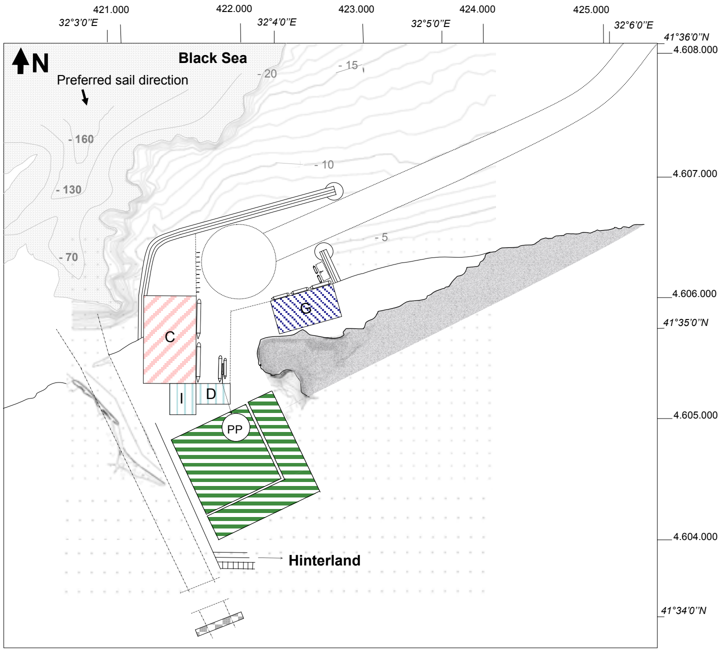
Alternative A




Alternative B



Alternative C




**Legend**

Mountain with basaltic rock

Industry

PP Power plant

Hydro dams upstream

Regulated river Filyos (not sailable)

Rail

Road

D/I Dry bulk terminal / intermediate storage area

G General cargo terminal

C Container terminal

T Berths for tugs

Slope of sand / revetment

Future expansion possibility

Jetty

Conveyor belt

| | | |
|---|---|---|
| Reference depth: | Chart datum (LAT) | |
| Coordinate system | | |
| • Ellipsoid: | WGS 1984 | unity: degree |
| • Datum: | ITRF 96 | unity: meter |

### 6.1.3 Evaluation of alternatives

In this sub-paragraph a **qualitative** multi criteria evaluation is presented. First a description per criterion is provided of the alternatives, as presented in Table 6-1. For more detailed information of the layouts is referred to Appendix C.

**Description per criterion**

*Nautical accessibility & safety*

The nautical accessibility and safety are strongly interrelated and are therefore considered as one criterion. Less hindrance by waves, wind and currents leads both to a better accessibility and safety of nautical operations.
Alternative A and B have an orientation WNW which is more or less in line with the nautically favourable route, considering the wave and wind climate. Cross currents will be faced, from the prevailing western and eastern direction, but are however in an acceptable low range (see § 2.3.8). For alternative C navigation is more difficult due to the cross waves, which are especially faced after the ship has passed the approach channel bend.

*Loading & unloading ability at berth*

The climate of waves, wind and currents at the berth influence the ability for loading and unloading of cargo. Since breakwaters are present, currents have a too low velocity to hinder operations at berth. Focus is therefore laid on the wave climate.
Considering the climate, with dominant waves from the range NW-N, alternative C has the best shelter against penetration of waves. The conditions for alternative A and C are comparable and have a vulnerable harbour entrance orientation with respect to the wave climate. Disturbance may become critical, which needs to be evaluated.

*Through transport & storage ability*

Regarding ease of through transport, a port location close to the power plant and hinterland connection facilities is wanted. It ensures a short transit time and low investment and maintenance costs for the transport modalities. From this point of view alternatives B and C are most attractive, because alternative A is situated 2 km eastwards and is bordered by the mountain range. In the later case longer distances and bends in the transport routes are required.
With respect to the storage ability, all layouts are designed on the same storage capacity and have the same shape of storage area. Distinction on basis of this sub-criterion is therefore not made.

*Robustness*

Alternative A provides an expansion facility for all terminals. Future extra berth lengths are possible over a length of 695 m. Furthermore, extra terminal extension is possible over a length of 225 m. It has to be noted that no berths can be placed along this length because of the berthed dry bulk vessels at the jetty.

In alternative B a large berthing area can be created in the future. North from the dry bulk terminal, reclamation and berth extension is possible of 800 m. Moreover, extension of the container or general cargo terminal is possible with one berth.

Alternative C has good possibility for expansion inside and outside of the boundaries, which are determined by the breakwaters. Inside the boundaries, dry bulk and general cargo can expand with a quay length up to 690 m. North from the container terminal expansion is possible. North from the natural slope, which ensures safety for ships entering the harbour basin, a berth length of 200 m is available. This is suitable for small size dry bulk and general cargo ships.
Outside of the port a separate harbour basin can be created rather easily by lengthening the western breakwater and building a second eastern breakwater parallel to the existing one.

*Coast morphological impact*

As appears from the simulation results in the refinement step, environmental disturbance by coast morphological impact has no serious consequences. Erosion occurs namely at an area which has no recreational or industrial function (see Figure D-9). Therefore no distinction between layouts is made on this criterion.

**Capital costs**

In a later stage of the project it turned out that the single soil boring at the western part is representative for the area. For both alternative B and C these conditions are very unfavourable for foundation of the breakwater and part of the terminal. There should be dredged a layer of up to about 25 m of clay and silt, which is a very costly operation.

Alternative C, with an NE approach channel orientation, also has the disadvantage of high dredging costs. An extra approach channel length is required of about 1,500 m and a width of about 1*B (= 40.5 m), in comparison with alternative A and B. The latter are using the natural depth of the trough.
Furthermore, account should be taken of little maintenance dredging in alternative C. In order to reduce costs the eastern breakwater is kept short, with 350 m length. Maximum storms prevail from northwestern direction but yearly storms from east may however occur.

*Estimation method and results*

In § F.2 the costs of the alternatives are determined, of which the results are provided in Table 6-2. Volumes of dredging and reclamation and lengths of hydraulic structures are calculated in order to derive the costs. It is multiplied with a cost ratio to estimate the total capital costs. The high costs for alternative B and C are visible in Table 6-2.

*Table 6-2 Cost estimates for alternatives A-C*

| Alternatives | Dredging & excavation | Reclamation costs including breakwater foundations | Breakwaters | Quay walls | Jetties | Trestle | Total |
|---|---|---|---|---|---|---|---|
| A | € 21,893,000 | € 28,414,000 | € 170,400,000 | € 21,233,000 | € 3,600,000 | € 800,000 | € 246,340,000 |
| B | € 89,615,000 | € 150,239,000 | € 138,600,000 | € 21,233,000 | € 5,600,000 | € 0 | € 405,287,000 |
| C | € 143,113,000 | € 197,973,000 | € 154,200,000 | € 21,233,000 | € 3,600,000 | € 800,000 | € 520,919,000 |

Notes

A reduction of breakwater costs is made by application of a 4 m thick sub layer of sand under the construction. A slope of 1:20 is applied (see Figure F-1) which, even in case the sand is obtained from offshore, ensures a cost reduction.
Capital costs for landside infrastructure, superstructures and equipment (see Table 1-1) are excluded in the consideration.

**Scoring and conclusion**

To give an impression of the layout performance, a quick scoring is provided in Table 6-3. A conclusion is drawn afterwards.

*Table 6-3 Quick scoring of alternatives**

| Criteria | Alternative A | Alternative B | Alternative C |
|---|---|---|---|
| Nautical accessibility & safety | + | + | -- |
| Loading & unloading ability at berth | - | - | + |
| Through transport ability | O | + | + |
| Robustness | + | + | ++ |
| | | | |
| Capital costs | € 246.3 mln | € 405.3 mln | € 520.9 mln |

** In which: ++ excellent, + good, O moderate, - poor, -- bad*

The offered functionalities of alternative B and C are promising. From a cost point of view they are however unattractive. Especially alternative C has high accompanied costs because of the long approach channel required.

Alternative A has good soil conditions for building of the breakwaters, terminals and quay walls. Moreover, it has the preferred nautical access route. **Therefore alternative A is selected as most promising layout for further refinement**.

## 6.2 Layout refinement

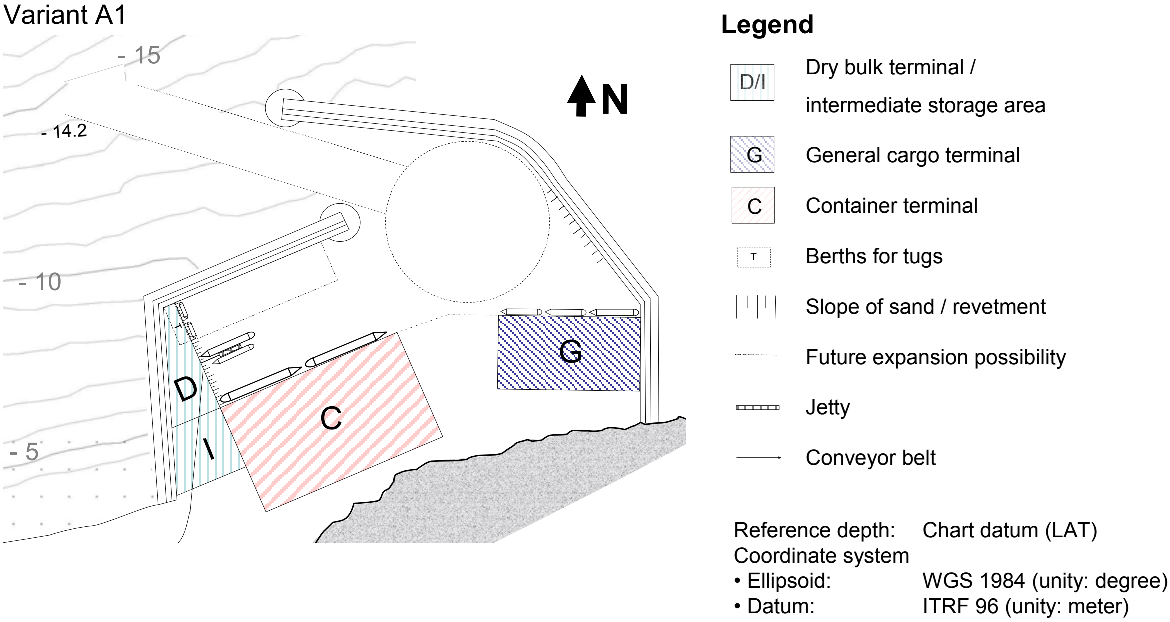
In this paragraph different layout configurations for the harbour basin of alternative A are presented. Various configurations of the terminals and berths are considered, of which three resulting layouts are provided in the first sub-paragraph. In the subsequent sub-paragraphs the simulations and evaluations are presented, followed by a selection of the best layout.

### 6.2.1 Layout variants

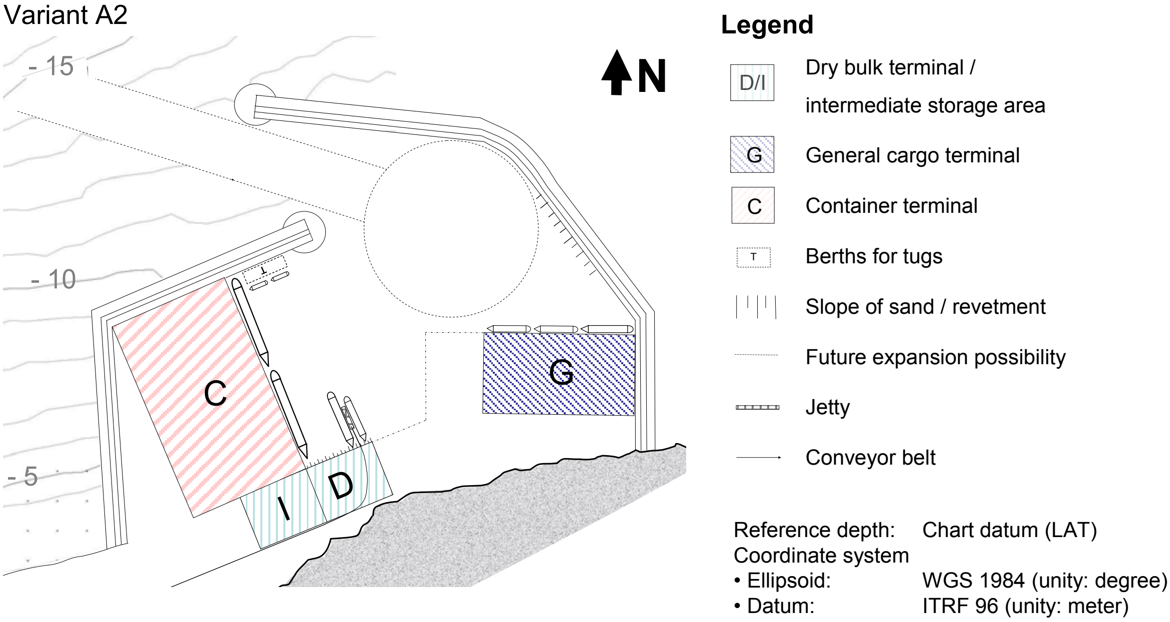
In Table 6-4 three variants are provided, of which variant A1 equals the layout presented in the previous step. All variants provide a location for container berths in the shadow zone of the breakwaters. Wave disturbance would otherwise exceed the maximum allowance of 5% downtime, following from the analysis in § E.4.2.

*Table 6-4 Port layout variants $A_{1\text{-}3}$; phase 2 (2030)*

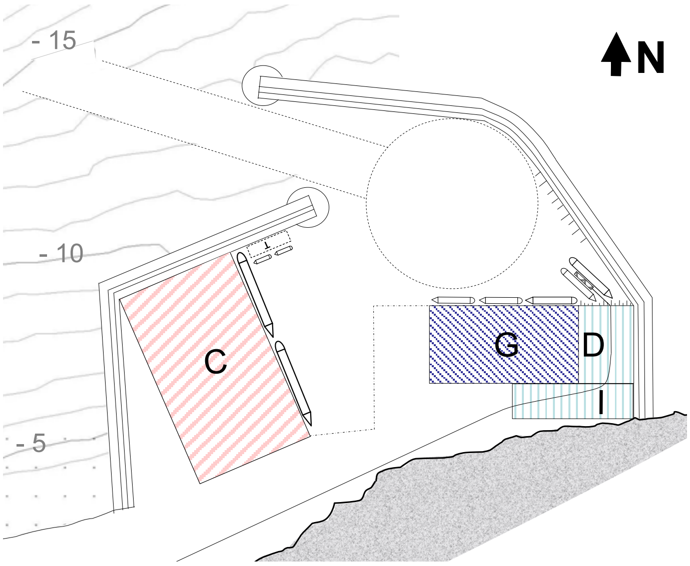
Variant A1




Variant A2



Variant A3




**Legend**

| | |
|---|---|
| D/I | Dry bulk terminal / intermediate storage area |
| G | General cargo terminal |
| C | Container terminal |
| T | Berths for tugs |
| | Slope of sand / revetment |
| | Future expansion possibility |
| | Jetty |
| | Conveyor belt |

Reference depth: Chart datum (LAT)
Coordinate system
• Ellipsoid: WGS 1984 (unity: degree)
• Datum: ITRF 96 (unity: meter)

### 6.2.2 Simulations

In this sub-paragraph the methods and results of the used models are presented.

**Coast morphological impact**

*Method*

To assess the impact of the port on the coastline a simulation is carried out with the use of the model UNIBEST-CL+. Below a short description is provided of the results. For more details and information about the model setup is referred to Appendix D.

*Results*

A schematisation of the coast with the port area and resulting coast line evolution is presented in Figure 6-1. The dominant eastward direction of longshore drift causes accretion at the west side of the guiding embankment. At the east side of the eastern breakwater erosion will occur.

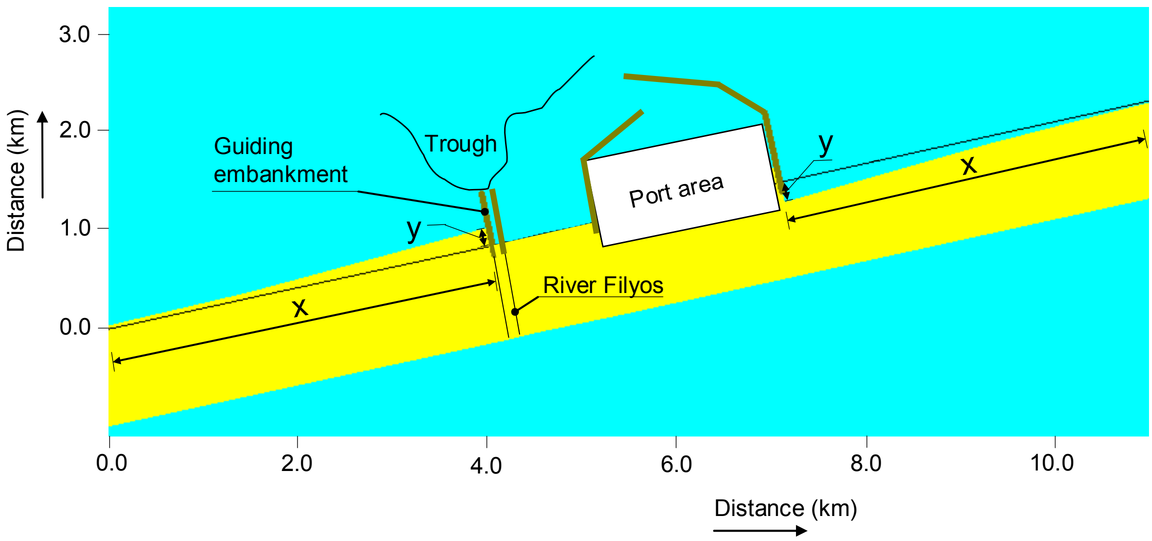



*Figure 6-1 Single line coastline evolution at Filyos after 50 years, with use of UNIBEST CL+*

Simulations show that the accreted zone progresses very slowly and **will not cause problems** for the port. After 200 years the length along the embankment (y) is estimated to be 314 m, which will not pass the end of the embankment.

The results for the erosion pattern are rather similar. Because the coastline is bordered by a mountain of basaltic rock, the erosion problem will shift about 2 km eastward; see Figure D-9. This beach provides a potential erosion width (y) of 400 m. Since this beach has no recreational or industrial purpose, erosion has no consequences. Further eastward, the coastline is curved and has a small incident angle with waves coming from the west. No erosion is therefore expected in this “activity free” area.

**Wave penetration**

*Method*

To analyse the harbour wave penetration, use is made of the model SWAN (Simulating WAves Nearshore). For explanation about the model is referred to Appendix E.

*Results*

The wave and wind direction causing the severest wave climate in the harbour are from western direction. An illustration of the simulations is provided in Figure 6-2, presenting the wave penetration for waves from direction 270-285° (N).

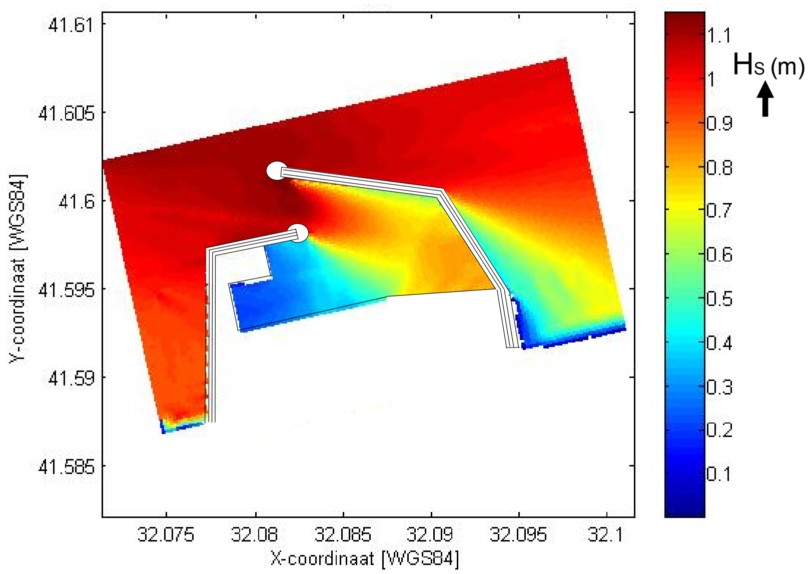



*Figure 6-2 Example of significant wave height in harbour, Dir. 270-285° (N); input u=7.2 m/s, Hs=1.25 m, Tp=7.2*

It is concluded that with this layout configuration it is not possible to place a container terminal in the eastern vulnerable area. Positioning berths for general cargo and dry bulk is however possible. General cargo will have a yearly downtime of about 2.1%. If a berth for dry bulk is placed at the eastern area the same percentage holds for unloading, which is set normative because of the considerable import of coal at Filyos.

Downtime percentages for container and dry bulk berths, in case placed at the west side of the harbour, are estimated to be respectively 1.8% and 0.7% per year.

Note

It must be noted that the effect of diffraction is not taken into account. SWAN does not include this effect properly. Because of the wide directional spreading, due to the wind sea dominated wave climate, wave heights and direction will differ from reality with acceptable low values (see § E.2.1).

### 6.2.3 Evaluation

On basis of the same criteria as in the previous paragraph an evaluation is carried out. This time it is a quantitative evaluation. Scores are given per criterion in a range of 1-5. To derive the corresponding total value, multiplication is done with a weight factor. This factor is used to include the importance of the criterion. On basis of the ratio of value over cost the best variant is selected.

**Description and scoring per criterion**

*Nautical accessibility & safety*

Regarding the SWAN simulations (see § 6.2.2), conclusions can be drawn about the nautical accessibility and safety. All variants have the same approach channel orientation, which is reasonably in line with the prevalent wave direction (see Figure 2-12). Inside the harbour there are differences in the accessibility. Especially the location of the dry bulk berths is considered in this respect. Below a short evaluation is provided.

With variant A1 bulk cargo vessels need to turn into the separate berthing area sharply and sail a distance of 800 m. In case land is reclaimed at the north area for expansion, indicated with striped lines, a more narrow space is left for manoeuvring of the vessels. This will cause a small reduction in safety.
Variant A2 a shorter distance must be travelled to the dry bulk berth and its future expansion than for variant A1. The future expansion will not hinder the accessibility.
Variant A3 in its turn provides the best accessibility for the dry bulk vessels, offering a berth close to the turning circle.

The following scores for this criterion are assigned for the variants:
A1 3.5
A2 4.0
A3 4.5

*Loading & unloading ability at berth*

The climate of waves, wind and currents at the berth influence the ability for loading and unloading of cargo. Since breakwaters are present, currents have a too low velocity to hinder operations at berth. The analysis of wind influence is left out of the scope and focus is laid on the wave climate. The berths for container ships, which are most vulnerable for wind because of their height above water, are however in line with the prevalent wind directions.

The location and orientation of the berths in the harbour with respect to the wave climate is considered here. This is based on Figure 6-2, which provides the wave climate during a critical angle of wave incidence into the harbour. Because the harbour configuration only differs in the shadow zone of the breakwaters, it enables a reliable analysis.

Variant A1 and A2 both have container and dry bulk berths situated in the shadow zone of the breakwaters. Due to the overlap of the breakwaters, little attenuation of waves is visible in this area. The berths for general cargo will be most vulnerable for the wave climate. With a percentage of 2.1% the downtime does not hinder port operations.

Variant A3 has the jetty for dry bulk vessels in the eastern part of the harbour, which is vulnerable. At this location it has the same downtime percentage as general cargo.

The following scores for this criterion are assigned for the variants:
A1 4.0
A2 4.0
A3 3.0

*Through transport & storage ability*

The location of the terminals determines the required distances of transport and bends in the route. From a cost and time point of view, short and straight transport lines to the hinterland are wanted; for road, rail and conveyor belt.

Variant A1 and A2 both have the container and dry bulk terminal situated at the west side of the port. Required lengths and amount of bends of the conveyor belt are rather equal. Variant A1 has the slight advantage of container orientation at the terminal, since through transport is possible without turning the containers.
At variant A3 the dry bulk terminal is situated in the east corner of the port. A long conveyor belt is required, which is unfavourable.

With respect to the storage ability, all layouts have comparable shapes of the storage areas. No distinction on this sub-criterion is therefore made.
The following scores for through transport ability are assigned for the variants:
A1 3.5
A2 2.5
A3 2.0

*Robustness*

There is regarded to the possibility for future expansion into the port boundaries, enclosed by the breakwaters.

Variant A1 has possibility to expand all terminal types. Future extra quays are possible over a length of 695 m. Furthermore, extra terminal extension is possible over a length of 225 m.
Variant A2 has possibility for expansion of the dry bulk and general cargo terminal. A quay length of 370 - 500 m and sufficient accompanied land area are available. For realisation of a container berth at this place more area would be preferred directly behind the quay (400-500 m).
Westward from the container terminal, in the triangular shaped area, expansion of the container storage area is possible.
The expansion possibilities of variant A3 are comparable with A2. A larger quay length in the range of 605 - 680 m is however possible.

The following scores for this criterion are assigned for the variants:
A1 4.0
A2 3.0
A3 3.5

*Coast morphological impact*

There are no clear differences between the outer contours of the variants. No distinction is made on basis of this criterion.

**Costs**

The costs for the layout variants differ on basis of breakwater and quay length. There are also differences in dredging volumes for the harbour basin. These are elaborated in § F.2, of which the results are presented in Table 6-5. Costs for landside infrastructure, superstructures and equipment (see Table 1-1) are excluded.

*Table 6-5 Cost estimates variants A,1-3*

| Variants | Dredging | Reclamation costs including breakwater foundations | Breakwaters | Quay walls | Jetty | Trestle | Total |
|---|---|---|---|---|---|---|---|
| A1 | € 21,893,000 | € 28,414,000 | € 170,400,000 | € 21,234,000 | € 3,600,000 | € 800,000 | € 246,341,000 |
| A2 | € 26,735,000 | € 20,352,000 | € 170,400,000 | € 21,234,000 | € 3,600,000 | € 800,000 | € 243,121,000 |
| A3 | € 23,633,000 | € 27,576,000 | € 170,400,000 | € 21,234,000 | € 3,600,000 | € 800,000 | € 247,243,000 |

**Weight factors**

In this appendix weight factors are assigned to indicate the importance of criteria used in the MCE. To derive these factors a table is made in which the criteria are compared to each other. A cell is given the number 1 if the row criterion is more important than the column criterion. Otherwise the value 0 is given. In case of the same importance, the number 0.5 is assigned.

*Table 6-6 Weight factors for the different criteria **

| | Nautical accessibility & safety | Loading & unloading ability at berth | Through transport ability | Robustness | Total |
|---|---|---|---|---|---|
| Nautical accessibility & safety | x | 0.5 | 1.0 | 1.0 | **2.5** |
| Loading & unloading ability at berth | 0.5 | x | 1.0 | 1.0 | **2.5** |
| Through transport ability | 0.0 | 0.0 | x | 0.5 | **0.5** |
| Robustness | 0.0 | 0.0 | 0.5 | x | **0.5** |

** The robustness of the design is considered more important than results from this analysis. Therefore 1 point is added to this criterion, resulting in a weight of **1.5**.*

**Results**

In Table 6-7 the results of the MCE are provided. The weight factors are multiplied with the scores given per criterion to derive the value. From the total value and costs, the ratio is determined to select the best alternative.

*Table 6-7 Total values and costs of variants*

| **Criteria** | **Weight** | **Variant A1** | | **Variant A2** | | **Variant A3** | |
|---|---|---|---|---|---|---|---|
| | | **Score** | **Total score** | **Score** | **Total score** | **Score** | **Total score** |
| Nautical accessibility & safety | 2.5 | 3.5 | 8.75 | 4.0 | 10 | 4.5 | 11.25 |
| Loading & unloading ability at | 2.5 | 4.0 | 10.0 | 4.0 | 10 | 3.0 | 7.5 |
| Through transport ability | 0.5 | 3.5 | 1.75 | 2.5 | 1.25 | 2.0 | 1.0 |
| Robustness | 1.5 | 4.0 | 6.0 | 3.0 | 4.5 | 3.5 | 5.25 |
| **Total value** | | | 26.5 | | 25.75 | | 25 |
| **Capital costs** | | | € 246.3 mln | | € 243.1 mln | | € 247.2 mln |
| **Value / cost** | | | **0.108** | | 0.106 | | 0.101 |

**It can be concluded that variant A1 has the highest value over cost ratio and is therefore considered best.**

# 7 CONCLUSIONS & RECOMMENDATIONS

## 7.1 Conclusions

This paragraph provides the conclusions that result from the thesis study. In the first sub-paragraph the procedure and most determining characteristics of layout development and selection are presented. In the second sub-paragraph the properties of the final layout are presented.

### *7.1.1 Layout development & selection*

**Layout alternatives**

Three significantly different layouts are developed and assigned a value, based on simulations and engineering judgement. All fulfil the requirements and design guidelines. The approach channel orientation has a high influence on the outcome of the evaluation. A WNW and ENE orientation are considered realistic and are implemented in the designs. The WNW orientation has the most favourable route from a nautical point of view. Furthermore, it has the advantage of using the present depth of the nearby trough. The ENE orientation provides a better expansion possibility outside of the breakwaters, in case positioned close to the trough.
Another important factor is formed by the soil conditions. Locating the port close to the trough, which is favourable from a through transport point of view, is accompanied with high costs to improve the soil.

On basis of a qualitative MCE and capital cost estimation alternative A turned out to be the most promising.

**Layout variants**

For the chosen alternative different layout configurations for the harbour basin and terminals are developed. The same location of the port and approach channel alignment is considered herewith. In the evaluation a quantitative MCE is carried out as well as estimation of capital costs. Both value and cost of the layout variants are in the same range. Variant A1, which is equal to alternative A, has turned out to have the highest value over cost ratio and is therefore considered best. In Figure 7-1 this layout is presented; for a more detailed view is referred to Figure C-1.

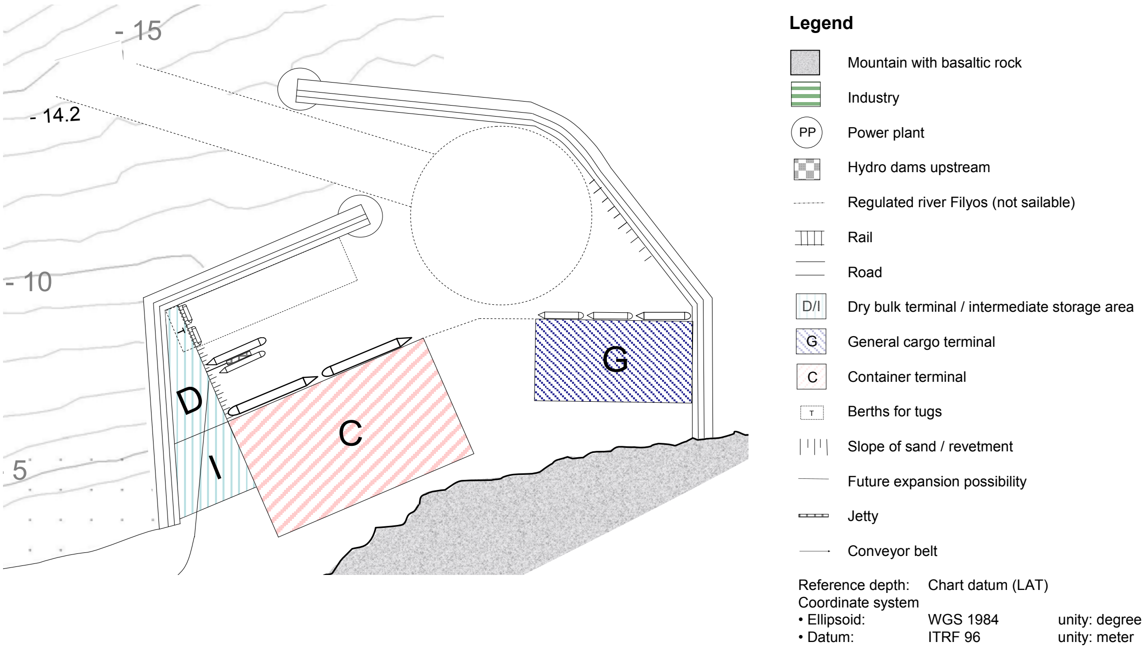



*Figure 7-1 Layout alternative A / variant A1, with highest value over cost ratio*

### *7.1.2 Final layout properties*

**Port components**

- Two breakwaters are implemented in the design in order to have maximum operation ability at the berths, during severe wave conditions.
- A one-way approach channel is considered sufficient for the forecasted amount of ship passages. The orientation of the channel is WNW, which is considered as optimum in terms of nautical accessibility and penetration of waves in the harbour.
- For the 3 general cargo and 2 container berths quay structures are applied. For the 2 dry bulk berths is chosen for a two sided jetty construction in combination with a trestle, for land connection.
- The capacity of berths and terminals fulfils the requirements set for the foreseen median scenario throughput of cargo until the year 2030.
- Estimated maximum design wave height ($H_S$) for the breakwater (1/225 yr) is 6.9 m in combination with a Tp of 12.4 s.
- Quay walls are constructed at a level MW +2.3 m. With a harbour basin depth of MW - 13.7 m a retaining height of 16 m results.

**Operation ability**

Analysis of harbour wave penetration by the model SWAN has provided insight in the operation ability of loading and unloading at berth, with respect to the wave climate. The general cargo berths are situated in the vulnerable eastern part of the harbour. An annual downtime of about 2.1% is expected according to the analysis. The same percentage holds for dry bulk operations, in case it is placed at this area.

Downtime percentages for container and dry bulk berths, in case placed at the west side of the harbour, are estimated to be respectively 1.8% and 0.7% per year.

**Robustness**

The layout provides an expansion facility for all terminals. Future extra quays lengths are possible over a total length of 695 m. Furthermore, extra terminal extension is possible over a length of 225 m, which is situated next to the dry bulk jetty.

**Coast morphological impact**

The morphological consequences for the coast are acceptable. The accreted zone at the left of the river guiding embankment will progress very slowly and will therefore not pass the head of the embankment during the foreseen operational period of 50 years for the port and later onwards. Moreover, sediment passing the embankment will mostly drop into the trough. Erosion will occur 2 km east from the port area. Because it is an activity free area, this is not problematic.

**Capital costs**

Estimation of capital costs have been carried out for the different layouts, with respect to the wet infrastructure, including hydraulic structures, and with the reclamation of land for the terminals. Investments on extra quay walls required from the year 2020 are postponed. Other investments are done from the start. The estimated capital costs amount € 246.3 million.

## 7.2 Recommendations

This paragraph provides an overview of different recommendations for further study for the port.

**Port components**

- Reassess the vessel traffic at least for the years after 2030. With a high sensitivity throughput scenario, scenario HS (see § 2.2.1) a two way channel may be needed before this year.
- Apply a simulation model to make a better estimation of the inter-arrival and service time of the ships.
- The option for yearly dredging and for an artificial sand by-pass system can be considered instead of building the eastern breakwater. About 3% of downtime needs to be accepted in this case. A cost benefit analysis should be made to make a decision.
- Consider a higher depth to draft ratio for the channel, in order to lower the required bottom width.
- A combined general cargo and container terminal (multipurpose terminal) can be considered in the beginning.
- Optimise the proposed ship-to-shore and terminal handling equipment.

**Wave penetration study**

- Use of a phase resolving model, like Bousinesq. The program Pharos of Deltares is most capable of taking into account diffraction and possible harbour resonance. Or alternatively, include diffraction patterns for two breakwaters. The model DIFFRAC from Deltares is capable for this purpose. Also the use of an application developed by RIKZ (2004) is an option.
- The effect of transmission and reflection of the breakwaters on the harbour wave climate should be further assessed. More information about the hydraulic structures is therefore required.
- Use wave data of longer period from buoy, or use a computer with high calculating processor for hindcasts in order to have long term operational conditions.
- Model the ship movement on basis of ship characteristics, elastic properties of fender and hawsers for more precise determination of the operational conditions.
- Refinement of harbour entrance and inner layout.
    - Optimisation of the breakwater orientation and length with wave modelling.
    - Optimisation of berth orientations with respect to wind.

**Morphology**

- To have a better estimation of the morphological processes, the influence of the trough and the river sediment should be taken into account. Therefore a more complex model is required, using the multiple line theory.
- The use of longer term wave conditions. In this case the 2 year recordings by the buoy are considered representative for the annual average conditions.
- Obtain and use site specific grain diameters ($D_{50}$ and $D_{90}$) along the cross-shore profile.

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| [8] | News site | *http://www.abc.net.au* |
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# APPENDIX A PHYSICAL CONDITIONS

In this appendix approximations are provided with respect to the physical conditions. It is fundamental for the information presented in § 2.3.

## A.1 Offshore soil conditions

This paragraph provides information about the offshore soil conditions. In Figure A-1 on the next page cross- and long-shore profiles are presented, which are based on several CPT's and borings made; indicated in the figure along the profiles. A distinction is made between silt and sand layers, providing essential information for the location choice of the port. Required dredging volumes and balance of reusable sand can be based on this soil information.

The soil tests provide inside in the soil conditions east from the old river branch. West from this branch and offshore, tests were carried out in a later stage of the project. One test is presented in Figure A-2, of which the position is indicated in Figure A-1 with the sign "X". The soil layer at this location consists mainly of silty and sandy clay. In a later stage of the project it became clear that this test is rather representative for the area close to the Filyos River mouth.

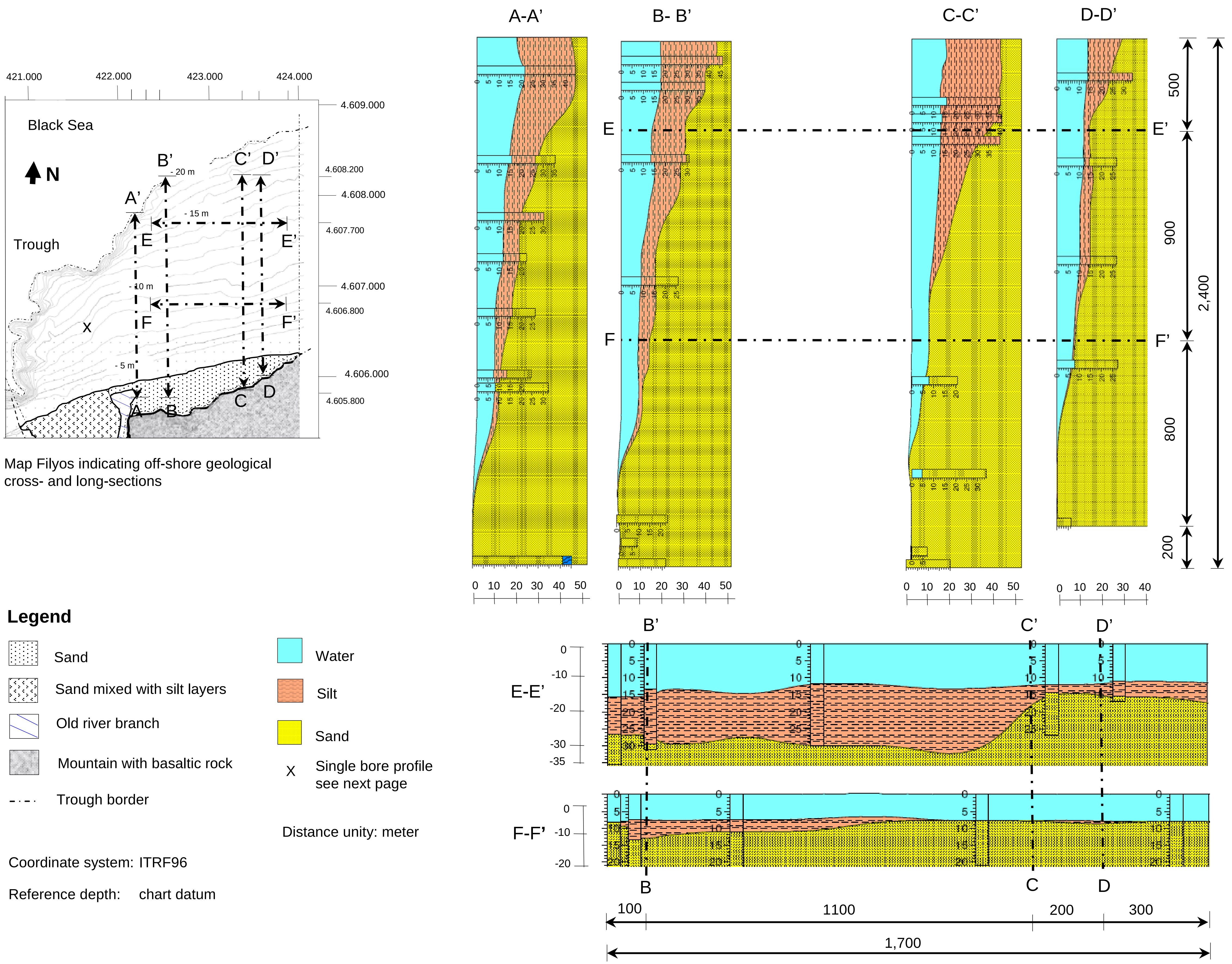
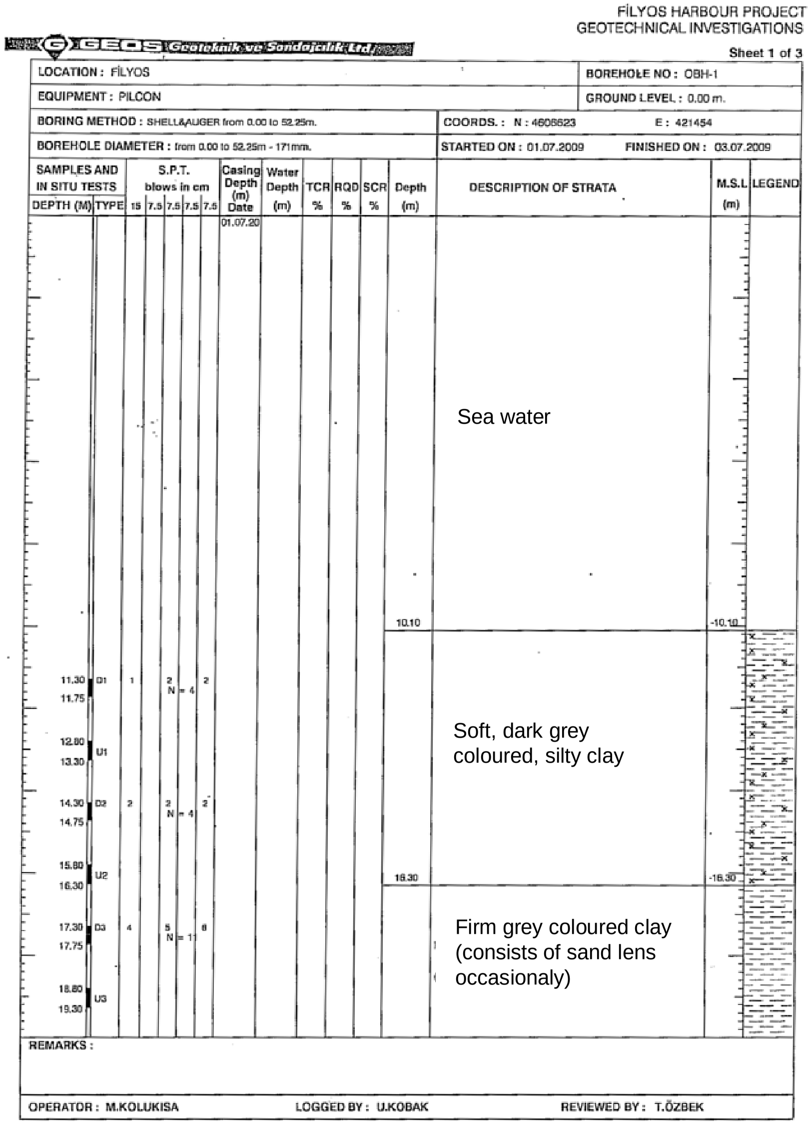



*Figure A-1 Map with long-shore and cross-shore sections presenting soil conditions; Rock Work results by Witteveen+Bos (2009)*

Supplement: single offshore boring, indicated on previous page



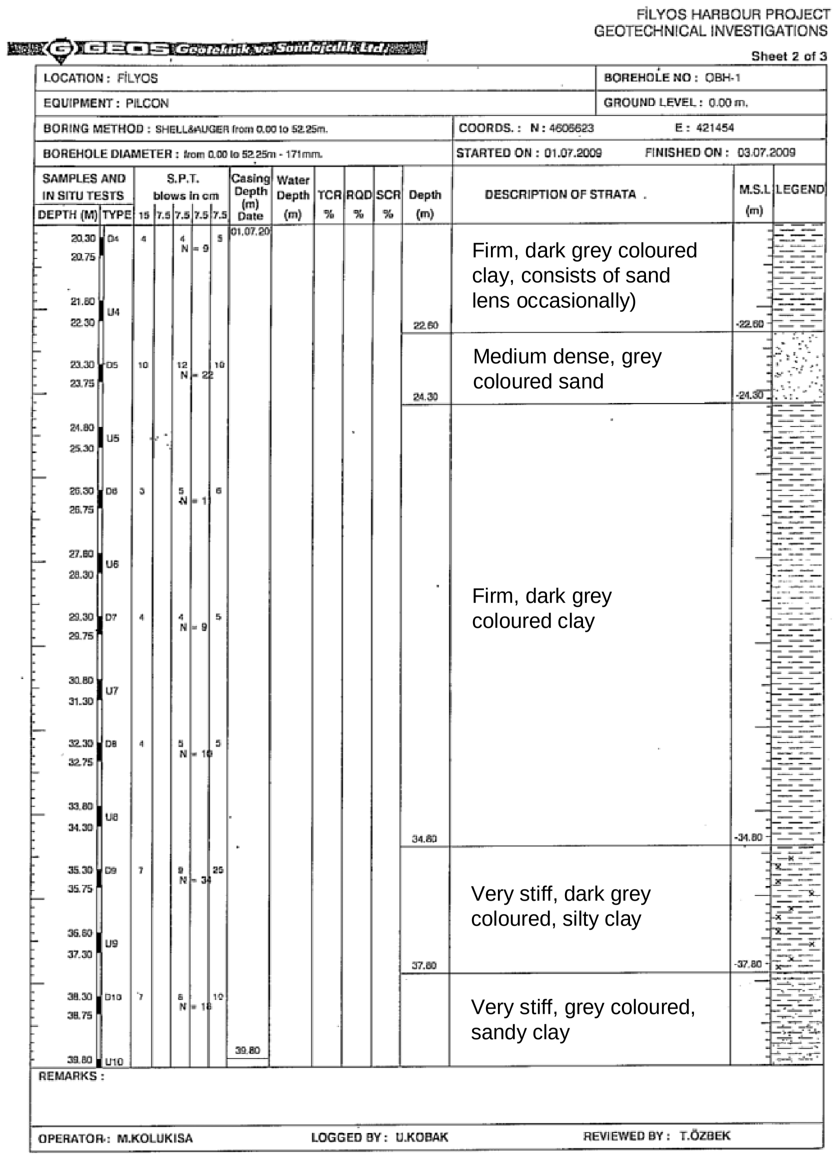




*Figure A-2 Off-shore boring profile; position indicated in Figure A-1 (Witteveen+Bos, 2009)*

## A.2 Extreme offshore wind conditions

For the design of quays and breakwaters information about the extreme water levels and wave heights is needed. These will be determined from the extreme wind conditions and bathymetry. The available offshore wind data of 8 years will therefore be extrapolated to derive extreme conditions in this paragraph.

### *A.2.1 Schematisation*

**Source location**

In front of Filyos long fetches can develop in the Black Sea, in which the water level will rise or fall under the influence of wind; called respectively wind set-up and draw-down. As a schematisation one offshore wind location (coordinates: 42° N 32° E, about 47 km from Filyos) is chosen that is representative for the different fetch lengths, see Figure A-4.

A correction factor of **1.3** is used for the wind velocity for reasons described in § 2.3.5. The period of available wind data is rather small to make a reliable extrapolation of the wind speeds per wind direction. Therefore the extreme wind speed is determined for all wind directions relevant for the project site: 255-90° (N).

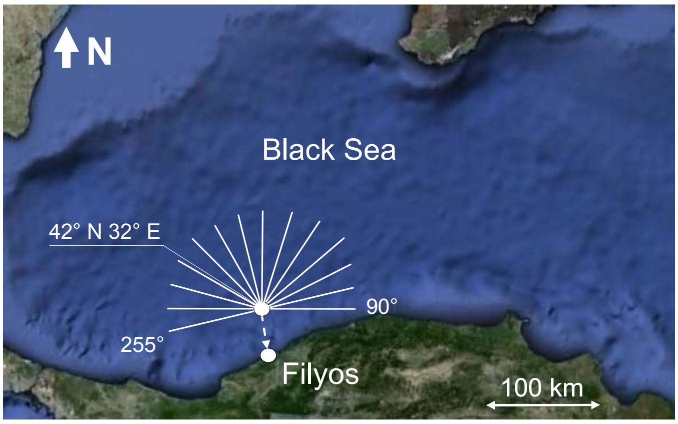



*Figure A-3 Location of normative wind for extreme conditions, with selected directional range 255-90° N*

**Approaches**

A primary condition for deriving the long term conditions is the independence of the recordings. However, consecutive high values within the same storms are statistically dependent. Therefore, two approaches are available to consider; namely the peak-over threshold and the annual maximum approach. Because for the latter a dataset of 20 years or more is preferred, a peak-over threshold approach is applied.

The Pareto distribution is based on the peak-over threshold approach. It provides the possibility for an objective fit, instead of fit by eye. Because of the use of three parameters a least square fitting technique is optional. In addition, inspection by eye is however wanted to verify that the fit is reasonable, in particular for high observed values which are of most interest.

### A.2.2 Peak-over-threshold

The extreme value theory tells that the distribution of the maximum in a sequence of values above a chosen threshold is the generalised Pareto distribution, according to Holthuijsen (2006). The value chosen for the threshold depends very much on the local conditions. The criterion is that a sufficient number of storms can be identified in the long-term period. For each such storm the maximum wind speed is then selected for the analysis.

The generalised Pareto distribution is given by (Holthuijsen, 2006):

$$\Pr\{\underline{U}_{10,peak} < U_{10,peak}\}_{threshold} = 1 - \left(1 + \left(\frac{\underline{U}_{10,peak} - A}{B}\right)\right)^{-1/C}$$

for $\underline{U}_{10,peak} \geq A$, if $C > 0$

for $A \leq \underline{U}_{10,peak} \leq A - B/C$, if $C < 0$

The parameter A is the threshold value, $A = H_{s,threshold}$. The parameter B (> 0) provides a normalisation (scaling) and the parameter C is a shape parameter.

The parameters are varied to derive a solid objective fit. By eye is checked whether the fit shows a reliable pattern. In Figure A-4 the results are plotted for a threshold value of 17.0 m/s; for the other parameters is referred to this figure.

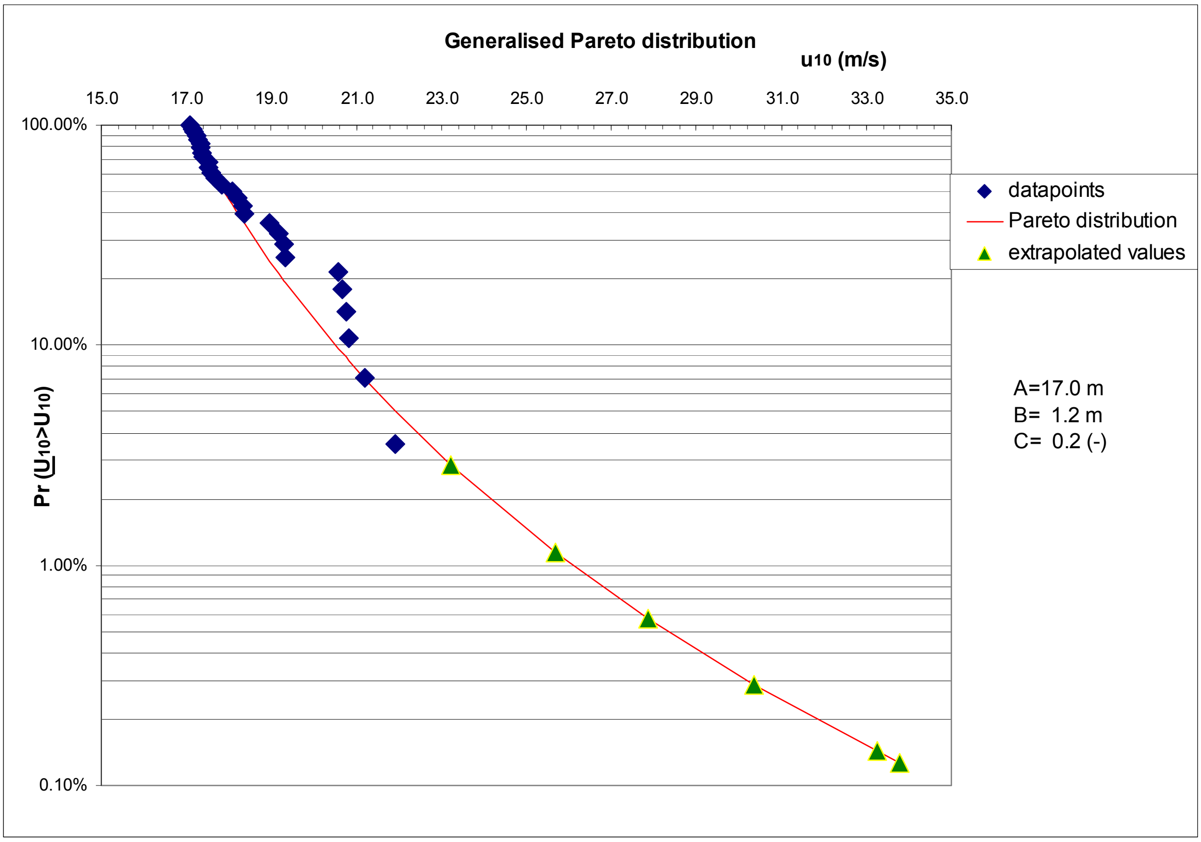



*Figure A-4 Long-term generalised Pareto distribution for 3-hour sustained wind speed (m/s). Location 42° N 32° E, directions 215° - 90° N, and threshold value 17 m/s*

**Note**

It is visible that there are two different trends in the datapoints. The six heighest values measured have a slightly different steepness. The amount of values is however very low as basis for a long-term distribution. Therefore a more conservative approach is chosen, in which the lower data points are included.

In Table A-1 the corresponding values of $u_{10}$ are provided for several return periods.

*Table A-1 Approximated wind velocities with the use of the Generalised Pareto distribution, waves in direction 255-90° (N)*

| Return period | $Pr\{\underline{u}_{10} > u_{10}\}$ (%) | $U_{10}$ (m/s) |
|---|---|---|
| 10 yr | 2.86 | 23.4 |
| 25 yr | 1.14 | 25.7 |
| 50 yr | 0.57 | 27.9 |
| 100 yr | 0.29 | 30.4 |
| 200 yr | 0.14 | 33.2 |
| 225 yr | 0.13 | 33.8 |

## A.3 Extreme nearshore wave conditions

For the breakwater design extreme wave conditions are required. This paragraph describes the method and results of wave translation based on the obtained wind conditions. Rough estimation is done for the design wave height and period in order to make a choice of breakwater structure. Moreover, capital costs of the structure are estimated with this information.

### *A.3.1 Input*

Based on the extreme wind velocities presented in the previous paragraph, for directions 255°-90° (N), nearshore deep water waves are approximated on basis of the formula of Bretschneider (1958; CUR, 2007). Of interest is the wave height with a return period of 1/225 yr which is the design criterion.
The program CRESS offers an application for this formula. At a distance of 5 km off shore the water depth exceeds MW -300 m. At this depth waves do not feel the bottom yet. Therefore, until this location calculations are done with a fetch length of 350 km. The result is presented in Table A-2.

*Table A-2 Nearshore deep water extreme waves, from 255°-90° (N)*

| Return period | Hs (m) | Tp, JONSWAP (s) |
|---|---|---|
| 225 yr | 11.41 | 13.4 |

The above nearshore deep water condition is put into the model SWAN at 5 km distance (see Appendix E). Waves originating from N direction have the highest fetch and can propagate easily to the port along the trough (see Figure 2-8) without feeling the bottom. This direction is therefore selected as input for the wave and wind field.

### *A.3.2 Results SWAN*

Results of the SWAN simulations are obtained at 5 output points, as indicated in Figure A-5. Corresponding wave conditions at the locations are presented in Table A-3.

*Table A-3 Extreme wave conditions along breakwater structure (1/225 yr)*

| Output # | Hs | Tp |
|---|---|---|
| 1 | 3.7 | 12.1 |
| 2 | 5.8 | 12.2 |
| 3 | 6.9 | 12.4 |
| 4 | 5.6 | 9.9 |
| 5 | 4.0 | 12.2 |

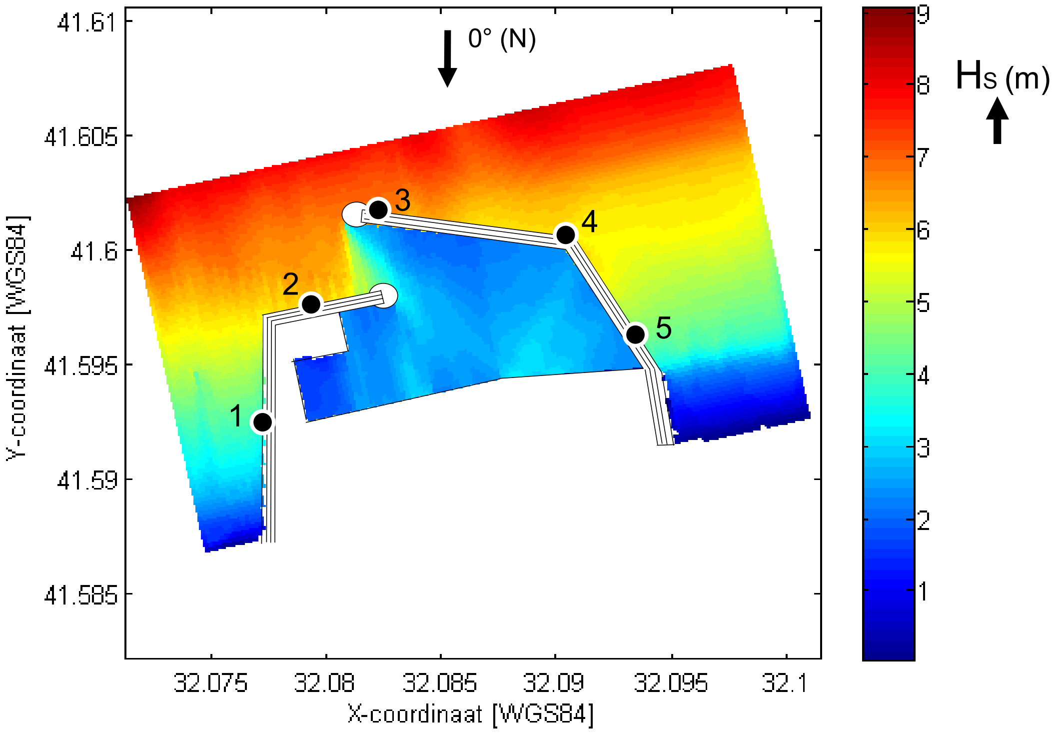



*Figure A-5 Extreme wave climate of waves from 0° (N) with an exceedance probability of 1/225 yr; including indicated output points for SWAN*

## A.4 Buoy location

Measurements of waves and currents have been carried out during the period from 21-Dec-1994 until 26-Dec-1996, on a 2 hourly basis. These measurements are obtained from Bergøe (2009).

The results from the measurements are used as comparison with the hindcasts for validation and calibration of the wave model. The location of the wave buoy, with a separate device to measure current velocities, is however not exactly known. Known from the data is, that it was situated above the seabed level of LAT - 13 m and between the indicated port boundaries (see Figure A-6). With this information the location can vary over a distance of about 3 km.

For the simulations with the model SWAN (see Appendix E) based on wind, a buoy location is selected. Because in 1991 a harbour entrance was planned at the trough border, this location is selected for the simulations; see the indicated red cross in Figure A-6.

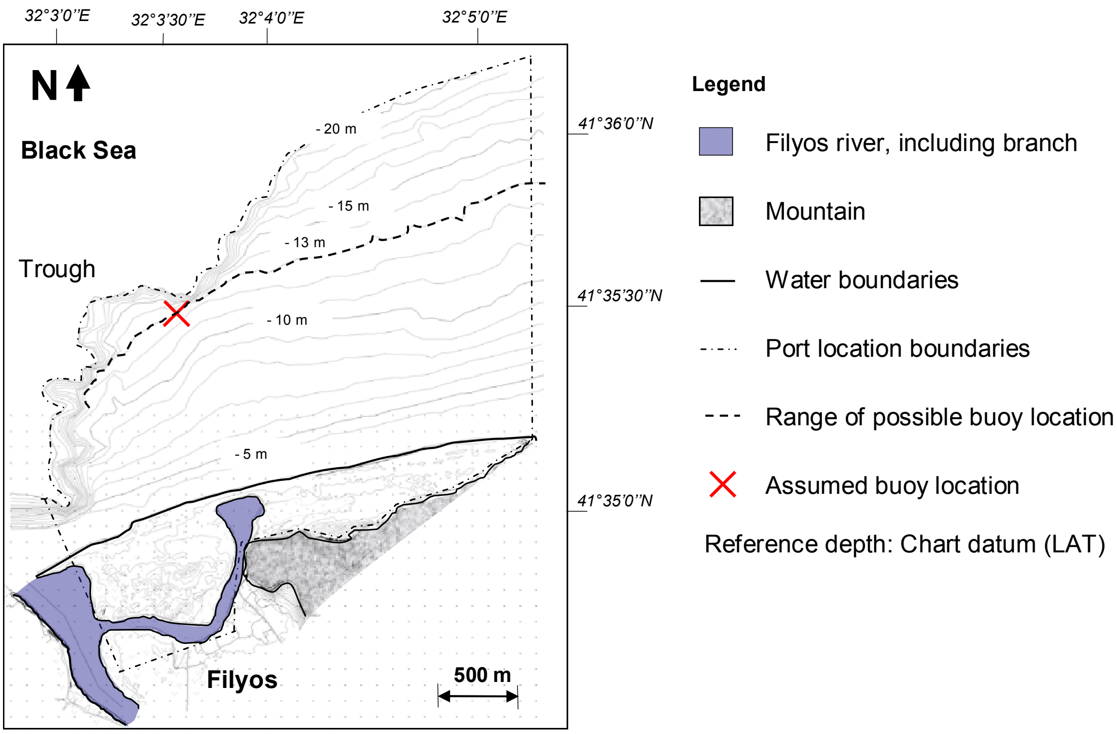



*Figure A-6 Range of buoy location with indicated chosen location for wave simulation*

## A.5 Extreme water levels at Filyos

In this paragraph the extreme water levels at Filyos are approximated. No measurements are namely available. Inside on the water levels is important for determining the dredging depth and to design the breakwaters and berth structures.

Next to the tidal range of 8 cm (as described in § 2.3.6), there is influence on the water level from:

- Atmospheric under and over pressure;
- Wind set-up and draw-down;
- Variation due to river discharge;
- Sea level rise.

In the following sub-paragraphs the influence of the above components are elaborated for the extreme conditions with respect to the mean water level.

### *A.5.1 Variation by atmospheric pressure*

According to Thoresen (2003) the water level rises or falls 0.9 cm for 1 mbar fall or rise of atmospheric pressure. Below a description is provided of the annual average atmospheric pressure at the Black Sea. Based on this information assumptions are made to derive the resulting influence on the water level for extreme conditions.

**Annual average conditions**

The following is known about the atmospheric pressure of the Black Sea. The pressures are commonly high in winter and low in summer. The average monthly pressures range from 997 mbar in July to 1,002 mbar in November, according to JICA (1991). Their deviations are smallest in June (5 mbar) and largest in December (20 mbar).

**Extreme conditions**

An assumption is made for the extreme conditions. A minimum pressure of 990 mbar and a maximum of 1,020 mbar are assumed for the long term (1/10, 1/50 and 1/100 yr). This results in a water level rise of **9 cm** and a fall of **18 cm** w.r.t. MW.

## *A.5.2 Wind set-up & draw-down*

In this sub-paragraph the wind set-up and draw down of water level is approximated. The bathymetry of the Black Sea has a deep and shallow part as visible in Figure 2-7. Therefore, it can be schematised as presented in Figure A-7. Below the applied formulas, parameters and results are provided.

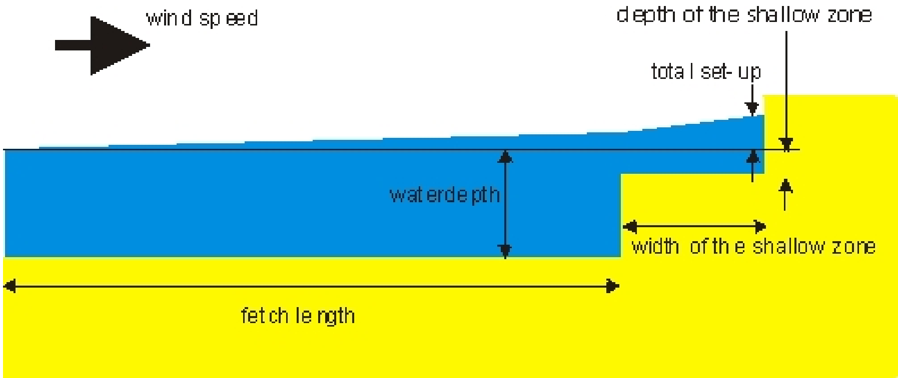



*Figure A-7 Deep and shallow components for wind set-up and draw-down (Ref. [6])*

**Formulas**

According to Ref. [6] the following formulas hold for the deep and shallow part (open sea formula):

$$\Delta h,\ deep = 0{,}5 \cdot \kappa \cdot \frac{u^2}{gh} \cdot F_{deep} \cdot \cos\varphi$$

$$\Delta h,\ shallow = \sqrt{\kappa \cdot \frac{u^2}{g} \cdot F_{shallow} \cdot \cos\varphi + h^2} - h$$ only valid for h / F < 0.001

**Parameters**

| | |
|---|---|
| $\rho_{air}$ | = 1.21 (kg / m$^3$) |
| $\rho_{water}$ | = 1,025 (kg / m$^3$) |
| $c_w$ [vi] | = 1.9 * 10$^{-2}$ (-) |
| $\kappa$ | = $c_w$ * ($\rho_{air}$ / $\rho_{water}$) = 2.2 * 10$^{-5}$ (-) |
| $U_{10,\ max}$ (1/x yr) | = see Table A-1 |
| $\varphi$ | = 0° |
| $h_{deep}$ | = 1 * 10$^3$ m |
| $h_{shallow}$ | = 10 m |
| $F_{deep}$ | = 350 * 10$^3$ m |
| $F_{shallow}$ | = 3 * 10$^3$ m |

xcv

[vi] According to Karelse and Van Os [1979] the friction factor $c_w$ varies between 0.8 * 10$^{-3}$ and 3 * 10$^{-3}$. In this case the average of these values is selected.

**Results set-up / draw-down**

In Table A-4 the resulting approximations for the water levels are presented for long term return periods. It is assumed that the deep and shallow water height variances can be added up, which is not a real representation.

*Table A-4 Approximated water level set-up and draw-down for return periods at coastline of Filyos*

| Return period | Set-up / draw-down |
|---|---|
| 10 yr | 0.41 m |
| 50 yr | 0.57 m |
| 100 yr | 0.67 m |

### *A.5.3 Variation due to river discharge*

The drainage basin covers almost third part of Europe. The average annual river discharge into the Black Sea amounts 340.6 km$^3$, whereas the Black Sea water surface amounts 432,000 km$^2$ according to Ref. [5]. Without water outflow this would result in a 79 cm rise of sea level. The surface level of the Black Sea is almost invariably 40 cm higher than that of the Marmara Sea and still more of the Mediterranean. The water head creates a current from the Black Sea - through the Straits and the Marmara Sea - to the Mediterranean Sea; see Figure A-8 for the described seas. The high river discharge ultimately results into the relatively small semi-enclosed Sea results in a **yearly water level variation of 30 cm** according to JICA (1991). This variation is assumed to be constant for the extreme conditions.

### *A.5.4 Sea level rise*

According to Thoresen (2003) the rise of sea level between 2000 and 2050 is estimated to be about 0.25 - 0.30 m, which is related to the prospected rise of the Caspian Sea water level. A rise of **30 cm per 50 year** (= 0.6 cm / yr) is therefore taken normative for the maximum water level.

### *A.5.5 Result*

Summating the approximated phenomena the in Table A-5 presented water levels result.

*Table A-5 Approximated water level maxima and minima at Filyos coast*

| Return period | Maxima (MW +) | Minima (MW-) |
|---|---|---|
| 10 yr | 0.9 m | 0.6 m |
| 50 yr | 1.3 m | 0.8 m |
| 100 yr | 1.7 m | 0.9 m |

**Notes**

For approximation of the minimum water level it is assumed that no future rise of the sea level rise will occur. Furthermore, the water level variation due to river discharge is set to zero for the minimum level.

For the design of structures and required dredging also information about the subsidence of land is needed. No information in this respect for this Turkish area is however available. Known is that seismic activities take place in the area (see § 2.3.3). Furthermore, the 50 m thick soil layer above the hard rock layer is considerably soft, see Figure 2-9. Annual subsidence should therefore be researched.

## A.6 Black Sea currents

The currents of the Black Sea are generally weak and inconstant, influenced by river discharges, winds and atmospheric disturbances. The tide forms a negligible effect in this regard due to the low tidal range of 8 cm. The current system is characterised by an anti-clockwise circulation and an almost steady flow from the Black Sea to the Mediterranean, through the Bosporus, the Marmara Sea, the Dardanelles and Aegean Sea, according to JICA (1991). An impression of the main flow is provided in Figure A-8.

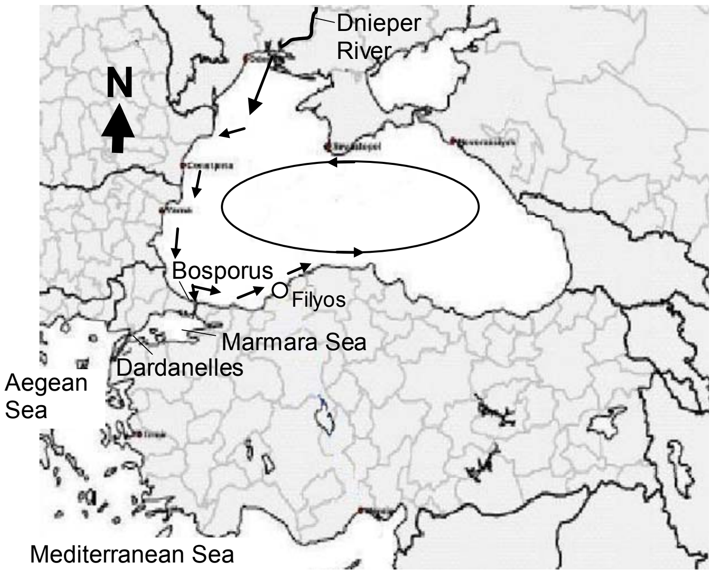



*Figure A-8 Map indicating main anti-clockwise circulation of Black Sea currents*

The outflow from the Black Sea to the Mediterranean is accelerated by the prevailing N and NE winds for about 9 months of the year, but it is decelerated or even converted into the inflow under southerly winds. Below the surface outflow, there exists the slower and more silted sub-surface inflow, compensating approximately one third of the outflow through both Straits.

The discharge from the Dnieper flows westwards and thence southwards along the coast, receiving the outflow of the Dniester on its way. The confluent current of river discharges sets southward and south-south-eastward and mostly flows out through the Bosporus. The remainder continues in the ENE direction along the Anatolian coast, where Filyos is situated. According to JICA (1991), the current velocity gradually decelerates from 25-40 to 15-25 cm/s.

## A.7 Longshore sediment transport

This appendix contains an approximation of the yearly longshore sediment transport at Filyos. Approximations of the transport are done with the use of the model UNIBEST LT. In the first sub-paragraph the setup and results of this model UNIBEST are provided. In the subsequent sub-paragraph a hand calculation is provided for verification. In the final sub-paragraph conclusions and recommendations are provided.

### *A.7.1 UNIBEST LT*

**Input**

In this section the input for UNIBEST LT is described.

*Wave data & tide*

The 2 year of wave data from the buoy measurements, see § 2.3.7, are used as input. Because tidal influence is very low, this is not taken into account.

*Cross-shore profile*

With UNIBEST LT the shape of the cross-shore profile can be taken into account (see Figure A-9). Because the coast line and bottom contour lines are rather straight it is assumed that the cross-shore profile is representative along the coast. The profile is derived from the available bathymetry at Filyos, see Figure 2-8. The average slope is about 1:100.

The dynamic boundary, indicated in pink in the figure, determines the sediment transport zone with respect to the initial profile. The maximum annual breaker depth is set to MW - 8.9 m (see § B.2.2). To have a margin, the dynamic boundary is set to MW -13 m, which is equal to the position of the wave buoy.

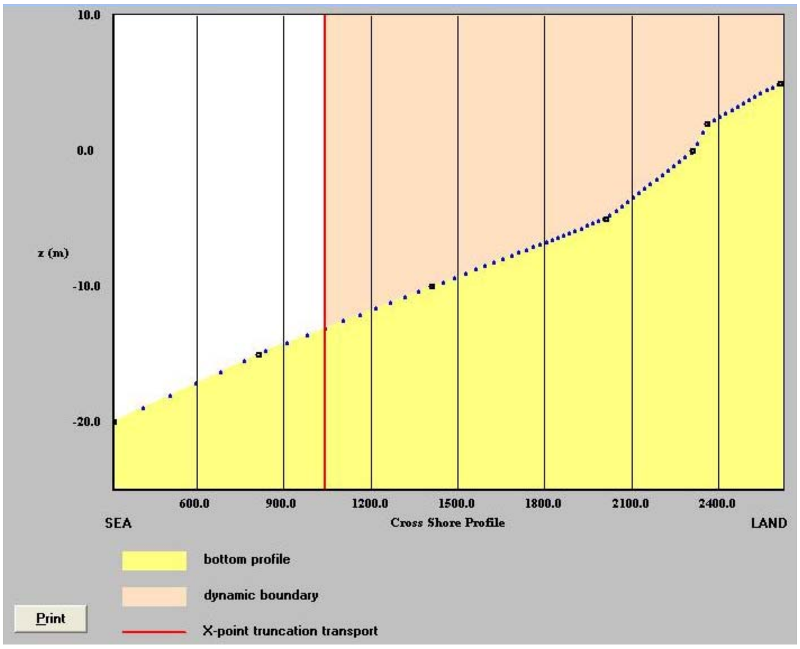



*Figure A-9 Uniform cross-shore profile at Filyos*

The blue dots represent the points where the model calculates results. Until the dynamic boundary layer the distance between the points (dx) is set to 100 m. From this point towards the coast a grid size of 20 m is chosen.

*Wave parameters*

For the wave parameter the default values are used, except for wave breaking γ (Table A-6). Here the same value is used as chosen in § B.2.2 for irregular waves (RIKZ, 2004). Due to the smaller breaker index, waves will break at deeper water. Therefore the sediment transport zone becomes larger. The total transport will however be lower, as will appear especially with the formula of Van Rijn.

*Table A-6 Wave parameters*

| Parameter | Default | Used |
|---|---|---|
| Wave breaking (γ) | 0.8 | **0.56** |
| Wave breaking ($\alpha_c$) | 1 | **1** |
| Bottom friction ($f_w$) | 0 | **0** |
| Bottom roughness ($k_b$) | 0.1 | **0.1** |

*Transport formulas & parameters*

In this sub-section the different formulas and parameters for transport are provided.

CERC

The CERC formula is a bulk transport formula, which has little physical back ground. In case currents are induced by waves, instead of by tidal influence, it gives a good quick approximation of the long shore transport. For more information about the formula is referred to § A.7.2, in which hand calculations are provided for verification.

Van Rijn and Bijker

The default transport parameters in the module are used of Van Rijn (1992) and Bijker (1967, 1971); see Table A-7. More information about the formulas can be found in the user manual of Kramer (2005).

*Table A-7 Default parameters in UNIBEST CL+ for Van Rijn (1992) and Bijker (1967, 1971)*

| | |
|---|---|
| $D_{50}$, Median (50%) grain diameter (μm) | *200* |
| $D_{90}$, 90% grain diameter (μm) | *300* |
| | |
| Additional, Van Rijn: | |
| Sediment density (kg/m$^3$) | *2,650* |
| Current related bottom roughness (m) | *0.05* |
| Wave related bottom roughness (m) | *0.05* |
| Fall velocity suspension material (m/s) | *0.02* |
| Viscosity () * 10e-6 | *1* |
| Correction factor (-) | *1* |
| Relative bottom transport layer thickness (-) | *0.03* |
| Porosity (-) | *0.4* |
| | |
| Additional, Bijker: | |
| Bottom roughness (m) | *0.05* |
| Sediment´s fall velocity (m/s) | *0.02* |
| Criterion deep water, $H_S/h$ | *0.07* |
| Coefficient b deep water (-) | *2* |
| Crietrion shallow water, $H_S/h$ | *0.6* |
| Coefficient b shallow water (-) | *5* |

**Output**

In Figure A-10 the output is presented for the eastward longshore transport, using the transport parameters of Van Rijn. The surface of the red area represents the amount of annual sediment transport. The green arrow shows the region in which 50% of the transport takes place. The angle of 31° represents the needed coastline rotation to achieve an equilibrium situation.

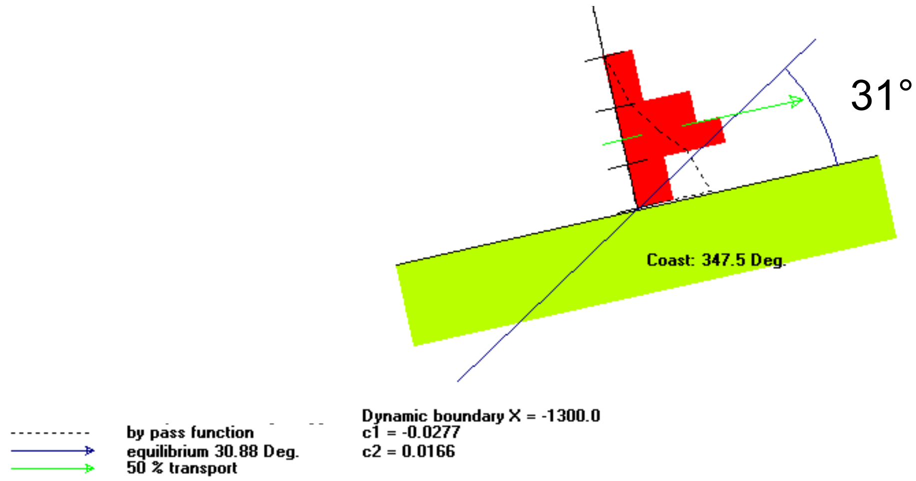



*Figure A-10 Model output for eastward longshore transport with formula Van Rijn*

The results for the longshore transport with the **default transport parameters** are presented in Table A-8.

*Table A-8 UNIBEST output longshore sediment transport ($S_x$, $m^3/yr$), for default transport parameters*

| Formula / transport direction | Eastward | Westward | Net |
|---|---|---|---|
| Van Rijn | 266,000 | 213,000 | 53,000 |
| Bijker | 271,000 | 196,000 | 75,000 |
| CERC | 691,000 | 452,000 | 239,000 |

*Important note*

It must be noted that in eastward direction the sediment transport is influenced by the presence of the trough, which interrupts the breaker zone. Sediment will partly be trapped in the trough. Therefore the eastward transport will be reduced considerably at the east side of the trough.

*Sensitivity*

In Van de Graaff (2009) a sensitivity analysis is carried out for the effect on the transport by input parameter values. The median grain size ($D_{50}$) and bottom roughness have the biggest effect. The bottom slope and the breaker parameter gamma have less influence, as visible in Figure A-11.

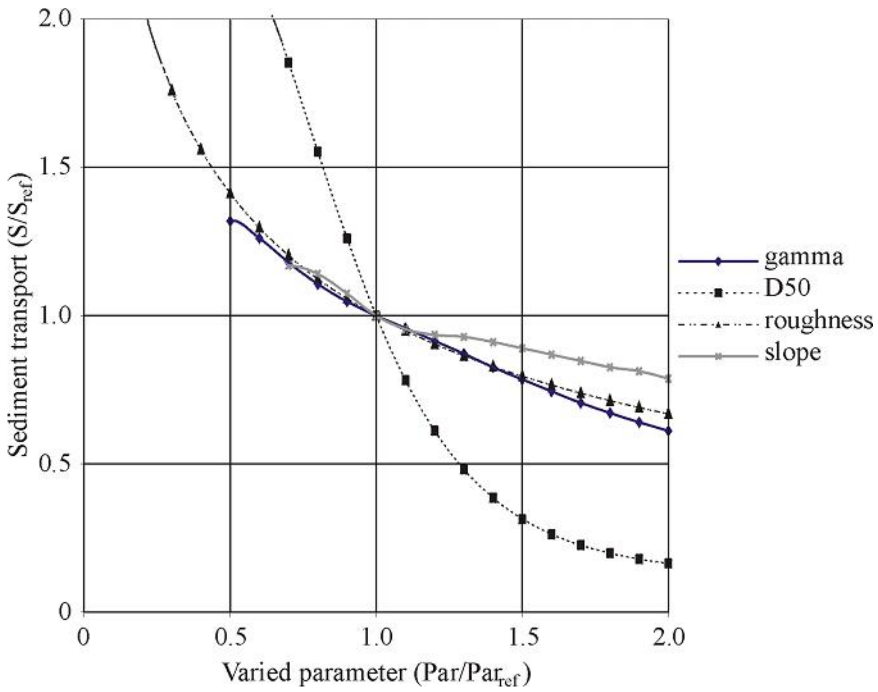



*Figure A-11 Sensitivity analysis of sediment transport for varied Bijker formula parameters (Van de Graaff, 2009)*

In the next sub-paragraph verification for the model output is carried out by a hand calculation. In the subsequent sub-paragraph conclusions and recommendations are provided.

### *A.7.2 Verification: hand calculation*

As stated in the previous sub-paragraph, the coastline at Filyos is rather long and straight. Moreover, since the influence of tide is neglectable, currents are mainly wave induced. Therefore the longshore drift can be estimated well with the CERC formula. This formula is called a bulk energy formula. It is based on the observation, that the longshore sediment transport is proportional to the longshore component of the wave energy flux per meter of coastline, present at the outer edge of the breaker zone. Explanation and elaboration of this formula is provided below.

**Cerc formula**

According to Van de Graaff (2009) the CERC formula reads:

$$S_x = A \cdot H_b^2 \cdot n_b \cdot c_b \cdot \cos\varphi_b * \sin\varphi_b \qquad \text{(A.1)}$$

An explanation of the parameters is provided below, accompanied by fundamental wave theory according to Holthuijsen (2006). The subscript b stands for the respective parameter at the breaker line.

| | | |
|---|---|---|
| $S_x$ | Longshore sediment transport through breaker zone ($m^3/s$) | |
| A | Coefficient | = 0.04 (-) |
| H | Significant wave height at breaker zone (m) | |
| n | Ratio of wave group celerity and wave propagation speed (-) | $= 0.5 \cdot \left\{1 + \frac{2 \cdot kh}{\sinh(2 \cdot kh)}\right\}$ |
| c | Wave propagation speed (m/s) | $= \left\{g \cdot \frac{\tanh(kh)}{k}\right\}^{1/2}$ |
| φ | Angle between wave crest and coastline (°) | |

**Input**

Below a description is given of the schematisation of the input data and used theory for translating the waves to nearshore.

*Data schematisation*

As input the wave climate, that is measured by a buoy at MW -13 m depth (§ A.4), is used. The wave conditions need to be translated to the different locations where wave breaking occurs.

The 2 years of wave data, consisting of 7,823 records, is put into directional bins of 15° and averaged. The bins 60°-75° and 75°-90° (N) will not cause longshore currents at the location and are therefore excluded (see Figure A-12). The directions of the wave rays are adjusted to the orientation of the coastline which is about 12.5° at Filyos.

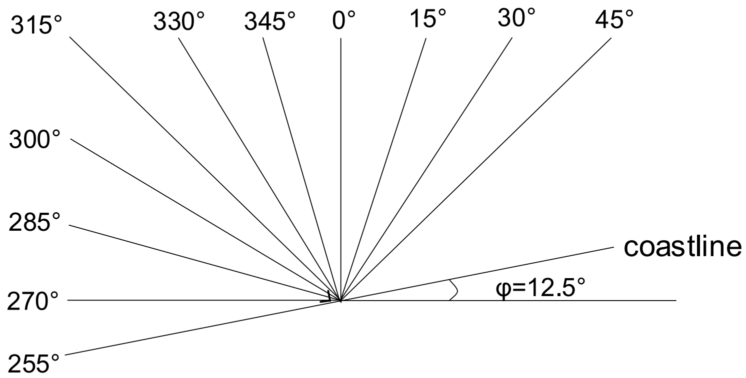



*Figure A-12 Wave direction bins (w.r.t. north) and coastline orientation*

The significant wave heights are put into bins of 0.5 m. Per direction and wave height bin, the average measured peak period $T_p$ is determined for further calculations.

*Wave translation*

The data needs to be translated to conditions at the breaker depth. Because this depth is variable, iterative hand calculations are carried out to determine the wave conditions. Below a description is given of important considerations in this respect.

Due to refraction, waves will turn towards the coastline. With Snellius law the incident angle at the breaker depth is determined:

$$\sin(\phi_b) = \frac{cb}{c_0}\sin(\phi_0) \qquad \text{(A.2)}$$

It is assumed that the wave height will not deviate from MW -13 m to the breaker zone. The breaker index γ for irregular waves is 0.56 (-) according to RIKZ (2004). Therefore the breaker depth, $h_b = H_S/\gamma$ = *Hs / 0.56.*

The wave length at the breaker depth is iteratively determined with the following fundamental formula (Holthuijsen, 2006):

$$L_{n+1} = L_0 \cdot \tanh(2\pi * h / L_n) \qquad \text{(A.3)}$$

Example

An example of the wave input and determined parameters per bin for the wave direction 0-15° is provided in Table A-9. The average angle of incidence for this directional bin with the coast is 7.5°+12.5°= 20° at the buoy, see Figure A-12. As visible in the table, waves with a low height have the largest refraction pattern, because of the long travelling distance to the shore. Waves with a height range of 0.0-0.5 m refract in this case from 20° to 4.9°.

*Table A-9 Example of wave input for directional range 0-15° (N) at buoy, translated to parameters at the breaker line*

| $H_s$, average | $T_p$, average | Observations | φb | $S_x$ (m^3/yr) |
|---|---|---|---|---|
| 0.25 | 5.5 | 503 | 4.9 | 1,000 |
| 0.75 | 6.2 | 128 | 7.7 | 5,000 |
| 1.25 | 6.7 | 38 | 9.3 | 6,500 |
| 1.75 | 7.4 | 27 | 10.5 | 12,000 |
| 2.25 | 8.2 | 13 | 11.4 | 11,000 |
| 2.75 | 8.6 | 9 | 12.4 | 14,000 |
| 3.25 | 9.0 | 1 | 13.3 | 2,500 |
| 3.75 | 9.7 | 9 | 14.1 | 34,000 |
| 4.25 | 10.0 | 7 | 14.8 | 37,000 |
| 4.75 | 11.0 | 2 | 15.5 | 15,000 |
| | | | **Total** | 138,000 |

To derive the total annual average sediment transport along the shore, multiplication of the CERC formula is needed with the frequency of occurrence per wave component (total observations is 7,823) and the number of seconds per year.

*Note*

The effect of refraction and shoaling on the wave height is not included due to insignificance. The real wave height can therefore deviate to a value of about 10% lower or higher with respect to these phenomena.

**Output**

Summating all annual transport volumes per wave direction range gives the total annual sediment transport. The transport that is expected in **westward** direction is equal to **369,000 $m^3$/year**, as presented in Table A-10.

*Table A-10 Estimated total annual average westward sediment transport at Filyos*

| Wave direction at buoy | Sx |
|---|---|
| 345-360° | 23,000 |
| 0-15° | 138,000 |
| 15-30° | 49,000 |
| 30-45° | 83,000 |
| 45-60° | 76,000 |
| **Total** | **369,000** |

For the eastward transport a rate of 642,000 $m^3$/year is determined with this calculation. The same remark as made in § A.7.1 holds. Sediment will be trapped partly in the trough.

### *A.7.3 Conclusions & recommendations*

**Conclusions**

From the previous paragraphs can be concluded, that the hand calculation with CERC corresponds highly with the calculations by UNIBEST LT with this formula.

Comparing the results of UNIBEST, it is visible that the CERC formula estimates a more than two times larger annual sediment transport. As previously stated, the formula however has less physical meaning. An important drawback is that, in contrary to the Bijker and Van Rijn formula, it does not give information about the transport distribution. It also does not take the slope of the beach profile and possible into account. The CERC formula was originally derived for beaches with uniform sand ranging 175 μm to 1000 μm, according to Van de Graaff (2009). Furthermore, no distinction is made between bed load and suspended load transport.

It can be concluded, that the results from Van Rijn and Bijker are more reliable due to the physical processes that are included. The results of both formulas differ slightly. Because **Van Rijn** has the highest physical justification, this transport will be used as **boundary conditions for the coast line evolution simulations** in Appendix D.

Because a river guidance embankment is planned, this structure will interrupt in the sediment transport process at the trough location. No reduction of the eastward longshore transport is therefore required.

**Recommendations**

- To have a better estimation of the morphological processes, the influence of the trough and the river sediment should be taken into account. Therefore a more complex model is required, using the multiple line theory.
- The use of longer term wave conditions. In this case the 2 year recordings by the buoy are considered representative for the annual average conditions.
- Use of specific grain diameters ($D_{50}$ and $D_{90}$) which are representative for the cross-shore profile.

# APPENDIX B DESIGN GUIDELINES & COMPONENT DIMENSIONS

This chapter provides an overview of the guidelines to determine the preferred shape, orientation, location and **minimum** dimensions of the components (expressed in $m^1$ and $m^2$). An overview of the needed components can be found in Table 1-1. The same sequence as in the table is followed, namely from arriving of the ships outside the harbour area until leaving of the cargo to the hinterland.

The calculations are carried out for **phase I** and **phase II**, which are respectively based on capacities for the years **2020** and **2030**. In some cases starting points are needed for the calculations, which are provided in Ch. 4.

## B.1 Approach channel

The need for an approach channel depends on the positions of the harbour entrance with respect to the current depth contour lines, as indicated in Figure 2-8. Regarding this figure and taking into account the expected vessel dimensions, an inner channel is needed in any case.

In this paragraph the dimensions for the required approach channel are calculated. First an introduction is given below, which provides important input for the design of the channel.

### *B.1.1 Introduction*

This sub-paragraph contains information about the ship characteristics and required number of tug boats for assistance.

**Ship characteristics**

To give an overview, in Table B-1 the ship dimensions are presented which are extracted from Table 2-8. The leading dimensions for the years 2020 and 2030 are presented with a bold font. Container ship type II will only arrive from 2020 onwards. Therefore two normative lengths and widths are indicated. Because the number of passages of Dry bulk I vessels is very low, the draught of container II vessels is taken normative. Therefore a limitation to enter the port for Dry bulk I vessels holds. Solely at tranquil climate conditions Dry bulk I vessels are allowed to enter the port.

To decide if a one- or two-way channel is needed, the yearly number of passages is important. In combination with the inter-arrival- and service time distribution a decision can be taken. Because no inland waterway will be present all the incoming ships via the approach channel will leave the port area via the same way. Therefore the yearly number of ships passing the channel are twice the calculated number of ships entering the port (see Table 2-8).

*Table B-1 Ship characteristics*

| Type | Yearly passages 2020 | Yearly passages 2030 | $L_{OA}$ (m) | Draught (m) | Beam (m) |
|---|---|---|---|---|---|
| Dry bulk I | 4 | 4 | **215** | 13 | **32.0** |
| Dry bulk II | 657 | 806 | 170 | 10 | 23.0 |
| General cargo I | 42 | 42 | 165 | 11 | 23.5 |
| General cargo II | 647 | 1533 | 140 | 9 | 21.5 |
| Container I | 198 | 738 | 200 | 9 | 27.0 |
| Container II | 50 | 148 | **300** | **12** | **40.5** |
| **Total passages** | **1,597** | **3,271** | | | |

**Number of tug boats**

Ships that are allowed to navigate into the harbour basin will be assisted by tugboats. The number of tugboats required can be derived from the total bollard pull. The bollard pull is determined from the ship size according to the following formula (Ligteringen, 2009):

$T_B = (\Delta / 100{,}000) * 60 + 40$ (tons)

Where delta is the water displacement in tons, according to:

$\Delta = L_{BP} * B * D * f$ (water)

For the leading container ship (type II) the following dimensions are estimated, with the use of figures from Ligteringen (2009):

| | | |
|---|---|---|
| $L_{BP}$ | = length between perpendiculars | = 285 (m) |
| B | = width between intersection of ship and water line | = 38 (m) |
| D | = draught | = 13 (m) |
| f | = shape factor | = 0.75 (-) |

It results in a required bollard pull ($T_B$) of 105 ton, which means that 2 tugboats with 60 ton pull capacity are sufficient.

### B.1.2 Orientation and alignment

The following should be taken into account for the channel:

- Orientation in line with the prevailing wave, wind and current conditions. This way ships have the least hindrance to manoeuvre. The preferred orientation in this respect is therefore NNW.
- Avoid bends in the channel near the port entrance.

### *B.1.3 One-way channel*

To determine if a one- or two-way channel capacity is needed, the ship passages need to be examined. Below an interpretation is given of the expected average daily traffic.

**Interpretation of passages**

The number of passages in the year 2020 amounts 1,597 / 350 days = 4.6 ships / day on average. This amount will rise to an average in 2030 of 3,271 / 350 days = 9.3 ships / day.

Because tugs are able to control ships at a speed of 4 knots, this operational speed can be selected as normative for the total sailing time into to and out from the berth area. Assuming a length from anchorage to berth of about 5,000 m, a one way travelling time of 5,000 m / 2 m/s = +/- 45 min is needed. For 2030 this would result in a daily total average travelling time of 9.3 ships / day * ¾ h = 7.0 h / day.

The inter-arrival and service time of the ships will however not be constant. Therefore a model is needed to make a well considered decision. For this port the inter-arrival and service time are interpreted as an Erlang 2 function, which is explained in § B.4.2. Given this density function and the fact that the port is operational for 24 h a day, no significant congestion can be expected with the use of a one way channel.

### *B.1.4 Channel depth*

The channel depth (below LAT) is estimated by summating the components as presented in Figure B-1.

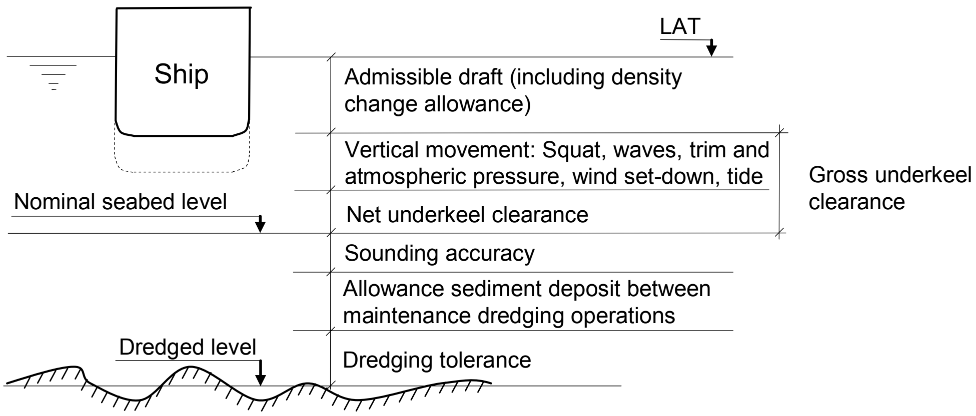



*Figure B-1 Channel depth components*

In Table B-2 the depth components are presented with corresponding value. Most of these values are estimated on basis of experience (Ligteringen, 2009). Applying a tidal window is not relevant in the low tidal range. For determining the vertical motion of the ship, due to wave response, the leading wave height ($H_S$) must be divided by 2. Ships are assumed to stay at the anchorage place, outside the port, for waves with an $H_S$ of above 2.0 m. Up to this wave height modern tug boats with experienced captains are able to assist. As a starting point, ships are not allowed to navigate into the port during higher significant wave heights. This corresponds with common nautical regulations of ports.

*Table B-2 Channel depth for phase I and II*

| Depth component | Value (m) | Comment |
|---|---|---|
| Draft design vessel | 12.0 | |
| Maximum sinkage (fore or aft), due to squat and trim | 0.5 | Estimated on basis of experience |
| Vertical motion due to wave response | 1.0 | $H_{s,max}$ / 2 = 2.0 / 2 |
| Tidal elevation above reference | - | No tidal window applied |
| Wind set-down (1/yr) | 0.2 | |
| Net under keel clearance | 0.5 | Sandy bottom |
| | | |
| Extra components (not guaranteed/nominal): | | |
| Sounding accuracy, sediment deposit allowance & dredging tolerance | 1.0 | |
| **Total depth, including tolerances** | **LAT -15.2** | |

**Verification**

This minimum depth, guaranteed LAT - 14.2 m, corresponds to a depth / draught ratio of 14.2 m / 12.0 m = 1.18 (-). For ships in a moderate wave climate normally a ratio of 1.3 or more is used. Considering the fact that ships are not allowed to enter for waves with an Hs of above 2.0 m, this margin seems safe. It can be considered however, to increase this ratio to give ships a better response, which will reduce the needed manoeuvring width. An optimum needs to be sought in this manner.

### *B.1.5 Channel length*

A minimum channel length in the harbour is required for the stopping procedure for ships. According to Ligteringen (2009) from passing the entrance with the ship stern, ships are able to stop in about 1.5 * $L_{OAmax}$ from a speed of 4 kn. This results in a total required length of **2.5 * $L_{OAmax}$ = 750 m**. Tug boats will not assist at the same time for the stopping procedure and turning manoeuvre. Therefore this length can be applied safely **until the centre of the turning circle** (see Figure B-2).

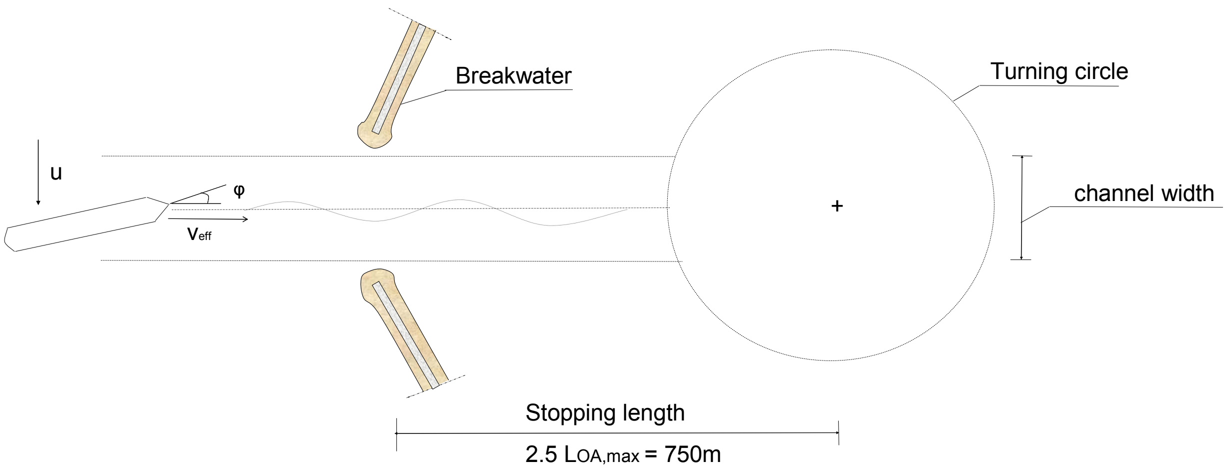



*Figure B-2 Approach channel with indicated stopping length*

**Note**

It is important to note that the above presented stopping length is an absolute minimum. Normally a longer length is needed for the inner channel, because tug boats cannot assist outside of the breakwaters when significant wave heights are higher than 2.0 m. The required entrance speed to maintain control would in that case also be higher.

### *B.1.6 Channel width*

This sub-paragraph describes the guidelines for the required channel width.

**Introduction**

Next to ship dimensions, climate conditions and available depth, the manoeuvrability of ships forms an important input for determining the channel width. The manoeuvrability on its turn also depends on the dimensions. The following ratios are decisive in this respect: L / B, B / D and Δ / p (mass/propulsive power) and B * D (block coefficient). Moreover, the size of rudder area and vulnerability to wind are important (Ligteringen, 2009).

**Straight section**

The bottom width of a single lane channel is calculated with the guidelines of PIANC and IAPH (1997). With respect to the straight section, for this project it is only necessary to calculate the outer channel dimensions. Because of needed entrance manoeuvrability, these dimensions also hold for the inner channel, according to the guideline provided by Ligteringen (2009). In Figure B-3 an overview is given of the space needed for calculation of the channel bottom width.

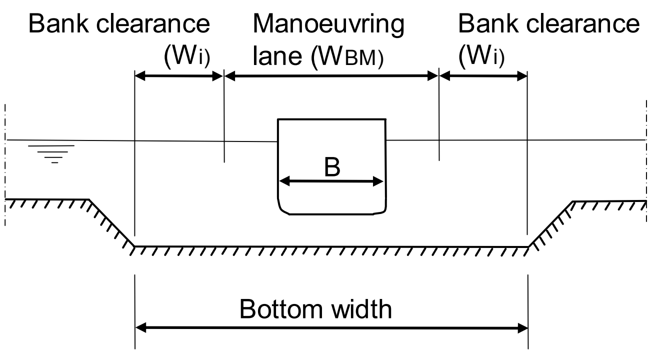



*Figure B-3 Bottom width of approach channel*

The width consists of the following components:
$W = W_{BM} + \sum W_i$

In which:
$W_{BM}$ = Basic manoeuvrability = 1.65 (moderate to poor manoeuvrable) * B
$W_i$ = Additional widths

The additional widths $W_i$ are presented in Table B-3. Conditions that determine the needed additional widths are presented in the left column. These conditions are derived from the physical conditions described in § 2.3. In some cases starting points were needed, which are presented in § 4.2.

*Table B-3 Additional straight section widths, orientation NW (PIANC, 1997, p. 21)*

| **Conditions** | **Selected $W_{i,}$ outer + inner harbour channel** |
|---|---|
| Vessel speed (knots) | |
| Fast > 12 | 0.1 B |
| **Moderate (8-12)** | **0.0** |
| Slow (5-8) | 0.0 |
| Prevailing cross-wind (knots) | |
| Mild ≤ 15 | 0.0 |
| **Moderate > 15-33** | **0.4 B** |
| Severe> 33-48 | 0.8 B |
| Prevailing cross-current (knots) | |
| Negligible < 0.2 | 0.0 |
| Low, 0.2 - 0.5 | 0.2 B |
| **Moderate > 0.5 - 1.5** | **0.7 B** |
| Strong > 1.5 - 2.0 | 1.0 B |
| Prevailing longitudinal current (knots) | |
| **Low ≤ 1.5** | **0.0** |
| Moderate > 1.5 - 3 | 0.1 B |
| Strong > 3 | 0.2 B |
| Significant wave height $H_s$ and length λ (m) | |
| Hs < 1 and λ < L (± 78% of time) | 0.0 |
| 1 < Hs < 3 and λ < L (± 21% of time) | **1.0 B** |
| Hs > 3 and λ » L (± 3% of time) | 2.2 B |
| Aids to navigation | |
| Excellent with shore traffic control | 0.0 |
| **Good** | **0.1 B** |
| Moderate with infrequent poor visibility | 0.2 B |
| Moderate with frequent poor visibility | ≥ 0.5 B |
| Bottom surface | |
| Depth < 1.5 D | |
| **Smooth and soft soil hardness** | **0.1 B** |
| Rough and hard | 0.2 B |
| Depth of waterway | |
| ≥ 1.5 D | 0.0 |
| **1.25 D < d < 1.50 D** | **0.1 B** |
| < 1.25 D | 0.2 B |
| Cargo hazard level | |
| **Low** | **0.0** |
| Medium | 0.5 B |
| High | 1.0 B |
| Bank clearance | |
| **Sloping channel edges & shoals** | **2 * 0.5 B** |
| Steep and hard embankments | 2 * 1.0 B |
| **Total width** | **3.4 B** |

With this additional width the following total bottom width results for phase II:
**$W_{channel, 2020\text{-}2030}$** = $W_{BM} + \sum W_i$ = (1.65 + 3.4) * 40.5 m = **205 m**

*Notes*

The width at the breakwater opening needs to be wider, because of the hard embankment. For bank clearance 2* 0.5 B should be added at this location, resulting in 246 m.

Because of smaller ship sizes before the year 2020, the width of the outer channel can be reduced between 2015 and 2020 to:

$W_{channel, 2015\text{-}2020}$ = $W_{BM} + \sum W_i$ = (1.65 + 3.4) * 32.0 m = 162 m

**Optional bend section**

In case an E-NE orientation of the approach channel is chosen, no combination with the available depth from the trough is possible. A long channel will then be needed from navigating from the Black Sea, out of northern direction, and turning into the harbour. For the later activity a bend in the channel is required. Needed dimensions are elaborated below.

The required bend bottom width and radius, as presented in Figure B-4, can be estimated with the use of figures in the guide of PIANC and IAPH (1997).

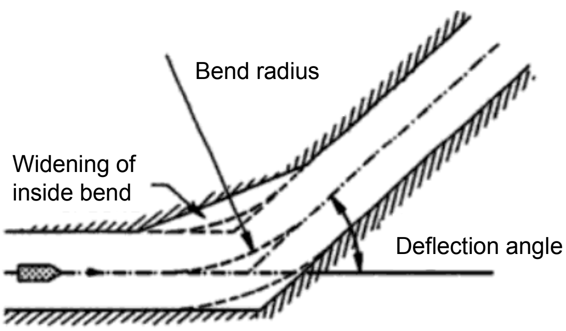



*Figure B-4 Optional channel bend section (Thoresen, 2003)*

*Bend width*

In a bend width a reserve angle is needed to encounter wind, waves and currents. From the figure in PIANC and IAPH (1997), the width of the swept track ($W_{s)}$ can be found as function of the design ship beam; namely: $W_s$ / B = 1.25.

As visible below, the calculated widths of the bends are smaller than the calculated width for straight channel sections. According to conceptual design standards, the width should in that case be at least equally sized as the straight section:

**$W_{s;\ 2020\text{-}2030}$** = 1.25 * B = 1.25 * 40.5 m (container II) = 50.6 m **-> 156 m**

Because of smaller ship sizes before the year 2020, the width of the outer channel can be reduced between 2015 and 2020 to:

$W_{s;\ 2015\text{-}2020}$ = 1.25 * B = 1.25 * 32.0 m (container I) = 40.0 m -> 123 m

*Bend radius*

In unfavourable climate conditions and without tug assistance, the ratio turning radius over the ship length (between perpendiculars) can be estimated from the figure in the guide of PIANC and IAPH (1997). The figure is based on a single rudder container ship with a rudder angle of 20°, which is advised for conceptual design by Ligteringen (2007).

The radius of the container ship will be leading because of the combination of length and low manoeuvrability. The following minimum radius result with the determined factor of 6.8:
$\mathbf{R_{max}}_{;\ 2020\text{-}2030}$ = 6.8 * $L_{pp}$ = 6.8 * 300 m (container II) = **2,040 m**

Reduction of the radius before the year 2020 is not attractive to consider.

## B.2 Breakwaters

Also in the harbour the climate conditions are important for the manoeuvrability of vessels. Therefore the use of breakwaters needs to be considered. Moreover, prevention of siltation is needed in order to provide sufficient nautical depth. A combination of both is possible, of which a consideration is provided below.

### *B.2.1 Breakwater essence & shape*

To decide about the need for wave protection, inside is needed of the accepted downtime in the port (Table 3-3). Moreover, the annual average wave climate conditions (§ 2.3.7) need to be compared with the normative conditions at berth (Table E-1). Also current conditions may have unacceptable values, which can be interrupted by a breakwater.

Because the wave heights are set normative for the determination of downtime, the directional distribution of $H_S$ of the buoy is again presented; see Figure B-6.

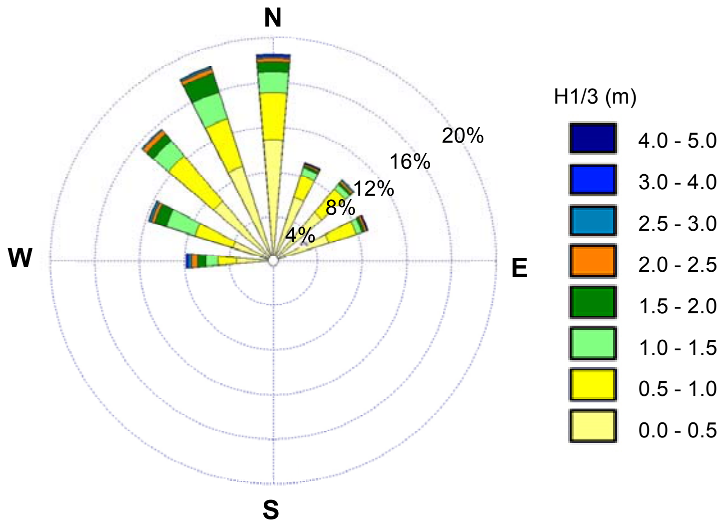



*Figure B-5 Directional distribution of* $H_{1/3}$ *for 1995-1996 (m)*

**West side**

At the buoy location the significant wave heights that from W and NW origin, are higher than 1.0 meter during more than about 12% of the time, according to the representative wave registrations of 2 years. This will result into unacceptable downtime for every type of ship handling. **A breakwater covering the western side is therefore required.**

The deep trough at the west side of this breakwater will catch most of the sediment that is being transported longshore from western direction. Besides, the planned river guidance embankment will interrupt into the transport. Therefore, no additional measures need to be taken with respect to preventing siltation.

**North side**

As can be concluded from Table 2-15, the northerly waves are also severe during the year. Hs > 1.0 m during more than 7% of time. Therefore protection against this direction is also needed.

**East side**

Wave conditions from the east cross the allowable wave heights for operations about 3% of time. Especially for container operations this will be unfavourable and reaching the allowable limit. Also the presence of long- and cross-shore currents, both with an annual average up to 1.5 kn, is unwanted. According to OCIMF (1997, op. cit. Ligteringen, 2009), the allowable current velocities are 3.0 knots and 0.75 knots for respectively parallel and perpendicular orientation.
Moreover, regarding the considerable transport of longshore sediment, there should be dredged yearly without this interruption by a breakwater. An artificial sand by-pass system also does not seem an economically attractive option in this case. More research about the selection is however recommended. **As a starting point it is chosen to protect the port from eastern wave by a breakwater and make an extension to prevent siltation.**

**Allocation and shape of entrance**

It has to be stated that - in contrast to the previously mentioned approach channel alignment in § B.1.2 - the entrance orientation and breakwater alignment must not be in line with the prevailing direction of wind, currents and especially waves. Therefore an agreement between both criteria is needed.

The entrance should, if possible, be located at the leeside of the harbour. It depends however also on the needed orientation and stopping length in the harbour. If it must be located on the windward end of the harbour, adequate overlap of the breakwaters should be provided. This way the ship is able to pass through the entrance and is able to freely turn with the wind, before it is hit broadside by the waves. This overlap of the breakwaters will also give extra protection against penetration of waves into the harbour.

Accordingly, in order to reduce the wave height within the harbour, and to prevent strong currents, the entrance should be no wider than necessary to provide safe navigation. The formation of a narrow sleeve should however also be avoided behind the breakwater heads. Otherwise there will be a funnel effect with waves going strait and unreduced through the harbour.

### *B.2.2 Breakwater extension*

Because of the longshore sediment transport from eastern direction, protection against siltation is needed. Lengthening of the breakwater is therefore a good option, instead of an expensive artificial bypass system or frequent maintenance dredging.

According to a rule of thumb the lengthening of breakwaters must be beyond the water depth where the yearly maximum significant waves will break, according to Ligteringen (2009).
$d = H_{S,max}\ (1/yr) / \gamma_{br}$

The parameter $\gamma_{br}$ (= $H_b/h_b$) is the breaker index, which for irregular waves is ≥ 0.56 (-) according to RIKZ (2004). This results in a needed lengthening of breakwaters until the water depth of:
5.0 m / 0.56 (-) = **MW – 8.9 m.**

### *B.2.3 Conclusion*

Protection from westerly and northerly waves by breakwaters is required. Especially the high waves from N-NW cause downtime of operations. Also protection from easterly waves is preferred. From a nautical point of view a NW orientation of the channel is wanted. An overlap of the breakwaters at the entrance is needed to prevent penetration of waves as much as possible.

Regarding the requirements, a NE orientation of the channel is the only realistic alternative. In that case account needs to be taken of the severe easterly sediment transport. Lengthening of the easterly breakwater is then preferred. In Figure B-6 a schematisation is provided of the possible main configurations.

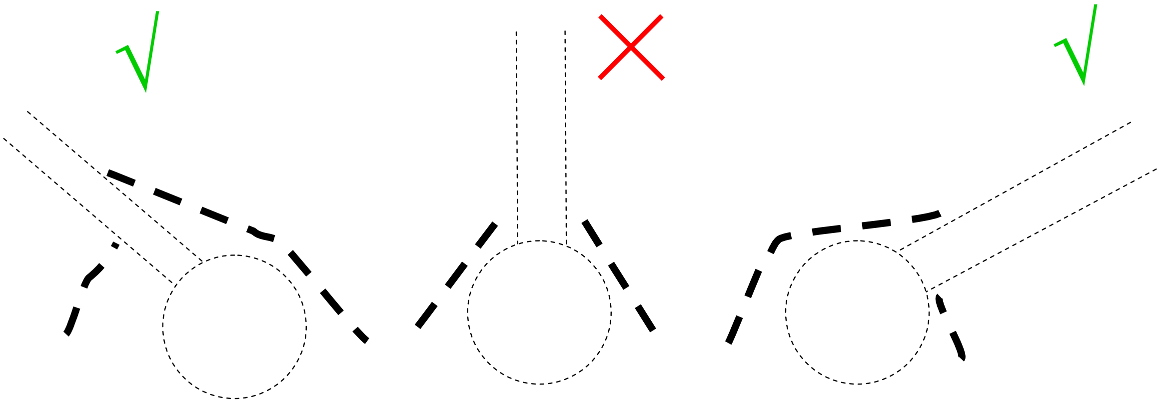


*Figure B-6 Schematisation of possible configurations of approach channel, turning circle and breakwaters*

Thorough optimisation of the configuration is off course needed. The required stopping length of 750 m, the required wet area in the harbour and the allocation of berths also need to be taken into account.

## B.3 Harbour basin

The harbour basin can be defined as the protected water area, which should provide safe and suitable accommodation for ships. Inside the basin a possibility to turn is needed for further navigating to the berth. The berths are usually accommodated in a berthing area. Both facilities are described in this paragraph.

### *B.3.1 Turning circle*

The turning circle should usually be in the central area of the harbour basin. The size will be a function of manoeuvrability and of the length of the vessel (Thoresen, 2003). It will also depend on the time permitted for the execution of the turning manoeuvre. The area should be protected from waves and strong winds. One should remember that ships in ballast have decreased turning performance.

The minimum diameter where the ship turns by going ahead and without use of bow thrusters and/or tugboat assistance, should be approximately 4 * LOA. In this case however, assistance by tugs is assumed. Therefore the minimum turning diameter is respectively 3 to 1.6 * LOA, depending on the conditions. With use of the main propeller and rudder and bow thrusters, the turning diameter could be 1.5 * LOA. Because container ships will face problems with turning under windy conditions, a diameter of **2.0 * LOA** is however taken into account. The following minimum diameter results: $\mathbf{D_{2020\text{-}2030}}$ = 2 * 300 m (container II) = **600 m**.

The **required depth** is set equal to the maximum depth at berth, which is equal to **LAT -13.7 m** (see Table 5-2).

### *B.3.2 Berthing area*

Instead of long shore front where ships are able to berth, dedicated berth areas can be created. The size of the berthing area and the berth will depend upon the dimensions of the largest ship and the number of ships that will use the port. The berth layout will be affected by many factors such as the size of the harbour basin for manoeuvring, satisfactory arrivals and departures of ships to and from the berth, whether or not the ships are equipped with bow rudder and bow thrusters, the availability of tugboats, and the direction and strength of wind, waves and currents.

Assuming assistance by tug boats, sufficient width of the berthing area is needed for safe towing in and towing out of the vessels, whilst other berths are occupied. For conventional cargo and container ships this results in 4 to 5 * B + 100, according to Figure B-7. Because of mediate wind conditions a factor 4.5 * B (= beam of ship) is taken. In case of very long basins of about 1,000 m it is desirable to have a width of about L + B + 50.

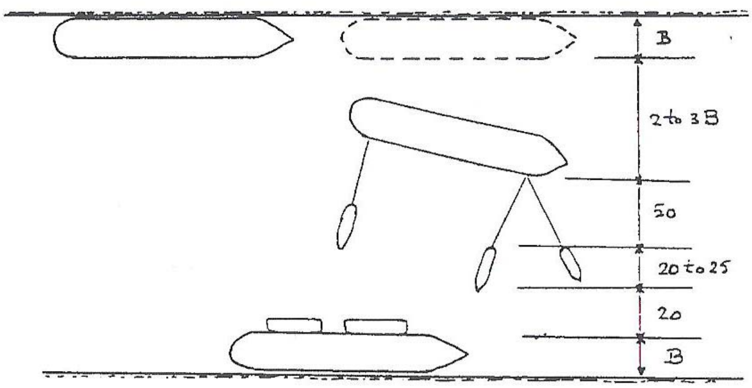



*Figure B-7 Berthing area width (Ligteringen, 2009)*

## B.4 Berths

In this paragraph firstly guidelines to minimise the wave hindrance at berth are provided. In the subsequent sub-paragraph an introduction is given about the number of required berths and corresponding dimensions. Subsequent paragraphs provide the corresponding calculations for dry bulk, general cargo and container berths.

### *B.4.1 Measures to minimise wave hindrance*

Except from the measures taken by the breakwater configuration, the wave climate at berth can be influenced by effective orientation and allocation of the berths.

**Berth orientation**

In order to reduce hindrance by wind and waves, it is advisable to align the berth as parallel as possible with the prevailing wind and wave direction (see Figure B-8). Usually berths need to be aligned with the current direction. However, considering the presence of breakwaters, no unallowable velocities will be reached. The angle with prevailing wind is especially important for container vessels, which have a high free board. The berth should be aligned within about 30° of the prevailing wind direction according to OCIMF (1997).

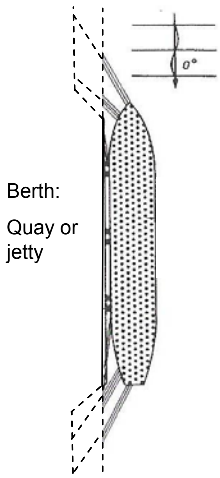



*Figure B-8 Minimisation of incident wind and wave angle at berth*

**Berth allocation**

Due to tight scheduling, port performance is most important for containers. Furthermore loading and unloading is hindered at less severe conditions than for dry bulk and general cargo, as visible in Table E-1. Therefore it is recommended to place the container berths at the berthing area, which is the least vulnerable to waves.

**Harbour shape**

In case of resonance in the harbour basin, also called seiches, it is effective to make the shape irregular. Moreover, in order to minimise the wave reflections, the use of a natural slope beneath loading platforms may be considered. For this purpose it is a good option instead of the use of quay walls.

### B.4.2 Introduction to queuing theory & dimensions

This sub-paragraph introduces the queuing theory, which is used in subsequent paragraphs to calculate the required number of berths. Moreover, guidelines for the berth dimensions are presented.

**Queuing system**

The number of berths required depends on the required service level. There are however a lot of interdependent factors that cause unwanted congestion. The complexity of this port system can be examined by researching the following factors, that effect the duration of ships staying in the port:

- Physical conditions (wind, waves, currents and to a certain extent tide);
- Number of suitable berths (dependent on ship length);
- Transhipment system;
- Storage capacity;
- Arrival pattern of ships;
- Sailing time from anchorage to the quay;
- Service time (loading and unloading efficiency).

In this project the physical conditions, berth dependency on ship length and the sailing time do not have a high influence on the port system. The former statement is justified with the assumption that sufficient protection measures against waves are taken.

**Work method**

For the above reasons the port system can be approached as a simple model. Therefore there is no need for a simulation system; especially in this conceptual design stage. Instead, estimation will be done on empirical ratios of berth productivity. The productivity is based on a fixed rate of occupation, in combination with the productivity of cranes and the number of operational hours per year. A more precise determination is possible by taking the variance of arrival- and service times of ships into account. This can be done by the queuing theory, of which more information is provided in the next section.

**Queuing theory**

With the queuing theory from Groenveld (2002) approximation of ship waiting times is possible. Based on acceptable waiting times the number of needed berths can be determined. With the theory the port system is schematised such, that it consists only of a queue (anchorage area) and a discrete number of berths. In addition, the inter-arrival time distribution and service time distribution are expressed mathematically. Such a queue-delay system can be represented as shown in Figure B-9. As a starting point the queue discipline “first come first served” is selected.

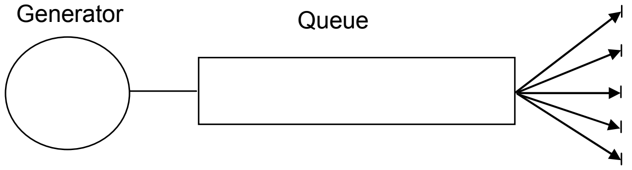



*Figure B-9 Representation of a queue-delay system (Groenveld, 2002)*

To provide a good service to ships, criteria have been formulated in § 3.2 for the waiting time as function of the average service time and the maximum turnaround time.

The factors determining the behaviour of a queuing system are:

- The customers arrivals;
- The service times of customers;
- The service system (queue-discipline, number of berths).

The customers arrivals and service times are expressed as statistical distributions. The service system can be described by the number of berths in the system and the queue discipline. The time taken to serve ships along the quay will have effect on the length of the queue that may from. This is even the case if the system has sufficient berths to meet the average rate of arrivals.

*Distributions*

D.G. Kendall assigned a letter to each of several distributions and described a queuing system by a three-part code consisting of a letter / letter / number combination. The first letter specifies the inter-arrival time distribution, the second stands for the service time distribution and number represents the number of berths.

The distribution of Erlang ($E_k$) is widely used to represent the arrival and service times, in case assumptions are possible with respect to the distribution. The probability density function f(t) of a variable t, as function of the parameters μ and k according to Groenveld (2002) holds:

$$f(t) = \frac{(k \cdot \mu)^k \cdot t^{k-1}}{(k-1)!} \cdot e^{-k\mu t} \qquad \text{if } t > 0$$

$$f(t) = 0 \qquad \text{if } t \leq 0$$

The formula may thought to be build up out of k negative exponential distributions (NED). The letter μ represents the arrival or service rate in this system, which is the expected value of the sum of different stages in the arrival/service process. In Figure B-10 the formula is plotted for different k-values.

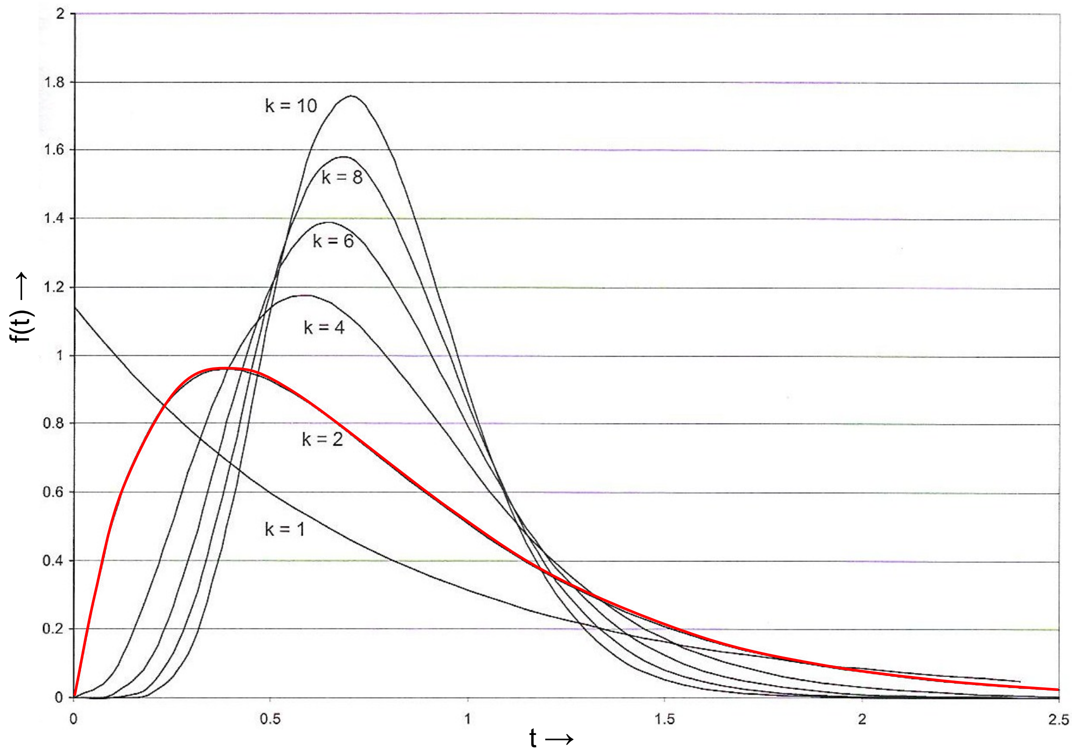



*Figure B-10 Erlang-k distribution with highlight of selected value k=2 (Groenveld, 2002)*

When the k-value is set to one, the negative exponential distribution results, which represents a random distribution of the inter-arrival or service time:

$f(t) = \lambda \cdot e^{-\lambda t}$ if t > 0

$f(t) = 0$ if t ≤ 0

Increasingly regular distributions can be described with higher order k-values. Erlang → ∞ stands for a completely fixed pattern. Practically applied distributions are however up to Erlang laws of 2nd to 4th order.

*Selection of distribution*

To choose a distribution, information is needed about the distinctiveness of patterns of call and variety of commodity types and sizes of shipment. In general, it can be stated that freighted traffic corresponds with a more random distribution of arrival and service time than liner traffic.

In this project there must be regarded at the expected traffic in the Filyos port. Of dry bulk especially coal will be delivered from Russia and Ukraine for the dedicated power plant. A more or less distinctive pattern of arrival and service time is therefore expected.

For general cargo and containers a more or less fixed arrival schedule and constant service time are important. Especially for container lines waiting times are unfavourable because of tight schedules.

From above can be concluded, that for all cargo types slightly fixed inter-arrival and service times are the best representation. Therefore a queuing system of E2 / E2 / n is selected for all types in the calculations. The value k=2 is highlighted in Figure B-10.

Methodology

In Table B-4 the ratios of average waiting times over service times are presented for an E2 / E2 / n system. These ratios depend on the occupancy and total number of berths. The occupancy can be calculated with:

$$u = \frac{\lambda}{\mu \cdot n}$$

In which:
λ = arrival rate
μ = service rate
n = number of berths

*Table B-4 Arrival and service time: Erlang 2 (Groenveld, 2002)*

| ***Berth occupancy rate*** | ***No. of berths*** | | ***Ratio:*** | ***Average waiting time*** | ***Vs.*** | ***Average service time*** | | |
|---|---|---|---|---|---|---|---|---|
| % | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 10 | 0.02 | | | | | | | |
| 15 | 0.03 | 0.01 | | | | | | |
| 20 | 0.06 | 0.01 | | | | | | |
| 25 | 0.09 | 0.02 | 0.01 | | | | | |
| 30 | 0.13 | 0.02 | 0.01 | | | | | |
| 35 | 0.17 | 0.03 | 0.02 | 0.01 | | | | |
| 40 | 0.24 | 0.06 | 0.02 | 0.01 | | | | |
| 45 | 0.30 | 0.09 | 0.04 | 0.02 | 0.01 | 0.01 | | |
| 50 | 0.39 | 0.12 | 0.05 | 0.03 | 0.01 | 0.01 | 0.01 | |
| 55 | 0.49 | 0.16 | 0.07 | 0.04 | 0.02 | 0.02 | 0.02 | 0.01 |
| 60 | 0.63 | 0.22 | 0.11 | 0.06 | 0.04 | 0.03 | 0.02 | 0.01 |
| 65 | 0.80 | 0.30 | 0.16 | 0.09 | 0.06 | 0.05 | 0.03 | 0.02 |
| 70 | 1.04 | 0.41 | 0.23 | 0.14 | 0.10 | 0.07 | 0.05 | 0.04 |
| 75 | 1.38 | 0.58 | 0.32 | 0.21 | 0.14 | 0.11 | 0.08 | 0.07 |
| 80 | 1.87 | 0.83 | 0.46 | 0.33 | 0.23 | 0.19 | 0.14 | 0.12 |
| 85 | 2.80 | 1.30 | 0.75 | 0.55 | 0.39 | 0.34 | 0.26 | 0.22 |
| 90 | 4.36 | 2.00 | 1.20 | 0.92 | 0.65 | 0.57 | 0.44 | 0.40 |

For example a quay with 2 berths with an average occupancy of 35%, has an average waiting over service time ratio of 3%.

In the calculations in this appendix the number of berths will be chosen that meets the service requirements that are stated in § 3.2.

**Quay dimensions**

In this section the formulas to determine the total berth length are presented. Moreover, the required extra bottom depth at berth is provided.

*Length*

When the number of needed berths of a quay is determined, a calculation for the length can be made. In case of multiple berths (n) the following formula holds (UNCTAD, 1985, op. cit. Ligteringen, 2009):

$L_q = 1.1 * n * (LOA_{average} + 15) + 15$

In case a single berth is needed, the quay length can be calculated as follows:

$L_q = LOA_{max} + 2 * 15$

*Bottom depth*

Sufficient depth for the ships needs to be guaranteed at the berthing area. The contribution of the same depth components as for the approach channel depth needs to be considered (see § B.1.4). In comparison with the approach channel no sinkage due to squat or trimming will take place at berth. Furthermore, there will be a reduction of vertical motion due to waves and of needed dredging volumes. As a starting point these influences are both halved. In Table B-5 the corresponding values are presented that result in addition to the draft into a depth of **1.7 m**. Regarding the 12 m draft of the normative vessel, the harbour basin depth required – outside of the berthing area - is therefore LAT - 13.7 m.

*Table B-5 Required extra depth at berthing area, next to vessel draft*

| **Depth component** | **Value (m)** | **Comment** |
|---|---|---|
| Vertical motion due to wave response | 0.5 | $H_{s, red}$ / 2 = 1.0 / 2 |
| Tidal elevation above reference | - | No tidal window applied |
| Wind set-down (1/yr) | 0.2 | |
| Net under keel clearance | 0.5 | Sandy bottom |
| | | |
| Extra components (not guaranteed/nominal): | | |
| Sounding accuracy, sediment deposit allowance & dredging tolerance | 0.5 | |
| **Total** | **1.7** | |

### B.4.3 Dry bulk

This sub-paragraph provides information about the calculations for the needed number of berths for the dry bulk terminal. As an introduction, a repetition of the annual throughput table is presented. Subsequently a proposal for the loading and unloading equipment is done.

**Annual throughput**

To give an overview of the dry bulk commodities and corresponding annual throughput, an overview is given in Table B-6. These numbers are extracted from Table 2-8. Iron ore and coal are presented separately from sand, gravel and fertilizers. This is chosen, because dedicated cranes and conveyor belts are needed for these groups of commodities. Mixture of the commodities by leftovers in the grabs and at the conveyor belt is not allowed. Therefore combined berths are needed.

*Table B-6 Annual throughput dry bulk in 2020 and 2030 (x 1,000 metric tons)*

| **Commodity** | **2020 import** | **2020 export** | **2030 import** | **2030 export** |
|---|---|---|---|---|
| Iron ore | 60 | 0 | 60 | 0 |
| Coal | 3,144 | 0 | 3,144 | 0 |
| *Subtotal* | *3,204* | *0* | *3,204* | *0* |
| | | | | |
| Sand & gravel | 114 | 421 | 213 | 935 |
| Fertilizers | 425 | 3 | 742 | 6 |
| *Subtotal* | *539* | *424* | *955* | *941* |
| **Total** | **3,744** | **424** | **4,160** | **941** |

**Loading & unloading equipment**

For unloading of dry bulk at berth an overhead trolley grabbing crane is chosen, of which an example is given in Figure B-11. The lifting capacity of this type of crane can go up to 85t. The gross unloading capacity amounts 4,200 metric tons per hour on coal (Ligteringen, 2009). The effective crane capacity is however considerably lower. An unloading capacity is therefore set to **1,500 ton per hour**, which is the average value from UNCTAD (1985). It must be stated that a different grab bucket will be needed for the handing of the fertilizers.

The maximum size of ships for export cargo is 25,000 DWT. Due to these low tonnages and little export calls a high crane capacity is not necessary. A crane with a load capacity of a few thousand tons per hour is sufficient. Therefore the same cranes can be used, with a capacity of 1,500 ton / h.

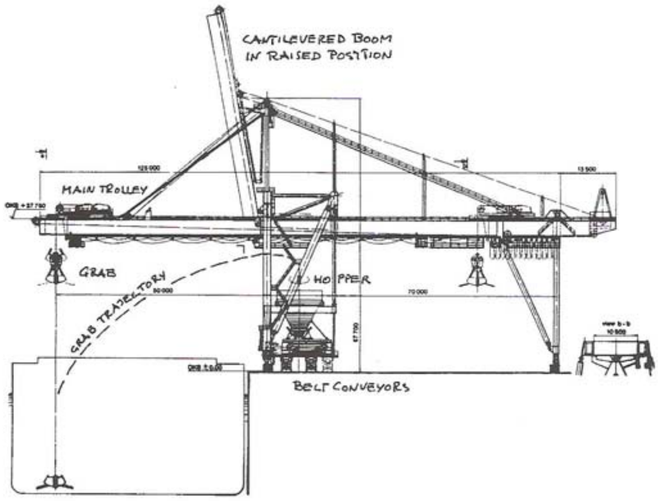



*Figure B-11 Overhead trolley unloader grabbing crane (Ligteringen, 2009)*

**Estimation**

As presented above, the effective loading and unloading productivity is 1,500 ton / (h * crane). Because ship sizes for dry bulk range from 170 to 215 m, 3 to 4 cranes can be applied at maximum. Assuming occupancy of 0.40, the berth productivity per crane amounts:

$C_b$ / N = p * $t_n$ * $m_b$ = 1,500 ton / h * 8,400 operational hours * 0.40 (-)
= 5,040,000 ton / (berth / (yr / crane))

*Conclusion*

With this productivity it can be concluded that sufficient capacity is provided per combined berth for both 2020 and 2030. To guarantee a good service level, the number of cranes needs to be adjusted. In the next section an iterative check is made to fit the number of berths and cranes with the required level of service.

**More detailed calculation**

To carry out a more detailed calculation, based on the queuing theory, the average load capacity of ships is needed. Therefore a derivation is given below.

*Average ship capacity*

The capacities of ships are (extracted from Table 2-11):
Dry bulk I (iron ore): 60,000 DWT
Dry bulk II (other commodities): 25,000 DWT

As a starting point, half of these ship capacities are used on average. The prospected throughput of iron ore comprises only 2% of the total transported dry bulk cargo. Therefore the following average ship capacity is taken into account: 0.5 * 25,000 = 12,500 DWT.

*Results queuing theory*

In Table B-7 the calculated number of berths with the use of queuing theory are presented for the combination of iron ore & coal.

*Table B-7 Queuing theory results for combined iron ore and coal (import + export); E2/E2/n queue*

| | **Comment / symbol** | **2020 + 2030** |
|---|---|---|
| Throughput (**x 1,000 metric tons**) | | 3,204 |
| Average ship load (DWT) | | 12,500 |
| Number of calls / yr | | 256 |
| Operational h / yr | | 8,400 |
| Average number of arrivals / h | λ | 0.030 |
| | | |
| Average loading & unloading rate (ton / h) | 3 cranes * 1,500 t / h | 4,500 |
| Average duration of handling one ship (h) | | 1.39 |
| Average service time (h) | Duration + 2 * 2.0 h | 5.39 |
| | (1 / μ) | |
| | | |
| **Results (average values)** | | |
| *With average ship load:* | | |
| Amount of berths | n | 1 |
| Occupancy | (λ / μ) / n | 0.16 |
| Waiting time / service time | - | 0.04 |
| Turnaround time (h) | (1 + WT/ST) * ST | 5.6 |
| | | |
| *With full ship load (iron ore: 60,000 DWT):* | | |
| Service time (h) | (1 / μ) | 13.3 |
| Turnaround time (h), | (1 + WT/ST) * ST | 16.0 |
| based on allowed waiting time (20%) | | |

In Table B-8 the number of berths which are determined with the use of queuing theory are presented.

*Table B-8 Queuing theory results combined berth sand, gravel & fertilizers (import + export); E2/E2/n queue*

| | **Comment / symbol** | **2020** | **2030** |
|---|---|---|---|
| Throughput (**x 1,000 metric tons**) | | 963 | 1,896 |
| Average ship load (DWT) | | 12,500 | 12,500 |
| Number of calls / yr | | 78 | 152 |
| Operational h / yr | | 8,400 | 8,400 |
| Average number of arrivals / h | λ | 0.009 | 0.018 |
| | | | |
| Average loading & unloading rate (ton / h) | 3 cranes * 1,500 t / h | 4,500 | 4,500 |
| Average duration of handling one ship (h) | | 1.4 | 1.4 |
| Average service time (h) | Duration + 2 * 2.0 h (1 / μ) | 5.4 | 5.4 |
| | | | |
| **Results (average values)** | | | |
| *With average ship load:* | | | |
| Amount of berths | n | 1 | 1 |
| Occupancy | (λ / μ) / n | 0.05 | 0.10 |
| Waiting time / service time | - | 0.008 | 0.017 |
| Turnaround time (h) | (1 + WT/ST) * ST | 5.4 | 5.5 |
| | | | |
| *With full ship load (25,000 DWT):* | | | |
| Service time (h) | (1 / μ) | 6.8 | 6.8 |
| Turnaround time (h), based on allowed waiting time (20%) | (1 + WT/ST) * ST | 8.2 | 8.2 |

**Resulting quay dimensions**

The below presented quay length and bottom width & depth for **2020 and 2030** result from the more detailed calculations.

*Dimensions with combined berth for iron ore & coal:*

L = $LOA_{max}$ + 2 * 15 m = 215 m + 2 * 15 m = 245 m

D = Draft $_{max}$ + depth components (Table B-5) = 12.0 m (not fully loaded) + 1.7 m = 13.7 m

*Dimensions with combined berth for sand, gravel & fertilizers:*

L = $LOA_{max}$ + 2 * 15 m = 170 m + 2 * 15 m = 200 m

D = 10.0 m + 1.7 m = 11.7 m

### B.4.4 General cargo

This sub-paragraph provides information about the calculations for the needed number of berths for the general cargo terminal. As an introduction, a specified annual throughput table is presented. Subsequently a proposal for the loading and unloading equipment is done.

**Annual throughput**

In Table B-9 the annual throughput forecast for general cargo is given per commodity. These are extracted from Table 2-8 with exclusion of the mentioned containerised general cargo of 17% in 2020 and 50% in 2030.

*Table B-9 Annual throughput forecast general cargo per commodity in 2020 and 2030 (x 1,000 metric tons)*

| Commodity | 2020 import | 2020 export | 2030 import | 2030 export |
|---|---|---|---|---|
| Metal products | 146 | 88 | 81 | 49 |
| Agricultural products | 123 | 41 | 120 | 44 |
| Food products | 86 | 10 | 85 | 12 |
| Chemicals | 239 | 156 | 417 | 268 |
| Machinery & other manufacturing | 891 | 636 | 956 | 974 |
| **Subtotal** | **1,485** | **932** | **1,659** | **1,347** |
| **Total** | | **2,417** | | **3,006** |

**Loading & unloading equipment**

On basis crane productivities that are provided by Fourgeaud (2000), productivity is derived that is considered realistic for the most common ship capacity of 25,000 DWT. Use will be made of a mobile crane, with the following characteristics:

Gross crane productivity: 160 ton / (h * crane)

Effective crane productivity, crane availability: 90%: 144 ton / (h * crane)

**Estimation**

As presented in the starting points, the effective crane productivity is 144 ton / h. Because of the ship size ranging from 140 to 165 m, 3 cranes can be applied. Assuming occupancy of 0.40, the berth productivity amounts:

$C_b = p * N * t_n * m_b$ = 144 ton / h * 3 cranes * 8,400 operational hours * 0.40 (-)

= 1,451,500 ton / (berth / yr)

With this productivity ratio the following number of berths required for 2020 and 2030 can be determined:

2020: 2 berths

2030: 3 berths

In the next section an iterative check is made of the offered service level in combination with number of berths and cranes.

**More detailed calculation**

To carry out a more detailed calculation, based on the queuing theory, the average load capacity of ships is needed. Therefore a derivation is given below.

*Average ship capacity*

The capacities of ships are (extracted from Table 2-11):
Metal products: 25,000 DWT
Other general cargo: 15,000 DWT

As a starting point half of the ship capacity is used on average. The number of metal products comprises about 10% of the total general cargo throughput. Therefore an average ship size of 8,000 DWT is taken normative.

*Results queuing theory*

In Table B-10 the number of berths which are determined with the use of queuing theory are presented.

*Table B-10 Queuing theory results general cargo; E2/E2/n queue*

| | **Comment / symbol** | **2020** | **2030** |
|---|---|---|---|
| Throughput (**x 1,000 metric tons**) | | 2,417 | 3,006 |
| Average ship load (DWT) | | 8,000 | 8,000 |
| Number of calls / yr | | 303 | 376 |
| Operational h / yr | | 8,400 | 8,400 |
| Average number of arrivals / h | $\lambda$ | 0.036 | 0.045 |
| | | | |
| Average loading & unloading rate (ton / h) | 3 cranes * 144 t / h | 432 | 432 |
| Average duration of handling one ship (h) | | 18.5 | 18.5 |
| Average service time (h) | Duration + 2 * 2.0 h<br>(1 / $\mu$) | 22.5 | 22.5 |
| | | | |
| **Results (average values)** | | | |
| *With average ship load:* | | | |
| Amount of berths | n | 2 | 3 |
| Occupancy | ($\lambda$ / $\mu$) / n | 0.41 | 0.34 |
| Waiting time / service time | - | 0.06 | 0.01 |
| Turnaround time (h) | (1 + WT/ST) * ST | 23.6 | 22.7 |
| | | | |
| *With full ship load (metal products: 25,000 DWT):* | | | |
| Service time (h) | (1 / $\mu$) | 57.9 | 57.9 |
| Turnaround time (h),<br>based on allowed waiting time (20%) | (1 + WT/ST) * ST | 69.5 | 69.5 |

*Note*

For the year 2030 3 berths are chosen because of the recommended maximum occupancy ratios by UNCTAD (1985). The ratio of 50% in case of 2 berths is otherwise exceeded.

**Resulting quay dimensions**

The following quay length and bottom width & depth result from the more detailed calculations:

| | | |
|---|---|---|
| $L_{2020}$ | = 1.1 * 2 * (0.8 * (165 m + 15 m)) + 15 m | = 335 m |
| $D_{2020-2030}$ | = Draft $_{max}$ + depth components (Table B-5) = 11.0 m + 1.7 m | = 12.7 m |
| $L_{2030}$ | = 1.1 * 3 * (0.8 * (165 m + 15 m)) + 15 m | = 490 m |

*Possible reduction*

If the berth needed for metal products is placed in front, the needed bottom depth and width can be reduced because of a smaller ship size.

### *B.4.5 Containers*

This sub-paragraph provides information about the calculations for the needed number of berths for the container terminal. As an introduction, a repetition of the annual throughput is presented. Subsequently a proposal for the loading and unloading equipment is done.

**Annual throughput**

The annual forecasted container throughput is presented in Table B-11. These numbers are obtained from Table 2-7 and corrected with the TEU factor of 1.67, which is derived below the table. Container crane capacities are namely in **movements** per hour. Therefore no distinction between TEU and FEU containers is made.

*Table B-11 Forecast of annual container throughput for 2020 and 2030 (x 1,000 containers)*

| | 2020 | 2030 |
|---|---|---|
| Containers | 37.1 | 221.0 |

The TEU factor can be derived given the fact that twice as much FEU as TEU containers will be handled according to (NEA, 2009):

$F = (N_{20'} + 2 * N_{40'}) / N_{tot} = (1+4) / 3 = 1.67$

In which:

$N_{20'}$ = number of TEU's
$N_{40'}$ = number of FEU's
$N_{tot}$ = sum of TEU's and FEU's

**Loading & unloading equipment**

Effective gantry crane productivity (see Figure B-12): 25 movements / (h * crane).

*Figure B-12 Container gantry cranes (Ref. [7])*

**Estimation**

Because of the container ship sizes ranging from 200 m to 300 m, 4 to 6 cranes can be applied at the quay. Assuming occupancy of 0.40, the annual productivity per berth for one crane amounts:

$C_b / N = p * t_n * m_b$ = 25 containers / h * 8,400 operational hours * 0.40 (-)
= 84,000 containers / (berth / (yr * crane))

From this information can be concluded that one berth will provide enough capacity with multiple cranes for 2030. The total accepted turnaround time for container ships is however low. Therefore multiple berths may be needed. In the next section an iterative check is made of the offered service level in combination with number of berths and cranes.

**More detailed calculation**

To carry out a more detailed calculation, based on the queuing theory, the average load capacity of ships is needed. Therefore a derivation is given below.

*Average ship capacity*

Taking into account the starting points for container types, the following average ship loads can be expected:

- 2020: (1,000 * 80 % + 5, 000 * 20%) * 0.5 ship load= 900 TEU

→ 900 / 1.67 TEU = 540 containers (TEU & FEU)

- 2030: (1,000 * 50 % + 5, 000 * 50%) * 0.5 ship load = 1,500 TEU

→ 1,500 / 1.67 TEU = 900 containers (TEU & FEU)

*Results queuing theory*

In Table B-12 the number of berths which are determined with the use of queuing theory are presented.

*Table B-12 Queuing theory results for containers; E2/E2/n queue*

| | Comment / symbol | 2020 | 2030 |
|---|---|---|---|
| Throughput (**x 1,000 containers**) | | 37.1 | 221.0 |
| Average ship load **(x 1,000 containers)** | | 0.9 | 1.5 |
| Number of calls / yr | | 42 | 148 |
| Operational h / yr | | 8,400 | 8,400 |
| Average number of arrivals / h | λ | 0.005 | 0.018 |
| | | | |
| Average loading & unloading rate (ton / h) | 6 cranes * 25 | 150 | 150 |
| Average duration of handling one ship (h) | | 6.0 | 10.0 |
| Average service time (h) | Duration + 2 * 2.0 h (1 / μ) | 10.0 | 14.0 |
| | | | |
| **Results (average values)** | | | |
| *With average ship load:* | | | |
| Amount of berths | n | 1 | 2 |
| Occupancy | (λ / μ) / n | 0.05 | 0.13 |
| Waiting time / service time | - | 0.01 | 0.01 |
| Turnaround time (h) | (1 + WT/ST) * ST | 10.1 | 14.1 |
| | | | |
| *With full ship load (5,000 / 1.67 = 3,000 containers):* | | | |
| Service time (h) | (1 / μ) | 24.0 | 24.0 |
| Turnaround time (h), based on allowed waiting time (10%) | (1 + WT/ST) * ST | 26.4 | 26.4 |

*Note*

For the year 2030 2 berths are chosen because 10% waiting time as percentage of service time is allowed. This criterion will just be met with one berth for average conditions but will be exceeded when maximum capacity container ships arrive. These ships are also normative for the number of needed cranes at the quay.

**Resulting quay dimensions**

With the determined number of berths the required quay length can be calculated.

$L_{2020}$ = 200 m + 2 * 15 m = 230 m

$D_{2020}$ = 9.0 m + 1.7 m = 10.7 m

$L_{2030}$ = 1.1 * 2 * (0.8 * (300 m + 15 m)) + 15 m= 570 m

$D_{2030}$ = 12.0 m + 1.7 m = 13.7 m

## B.5 Terminal storage areas

In this paragraph the needed surfaces of the terminal storage areas are derived. As with the previous paragraph, first a rough estimation of the needed storage areas is made with the use of capacity ratios. Afterwards more detailed calculations are carried out.

### *B.5.1 Dry bulk*

This sub-paragraph provides information about the calculations for the needed storage area for the dry bulk terminal. As an introduction, a repetition of the annual throughput table is presented. Subsequently a proposal for the storage and handling equipment is done.

**Forecasted throughput**

In Table B-13 the throughput forecast for dry bulk per commodity is given, as extracted from Table 2-8.

*Table B-13 Annual throughput dry bulk in 2020 and 2030 (x 1,000 metric tons)*

| Commodity | 2020 import | 2020 export | 2030 import | 2030 export |
|---|---|---|---|---|
| Iron ore | 60 | 0 | 60 | 0 |
| Coal | 3,144 | 0 | 3,144 | 0 |
| *Subtotal* | *3,204* | *0* | *3,204* | *0* |
| | | | | |
| Sand & gravel | 114 | 421 | 213 | 935 |
| Fertilizers | 425 | 3 | 742 | 6 |
| *Subtotal* | *539* | *424* | *955* | *941* |
| **Total** | **3,744** | **424** | **4,160** | **941** |

**Storage type & handling equipment**

Because of the type of dry bulk commodities, storage on open terrain is preferred. In case weather conditions may affect the quality of the material, a covered storage is required. Open storage results in stockpiles of meters high. An example of an open storage facility for dry bulk is visible in Figure B-13. The availability of space is scarce in the port area. Therefore the height needs to be maximised to use as little area as possible. This however depends on the bearing capacity of the subsoil, the characteristics of the materials (angle of repose) and on the outreach and height of stackers and reclaimers.

*Figure B-13 Example of open dry bulk storage and transport by conveyor belt (Ref. [8])*

Transportation to the storage area by a conveyor belt is preferred for the commodities. Shovels can be used for local smoothening of the grains.

*Storage exception for coal*

For coal however a different storage facility is planned. It will be directly transferred to the power plant via a conveyor belt system. Therefore no storage area is strictly needed for this commodity. To prevent malfunctioning of the conveyor belt an advanced system is however necessary. Otherwise an intermediate storage area for coal is essential in case of a transport calamity.

**Estimation**

To estimate the needed terminal area for dry bulk, the following capacity ratios are used (Ligteringen, 2009):

Coal: 15-25 ton / ($m^2$ * yr)
Iron ore: 30-40 ton / ($m^2$ * yr)

The capacity ratios for sand, gravel and fertilizers are not known at the moment. These ratios will be lower than for coal and iron ore. Coal forms about 80% of the total throughput for the long term. Therefore an average capacity is taken into account of 20 ton / (m * yr).

Total throughput (import + export) / capacity ratio presented:
2015 3,913,000 yr / 20 (ton / ($m^2$ * yr)) = 19.65 ha
2030 5,101,000 yr / 20 (ton / ($m^2$ * yr)) = 25.51 ha

**More detailed calculation**

The following formula, provided by Ligteringen (2009), is used to calculate the gross storage areas ($m^2$) for the different commodities:

$$O = \frac{C * f_1 * f_2 * \bar{t}_d}{\rho * h * 365 * m}$$

The parameters presented below are used for this formula. The dimensionless parameters are more or less standard proportions, used for dry bulk storage capacity calculations. The average stacking height is also an own starting point, chosen with common sense. The number of dwell time days are obtained from Witteveen+Bos.

| | | | |
|---|---|---|---|
| C | = | annual throughput that passes the storage area, see Table B-13 | |
| $f_1$ | = | proportion gross/net surface in connection with traffic lanes | = 1.3 (-) |
| $f_2$ | = | bulking factor due to cargo specific requirements | = 1.0 (-) |
| $\bar{t}_d$ | = | average dwell time of cargo | |
| | | iron ore | = 30 (days) |
| | | other bulk | = 20 (days) |
| ρ | = | density of commodity (metric ton / $m^3$), see Table 4-3 | |
| h | = | average stacking height, all bulk commodities[vii] | = 4 (m) |
| m | = | average rate of occupation | = 0.7 (-) |

In Table B-14 the densities of the dry bulk commodities handled are presented (Ligteringen, 2009).

cxxxvii

[vii] Taking into account the angle of repose and availability of space

*Table B-14 Dry bulk densities*

| **Commodity** | **Bulk density, ρ (metric ton / m$^3$)** |
|---|---|
| Iron ore | 2.5 |
| Coal | 0.8 |
| Sand & gravel | 1.6 |
| Fertilizers | 0.8 |

The results of the calculations are provided in Table B-15. The intermediate area for coal in case of conveyor belt clogging is also presented.

*Table B-15 Minimum storage areas dry bulk in 2020 and 2030 (ha)*

| **Storage area** | **Iron ore** | **Sand & gravel** | **Fertilizers** | ***Coal (intermediate area)*** | **Total** |
|---|---|---|---|---|---|
| $O_{2020}$ import | 0.09 | 0.18 | 1.35 | *5.00* | 1.62 / *6.62* |
| $O_{2020}$ export | 0.00 | 0.67 | 0.01 | *0.00* | 0.68 |
| **Total 2020** | *0.09* | *0.85* | *1.36* | *5.00* | **2.3 / 7.3** |
| $O_{2030}$ import | 0.09 | 0.34 | 1.36 | *5.00* | 1.79 / *6.79* |
| $O_{2030}$ export | 0.00 | 1.49 | 0.02 | *0.00* | 1.51 |
| **Total 2030** | *0.09* | *1.83* | *1.38* | *5.00* | **3.3 / 8.3** |

An example of a dry bulk terminal is in given in Figure B-14, which picture is taken at Maasvlakte in Rotterdam.

*Figure B-14 Example of a dry bulk terminal, Maasvlakte (Rotterdam) (Ref. [9])*

### *B.5.2 General cargo*

This sub-paragraph provides information about the calculations for the needed storage area for the general cargo terminal. As an introduction, a specified annual throughput table is presented. Subsequently a proposal for the storage and handling equipment is done.

**Forecasted throughput**

In Table B-16 the throughput forecast for general cargo is given per commodity. These amounts are extracted from Table 2-8 with exclusion of the mentioned containerised general cargo of 17% in 2020 and 50% in 2030.

*Table B-16 Annual throughput forecast general cargo per commodity for 2020 and 2030 (x 1,000 metric tons)*

| Commodity | 2020 import | 2020 export | 2030 import | 2030 export |
|---|---|---|---|---|
| Metal products | 146 | 88 | 81 | 49 |
| Agricultural products | 123 | 41 | 120 | 44 |
| Food products | 86 | 10 | 85 | 12 |
| Chemicals | 239 | 156 | 417 | 268 |
| Machinery & other manufacturing | 891 | 636 | 956 | 974 |
| **Subtotal** | **1,485** | **932** | **1,659** | **1,347** |
| **Total** | | **2,417** | | **3,006** |

**Calculation**

Because of the diversity of the products making estimation on basis of capacity ratio does not make sense. Therefore comparison with estimated surface areas is not made in this section.

The needed storage yard area (sheds) can be calculated with the following formula, according to Ligteringen (2009):

$$O = \frac{C * f_1 * f_2 * \bar{t}_d}{\rho * h * 365 * m}$$

The parameters presented below are used for this formula. The dimensionless parameters are more or less standard proportions, used for general cargo storage capacity calculations. The average stacking height is also an own starting point, chosen with common sense. The number of dwell time days are obtained from Witteveen+Bos.

| | | | |
|---|---|---|---|
| C | = | annual throughput that passes the storage area, see Table B-16 | |
| $f_1$ | = | proportion gross / net surface in connection with traffic lanes | = 1.5 (-) |
| $f_2$ | = | bulking factor due to cargo specific requirements | = 1.2 (-) |
| $\bar{t}_d$ | = | average dwell time of cargo | = 15 (days) |
| ρ | = | commodity density (metric ton / $m^3$), see Table B-17 | |
| h | = | average stacking height | |
| | | metal products, chemicals & machinery: | = 2 (m) |
| | | agricultural products & food: | = 4 (m) |
| m | = | average rate of occupation | = 0.7 (-) |

In Table B-17 the densities of the different commodities are presented.

*Table B-17 General cargo densities*

| **Commodity** | **Bulk density, ρ (metric ton/ $m^3$)** |
|---|---|
| Metal products | 3.0 |
| Agricultural | 0.6 |
| Food products | 0.8 |
| Chemicals | 1.0 |
| Machinery & other manufacturing | 2.5 |

The gross storage areas resulting from the calculations are provided in Table B-18.

*Table B-18 Minimum storage areas for general cargo in 2020 and 2030 (ha)*

| | **Metal** | **Agricultural** | **Food** | **Chemicals** | **Machinery & other** | **Total** |
|---|---|---|---|---|---|---|
| $O_{2020}$ import | 0.26 | 0.54 | 0.28 | 1.26 | 1.88 | 4.22 |
| $O_{2020}$ export | 0.15 | 0.18 | 0.03 | 0.82 | 1.34 | 2.52 |
| ***Total 2020*** | *0.41* | *0.72* | *0.31* | *2.08* | *3.22* | **6.74** |
| $O_{2030}$ import | 0.15 | 0.53 | 0.27 | 2.21 | 2.02 | 5.18 |
| $O_{2030}$ export | 0.09 | 0.20 | 0.04 | 1.41 | 2.06 | 3.80 |
| ***Total 2030*** | *0.24* | *0.73* | *0.31* | *3.62* | *4.08* | **8.98** |

### *B.5.3 Containers*

This sub-paragraph provides information about the calculations for the needed storage area for the container terminal. As an introduction, a repetition of the annual throughput table is presented. Subsequently a proposal for the storage and handling equipment is done.

**Forecasted throughput**

In Table B-19 the forecasts of the annual container throughput are presented in TEU's, which are copied from Table 2-7. The total number of containers is lower because FEU containers will also be handled (TEU factor is 1.67). For the calculation of the storage area however, the converted number of TEU containers is leading.

*Table B-19 Forecast of annual container throughput for 2020 and 2030 (x 1,000 TEU's)*

| | **2020** | **2030** |
|---|---|---|
| Containers | 62.0 | 369.0 |

As an own starting point, the following proportions export / total cargo counts, which are the same as for general cargo as presented in Table 2-8:

- 2020: 15.4%
- 2030: 32.7%

This leads to the results presented in Table B-20.

*Table B-20 Annual container throughput, import vs. export, for 2020 and 2030 (x 1,000 TEU's)*

| | **2020** | **2030** |
|---|---|---|
| Import | 48.8 | 248.0 |
| Export | 13.2 | 121.0 |
| **Total** | **62.0** | **369.0** |

**Storage type**

This section gives a description of the various storage types required. Moreover, it provides a ratio for the containers that are empty and/or will pass the CFS.

*Import, export and empties*

For the above given import and export containers a separate area is needed for logistic reasons. With export containers the distance to the berthed ships is shortest, because reduction of waiting time for the merchant ship is more important than at the landside. Container ships have tight schedules and therefore waiting costs are high.

A part of the import and export containers will be empty. These empty containers have a much longer dwell time and an area most far away from the quay is preferred. Sometimes the empty containers are even placed outside the terminal because of scarce space.

The mentioned containers will be stored on open terrain. An example open storage is given in Figure B-15.

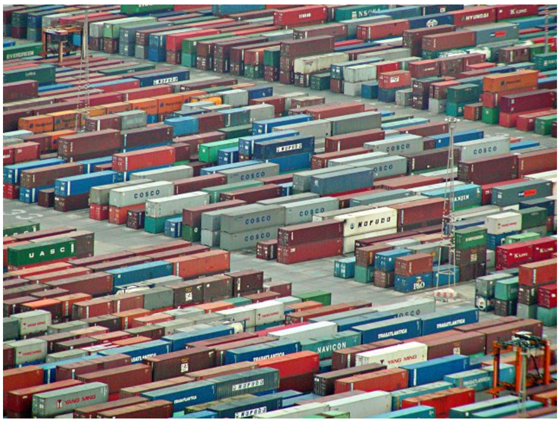


*Figure B-15 Example of open container storage on pavement (Ref. [10])*

*CFS*

Part of the full containers will pass a Container Freight Station (CFS). This covered shed provides facility for stripping and stuffing of the containers. The former is needed in case of different destinations, the latter in case of different origins. At one side of this shed trailers unload and load containers, while at the other side trucks take this order.

*Ratio of empty containers and CFS*

Given is that about 25% of total containers handled will be empty. Moreover, empties are more being exported than imported. The following own starting points are made:

- 40% of empty containers handled are import
- 60% of empty containers handled are export

The following ratios are considered reasonable to go through the CFS:

- 30% of imported full containers
- 10% of exported full containers

This results into the number of containers per stack type, as presented in Table B-21.

*Table B-21 Number of annual throughput per stack type (x 1,000 TEU's)*

| Stack type | 2020 | 2030 |
|---|---|---|
| Import | 29.8 | 147.8 |
| Export | 3.5 | 59.1 |
| Empties | 15.5 | 92.3 |
| CFS | 5.4 | 40.8 |
| *Total* | *62.0* | *369.0* |

**Handling equipment**

Because of the reasonable number of FEU containers, the use of straddle carriers is preferred (see Figure B-16). This equipment is able to handle between berth and storage yard and from there to the hinterland transport (truck stations). Straddle carriers are space efficient and the storage area needed is about 15 $m^2$ / TEU.

*Figure B-16 Straddle carrier (Ref. [11])*

**Estimation**

In the literature of Ligteringen (2009) a capacity ratio is given to determine the needed container storage area. A range is given from 6-10 ton / ($m^2$ * yr). Because of the high equipment chosen, the above range is chosen as indication. With the throughput tonnages from Table 2-6, the following areas result:

Gross storage area, 2020: 456,000 (ton / yr) / 10 (ton / ($m^2$ * yr)) = 4.6 ha
Gross storage area, 2030: 3,005,000 (ton / yr) / 10 (ton / ($m^2$ * yr)) = 30.0 ha

**More detailed calculation**

The required surface area for the open storage yards (import, export, empties) can be calculated with the following formula:

$$O_{open} = \frac{C_i \cdot \bar{t_d} \cdot F}{r \cdot 365 \cdot m_i}$$ (Ligteringen, 2009)

The parameters presented below are used for this formula. The dimensionless parameters are more or less standard proportions, used for container storage capacity calculations. The number of dwell time days are checked on correctness by Witteveen+Bos.

| | | | |
|---|---|---|---|
| $C_i$ | = | annual number of containers (TEU) that passes the storage area per stack type, see Table B-21. | |
| O | = | area required ($m^2$) | |
| $\bar{t_d}$ | = | average dwell time | |
| | | import | = 6 days |
| | | export | = 5 days |
| | | empties | = 12 days |
| F | = | required area per TEU, inclusive equipment travelling lanes (see proposed equipment) | = 15 $m^2$ |
| r | = | average stacking height / nominal stacking height | |
| | | import | = 0.6 (-) |
| | | export | = 0.8 (-) |
| | | empties | = 0.9 (-) |
| $m_i$ | = | acceptable average occupancy rate | |

| | |
|---|---|
| import | = 0.7 (-) |
| export | = 0.7 (-) |
| empties | = 0.8 (-) |

For the needed surface area for the CFS the following formula can be applied:

$$O_{CFS} = \frac{C_i \cdot V \cdot \bar{t}_d \cdot f_1 \cdot f_2}{h_a \cdot m_i \cdot 365} \quad \text{(Ligteringen, 2009)}$$

The parameters presented below are used for this formula. These parameters are more or less standard proportions, used for container storage in a CFS.

For the calculation of the CFS:

| | | | |
|---|---|---|---|
| $C_i$ | = | annual number of containers (TEU) that passes the storage area per stack type, see Table B-21. | |
| V | = | contents of 1 TEU container | = 29 $m^3$ |
| $f_1$ | = | gross area / net area (accounting for internal travel lanes) | = 1.4 (-) |
| $f_2$ | = | bulking factor | = 1.1 (-) |
| $h_a$ | = | average height of cargo in the CFS | = 2.0 m |
| $m_i$ | = | acceptable average occupancy rate | = 0.65 (-) |
| $\bar{t}_d$ | = | average dwell time | = 3 days |

The variables and corresponding values are presented in the list of starting points in § 4.4. The variable C corresponds with annual throughput as presented in Table B-21. The results of the required gross container storage areas are presented in Table B-22.

*Table B-22 Required gross container storage areas per stack type for 2020 and 2030 (ha)*

| Stack type | 2020 | 2030 |
|---|---|---|
| Import | 1.75 | 8.67 |
| Export | 0.13 | 2.17 |
| Empties | 1.06 | 6.32 |
| CFS | 0.15 | 1.15 |
| **Total (ha)** | 3.09 | 18.31 |

The estimated storage areas are reasonably in line with the more detailed calculations. The latter are used as input for the layout.

An example of the areas and the preferred arrangement is given in Figure B-17. **The surfaces in the figure are only indicative**; the storage areas must be equal to the in Table B-22 presented values. In contradiction to the figure, empties are often stacked outside of the gate. Because of the long dwell time for these containers, the need for quick handling is smaller.

Also an area is reserved for offices, parking and transfer areas. It is likely that some food products will be containerised, which necessitates the indicated area for reefers (refrigerated containers).

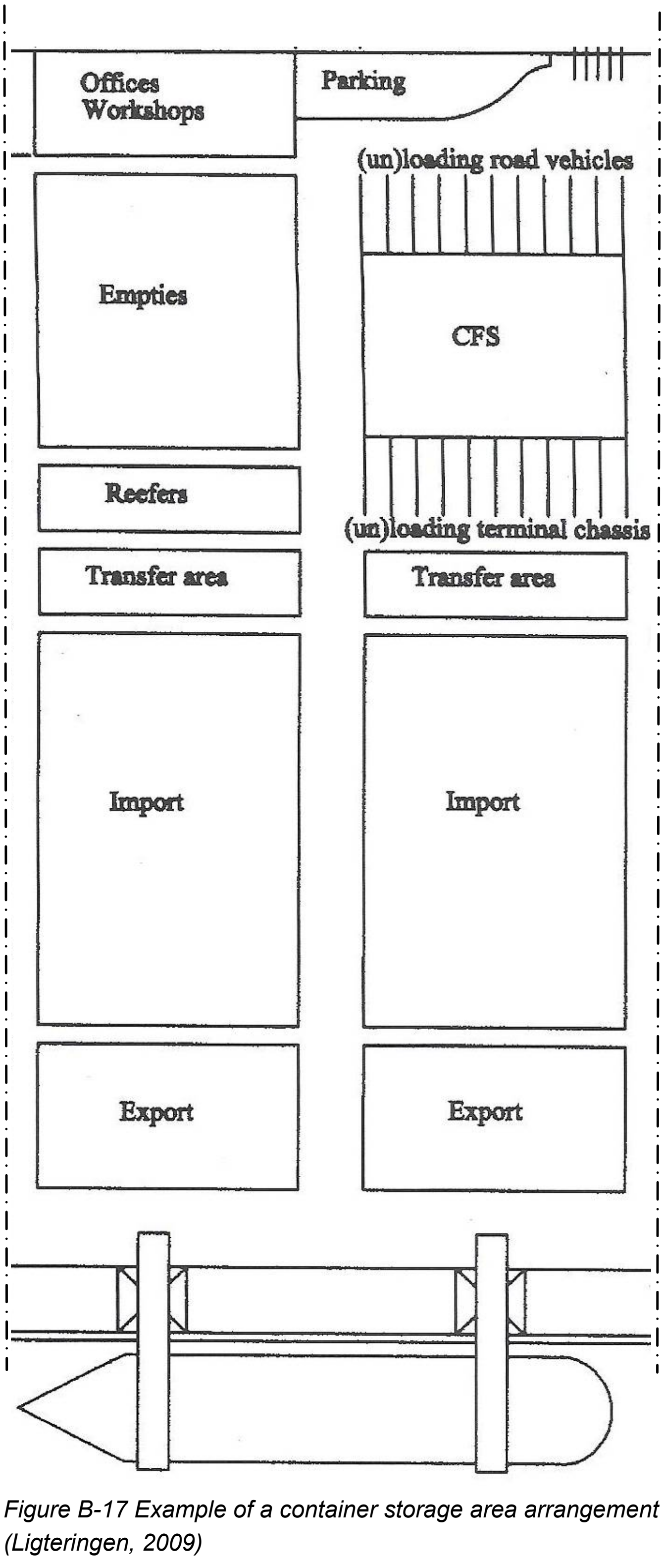



*Figure B-17 Example of a container storage area arrangement (Ligteringen, 2009)*

## B.6 Rail and road capacity

This paragraph gives an approximation of the required and available capacity of the rail and road. It is based on the cargo flow forecast provided in § 2.2.2.

### *B.6.1 Rail*

**Hinterland**

A total cargo flow of 492,000 tons is expected to be transported by rail to and from Karabük during 2020-2030. This load of cargo will not give high requirements with respect to the rail capacity. With 350 workable days per year, an average of 1,400 ton/day is expected. Assuming a loading capacity of 15 ton per rail wagon and ten wagons connected, 10 trains per day enter and leave the port on average. The current line capacity of 15 to 20 trains per day is therefore sufficient for variances in rail traffic.

**Terminal**

At the dry bulk terminal, the amount of daily trains can be handled with a single rail. A dedicated push and pull locomotive can be considered for arranging the rail wagons to its terminal destination.

### *B.6.2 Road*

**Hinterland**

Traffic by trucks is expected of 3.4 million and 6.8 million ton respectively for the year 2020 and 2030.

Assuming a truck capacity of 17 ton, about 400,000 trucks will enter and leave the port per year in 2030. Further assuming 350 workable days per annum, this results in 1,150 trucks per day on average. A 24 hour working schedule for the port can be assumed and there will be different shifts per day. Most exported cargo will enter the port early and imported cargo will leave the port later on. Therefore, hourly peak traffic of about 100 trucks can be expected.

The road will mainly be used for the traffic of trucks. One road with two lanes will be sufficient. If the amount of passenger cars increases in the future, expansion to more lanes needs to be considered to avoid hindrance.

**Terminal & gates**

Assuming a handling time per truck at the terminal of 10 min. on average, 17 trucks need to be handled at the same time. Because there is a separate container and general cargo terminal, with assumed equal throughput in 2030, no congestion can be expected at the terminal roads and marshalling yards. In Figure B-18 an example of a storage shed and truck marshalling yard is presented.


*Figure B-18 Terminal shed and marshalling yard (Ref. [12])*

At the gates administrative procedures and weighing will take place. Therefore, it can be expected that about 4 lanes are needed at the entrance.

# APPENDIX C LAYOUTS

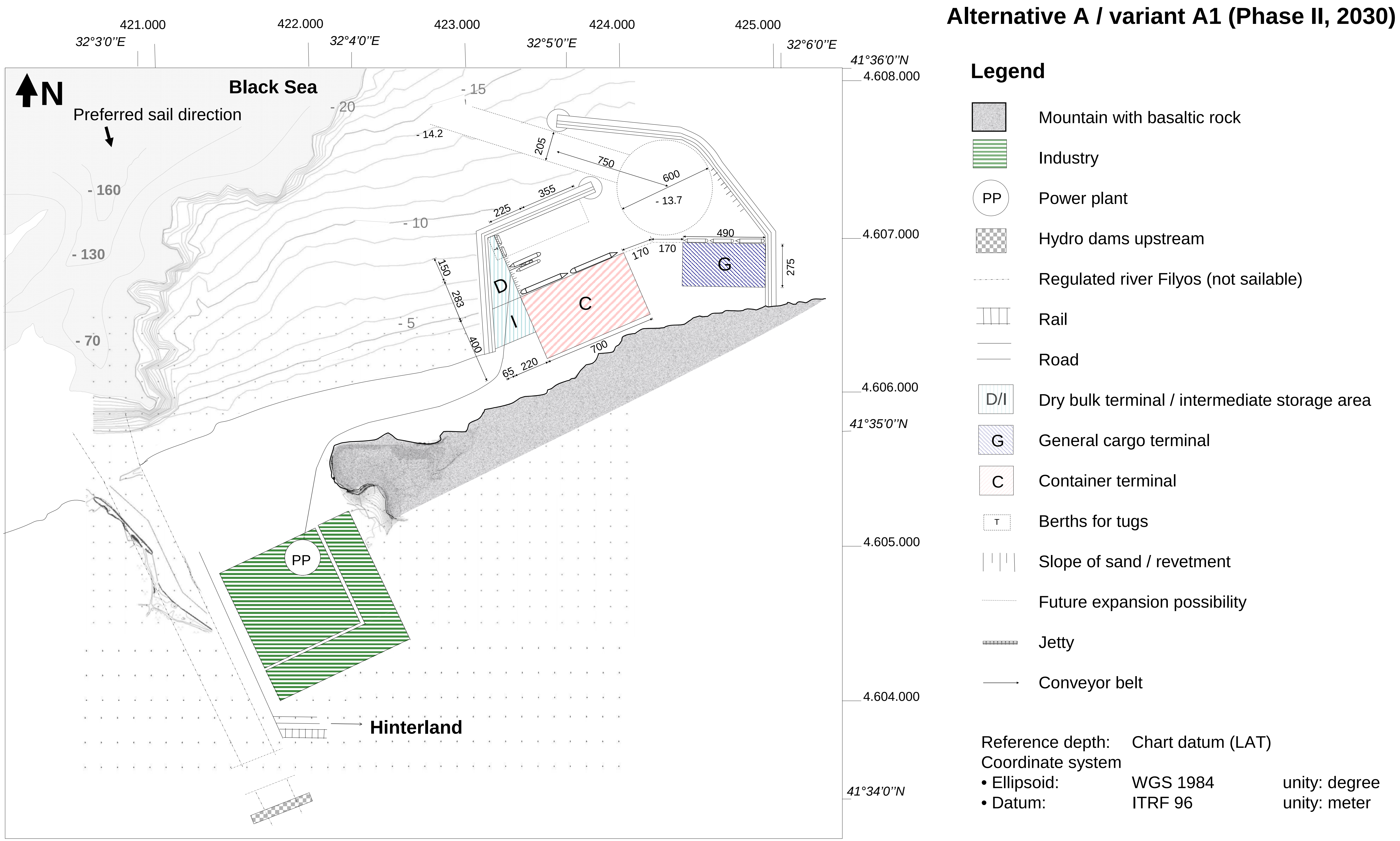
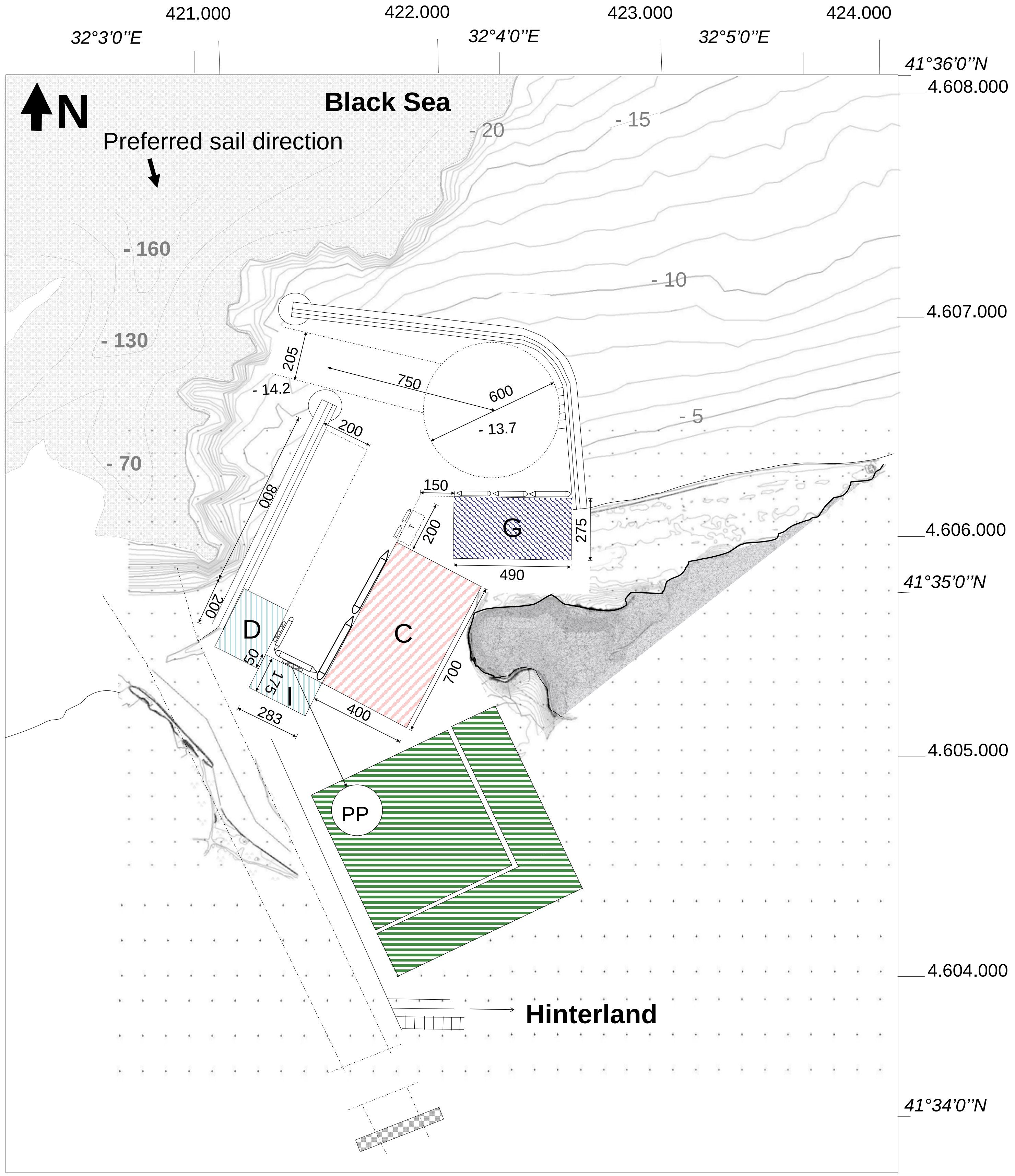



*Figure C-1 Layout alternative A / variant A1, phase II (2030)*




## Alternative B (Phase II, 2030)

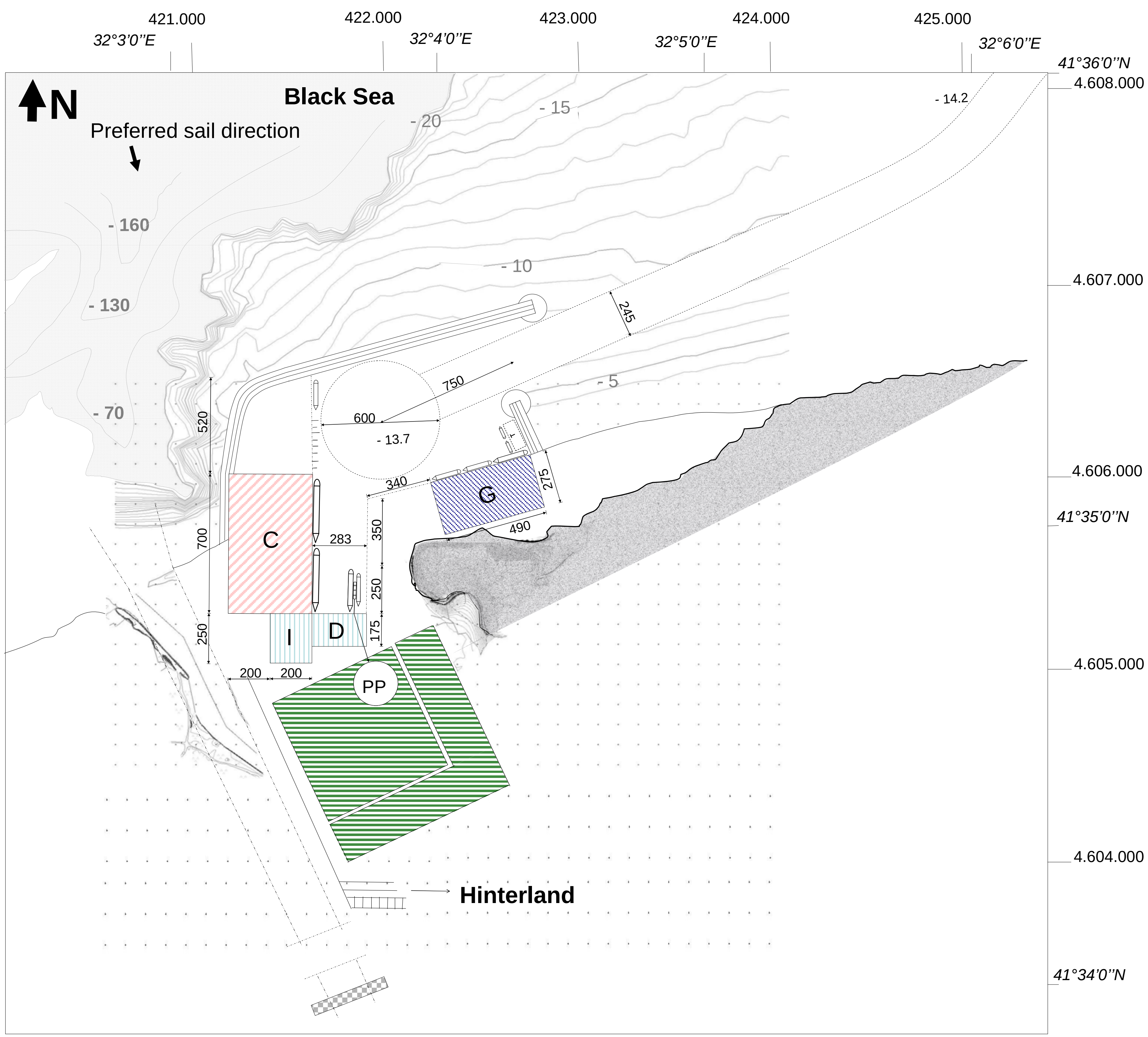
### Legend

- Mountain with basaltic rock
- Industry
- PP — Power plant
- Hydro dams upstream
- Regulated river Filyos (not sailable)
- Rail
- Road
- D/I — Dry bulk terminal / intermediate storage area
- G — General cargo terminal
- C — Container terminal
- T — Berths for tugs
- Slope of sand / revetment
- Future expansion possibility
- Jetty
- Conveyor belt

| | | |
|---|---|---|
| Reference depth: | Chart datum (LAT) | |
| Coordinate system | | |
| • Ellipsoid: | WGS 1984 | unity: degree |
| • Datum: | ITRF 96 | unity: meter |

*Figure C-2 Layout alternative B, phase II (2030)*

## Alternative C (Phase II, 2030)




### Legend

- Mountain with basaltic rock
- Industry
- PP Power plant
- Hydro dams upstream
- Regulated river Filyos (not sailable)
- Rail
- Road
- D/I Dry bulk terminal / intermediate storage area
- G General cargo terminal
- C Container terminal
- T Berths for tugs
- Slope of sand / revetment
- Future expansion possibility
- Jetty
- Conveyor belt

| | | |
|---|---|---|
| Reference depth: | Chart datum (LAT) | |
| Coordinate system | | |
| • Ellipsoid: | WGS 1984 | unity: degree |
| • Datum: | ITRF 96 | unity: meter |

*Figure C-3 Layout alternative C, phase II (2030)*

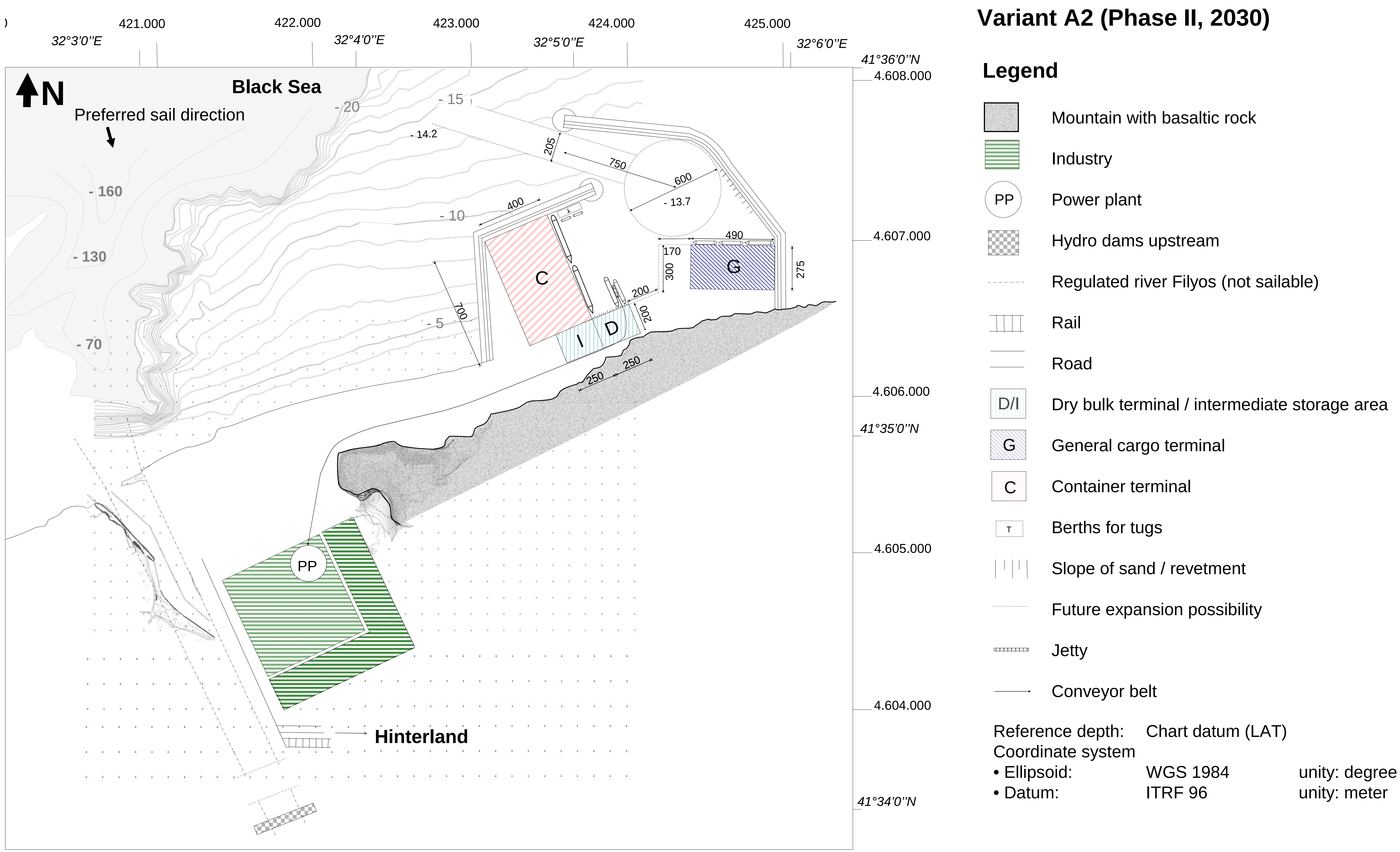



*Figure C-4 Layout variant A2, phase II (2030)*

## Variant A3 (Phase II, 2030)

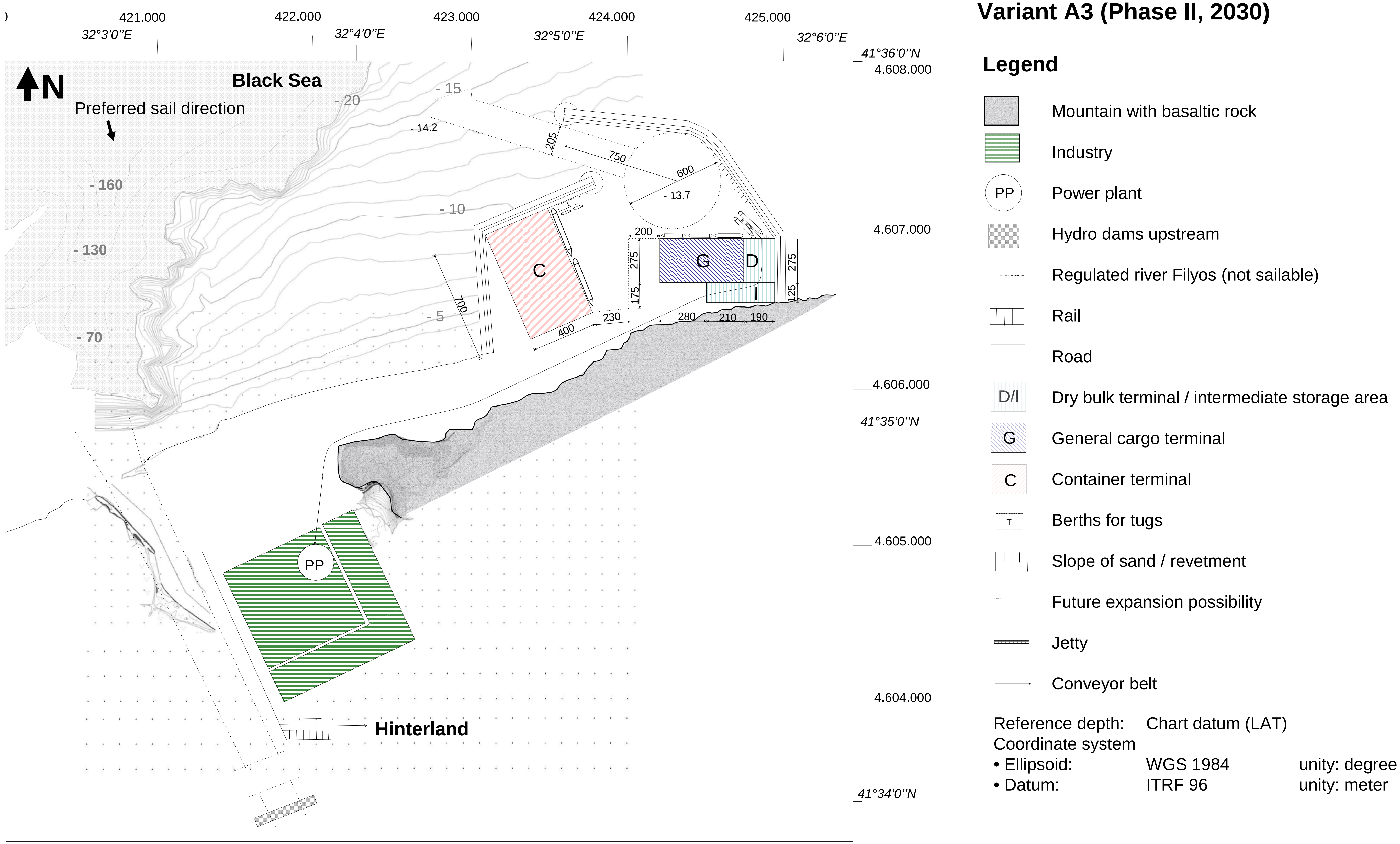



*Figure C-5 Layout variant A3, phase II (2030)*

# APPENDIX D COAST MORPHOLOGICAL IMPACT

This appendix provides the assessment done about the morphological consequences for the coastline by building the port Filyos. Based on the determined longshore transport in § A.7.1 with the model UNIBEST, the coastline evolution is simulated with the CL+ feature of the model. This model is based on the theory single line theory, which provides a good fundament for a first assessment.

In the first paragraph information of the single line theory is provided. In the second paragraph the setup and results of the model UNIBEST CL+ are described.

## D.1 Single line theory

The single line theory provides a simple approach for the coastline development. This theory is first described by Pelnard-Considère (1956). The information in this paragraph is abstracted from Van de Graaff (2009).

### *D.1.1 Introduction*

It is assumed that the shape of the cross-shore profile is constant, while the position of the coastline is changing in time. The entire profile moves seaward or landward with a horizontal distance *a,* depending on the sediment balance (see Figure D-1). It requires the assumption that a more or less horizontal part in the underwater profile is present, which is a realistic at Filyos for the part until the trough border at a depth of MW -20 m.

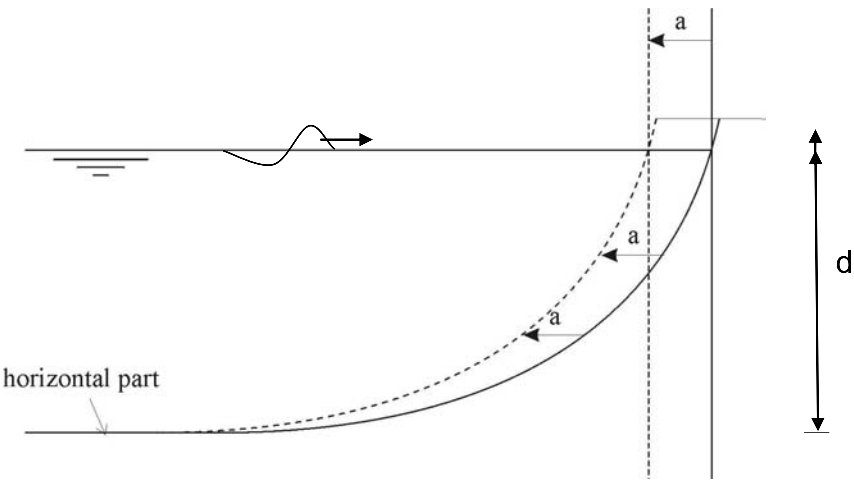



*Figure D-1 Single line theory*

The closure depth (d) can be regarded as the depth where, for the considered period of time, only relatively small cross-shore sediment transport takes place. It is dependant from the water level and wave climate.

### *D.1.2 Equations*

To derive the required equation, a coastal section can be considered with length dx, as indicated in Figure D-2. A longshore sediment input $S_x$ comes in from the left border and a transport of $S_x + dS_x$ leaves at the right border. Starting at time t, the shoreline moves until t+dt over a distance dy. This movement occurs over the closure depth height d. According to the principle of continuity the following equation holds:

$$\frac{dS_x}{dx} = -d\frac{dy}{dt} \quad [E.1]$$

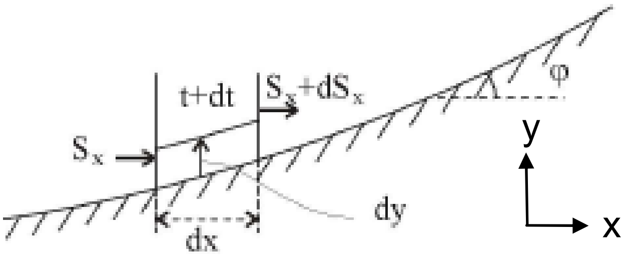



*Figure D-2 Definition sketch for single line theory*

Because the shoreline dynamics are of interest, the equation of motion can be used. Assuming that wave conditions do not vary; only the wave angle with respect to the orientation of the coastline varies because of the coastline curvature.
An (S,φ) diagram provides information to determined the equation of motion. This diagram shows the longshore transport as function of the angle of incidence at deep water; see the example in Figure D-3. It is visible that for small angles of incidence with the coast, S changes linearly with small changes in wave angle. This holds for the ranges 0-20° and 60-80° in the figure.

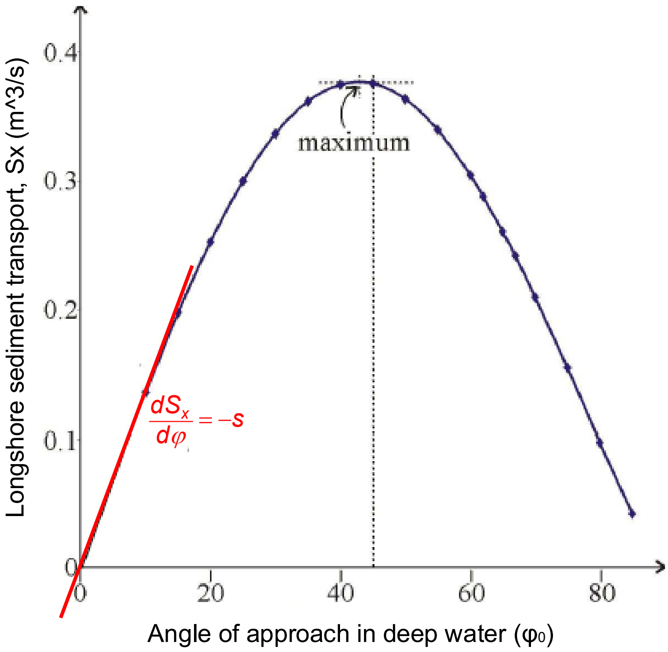



*Figure D-3 Example of an (S,φ) diagram*

Because of the linear relation for small angles, the tangent of the diagram can be used at the point where φ=0°. This assumption results in the fact that an overestimation will be made for

The equation of motion then becomes:

$$\frac{dS_x}{d\varphi} = -s \qquad [E.2]$$

In which:

s= coastal constant defined by Eq. [E.2] (m$^3$/yr) / rad

From Figure D-2 it follows that the angle of coastline itself, φ is equal to dy/dx. This means that as long as dφ remains small:

$$\frac{d\phi}{dx} = \frac{d^2y}{dx^2} \qquad [E.3]$$

Combining Eq. E.2 and E.3 gives the following parabolic differential equation holds for one-line modelling:

$$-s\frac{d^2y}{dx^2} + d\frac{dy}{dt} = 0 \qquad [E.4]$$

To solve this equation one initial condition and two boundary conditions are needed. In case of Filyos, this is the coastline position at t=0 and the sediment transport on both borders of the coastal area.

### D.1.3 Expected development

As approximated in § A.7.1 at Filyos there is a dominant coastal drift in eastern direction. The implementation of a breakwater will block the sediment transport along the coast. In the single line theory it is assumed that all sediment will be blocked, which means that S=0 at the breakwater. A situation exists at the left coastal border of the breakwater, as presented in Figure D-4. Because no transport is possible at x=0, the orientation of the coastline will adjust to this situation. It will rotate in such a way that the wave angle relative to this rotated coast angle becomes zero.

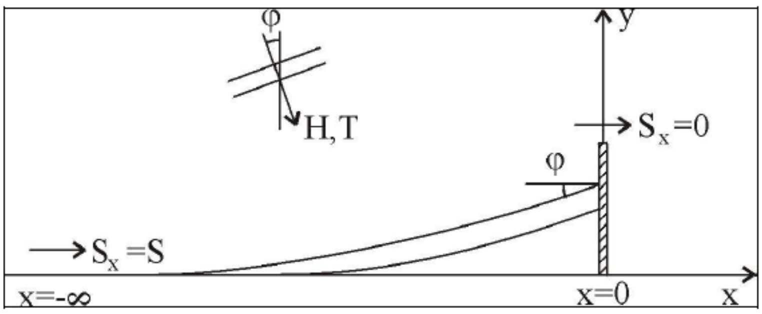



*Figure D-4 Accretion of the coast near a breakwater, with wave conditions at the horizontal part of the coastal area*

The following boundary conditions hold for this situation:

Initial boundary: y=0, for t=0 and for -∞ < x < 0

Left boundary: $S_x$=S, for x= -∞ and for all t

Right boundary: $S_x$=0, for x= 0 and for all t

For the formula of y (x,t) is referred to Van de Graaff (2009). An example of the result is provided in Figure D-5. At the updrift side accretion of sediment will take place and on downdrift side erosion. The result of theory is a mirrored profile with a parabolic shape, as visualised in the figure.

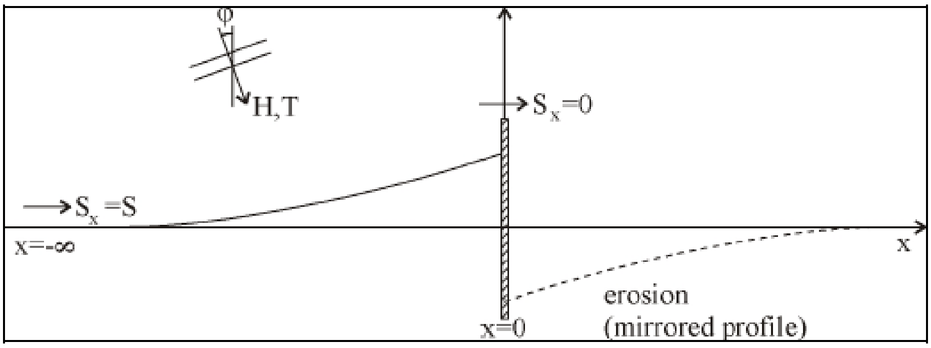



*Figure D-5 Coastline development at the up- and downdrift side of a breakwater*

**Note**

Because of the changing coastline, the distance between the coast line and the breakwater head becomes smaller. Therefore the transport zone will shift seawards and may extent beyond the reach of the breakwater. A sediment by-pass will occur in that situation, causing accretion at the downdrift side; see Figure D-6.

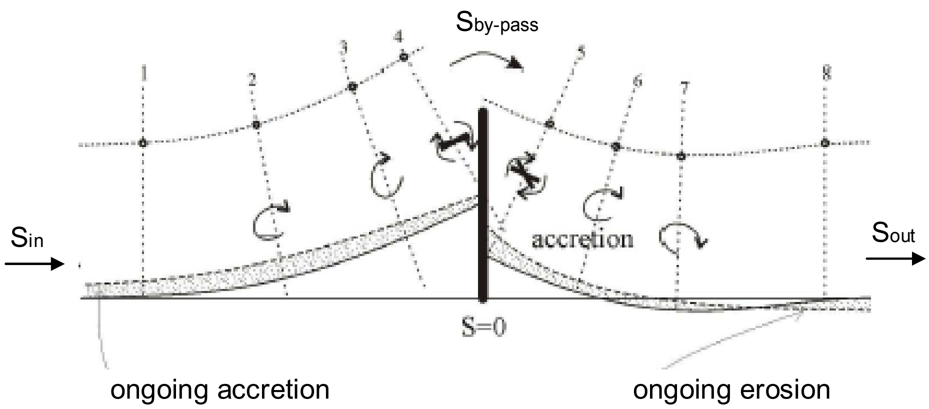



*Figure D-6 Excluded effect in single line theory: transition of the transport zone with respect to the breakwater, creating a sediment by-pass*

In the single line theory this effect is not included. In the situation at Filyos the guiding embankment at the west side of the river Filyos will interrupt in the transport process. This structure reaches until the trough, which can be interpreted as a sink for the sediment. Therefore, the fact that this phenomenon is excluded is not important.

## D.2 UNIBEST CL+

In this paragraph the in- and output of UNIBEST are presented.

### *D.2.1 Setup*

In this sub-paragraph the model setup is described, in addition to the settings provided in § A.7.1.

**Coastline & objects**

A rough schematisation is done by assuming a straight coastline for the stretch at both sides of the port area; see Figure D-7.

The eastern breakwater is put in the model as a groyn of 1,200 m length, which blocks the sediment transport completely. At the west side the guiding embankment of the Filyos river will interrupt in the transport process, over a length of about 600 m. This will also be modelled as a groyn. Regarding the assumptions made in the note below, the boundary conditions hold, as indicated in the figure.

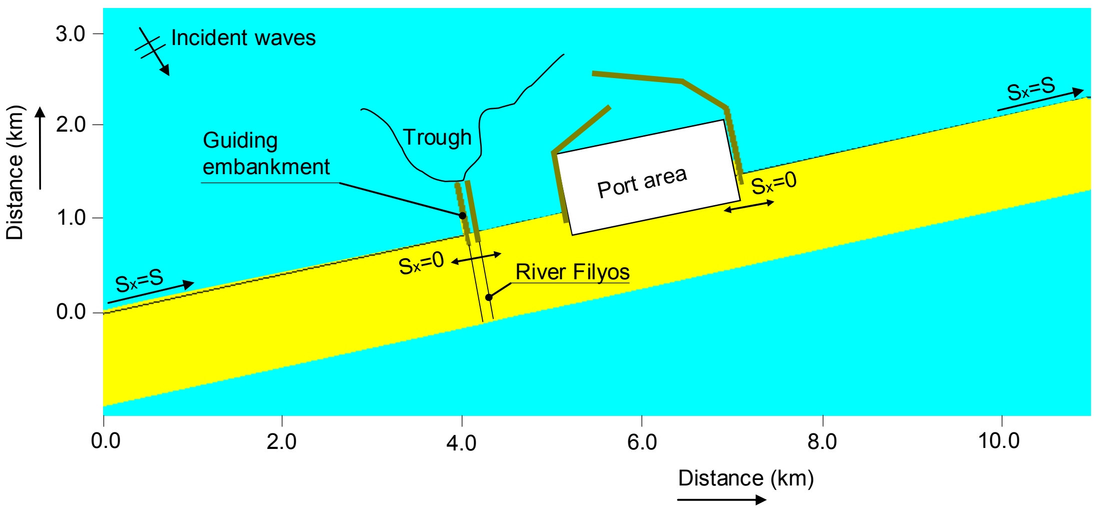



*Figure D-7 Schematisation of coastline and objects*

**Important note**

It is assumed that sediment which passes the embankment will drop into the trough. The same condition is assumed for the sediment discharge from the river Filyos.

Closure depth

To calculate the coastline change in meters, the closure depth is required. It will be deeper than the depth of the breaker line, which is equal to MW -8.9 m (§ B.2.2). Moreover, phenomena that raise the water level need to be included. Except from the depth components enumerated in Table B-2, the wave run-up and set-up need to be taken into account. The closure depth is therefore set to MW -10.0 m. It is assumed that the profile moves horizontally over a height d, independent of the question whether it is an accreting or eroding coast.

### *D.2.2 Results*

For a selection of time periods the coastline evolution is simulated. The resulting coastline for a time interval of 50 years is presented in Figure D-8. The dominant eastward direction of longshore drift is visible in the figure. It must be noted that, due to the scale of the figure, it is not visible that the coastline has a parabolic shape as presented in Figure D-5.

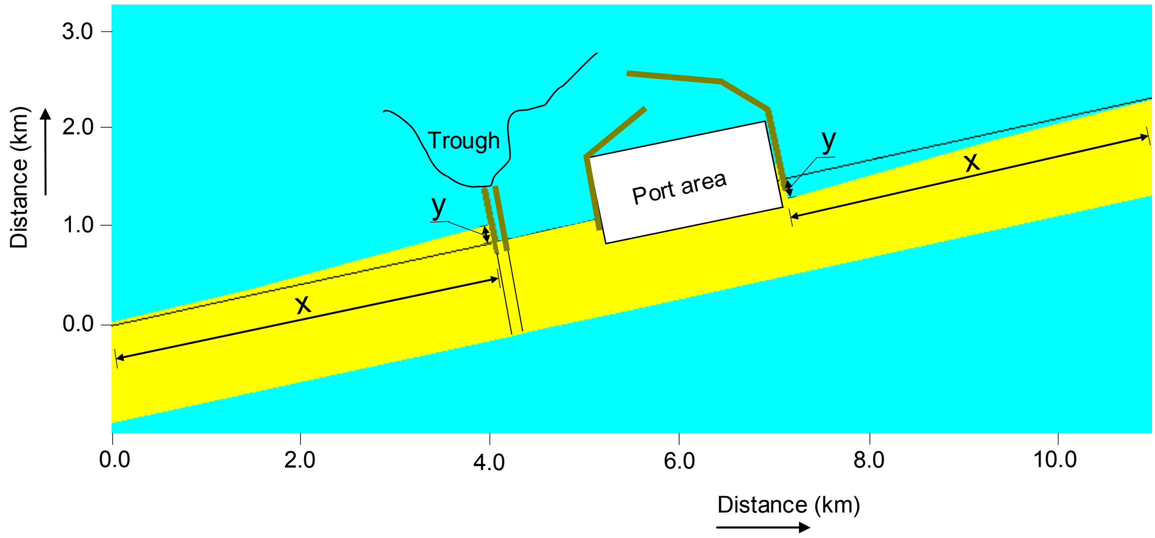



*Figure D-8 Single line coastline evolution at Filyos after 50 years, with use of UNIBEST CL+*

In Table D-1 the coastline changes due to accretion and erosion are presented for several time intervals. The results show an almost mirrored profile. The amount of accretion (y) at the guiding embankment is however lower, because the transport zone reaches beyond of the embankment head.

The length (x) is the length for which there is any change of coastline. This length is larger than indicated in the figure, where the stretch of considerable change is indicated. The results of simulating different time intervals showed that an equilibrium length is found at about 7,700 m.

*Table D-1 Sizes of accretion and erosion after time intervals, using default transport parameters of Van Rijn (in m)*

| Time period (years) | Length (x) | Accretion (y) | Erosion (y) |
|---|---|---|---|
| 10 | 3,500 | 41 | 51 |
| 50 | 6,500 | 148 | *175* |
| 100 | 7,000 | 224 | *273* |
| 200 | 7,500 | 314 | *411* |

Since erosion develops at the eastern side, which is bordered by the basaltic rocky mountain (see Figure D-9), the erosion length (x) will not occur at this location. Instead, the problem will shift downdrift of the coast at the nearest stretch of sand, which is about 2 km east. It provides a potential erosion width (y) of 400 m. Since this beach has no recreational or industrial purpose, erosion has no consequences. Further eastwards, the coastline is curved and has a small incident angle with waves coming from the west. No erosion is therefore expected in this “activity free” area.


*Figure D-9 Schematisation of future erosion area*

# APPENDIX E HARBOUR WAVE PENETRATION

As presented in the requirements, an important characteristic is the wave climate inside the harbour. It influences both the navigability and the ability for loading and unloading at berth. A preliminary assessment of these conditions is therefore made for the chosen alternative A. On basis of the resulting wave climate, the best variant will be chosen.

## E.1 Approach

### *E.1.1 Schematisation*

In order to assess the operational conditions, assessment is required about the harbour wave penetration. Moreover, insight is required of the ship's natural period of oscillation and the elastic properties of fenders and hawsers. A simplified approach will however be carried out in this appendix. Use is made of Table E-1 with indicative values for the operational wave height limits, originating from PIANC (1987). It refers to the heights of residual deep water waves with periods in the range of about 7 to 12 seconds. Locally generated waves have a short period and have relatively little effect on the moored ships. No further variance in wave period is included.

For dry bulk a distinction of allowable wave heights is made between loading and unloading. The unloading conditions for dry bulk are most important (because of import of coal) and are therefore considered normative.

*Table E-1 Indicative limiting operational wave heights Hs (m) (PIANC, 1987)*

| Ship type | 0° (head or stern) | 45° - 90° (beam) |
|---|---|---|
| General cargo | 1.0 | 0.8 |
| Container, Ro/Ro ship | 0.5 | |
| Dry bulk (30,000 - 100,000 DWT); loading | 1.5 | 1.0 |
| Dry bulk (30,000 - 100,000 DWT); unloading | 1 | 0.8 - 1.0 |

### *E.1.2 Model choice*

Based on the normative conditions at berth (see Table E-1) and the harbour bathymetry, choice is made for the model SWAN Simulating WAves Nearshore (SWAN), v. 40.72 (ref. [3]). This model is able to translate the offshore wave climate to the wave conditions at the harbour entrance. Moreover, it is able to determine the wave climate in the harbour and at the berths. It is however not possible to take the physical phenomenon diffraction properly into account. As will appear in the next paragraph, the influence of disabling diffraction is small to the extent which is relevant for the preliminary design phase.

## E.2 Introduction to SWAN

First an introduction is given about the properties of SWAN. The physical phenomena relevant for the assessment are described, in combination with its limitations.

### *E.2.1 Model abilities and limitations*

In Table E-2 an overview is provided of important physical processes that are included and excluded the SWAN model. The first row presents the processes involved in the translation of the offshore to nearshore conditions. In the second row additional processes are presented, which are important for simulating the penetration of waves into the harbour.

*Table E-2 Important physical processes included and excluded in SWAN*

| **Off –shore to near shore** | **Wave growth** | **Dissipation (bottom friction & wave breaking)** | **Triad and quadruplet interactions** | **Refraction** | |
|---|---|---|---|---|---|
| | x | x | x | x | |
| **Additional, harbour wave penetration** | **Wave set-up & shoaling** | **Transmission** | **Reflection** | **Diffraction (2 breakwaters)** | **Resonance** |
| | x | x | x | - / x | - |

x included
- / x included, but restricted
- excluded

As indicated in the table, the physical process diffraction and resonance are not (fully) taken into account in the model. A discussion about the way diffraction is implemented and the relevance for the project is provided below.

**Diffraction**

*Model abilities*

The implementation of diffraction in SWAN is a widely discussed topic. Since it is a conventional spectral model, this process can not be completely included in the model. Therefore a phase-resolving model like Bousinesq is needed.

According to Booy *et al.* (2003) the process can however be included using a phase-decoupling refraction-diffraction approximation. The approximation is based on the mild-slope equation for refraction-diffraction, omitting phase information. For diffraction of random, short-crested waves, based on the mild-slope equation the results agree reasonably well with observations and analytical solutions for non complex cases. Singularities in the wave field could not properly be accounted for, e.g. at the tips of the breakwaters).

To the most recent version of SWAN (v. 40.72) adjustments are made with respect to the approximation. **According to the SWAN Team (2009) the approximation can not be used for harbours**. Own simulations with the model supported this statement, considering the high numerical diffusion close to the reflecting quay wall structures.

*Relevance of diffraction*

Enet *et al.* (2006) researched the diffraction effect into the harbour for wind waves and swell waves in SWAN v. 40.51. It resulted, amongst others, in the conclusion that the effect of diffraction on direction is significantly reduced in case of wide directional spreading, which is characteristic for wind waves. Below a description is provided about the origin of waves at Filyos and the consequences of the directional spreading.

Waves generated by local wind (wind-sea) have wave steepness ($H_S/L$) above 0.02. For offshore generated waves (swell), the steepness generally does not exceed 0.08. As can be derived from Table 2-16, locally generated waves are dominant (using the relation $L_0 = \frac{g}{2 \cdot \pi} T_p^2$). As a consequence, the waves have a high directional spreading.

Goda (2000) researched the wave propagation pattern for two breakwaters. In Figure E-1 diffraction diagrams for random and normal incident waves are provided. It provides the effective diffraction coefficient $K_d$, which is the ratio of residual wave height and the incident wave height at the opening. Considered are two cases; one with a high directional spreading ($s_{max}$=10), which is relevant for Filyos, and one with a low directional spreading ($s_{max}$=75).

The breakwater opening (*B*) is considered equal to the wave length (*L*) in the figure, which is a rather good approximation for the long waves entering the port Filyos. It is however still below the criterion of *B/L < 5*, which means that the diffraction patterns of both breakwaters will interfere with each other. Therefore, in case diffraction is included, superposition of patterns by two semi-infinite breakwaters is not possible.

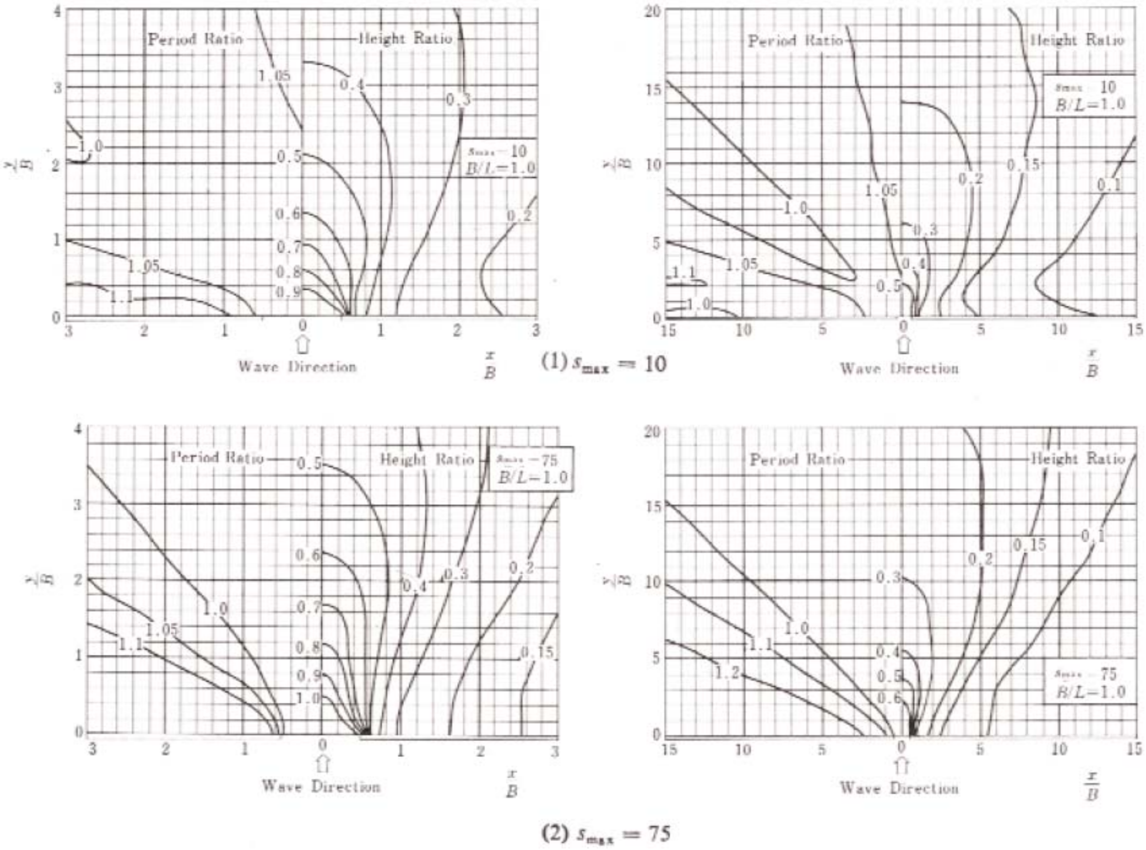



*Figure E-1 Diffraction diagram for a breakwater opening B/L = 1.0 for random waves of normal incidence; wind sea waves($s_{max}$=10) and swell ($s_{max}$=75); CUR 2007 (Goda, 2000)*

*Conclusions & recommendations*

As can be concluded from the figure, the influence of directional spreading is high with respect to direction. Regarding the residual wave heights (*Kd*), it can be noted that a high reduction is obtained at the shadow zone of the breakwaters; up to a factor 0.10-0.15 at distance of 5 *B* from the breakwater tip. Because especially the wave climate at the berths is of importance, the relevant effect of diffraction on the wave height is insignificant.

It can be concluded that the effect of diffraction in this wind sea climate is not significant with respect to the change of wave direction and height at the berth structures, situated at the shadow zone of the break waters.

# E.3 SWAN Input

## E.3.1 Wind & wave data

**Wind source**

The 8 years of Black Sea wind data (§ 2.3.5) are used as input in the model. This provides sufficient long term statistics for the design of the port with respect to the wave climate.

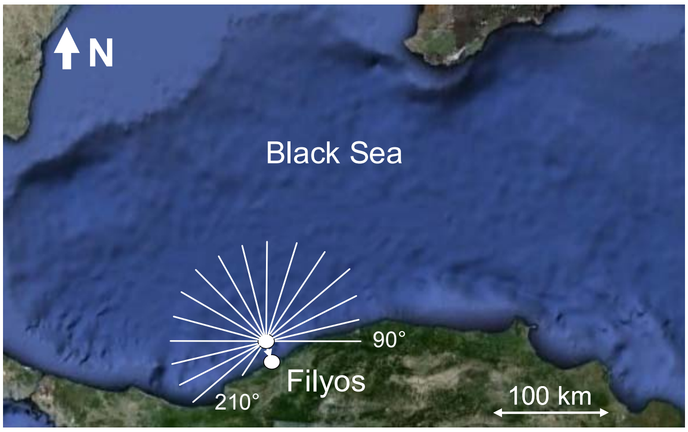



*Figure E-2 Location of normative wind with selected directional range 210-90° (N), 5 km from coast*

**Wind & wave discretisation for fine grids**

Using a non-stationary model for simulating 8 years requires much time for computer calculation in case of fine grid sizes (see § E.3.2). Therefore for the fine grids (L3 and L4) a stationary model is used. The wave output of the L2 grid, situated 5 km from the coastline is discretised into bins of direction 15°, in the range 210 - 90° (N) (see Figure E-2), and $H_S$ of 0.5 m with annual probability of occurrence. This results in 7 cases as presented in Table E-3.

The wind that corresponds to the waves is estimated using the formula of Bretschneider (1958; CUR, 2007). This wind will also be put in the model 5 km from the coast, assuming an equal off shore and near shore wind climate. A fetch length of 350 km is assumed with respect to all directions in this range, corresponding with an average wind duration of about 6 hours; resulting in a developed sea state. The resulting surface wind velocities (u) of the formula are obtained with the program CRESS and presented in Table E-3.

The corresponding peak period (Tp) presented is obtained from the output, assuming a JONSWAP spectrum holds. According to Holthuijsen (2006), this spectrum is characteristic for wind-sea in oceanic waters, which is comparable with the situation of waves approaching Filyos from the Black Sea. The average values of the bins are used as input.

*Table E-3 Approximated nearshore wind and wave climate, 5 km from coast*

| Case | u10 | U, average | Hs (m) | Hs average | Tp JONSWAP | Tp, average | 0-15 | 15-30 | 30-45 | 45-60 | 60-75 | 75-90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0-4.4 | **2.2** | 0.0-0.5 | **0.25** | 5.9 | **4.9** | 7.5% | 8.4% | 8.9% | 5.6% | 2.2% | 1.1% |
| 2 | 4.4-6.3 | **5.4** | 0.5-1.0 | **0.75** | 6.9 | **6.4** | 3.4% | 4.5% | 3.1% | 0.5% | 0.1% | 0.0% |
| 3 | 6.3-8.0 | **7.2** | 1.0-1.5 | **1.25** | 7.5 | **7.2** | 1.1% | 1.5% | 0.1% | 0.0% | 0.0% | 0.0% |
| 4 | 8.0-9.5 | **8.8** | 1.5-2.0 | **1.75** | 8.1 | **7.8** | 0.4% | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% |
| 5 | 9.5-11.0 | **10.3** | 2.0-2.5 | **2.25** | 8.6 | **8.4** | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 6 | 11.0-12.2 | **11.6** | 2.5-3.0 | **2.75** | 8.9 | **8.8** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 7 | 12.2-13.6 | **12.9** | 3.0-3.5 | **3.25** | 9.3 | **9.1** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 8 | 13.6-15.1 | **14.4** | 3.5-4.0 | **3.75** | 9.7 | **9.5** | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| | **Total** | | | | | | **12.6%** | **14.7%** | **12.1%** | **6.1%** | **2.2%** | **1.1%** |

| Case | 210-225 | 225-240 | 240-255 | 255-270 | 270-285 | 285-300 | 300-315 | 315-330 | 330-345 | 345-360 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.8% | 2.1% | 2.6% | 2.6% | 3.4% | 2.9% | 3.4% | 4.1% | 4.0% | 3.8% | 64.2% |
| 2 | 0.0% | 0.1% | 0.9% | 1.1% | 0.9% | 1.1% | 1.4% | 1.9% | 3.4% | 3.6% | 26.0% |
| 3 | 0.0% | 0.0% | 0.1% | 0.1% | 0.2% | 0.4% | 0.4% | 0.8% | 1.4% | 1.2% | 7.2% |
| 4 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 0.1% | 0.2% | 0.4% | 1.6% |
| 5 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 0.2% | 0.6% |
| 6 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 0.1% | 0.2% |
| 7 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 0.1% | 0.2% |
| 8 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.02% | 0.02% |
| | **1.8%** | **2.2%** | **3.6%** | **3.8%** | **4.5%** | **4.5%** | **5.2%** | **6.9%** | **9.3%** | **9.4%** | **100.0%** |

It must be noted that 8.3% of the waves origins from the direction 90 - 210° (N) at the output location. Because these are excluded, the total percentage of wave characteristics is multiplied with a factor 100% / 91.7%.

### *E.3.2 Grids & bottom files*

The 8 year wind data are used for the instationary calculations of L1 and L2, in combination with a bottom grid of the Black Sea obtained from ECWM (2008). Wave and wind information results at at a distance 5 km from shore, which is situated at a water depth of 300 m. From this point onwards to the harbour 2 grid levels are used, namely L3 and L4.

The information of echo sounding, land and trough boundaries available from charts are used for the nearshore depth conditions. For information further from the coastline satellite data is available from the above mentioned ECWM. It has a lower resolution which however fulfils the requirements at deep water, in which case waves are not influenced by the bottom.

The data is put into Quickin, which is an application of Delft 3D to create bottom files. In Figure E-3 an example of the points (samples) is presented. The areas with a high resolution are interpolated with the use of “grid cell averaging”, which is advised by Deltares (2009). For the lower resolution samples originate triangular interpolation is used.

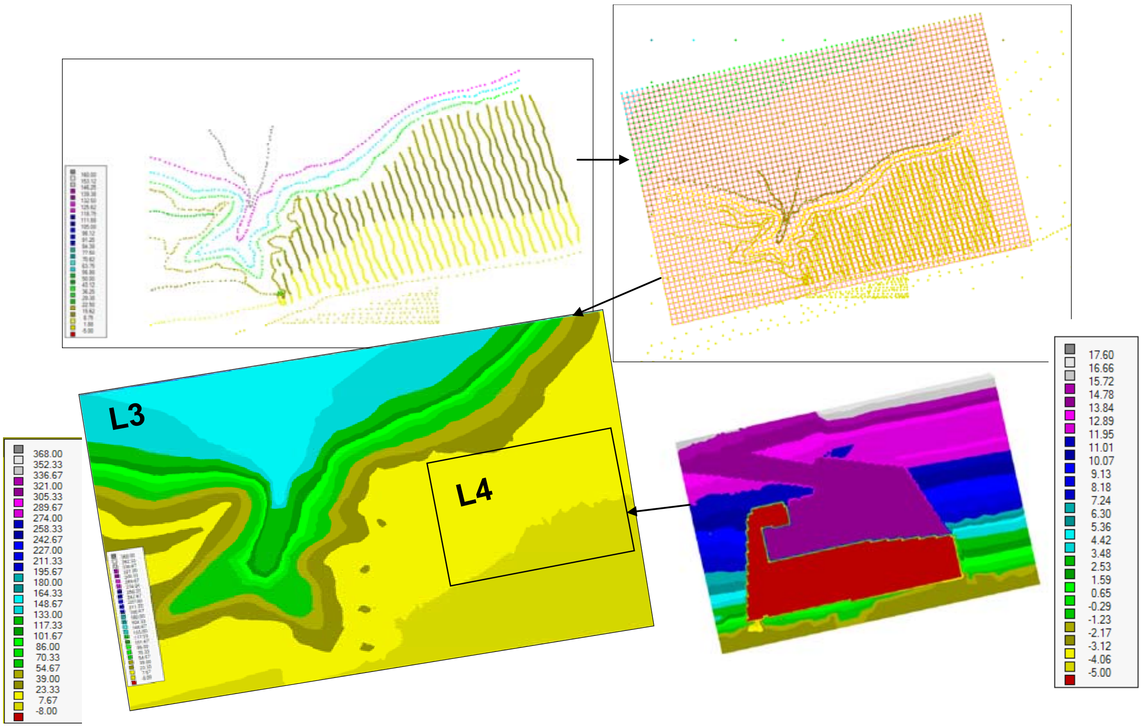



*Figure E-3 Converting samples to SWAN depth files in Quickin for the grids L3 and L4*

Note
The trough and land boundaries are read from charts (JICA, 1991; Witteveen+Bos, 2009) and therefore have an accuracy of about 50 m.

### *E.3.3 Script file level 4*

Most physical parameters are set to default values, as visible in the script file of this sub-paragraph. For explanation is referred to SWAN TEAM (2009).

**Parameters**

*Diffraction*

As previously argumented, diffraction is not taken into account in this project.

*Transmission*

For transmission of waves SWAN uses a fixed ratio for the residual wave height and incoming wave height. For all breakwaters a transmission of 0.3 is chosen, which is common for rubble mound breakwaters.

*Reflection*

In case of quay walls, the reflection coefficient is set to 1.0. The breakwater reflection coefficient is set to 0.4

**Script file**

In this section the Level 4 script of the .swn file for SWAN is provided. It contains the most detail of the scripts, since line elements of structures are included. The physical parameters of the other levels are set equal and can be derived herewith.

```
 $****************************** HEADING *********************************
 $
 PROJECT  'Filyos'  '1'
    'Level 4 calculations'
 $
 $****************************** MODEL INPUT *****************************
 $

$
$ ***Start-up commands***
$
  SET            &
                 LEVEL = 0      &
                 MAXMES = 1000         &
                 MAXERR = 0            &
                 GRAV = 9.81    &
                 RHO =  1025.00        &
         NAUTICAL               &
                 MODE STATIONARY   &
                 COORD SPHERICAL

$
$  ***Computational grid***
$
```

```
  CGRID        &
        REGULAR      &
                     XPC=   32.0752        &
                     YPC=   41.5846        &
                     ALPC= 12.5    &
                     XLENC=        0.027   &
                     YLENC=        0.018   &
                     MXC=   135    &
                     MYC=   90     &
                     CIRCLE                &
                     MDC=   36     &
                     FLOW=         0.04    &
                     FHIGH=        1.0

$
$  ***Bottom grid (below reference level is positive)***
$
 INPGRID       &
               BOTTOM       &
                     REGULAR      &
                            XPINP=        32.0752        &
                            YPINP=        41.5846        &
                            ALPINP=       12.5           &
                            MXINP=        135            &
                            MYINP=        90             &
                            DXINP=        0.0002         &
                            DYINP=        0.0002         &
                            EXC 0
  READINP      &
               BOTTOM 1.0   &
                     FNAME= 'L2.dep' 3 0

$
$   ***Wind: velocity, direction and growth***
$
        WIND         &
               VEL=   7      &
               DIR=   307.5

$
$   ***Wave conditions***
$ case 3, 170-285 degrees

  BOUN NEST 'nestoutL1.mat'

 $
 $  ***Physics***
 $
```

```
 GEN3 KOMEN
 BREAKING CONSTANT       &
             ALPHA=      1.0     &
             GAMMA=      0.73    &

 FRICTION JONSWAP &
             CFJON=      0.0670

 DIFFRACTION             &
             IDIFFR=     0       &
             SMPAR=      0.2     &
             SMNUM=      6       &
             CGMOD=      1

 QUADRUPL
 TRIAD

       $ Limiter for de-activating quadruplets
 LIMITER     URSELL= 10 QB= 1

 $
 $  ***Numerical properties of SWAN***
 $

NUMERIC ACCUR      &
       DREL= 0.02  &
       DHOVAL=     0.02    &
       DTOVAL=     0.02    &
       NPNTS=      99.00   &
             STAT &
                   MXITST= 30

 $
 $  ***Objects***
 $

       $ Breakwater1
 OBSTACLE TRANSM  0.3  REFL  0.4  RSPEC LINE  32.09507  41.59106  32.09405  41.59470
32.09016  41.60013
 OBSTACLE TRANSM  0.3  REFL  0.4  RSPEC LINE  32.09016  41.60013  32.08183  41.60092

       $ Breakwater2
 OBSTACLE TRANSM  0.3  REFL  0.4  RSPEC LINE  32.07724  41.58730  32.07759  41.59665
32.08281  41.59786

       $ Quay walls
 OBSTACLE TRANSM  0.0  REFL  1.0  RSPEC LINE  32.08045  41.59738  32.08082  41.59546
32.07840  41.59511
```

```
 OBSTACLE TRANSM  0.0  REFL  1.0  RSPEC LINE  32.07840  41.59511  32.07905  41.59222
32.08740  41.59406
 OBSTACLE TRANSM  0.0  REFL  1.0  RSPEC LINE  32.08740  41.59406  32.09405  41.59470

 $
 $***************************** OUTPUT REQUEST *************************
 $

 $
 $ ***Output definitions***
 $

 POINTS 'D_C_G' 32.07895  41.59388  32.08312  41.59343  32.09083  41.59451

 BLOCK 'COMPGRID' NOHEADER     'blockl2.mat'     LAY 3   HS  &
        XP YP HSWELL  DIR   PDIR   TDIR   TM01   TMM10  &
        DHSIGN   DRTM01   FSPR   DSPR   DEPTH   WATLEV  &
        DISSIP   QB   TRANSP   FORCE   UBOT   URMS &
        RTM01   RTP  TPS   TMM10   RTMM10   TM02  &
        BOTLEV VEL  WLEN STEEPNESS  FRCOEFF   WIND &
        TMBOT   LEAK   DISBOT   DISSURF   DISWCAP &
        RTM01   TSEC   DIST SETUP   BFI   GENE &
        GENW   REDI   REDQ   REDT   PROPA &
        PROPX PROPT PROPS RADS

 BLOCK 'COMPGRID' HEADER        'blockl2.tab'     LAY 3   HS  &
        XP YP HSWELL  DIR   PDIR   TDIR   TM01   TMM10  &
        DHSIGN   DRTM01   FSPR   DSPR   DEPTH   WATLEV  &
        DISSIP   QB   TRANSP   FORCE   UBOT   URMS &
        RTM01   RTP  TPS   TMM10   RTMM10   TM02  &
        BOTLEV VEL  WLEN STEEPNESS  FRCOEFF   WIND &
        TMBOT   LEAK   DISBOT   DISSURF   DISWCAP &
        RTM01   TSEC   DIST SETUP   BFI   GENE &
        GENW   REDI   REDQ   REDT   PROPA &
        PROPX PROPT PROPS RADS

TABLE ' D_C_G'       HEAD  'Hs_D.tab'  TIME  HS  HSWE  DIR  PDIR  TDIR  TM01  TM02  TPS
TMM10 _

 $
 $***************************** START COMPUTE *************************
 $

 TEST  ITEST=   0  ITRACE=   0

COMPUTE
STOP
```

## E.4 SWAN output

This paragraph presents the output at the buoy location for the period 1994-1996, as validation and calibration of the model. Subsequently, the operational conditions at the berths for the period 1992-1999 are presented.

### *E.4.1 Model validation with buoy*

This sub-paragraph provides the output of SWAN at the approximate buoy location (32.0578° E, 41.5944° N). One output location is therefore chosen, as described in § A-4.

**Results**

In Table E-4 the output of SWAN is provided. The L3 calculations, using a spatial grid of 110*110 m, suffices for this purpose. The percentages correspond with the cases and directional bins of the input.

The peak period (*Tp*) is calculated by 1.2 * mean wave period ($T_{m01}$); which relation holds for a JONSWAP spectrum with an average peak enhancement factor (γ =3.3), according to Goda (2000, op.cit. Verhagen *et.al.*, 2009).

*Table E-4 SWAN output at the approximate buoy location*

| Case | u10 | φo = 0-15° | φo = 15-30° | φo = 30-45° | φo = 45-60° | φo = 60-75° | φo = 75-90° | φo = 210-225° | φo = 225-240° |
|---|---|---|---|---|---|---|---|---|---|
| | | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ |
| 1 | 2.2 | 0.27 3.3 7.2<br>7.5% | 0.26 3.5 20.5<br>8.4% | 0.25 3.3 32.9<br>8.9% | 0.26 2.6 52.3<br>5.6% | 0.27 2.6 58.7<br>2.2% | 0.27 2.3 68.4<br>1.1% | 0.09 2.5 275.8<br>1.8% | 0.16 2.3 277.4<br>2.1% |
| 2 | 5.4 | 0.75 4.3 6.3<br>3.4% | 0.71 4.0 18.4<br>4.5% | 0.62 3.5 30.6<br>3.1% | 0.59 3.2 42.7<br>0.5% | 0.64 3.8 50.5<br>0.1% | 0.0% | 0.0% | 0.48 3.0 260.7<br>0.1% |
| 3 | 7.2 | 1.15 5.7 6.0<br>1.1% | 1.05 5.4 17.3<br>1.5% | 0.88 4.3 29.7<br>0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 4 | 8.8 | 1.57 6.5 5.6<br>0.4% | 1.41 5.9 16.4<br>0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 5 | 10.3 | 1.98 7.0 5.2<br>0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 6 | 11.6 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 7 | 12.9 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 8 | 14.4 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

| Case | u10 | φo = 240-255° | φo = 255-270° | φo = 270-285° | φo = 285-300° | φo = 300-315° | φo = 315-330° | φo = 330-345° | φo = 345-360° |
|---|---|---|---|---|---|---|---|---|---|
| | | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ | Hs Tp φ |
| 1 | 2.2 | 0.23 2.3 263.8<br>2.6% | 0.25 2.8 272.0<br>2.6% | 0.27 2.9 281.5<br>3.4% | 0.27 3.2 295.7<br>2.9% | 0.27 3.5 309.8<br>3.4% | 0.28 3.1 325.4<br>4.1% | 0.28 3.1 338.5<br>4.0% | 0.28 3.2 352.9<br>3.8% |
| 2 | 5.4 | 0.58 3.4 266.1<br>0.9% | 0.62 3.6 275.8<br>1.1% | 0.69 4.0 287.1<br>0.9% | 0.76 4.2 299.7<br>1.1% | 0.74 5.2 312.5<br>1.4% | 0.74 5.2 325.7<br>1.9% | 0.79 4.3 338.7<br>3.4% | 0.77 4.3 352.9<br>3.6% |
| 3 | 7.2 | 0.88 4.3 269.1<br>0.1% | 0.90 4.6 278.6<br>0.1% | 1.02 5.2 290.3<br>0.2% | 1.15 6.0 302.9<br>0.4% | 1.21 6.0 314.6<br>0.4% | 1.23 6.0 327.0<br>0.8% | 1.24 5.9 339.5<br>1.4% | 1.20 5.9 353.0<br>1.2% |
| 4 | 8.8 | 0.0% | 0.0% | 0.0% | 0.0% | 1.69 6.7 316.1<br>0.1% | 1.71 6.7 327.9<br>0.1% | 1.73 6.7 340.0<br>0.2% | 1.65 6.6 353.1<br>0.4% |
| 5 | 10.3 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2.21 7.4 340.5<br>0.1% | 2.12 7.2 353.2<br>0.2% |
| 6 | 11.6 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2.71 7.9 340.7<br>0.1% | 2.58 7.7 353.2<br>0.1% |
| 7 | 12.9 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3.19 8.3 340.8<br>0.1% | 3.04 8.2 353.2<br>0.1% |
| 8 | 14.4 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3.51 8.6 353.1<br>0.02% |

Since waves are refracted from 300 m depth to the approximate buoy location, the wave classes need to be rearranged for directions. Also the wave heights are influenced by the various physical processes included in the model. Rearrangement into new classes is therefore done, resulting in the annual distribution in Table E-5.

*Table E-5 SWAN output rearranged in classes; annual distribution during Jan. 1995 - Dec. 1996*

| Hs / Dir | 0-15 | 15-30 | 30-45 | 45-60 | 60-75 | 75-90 | 255-270 | 270-285 | 285-300 | 300-315 | 315-330 | 330-345 | 345-360 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.0-0.5** | 7.50% | 8.40% | 8.90% | 7.80% | 1.10% | 0.00% | 2.70% | 9.90% | 2.90% | 3.40% | 4.10% | 4.00% | 3.80% | 64.50% |
| **0.5-1.0** | 3.40% | 4.60% | 3.60% | 0.10% | 0.00% | 0.00% | 1.00% | 1.20% | 2.00% | 1.40% | 1.90% | 3.40% | 3.60% | 26.20% |
| **1.0-1.5** | 1.10% | 1.80% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.20% | 0.80% | 0.80% | 1.40% | 1.20% | 7.10% |
| **1.5-2.0** | 0.70% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.20% | 0.20% | 0.40% | 1.50% |
| **2.0-2.5** | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.10% | 0.20% | 0.30% |
| **2.5-3.0** | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.10% | 0.10% | 0.20% |
| **3.0-4.0** | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.10% | 0.10% | 0.20% |
| **Total** | 12.70% | 14.80% | 12.50% | 7.90% | 1.10% | 0.00% | 3.70% | 11.10% | 5.10% | 5.60% | 7.00% | 9.30% | 9.40% | 100.00% |

**SWAN vs buoy**

To make a comparison, the annual distribution of the wave recordings is presented in Table E-6.

*Table E-6 Buoy wave recordings; annual distribution during Jan. 1995 - Dec. 1996*

| Hs / Dir | 0-15 | 15-30 | 30-45 | 45-60 | 60-75 | 75-90 | 255-270 | 270-285 | 285-300 | 300-315 | 315-330 | 330-345 | 345-360 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.0-0.5** | 6.43% | 4.75% | 4.64% | 5.19% | 5.16% | 1.01% | 2.22% | 2.52% | 2.52% | 3.16% | 4.61% | 4.92% | 8.29% | 55.43% |
| **0.5-1.0** | 1.61% | 1.14% | 1.37% | 2.76% | 2.03% | 0.23% | 0.61% | 1.04% | 1.94% | 2.15% | 3.00% | 2.61% | 4.50% | 24.99% |
| **1.0-1.5** | 0.49% | 0.68% | 0.47% | 0.55% | 0.35% | 0.06% | 0.32% | 0.72% | 1.18% | 1.57% | 1.62% | 1.78% | 1.42% | 11.20% |
| **1.5-2.0** | 0.35% | 0.13% | 0.36% | 0.15% | 0.19% | 0.03% | 0.10% | 0.46% | 0.66% | 0.86% | 0.54% | 0.82% | 0.46% | 5.10% |
| **2.0-2.5** | 0.17% | 0.09% | 0.13% | 0.06% | 0.14% | 0.03% | 0.06% | 0.23% | 0.13% | 0.31% | 0.15% | 0.20% | 0.09% | 1.79% |
| **2.5-3.0** | 0.12% | 0.01% | 0.05% | 0.01% | 0.01% | 0.03% | 0.08% | 0.12% | 0.18% | 0.10% | 0.04% | 0.09% | 0.06% | 0.89% |
| **3.0-4.0** | 0.13% | 0.03% | 0.01% | 0.03% | 0.03% | 0.01% | 0.05% | 0.06% | 0.05% | 0.00% | 0.00% | 0.00% | 0.03% | 0.42% |
| **4.0-5.0** | 0.12% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.01% | 0.00% | 0.00% | 0.00% | 0.01% | 0.04% | 0.18% |
| **Total** | 9.39% | 6.83% | 7.03% | 8.76% | 7.91% | 1.39% | 3.45% | 5.15% | 6.66% | 8.14% | 9.97% | 10.43% | 14.89% | 100.00% |

*Directions*

Regarding the tables, the angles of incidence at the buoy location are in the same range. The prevailing direction of the NNW wave recordings of the buoy is a little shifted and spread over the NE directions of origin.
This can be explained by the uncertainty of the buoy location. A location more eastward will force more refraction of waves towards the coast. Moreover, the schematization in bins of 15 degrees, which are all averaged in direction, has an accompanied inaccuracy.

*Heights*

Comparing the tables, it is visible that the resulting wave height ranges of the hindcasts are significantly smaller. This was expected since the recordings of wind are 6 hourly, and therefore have a too low velocity. The distribution of the heights per direction is comparable. There is however significant difference between the classes 0.5-1.0 m from hindcasts and from the buoy. This can also be explained by the applied discretisation.

The highest occurring $H_S$ in the hindcasts is 3.51 m against a buoy recording of 5.0 m. A factor of 1.4 for the $H_S$ of the hindcasts is therefore suggested. Regarding the other wave height ranges this is plausible. This factor is used for the estimation of the operational conditions in the harbour.

### *E.4.2 Operational conditions*

The buoy was located near the future harbour entrance. To have an estimate about the operational conditions in the harbour, a few scenarios are considered with stationary calculations, L3 and L4. Therefore, this time the harbour bathymetry is implemented in the bottom file. Moreover, the breakwater and quay wall objects are defined in SWAN, as presented in the script provided in § E.3.3. The considered harbour configuration is given in Figure E-4. Herewith conclusions can also be drawn for slightly different shapes of the basin.

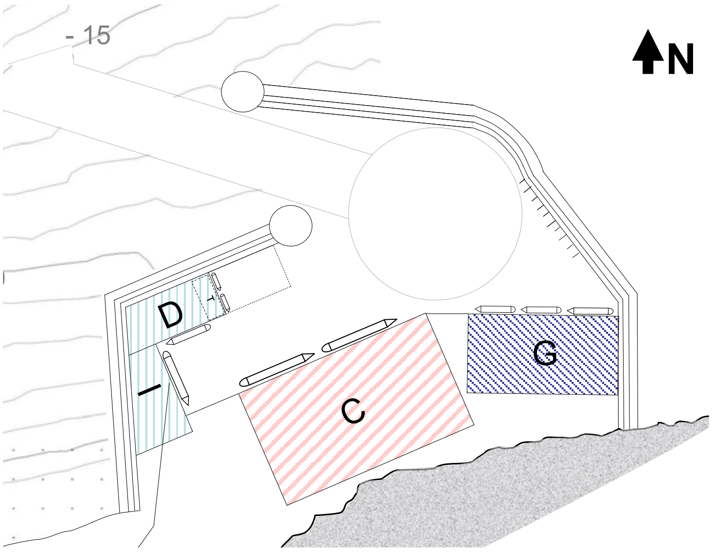



*Figure E-4 Reference harbour configuration*

**Results**

**Test 1**

As illustration incident waves and wind of class 3 are put in the model. The settings are: wind velocity 7.2 m/s, Hs 1.25 m, Tp 7.2 s (see § E.4.1). The wave and wind direction causing the severest wave climate in the harbour are from western direction. In Figure E-5 an example is presented for the direction 270-285° (N). Waves from directions 285-330° (N) show a more or less identical pattern. Below a short evaluation is provided.

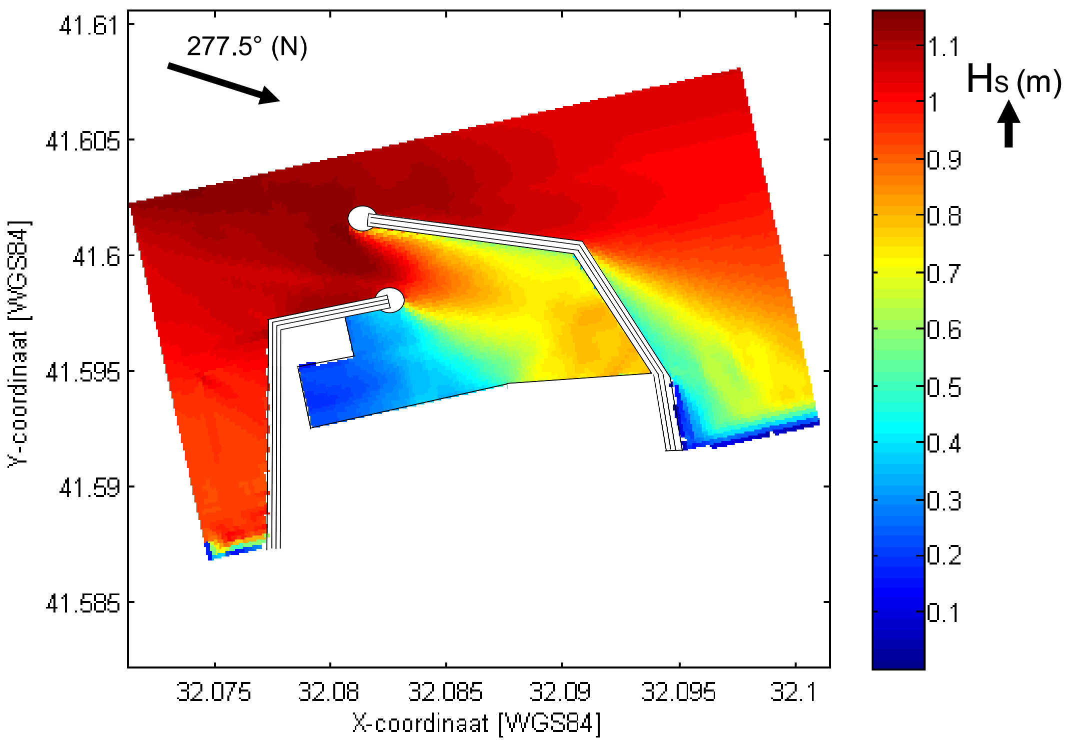



*Figure E-5 Significant wave height in harbour, input u= 7.2 m/s, Hs=1.25 m, Tp=7.2, Dir 270-285° (N); with quay walls*

*General cargo*

As visible from Figure E-5, the general cargo terminal is vulnerable for the considered case. Waves will first grow while travelling towards the harbour. Then directional spreading will force the waves to turn into the basin. The biggest bundle is pushed forward and is slightly reduced towards the inner side of the eastern breakwater. The partial reflection of the breakwater and full reflection of the quay walls enforce the wave amplitude. An oblique incident $H_S$ of 0.8 m is remaining at the berth; an $H_{S,berth} / H_{S,offshore}$ of 0.64 results for this case.

*Containers and dry bulk*

Regarding the same Figure E-5, residual wave heights at the western berthing area are low and do not form a threat for the operations at the berths.

*Note*

Influence on the wave climate in the harbour basin can also be made by application of non-reflective berths structures. In Figure E-6 the results are presented for the case in which all berth structures have no reflectivity. It results in a considerable $H_S$ reduction of about 25%.

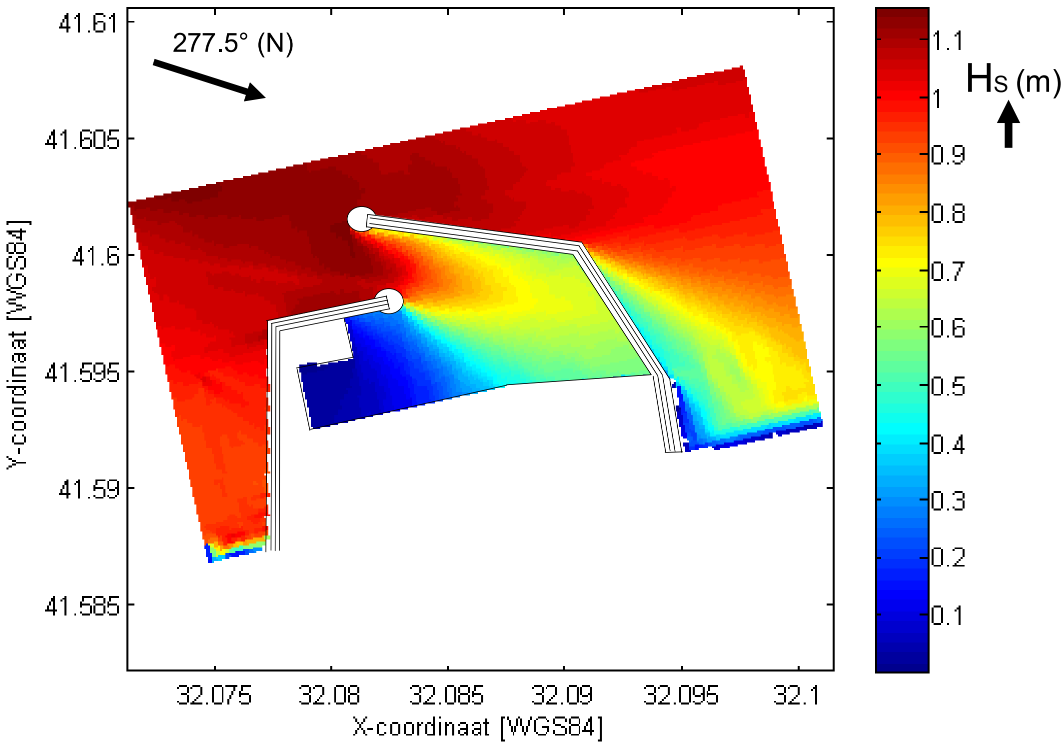



*Figure E-6 Significant wave height in harbour, input u= 7.2 m/s, Hs=1.25 m, Tp=7.2, Dir 270-285°; without reflection of quay walls*

**Test 2**

The same conditions (class 3) at the boundary of L3 are applied for incident waves from the range 0-15° (N), see Figure E-7. A more or less uniform remaining $H_S$ remains in the harbour of about 0.6 m. Container ships will face problems for loading and unloading at this wave height, according to Table E-1. More simulations showed that lengthening of the eastern breakwater for this wave directions has little effect on the wave height. Waves will still partly turn into the basin by the directional spreading of the locally generated waves. Waves which origin more from eastern direction do not have a significant resulting height in the harbour.

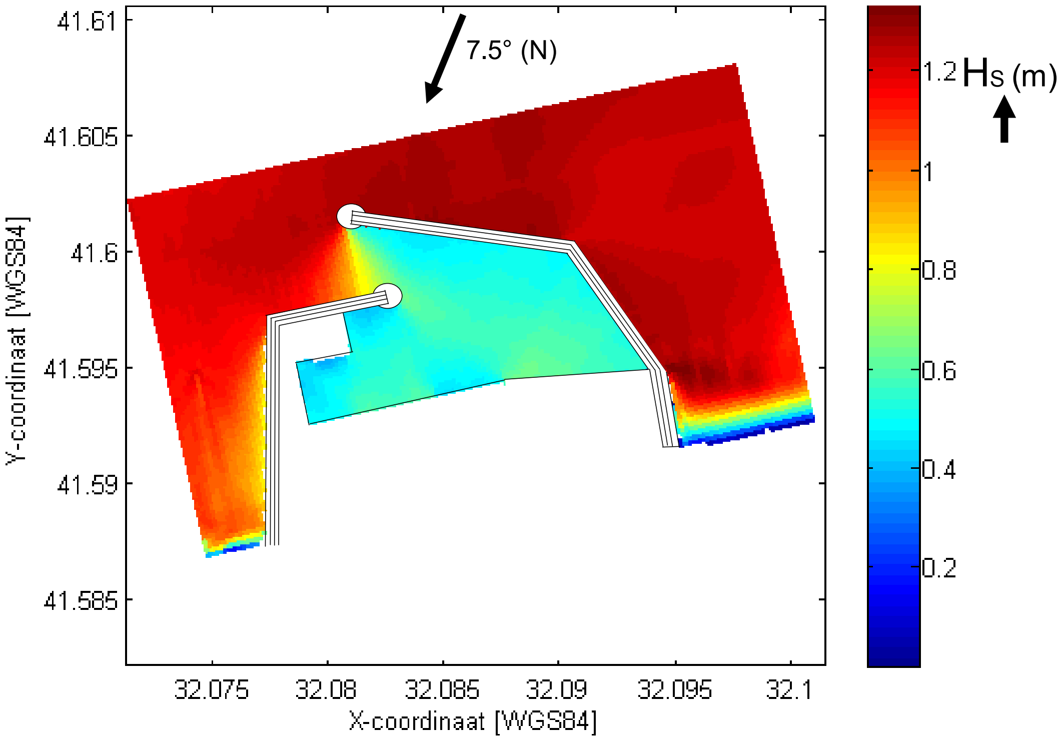



*Figure E-7 Significant wave height in harbour, input Hs=1.25, Tp=7.2, Dir 0-15° (N); with reflection of quay walls*

**Resulting downtime**

As can be concluded from the previous section, wave hindrance at the berth can be caused by waves originating in the range from western and northern direction.

*General cargo (test 1)*

Regarding Table E-1, downtime for general cargo vessels will be caused for waves, in case of an incidence of 45-90° with the ship axis, with $H_S$ exceeding 0.8 m. This corresponds to an $H_S$ offshore (5 km from coast) higher than 1.25 m, originating from the range 270-285° (N); see Figure E-5. As can be concluded from the previous section, the heights have an underestimation with a factor of about 1.4.

Downtime is estimated by summating the chances of exceedance for waves originating in the range 255-330° (N) in Table E-3. Applying the factor of 1.4 at the input table, downtime already takes place at an offshore wave height of 1.25 / 1.4 = 0.9 m. As a conservative approach, waves from class 3 ($H_S$ > 0.75 m) and higher are summated for the range of origin. As will appear from the next case, the climate conditions from the other range do not cause hindrance for the general cargo berths. Because 10% downtime is allowed (see Table 3-3), lengthening of the eastern breakwater is therefore not needed in this configuration.

*Containers and dry bulk (test 1 and 2)*

At east part of the harbour

In case of placing container berths in the eastern area of the harbour it will become more critical, because of the lower allowed downtime criterion of 5%. Because especially with container vessels also hindrance from wind is experienced, this is not considered an option. For dry bulk cargo the same criterion for downtime holds as for general cargo in case of unloading, which is set normative because of the considerable import of coal. A downtime of 2.1% for dry bulk is therefore expected at this location.

At west part of the harbour

In case container berths are placed at the western area, also some downtime is faced. Summating the percentages of direction 0-15° (N) for waves from class 3 ($H_S$ > 0.75 m), results in a maximum downtime percentage of 1.8%. For dry bulk 0.5 m higher wave heights are allowed. Therefore the exceedance probability from class 4 ($H_S$ > 1.25 m) is considered, resulting in a downtime of 0.7%.

## E.5 Conclusions & recommendations

### *E.5.1 Conclusions*

The hindcasts are validated and calibrated with the buoy recordings, covering the period 1995-1996. The percentages of downtime resulting from the analysis for the respective berths are presented below.

East of harbour:

- General Cargo 2.1%
- Dry bulk 2.1%

West of harbour:

- Containers 1.8%
- Dry bulk 0.7%

### *E.5.2 Recommendations*

The following can be recommended on basis of the wave study.

- The effect of transmission and reflection of the breakwaters on the harbour wave climate should be further assessed. More information about the hydraulic structures is therefore required.
- Use of the model Pharos, which is a phase averaging model. It takes diffraction properly into account.
- Or alternatively, include diffraction patterns for two breakwaters. The model DIFFRAC from Deltares is capable for this purpose. Also the use of an application developed by RIKZ (2004) is an option.

# APPENDIX F CAPITAL COST ESTIMATES

In this appendix estimation is done for the capital cost differences of the port layouts. There is regarded to the wet infrastructure, including hydraulic structures, and of the reclamation of land for the terminals. For these concept designs cost ratios are used to provide a rough comparison. These are provided in first paragraph. In the second paragraph the resulting capital costs for the layout alternatives and variants are derived.

## F.1 Cost ratios

### *F.1.1 Dredging & reclamation*

**Offshore**

Based on a project of Witteveen+Bos (2009) in Latvia the costs for dredging of large areas uncontaminated soil is estimated to amount **€ 3 / m$^3$**. For sailing and dumping at a side offshore an extra **€ 1 / m$^3$** is taken into account.
In case the sand is locally used for reclamation of land, a reduction will be made in costs because of the shorter transport distance. On the other hand, equipment and personnel is needed to ensure the precision of the reclamation. Overall this results in a total price of **€ 5 / m$^3$**, as set normative by this reference. In case the local sand buffer does not suffice, sand needs to be gained from reclaimed another winning location. For this procedure a total price of **€ 6 / m$^3$** is taken into account.

For reclamation under the breakwater a high precision is required, since all operations are under water. There is accounted for a price of **€ 8 / m$^3$**.

**Landbased**

For the costs of landside operations the same reference is used. For excavation of soil on land **€ 2.5 / m$^3$** is accounted. Supply and fill of sand for soil improvement is set to **€ 10 / m$^3$**.

### *F.1.2 Breakwaters*

The costs of the breakwater constructions depend to a large extent on the design lifetime, probability of failure and the design wave height.

**Design parameters**

*Normative storm frequency*

The design lifetime of the breakwater is 50 years (see § 3.4). The acceptable probability of failure after 50 years is chosen at 20%, corresponding to various examples in PIANC publications. With the following equation the normative storm frequency (Ultimate Limit State) is determined, see 'd Angremond *et al.* (2008).

$$p = 1 - \exp(-\frac{1}{x} \cdot 50) = 0.20$$

$$0.80 = \exp(-\frac{50}{x})$$

$$x = -\frac{50}{\ln 0.80} = 225$$

*Design wave height*

As determined in § A.3, the maximum design $H_S$ at the construction for an exceedance probability of 1/225 years is 6.9 m in combination with a Tp of 12.4 s. Regarding these conditions, the use of concrete armour units is assumed.

Further information:

- The depth of the breakwater is up to MW -12.5 m. Most of the breakwater construction is situated at a depth of MW -10 m.
- Given the fact that many rubble mound breakwaters are build along the Anatolian coast, the availability of quarry stone is not considered an issue.

**Reference project**

Regarding the design criteria, a price per meter can be derived from comparable reference projects. The following price is used, as obtained from project Dung Quat oil refinery in Vietnam, build in 2001. This project has comparable design parameters, a depth of 16 m, $H_S$ 7.3 m and $T_P$ of 13.8 s according to Ref. [13].

According to Ref. [14] this breakwater has a total cost of USD 93.75 million for a length of 1,600 m, resulting in a cost of USD 58,600 / $m^1$. With the EUR-USD currency in May 2010 of about 1.25 (Ref. [15]), it corresponds to a European price of about € 46,900 / $m^1$. Prices of stones and labour are however considerably higher in Turkey and prices have grown since 2001. A price of € 60,000 / $m^1$ is therefore considered normative. These costs can be reduced by reusing the dredged sand for the breakwater. This is discussed below.

**Cost reduction with sand reusage**

Sand can be used as base layer for the breakwater construction. At a depth of 0.75 * $H_S$ this sand layer will not be affected in stability by waves, according to Vellinga (1986).

*Cross-section*

With assumed slopes of the breakwater a cross section is made for the breakwater at 10 m depth, see Figure F-1. The required volume at this depth is considered representative for the whole breakwater length.

A water level of MW + 1.8 m is taken into account for water level change due to the components enumerated in § A.5 and due to an assumed land subsidence of 50 cm. An additional 6.0 m is taken into account for the crest level height, which is equal to the design wave height.

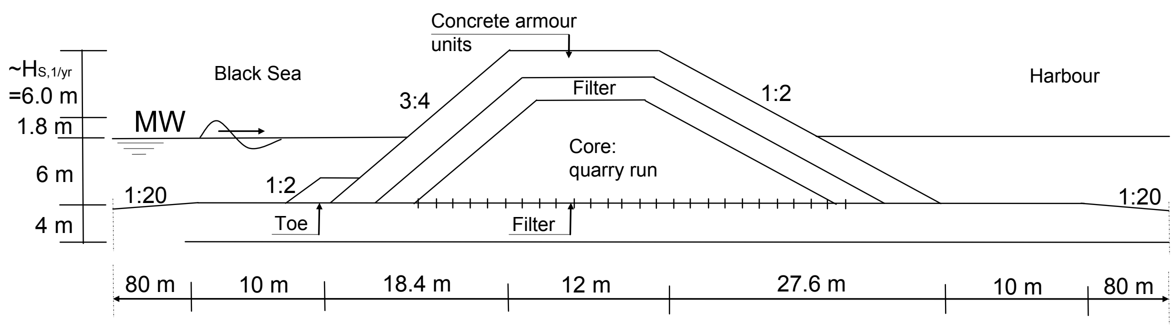



*Figure F-1 Sketch of normative breakwater cross-section with under layer of sand*

Applying a base layer of sand of 4 m thick, a reduction in construction volume (quarry and concrete armour stones) of about 25 % is achieved. Because extra care should be taken during construction, a cost reduction of 20% (€ 12,000) is taken into account. A sand volume of 632 $m^3$ / $m^1$ is required in this case for the layer, assuming a flat bed. Even in case sand is unavailable from local dredging, this option is economically attractive.
The thickness of the layer is chosen at a water depth of 10 m, which is considered representative. It may increase seaward and must decrease landward. Although waves decrease in height landward, waves will influence the stability of the top sand layer.

*Discussion sand core*

A reduction of quarry stone costs for the breakwater core might also be realised by reusing the volumes of dredged sand. According to Kim (2010) this is however not recommended. It acts as quasi-impervious and will increase the wave setup, run up, overtopping and reflection, which in its turn might be detrimental for the stability of the structure. Moreover, the operations on and behind the breakwater, as well as navigation and seabed stability are affected negatively. Furthermore difficulties arise with implementing the various complex and costly filter layers (geometrically open or closed) in the design. Especially in the case at Filyos, which has a high design wave height. Applying geotextile filters or geotextile sand containers still not have a better effect on the wave load and, especially the former, is also difficult to construct. It can be concluded that this option is not realistic.

**Resulting costs**

The price of the reference project has been adjusted to Turkish standards. Taking into account the reduction due to applying a sand base layer, a total cost of **€ 48,000 / $m^1$** is set normative. In case a large base layer is already required because of soil improvement - needed in the large silty areas – no extra layer will be applied. In this case a cost of **€ 60,000 / $m^1$** is taken into account.

### F.1.3 Quay walls

The costs of quay wall structures can be expressed as retaining height of the soil. The retaining height is the difference between the construction depth and the height of the ground surface behind the quay structure.

**Structure costs**

According to CUR (2005) the following costs per retaining height hold in the Netherlands, as presented in Table F-1. Since the costs originate from 2005, the above price range holds as starting point. The retaining height is considered uniform for the terminals, with a harbour basin depth of MW - 13.7 m (see Table B-5). With a maximum 1/50 yr water level of MW + 1.3 m (see Table A-5), an assumed land subsidence in this period of 50 cm and a margin of 50 cm the land level is situated at MW + 2.3 m. The total retaining height herewith is 16 m. From Table F-1, a cost results of € 16,000 / $m^1$.

*Table F-1 Costs in relation to retaining height **

| Retaining height (m) | Costs per retaining height € / $m^1$ |
|---|---|
| 5-10 | 350 - 650 |
| 10-20 | 650 - 1000 |
| 20-30 | 1000 - 1300 |

** This table does not include the costs of engineering, bottom protection, fendering and dredging in front of the quay.*

Based on a project of Witteveen+Bos (2009) in Latvia a cost of € 3,900 / $m^1$ quay wall is taken into account for the fendering. This price includes the installation.

Dredging in front of the quay is included in dredging volumes in § F.1.1. For the bottom protection in front of the quay, the above reference of Witteveen+Bos is used. A cost of € 2,250 / $m^1$ is set normative.

**Engineering costs**

The engineering costs as percentage of the construction costs are 3.9% for constructions exceeding € 1,500,000.

**Resulting costs**

The total costs / $m^1$ are estimated at 1.039 * € 16,000 + € 3,900 + € 2,250 = **€ 22,750 / $m^1$ quay wall**.

### *F.1.4 Jetties & trestles*

From common design practice for one sided **jetties** up to 10 m water depth, a price of **€ 35,000 / $m^1$** can be used for western country standards. For jetties serving ships at two sides a price of **€ 45,000 / $m^1$** is taken into account.

For the **trestle**, which supports the conveyor belt to the land has a price of **€ 10,000 / $m^1$**.

### *F.1.5 Overview of cost ratios*

An overview of the determined cost ratios is provided in Table F-2.

*Table F-2 Cost ratios port*

| Cost ratios | Price | Per unit |
|---|---|---|
| Dredging | € 3 | m^3 |
| Dredging, sailing & offshore dumping | € 4 | m^3 |
| Dredging & reclamation | € 5 | m^3 |
| Reclamation with offshore sand | € 6 | m^3 |
| Reclamation under breakwater | € 8 | m^3 |
| Reclamation under breakwater, offshore sand | € 12 | m^3 |
| | | |
| Excavation on land | € 2.5 | m^3 |
| Sand fill on land | € 10 | m^3 |
| | | |
| Breakwaters, reduced | € 48,000 | m |
| Breakwaters, normal | € 60,000 | m |
| Quay walls | € 22,750 | m |
| One side jetty | € 35,000 | |
| Two sided jetty | € 45,000 | m |
| Trestle | € 10,000 | m |

## F.2 Alternatives & variants

In this paragraph the costs for the alternatives and variants are elaborated. The first sub-paragraph provides the applied method for the derivation of the costs of the layout alternatives. This is followed by the presentation of the corresponding cost results. In the second sub-paragraph the results for the layout variants are provided.

### *F.2.1 Alternatives*

The dimensions of the hydraulic structures can directly be derived from the layout drawings. The volumes for dredging and reclamation require more explanation. Therefore a description of the approach is provided per alternative.

**Alternative A**

*Method for dredging & reclamation*

Dredging volumes and balance of reusable sand of the layouts are based on the soil information that is provided in Figure A-1. Estimation of dredged area: MW - 13.7 m depth. The terminals will be reclaimed at a height of MW + 2.3 m.

From Figure A-1 can be concluded, that at the location of the port area (between ITRF 96 coordinates 423.000 - 425.000) sand is present from the coast until the MW - 10 m bottom depth line. From this point seaward a silt layer is present which rapidly increases in thickness to a depth of MW - 15 m. Dredged soil volume beyond the MW -10 m line is therefore not taken into account for reclamation.

Per layout the dredged and reclaimed surfaces are estimated. Reclamation required for phase 2 is already accounted for in the first phase of the port realisation. An example of the area estimations is provided in Figure F-2. The red rectangles are the schematised dredged areas, the blue rectangles the reclaimed land areas. An average depth of the areas is taken resulting in volumes as presented in Table F-3. It has to be noted that the offshore areas available for future expansion are not reclaimed yet.

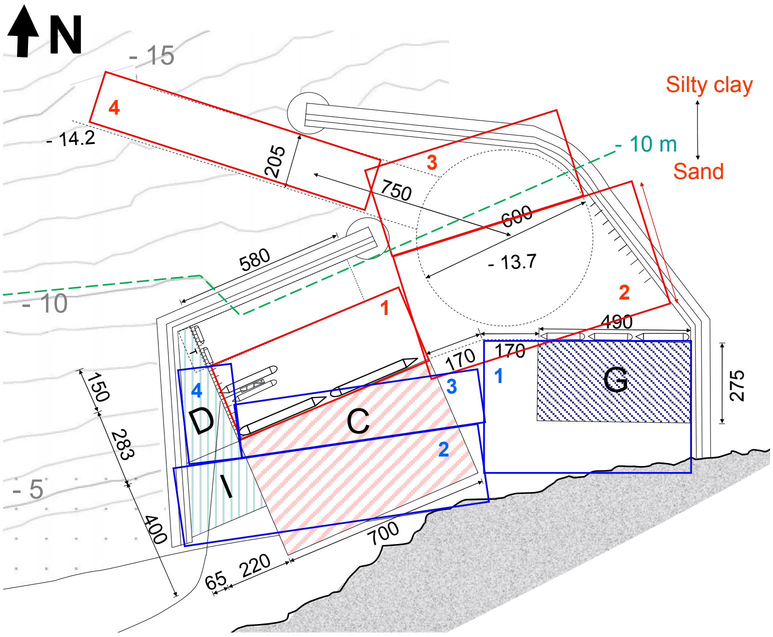



*Figure F-2 Example of calculations of dredging & reclaiming quantities for alternative A(1)*

For the breakwater part which is build beyond the MW - 10 m line, soil improvement is required. Over a length of 830 m a surface of 3 m * (78 m + 2 *80 m) (=height * width) is dredged.

*Results*

In Table F-3 the cost results for alternative A are presented. All investments are done in the first phase, except from the extra quay lengths required after the year 2020. With an assumed effective interest rate (interest vs. inflation) of 3% the net present value is determined.

*Table F-3 Cost estimation alternative A*

| **Alternative A** | | | | |
|---|---|---|---|---|
| **Area nr.** | **Dredging sand (m^3)** | **Dredging silt (m^3)** | **Unit price** | **Costs** |
| 1 | 1,426,320 | | | |
| 2 | 2,400,330 | | | |
| 3 | | 705,600 | | |
| 4 (approach channel) | | 348,500 | | |
| Foundation breakwater (**North** of MW - 10 m) | | 592,620 | | |
| **Total dredging** | 5,473,370 | | € 4 | **€ 21,893,000** |
| | **Reclamation sand (m^3)** | | | |
| 1 | 1,779,740 | | | |
| 2 | 1,300,320 | | | |
| 3 | 1,315,370 | | | |
| 4 | 551,760 | | | |
| Foundation breakwater (**North** of MW - 10 m) | 393,420 | | | |
| Sub total reclamation | 5,340,610 | | | |
| - Sand from local dredging | 3,826,650 | | € 1 | € 3,826,650 |
| - Sand other location | 1,513,960 | | € 6 | € 9,083,760 |
| | | | | |
| Sand underlayer breakwater | Underlayer length (m) | Volume (m^3) | | |
| Two sided | 1,640 | 1,036,480 | € 8 | € 8,291,840 |
| One sided (bordering port area) | 1,910 | 901,520 | € 8 | € 7,212,160 |
| **Total reclamation (incl. underlayer)** | | | | **€ 28,414,000** |
| | | | | |
| **Quay walls** | **Length (m)** | | | |
| General cargo, 2020 | 335 | | € 22,750 | € 7,621,250 |
| 2030 | 155 | 10 yr, i= 3% | ,, | € 2,623,861 |
| Containers, 2020 | 230 | | ,, | € 5,232,500 |
| 2030 | 340 | 10 yr, i= 3% | ,, | € 5,755,566 |
| **Subtotal quay walls** | | | | **€ 21,233,000** |
| **Jetty** | 80 | | € 45,000 | **€ 3,600,000** |
| **Tresle** | 80 | | € 10,000 | **€ 800,000** |
| **Breakwaters** | 3,550 | | € 48,000 | **€ 170,400,000** |
| **Total** | | | | **€ 246,340,000** |

## Alternative B

*Method for dredging & reclamation*

The same method of volume determination is applied as with alternative A. The soil conditions however differ. Further than MW - 6 m line the soil mainly consists of silty clay, increasing to a maximum thickness of 20 m. Therefore there is accounted for soil improvement for the breakwater. It is assumed that on average a 15 m thick layer must be dredged for the foundation. For the land side is assumed that an average level of MW + 1 m is present, of which 3 m needs to be excavated. Reclamation with sand is set to a level of MW + 2.3 m.

In Table F-4 the costs are presented. The prices for quay walls are equal to alternative A. The breakwater length is shorter which results in a reduction of the total costs.

*Table F-4 Cost estimation alternative B*

| Alternative B | | | | |
|---|---|---|---|---|
| **Area nr.** | **Dredging sand (m^3)** | **Dredging silt (m^3)** | **Unit price** | **Costs** |
| 1 | 2,191,269 | 755,610 | | |
| 2 | 1,175,850 | 526,500 | | |
| 3 | | 2,592,900 | | |
| 4 (approach channel) | | 861,900 | | |
| Foundation breakwater (**north** of MW -6m depth) | | 12,915,900 | | |
| **Total dredging** | 21,019,929 | | € 4 | **€ 84,080,000** |
| | **Landside excavation silt top layer (m^3)** | | | |
| 1 | | 1,161,000 | | |
| 2 | | 441,000 | | |
| 3 | | 612,000 | | |
| **Total excavation on land** | | 2,214,000 | € 2.5 | **€ 5,535,000** |
| | **Landside reclamation sand (m^3)** | | | |
| 1 | 1,664,100 | | | |
| 2 | 889,350 | | | |
| 3 | 877,200 | | | |
| **Total land side reclamation** | 3,430,650 | | € 10 | **€ 34,307,000** |
| Reclamation for breakwater (**north** of MW -6m depth) | 7,200,900 | | € 8 | € 57,607,200 |
| Total required sand volume | 10,631,550 | | | |
| - Sand from local dredging | 3,367,119 | | € 1 | € 3,367,119 |
| - Sand dredging other location | 7,264,431 | | € 6 | € 43,586,586 |
| | | | | |
| Sand underlayer breakwaters (**south** of MW -6m depth) | Underlayer length (m) | Volume (m^3) | | |
| Two sided | 1,350 | 853,200 | € 12 | € 10,238,400 |
| One sided (bordering port area) | 200 | 94,400 | € 12 | € 1,132,800 |
| **Additional reclamation costs** | | | | **€ 115,932,000** |
| | | | | |
| **Quay walls** | **Length (m)** | | | |
| General cargo, 2020 | 335 | | € 22,750 | € 7,621,250 |
| 2030 | 155 | 10 yr, i= 3% | ,, | € 2,623,861 |
| Containers, 2020 | 230 | | ,, | € 5,232,500 |
| 2030 | 340 | 10 yr, i= 3% | ,, | € 5,755,566 |
| **Subtotal quay walls** | | | | **€ 21,233,000** |
| **Jetties** | 160 | | € 35,000 | **€ 5,600,000** |
| **Breakwaters** | 1,550 | | € 48,000 | € 74,400,000 |
| | 1,070 | | € 60,000 | € 64,200,000 |
| **Total breakwaters** | | | | **€ 138,600,000** |
| **Total** | | | | **€ 405,287,000** |

### Alternative C

The same line criteria for the soil conditions are used as for alternative B. The resulting costs are provided in Table F-5.

*Table F-5 Cost estimates alternative C*

| Alternative C | | | | |
|---|---|---|---|---|
| **Area nr.** | **Dredging sand (m^3)** | **Dredging silt (m^3)** | **Unit price** | **Costs** |
| 1 | 1,920,438 | 492,420 | | |
| 2 | 3,589,740 | 1,398,600 | | |
| 3 | | 2,428,750 | | |
| 4 (approach channel) | | 2,772,960 | | |
| 5 (approach channel) | | 883,200 | | |
| Foundation breakwater (**north** of MW -6m depth) | | 20,848,500 | | |
| **Total dredging** | 34,334,608 | | € 4 | **€ 137,338,000** |
| | **Landside excavation silt top layer (m^3)** | | | |
| 1 | | 730,800 | | |
| 2 | | 1,050,000 | | |
| 3 | | 529,200 | | |
| **Total excavation on land** | | 2,310,000 | € 2.5 | **€ 5,775,000** |
| | **Landside reclamation sand (m^3)** | | | |
| 1 | 1,047,480 | | | |
| 2 | 1,855,000 | | | |
| 3 | 758,520 | | | |
| **Total land side reclamation** | 3,661,000 | | € 10 | **€ 36,610,000** |
| Reclamation for breakwater (**north** of MW -6m depth) | 11,623,500 | | € 8 | € 92,988,000 |
| Total required sand volume | 15,284,500 | | | |
| - Sand from local dredging | 5,510,178 | | € 1 | € 5,510,178 |
| - Sand dredging other location | 9,774,322 | | € 6 | € 58,645,932 |
| | | | | |
| Sand underlayer breakwaters (**south** of MW -6m depth) | Underlayer length (m) | Volume (m^3) | | |
| Two sided | 280 | 176,960 | € 12 | € 2,123,520 |
| One sided (bordering port area) | 370 | 174,640 | € 12 | € 2,095,680 |
| **Additional reclamation costs** | | | | **€ 161,363,000** |
| | | | | |
| **Quay walls** | **Length (m)** | | | |
| General cargo, 2020 | 335 | | € 22,750 | € 7,621,250 |
| 2030 | 155 | 10 yr, i= 3% | ,, | € 2,623,861 |
| Containers, 2020 | 230 | | ,, | € 5,232,500 |
| 2030 | 340 | 10 yr, i= 3% | ,, | € 5,755,566 |
| **Subtotal quay walls** | | | | **€ 21,233,000** |
| **Jetty** | 80 | | € 45,000 | **€ 3,600,000** |
| **Trestle** | 80 | | € 10,000 | **€ 800,000** |
| **Breakwaters** | 650 | | € 48,000 | € 31,200,000 |
| | 2,050 | | € 60,000 | € 123,000,000 |
| **Total breakwaters** | | | | **€ 154,200,000** |
| **Total** | | | | **€ 520,919,000** |

### Overview of cost estimates layout alternatives

An overview of the costs of the alternatives is provided in Table F-6.

*Table F-6 Overview of cost estimates of alternatives A-C*

| Alternatives | Dredging & excavation | Reclamation costs including breakwater foundations | Breakwaters | Quay walls | Jetties | Trestle | Total |
|---|---|---|---|---|---|---|---|
| A | € 21,893,000 | € 28,414,000 | € 170,400,000 | € 21,233,000 | € 3,600,000 | € 800,000 | € 246,340,000 |
| B | € 89,615,000 | € 150,239,000 | € 138,600,000 | € 21,233,000 | € 5,600,000 | € 0 | € 405,287,000 |
| C | € 143,113,000 | € 197,973,000 | € 154,200,000 | € 21,233,000 | € 3,600,000 | € 800,000 | € 520,919,000 |

## *F.2.2 Variants*

Differences in cost for the variants of alternative A (=variant A1) are made by differences in dredging and reclamation volumes. The hydraulic structure costs are equal. To be complete, the costs for the soil works of variant A2 and A3 are provided in Table F-7.

*Table F-7 Dredging & reclamation costs for variant A2 and A3*

**Variant A(2)**

| Area nr. | Dredging sand (m^3) | Dredging silt (m^3) | Unit price | Costs |
|---|---|---|---|---|
| 1 | 2,425,500 | | | |
| 2 | 2,611,440 | | | |
| 3 | | 705,600 | | |
| 4 (approach channel) | | 348,500 | | |
| Foundation breakwater | | 592,620 | | |
| **Total dredging** | 6,683,660 | | € 4 | **€ 26,735,000** |
| | **Reclamation sand (m^3)** | | | |
| 1 | 2,457,000 | | | |
| 2 | 378,480 | | | |
| 3 | 1,760,880 | | | |
| Foundation breakwater | 393,420 | | | |
| Sub total reclamation | 4,989,780 | | | |
| Sand from dredging | 5,036,940 | | € 1 | € 5,036,940 |
| Of which used for underlayer breakwater | 47,160 | | | |
| | | | | |
| Sand underlayer breakwater | Breakwater length (m) | | | |
| Two sided | 1,640 | 1,036,480 | € 8 | € 8,291,840 |
| One sided (bordering port area) | 1,910 | 901,520 | € 8 | € 7,212,160 |
| | | -47,160 | € 4 | -€ 188,640 |
| **Total reclamation (incl. underlayer)** | | | | **€ 20,352,000** |
| **Total** | | | | **€ 47,087,000** |

**Variant A(3)**

| Area nr. | Dredging sand (m^3) | Dredging silt (m^3) | Unit price | Costs |
|---|---|---|---|---|
| 1 | 2,048,200 | | | |
| 2 | 2,213,400 | | | |
| 3 | | 705,600 | | |
| 4 (approach channel) | | 348,500 | | |
| Foundation breakwater | | 592,620 | | |
| **Total dredging** | 5,908,320 | | € 4 | **€ 23,633,000** |
| | **Reclamation sand (m^3)** | | | |
| 1 | 2,457,000 | | | |
| 2 | 378,480 | | | |
| 3 | 2,334,500 | | | |
| Foundation breakwater | 393,420 | | | |
| Sub total reclamation | 5,563,400 | | | |
| - Sand from dredging | 4,261,600 | | € 1 | € 4,261,600 |
| - Sand other location | 1,301,800 | | € 6 | € 7,810,800 |
| | | | | |
| Sand underlayer breakwater | Breakwater length (m) | | | |
| Two sided | 1,640 | 1,036,480 | € 8 | € 8,291,840 |
| One sided (bordering port area) | 1,910 | 901,520 | € 8 | € 7,212,160 |
| **Total reclamation (incl. underlayer)** | | | | **€ 27,576,000** |
| **Total** | | | | **€ 51,209,000** |

An overview of the resulting costs for the variants is provided in Table F-8.

*Table F-8 Overview of cost estimates for variants A,1-3*

| Variants | Dredging | Reclamation costs including breakwater foundations | Breakwaters | Quay walls | Jetty | Trestle | Total |
|---|---|---|---|---|---|---|---|
| A1 | € 21,893,000 | € 28,414,000 | € 170,400,000 | € 21,234,000 | € 3,600,000 | € 800,000 | € 246,341,000 |
| A2 | € 26,735,000 | € 20,352,000 | € 170,400,000 | € 21,234,000 | € 3,600,000 | € 800,000 | € 243,121,000 |
| A3 | € 23,633,000 | € 27,576,000 | € 170,400,000 | € 21,234,000 | € 3,600,000 | € 800,000 | € 247,243,000 |