Delft University of Technology

CIE4061-09 Multidisciplinary Project
Durban Dig-Out Port Research

Part 1 Report - Global Port Layout

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Preface

In this report the first objective of our Multidisciplinary Project is presented. A Port Layout is proposed for the Durban Dig-Out Port in which special attention is paid to the environmental sensitive mangroves in the port development area. As a project team we are satisfied with the project so far and eager to continue with the second and third objective, which are the preliminary design of specific structures and recommendations for the Transnet Ports Authority. Our stay in South Africa has been successful and pleasant from the start. In this, the WSP and Transnet staff have played a significant role and we would like to show our gratitude towards them.

Stellenbosch,
December 2014,
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Chapter 1

Introduction

In this chapter the research and the project are introduced. Afterwards the context and the outline of this report are presented.

1.1 Multidisciplinary Project

Delft University of Technology (DUT) offers their master students Civil Engineering the elective course CIE4061-09: Multidisciplinary Project. The purpose of the course is to solve an engineering problem in practise, with a group of students specialising in different areas. The course is rewarded with 10 European Credits (ECTS) per person, equivalent to a work load of 280 hours. The five members of Project Durban have elected the course and arranged a period of 12 weeks attached to WSP Group Africa in Stellenbosch, South Africa. In this period research is conducted for Transnet National Ports Authority (TNPA), towards the Dig-Out Port Project in Durban (DDOP), South Africa. The lessons learned at DUT are applied and during the research the team faces discrepancies between the Dutch theoretical lessons learned in university and the practical South African solutions based on experience.

Below, the team members and their specialisation area are introduced:

- Rik Gijsman - Coastal Engineering;
- Frans de Haan - Hydraulic Structures;
- Rick de Koning - Hydraulic Structures;
- Tuan Le - Ports Engineering;
- Sander Steeneken - Geo-Engineering.

This research is performed for Transnet National Ports Authority (TNPA). Transnet SOC Ltd. is a state owned company with different operational divisions:

- National Ports Authority (TNPA);
- Port Terminal (TPT);
- Freight Rail (TFR);
- Rail Engineering (TRE);
- Pipelines (TPL);
- Supporting, including Transnet Capital Projects.
Transnet has approximately 50,000 employees, a revenue of R49 billion per year (± €3.5 billion) and assets worth R150 billion (± €11.9 billion). TNPA assets contain more than one third (± R56 billion) of the total, since it owns the eight commercial ports in South Africa [TNPA, 02-2014].

During the project, the team is supervised from Delft University of Technology side by ir. Bas Wijdeven and dr. ir. Phil Vardon. From WSP Group Africa side the team is supervised by Andre van Tonder Pr Eng and Rob Leach. Other involved parties are sponsors Boskalis, Van Oord and Delft Infrastructure & Mobility Initiative.

1.2 Durban Dig-Out Port Project

The port of Durban is South Africa’s premier port and hub of the whole region, especially for the Johannesburg (Gauteng Province) area. The expectations are that the port is not able to cope with the vessel and cargo increase in the coming decades. For the next 30 years, a container demand growth of 4% per year is expected [TNPA, 05-2014]. For the economic situation of South Africa, it is of utmost importance that the port expands accordingly in order to support the economic growth of the country.

Since the current port is located within an environmentally sensitive area and surrounded by developed urban properties, sufficient expansion of the port at its current location is not feasible [A. Mather and K. Reddy, 2008]. The focus is therefore changed from expanding the port to the development of a new port in the direct surroundings of Durban. The old international airport, located along the coastline, is a suitable new location, see Figure 1.1. The property, located about 11 km south-eastwards from the city centre, is not in use since the FIFA world cup of soccer in 2010. Durban has built a new international airport north of the city (King Shaka International Airport). Due to the growing demand of throughput for the containers, liquid bulk and vehicles, the current port of Durban will eventually not be sufficient to handle the capacity demand anymore [TNPA, 05-2014]. A part of the current port will therefore be expanded. However, this expansion is not sufficient to handle all cargo for the coming 30 years. The design of the Durban Dig-Out Port needs to cover the lack of space for capacity increase of the current port. A container terminal with a 10,000,000 TEU throughput per year, a liquid bulk terminal with 5,000,000 kL throughput per year and a vehicle terminal of 300,000 of units per year need to be constructed, in order to meet the demand forecasts.
Figure 1.1: Location of the project shown at two scales (Source: Google Maps)
1.3 Research Objectives

The project team has three distinguishable objectives which are summarised hereafter. The focus lies with supplying TNPA with a full solution of the port expansion at the Durban Dig-Out Port (DDOP). These research objectives are also defined in the Task Brief, which is agreed on November the 17th 2014 by David John McGillewie and Selvan Pillay from TNPA.

**Part 1: Design Global Port Layout**  Create a global port layout for the complete Durban Dig-Out Port. The design is based on capacity demand, planning, boundary conditions and the lifetime of the port. This global port layout will include:

- Breakwaters;
- Sand by-pass system;
- Channels;
- Basins;
- Turning circles;
- Quay walls;
- Fenders;
- Road and rail connections;
- Navigation aids;
- Port Control and Port Authority Admin Buildings.

**Part 2: Preliminary Design**  Create a preliminary design for specified aspects of the designed DDOP layout, which fit within the various disciplines of the team (coastal-, geo- and hydraulic engineering). To give the reader an idea, possible aspects are engineering the breakwater, entrance channel, quay-wall and modelling coastal- and geo-engineering aspects.

**Part 3: Recommendations on vessel size and schedule for delivery**  Comment on the TNPA’s choice of container design vessel size for the new port in the Durban area over the next 50 years. Also a schedule for the delivery of the DDOP is given in this part.

1.4 Context of the Report

This report presents the final outcome of Part 1 of the Project Durban research regarding the Durban Dig-Out Port. Before this report, Project Durban has written an analysis report. In that report the research is introduced and the project and the local conditions are investigated [Project Durban, 2014]. In this report the first objective, the design of a global port layout, is presented. After this report, Project Durban continues their research, aiming at objectives 2 and 3, the preliminary design and recommendations for the port authority. These results will be presented by the end of January 2015.
1.5 Report Outline

The outline of this report is as follows. In Chapter 2, the cargo condition requirements of the Durban Dig-Out Port are presented. The annual throughput requirement and the expected vessel sizes are discussed. The arrival and service pattern of the vessels in the current port is also investigated. Afterwards in Chapter 3, the required number of berths and terminal areas are estimated for the container, liquid bulk and car terminals. The nautical areas required to handle the expected vessels are determined in Chapter 4. The dimensions are calculated with simplified calculation methods to determine their order of magnitude. In Chapter 5 the port layout is introduced. The beneficial factors and the considerations for the port layout are explained. The actual dimensions and potential port performance is presented in Chapter 6. Finally, the report is concluded with remarks and recommendations for further research in Chapter 7.
Chapter 2

Cargo Conditions

In this chapter the necessary cargo information for the port layout design is summarised. The required throughput and the design vessel sizes lead to the required amount of ships that the Durban Dig-Out Port needs to handle. At the end of this chapter, the queuing systems of the different commodities are elaborated. In Chapter 3, the queuing system is used to determine the waiting times of the port. Based on that, the amount of berths are calculated. Also the terminal areas necessary are determined. In Chapter 4 the nautical dimensions of the port are calculated based on the vessel dimensions.

2.1 Throughput

The yearly throughput per cargo type is presented in Table 2.1. These amounts of cargo are the requirements for the DDOP and the basis for the calculations hereafter.

Table 2.1: Yearly required cargo throughput

<table>
<thead>
<tr>
<th>Type of cargo</th>
<th>Required throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container</td>
<td>10,000,000 [TEU/year]</td>
</tr>
<tr>
<td>Liquid bulk</td>
<td>5,000,000 [kL/year]</td>
</tr>
<tr>
<td>Car</td>
<td>300,000 [units/year]</td>
</tr>
</tbody>
</table>
2.2  Vessel Dimensions

For the DDOP design, both the average and the design vessel dimensions are used. The average vessel dimensions are based on the current vessel calling at the Port of Durban. The average dimensions of the largest 10% of vessels is assumed to be the average for the DDOP, since the larger vessels will be located at the new port. The design vessel capacity is given by TNPA as a requirement. The related design vessel dimensions where extrapolated from vessel size trends [Project Durban, 2014]. The design container vessel is used for the dimensions of the entrance channel and the turning circle, since this is the largest vessel expected. If only one berth is required, the design vessel dimensions will be used. In Table 2.2, 2.3 and 2.4 an overview of the design and average vessel dimensions is given for the different cargo types.

Table 2.2: Container vessel dimensions

<table>
<thead>
<tr>
<th>Average vessel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ($L_{OA}$)</td>
<td>328 [m]</td>
</tr>
<tr>
<td>Width ($W$)</td>
<td>43.4 [m]</td>
</tr>
<tr>
<td>Draft ($D$)</td>
<td>14.1 [m]</td>
</tr>
<tr>
<td>Capacity</td>
<td>8800 [TEU]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design vessel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ($L_{OA}$)</td>
<td>430 [m]</td>
</tr>
<tr>
<td>Width ($W$)</td>
<td>65 [m]</td>
</tr>
<tr>
<td>Draft ($D$)</td>
<td>16.3 [m]</td>
</tr>
<tr>
<td>Capacity</td>
<td>22,000 [TEU]</td>
</tr>
</tbody>
</table>

Table 2.3: Liquid bulk vessel dimensions

<table>
<thead>
<tr>
<th>Average vessel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ($L_{OA}$)</td>
<td>190 [m]</td>
</tr>
<tr>
<td>Width ($W$)</td>
<td>28 [m]</td>
</tr>
<tr>
<td>Draft ($D$)</td>
<td>11.1 [m]</td>
</tr>
<tr>
<td>Capacity</td>
<td>23,000 [kL]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design vessel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ($L_{OA}$)</td>
<td>250 [m]</td>
</tr>
<tr>
<td>Width ($W$)</td>
<td>38 [m]</td>
</tr>
<tr>
<td>Draft ($D$)</td>
<td>14 [m]</td>
</tr>
<tr>
<td>Capacity</td>
<td>60,000 [kL]</td>
</tr>
</tbody>
</table>
Table 2.4: Car vessel dimensions

<table>
<thead>
<tr>
<th></th>
<th>Average vessel</th>
<th>Design vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ($L_{OA}$)</td>
<td>233 [m]</td>
<td>302 [m]</td>
</tr>
<tr>
<td>Width ($W$)</td>
<td>30.5 [m]</td>
<td>36 [m]</td>
</tr>
<tr>
<td>Draft ($D$)</td>
<td>10.4 [m]</td>
<td>12.4 [m]</td>
</tr>
<tr>
<td>Capacity</td>
<td>6000 [units]</td>
<td>8000 [units]</td>
</tr>
</tbody>
</table>

2.3 Amount of Vessels

The required amount of vessels that have to be handled yearly are calculated using the vessel capacity and the required throughput per year. A distinction is made between design vessels and average vessels to investigate not only the immediate cargo handling capacity but also the future situation in which the design vessel capacities are more common. The values are given in Table 2.5.

Table 2.5: Yearly required amount of vessels handled at the DDOP

<table>
<thead>
<tr>
<th></th>
<th>Container</th>
<th>Liquid bulk</th>
<th>Car</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average 1130 [vessels/year]</td>
<td>Design 450 [vessels/year]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average 220 [vessels/year]</td>
<td>Design 80 [vessels/year]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average 50 [vessels/year]</td>
<td>Design 40 [vessels/year]</td>
<td></td>
</tr>
</tbody>
</table>
2.4 Queuing System

In order to determine the number of berths and the corresponding quay lengths, a calculation related to the capacity and waiting times of the DDOP is performed. The theory for this calculation is named the ‘Queuing Theory’ hereafter. The theory relates the number of servers (berths locations) to the waiting time of the vessels. In this section the queuing system and its parameters are elaborated for the different terminals at the current port of Durban. The queuing system displays the vessel inter arrival time distribution and service time (loading/unloading time at the quay) distribution. The patterns for the DDOP are assumed to be similar.

2.4.1 General Distributions

The queuing behaviour is a relation between the distribution of inter-arrival times, the distribution of service times and the number of servers (berth locations). In this subsection the typical distributions are summarised:

- Negative exponential distribution \([M]\);
- Erlang distribution \([E_k]\);
- Deterministic distribution \([D]\).

Hereafter, the distributions are determined for the inter-arrival- and service times. A commonly found distribution for specialised terminals is the Erlang distribution for both inter-arrival time and service time [R. Groenveld, 2007].

2.4.2 Available Data Port of Durban

To determine the inter-arrival- and service probability distribution functions, data provided by TNPA from the current port of Durban is used. The inter-arrival- and service times are extracted from the Vessel Traffic System (VTS). Data from the years 2012, 2013 and 2014 is available. However, the amount of data differs per year. To minimise the influence of possible unexpected events in one specific month, the year with the most data available is decided normative for this research. This is the year 2013.

To make the amount of data workable, the inter-arrival times for the months January, April, May, June, Augustus and November 2013 are determined. The arrival time at the port is taken as the time the vessel arrives at the breakwater. Regarding the service time, only the months April, May, June and November 2013 are used in the analysis, since the data set is not complete for the service times. The type of movement (arrival and departure), cargo type (containers, liquid bulk and cars) and the date and time at the breakwater are used in the analysis. An overview of the amount of data points that are used in the determination of the probability distribution function per cargo of the inter-arrival- and service time is shown in Table 2.6.

The amount of data points coincide with the amount of days in the data set. Therefore, the amount of data points for the inter-arrival probability distribution function are the same for the different cargo commodities. Service time is considered in the same months (excluding January 2013 and August 2013). Service time however has a focus on the amount of vessels. Therefore, the numbers differ. The number of data points for container vessels is larger than for liquid bulk
Table 2.6: Used amount of data points for determination of Queuing Theory parameters

<table>
<thead>
<tr>
<th></th>
<th>Inter Arrival Time</th>
<th>Service Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Containers</td>
<td>184</td>
<td>330</td>
</tr>
<tr>
<td>Liquid Bulk</td>
<td>184</td>
<td>184</td>
</tr>
<tr>
<td>Car</td>
<td>184</td>
<td>131</td>
</tr>
</tbody>
</table>

vessels, since there are more container vessels handled than liquid bulk vessels. Again, for liquid bulk, the amount of data is larger than for cars since there are less car carriers handled than liquid bulk vessels.

With the data, the inter-arrival time of the vessels is elaborated. At the different dates within the months considered, the amount of ships per date are used to determine the probability distribution function of the different cargo that need to be handled in the Port of Durban. The distribution is visualised in Figure 2.1, where the number of vessels and their related frequency are shown.

For the service time, the total service hours are needed to create a probability distribution function. From the data the inter-arrival- and departure time are extracted and used to determine the total amount of service hours. The distribution is visualised in Figure 2.2, where the number of service hours and their related frequency are shown.

2.4.3 Arrival and Service Time Port of Durban

The data described in the previous subsection is used to determine the probability distribution functions for the different scenarios. The software used to process the data and fit the most suitable probabilistic distribution function is ‘EasyFit’. The raw data is entered in the program and the algorithm finds the closest fit for the probabilistic distribution function to the data.

Figure 2.1a, 2.1b and 2.1c show the probability distribution function for the inter-arrival time of the vessels in the port of Durban. It can be seen that the arrival time can be estimated by an Erlang distribution with 2 degrees of freedom. In order to determine the best fit, various distributions (Erlang, Exponential, Weibull and Rayleigh) are compared with three different tests: Kolmogorov Smirnov, Anderson Darling and Chi-Squared method. In all tests, the Erlang distribution is ranked as number one for all types of cargo.

Figure 2.2a, 2.2b and 2.2c show the probability distribution function for the service time of the vessels in the port of Durban.

It can be seen from these figures that these probability distribution functions are the same as the arrival time probability distribution functions, namely an estimation of the Erlang distribution. In the same way, three tests are done in order to determine if the Erlang distribution is the best fit. Using the Kolmogorov Smirnov, Anderson Darling and Chi-Squared method, the conclusion is that Erlang distribution is the best fit.

Therefore it is concluded that for all distributions the Erlang distribution with 2 degrees of freedom is applicable to all the different commodities for the inter-arrival- and service time (E2/E2/n).
(a) Arrival time: Erlang probability distribution function for Container cargo

(b) Arrival time: Erlang probability distribution function for Liquid bulk

(c) Arrival time: Erlang probability distribution function for Car cargo

Figure 2.1: Overview of the probability distribution functions of the arrival time for different cargo considered in the port of Durban
(a) Service time: Erlang probability distribution function for Container cargo

(b) Service time: Erlang probability distribution function for Liquid bulk

(c) Service time: Erlang probability distribution function for Car cargo

Figure 2.2: Overview of the probability distribution functions of the service time for different cargo considered in the port of Durban


Chapter 3

Terminal Dimensions

In this chapter, the general dimensions of the port terminals are discussed. For the three different cargo terminals the required amount of berths, the relative quay length and the storage area are approximated. The calculations are based on PIANC guidelines [PIANC 1997, PIANC 2014] and the book ‘Ports and Terminals’ [H. Ligteringen and H. Velsink, 2012]. If a different methodology is followed, this is indicated with a remark.

3.1 Container Terminal

3.1.1 Number of Berths

The number of berths is determined with the amount of average and the amount of design vessels separately. It is found that both calculations resulted in the same number of berths, since the mooring time at the berth is insignificant compared to the service time. Therefore, the calculations with only average vessels are discussed in this report. The distribution of the amount of loading and unloading of containers per average vessel is unknown. Therefore an assumption is made about the amount of TEUs handled per vessel. Every vessel will be 100 % loaded or unloaded or for 50 % unloaded and loaded again. For all three situations the handled TEUs are the same which gives a representative service time. Note that this is not the real situation, but the assumption is that it is the average situation for all ships handled.

In the calculations, the approach named ‘Queuing method with maximum waiting time requirement’ is followed. Since this is a simplified method, two other approaches are followed to compare the final results. The three approaches are summarised hereafter:

- Queuing method with maximum waiting time requirement;
- Queuing method with TNPA efficiency requirement;
- Rule of thumb with TNPA efficiency requirement.

Queuing Method with Maximum Waiting Time Requirement

The first approach is based on the arrival and service rate of the port. In the calculation the available time is used to determine the potential amount of vessels the port can handle. Based on the maximum allowable waiting time, the number of berths is determined.
Arrival Rate ($\lambda$): as described in Chapter 2, the amount of average container vessels the DDOP needs to handle yearly is equal to 1130 vessels per year, see Table 2.5.

Service Rate ($\mu$): the service time of the container terminals is determined by the amount and type of cranes. In the DDOP every berth has 4 cranes available which are able to transport 28 containers hourly.

In the current port of Durban the TEU-factor is 1.6. Expecting a TEU-factor of 1.8 for the DDOP, the average container vessel (8847 TEU) transports 4915 containers. With the assumption that a vessel is totally loaded or offloaded, the service time at the berth is 43.9 hours per average vessel. Including 2 hours of mooring time makes the service time 45.9 hours in total. Since the port operates 363 days per year, there are 8712 hours per year available for cargo handling. Extracting a crane downtime of 30 percent, the effective hours per year become 6099 hours. Therefore one berth location is able to handle 133 average vessels per year.

Berth Utilisation ($u$): The amount of berths is determined by the berth utilisation (Equation 3.1) and the acceptable waiting time. The acceptable utilisation value depends on the queuing system in this method. The queuing system determines the waiting time of the vessels, for container vessels this system is $E_2/E_2/n$ (see Section 2.4.3 for the distribution explanation).

\[
u = \frac{\lambda}{\mu \cdot n}\tag{3.1}\]

In which,
- $u =$ berth utilisation [-]
- $\lambda =$ arrival rate [vessels/year]
- $\mu =$ service rate [vessels/year]
- $n =$ amount of berths [-]

Commonly, a maximum waiting time of 30 percent of the service time is acceptable. Being conservative, the number of berths is calculated to be 14 berths. The reason for this is elaborated at the end of this subsection.

Queuing Method with TNPA Efficiency Requirement
The second approach is similar to the first. However, the decision for the amount of berths is this time not based on the queuing system and an acceptable waiting time, the utilisation factor is stated not to become larger than 0.5. Both the inefficiency due to crane downtime and due to berth occupation are covered by this assumption. This is a more simplified approach in which the vessel arrival pattern is not included. From this methodology follows that the amount of berths necessary at the container terminal is 12 berths at minimum.

Rule of Thumb with TNPA Efficiency Requirement
With a rule of thumb given in Equation 3.2 the amount of berths can be calculated. The number of berths are input in the denominator of the equation. The output, which is the utilisation factor, cannot be larger than 0.5. A number of 12 berths is found sufficient.

\[
u = \frac{N_c}{P \cdot f_{TEU} \cdot N_{cb} \cdot n_{hy} \cdot n}\tag{3.2}\]
In which,
\[ u = \text{berth utilisation factor: } 0.47 \text{ [-]} \]
\[ N_e = \text{annual troughput: } 10,000,000 \text{ [TEU/year]} \]
\[ P = \text{net production per crane: } 28 \text{ [moves/hour]} \]
\[ f_{TEU} = \text{TEU factor: } 1.8 \text{ [-]} \]
\[ N_{cb} = \text{number of cranes per berth: } 4 \text{ [-]} \]
\[ n_{hy} = \text{number of operational hours per year: } 8712 \text{ [hours/year]} \]
\[ n = \text{number of berths: } 12 \text{ [-]} \]

**Conclusion**

Since the Queuing method with maximum waiting time requirement is the most accurate, it is decided to follow that approach. However, a maximum average waiting time of the vessels has to be defined. There are two reasons for being conservative in the decision of the maximum waiting time. The first is that the variability between the approaches shows that the calculation methods have inaccuracies and uncertainties. Next to that, the estimated waiting time will increase due to the complexity of number of berths. The used approach does not take that complex queuing system properly into account. Therefore the new DDOP will be designed having **14 container vessel berths**. The utilization value related is 0.61.

### 3.1.2 Quay Length

Given the amount of berths and the dimensions of the container vessels, the total necessary quay length is calculated. If two berths are designed next to each other, the calculation is done with the average vessel dimensions. It is not expected that only design vessels will moor at the quay, but always a variety of vessels. Therefore the total length of the quay is based on the length of the average vessel. However, if there is only one berth, the design vessel dimensions need to be used. Otherwise there will not be enough quay length to accommodate the design vessels. The equations are elaborated below.

For a single berth the following equation is used:

\[ L_{n=1} = L_{OA,Design} + (2 \cdot 40) \]  \hspace{1cm} (3.3)

Using Equation 3.3 and the length of the design vessel, the required length of a single container berth is **510 m**.

For more than one berth two approaches are distinguished: the PIANC method (Equation 3.4) and the Port of Durban method (Equation 3.5).

\[ L_{n>1,PIANC} = 1.1 \cdot n \cdot (L_{OA,Average} + 15) + 15 \]  \hspace{1cm} (3.4)

\[ L_{n>1,PoD} = n \cdot (L_{OA,Average} + 40) + 40 \]  \hspace{1cm} (3.5)
Designing all 14 berths in a row gives a total length of 5300 m according to Equation 3.4 and 5200 m according to Equation 3.5. Please note that the total length of quay changes if there are several sections with berths. This is elaborated more in the final layout of the Durban Dig-Out Port (Chapter 5).

**Remark**
The Port of Durban method is in this case more accurate, because it is based on the bollard distance. This distance is equal to 40 m, implying that this is the necessary space between two vessels. A check with the PIANC rules is done, to get a rough estimate of the order of magnitude of the result. Since the results of both methods are in the same order of magnitude, it is decided to follow the current Port of Durban policy with regard to quay lengths. The local guidelines are followed, based on the advise of TNPA.

### 3.1.3 Container Terminal Area

The terminal area is determined with Equation 3.6, which takes into account the dwell time and the type of container handling cranes. The equation gives an approximate area for the required container surface. The necessary container terminal area is found to be 155 ha.

\[
A = \frac{N_c \cdot T_d \cdot A_{TEU}}{r_{st} \cdot m_c \cdot 365}
\]

In which,
- \(A\) = required terminal area: \([m^2]\)
- \(N_c\) = throughput: 10 million [TEU per annum]
- \(T_d\) = dwell time: 4.5 [days]
- \(A_{TEU}\) = required area per TEU inclusive equipment travelling lanes: 7 \([m^2]\)
- \(r_{st}\) = average stacking height / nominal stacking height: 0.7 [-]
- \(m_c\) = occupancy rate: 0.8 [-]

However, the container terminal exists not only of container stacks. Infrastructure is required for the cranes to be able to maneuver in between the stacks. Based on other ports, it is found that the total container terminal is approximately 50 percent larger than the container surface. This gives a total area of 230 ha.

### 3.2 Liquid Bulk Terminal

#### 3.2.1 Number of Berths

Also for the liquid bulk terminal, the three different strategies are applied to investigate the variability.

**Queuing Method with Maximum Waiting Time Requirement**

*Arrival Rate (\(\lambda\))*: the amount of average liquid bulk vessels yearly handled in the DDOP is equal to 219 vessels per year.
Service Rate ($\mu$): The unloading capacity of the liquid bulk terminal (petroleum products only) is 1000 kL/hour. With the similar assumption that a vessel is completely loaded or offloaded, the service time at the berth is 23 hours per average vessel. Including the 2 hours of mooring the total service time becomes 25 hours. Since the expected downtime is roughly 20% (due to e.g. cleaning of the pipelines), the amount of effective hours per year is 6970. Therefore one berth location is able to handle 280 average vessels per year.

Berth Utilisation ($u$): The amount of berths is again determined by the berth utilisation and the acceptable waiting time. The acceptable utilisation value depends on the queuing system, which is for liquid bulk also E2/E2/n (see Section 2.4.3 for the distribution explanation).

Conclusion

A similar assumption is made for the amount of liquid bulk berth locations. The two other approaches determine the amount of berths at 2 (both the Queuing method with TNPA requirement and the simplified method with TNPA requirement). In order to be conservative and take complexity of the system into account, it is decided to design for 3 berth locations. The utilisation value related is 0.26. The utilisation is calculated with Equation 3.1.

3.2.2 Jetties

The liquid bulk vessels do not moore on a standard quay wall with regard to safety and wave response. The berth facilities are designed as separate jetties. Therefore the 3 berth locations are designed for the maximum liquid bulk vessel size. According to Equation 3.3 the length reserved for each ship becomes 250 m, excluding a safety margin at both sides of the berths.

Remark

Please note, the liquid bulk berth length determination is not equal to other commodities, because the jetties length is not necessarily equal to the ship length.

3.2.3 Liquid Bulk Terminal Area

There are no standard guidelines to determine the liquid bulk terminal area. It is dependent on several factors, e.g. destination of cargo, economic efficiency and logistics. The required area is mainly determined by the type of storage of the liquid bulk. If the liquid bulk is for transhipment only, the dwell time of the liquid bulk is in the range of nine days. The throughput value can then be relatively high. If the liquid bulk is stored for a longer period of time, for example 30 days, the throughput becomes significantly smaller. This results in more necessary storage facilities and hence a higher required terminal area. Another possibility is that the liquid bulk, after a relatively short storage period, is pumped away. The old existing Durban to Johannesburg Pipeline, known as DJP, which has been in place for many years, has reached the end of its design life. This line is still being used and Transnet has yet to decide on the future of this line. Transnet has recently build a new Durban to Johannesburg Multi Product Pipeline, known as MMP, but this line which is being used is not yet operating at its full design capacity, as various additional pump station terminals are still in construction. If this pipeline is used in the future for the DDOP as well, this could lead to a smaller required terminal area.
3.3 Car Terminal

3.3.1 Number of Berths

For the car terminal, the three different strategies are again applied to investigate the variability. Only the ‘Queuing method with maximum waiting time’ is elaborated.

**Queuing Method With Maximum Waiting Time Requirement**

*Arrival Rate* ($\lambda$): the amount of average car carriers yearly handled in the DDOP is equal to 50 vessels per year.

*Service Rate* ($\mu$): the loading/unloading capacity of the car carriers is 120 units/hour. This is a relatively low value compared to other ports, since there are special types of vehicles loaded and unloaded. With the assumption that a vessel is totally loaded or unloaded, the service time at the berth is 50 hours per average vessel. Including the 2 hours of mooring the total service time becomes 52 hours. Since the expected downtime is roughly 10 percent (due to e.g. wave response), the amount of effective hours per year is 7841. Therefore one berth location is able to handle 150 average vessels per year.

*Berth Utilisation* ($u$): The amount of berths is again determined by the berth utilisation and the acceptable waiting time. The acceptable utilisation value depends on the queuing system, which is also for car carriers E2/E2/n (see Section 2.4.3 for the distribution explanation).

**Conclusion**

The two other approaches determine the amount of berths equal to one (the Queuing method with TNPA requirement and the simplified method with TNPA requirement). In order to be conservative and take complexity of the system into account, it is decided to design for 2 berth locations. The utilisation value related is 0.17.

3.3.2 Quay Length

For the car carriers it is convenient if they are able to load/unload from the side of the vessel and from the stern. Therefore two single berth locations are designed. These are based on the maximum car vessel size. The length of the two berths locations is calculated with Equation 3.3 and is 380 m per berth.

3.3.3 Car Terminal Area

The dimensions of the car terminal are based on a rule of thumb. Approximately 1 ha is required for a vehicle throughput of 25,000 per year [H. Ligteringen and H. Velsink, 2012]. For the 300,000 vehicles throughput per year, this results in a required area of 12 ha.

**Remark**

The used rule of thumb is based on an average transit time of two days, which is high for a modern car terminal. For the DDOP no multi storey parkades will be applied, but only a stacking area at ground level. For this reason the determined required area of 12 ha is used for a first estimated value.
3.4 Summary

In this section the different required terminal dimensions of the Durban Dig-Out Port are summarised.

Table 3.1: Container terminal parameters

<table>
<thead>
<tr>
<th>Container</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization</td>
<td>0.61</td>
<td>-</td>
</tr>
<tr>
<td>Amount of berths</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td>Quay length</td>
<td>5200</td>
<td>m</td>
</tr>
<tr>
<td>Storage area</td>
<td>230</td>
<td>ha</td>
</tr>
</tbody>
</table>

Table 3.2: Liquid bulk terminal parameters

<table>
<thead>
<tr>
<th>Liquid bulk</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization</td>
<td>0.26</td>
<td>-</td>
</tr>
<tr>
<td>Amount of berths</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Reserved length per berth</td>
<td>330</td>
<td>m</td>
</tr>
</tbody>
</table>
Chapter 4

Nautical Dimensions

In this chapter the basic dimensions of the required nautical areas in the Durban Dig-Out Port are elaborated. The calculations are based on PIANC guidelines [PIANC 1997, PIANC 2014] and the book 'Ports and Terminals' [H. Ligtering and H. Velsink, 2012]. The nautical areas in the port are the approach channel, the turning circle and the mooring basins. If a different methodology is followed, this is indicated with a remark.

4.1 Approach Channel

The approach channel suits incoming vessels entering the port. The channel starts in deep water and ends in the turning circle inside the port. In this section the dimensions of the channel are calculated. Since there will be a Vessel Traffic System present in the port, the minimum required dimensions are designed following PIANC. The governing vessel is the design container vessel, since this is the largest vessel that has to enter the port.

4.1.1 Length

The stopping manoeuvre of the incoming vessels determines the length of the approach channel within the breakwater. Tugboats assist incoming vessels to increase safety and control the stopping procedure. The environmental conditions determine whether the tugboats are able to tie up before a ship enters the breakwater or not. Otherwise the tugboats have to assist in the more sheltered zone within the breakwater. The limited environmental conditions in which the tugs can operate are:

- wind velocity \( \leq 10 \text{ m/s} \);
- current velocity \( \leq 1.0 \text{ m/s} \);
- significant waveheight \( H_s \leq 2.0 \text{ m} \).
The hydraulic conditions at the DDOP are:

- wind velocity \( \geq 10.1 \text{ m/s} \) with exceedance percentage of 10%;
- current velocity \( \leq 0.8 \text{ m/s} \);
- significant waveheight \( H_s \geq 2.34 \text{ m} \) with exceedance percentage of 10%.

Following the requirements the conclusion is that the tugboats need to tie up within the breakwaters. Otherwise, the environmental conditions will cause too much downtime. Therefore, the length within the breakwater will be determined by the following three factors:

- \( L_1 \): The length required to reduce to the entrance speed;
- \( L_2 \): The length required to tie up and position the tugboats;
- \( L_3 \): The stopping length.

\( L_1 \) : To determine the length required for the vessel speed reduction, Equation 4.1 is used. For sufficient rudder control the vessel needs enough speed with regard to the hydraulic conditions. The maximum entrance speed of the incoming vessels is 5.5 m/s (10 kn). Before the procedure of tying up the vessel, the speed has to be reduced to 2 m/s (4 kn), which is the minimum vessel speed. Given these values, length \( L_1 = 1129 \text{ m} \).

\[
L_1 = (v_s - 2) \cdot \frac{3}{4} \cdot L_{OA} \tag{4.1}
\]

\( L_2 \) : The time for tying up tugboats is in a range of 10 minutes. This period depends on the expertise of the crew and the environmental conditions. During the tying up of the vessel, it sails at a speed of 2 m/s. This combination of time and vessel speed gives \( L_2 = 10 \cdot 60 \cdot 2 = 1200 \text{ m} \).

\( L_3 \) : When the tugboats are attached to the vessel, the vessel can safely decrease its speed in order to turn at the end of the entrance channel. The length required for this is estimated to be: \( L_3 = 1.5 \cdot L_{OA} = 645 \text{ m} \).

Adding the three lengths, the minimal total length of the approach channel for the DDOP is calculated to be 2974 m. This length is from the tip of the breakwater to the centre of the turning circle.

**Remark**

The length of the approach channel is based on theoretical values and methodologies. The operational experience available in the Port of Durban is not taken into account. The results found are therefore conservative. If operational port experience is applied, there is much room for optimisation. For instance, in this section, the location for tying up the tugboats and the assumed maximum entrance speed have a large influence on the length of the breakwaters. These values are based on theoretical background in this design. In Section 5.7.2 more attention is given regarding the operational aspects of the design.
### 4.1.2 Width

The average inter-arrival time is approximately 6.2 hours and the mooring time of a vessel is 2 hours. Therefore, it is decided to design a one-way channel able to suit the design container vessel. According to PIANC [PIANC 1997], a distinction is made between the outer channel and the inner channel. The outer channel starts at the tip of the breakwaters and runs till 860 m within the breakwaters (two times the design container vessel length). From 1290 m (three times the design container vessel length) within the breakwater until the turning circle, the inner channel is located.

The approach channel width for a one way lane is determined by Equation 4.2.

\[
W = W_{bm} + 2W_b + W_a
\]  

(4.2)

In which,
- \( W \) = total approach channel width [m]
- \( W_{bm} \) = basic manoeuvring width [m]
- \( W_b \) = bank clearance [m]
- \( W_a \) = additional width [m]

In Table 4.1 the different width factors are presented. These factors are multiplied by the width of the design vessel and added to the total width of the channel. The additional widths are based on site conditions at the DDOP, these are elaborated in Table 4.1.

Using Equation 4.2 the outer channel width becomes at least 319 m and the inner channel width 273 m.
4.1.3 Depth

The depth of the approach channel is determined with Equation 4.3. The design water level, which is the lowest astronomical tide level, is +0 m CD.

\[ h = D - h_t + s_{max} + a + h_{net} \]  

(4.3)

In which,

- \( h \) = total approach channel depth [m];
- \( D \) = draft of the design vessel: 16.3 [m];
- \( h_t \) = tidal elevation above reference level, below which no entrance is allowed. For the DDOP no tidal window will be applied. Vessels have to be able to enter the port at low water: 0 [m];
- \( s_{max} \) = maximum sinkage due to squat and trim. The equation to determine this parameter is given in Equation 4.4.

\[ s_{max} = 3.98 \cdot \frac{C_b}{30} \cdot k^{0.81} \cdot v_s^{2.08} = 0.76[m] \]  

(4.4)

In which,

- \( v_s \) = minimum vessel speed: 2 [m/s]
- \( C_b \) = block coefficient: 0.8 [-]
- \( k \) = blockage coefficient = \( \frac{A_s}{A_{ch}} \) = 0.143 [-]

\( A_s \) = the vessel cross sectional area in the plane of the water surface: 847.6 [m²]
\( A_{ch} \) = the channel cross sectional area: 5911 [m²]. \textit{This value is found by means of iteration, since the channel dimensions were not known.}

- \( a \) = the vertical motion due to wave response: 1 [m]; \textit{this value is estimated as } \( H_s \cdot 0.5 \) \textit{and } \( H_s \) \textit{is approximately } 2 \textit{m.}
- \( h_{net} \) = net underkeel clearance: 0.5 [m].

Implementing the approximated values in Equation 4.3, the approach channel depth is determined to be at least 18.6 m.
4.2 Turning Circle

The inner channel of the approach channel ends in the turning circle. In this area incoming vessels are able to turn towards the berth basins. Since the required diameter $D \geq 2 \cdot L_{OA}$ of the design container vessel, the turning circle is designed with a diameter of 860 m.

4.3 Basins

In this section the dimensions of the berth basins are discussed. The length of the basin is determined by the quay length of the terminals. It is convenient for the vessels to be able to turn around in the basin. The width is therefore determined by $W_{\text{basin}} \geq W_{\text{vessel}} + L_{OA} + 50$. For an average vessel to be able to turn the minimum width of the basin becomes 422 m. For a design vessel this value is 545 m. The decision about which vessels are able to turn is based on the available space.

The depth of the basin is determined with the policy of the Port of Durban [TNPA, 12-2008]. The following factors are included in the depth determination:

- Design vessel draft: 16.3 [m];
- Out of trim: $0.3 + 0.04 \cdot (16.3 - 10) = 0.6$ [m];
- Underkeel clearance: 0.6 [m];
- Allowance siltation: 0.5 [m];
- Sounding accuracy: 0.1 [m];
- Allowance dredging: 0.3 [m].

The above values sum up to a minimum depth of 18.4 m in the design vessel berth basin.

Remark

The policy of the Port of Durban for the determination of the basin depth is based on operational inaccuracies. The PIANC methodology is based on theoretical processes as can be seen in the determination of the entrance channel depth. For the determination of the depth of the basin, the local guidelines are followed, based on the advise of TNPA. The TNPA guidelines are conservative and can be changed with permission from the Chief Engineer.
4.4 Summary

In this section the different required nautical dimensions of the Durban Dig-Out Port are summarised, based on the theory and/or TNPA guidelines.

Table 4.2: Summarised dimensions of the approach channel and basin

<table>
<thead>
<tr>
<th>Approach channel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>2974 [m]</td>
</tr>
<tr>
<td>Width</td>
<td></td>
</tr>
<tr>
<td>- inner channel</td>
<td>273 [m]</td>
</tr>
<tr>
<td>- outer channel</td>
<td>319 [m]</td>
</tr>
<tr>
<td>Depth</td>
<td>18.6 [m]</td>
</tr>
<tr>
<td>Turning circle</td>
<td>860 [m]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Basin</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum width required for turning</td>
<td></td>
</tr>
<tr>
<td>- average vessel</td>
<td>422 [m]</td>
</tr>
<tr>
<td>- design vessel</td>
<td>545 [m]</td>
</tr>
<tr>
<td>Depth</td>
<td>18.4 [m]</td>
</tr>
</tbody>
</table>

Figure 4.1: Summary diagram of entrance channel
Chapter 5

Proposed Durban Dig-Out Port Layout

Considering the conclusions of the analysis report of Project Durban [Project Durban, 2014] and the dimensions calculated in the previous chapters, a conceptual design is proposed for the Durban Dig-Out Port. In this chapter the conceptual design is presented and discussed. Key points in the design are the protection of the mangrove area and an optimal convenience for navigation. Other important issues addressed are the mitigation of incoming waves, the terminal efficiency and the safety of the design. In Chapter 6, the performance of the proposed layout is given.

5.1 Port Layout

On the next page, the proposed layout is presented. All elements in the drawing are elaborated in the sections afterwards.
5.2 Care for the Mangroves

Three types of mangroves are present in the Isipingo estuary. These species are of utmost importance for the estuary and need to be preserved. Only then the estuary can behave in ecological balance. In the port, the condition of the estuary is taken into account. Moreover, it is considered as one of the key elements in the design. In this section the current condition of the current estuary is briefly discussed first. Afterwards the proposed layout is elaborated.

Condition of the Isipingo Estuary

The Isipingo estuary has an area of 14.3 ha, mostly covered by mangrove trees. The mangroves sustain themselves by fresh water supply from Isipingo-Umlazi catchment and salt water from the tidal inflow. To improve the condition of the estuary a re-establishment of adequate flow through the system is required. Currently some issues are present with regard to the mangroves. One problem is the human induced pollution of the water. The other major problem is water supply. The Isipingo-Umlazi catchment is changed by human activities such that only 3% of the natural annual runoff from rainfall enters the estuary. Due to the low amount of fresh water supply, the runoff to the ocean is not sufficient to keep the entrance open. The alongshore sediment transport has closed the entrance to the ocean. This closure causes a shortage of sea water in the estuary. Currently this is solved with a pipeline connection between the estuary and the ocean. Research concludes that this pipeline is not able to keep a sufficient amount of water flowing in and out in the future [SSI and MER, 2011].

Integration of the Estuary with DDOP

In the proposed layout, the mangrove area of the Isipingo estuary remains untouched. This is accomplished by adjusting the orientation of the approach channel. The channel is orientated in the South-East direction. Moreover, the mangroves are not only untouched, there is even more space created for the protected trees. Potentially, the mangrove area can be expanded in the direction of the entrance channel. Almost 14 ha of land is available for the existing estuary. This area can be used to improve the current condition of the estuary. Not only new space becomes available for the nature, there is also a second advantage in the proposed layout. If the estuary expands in the direction of the approach channel, a water exchange system can be realised. This could help in sustaining the mangroves because the open connection to the ocean in not necessary anymore. It also reduces the probability of flooding in the estuary, since the water has an open outflow to the sea. A system will be designed in which the discharge can be controlled. This is to prevent problems when the water at seaside becomes too high and the estuary gets flooded with seawater. Furthermore, this system is able to close the estuary from the channel, in case of an emergency with the nearby liquid bulk terminal. Pollution of the mangroves will then be prevented.

Concluding, the orientation of the approach channel is based on the location and interaction with the Isipingo estuary. This layout does not only create new space for the mangroves to expand, but it also supports the estuary with a new exchange system from the entrance channel.
5.3 Convenient Navigation

The direction of the entrance channel is not only beneficial for the mangroves, it also causes the central location of the turning circle. For this reason the basins are relatively short and manoeuvring of the vessels becomes convenient. In this section the navigational convenience of the DDOP port layout is discussed. The port layout is reviewed by pilots from the Port of Amsterdam and Port of Rotterdam. They agreed on the navigational convenience of the layout.

Turning Circle
As mentioned in the introduction, the turning circle is positioned at a central location, in between the two port basins. The turning circle marks the end of the entrance channel. Ships can turn in this circle to continue to their destination easily. Vessels have shorter distances to travel inside the port. As a result, none of the berths are isolated.

Wind Direction
The dominant wind direction is either in north-east direction or in south-west direction. This implies that the wind is parallel to most quays in the proposed design, allowing the wind to blow in the longitudinal axis of the vessels.

Port Basins
The width of the port basins is designed for an average vessel to be able to turn, therefore they can easily manoeuvre at the berths. A design vessel will not be able to turn inside the basin. The position of the turning circle makes the distance to the container berth small.

The southern basin in which the car terminal is located is not rectangular. An angle is introduced in the corner of the car terminal in order to make the berths in that basin more approachable. Furthermore, the width of the northern basin starts wider to make sure vessels can conveniently turn in the turning circle.

Liquid Bulk Location
The liquid bulk jetties are positioned in the entrance channel of the port, close to the breakwaters. The entrance channel is widened for this purpose. This positioning has the advantage that the sail-out time of the liquid bulk vessel is short, keeping in mind the hazardous cargo they carry. The liquid bulk jetties are located in the inner bend of the entrance channel. The safety issues involved are elaborated in more detail in Section 5.6.
5.4 Wave Mitigation

The direction of the approach channel has benefits for the environment and for navigation. The wave climate however could cause high amounts of wave action inside the port, since the main wave direction is aligned with the approach channel direction. The waves could lead to large downtime and that has a direct impact on the port efficiency. Waves therefore have to be prevented inside the port. Especially container operations are sensitive to wave action. Car- and liquid bulk operations are less sensitive. In this section the taken measures to mitigate the incoming waves are discussed.

Swell Waves
In order to prevent swell waves approaching from the SSE entering the port, two breakwaters are designed of which the tips are exactly aligned with the wave direction, see Section 5.1. To make this possible, there is a slight bend introduced in the approach channel (28.3 degrees over 1480 m). According to the ‘Port Designer’s Handbook’ [Thoresen, 2003] it is preferred to avoid bends in the entrance channel for navigational purposes. However, in this design it is decided that the prevention of swell waves entering the port is of utmost importance. If that is the case, a radius of at least $5 \cdot L_{OA}$ is acceptable for navigation (2150 m). The introduced bend in the entrance channel has a radius of 3000 m and is therefore acceptable. [Thoresen, 2003].

Wind waves
Not only swell waves are apparent along the Durban coast. Also wind waves (short waves) are present, approaching from the SE to ENE direction. These waves are not directly blocked by the breakwaters. In this port design, measures are included to dissipate the incoming wave energy. Only waves with SE wave direction are able to transmit into the turning circle of the port. In order to mitigate these waves, a wave dissipation area is designed at the end of the entrance channel. This area is also included with regard to navigational safety, as is discussed in Section 5.6. The other waves able to transmit through the breakwaters will run up on the inside of the southern breakwater. The inside slope of the southern breakwater is designed to dissipate as much wave energy as possible. Further research is necessary to investigate the workability of the liquid bulk terminal, since it is relatively exposed to the waves. The construction of an inside breakwater can be considered.

Sand Bypass System
Durban’s coastal stretch is interrupted by the breakwaters of the DDOP. The current net alongshore sediment transport is approximately 500,000 m$^3$/year northwards [WSP, 2008] and sediment will start accumulating at the south side of the southern breakwater. Next to that, sediment will accumulate at north side of the northern breakwater. The wave climate in combination with secondary current patterns due to the sheltering zone of the breakwater also causes southward directed sediment transport.

The alongshore sediment transport at the Durban coast is however mainly induced by the obliquely incident waves from the south. Downstream of the breakwaters (north side), where the waves reach the coast again, the alongshore sediment will start transporting sediment from the existing beaches. Erosion of the bluff, which is a steep and high sand dune, has to be controlled and prevented. The upstream accumulating sediment is used to prevent erosion of the bluff by means of a sand by-pass system.
A water based mobile sand bypass system is proposed. This system is the most flexible with regard to future changes and requires the least maintenance. Next to that, the current Port of Durban makes use of the same sand by-pass system and a dredge vessel is available. To determine the exact location of the sand trap, further research is necessary.

5.5 Terminal Efficiency

The different commodities require different hinterland connections. The proposed layout makes optimal use of the location of the Toyota car factory and the SAPREF refinery. Also the container terminals are enclosed by road and rail infrastructure. In this section the location of the terminals are elaborated in detail.

Containers
The container terminals are separated into two parts. The north part consists of a total of 11 berths, two times five berths in a straight line and a single berth on the east side of the turning circle. Both the two times five berths can accommodate either five average vessels or three design vessels. The single berth can only accommodate an average vessel. It is not possible to locate the single berth in line with the five others berths, since this leads to a berth that interferes with the minimal area of the turning circle. The single south berth can accommodate a feeder vessel and the two berths west can accommodate either two average vessels or one design vessel. The container terminals in the south part are connected with the container terminals in the north by means of road transport.

Liquid Bulk
The liquid bulk products delivered are petroleum products. Focussing on the hinterland, which is the SAPREF refinery, this location of the liquid bulk is favourable. The total area available within the project boundaries is approximately 18 ha. Collaboration with SAPREF is preferred when the need for capacity is higher than the project area can accommodate. Liquid bulk can be pumped, which creates other options when collaboration with SAPREF is not an option.

Car
The car terminals are located south of the turning circle and east of the basin. Logistically this is the preferred location since the Toyota factory is close to the south project boundary. The cars can be stored or loaded on a vessel.

Road and Rail Connection
Road and rail connections are necessary to process the cargo in and out of the port. The north part of the container terminals both have a road- and rail connection in and out of the port. The south part of the container terminals are only connected to the north part by road. From there the containers can be transported by road or rail. This is mainly due to the office buildings that are present north of the this area. Car cargo arrives and departs the port area via the road that is currently present in the area perpendicular to the berths. Probably this road needs to be upgraded, since this is currently one lane road.
5.6 Safety

Creating a safe port, where the chance of any hazards is as small as possible is of vital economic, social and environmental importance. The measures undertaken to create safety in the DDOP are elaborated in this section.

Approach Channel
The length of the approach channel is long enough to ensure safety for the incoming vessels. Because ships have less rudder control when their speed is low, the last part of the entrance channel is straight. In that part ships will reduce their speed to the allowed minimum speed. The placement of the approach channel in the layout is checked by a pilot who is qualified to bring ships into a port in real life. Because of the relative long approach channel, the small bend will not result in safety issues. At the end of the approach channel a run-up place for ships is designed. If a ship enters the port with a too high speed and it is not able to slow down, the run-up zone is available to stop the ship. This area for emergency cases is placed at the end of the entrance channel. The navigation aids are not given in detail in the sketch. To ensure safety while entering the port, the normal required navigation aids are applied. Furthermore, the tugboat harbour is placed centrally next to the entrance channel to support the incoming and outgoing vessels.

Liquid Bulk Terminal
Petroleum products are the major liquid bulk throughput for the DDOP. This throughput can be seen as hazardous cargo and measures need to be taken for the following issues:

- Liquid bulk terminal in relation to the entrance channel;
- Liquid bulk terminal in relation to the port terminals;
- Vulnerability of the mangroves.

With regard to the liquid bulk terminal in the entrance channel, there is a chance of collision of vessels approaching and vessels manoeuvring at the liquid bulk terminal. Therefore the approach channel is widened at the location of the liquid bulk terminal, in order to have sufficient width according to PIANC. The liquid bulk terminal is positioned in the inner bend of the approach channel. This makes the probability of collision small, because ships have a tendency to sail to the outer bend of the channel.

The location of the liquid bulk terminal close to the port entrance has the advantage that the vessels can sail to the ocean in case of an emergency e.g. a fire. Furthermore, the terminal is isolated from the other terminals, making the effects of a possible disaster smaller.

Leakage from the liquid bulk terminal can have extensive environmental impact on the Isipingo estuary. In order to prevent the liquid bulk from leaking into the estuary, a floating protection element is proposed in between the liquid bulk terminal and the entrance channel, in case of an emergency. Furthermore, the connection between the entrance channel and estuary is controlled with a sluice. This sluice closes in case of an emergency.
5.7 Flexibility in the Design

Two possible variations in design are discussed in this section. These alternatives do not include the safety standards in the same order as the proposed layout. They however have other benefits. For instance the relocation of the turning circle leads to a higher container terminal efficiency. Adaptation of the maximum entrance channel speed or following the regulation of tying up tugboats outside of the breakwaters results in shorter breakwaters and therefore less costs.

5.7.1 Relocation of turning circle

If for instance the container growth is larger than expected, it is preferred to increase the amount of container berths and the stacking area. In the proposed layout, the alternative is to relocate the turning circle in order to increase the amount of container berths to 15. In the figure on the next page the possible alternative on the DDOP design is outlined.

The safety zone is replaced by 2 container berths. An advantage is the large container terminal in the west, which provides more logistic efficiency. As a consequence of moving the turning circle southeast, the berth of the north eastern container terminal is erased. The tug boat berths are positioned slightly to the north, next to the container terminal on the north east side.

Next to the advantage of an extra berth and more logistic efficiency, this adaptation has disadvantages. The waves penetrating the port cannot be dissipated as much as before and therefore higher service downtime is expected. Furthermore, the removal of the safety zone increases the probability of ship collision at the berths. Finally, the turning circle is not aligned with the basins and entrance channel, which makes navigation less convenient.

In terms of safety and the current predictions, it is not recommended to implement this alternative. This design becomes an option if the container throughput demand exceeds the current predictions. Also from a cost-benefit perspective it could be favourable. It does however not including the safety requirements of PIANC [PIANC 1997]. Transformation of the port has to be decided based on the experience with regard to safety in the proposed layout.
5.7.2 Reduction of entrance channel and breakwater length

The entrance channel dimensions in the layout are based on PIANC guidelines. With help from more experienced port engineers, it is concluded that the length of the entrance channel and the related breakwaters are based on very conservative regulations. Cost considerations are not taken into account in the layout and optimisation of the layout is possible. When costs are included in the design, a solution has to be found which is safe but also cost effective. From the operational side, assumptions in this can be made differently. The current design is based on an extremely safe scenario which can be based on a more average situation. Hereafter, two alternative options are proposed which already try to optimize the entrance channel and breakwater length.

Entrance Speed Reduction

The first alternative is reducing the maximum entrance speed of the vessels. The length necessary to reduce the vessel speed than become shorter. As a consequence, the length of the entrance channel and the length of the breakwaters becomes shorter. The construction costs of the breakwater and the dredging costs of the entrance channel are lower in that case.

In order to have sufficient rudder control, the entering vessel needs to have a speed of four times the cross current speed [Ligteringen and Velsink (2012)]. At the DDOP, the cross current is 0.8 m/s and the minimum entrance speed is therefore 3.2 m/s. When the maximum entrance speed is reduced to 6 knots (3.3 m/s) instead of 10 knots (5.5 m/s), the vessel still has proper rudder control and is able to enter the port safely. The reduction of the entrance speed has a beneficial effect on the required length to reduce speed \((L_1)\), which reduces from 1129 m to 419 m. The length of the entrance channel \((L_1 + L_2 + L_3)\) becomes 2264 m instead of 2974 m. The entrance channel, and therefore the breakwater length as well, is reduced with 710 m. In the layout on page 34 a reduced entrance channel length is included.

Tug Boat Tying up to Vessel Outside the Breakwaters

In Chapter 5 the length of the breakwaters is determined assuming that the tugboats tie-up within the breakwaters. The apparent environmental conditions otherwise cause too much downtime. The wind direction is however important in the procedure of tying up the tug boats. The wind direction is perpendicular to the sailing direction of the vessels. In order to safely guide the vessel into the breakwaters, the decision could be made to tie-up the tug boats outside the breakwaters.

In that case, the tying-up length is not necessarily within the breakwaters protection anymore. As a result the entrance channel \((L_2)\) reduces to zero. The length of the approach channel within the breakwaters is then determined by the sum of \(L_1\) and \(L_3\). The entrance speed is assumed at the speed limit of 6 knots, because the tug boats are already attached. The maximum entrance speed of 10 knots is not possible when tugboats are attached. This length of the entrance channel within the breakwaters becomes:

- \(L_1\): length for reduction of speed from 3.3 m/s (6 kn) to 2.2 m/s (4 kn): 420 [m];
- \(L_2\): length for tying up the tugboats: 0 [m] \((\text{outside the breakwaters})\);
- \(L_3\): length for reduction of speed to minimum required speed for turning: 645 [m].
The total length of the entrance channel within the breakwaters becomes 1064 m. From an operational perspective, this is a large reduction of the breakwater length. The length of the breakwaters is in this case not determined by operational aspects. Wave penetration in the port becomes the governing mechanism. In order to give a proper estimation of the breakwater length for this alternative, further research on waves and sediment transport is necessary.

**Conclusion**

As mentioned before, the two alternatives can only be applied if they are approved to be operationally safe. The reduction of the entrance channel length cannot be implemented without further research on this topic. Also the operational consequences of relocating the tying up location of the tugboats have to be investigated in more detail. In this stage of the project it is therefore not possible to implement the alternatives. In a more detailed design of the proposed layout, the two alternatives given above can be used to optimize the design in terms of safety and costs. This conceptual design is mostly based on the conservative but safe guidelines of PIANC.
5.8 Flexibility with Regard to the Future

The DDOP is designed for a lifetime of 50 years. The proposed layout takes possible changes in cargo demand predictions, availability of equipment and changes in boundary conditions into account. The design incorporates flexibility with regard to possible future changes. This section outlines the flexibility of port terminals. This is one of the beneficial aspects of the proposed layout.

Flexibility in port terminals is of vital importance. It makes it possible to adapt to changing economic conditions of the different commodities. The current DDOP layout contains 14 container berths designed for a throughput of 10,000,000 TEU per year. If for instance the container demand growth is higher than expected, the alternative of relocating the turning circle can be applied. If the throughput demand will be lower than expected, a smaller amount of berths and terminal area is necessary for containers. In that case, the 3 container berths at the southern side of the turning could change in car terminals. The car companies which are located at that side of the port can expand their storage area and use the berths to accommodate more vessels. Since both containers and cars make use of an open storage area, it is not that difficult to transform a container terminal to a car terminal. Furthermore, car carriers can use their ramp on the container terminal berth to load or unload without any obstruction. Only for the container cranes, vehicles and trains, a different location has to be found.
Chapter 6

Port Performance

In Chapter 5 the port layout is introduced. In this chapter the values of the governing aspects of the port are given in the figure below. After that, the values are summarised in Table 6.1.
In Table 6.1 the dimensions of the DDOP layout are given.

**Table 6.1: Summary of dimensions DDOP layout**

<table>
<thead>
<tr>
<th>Subject</th>
<th>value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quay length</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- North of turning circle</td>
<td>1890</td>
<td>m</td>
</tr>
<tr>
<td>- South of turning circle</td>
<td>870</td>
<td>m</td>
</tr>
<tr>
<td><strong>Container terminal north side</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- area</td>
<td>115</td>
<td>ha</td>
</tr>
<tr>
<td>- max length</td>
<td>2320</td>
<td>m</td>
</tr>
<tr>
<td>- max width</td>
<td>575</td>
<td>m</td>
</tr>
<tr>
<td><strong>Container terminal east side</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- area</td>
<td>90</td>
<td>ha</td>
</tr>
<tr>
<td>- max length</td>
<td>2234</td>
<td>m</td>
</tr>
<tr>
<td>- max width</td>
<td>436</td>
<td>m</td>
</tr>
<tr>
<td><strong>Container terminal south side</strong></td>
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<td></td>
</tr>
<tr>
<td>- area</td>
<td>32</td>
<td>ha</td>
</tr>
<tr>
<td><strong>Liquid bulk terminal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- area</td>
<td>18</td>
<td>ha</td>
</tr>
<tr>
<td><strong>Car terminal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- area</td>
<td>11</td>
<td>ha</td>
</tr>
<tr>
<td><strong>Basin</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- width</td>
<td>422</td>
<td>m</td>
</tr>
<tr>
<td>- depth</td>
<td>18.4</td>
<td>m</td>
</tr>
<tr>
<td><strong>Entrance channel</strong></td>
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<td></td>
</tr>
<tr>
<td>- length</td>
<td>2974</td>
<td>m</td>
</tr>
<tr>
<td>- inner width at bottom</td>
<td>273</td>
<td>m</td>
</tr>
<tr>
<td>- inner width at surface</td>
<td>385</td>
<td>m</td>
</tr>
<tr>
<td>- outer width at bottom</td>
<td>319</td>
<td>m</td>
</tr>
<tr>
<td>- outer width at surface</td>
<td>430</td>
<td>m</td>
</tr>
<tr>
<td>- depth</td>
<td>18.6</td>
<td>m</td>
</tr>
<tr>
<td>- assumed slope angle</td>
<td>1:3</td>
<td></td>
</tr>
<tr>
<td><strong>Length breakwater north</strong></td>
<td>1085</td>
<td>m</td>
</tr>
<tr>
<td><strong>Length breakwater south</strong></td>
<td>1885</td>
<td>m</td>
</tr>
<tr>
<td><strong>Turning circle diameter</strong></td>
<td>860</td>
<td>m</td>
</tr>
<tr>
<td><strong>Run-up safety zone width</strong></td>
<td>90</td>
<td>m</td>
</tr>
</tbody>
</table>
Chapter 7

Remarks and Recommendations

7.1 Uncertainties in the Design

In this report, the following uncertainties have to be kept in mind.

Design Method
During the research the guidelines of the Delft University of Technology lectures are mostly followed. Several times this method turned out to be contradictory to the Port of Durban (South African) methodology. For instance in the determination of the number of berths different results are found. Also in the estimation of the nautical area dimensions both methods are applied and compared. After argumentation, one of the two methodologies is followed. This however does not mean that this is always the right solution and it brings uncertainty into the designed layout.

Not only the methods are different, they also bring uncertainties themselves. There used approaches are sometimes rough estimates. Especially the estimation of the terminal areas and their related throughput per hectare value are very sensitive for changes of the parameters in the equation.

Economic Growth Scenario
The throughput numbers are based on an assumed container growth of 4.6% yearly, a liquid bulk growth of 4.4% yearly and a car growth of 2.6% yearly. These predictions are however uncertain. The economic growth could also be larger or smaller, which could require a different port layout.

Boundary Conditions
Not only is the economical input uncertain. The wave, wind and ground conditions are based on several assumptions. The port dimensions are based on an approximate input value. More detailed research into the boundary conditions could have an effect on the port layout. Especially the entrance channel dimensions are sensitive for changes in the wave and wind conditions.
Cost Considerations
It has to be reminded that the proposed DDOP layout is purely an engineering solution. The only cost consideration made is the location of the turning circle inlands, which make the construction of the breakwaters easier. In large scale projects the costs have large influence on the design. Further research into the costs could lead to a change in the port layout.

Liquid Bulk Terminal
In the design, an area of 18.3 ha is reserved for the liquid bulk terminal. This is determined by the available space next to the liquid bulk terminals. There are no standard guidelines to determine the necessary area for liquid bulk, since this depends fully on the type of liquid bulk and the final destination. It is possible that the liquids are transported directly by pipeline, as is the case in the current port of Durban. Further research into the terminal operator and the destination of the liquid bulk is necessary to determine the required liquid bulk terminal area.

7.2 Possibilities for Future Research

The following topics are recommended for further research.

Queuing System
The inter-arrival pattern of the vessels and the queuing mechanism for a port with 19 berths are relatively complex. Further research is recommended into the queuing system; this could support or decline the decision for a single-lane entrance channel.

Mangrove Dynamics
The proposed port layout initiates possibilities to create an interaction between the entrance channel and the mangroves. Since the estuary is in a bad state currently, this could help the recovery. More research is recommended into the dynamics of the Isipingo estuary.

Breakwater Length
As mentioned the length of the breakwaters is an topic for further research. There has to be decided if the breakwaters are used for operational aspects or only for the prevention of wave penetration. Also the structural design of the breakwaters is a topic for further research.

Erosion
Erosion along the Durban coast might impact the bluff considerably. The impact of the port construction on the coast is recommended for further research.
Wave Penetration
Wave penetration of the proposed port layout is something that requires further research. Some directions from the apparent waves along the Durban coast are able to enter through the breakwaters. More research is necessary to determine the navigability of the port and to estimate the downtime of the terminals as a result of the wave penetration. Especially the wave conditions at the liquid bulk terminal need special attention. The vessel safety zone at the end of the entrance channel can be optimised to both absorb wave energy and suit as run-up location for vessels.

Hinterland Connections
The layout has included basic road and rail dimensions. Further research is necessary to adjust the road dimensions to the throughput numbers and to the existing roads.

Terminal Design
The global areas required are estimated and included in the port layout design. These are based on rules of thumb and related to other ports. Research regarding the most efficient terminal layout is recommended. The research needs to include the opinions of the terminal operators.

Balance of Cut and Fill
To minimize the amount of subsoil that will be dumped into the ocean during construction of the DDOP, the principle of cut and fill should be investigated. The following might be worth investigating:

- Use the dugout sand as fill to equalize the ground of the different terminals. The interesting point in this research is determining the quality of the sand. Only high quality sand can be used as construction material.
- Use the dugout sand as fill for the inside of the southern breakwater. Due to the breakwater the sediment transport in this area is low. The sand could be useful to mediate the wave energy from the waves running up the breakwater.

Geotechnical investigation
TNPA carried out a geotechnical investigation for the DDOP area. This investigation included 80 boreholes and Cone Penetration Tests (CPT) and Standard Penetration Tests (SPT). Nevertheless, the amount of boreholes is small for the area of the project (720 ha). The subsoil plays an important part of the project since it concerns a dig-out port. Also a lot of ground retaining structures, like quay walls, need to be constructed. Therefore, extensive geotechnical investigation, including laboratory testing of samples should be done to get an accurate insight in the subsoil.

Liquid Bulk
To maximize efficiency with respect to the liquid bulk cargo, research can be conducted focussing on designing an additional turning circle close to the jetties of the liquid bulk. The main advantage is that the liquid bulk vessels do not have to sail to the turning circle in the port to only turn.
Bibliography


