MASTERPLAN FOR THE PORT OF FUJAIRAH EXPANSION PROJECT

Master thesis

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Delft, October 2007

Preface

This is the final report of the Msc. thesis for my study at Delft University Faculty of Civil Engineering and Geosciences. The project was carried out with Ingenieursbureau M.U.C. and under guidance of Prof. ir H. Ligteringen, ir F.A.M. Soons and ir. H.J.Verhagen.

In January 2006 M.U.C. was assigned to prepare tender documents for the civil and marine works of the expansion of the Port of Fujairah. Included in this assignment where the detailed technical designs of quay walls, coastal protection works and a liquid bulk jetty and the development of a new port layout.
Although there was a strong demand by the port authorities to finish the designs and tender documents, a clear masterplan which should guide the expansion project was not present yet. In fact no study on the subject of throughput and shipping expectations or throughput capacities was carried out.

The absence of a masterplan gave the opportunity for this thesis. During the preparation of this report, b.v. Ingenieursbureau M.U.C. focused on the preparation of tender documents and designs of quay walls and liquid bulk jetties whereas in my thesis attention was paid to planning aspects. Uncertainties such as the involvement of DP World for the container terminal, the required capacity of the liquid and dry bulk terminals or the realization of the Fujairah Land Reclamation Project have changed plans many times during the process. Finally the graduation project was uncoupled from the actual developments in Fujairah to be able to finalize the report.

The parts of the study on hydraulic subjects where carried out under guidance of Alkyon. The information on liquid bulk trade in Fujairah and oil terminals where gained with help from Capt. P. Nix, who has been terminal manager of the Vopak (VHFL) terminal in Fujairah for several years. The greater part of the information that was used to carry out this study was gathered during several visits to Fujairah. Further many (port) development projects in the area of Fujairah have been visited to be able to put together this report.

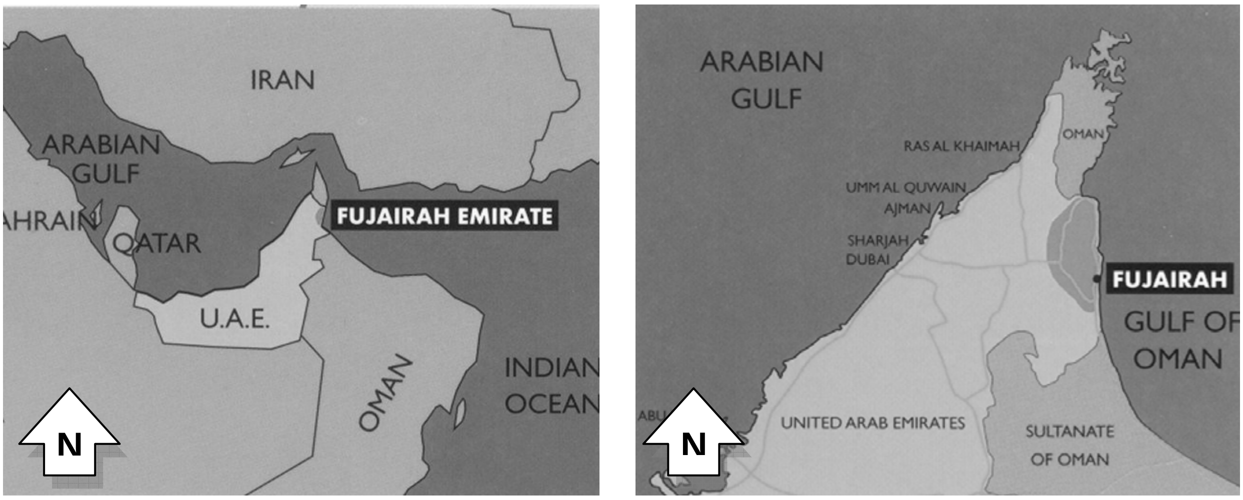
First of all I would like to thank my graduation committee for the guidance and advices during the project. Further I owe thanks to MUC for providing a good working environment, Alkyon for providing technical support, Paul Nix for the valuable information and my family and friends for their support.

Special thanks to Jan Udink and his family who made me feel welcome in Fujairah and made it possible to carry out this study in the first place.

Gert-Jan Roelevink
Delft, October 2007

Summary

The Port of Fujairah is situated on the Eastern coast of the UAE, approximately 70 nautical miles south from the Straits of Hormuz. The port mainly serves as a dry bulk export port and oil terminal. The export of aggregates is a the main activity in the port, together with the bunker trade. Other commodities are being handled in the port, though on a much smaller scale. Currently the port faces a capacity shortage.



Location of Fujairah

The market for aggregates in the Middle East is growing considerably due to rapid developments and expansion plans in this region. Fujairah as a main supplier of high quality aggregates wants to anticipate and increase its export. The aggregate ship loader of the Port of Fujairah however has reached its maximum capacity several years ago. The quay that was originally built for container handling is now being used to load bulk carriers with ship based cranes. Besides the inefficiency of this operation, the capacity of this solution has also grown to its limit. It is not possible to improve this operation by placing a new ship loader on the quay since it is leased out to Dubai Port including Container Handling facilities.
In addition to the expansion of the export capacity of dry bulk facilities, there are plans to build a new steel factory in Fujairah for which additional dry bulk unloading facilities are required. The raw material for this plant is planned to be brought in by ship. Vessels will be unloaded in the Port of Fujairah.

Besides dry bulk loading facilities, the Port of Fujairah currently offers liquid bulk loading and unloading facilities. These facilities are primarily being used for the loading and unloading of oil carriers that supply the oil storage of the Fujairah Refinery (FRCL). This refinery does not operate as a refinery but is only utilized as oil storage facility.
Although currently three oil terminal berths (OTB's) can satisfy the required capacity, the oil storage market is tending to grow rapidly. At the moment many single hull oil storage ships operate in the waters in front of Fujairah. Due to new international regulations that require a double hull for off shore oil storage, a great part of this off shore storage will be shifted to onshore. Several local oil storage firms have expressed their interest to increase their storage capacity and to build new oil storage tanks in Fujairah. The Port of Fujairah wants to anticipate and build the loading and unloading facilities for the ships that are to supply these new oil storage tanks. Besides oil, some growth in the demand for throughput capacity of chemicals is foreseen.

However the Port of Fujairah is not using their container loading facilities actively, Dubai Port that is current leasing the quay and cranes in the Port of Fujairah has expressed their desire to be able to unload bigger vessels and handle more containers. This is not possible with the current facilities. The Port of Fujairah intends to investigate the possibilities for the handling of large size container vessels.

For the above mentioned reasons, the local authorities of Fujairah are planning to expand the existing Port of Fujairah. The expansion should supply for the anticipated growth of the coming 25 years. The Port of Fujairah Authorities have invited B.V. Ingenieursbureau M.U.C. to carry out a masterplan study for this expansion project.

The objective of this study is twofold. The first objective is to find a favorable layout for the Expansion of the Port of Fujairah in which the port can expand its activities for the coming 25 years. The second objective is to propose technical designs for the civil and marine works of the expansion project. In fact this study covers the masterplan process including analysis, generation of layout alternatives, evaluation nd selection of these alternatives and preliminary engineering. Further evaluation of the most promising alternatives should be part of further study.
The Port Authorities have indicated that the emphasis is on realization of the first construction phase on the short term. This means that the proposed technical solutions for the civil and marine parts of the project will directly be used for startup of the first construction phase of the project.

The port expansion should be realized, preferably north of the existing port and south of the existing oil terminal that is run by VHFL. VHFL is a joint Venture between Vopak and Horizon Terminals Ltd. These spatial constraints will have an essential influence on the shape of the port expansion. South of the port there is space for developments. The authorities have indicated however that this location will preferably be used for other purposes.

Since it is extremely difficult to make a realistic forecast of the demand in throughput capacity, several throughput scenarios have been composed. For the greater part of the commodities in the port, throughput development depends on many unknown factors. Especially the regional demand for export products is hard to predict.
For these reasons, three scenarios of growth in demand for throughput capacity have been composed for each of the above mentioned commodities. These three scenarios represent low, medium and strong growth which all result in a number of layout requirements for the new port expansion.
To determine the requirements for the new port a basic simulation model was developed. The model is based on the Monte Carlo method which uses random numbers. The number of input variables makes it impossible to use the queuing theory.

Based on the spatial constraints and the requirements according to the composed scenarios, a number of layout alternatives have been proposed. A monetary evaluation as well as a multi criteria analysis finally resulted in the selection of a limited number of most promising layouts. Several layouts where not capable of supplying the required throughput capacity according the highest growth scenario. For a valid assessment, all layouts have been evaluated for each scenario separately.
For the marine and civil parts of the project, the quay walls, coastal protection works, liquid bulk terminal and dredging, several principle technical designs where proposed. The cost estimations that where used for the monetary evaluation where based on these designs. These designs are discussed in detail in the annexes to this document.

The final conclusion is that realization of the port expansion north and partly south of the existing port is necessary to reach the throughput capacity as described by the highest growth scenario.
The area south of the port was originally reserved for other developments. The available area, north of the existing port however does not provide enough space for a terminal that is capable of achieving the anticipated throughput. It is proposed to realize the container terminal south of the existing port and to handle other commodities at the preferred location, north of the existing port. An additional advantage is that the soil that is gained by dredging the harbour basin for the container terminal can be used for the Fujairah Land Reclamation Project. This project will be realized 1.5 km north of the existing port.
The masterplan is worked out to a level that it can be used for preparations of tender documents. This means that several subjects on the field of port planning have been described superficially and that other, more detailed technical parts of the expansions plan have been paid more attention to.

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List of abbreviations

CD	= Chart Datum
ECH	= Empty Container Handling truck
FHD	= Fujairah Harbour datum
HAT	= Highest Astronomical Tide
HWL	= High Water Level
IB	= Industrial Berth
LAT	= Lowest Astronomical Tide
MARPOL	= Marpol" is short for marine pollution
MCA	= Multi Criteria Analysis
MHHW	= Mean Higher High Water
MHLW	= Mean Higher Low Water
MLHW	= Mean Lower High Water
MLLW	= Mean Lower Low Water
MSL	= Mean Sea Level
NPV	= Net present value
OSTT	= Open Sea Tanker Terminal
OTB	= Oil Tanker Berth
P.o.F.	= Port of Fujairah
RTG	= Rubber Tired Gantry
TGS	= 20-foot container ground slots
SBB	= South Breakwater Berth
SPM	= Single Point Mooring (buoy)
STB	= Sea Tanker Berth
VHFL	= Vopak Horizon Fujairah Ltd.

1 Introduction

1.1 Introduction

1.1.1 Fujairah

Fujairah is one of the seven emirates of the United Arab Emirates. The United Arab Emirates has a highly industrialized economy that makes the country one of the most developed in the world. Fujairah is the only emirate that borders the UAE s east coast, overlooking the Gulf of Oman. Within its territory there are some coastal enclaves belonging to Sharjah (Khor Fakkan, Kalba and part of Dibba and some landlocked enclaves belonging to Oman (Madhab and part of Dibba). The area of the emirate is 1165 kms2, which is equivalent to 1.5% of the country s total area, excluding the islands. Fujairah has dramatic mountain scenery, which has been a major factor in its fast developing tourism trade. Fujairah s port, built in 1982, has been enlarged and sea road and sea air traffic expanded considerably. It is now the world s third largest tanker refueling and bunkering station.

1.1.2 The port of Fujairah

The Port of Fujairah is situated on the Eastern coast of the UAE, approximately 70 nautical miles south from the Straits of Hormuz. The port mainly serves as a dry bulk export port and oil terminal. The export of aggregates is the main activity in the port, together with the bunker trade. Other commodities are being handled in the port, though on a much smaller scale.

1.1.3 Problem definition

The market for aggregates in the Middle East is growing considerably due to rapid developments and expansion plans in this region. Fujairah as a main supplier of high quality aggregates wants to anticipate and increase its export. The aggregate ship loader of the Port of Fujairah however has reached its maximum capacity several years ago. The quay that was originally built for container handling is now being used to load bulk carriers with ship based cranes. Besides the inefficiency of this operation, the capacity of this solution has also grown to its limit. It is not possible to improve this operation by placing a new ship loader on the quay since it is leased out to Dubai Port including Container Handling facilities.
In addition to the expansion of the export capacity of dry bulk facilities, there are plans to build a new steel factory in Fujairah for which additional dry bulk unloading facilities are required. The raw material for this plant is planned to be brought in by ship. Vessels will be unloaded in the Port of Fujairah.
Besides dry bulk loading facilities, the Port of Fujairah currently offers liquid bulk loading and unloading facilities. These facilities are primarily being used for the loading and unloading of oil carriers that supply the oil storage of the Fujairah Refinery. This refinery does not operate as a refinery but is only utilized as oil storage facility.
Although currently three oil terminal berths can satisfy the required capacity, the oil storage market is tending to grow rapidly. At the moment many single hull oil storage ships operate in the waters in front of Fujairah. Due to new international regulations that require a double hull for off shore oil storage, a great part of this off shore storage will be shifted to onshore. Several local oil storage firms have expressed their interest to increase their storage capacity and to build new oil storage tanks in Fujairah. The Port of Fujairah wants to anticipate and build the loading and unloading facilities for the ships that are to supply these new oil storage tanks. Besides oil, some growth in the demand for throughput capacity of chemicals is foreseen.

However the Port of Fujairah is not using their container loading facilities actively, Dubai Port that is current leasing the quay and cranes in the Port of Fujairah has expressed their desire to be able to unload bigger vessels and handle more containers. This is not possible with the current facilities. The Port of Fujairah intends to investigate the possibilities for the handling of large size container vessels.
For the above mentioned reasons, the local authorities of Fujairah are planning to expand the existing Port of Fujairah. The expansion should supply for the anticipated growth of the coming 25 years. The Port of Fujairah Authorities have invited B.V. Ingenieursbureau M.U.C. to carry out a masterplan study for this expansion project. The port expansion should be realized, preferably north of the existing port and south of the existing oil terminal that lies 1.5 km north of the existing port.

1.2 Objective

The objective of this study is twofold. The first objective is to find a favorable layout for the Expansion of the Port of Fujairah in which the port can expand its activities for the coming 25 years. The second objective is to propose technical designs for the civil and marine works of the expansion project.

To achieve these goals, the following research objectives are formulated:

- Collect relevant economic, infrastructural, hydraulic and geotechnical information.
- Compose growth scenarios for different commodities.
- Calculate terminal dimensions and berth lengths to develop layout alternatives and selection of the most promising layout alternatives.
- Provide technical proposals for civil and marine works of the expansion project.

1.3 Scope of this study

The purpose of the masterplan is to have a blue print for future development, reserving space where it may need in the future, taking into account of regulatory, and creating an efficient and economic port operation. This Masterplan Study should take into account the existing port capacity, hinterland connections, industrial developments and environmental constraints.
This study covers several steps in the masterplan process. These steps include the analysis phase, the generation of layout alternatives, the evaluation and selection of these alternatives and preliminary engineering. Optimization of the most promising alternatives should be part of further study. This is further illustrated in graph 1.1
An economic analysis or separate study on cargo flow and shipping expectations did not go ahead of this study. This means that this subject lies within the scope of this study but is based on a large number of assumptions.
The environmental impact assessment of the port expansion, social impacts and safety aspects will only be discussed superficially in this study. Further, nautical, hydraulic and cost optimization of the most promising alternative will not be part of this study.
The Port Authorities have indicated that the emphasis is on realization of the first construction phase on the short term. This means that the proposed technical solutions for the civil and marine parts of the project will directly be used for startup of the first construction phase of the project.

Analysis	- Boundary conditions - Cargo flow/ shipping forecast - Principal dimensions - Spatial aspects	Part of this study
Generation of alternatives		
1st Evaluation	- Screening	
1st Selection	- Most promising alternative	
2nd Evaluation	- Preliminary engineering and conceptual plans	
Finalization	- Evaluation and selection - Hydraulic / nautical optimization - Detailed site investigations - Cost benefit analysis	Subject of further study

graph 1.1 Masterplan process

1.4 Backgrounds

B.V. Ingenieursbureau MUC caries out the masterplan study as assigned by H.H. Sheikh Saleh bin Mohammad Al Sharqi. This entails that the study is to be carried out, keeping in mind that the Port Expansion Project must serve the interests of the emirate of Fujairah as a whole.

1.5 Structure of this report

In this first chapter of this report, an introduction is given of the project and the main objectives and project limitations. The present situation of the Port of Fujairah is described in detail in chapter two. In this chapter an evaluation of the capacity and possibilities of the current port is made. In chapter three, the relevant environmental boundary conditions are described. These comprise data on wind, wave, currents and geotechnical conditions. The derivation of these boundary and the sources used to find them, can be found in Annex 1 to this report. With the information described in chapter two and three it is attempted to construct a thorough foundation for the study of further development of the port.

Based on expectations of the port of Fujairah several throughput scenarios are composed in chapter four. These scenarios are used to determine quay lengths and number of berths for the new port by execution of several simulations.

In chapter five, several layout alternatives for the new harbour basin as well as for the Open Sea Tanker Terminal and onshore areas are proposed. These layouts are evaluated using a monetary evaluation and multi criteria analysis in chapter six. The analysis will focus on throughput capacity, growth possibilities, cost and safety of navigation. For the estimation of cost of quay walls coastal protection, dredging and the OSTT, several principle designs are made in Annex 4 - Annex 7. The result of the evaluation is the selection of a number of most promising alternatives. The optimization of these layouts will be part of additional study.

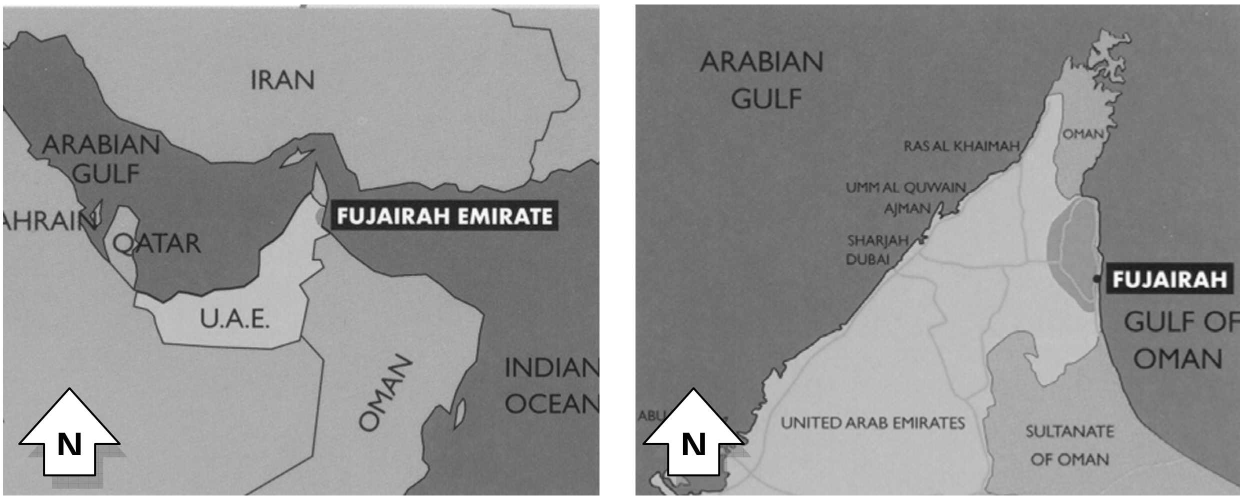
2 Port of Fujairah present situation

2.1 Introduction

In this chapter a description is given of the current Port of Fujairah. This comprises a rough description of the port regarding the water and land areas of the harbour. Subsequently the present commodities and throughput numbers are described in this chapter. Information for this chapter is gathered during several site visits and interviews with the Port of Fujairah port Authorities.
Further, several reports (among others; the yearly “Bulk loader and lift grab report” and “Statistical report”) made available by the Port of Fujairah have been used.

2.2 Description of the harbour

Fujairah Port is situated on the Eastern coast of the UAE, approximately 70 nautical miles south from the Straits of Hormuz. This strategic position has proved to be attractive to both a range of users of the multi-purpose port and for the significant numbers of vessels calling at the Fujairah Anchorage for Bunkers, Supplies and Service.
Fujairah was developed in the early 1980s to provide the Arab Emirates with a major container facility outside the straight of Hormuz. From this site it was possible to carry out containers by road into the rest of the UAE, should conditions in the Arabian Gulf become unstable. It has since developed as a container transshipment centre with APL as its major carrier. A land bridge system is operated to link it to the rest of the United Arab Emirates.
The other major Port activity is as a center for supply boats servicing ships waiting for orders offshore.
In the mild 1990s, a small refinery was built immediately to the North of the port, with its oil being handled from vessels lying to a pair of buoys at the north end of the harbour.



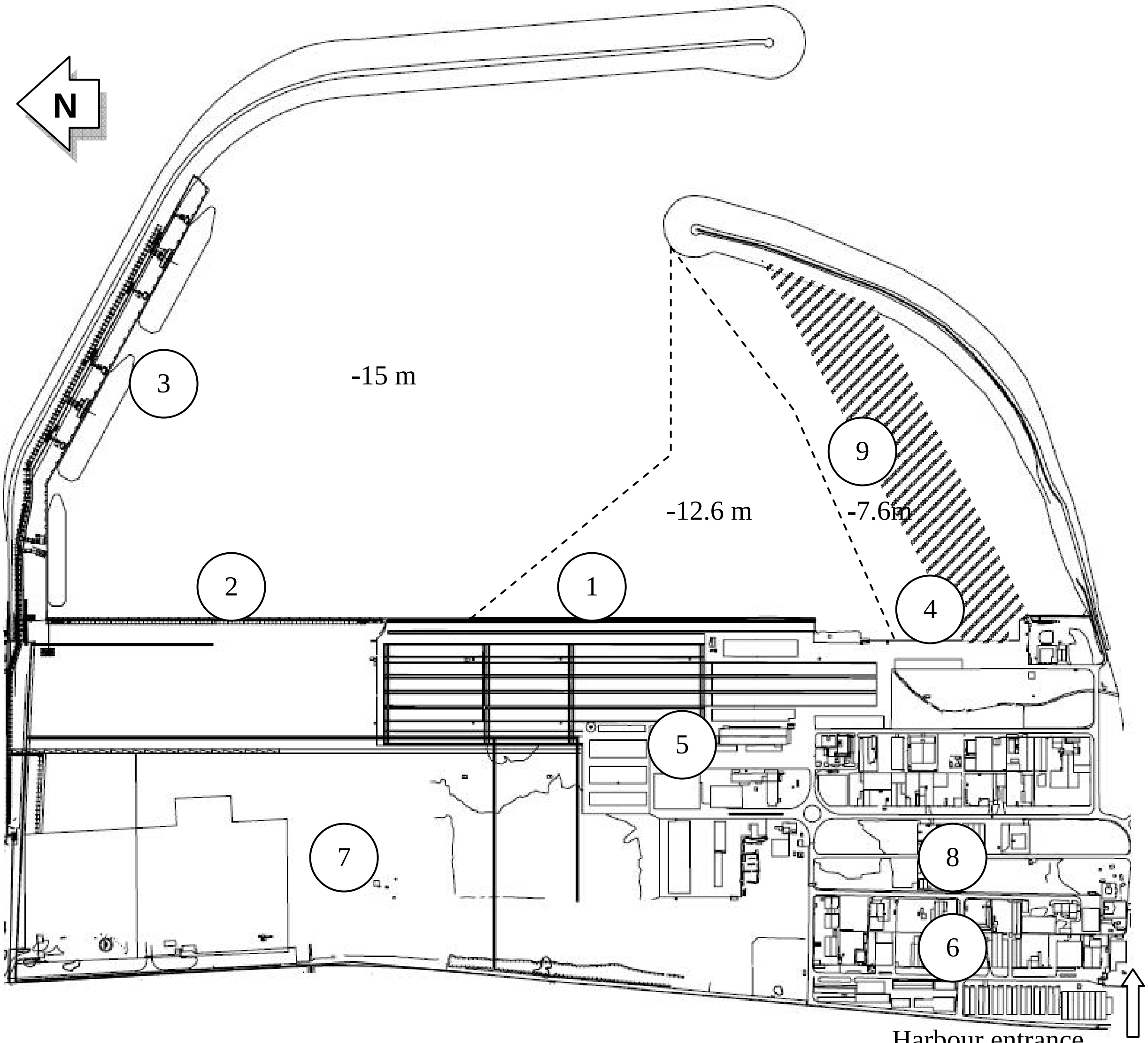
2.1 Location of Fujairah

The harbour is entirely artificial, being formed by a pair of rubble mound breakwaters, armoured on the outside with pre-cast concrete Dolos armour units and locally quarried rock. These breakwaters curve out from the shoreline and overlap so that the entrance faces South-southeast. This produces generally calm conditions in the port, particularly at the south end where a floating jetty is operated.

The original design of the breakwaters is based on a wave analysis performed on the basis of hind casting from local wind conditions. But wave recordings carried out during the construction of the port, demonstrated that the main wave action originated well out in the Gulf of Oman and that local wind had little effect. One result of this is that the design of the Fujairah breakwaters is conservative and they suffer no significant overtopping. The other result is that at certain times there is significant penetration of southerly waves into the harbour. Local reporting indicates that these events are rare and that the maximum local wave action near the root of the north breakwater has amplitude of less than one meter. The breakwaters are founded onto the original seabed and the area within the harbour basin was then dredged according to the requirements for each zone of the harbour. The soils are generally sandy becoming more cemented with depth until they can be classified as rock.
All berthing facilities of the PoF are quay walls, also for oil handling and aggregate loading. VHFL uses only open sea tanker facilities, no quays.

2.2 Port of Fujairah Nautical chart

As described in paragraph 2.4 the Port of Fujairah has been expanding during its existence. In these projects different quay wall solutions have been chosen. The main quay wall consists both of combi wall structures and of blockwork walls. The part of the quay on which container cranes operate is a combi wall; the part on which the aggregate ship loader operates is a blockwork wall. The OTB's and the South breakwater berth that is currently under construction are combi wall structures. The water depth in front of the quays differs and is shown in figure 2.3.



1: Container and aggregates berths
2: Aggregates Berths
3: Oil Tanker Berths
4: Service vessel berths
5: Port operation area
6: Free zone facilities
7: Development area
8: Commercial facilities
9: Development of South Breakwater Berths

2.3 Layout of the existing Port of Fujairah

2.3 Parties involved

2.3.1 Port of Fujairah.

The Port of Fujairah is the largest Multi Purpose Port on the Eastern Seaboard of the UAE. Its strategic position has proved attractive to both the range of users of the multi- purpose Port and the significant numbers of vessels calling at the Fujairah Anchorage for Bunkers, Supplies and Service. Fujairah along with Singapore and Rotterdam ranks as one of the top 3 Bunkering points in the World.

2.3.2 VHFL

North from the Port of Fujairah an oil terminal is run by Vopak in combination with Horizon Terminal Ltd. The Joint venture is called Vopak Horizon Fujairah Ltd. (VHFL). A wholly owned Enoc subsidiary. EBFL has also committed to contracting 1 of 2 bunker VHFL berths to improve facilities for customers. EBFL is a joint venture between ENOC, which holds 51-pc of the equity, the Fujairah Government, which has a 25-pc stake, the Kuwait's Independent Petroleum Group (IPG) with the remaining 24-pc. The joint venture provides offshore and inport marine products in Fujairah. Vopak (former companies Van Ommeren and Pakhoed) Vopak provides independent storage and handling of liquid oil products, chemicals, vegetable oils and liquefied gases.
This terminal operates independently from the Port of Fujairah. Only the marine operations are under control of the Port of Fujairah. VHFL offers storage facilities for different types of products to clients all over the world.

2.3.3 Fujairah Refinery Company Ltd.

The Refinery which is owned by Fujairah Refinery Company Ltd (FRCL), has two crude distillation units with a total of 82,000 barrels per day (bpd) of crude processing capacity. It is operated by Petrofac on behalf of its shareholders. Glencore and Texaco have processing agreements with FRCL. Currently the Refinery however is only utilized as storage facility.

2.3.4 D.P. World

DP World is one of the largest marine terminal operators in the world with 42 terminals spanning 22 countries. DP World is currently in control of the container handling facilities of the Port of Fujairah. The quay wall, cranes, stacking area as well as other equipment are leased out to D.P. World. The main reason of the take over of the Container Facilities by D.P. World is that Dubai Port wishes to have container handling facilities on the East Coast of the UAE in case problems arise in the straight of Hormuz. D.P. World wishes to increase the capacity of the container terminal dramatically and wants to be able to handle larger vessels in Fujairah. Not only to have these facilities as a backup, but also to actually use the Port of Fujairah for increasing their container throughput.

2.3.5 B.V. Ingenieursbureau M.U.C.

B.V. Ingenieursbureau M.U.C. was invited by the Port of Fujairah to carry out the masterplan study for the Port of Fujairah Expansion Project.

2.4 History

2.4.1 Port of Fujairah

Fujairah was developed in the early 1980s to provide the Arab Emirates with a major container facility outside the straight of Hormuz (figure 2.1). From this site it was possible to carry out containers by road into the rest of the UAE, should conditions in the Arabian Gulf become unstable. It has since developed as a container transshipment center with APL as its major carrier. A land bridge system is operated to link it to the rest of the United Arab Emirates. The other major Port activity is as a center for supply boats servicing ships waiting for orders offshore.
In the mild 1990s, a small refinery was built immediately to the North of the port, with its oil being handled from vessels lying to a pair of buoys at the north end of the harbour.

2.4.2 Dry bulk ship loader

In November 2002 the Port of Fujairah Bulk Loader became fully operational coinciding with the completion of an additional 600 meters of main quay dredged to 15 meters. The planning, building and commissioning of the Bulk Loader was based on the need to meet a sustained and growing demand for quality aggregate exports from the Emirate building projects in the Inner Gulf and beyond. Previously shipments were handled by vessels using their own gear and performing a load and grab operation from the quay.

2.4.3 Take over by Dubai Port

Since the Dubai Port has leased the Port of Fujairah container handling facilities for strategic reasons, container throughput has decreased. The emphasis is now on loading of aggregates and oil loading and unloading.

2.4.4 Vopak Horizon Fujairah Ltd.

In the nineties Vopak in combination with other parties (VHFL) opened an oil storage facility North of the Port of Fujairah. The mild wave climate made it possible to run this facility outside the harbour basin. The facility included a jetty with 2 berths and a single point mooring facility 2 kilometers from the coast for loading and unloading the ships that provide the material.
However the marine operations controlled by Port of Fujairah Marine Department, the terminal operation of this storage facility are not controlled by Port of Fujairah. In 2004 the construction two extra berths finalized (VHFL berth 3 and 4). Currently there are preparations being made to construct two additional berths.

2.4.5 Construction of Oil Terminal Berth

In 2006 the construction of an Oil Terminal Berth (OTB) inside the harbour basin was finalized. This OTB consists of a quay wall on which maximal five small ships or three medium sized ships can berth. The quay wall lies parallel to the northern breakwater of the existing port. The main function of this facility is to serve as load and unload facility for the Fujairah Refinery (FRCL)

2.4.6 Current construction works

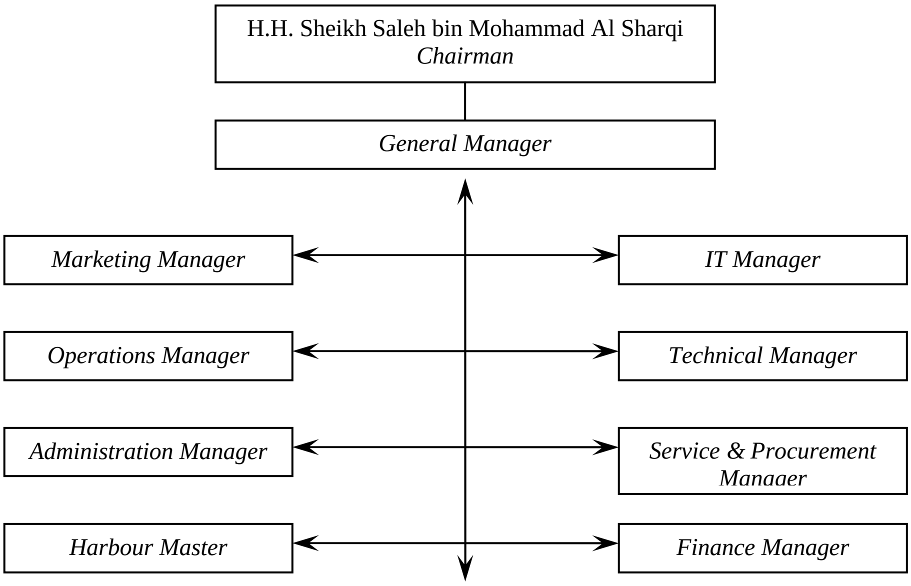
Currently a new quay wall is constructed inside the harbour basin attached to the southern breakwater. This quay wall, further mentioned as South Breakwater berth (SBB) is meant for handling of general cargo from smaller ships.

2.5 Port functions and organisation

2.5.1 Port operation

The port operates as a Landlord port. This means that the land of the port is owned by the Port Authorities and concessions are given to companies for provisions of cargo handling and storage services. The port authorities are responsible for the infrastructure, the nautical safety and access, including access channels and harbour basins. A more detailed description about port operations per commodity is given in the following paragraphs.

Chairman of the Port of Fujairah is His Highness Sheikh Saleh bin Mohammad Al Sharqi. The port is controlled by the general manager. The general manager has a staff of eight managers, each operating on a different area. Figure 2.4



2.4 Corporate profile Port of Fujairah

2.6 Water area

2.6.1 Port of Fujairah

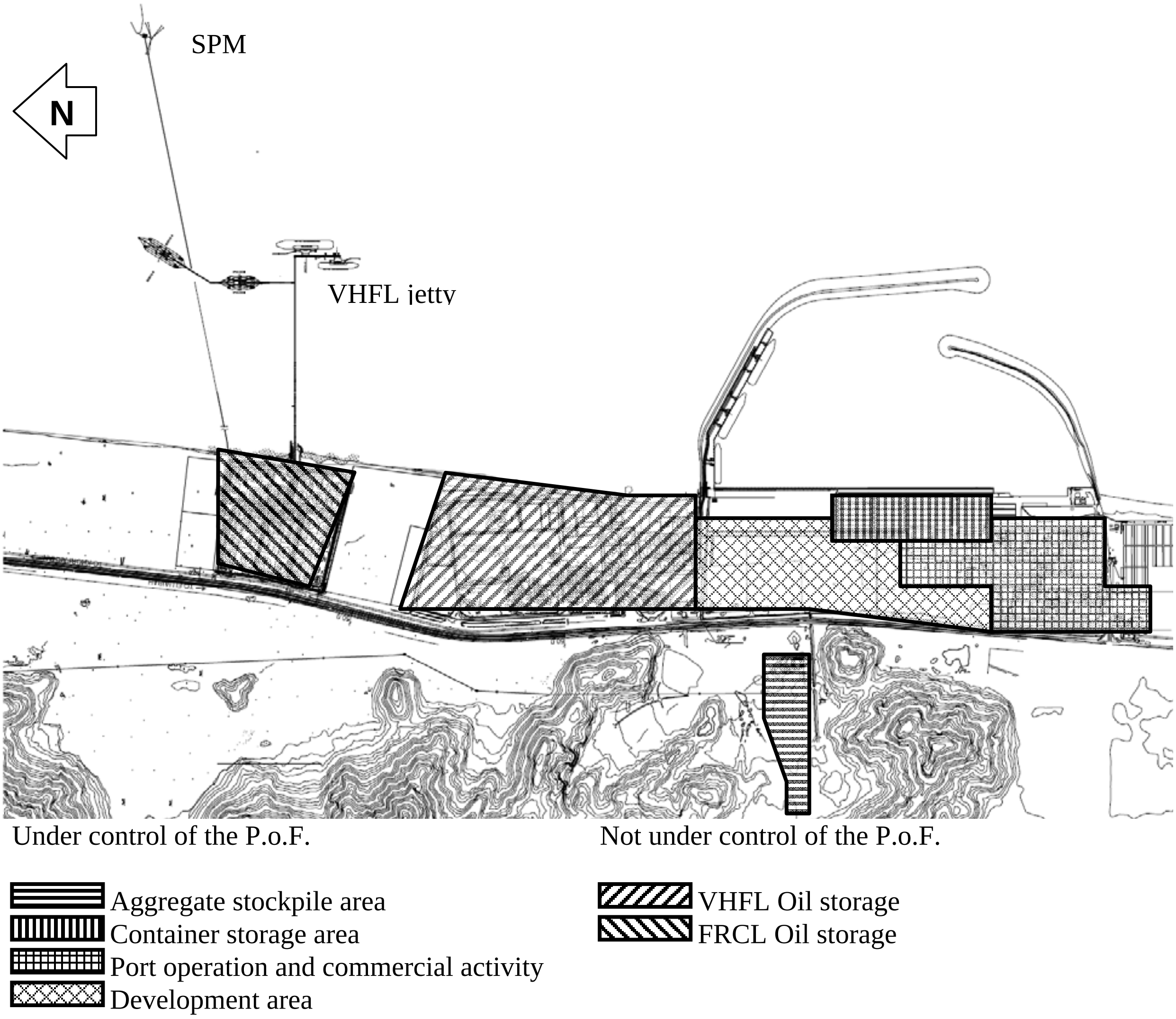
The area inside the harbour basin (shown in figure 2.3) is approximately 1.5 km in a north south direction and 1 km east west. The depth of the basin is CD -15 m in front of the Oil Terminal Berths, the aggregate berths and the container berths. The rest of the harbour basin has a depth of CD -12.6 m
The access channel has a depth of CD- 15 m. It is directed to the Southeast. The depth outside the harbour basin at the access of the harbour basin is 13 m. The slope of the sea bottom at this location is 1:100. This means that the access channel is short and the surface level difference between the original sea bottom and the access channel surface level is small. The width of the access channel between the breakwaters at the location of the harbour entrance is 230 m. This means that the access channel has one lane. There are currently no capacity problems regarding this restriction.
For approaching ships, the direction of the access channel is not the most favorable regarding wind and wave directions. However since the wave and wind climate in Fujairah is very mild

2.6.2 VHFL jetty

At the location of the VHFL jetty some dredging works haven taken place several years ago to bring the sea bottom in front of the largest berths at CD -18 m. There are no coastal structures in the vicinity of the jetty that hinder navigation around these berths. The coast in front of the VHFL terminal is a beach that dissipates wave energy.

2.7 Land area

The land area that is controlled by the Port of Fujairah has the same length in the North-West direction as the water area. The width of this area is approximately 500 m. Additionally to the area right behind the quay wall, there is an aggregate stockpile area Figure 2.5 shows the layout of the land area of the Port of Fujairah.



2.5 Current layout Port of Fujairah and land areas

The land area can be divided in 5 main areas. The use per area and the boundaries of these areas are shown in figure 2.5. Within the Port of Fujairah gates the three main areas are a container storage area, port operation area, container storage area and an area for commercial activity. The activities on these areas are further described in the following paragraphs.

2.8 Commodities

The main activity in the Port of Fujairah is currently the loading of aggregate ships and handling oil vessels. Besides for the OTB's inside the port, the marine services for the VHFL berths outside the port are controlled by the Port of Fujairah. The following number of vessels per commodity has called Fujairah port 2006:

Vessel type	Calls	Tonnage
Bulk cargo	353	14,685,443
Oil	1,719	27,631,004
General cargo	107	164,997
Container	111	-
Navy vessels	72	-
Other	61	-
Total	**2423**	

table 2.1 Number of calls and tonnage per commodity 2006

(Oil vessels include calls for EMARAT, GPS, VHFL and VSPM terminals)

It can be seen that general cargo, containers and other commodities form a minor part of the port throughput. However container throughput is decreased dramatically in the past years, the container handling facilities and quay wall are still a source of income for the Port of Fujairah since they are leased by Dubai Port.

2.9 Dry bulk

2.9.1 Dry bulk differentiation

Dry bulk cargo handled in the Port of Fujairah can be differentiated as shown in table 2.2:

Bulk cargo	Vessel calls	Tonnage
Aggregates (export)	313	14,029,746
Clinker (import)	20	307,968
Other bulk	20	347,729
Total	**353**	**14,685,443**

table 2.2 Calls and tonnage of bulk vessels differentiated for 2006

Aggregates form the largest quantity of dry bulk throughput in the Port of Fujairah. In fact the tonnage of exported aggregates forms 95.5 % of the total dry bulk throughput. The other material that form the resulting 5 % are Clinker (2%), Copper slag (0.8%), Coal (0.8%) and Cement (0.3%) and other (0.3%).

2.9.2 Aggregates

Aggregate

Construction aggregate, or simply, aggregate, is the broad category of basic materials used in construction, in this case crushed stone. Aggregates are a basic resource, necessary for any kind of modern construction. Aggregates are the basic input materials to concrete and asphalt. Additionally, aggregates are used as base materials under foundations and roads. Fujairah is one of the main producers of aggregates in the Middle East. The material is well known throughout the region for its high quality. Due to the developments and economic activities in the region, the demand for good quality aggregates is high. Aggregates from Fujairah are produced by blasting and crushing of rock material in several quarries in the area.

Currently, the aggregate loading facilities are not capable of offering the required capacity. The market for aggregates in the Middle East is growing considerably due to rapid developments and expansion plans in this region. Fujairah as a main supplier of high quality aggregates wants to anticipate and increase its export.

The aggregate ship loader of the Port of Fujairah however has reached its maximum capacity several years ago. Currently the quay that was originally built for container handling is now being used to load

bulk carriers with ship based cranes. Besides that this is an inefficient, time consuming operation, the capacity of the operation has grown to its limit. It is not possible to improve the operation by placing a new ship loader on this quay since the quay including Container Handling facilities is being rent by Dubai Port. Aggregates are loaded on berths 5 and berth 6 in the existing harbour. Berth 6 is strictly allocated for aggregate loading and berth 5 was originally arranged for container handling but is used now in case berth 6 is occupied.
The occupancy of the quay wall on which the aggregate ship loader is operating, has been very high during the last years. In 2006 the occupancy reached 90%. The occupancy of the berth on which aggregates are loaded using ship based cranes is lower. This is due to the fact that this berth is only being used when the ship loader is occupied.
Due to the shortage in export capacity, currently a great part of the material produced in Fujairah is transported by truck to Dubai. This causes a constant stream of trucks on the 140 km long main road between Fujairah and Dubai. Another large part of the material is loaded on a temporary ramp structure. South from the Port of Fujairah, an artificial peninsula for holiday residences is currently under construction. The reclamation works for this peninsula are expected to finalize in 2010. Until this moment the reclaimed land is used for loading of barges with aggregates and large rock. The material is brought in from the quarries by truck and stored on the peninsula. The temporary ramp structures are used by dumper trucks with which the barges are loaded. Since no large structures are required, this is a relatively cheap operation. However due to the water depth in front of the ramp structure, the size of the ship is limited. The advantage of the operation is that besides aggregates, also large rock can be handled, which is not possible with the ship loader. Almost all material that is loaded on the ramp structure is shipped to Qatar and projects in Raslaffen.

Quarries
There are about 60 quarries in Fujairah. Currently 19 of these quarries use the Fujairah harbour as export facility. The three main quarries that export aggregates through the Port of Fujairah are:

- Tiger Transport
- Arabian Est. Transport & Supply
- Fujairah Rock & Aggregate company

These quarries take charge of almost 60 % of the total aggregate export through the port of Fujairah. The operation of a quarry is a discontinue process. The production starts with the preparation of a part of rock to be blasted. After blasting the rock is brought to the crushers by large dumper trucks. In several steps the material is reduced in size. Some rocks have to be re-blasted when they do not fit in the crusher.

2.9.3 Transport of aggregates to the ships

Two main transport modes for transport of aggregates from the quarries to the exporting ships that are currently used can be differentiated are by conveyor belt and ship loader and by lift and grab operation. Loading by conveyor belt is a continue transport process between stockpile area and the ship. The lift and grab operation is a discontinue process.

Ship loader
The material is transported by truck from the quarries to the Port of Fujairah stacking area. The stacking area lies west from the Road to Khor Fakkan. At the place a part of the material is stored and from there transported to the quay by a ship loader - conveyor system. The major part of the material is transported to the conveyor loading point by truck as the vessel is laden. The aggregate ship loading system consists of a ship loader crane, and a conveyor belt from the stacking area to this ship loader crane. The loading of the aggregates is by this means, a continuous process. The ship loader crane is traveling on the quay wall to which the ship is berthed and is fed by the conveyor belt.

The Port of Fujairah owns both the stacking area and the ship loader. This stacking area has a total area of 368,000 m^3, which is put out to lease to quarries and stevedoring firms. The total length of this transport line is 5 km.

Lift and grab operation
The material is transported directly to the quay by truck and then loaded on the ship by ship born cranes. Loading of aggregates by ship born cranes is not desirable and only takes place when the ship loader is occupied by an other ship. Loading of ships by ship born cranes takes place, directly south of the ship loader berth on the container berths. This quay is actually put out to leas to Dubai Port but can be used when no container ships are calling.
This operation is carried out by the shipping companies themselves. For such an operation there may be up to 25 trucks used to bring the material from the stockpile areas of the quarries to the quay. These quarries are up to 20 km from the Port of Fujairah. There are up to four cranes that move the material on the ship. The operation of all these trucks and cranes makes this a labor-intensive operation.

2.9.4 Aggregate loading capacities

Capacity ship loader
The ship loader operation (conveyor belt and ship loader crane) allows the capability of loading 2,200 T.P.H maximal. The average capacity of the ship loader however is 1,700 T.P.H. During the last years from 2003, the throughput increased from 7.1 M ton yearly to 9.95 M ton yearly. In 2006 a berth occupancy of 90% was reached. The net time that the ship loader was operating in 2006 was 6570 hours. This means that the net loading rate during this year was 1515 ton per hour. It can be stated that 10 M ton per year is the maximum capacity that can be reached with this equipment and configuration.

Grab and lift operation
The capacity of the ship born cranes differs per ship and depends among other tings on the amount of cranes and the size and speed of these cranes on the receiving ship. Further the transport from the quarries to the ships plays an important role.
Regarding the available ship loader and grab and lift statistics, it can be seen that the average loading rate is 1025 ton per hour. Since 2004 the amount of material that is being loaded by ship born cranes has increased from 1.7 M ton to 5.3 M ton in 2006. It can be stated that also this type of operation has reached its limit.
The total capacity of both operations; ship loader and grab and lift operation is estimated to be maximal 16 M ton per year. However this capacity can theoretically be reached, it may not be an optimal situation since waiting times can get unacceptably high in this situation. By ship loader and by grab and lift operation, together the following aggregate throughput was reached in the last years.

- Total 2003: 7,102,872 ton
- Total 2004: 8,897,510 ton
- Total 2005: 11,803,505 ton
- Total 2006: 14,685,443 ton

The numbers in this paragraph show that the export of aggregates by ship is limited by the aggregate ship loading capacities of the Port of Fujairah. A great part of the produced amount of aggregates is currently exported by road. Extension of the port of Fujairah aggregate sea - export facilities is therefore desirable.

2.9.5 Vessels

In 2006 there where 313 vessels calling the Port of Fujairah for loading of aggregates. Given the fact that these ships where empty at arrival, this means that the average cargo tonnage of these ships was 49 K ton

The average time that a vessel stays in the port differs for the different loading operations. Loading by ship loader is quicker than by ship born cranes. Loading these ships takes place with a First Come First Served (FCFS).system. The cargo tonnage of ships calling the Port of Fujairah for loading of aggregates in 2004, 2005 and 2006 was:

Year	**10 – 20 K**	**20 – 30 K**	**30 – 40 K**	**40 – 50 K**	**50 – 60 K**	**60 – 70 K**	**Total**
2004	26	29	26	57	85	44	267
2005	26	29	26	50	59	23	213
2006							313

table 2.3 Cargo tonnage of aggregate ships calling the Port of Fujairah

2.9.6 Destination of the material

The material exported though the Port of Fujairah is mainly shipped to the following places:

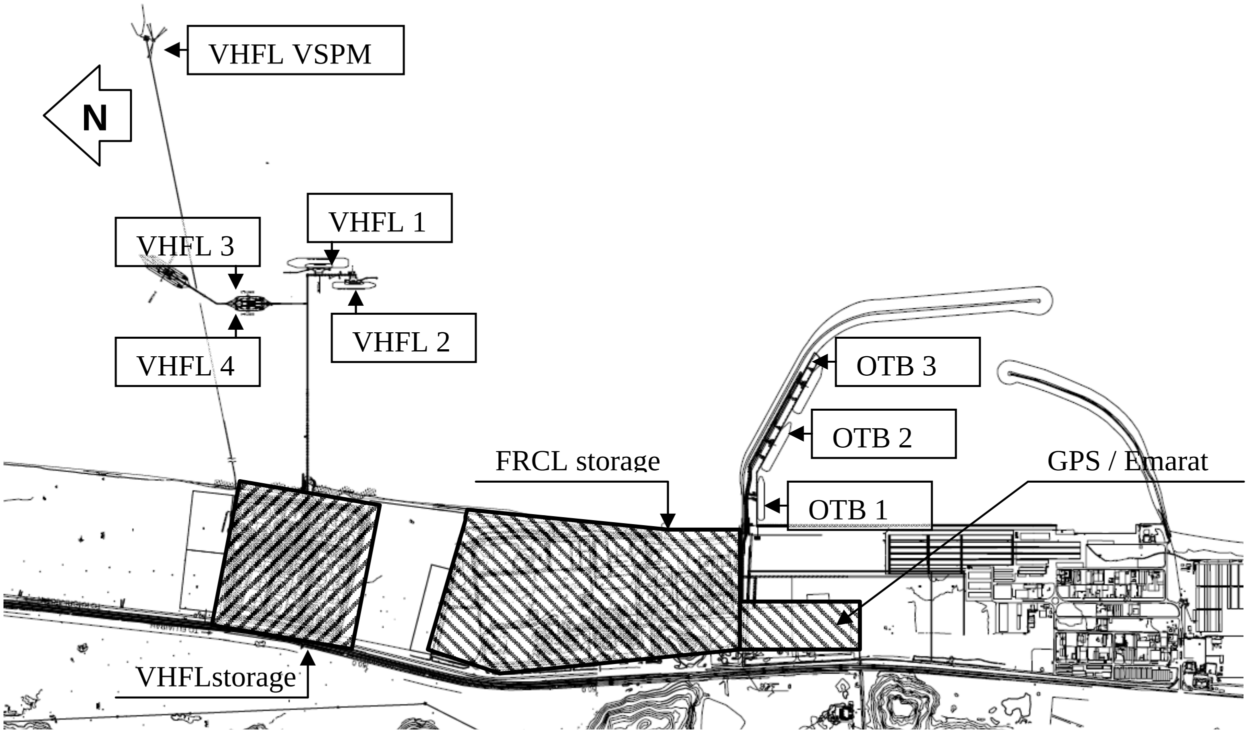
- Qatar (59%)
- Kuwait (37%)
- Bahrain (4 %)

A large part of the material produced in Fujairah is transported to Dubai and Abu Dhabi. As mentioned, this material is mainly transported by road. Additional to the amount of material to Qatar, is the material that is handled on the temporary ramp structures, South of the Port of Fujairah.

2.10 Liquid bulk

Fujairah does not have known significant oil reserves; no oil is produced in Fujairah. The oil handling facilities only supply for the loading and unloading of ships that fill and empty storage tanks. These storage tanks are mostly used for speculative storage of oil (further explained in next paragraph). The materials that are stored in Fujairah are mainly crude oil and petrol’s. No oils for consumption are handled or stored.
There are two main facilities for oil handling in Fujairah.

- Oil Terminal Berths (OTB’s), 3 berths in the harbour basin of the Port of Fujairah
- The independently operating VHFL terminal outside the harbour basin, four berths and one SPM.



2.6 Oil handling and storage facilities Fujairah

2.10.2 Liquid bulk loading and unloading facilities

As mentioned there are two main unloading facilities. The OTB's inside the harbour basin formerly where jetties. In 2006 however the construction of the OTB quay wall was finalized. Following the curve of the breakwater, there is a bend in this quay wall. The OTB's 2 and 3 can both handle one medium sized ship or two smaller ships at the same time. This is made possible by placing four 16" loading arms as well as two times two 12" inch loading arms.
The total length of the OTB quay wall is 840 m (OTB1 = 240 m, OTB2 and OTB3 each 300 m). There are totally 8 sets of loading arms (total 20 loading arms) on this quay wall. OTB 1 is dedicated to the FRCL refinery. There are 2 sets of loading arms (total 4 loadings arms, two black and two white) Each loading arm is 12". OTB2 and OTB3 both have 2 sets of 2 loading arms each 12" (two black and two white) for 2 small vessels (20,000 – 25,000 DWT). Besides these small loading arms, there are 4 loadings arms, each 16" (two black and two white) for 1 larger vessel (240 – 250 m, 70,000 DWT).

VHFL is a joint-venture between the government of Fujairah (share 20%), the ENOC-subsidiary Horizon Terminals (30%), Vitol (10%), the Independent Petroleum Group IPG from Kuwait (10%) and Koninklijke Vopak N.V., having a share of 30% and is responsible for all operational tasks and the terminal management.
VHFL initially began in 1998 in Fujairah with a storage capacity of 500.000 m^3 and two jetties with a capacity of respectively 150.000 DWT and 60,000 DWT. Since then the storage capacity is expanded up to 1,1 million m^3 and a SPM load and unload facility was installed on which ships up to 175.000 DWT can berth. It is proven that this SPM operates efficiently but maintenance costs are fairly high.
Currently VHFL has four berths on two finger piers. There are plans to build an extra finger pier directed to the north, attached to the most sea ward finger.

In table 2.4 the amount of handled material is given.

Oil berth	Unload (ton)	Load (ton)
OTB1 - FRCL 1	1,344,518	1,295,866
OTB1 - FRCL 2	312,468	453,688
OTB 2	907,820	1,705,310
OTB 3	2,052,914	1,211,656
OTB Total	**4,617,720**	**4,66,520**
VHFL 1	3,439,564	3,312,263
VHFL 2	1,757,704	2,916,733
VHFL 3	238,458	1,109,937
VHFL 4	60,581	1,467,589
VHFL SPM	3,154,884	2,032,342
VHFL total	**8,651,190**	**10,838,863**
TOTAL	**13,268,910**	**15,505,383**

table 2.4 Calls and tonnage of loading and unloading of liquid bulk vessels per terminal for 2006.

It can be seen that currently the greatest part of the tonnage vessel loading and unloading (65 %) takes place at the VHFL berths. In the beginning of 2006, the OTB's where not fully operational. This is partly the reason that throughput for these berths was lower in this year. It is expected that in 2007 the OTB will draw near the numbers that VHFL reaches with their facilities.
The berth occupancies for the OTB's and the VHFL berths are given in table 2.5.

Berth	hours	% utilization
OTB1	231	2.64 %
OTB2	4148	47.35 %
OTB3	4643	53.00 %
VHFL 1	7108	81.14 %
VHFL 2	6986	79.75 %
VHFL 3	4461	50.92 %
VHFL 4	3484	39.77 %
VHFL VSPM	4441	50.70 %

table 2.5 Berth occupancy liquid bulk berths Port of Fujairah and VHFL

It can be seen that VHFL reaches higher occupancy rates than the Port of Fujairah. This can partly be explained by the fact that Vopak operates on a global level and therefore attracts customers all over the world and can offer services all over the world. An other reason is the fact that there is a direct link between the storage facility and the jetty. The Port of Fujairah only offers the service of the oil handling facility and does not operate any storage facility.
Due to the high occupancy rates, anchorage waiting times tend to grow unacceptably high at the VHFL jetty. For this reason a new finger pier will be build. At the completion of this facility, occupancy rates will probably decrease. Currently there is no pipeline between the Port of Fujairah and the VHFL terminal. This means that the Port of Fujairah can not cooperate with VHFL in case of occupied berths at the jetty.
The material is transported thru pipes by pumping. Material from ship to shore is moved by ship based pumps. Material from shore to ship is moved by ships at the terminal. Ship based pump capacities vary per ship. On average their capacity makes it possible to pump min 200 ton/hr and max 2000 ton/hr. But this rate also depends on factors like material properties, and pipe dimensions. The port of Fujairah does not run pumps. Oil to the ships is moved by pumps located at the storage facilities. In fact the Port of Fujairah only operates as an interface between terminal and ship taking care only for the marine operations. The customers pay for the use of loading arms and other quay facilities and marine facilities.
The Port of Fujairah itself has no storage facilities. Their only role in this market is to provide for the load and unloading facilities for onshore storage companies. When these facilities are used by shipping or storage agencies a certain user rate per ton transported oil must be paid to the Port of Fujairah. Besides

this, the Port of Fujairah provides for the marine services. Although the direct benefits for the Port of Fujairah itself are not very large, there are secondary profits for the Government of Fujairah.

2.10.3 Liquid bulk storage facilities

Oil storage takes place for the following reasons.

For speculative reasons
Oil is purchased at moments that oil prices are relatively low, stored in tanks and sold when the price of the product is higher. In Fujairah a large part of the storage capacity is used for speculative storage. The oil stays in the tank for up to 3 months. This is a relatively long period which means that berth occupancy is low.

For break of bulk and make of bulk
Break of bulk is the distribution of oil from one large vessel over multiple smaller ships. Make of bulk is the reverse process. Sometimes the material is pumped directly from the bigger vessel to the smaller vessels. Since the operation rates of the large ships are very high it is however cheaper to quickly unload the vessel and store the oil temporary. The smaller vessels are filled from the tanks. The same holds for make of bulk. The berth occupancy for this kind of storage is high.

Storage for the bunker market
A significant fraction of the storage and oil handling facility in Fujairah is used for bunkering. (Bunker fuel is any type of fuel oil used on board of ships). This is due to the strategic position of the Port of Fujairah outside the straight of Hormuz. Daily insurance rates increase when this strait is crossed since the Arabian Gulf remains a high risk area. For this reason ships repair and bunkering is done outside the Arabian Gulf. Bunkering requires high berth occupancy per storage volume.
The size of the Fujairah bunker market is approximately 10 million tonnes per year including Khor Fakkan and the smaller, less known Kalba. Fujairah bunker market is characterized by small margins and high volumes. Although this is not common practice, there are only a few players in the market. Enoc Bunkering Fujairah Ltd (EBFL) and FAL Energy control approximately 85% of the market, with the remaining 15% shared among few local players. (Akron, FNBC and Aegean). EBFL & FAL have moved their bunker storage ashore recently to Fujairah Refinery and VHFL tanks respectively. It is expected that environmental regulations will eventually force offshore storage to shift to storage onshore. The UAE authorities enforced legislation demanding that vessels older than 25 years will no longer get an extension of their navigation license, and thus become unsuitable for floating storage.

For blending
Products with a relatively low quality are blended with material having a relatively high quality. The low quality material that is usually cheaper can be improved in this way so that finally the material requirements are reached. Since the material stays in the tanks for a short period the berth occupancy is high for blending. Blending takes place in the VHFL terminal. The main sources of supply for this business are the refiners in Arabian Gulf (Saudi Arabia, Iran, Iraq and Kuwait). It is expected that the supply is decreasing (especially from Saudi Arabia and Kuwait) due to the increasing cracking capacity and increasing demand of these countries. Given the diversity of grades coming out of the refineries in the region there is a strong demand for blending and accumulation of cargoes.

Industrial process
The Fujairah refinery (FRCL storage, see figure 2.6) does not operate as refinery but merely as an oil storage facility. If it is decided to start any industrial process, storage capacity is required to store the crude oil as well as the refined product.
It is not foreseen that the existing refinery will restart operating as a refinery but there are plans

For strategic reasons

Strategic storage which mostly takes place under governmental control is the storage of oil for tactical purposes. When there are anticipated threats for the oil supply of a country or as a buffer in the oil reserves. Strategic storage requires high storage volumes. The oil is stored for a long period, up to five years. This means that the required load and unload capacity at the berths is low. This type of storage currently is rare in Fujairah. VHFL has indicated that they have turned down a number of requests for long term storage due to capacity shortage. This means that there is a demand for this kind of storage. If there are plans to strategically store oil in Fujairah, the required extra capacity on the jetty will be relatively small.

There are four main storage facilities in Fujairah. The total storage volumes is $2.04 \cdot 10^6$ m^3.

- FRCL $0.42 \cdot 10^6$ m^3
- VHFL: $1.12 \cdot 10^6$ m^3
- Emarat and GPS $0.5 \cdot 10^6$ m

The locations of these terminals are shown on figure 2.6. All these tanker companies only store crude oil and petroliums. No oils for consumption are stored.

2.11 Container handling

2.11.1 Evaluation of Fujairah container terminal

Container handling was one of the major activities of the port of Fujairah shortly after construction of the port. Nowadays the container handling facilities and the quay that was originally allocated for container handling is been leased out to Dubai Port. However this particular part of the Port of Fujairah is leased out, it is still being used. The container throughput however has dramatically decreased. Container throughput is low nowadays but Dubai Port still recognizes the value of the Port of Fujairah and its location outside the street of Hormuz. In January 2005, DPI signed agreements with the port authorities of Abu Dhabi and Fujairah Port, which paved the way for greater cooperation in the UAE's container terminal operations, giving consistent and equal service levels for customers.

2.11.2 Throughput

The container terminal has a quay length of 1,330m and a depth: 11.5-15m. On this quay 6 Panamax gantry cranes (40 ft) operate. The total area behind the quay wall is 200,000 m2 in concession agreement including space used for workshop, shed and offices etc. 7,500 TGS (20' Ground slots) under RTG's (Rubber Tired Gantries) plus approx 500 TGS in block stacks for Empties using ECH's (Empty Container Handling truck). Currently the port uses 11 RTG's (1 over 3) handling 35ft – 40ft containers.
The capacity of the Port of Fujairah container terminal is approx 1.6 million TEU. In 2005 the throughput was 65,700 TEU (4% of the total capacity).

2.12 Other port functions

2.12.1 General cargo

The Port handles a significant proportion of the Steel Billets, Steel Bars, Copper Concentrate, Chrome Ore, Iron Ore, Coal, Bagged Aluminum Hydroxide and Industrial Salt, which moves to and from the UAE , GCC countries and beyond. A major proportion of the Project cargo associated with the UAE Federal Qidfa Desalination plant Facility, including the water and Gas Pipeline was handled through the

Port of Fujairah. The Port of Fujairah has a paved storage area of half a million square meters which can accommodate general and project cargo.

2.12.2 Ro-ro

Car carriers and Ro-Ro vessels equipped with quarter ramp can be handled. The container storage yard is currently also used for storage of cars after arrivals of Ro-Ro vessels.

2.13 Income and expenses

Financial benefits for the Port of Fujairah are categorized in rates for load and unload operations and rates for marine services. Additional to these two sources of income, users of the aggregates stockpile area, west of the Port, pay a renting rate for the stockpile surface that is leased. Operation rates are charged per ton for bulk and general cargo. For containers no operation rates are charged by the Port of Fujairah. The container quay wall, cranes and other facilities are leased out to Dubai Port so operation charges are raised by that party. For operations on the VHFL jetty also only charges are raised for marine services.
The current operation rates (2007) for the various commodities are given in table 2.6:

Commodity	Marine rate [Dh/hr]	Operation Rate	
Container vessel, mother	25,000	0	Dh/TEU
Container vessel, feeder	12,000	0	Dh/TEU
General cargo	15,000	16	Dh/ton
Navy vessel	30,000	20	Dh/ton
Bulk cargo vessels (other than aggregates)	15,000	4	Dh/ton
RoRo Vessels	15,000	400	Dh/vhcl
Aggregate vessels by conveyor	18,000	3.8	Dh/ton
Aggregate vessel by Lift and Grab	20,000	4.25	Dh/ton
Oil vessels, OTB	10,000	1	Dh/ton
Oil vessels, VHFL	16,000	0	Dh/ton

table 2.6 Marine and operation rates Port of Fujairah

The stockpile area that is leased out has a total surface of 368,000 m^2. The rental rate is 5 Dh/m^2 per year. Recent years the stockpile area was fully occupied. A part of this rate (2 Dh) is paid as a royalty to the Government of Fujairah which means that 3 Dh is income for the Port of Fujairah.

2.14 Surrounding ports

2.14.1 Khor Fakkan and Port Khalid(Sharjah)

Several kilometers north of the Port of Fujairah, in the emirate Sharjah also outside the strait of Hormuz, operates Khor Fakkan Container Terminal (KCT). KCT is a direct competitor on this market for Fujairah and is merely a container port on which no other commodities are handled. The management and operation of KCT is taken over by Gulftainer. Gulftainer has the exclusive handling containers on KCT as well as on Sharjah Container Terminal in Port Khalid (600 m quay). Since Gulftainer has taken over this function, the throughput has increased dramatically. In 2006, KCT and SCT handled 2.01m TEU, slightly lower than in 2005, owing to the break-up of the Supergalax consortium. However, Gulftainer expects growth to top 10% this year.
Gulftainer Company Limited was established in 1976 in the Emirate of Sharjah in the UAE. The company's prime role is to manage and operate the container terminals in Port Khalid and also

Khorfakkan on behalf of Sharjah Port Authority. Khor Fakkan has a 1,460 meter long quay having a 16 meter draft alongside. Containers are handled by fourteen ship to shore gantries.

2.14.2 Jebel Ali

Jebel Ali is located 35 km southwest of the city of Dubai. Jebel Ali is the home port of DP World with which the Port of Fujairah is to cooperate. The port was constructed in the 1970's. With 67 berths, Jebel Ali is the biggest port in the Middle East. Jebel Ali is operated by Dubai Port (DP World). DP World is a company owned by the government of Dubai. DP World has taken delivery of 14 mega gantry cranes, installed at the Jebel Ali container terminal in 2005 and an additional 6 in 2006, bringing the total to 45. These gantries are able to lift two 40 foot or four 20 foot containers simultaneously. In 2006 the total throughput was 8.9 million TEU. DP world aspires to increase the container transport through the port of Fujairah to Dubai.

2.15 Relation with other projects

Although this study primarily focuses on the Port of Fujairah expansion project, several other developments in the Fujairah region will be discussed in this report. For some of these projects, there is a direct interaction with the expansion of the Port of Fujairah.

2.15.1 Fujairah Land Reclamation Project

North of the proposed location for the expansion plans reclamation of a strip of land is proposed. This Reclamation Project is initiated to anticipate on the foreseen growth in the demand for oil storage capacity in Fujairah. This growth is described in paragraph 4.4.3 of this report. The feasibility study for the reclamation project is not carried out by order of the Port of Fujairah Authorities but for the Municipality of Fujairah Some choices made in this study depend on the development of this project. Especially the required soil for the reclamation project affects the choice for the preferred layout of the Port expansion. B.v. Ingenieursbureau M.U.C. is involved in this project as technical consultant for the Municipality of Fujairah

2.15.2 Railway Dubai -Fujairah

DP world is planning to construct a railway between Dubai and Fujairah. This railway is planned to be executed simultaneously to the expansion of container handling facilities in Fujairah and Khor Fakkan and will mainly be used for container transport. BV. Ingenieursbureau is not involved in the development of this transport line.

2.15.3 Road Fujairah - Khor Fakkan construction works

The road between Fujairah and Khor Fakkan is currently under construction. The number of lanes is expanded to four and its alignment is changed to give room for industrial development on the onshore part of the reclamation project location.

2.15.4 Expansion of the VHFL jetty

VHFL anticipates on the growth in the demand for oil storage capacity in this region as well. VHFL is currently expanding their storage capacity as well as the throughput capacity of their jetty.

2.15.5 Peninsula holiday resort project

South of the Port of Fujairah an artificial peninsula is under construction. The final destination for this peninsula will be for holiday residences. It will take several years until it will be completed to serve this purpose. Until this time it is used for the loading of dry bulk barges. These barges are currently loaded here at high rate and for extremely low cost.

2.16 The Hinterland of Fujairah

The only Hinterland transport mode from and to the Port of Fujairah is road transport. There is no inland waterways transport system in the UAE and, however there are construction plans, there is currently no railway system.

Fujairah lies three hours or less from the UAE’s main centers of population, Dubai, Sharjah and Abu Dhabi. Fujairah currently mainly operates as a bunker port and as a port where material is loaded produced in the vicinity of Fujairah. Therefore, the main over land transport stream to the harbour is aggregate trucks. These trucks come from the quarries in the Fujairah region, all less than 30 km from the port.

There are two main roads between Fujairah and Sharjah, Dubai and Abu Dhabi. These four lane motorways are currently intensively used by trucks transporting rock from Fujairah to Dubai. The road between Fujairah and Khor Fakkan is currently being reconstructed into a four lane motorway.

3 Hydraulic and geotechnical boundary conditions

3.1 General

In this section the site conditions that are relevant for the design of elements of the new northern Port of Fujairah extension, are briefly described. A more profound description of the environmental and hydraulic boundary conditions is given in Annex 1. This annex also evaluates the different sources and recordings that where analyzed to come to this summary.
All variables have units according to the international SI conventions. Wave and wind directions refer to the direction from which the waves and winds are coming. The direction is given in degrees, measured clockwise with respect to North.

3.2 Environmental conditions

3.2.1 Wind

Winds in Fujairah are fairly light. Wind speeds of 8 m/s are not exceeded 90 % of the time but strong winds from the west do occur. These winds are described as Katabatic winds by the Port Authorities. It is expected that these north-westerly winds are caused by the “Shamal” weather system.

Wind speed (m/s)	Percentage of occurrence (%)
< 2.0	14.6
< 4.0	52.8
< 6.0	78.7
< 8.0	88.0
< 10.0	93.5
< 12.0	96.9
< 14.0	98.5

table 3.1 Omnidirectional wind speeds according to records made at the VHFL-jetty.

With a return period of 100 years, wind speeds of 34 m/s can be reached. These winds most likely come from the Northwest.

3.2.2 Temperature

Fujairah has a tropical climate with a daily average temperature of 34.2°C in summer and 17.8°C in winter. Temperatures vary between 12.1°C and 24.5°C in winter and between 27.6°C and 42.3°C in summer.

3.2.3 Visibility

Visibility at Fujairah is generally good but during strong offshore winds, there can be problems with dust. Visibility is still possible over a hundred meters, allowing berthing using modern navigation aids.

3.2.4 Water levels

Extreme High Water		FHD + 3.14 m
Highest Astronomical tide	HAT	FHD + 2.8 m
Mean Higher High Water	MHHW	FHD + 2.6 m
Mean Lower High Water	MLHW	FHD + 2.3 m
Mean Sea Level	MSL	FHD + 1.7 m
Mean High Lower Water	MHLW	FHD + 1.4 m
Mean Lower Low Water	MLLW	FHD + 0.2 m
Lowest Astronomical tide	LAT	FHD - 0.1 m

table 3.2 Water levels

Water levels are indicated according to Fujairah Harbour Datum (C.D.).
Fujairah Harbour Datum = Admiralty Datum – 0.1 m

3.2.5 Sea water density and temperature

The seawater at Fujairah has a density 1024.2 kg/m^3. This value has been determined by sample analysis. Seawater temperatures vary between 22° C and 24° C in winter and between 30° C and 33° C in summer.

3.3 Currents

Current velocities at the location of the proposed Port expansion are relatively low, not exceeding 0.2 m/s most of the time. Currents are aligned parallel to the coast, mainly directed to the North but currents directed to the South do occur a few hours per day during low water and in July, during the Monsoon period.
At the location of the VHFL-jetty, current speeds and directions where measured hourly for several years. These measurements show a north-easterly directed current with velocities that are relatively low and do not exceed 0.54 m/s, 90 %.

Current velocity (m)	Percentage of occurrence (%)
< 0.05	0.03
< 0.10	0.08
< 0.15	0.20
< 0.20	0.31
< 0.25	0.47
< 0.30	0.74
< 0.35	1.71
< 0.40	5.67
< 0.45	20.59
< 0.50	54.04
< 0.55	93.31

table 3.3 Current velocities according to measurements made at the VHFL-jetty..

Alkyon Hydraulic Research and Consultancy has carried out a numerical modelling study to estimate flow velocities for the waters in front of Fujairah. According to this study the flow velocity is in the order of 3 to 10 cm/s, depending on the location (nearshore or offshore). The flow is directed towards the north during the flood phase of tide and directed towards the south during the ebb phase of the tide.

3.4 Waves

3.4.1 Normal wave climate

The normal wave climate at the location of the proposed new Port expansion is mild. Waves are relatively low, only exceeding 1.5 m 0.5% of the time (1.8 days per year). The main wave direction is from the East and Southeast. Wave data is available from ship and satellite observations and measurements at the VHFL-jetty.
Wave heights for different directions at the location of the new Port Expansion, according to transformed ship observations are distributed according to table 3.4.

Hs (m)	15° - 45° [%]	45° - 75° [%]	75° - 105° [%]	105° - 135° [%]	135° - 165° [%]	165° - 15° [%]	Total [%]
> 0.2	7.86	4.96	7.43	12.67	6.71	.19	39.83
0.2 - 0.4	2.93	3.13	5.48	9.02	2.94	.01	23.51
0.4 - 0.6	1.03	1.42	3.48	5.53	1.20	.	12.66
0.6 - 0.8	.19	.72	2.23	3.23	.39	.	6.76
0.8 - 1.0	.06	.25	.96	1.40	.20	.	2.87
1.0 - 1.2	.02	.14	.37	.68	.08	.	1.28
1.2 - 1.4	.01	.06	.12	.29	.03	.	.51
1.4 - 1.6	.	.01	.06	.13	.02	.	.21
1.6 - 1.8	.	.	.03	.07	.01	.	.11
1.8 <	.	.	.01	.06	.	.	.07

table 3.4 Percentages of time that the wave heights in the given direction are exceeded at the location of the VHFL-jetty according to transformed ship observations.

In this table the percentage of time is shown that wave heights are exceeded and come from the given direction and in the last column, the total percentage of time that wave heights are exceeded (joint probability of wave height and direction).

3.4.2 Extreme wave climate

R	345°-15°		15°-45°		45°-75°		75°-105°		105°-135°		135°-165°		165° - 195°	
	H_{s0}	Dir	H_{s0}	dir	H_{s0}	dir	H_{s0}	Dir	H_{s0}	dir	H_{s0}	dir	H_{s0}	Dir
1	1.14	35.6	1.34	39.6	1.81	62.4	1.96	90.0	2.41	115.4	1.97	132.2	1.04	147.4
5	1.36	40.9	1.59	43.0	2.29	64.3	2.30	90.0	2.90	113.5	2.62	129.7	1.26	141.4
10	1.45	42.7	1.69	44.5	2.51	65.0	2.40	90.0	3.10	112.6	2.78	128.1	1.35	139.2
25	1.59	44.9	1.82	46.1	2.77	66.0	2.61	90.0	3.38	111.8	3.01	126.6	1.48	136.7
50	1.69	46.4	1.92	47.2	2.97	66.8	2.74	90.0	3.58	111.1	3.21	125.7	1.59	135.1
100	1.80	47.8	2.03	48.4	3.17	67.6	2.87	90.0	3.80	110.7	3.37	124.8	1.69	133.6
200	1.90	49.0	2.12	49.3	3.37	68.2	2.99	90.0	4.00	110.2	3.54	123.6	1.80	132.2

table 3.5 Extreme near shore wave (depth line 14) heights and directions for given return period and direction according to corrected ship observations.

It can be seen that the highest waves near shore (at a depth of 14 m) come from a direction between 105° and 135°. This means that although offshore waves from a more southern direction are higher, due refraction waves from a direction between 105° and 135° are decisive.

For different water depths, wave characteristics can be summarized according to table 3.6.

Return period	off shore	d = 22 m	d = 18 m	d = 14 m	d = 10 m	d = 6 m
1 Yr.	2.42 m	2.36 m	2.31 m	2.26 m	2.24 m	2.27 m
10 Yr.	3.26 m	3.08 m	3.03 m	3.01 m	3.05 m	3.07 m
100 Yr.	4.09 m	3.80 m	3.78 m	3.80 m	3.84 m	3.85 m
200 Yr.	4.33 m	4.01 m	4.00 m	4.04 m	4.06 m	4.08 m

table 3.6 Near shore significant wave heights for different return periods and water depths

3.5 Seismic considerations

In normal practice the seismic loads are considered with the UBC 1997. According the UBC 1997 however Fujairah is in seismic zone 0. This will imply no seismic action thus no expected earthquake. The seismic loading according UBC 1997 will be based on a vertical acceleration of 0.06 g and a vertical acceleration of 0.075 g.

3.6 Geotechnical

3.6.1 Sea bottom

For the Northern Port extension project a full geotechnical investigation has been carried out. This geotechnical investigation comprises 28 boreholes with full data per bore hole.
The existing sea bed profile as reported by Fugro in the Soil Investigation report as mentioned above consist of upper soil sediments and underlying bedrock. The sub seabed conditions of the dredging area consist mainly of very loose, grey to black, medium to fine sand in the upper soil layer. Below this top layer there is a soft rocky layer which consists most of the time of weak to very weak sandstone, but is also known to consist of siliceous calcarenite, and conglomerate. At a few places these 'harder' layers have, according to the soil laboratory tests report, an Unconfined Compressive Strength (UCS) higher than 2 MPa.

The estimated composition of the soil in the dredging area for land reclamation consists approximately:

- 53 % of sandy material
- 47 % of soft rocky material

The highest UCS encountered during the soil investigation in the designated dredge area was 20.78 MPa. This particular material has been defined as weak to moderately weak conglomerate/calcirudite.

Further composition percentage of the soil available at the dredging area can be seen in table 3.7:

Soil Type	**Percentage of Soil composition (%)**
Sand	38.9
calcareous sandstone	28.4
carbonate sand	8.1
Carbonate sandstone	6.5
Calcarenite	6.4
Calcirudite	5.2
Calcareous sand	3.9
Cobbles	1.4
Calcareous siltstone	0.5
Calcisiltite	0.4
carbonate silt	0.3
TOTAL	**100**

table 3.7 Soil composition

3.7 Surface levels

3.7.1 Sea bottom profile

The Bathymetry of the near shore area in front of the reclamation project area is determined by Gulf Cobla by survey done in April ’06. The bathymetry drawings from this survey show parallel depth contours and a bottom slope of approximately 1:100. For a further confirmation of the sea bottom profile, the sea bottom levels as mentioned in an off shore soil investigation report by Fugro Middle East where analyzed. The levels mentioned in this report where rather consistent with the result of the survey done by Gulf Cobla.

The existing quay walls of the port of Fujairah and the pavement of the port areas have a surface level of CD+ 4.75 m.

3.8 Sedimentation

Based on the available information on the existing harbour basin (and entrance channel) there are no signs of significant sedimentation. A relatively steep profile (above water level) can be seen just north of the existing port. This could be interpreted as downdrift erosion.

The existing Port of Fujairah and the port expansion project location is enclosed on both sides by the Naval Base and the Marina. Both the Naval Base and the Marina have breakwaters that curve out seaward. These hard structures are assumed to have a positive effect on the sedimentation at the project location. This effect will probably be that any sediment is stopped by these hard coastal structures.

The harbour master reports that no maintenance dredging is required in Fujairah. Regarding the current velocities and sediment characteristics not much sedimentation or erosion is expected. This can be confirmed by the fact that scour around the piles of jetties in Fujairah is negligible.

4 Layout requirements new port expansion

4.1 Introduction

In this part of the study the requirements for the new port layout are described. These requirements are subdivided in functional requirements and throughput requirements. Based on expectations by the port of Fujairah several throughput scenarios will be composed. These scenarios give an upper and lower limit to the expected demand for throughput capacity in the new port. Subsequently a shipping forecast will be made based on global vessel statistics. Both throughput scenarios as vessel statistics where used as input values for a simulation study. By this study the required number of berths and cranes and the required quay lengths for the new layouts will be determined.
The invitation for the masterplan study came with a number of requirements. It has however been made clear by the Fujairah Port Authorities that these requirements only form the basis for the study and that all the relevant topics to arrive at the scheme should be studied.

4.2 Commodities

The main commodities that are part of the masterplan study are:

- Liquid bulk
- Dry bulk
- Containers

4.2.1 Dry bulk

The market for aggregates in the Middle East is growing considerably due to rapid developments and expansion plans in this region. Fujairah as a main supplier of high quality aggregates wants to anticipate and increase its export. The aggregate ship loader of the Port of Fujairah however has reached its maximum capacity several years ago. The quay that was originally built for container handling is now being used to load bulk carriers with ship based cranes. Besides the inefficiency of this operation, the capacity of this solution has also grown to its limit. It is not possible to improve this operation by placing a new ship loader on the quay since it is leased out to Dubai Port including Container Handling facilities.
In addition to the expansion of the export capacity of dry bulk facilities, there are plans to build a new steel factory in Fujairah for which additional dry bulk unloading facilities are required. The raw material for this plant is planned to be brought in by ship. Vessels will be unloaded in the Port of Fujairah.

4.2.2 Liquid bulk

Besides dry bulk loading facilities, the Port of Fujairah currently offers liquid bulk loading and unloading facilities. These facilities are primarily being used for the loading and unloading of oil carriers that supply the oil storage of the Fujairah Refinery (FRCL). This refinery does not operate as a refinery but is only utilized as oil storage facility.
Although currently three oil terminal berths (OTB's) can satisfy the required capacity, the oil storage market is tending to grow rapidly. At the moment many single hull oil storage ships operate in the waters in front of Fujairah. Due to new international regulations that require a double hull for off shore oil storage, a great part of this off shore storage will be shifted to onshore. Several local oil storage firms

have expressed their interest to increase their storage capacity and to build new oil storage tanks in Fujairah. The Port of Fujairah wants to anticipate and build the loading and unloading facilities for the ships that are to supply these new oil storage tanks.
Besides oil, the Port of Fujairah wants to anticipate on a possible growth in the demand for throughput capacity of chemicals.

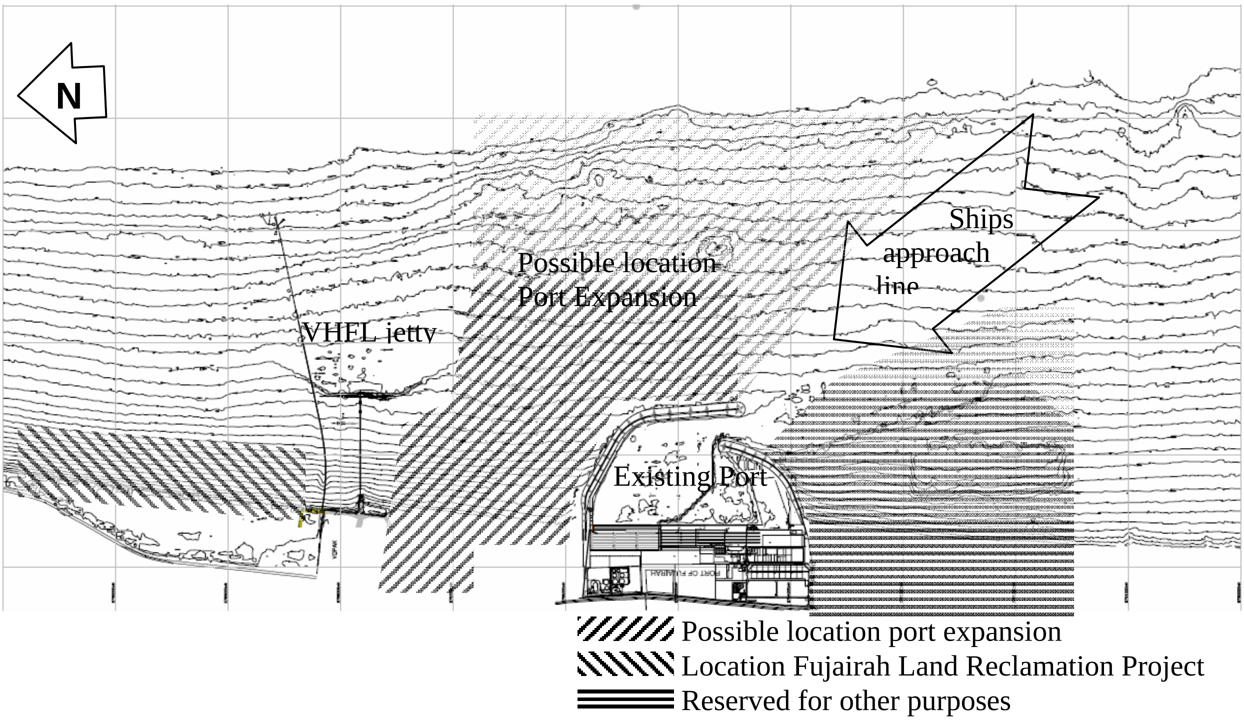
4.2.3 Containers

However the Port of Fujairah is not using their container loading facilities actively, Dubai Port that is current leasing the quay and cranes in the Port of Fujairah has expressed their desire to be able to unload bigger vessels and handle more containers. This is not possible with the current facilities. The Port of Fujairah intends to investigate the possibilities of handling large size container vessels.

4.3 Location and layout

4.3.1 Location of the port expansion

The two main requirements given by the Port of Fujairah Authorities for the location of the new Port expansion are that the port is in the vicinity of the existing Port of Fujairah and that the port expands northward. The preferred location for the port expansion project is shown in figure 4.1.



4.1 Possible location for port Expansion

The main reasons to realize the port in the vicinity of the existing port are the following:

- To limit the distance between all existing harbour facilities and the new port. The distance that the tugs have to travel for berthing assistance is very important and should be minimized. Finally it will be necessary to settle a new tugboat facility inside the new harbour basin, but for the earlier phases, the tugboat facility of the existing port will most likely be used.

- To limit the distance between the aggregate stacking area and the aggregate berths. This distance determines the length of the conveyor belts. The length of a conveyor belt partly determines the construction cost as well as operation cost.
- To limit the distance between the oil storage facilities and the oil tanker terminal. Long oil transport pipes will require booster stations. Booster stations ensure adequate flow velocities in the pipes. Because of the extra construction and operation cost of these facilities, they should be avoided if possible. However when flow velocities are too low, load or unload operations will last unacceptably long.

Realization of the new port expansion north of the existing port is preferred for the following reasons:

- There are several developments planned south from the existing port. Southward expansion is impossible without affecting these plans. One of these plans is the construction of a dry dock on this location. There are intentions to develop this area with other functions than port function. However it is preferred not to use this land, southward expansion is not excluded from possibilities.
- An expansion of the port southward will affect the approach of ships to the existing port. The approach channel of the existing port is directed to the south. Breakwaters for a new port expansion will form an obstruction. In general the safe approach of the existing port should be maintained.
- North from the VHFL a strip of land is planned to be reclaimed from the sea. On this strip of land several oil storage tanks will be realized. The distance from the oil terminal to these tanks should not be too long to avoid the necessity of booster pumps or low flow velocities.

The location of the berths for different commodities within the port expansion depends on the specific requirements for the berthed vessels and connections to onshore facilities.

With the generation of layouts the navigational safety of ships approaching the existing harbour, the VHFL terminal and the new port expansion will have to be taken into account. Sufficient space for turning is required. These requirements are further described in paragraph 4.9. The requirements for the location of the main commodities in the port expansion are described in the following paragraphs.

4.3.2 Location and alignment of the oil terminal

Since the wave climate in front of Fujairah is mild and oil vessels have large critical wave heights, it may be possible to operate an open sea tanker terminal without having excessive downtime. The tanker terminal north of the existing port that is operated by VHFL can operate economically in an unsheltered area. Realization of the oil terminal outside the harbour basin is preferred since a breakwater protecting the oil terminal at deep water will be very expensive. For this reason the feasibility of an open sea tanker terminal is investigated. The feasibility of handling oil at open sea partly depends on the downtime at the jetty.

Downtime at a new terminal at open sea depends on:

- Waves
- Currents
- Wind

Downtime due to waves occurs when the critical wave height, for which load or unload operations are aborted is exceeded. The critical wave height depends on the vessel type and size and the angle of attack. The critical wave height for oil vessels is relatively large. The wave parameters height and direction differ over the water depths due do refraction and shoaling. Further the reflection of waves by coastal structures influences the wave height at the berths.

In table 3.4 the wave climate at the project location is given. This table is used to estimate downtime at an unsheltered area. It is assumed that an open sea tanker terminal will be realized at a depth of between

CD - 14 m and CD – 18 m. Due to refraction and shoaling, the direction and height of waves at the location of the open sea tanker terminal.
At the VHFL terminal, operations are aborted when a wave height of 1.2 m at the bow of the ship is exceeded, 1.5 m bow quartering waves and 2 m head and stern waves. These criteria are used for all ship dimensions at the VHFL jetty. Using the data presented in table 3.4, it is estimated that operations must stopped for not more 0.99 % of the time which is 3 – 4 days per year. The real average downtime at the VHFL jetty is 3 – 5 days per year which is comparable.
For the new terminal the limiting wave criteria as given in table 4.1 are assumed.

Liquid bulk vessels	**Beam waves**	**Bow quartering**	**Head waves**
15,000 DWT	1	1.2	1.5
> 50,000 DWT	1.2	1.5	2

table 4.1 Critical wave height for ships berthed on VHFL jetty.

With these criteria and the wave parameters from table 3.4, the downtimes of two vessel sizes are estimated. The results are given in table 4.2. Downtime in

Liquid bulk vessels	**% of time exceedence**	**Downtime per year**
15,000 DWT	2.65 %	9 – 10 days
50,000 DWT	0.99%	3 – 4 days

table 4.2 Estimated downtime on OSTT

Current velocities may affect oil handling at open sea. As can be seen in table 3.3, current velocities in Regarding the estimated downtime due to wave height exceedence and the experience that VHFL has with oil handling at open sea, it seems feasible to realize the oil terminal outside the area sheltered by breakwaters.
front of the coast of Fujairah are very low. This table indicates that 90% of the time, the current velocity stays below 0.54 m/s. It is assumed that these velocities do not affect the operation.
Wind is assumed to have the same effect inside the harbour basin as outside the harbour basin and does therefore not influence the location of the oil terminal.
When the liquid bulk terminal is realized outside the protected harbour basin, the orientation of these berths with respect to prevailing wave and current directions influences the downtime of this terminal. Berthed vessels are generally more sensitive for bow waves than for head or stern waves. This is due to the fact that the width of the ship is smaller than its length. A wave attacking a vessel at the bow will cause a roll angle that is larger than the pitch angle caused by the same wave, attacking the vessel from the head or the stern. Since the prevailing wave direction is from the Southeast (as can be seen in table 3.4) and the highest waves are expected to come from this direction, the preferred alignment is with the head of the vessels in South-eastern direction. VHFL however has aligned their berths perpendicular to the beach. This means that waves from the dominant direction attack the ships obliquely.
Besides a jetty attached to the shore, the feasibility of Single Point Mooring Buoys will have to be investigated. The location of these facilities can be near the proposed location of the oil terminal or in front of the Fujairah Land Reclamation project area.

4.3.3 Location of aggregate berths

Loading of dry bulk vessels can be executed in a relative exposed location. Dry bulk vessels are filled at one single point which is not connected to the ship. Unloading operation of dry bulk vessels has a lower critical wave height. To operate the grab or bucket wheel in the vessel the ship must be kept relatively stable as contact with the ship is unavoidable. The downtime on the quay due to exceedence of the critical wave height partly dictates the location of the dry bulk quay wall. The port authorities desire a flexible port in which quay functions can be changed if demand for handling capacity of commodities shift. It is assumed that dry bulk berths (loading and unloading) can not operate economically at open

sea. The locations of the dry bulk berths in the proposed harbour layouts will therefore be in a sheltered area protected by breakwaters.
Regarding the location of the dry bulk berths, a short distance between stockpile area and quay wall is preferred, to limit the length of relative expensive conveyors. Since the stockpile area will not be directly behind the quay wall, and material is transported by conveyor belt, the required land behind the quay does not need to be very wide.

4.3.4 Location container terminal

The critical wave height for container handling is very low. Container handling has the risk of the spreader getting stuck in the cell guide due to vessel motion. The container terminal should therefore be realized at a location sheltered from waves. Other than dry bulk and oil handling, container handling requires a relatively large area behind the quay wall for stacking containers.

4.4 Cargo flow

4.4.1 Throughput scenarios and phases

A thorough market and cargo flow investigation reaches beyond the scope of this study. For this reason three scenarios will be used for each commodity, weak, medium and strong growth of the demand for throughput capacity. These scenarios are not forecasts but only assumed possible developments of the size of the cargo flows through the Port of Fujairah. For each commodity, three scenarios are composed:

- Scenario 1: Strong growth, representing the upper limit of the demand for throughput capacity.
- Scenario 2: Medium growth
- Scenario 3: Weak growth or decrease in the demand for throughput capacity.

Off course the size of the cargo flow does not only depend on the demand for a certain product but also on the available handling capacity of the port, availability of vessels to transport the material. On the one hand, there is the direct demand for a product. On the other hand, the presence of the port facilities will help attract new industries. This complicated interaction is very hard to predict and reaches beyond the scope of this study.
Developments that can not be foreseen at this moment can have a great impact on the throughput figures of the expanded Port of Fujairah. An example of a political decision which has had great influence is the decision to let the floating storage phase out. This will have as a consequence that the bunkering market will be served from the port, and onshore storage capacity will have to increase dramatically. Other developments in the Middle East and the growth of the population in the area will have a large effect on the demand for aggregates used in the building industry. Because of uncertainties and the restriction of this study on this subject, the margins between the scenarios on the long term will be quite large. The scenario will not be a throughput forecast but will be assumptions within reasonable limits. The scenarios will be based on several grounds:

- Production possibilities and size restrictions.
- Third parties information
- Port Authorities Expectations
- Extrapolation of the growth of current cargo flows and near future forecasts.

For the commodities aggregates, other dry bulk, liquid bulk and containers a throughput scenario has been composed. Although these commodities are partly independent, there is a certain relation between

them. Economic growth will generally increase the demand for all commodities and regression will restrain the growth or cause a decrease in the demand.
To follow the growth of the cargo flow through the port, the expansion project will be executed in three phases. Since the rate of this growth is not known, the timing of these phases can not be determined exactly at the moment. Only the recent throughput capacity demand can be approximated and the demand for the near future can be forecasted. The second and the third phase are executed when it is foreseen that the need for new facilities will be there within several years.

- Phase1
  The first phase will supply for the current demand in throughput capacity and will serve for the required capacity for the coming 5 years. This is more or less known for aggregates and oil. For containers, the plans from Dubai Port are less transparent.
- Phase2
  The second phase will cater for the following 10 years of the project. The layout of this phase differs for the different scenario's. If there are large differences between the main commodities. It may be possible to split the execution of this phase in time for different commodities.
- Phase3
  The last phase will be the fully developed port after 25 years. Different fully or partly developed layouts will be proposed for this phase for different scenarios. This layout will be the final layout of the port for the expansion plan as described in this study.

4.4.2 Dry Bulk

<u>Aggregates</u>
Within the handling of dry bulk, the emphasis is on loading of aggregates. The capacity shortage of this commodity has lead to the expansion plans in the first place. The current bulk loading facilities are by far not capable to supply in the need for aggregate loading capacity. These facilities, as described in paragraph 2.9, are capable of loading 10 M ton per year.
Rock that is produced in Fujairah is transported all over the Middle East. As described in paragraph 2.9 the main part of the material is shipped to Qatar, Kuwait and Bahrain. Additional to these destinations, Dubai will be an important client for the aggregate producing companies in Fujairah. As the material is currently transported by road, a shift to ship transport in the near future is expected.
Currently there is a demand for aggregate loading facilities that can handle 25 M ton per year. This number is based on interviews with the Port of Fujairah Marketing Manager and Managing director of Fujairah Rock and Aggregate. This demand is expected to increase during the next years. After a period of 25 years, a total export of between 15 and 100 million tons per year is expected to be within reasonable limits. It is expected that the throughput of aggregates will reach at least 40 M ton within the next 10 years. These expectations are used to compose three scenarios.

- Scenario A1: The demand for aggregates loading capacity in the Port of Fujairah will increase during the entire project duration. After 25 years, the yearly the demand will be 100 million tons per year. At the end of phase 1 the throughput has reached 40 million ton per year and at the end of phase 2 it has reached 75 million ton per year.
- Scenario A2: The demand for aggregates loading facilities in the Port of Fujairah will grow moderate during the first project years but this growth will come to an end after 15 years at the end of phase 2. At the end of phase 1, a demand of 35 million ton per year is reached. At the end of phase three the yearly throughput is 50 million tons.
- Scenario A3: The demand of aggregates loading capacity will follow the current growth of last years during the first project years. After 10 years when a throughput of 35 million tons per year is reached growth will come to and end. The yearly throughput will decrease to 20 million at the end of phase 2 and finally be 10 million at the end of phase 3.

Regarding the production of aggregates, there is virtually no limit to the possible amount of material produced per year and to the available amount of material. The amount of quarried rock is negligible in relation to the total volume of available rock in Fujairah.

Other dry bulk

There are plans to build a new steel factory in Fujairah. The factory will include 2 units, 1 for producing sponge iron and the other one for producing steel. The sponge iron unit will produce 1.2 M tons a year, while the production capacity of the steel unit will be 180,000 tons per year.
Further there are plans to build a new cement factory in Fujairah in the near future. The clinker for this factory is planned to be shipped in via the Port of Fujairah. The proposed location for this new factory is in the close vicinity of the Port, most likely west from the road between Fujairah and Khor Fakkan.
As described in paragraph 2.9, there is a small amount of clinker being shipped in (table 2.2). Currently no shore based unloading facilities are present in the Port of Fujairah. The material is unloaded by ship based cranes and transported to its final destination by truck. However, after the new factory has been realized, the amount of imported material is expected to increase significantly and other facilities are probably required. The new factory is expected to be realized in 2010. Interviews with the Port of Fujairah Marketing manager have pointed out that the expected required preliminary amount of material is 2 million ton per year and finally after the factory is in full operation, up to 5 million ton per year. Other plans are the realization of an aluminum factory in Fujairah. In case these plans are realized, large amounts of bauxite will be imported in the port of Fujairah.

- Scenario B1: This scenario represents the situation as described above with the construction of a cement factory in 2010 and a aluminum factory in 2018. The growth in the demand for dry bulk unloading facilities is high due to these developments. At the end of 2015 the throughput is 3 million tons per year. Finally at the end of the project term the throughput reaches 7 million ton per year.
- Scenario B2: The demand for import of clinker increases moderately in the first project years. The construction of the cement factory is postponed 7 years and is finally realized in 2018. At the end of phase 3, the demand for Clinker unloading facilities reaches 3 million ton per year.
- Scenario B3: This scenario represents the situation in which the cement factory is not realized. There is only a small growth in the demand for dry bulk throughput capacity. At the end of the project term, the import of dry bulk reaches 0.7 million ton per year.

Besides the construction of the cement factory and the bauxite plant, there are no other known developments that require large amounts of raw material to be imported.

4.4.3 Liquid bulk

Market for storage volume

The oil market in Fujairah is expected to grow significantly. Especially the bunker market, the blending market and the strategic storage market are expected to increase. Additional to the expected increase of these markets, the floating storage is expected to phase out. This means that the emphasis will be on shore storage in the future. Several companies have spoken out their intention to build oil storage tanks in Fujairah. The Port of Fujairah wants to benefit from these developments and offer oil handling facilities. The port has no intention to start up oil storage business.
It is not expected that Fujairah Refinery will be started as a refinery again, especially when other companies will start refineries in Fujairah. This capacity will probably stay in the market as storage capacity. Abu Dhabi's government-owned International Petroleum Investment Company (IPIC) has said it will go ahead with the new oil refinery at Fujairah at the location of the Fujairah Land Reclamation Project. IPIC has expressed their intention to use 160 ha of this project area. In addition to plans for a new oil refinery and water treatment plant at Fujairah, IPIC said it plans to build a strategic pipeline to transport oil from Habshan in Abu Dhabi to the port.

The market for bunker-fuels in Fujairah is foreseen to continue its growth and more and more volumes in this industry will need to be handled onshore. The market for building bulk and blending on specification of fueloil will continue, even as supply and demand patterns in producing and receiving countries are subject to change.
Regional developments in the Arabian Gulf will have a positive impact on bunker sale volumes in Fujairah. The seven countries within the Arabian Gulf basin have embarked on massive scale development projects, particularly in the area of oil, gas and chemicals leading to an anticipated increase in vessel activity passing the Strait of Hormuz.
The UAE authorities have observed the MARPOL regulations, though the UAE is not yet a signatory to the MARPOL regulation. Marpol is the International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. (Marpol" is short for marine pollution) The Port of Fujairah has banned single hull tankers older than 25 years from entering its territorial waters (except for non-oil related activities). The port also announced that single hull tankers aged between 15 and 25 years involved in moving dirty petroleum products must have so called CAS Certificate (Condition Assessment Scheme) and flag state SOC.

Oil handling

The amount of oil through the port of Fujairah is directly linked to the volume of oil stored. The cargo flow through the Port of Fujairah is determined by two main factors:

- The total storage volume that must be served and the average occupancy of these storage tanks.
- The term that oil is stored in the storage tanks in Fujairah.

At the moment it is known that in addition to the existing oil storage firms at least three new parties have shown interest in investing in storage tanks in Fujairah. These firms are Enoc and Joint Venture I and Joint Venture II. The total volume that these parties intend to install is roughly 3 million m^3.
For the total development of the demand for storage volume, three scenarios have been composed. It is assumed that there will be growth in the demand for oil storage in any case. In the first phase, the demand is more or less equal for all three scenarios. After phase 1, the total demand for oil storage is expected to reach 3 - 4 million m^3. The scenarios represent the following growth in demand for storage capacity:

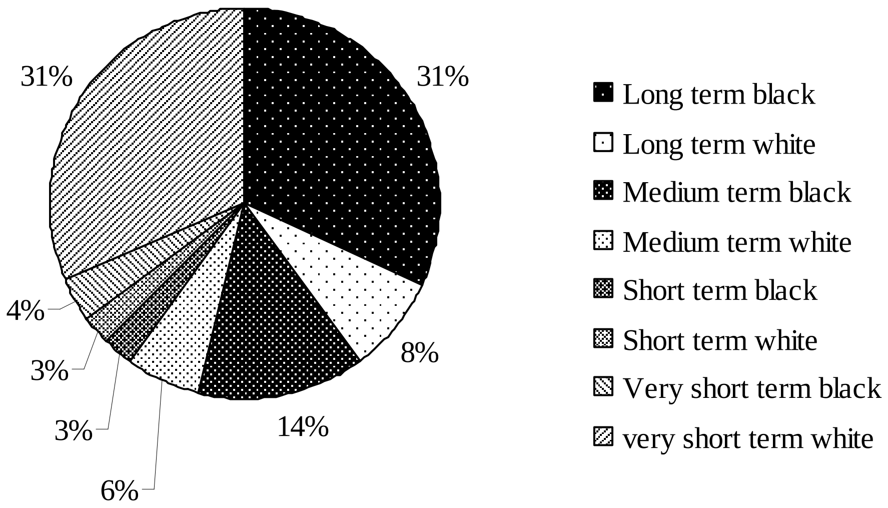
- Scenario C1: In this scenario, the demand for storage capacity will eventually increase to a level of 11 million m^3 in the third phase. The growth will continue during the first half of the third phase.
- Scenario C2: Medium growth in the demand for oil storage capacity. After phase 3 the demand will be 8 million m^3.
- Scenario C3: For this scenario, the growth in the demand in the second phase is less. In the third phase hardly any growth. The demand at the end of phase 3 is 6 million m^3.

The term that oil is stored determines the cargo flow through the port. Long term storages will require less capacity from loading and unloading facilities than short term storages. It is assumed that during the entire project life the storage terms are distributed equally. These terms are divided in long term, medium term, short term and very short term storage. These can be devided as follows.

- Long term storage (> 1 year), mostly strategic, is generally large volumes. This type of storage does not have a large effect on berth occupancy. The material is brought in with large vessels. It is assumed that the demand for this type of storage is 40% of the total demand for storage capacity. Further it is assumed that the long term storages are mainly crude oils, 80%, against 20% petroliums.
- Medium term storage (6 – 12 months) are mostly speculative storage. Since the material stays relatively long in the tanks, the occupancy at the berths is not high. It is assumed that the demand for this type of storage is 20% of the total demand for storage capacity. Like Long term storages it is again assumed that these types of storages mainly concern crude oils, 70%, against 30% petroliums.

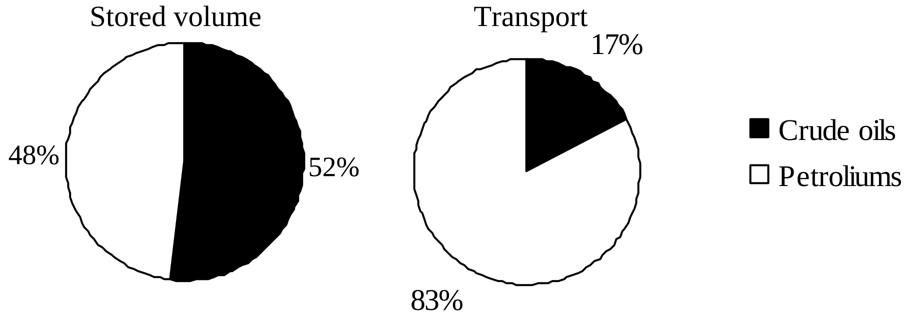
- Short term storage (3 – 6 months): Generally speculative storage. It is assumed that the demand for this type of storage is very low, 5% of the total demand for storage capacity. This type of storage is assumed to be as much crude oils as white products.
- Very short term storage (<3 months): Storage for blending, bunker fuel storage and break of bulk and make of bulk. Since the material is for a short period in the tanks, the occupancy at the berths is largely determined by these types of storage. It is assumed that the demand for this type of storage is very rather high regarding the fact the bunker trade is and will be very important for the Port of Fujairah. Therefore it is assumed that the demand will be 35% of the total demand for storage capacity. Since blending and storage for the bunker market are white products, it is assumed that the largest parts of this storage are white products (petroliums).

This can be graphically represented as shown in graph 4.1.



graph 4.1 Oil storage terms and percentage of black or white products.

According to the above mentioned assumptions, a storage tank is filled and emptied, 4.8 times per year on average. The total stored volume of black products (crude oil, 52%) is almost as big as the total volume of white products (petroliums, 48%) as can be seen in graph 4.2. The second pie in graph 4.2 shows the total handled volume of oil. The amount of handled white product is considerably larger. This is due to the fact that the storage term of petroliums is generally shorter than that of crude oils.



graph 4.2 Storage and transport of black and white products (crude oils and petroliums)

According these assumptions, for storing one ton of oil for one year, 9.6 ton of oil is handled at the berths. Of this total amount of transported material, 1.63 ton will be black products and 7.97 ton will be white products.

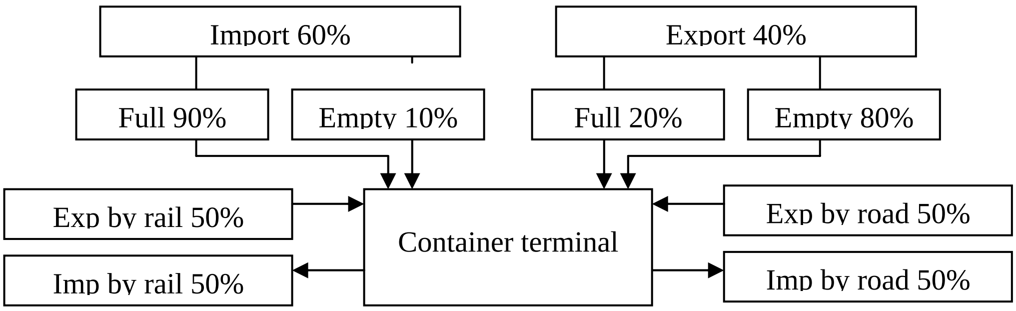
In the case that the demand for oil storage capacity develops according to scenario C1, the total throughput after 25 years will be more than 100 million ton per year. According scenario C3, the throughput will be 50 million ton per year.

4.4.4 Containers

DP World has signed management contracts in Fujairah. DP World plans to build up its container traffic to complement operations at Jebel Ali. The port is seen as an east coast hub that could handle 6,000 TEU container ships and can reach a throughput of 3 million TEU per year. In this way the port will give a strategic position. Dubai Port has the intention to improve the existing container facilities and to build new quay walls and storage areas. Parallel to increasing container handling capacity in Fujairah, Dubai Port has the intention to construct a railway connection between Fujairah and Dubai.
Currently, the amount of containers handled in the Port of Fujairah is very low. However because of the above mentioned developments, the required container handling capacity of the Port of Fujairah is expected to grow significantly.
Again three scenarios have been composed according to which container throughput may develop.

- Scenario D1: This scenario represents very strong growth in the demand for container handling capacity in the Port of Fujairah. Immediately after the start of phase 1, the demand increases until a throughput capacity of more than 1 million TEU per year is required. After phase 2, the demand is 3.5 million TEU.
- Scenario D2: Represents moderate growth. After phase 3 a throughput of 3 million TEU is required.
- Scenario D3: Represents limited growth. The final demand for throughput capacity is 1 million TEU after phase 3. In phase 1 there is hardly any growth.

Based on Dubai Port Statistics, it is assumed that 60% of the total container throughput is import and 40% is export. It is further assumed that all these containers are transported over land, where 50% is transported by the planned railway line to Dubai and 50% is transported by truck. It will probably take several years until the railway line is operational. Until finalization of this project, all containers are to be transported by truck. Modal split as shown in 4.2 is assumed for further calculation.



4.2 Modal split container cargo

4.4.5 Other commodities

The Port of Fujairah Authorities have indicated that an increase in the trade of chemicals is expected. Currently chemicals are being handled on a small scale within the existing Port. Volumes and requirements for this commodity are not known yet. For this study the possibility of chemicals handling is considered.

4.4.6 Summary

The scenarios described in the previous paragraphs are summarized in table 4.3.

Aggregate loading	Sc 1 [M ton/yr]	Sc 2 [M ton/yr]	Sc 3 [M ton/yr]
2007	15	15	15
End of phase 1: 2012	40	30	25
End of phase 2: 2022	85	50	20
End of phase 3: 2032	100	50	15

Dry bulk unloading	Sc 1 [M ton/yr]	Sc 2 [M ton/yr]	Sc 3 [M ton/yr]
2007	0.2	0.2	0.2
End of phase 1: 2012	2.0	1.0	0.5
End of phase 2: 2022	6.0	3.5	0.5
End of phase 3: 2032	7.0	4.5	0.5

Liquid bulk	Sc 1 [M ton/yr]	Sc 2 [M ton/yr]	Sc 3 [M ton/yr]
2007	20	20	20
End of phase 1: 2012	35	30	30
End of phase 2: 2022	85	70	50
End of phase 3: 2032	110	80	55

Container	Sc 1 [M ton/yr]	Sc 2 [M ton/yr]	Sc 3 [M ton/yr]
2007	0.2	0.2	0.2
End of phase 1: 2012	1.0	0.5	0.3
End of phase 2: 2022	3.0	2.0	0.5
End of phase 3: 2032	3.5	3.0	0.8

Chemicals	Sc 1 [M ton/yr]
2007	0.1
End of phase 1: 2012	0.2
End of phase 2: 2022	0.5
End of phase 3: 2032	1

table 4.3 Summary throughput scenarios

4.5 Shipping forecast

4.5.1 Vessel sizes

Numbers of vessels and vessel dimensions partly determine the development of the port expansion. Important dimensions are the length over all (LOA), draught and beam. The length governs the length and layout of single berth terminals, the length of the quays. The length also influences the width and bends of channels and the size of the turning areas. Beam or breadth; governs the reach of cargo handling equipment and influences the width of the channels and basins. Draught; governs the water depth along the berths, in channels and in basins. Further , the vessel size distribution has a large influence on the capacity of the new facilities.

The Port of Fujairah Authorities demand that Cape size aggregate vessels can be handled in the new port expansion. These vessels have a size of generally 150,000 to 175,000. The longest vessels with this weight have a length of 300 m. The draught of this class is up to 18 m. According to Lloyd's register vessel statistics, there is a large group of these vessels.

The Port of Fujairah Authorities also demand that the new liquid bulk terminal must be able to handle oil tankers up to cape size. These tankers also have draughts up to 18 m.
The water depth in front of the current aggregate loading berths is 15 m. According to the Lloyd's register of shipping of 1999, 67% of the ships with this draught have a size between 70,000 and 80,000 DWT. From the ships with this size, 55% had a length over all of between 225 and 229. This means that the largest expected dry bulk vessels in the existing port of Fujairah have a length of 230 m. Statistics from the Port of Fujairah about the measured length of ships calling the Port of Fujairah show that the largest group of vessels do not have the maximum length and that the maximum length is indeed 230 m.
The point of gravity lies between 180 and 200 m.
Further, the LOA of dry bulk vessels as by the data from Lloyd's tables seems to be consistent with the actual distribution of vessel sizes calling the Port of Fujairah. In these statistics the point of gravity of this range, also lies around a length of 190 m as well. Of course, the percentages of the total sum are different, but this is due to the fact that for the Lloyd's register statistics, an amount of ships larger than 230 m is taken into account. For further calculations, the distribution of lengths according to Lloyd's register vessel statistics will be used for forecasts of ship sizes calling the new Port of Fujairah and throughput estimations. These estimations will be carried out by simple simulation models. In these models, average dimensions of four different ship sizes (Handysize, Handymax, Suezmax and Panamax and Cape Size) will be use.
Handysize, refers to a dry bulk vessel with deadweight of 15,000–50,000 tons. Above this size are Handymax bulkers. Handysize is the most widespread size of bulk carrier, with nearly 2000 units in service for a total of 43 million tons of carriage. Handymax is typically between 35,000 and 60,000 deadweight tonnage. A handymax is typically 150-200 meters in length, though certain bulk terminal restrictions such as those in Japan mean that many handymax ships are just under 190 meters in overall length. Modern handymax designs are typically 52,000-58,000 DWT in size, have five cargo holds and four cranes of 30 metric ton lifting capacity. These smaller Handysize and Handymax vessels are general purpose in nature, and not only comprise 71% of all bulkers, but also have the highest rate of growth. This is partly due to new regulations coming into effect which put greater constraints on the building of larger vessels. The growth of the economy of the People's Republic of China (with its great demand for raw materials) and increasing congestion in the Suez and Panama canals has led to an increase in the number of capesize vessels ordered.

4.5.2 Dry bulk vessels

Data from Lloyd's register of shipping on dry bulk vessels are summarized in table 4.4.

Dry bulk vessels	DWT	Length [m]	Draught [m]	Breadth [m]	%
Handysize	6,000 – 50,000	120 – 220	6 – 12.5	15 – 30	71 %
Suezmax/Panamax	50,000 – 100,000	200 – 250	10 – 15	30 – 40	21 %
Cape size	100,000 – 150,000	240 – 285	15 – 17.5	38 – 48	4 %
Cape Size	150,000 – 175,000	265 – 300	17 – 18	45 – 48	4 %

table 4.4 Dry bulk vessel size distribution according to Lloyd's register vessel statistics

4.5.3 Liquid bulk vessels

The distribution of liquid bulk vessel sizes can also be made according to Lloyd's register vessel statistics. These data are shown in table 4.5. Though for the different storage types (for example bunkering) specific vessels are used to transport the oil to and from the storage tanks. For this reason, the data as given in table 4.5 will not be used for estimation of throughput capacities but the specific vessel dimension that is connected to the type of storage. This is further described in paragraph 4.7.3.

Oil tankers	DWT	Length [m]	Draught [m]	Breadth [m]	%

Handysize	6,000 – 50,000	120 – 205	6 – 13	16 – 32	50 %
Suezmax/Panamax	50,000 – 100,000	190 – 260	11 – 16	30 – 46	31 %
Cape size	100,000 – 150,000	230 – 280	13 – 17.5	38 – 50	16 %
Cape Size	150,000 – 175,000	265 – 300	15 – 18	43 – 54	3 %

table 4.5 Liquid bulk vessel size distribution according to Lloyd's register vessel statistics

Since detailed insight in future development of ship types and ship sizes is not available and falls beyond the scope of this study, assumptions will be made on which agreement is reached with the Fujairah Port Authorities. The basis of these assumptions will be information derived from Lloyds Register vessel statistics (1999).

4.5.4 Container vessels

It is assumed that as a result of the size of container flows around the world and their potential, containerships are the only ships that will increase further in size. For other commodities than containers (oil and dry bulk), it is assumed that ship sizes have reached their optimum and will not develop significantly. It is further assumed that the optimal container vessel size will lie between 17.500 and 20,000 TEU and that the Europe – Far East routes and the Trans Pacific routes are the only routes where ships of this size can perform economically.
As mentioned, container vessels are likely to increase in size significantly, especially at the routes between Europe and the Middle East. These vessels that can carry up to 20,000 TEU are likely to have a larger draught than the 15 m of the existing port but will not exceed an 18 m draught.
General cargo does not form part of the commodities in the primary studies for the new port extension. However use of the new port extension by general cargo ships is not excluded from this study, it is not expected that the design is influenced by these ships.
As mentioned above, container vessels are the only ships that are expected to increase in size significantly. In table 4.6, the assumed distribution of container vessel sizes are given.

Commodity	**TEU**	**Length [m]**	**Draught [m]**	**Breadth [m]**	**%**
Container vessels	100 – 1000	75 – 185	3 – 10.5	11 – 28	34 %
	1000 – 2000	145 – 214	8 – 12	23 – 33	32 %
	2000 – 3000	180 – 260	10 – 12.5	29 – 33	16 %
	3000 – 4000	235 – 285	11.5 – 13	32 – 33	10 %
	4000 – 5000	250 – 300	12.5 – 14.5	32 – 38	5 %
	5000 – 7000	265 – 315	12.5 – 11	38 - 42	3 %

table 4.6 Container vessel size distribution according to Lloyd's register vessel statistics

4.6 Functions of the existing port in the expansion plans

The existing port facilities will also play a role within the port expansion plans. The following commodities will partly stay in the existing harbour basin.

- Dry bulk export (existing ship loader)
- Liquid bulk (OTB 1 – OTB3)

Further, other vessels that are currently handled in the existing port on a smaller scale will remain in the existing harbour basin and have more room for expansion.

4.6.1 Aggregates loading

It is assumed that the loading of dry bulk is an operation for which one ship loader can operate independently from others. Transport between vessels is not expected. This means that the berths for aggregates loading do not have to be close to each other. It is proposed that the ship loader inside the existing harbour basin remains operational as the port expands.

4.6.2 Oil terminal berths

The facilities for the oil terminal berths are also proposed to remain in the existing harbour basin. These facilities can operate independently as well. The new oil terminal and especially the central manifold of this terminal is preferred to be located in the vicinity of the existing OTB's. OTB berth 2 and 3 are able to handle one medium size vessel or two smaller vessels at the same time. As the larger and medium size liquid bulk vessels will be handled on the new berths, outside the harbour basin, the emphasis of the OTB will be on the handling of the smaller liquid bulk vessels.

4.6.3 Removal of container facilities out of the Port

More than for the dry or liquid bulk terminal, the stocking area for the container terminal is preferred to be located close to the waterfront. A significant part of the containers to be handled is transported between vessels. For this reason it is assumed that the container terminal can operate more efficiently when it is concentrated at one location. The container facilities in the existing port can not be expanded at this location. It is therefore proposed that these facilities will be relocated to the new port expansion.

4.6.4 Other commodities

In the existing harbour basin, commodities that are currently handled on a smaller scale will have more room for expansion. The following vessels will be handled within the existing harbour basin:

- General cargo vessels
- Navy vessels
- RoRo Vessels
- Cruise ships

Further vessels for repair and maintenance services will stay in this part of the Port of Fujairah. The mild wave climate in the existing harbour basin will provide good working conditions for these smaller vessels. In the existing port, an area of 20 ha is available for container stacking. This area can be used for the expansion of the port offices, stevedoring offices, ship repair services, diving services, oil storage facilities etc.

4.7 Number of berths and quay length

4.7.1 Introduction

In the previous chapters, demand for throughput capacity scenarios where composed and vessel size distributions where assumed. In this paragraph, the required number of berths and cranes to reach the required throughput is determined. The aim will be to maximize the berth occupancies and minimize quay length and waiting time. Berth occupancies and waiting times are determined by simple simulation runs. The details and results of the various simulations are given in Annex 3. Simulation is required if analytical solutions are not available. In this situation this is due to the fact that the berth concept is replaced by the total length of the quay concept and all arriving ships can not be accommodated at all berths.

Subsequently the required quay length is determined. For multiple berths in a straight continuous quay front, the quay length is based on the average vessel length, according to formula [4.7.1].

$$L_q = 1.1 \cdot \left(\overline{L}_s + 15\right) + 15 \qquad [4.7.1]$$

This allows for a gap of 15 m between the ships moored next to each other and additional 15 at the two outer berths. The factor 1.1 allows from a study carried out by UNCTAD. For a number of actually observed ship length distributions and for the relation average berth length / average vessel length as a variable, the probability of additional waiting time as a result of simultaneous berthing of several above-average vessels was determined (UNCTAD, 1984).
The required length as determined in this part of the report will only give an indication which will be used to compose different harbour layouts. Allocating different function to one quay wall may reduce the total required quay length.

4.7.2 Dry bulk

Aggregates

As discussed in paragraph 4.5, the dry bulk terminal at least for phase 1, will be designed for cape size vessels. (150,000 – 175,000 DWT) and smaller.
The loading of aggregates will be a continuous process where ship loaders will be fed by a conveyor belt system from the stockpile area. The port has ordered cranes that have loading rates of maximum 4.4 ton per hour. The average loading rate of this crane is 3,400 ton per hour. They are capable of loading ships up to 175,000 DWT. These cranes are travelling shiploader types which mean that they can move parallel to the quay.
To determine the required number of cranes for the port expansion and the composed scenario's according to the previous chapter, a basic simulation of the port system has been carried out.
For this simulation the following assumptions have been made:

- Ships sizes of dry bulk vessels that call the future Port of Fujairah are distributed according to table 4.4. It is also assumed that the average parcel size of these ships is the average dead weight tonnage.
- The existing port (only the aggregate ship loader and not lift and grab operation) is part of the system. The average loading rate for this berth is 1,700 ton per hour. Ships calling the Port of Fujairah will be berthed in the existing port first. Since the maximum draft is only 15 m in the existing port, only ships up to 100,000 DWT can be handled in the existing port.
- Ships are handled according to a "first in first out" system. If the size of the vessel admits it, it will first be berthed at the existing port. If this berth is occupied it will be berthed at a quay in the new port expansion.
- The average idle time is 3 hours. This is the time that the berth can not be used by other ship while the ship loader is not operating. This time is used for mooring the ship, administrative processes and for getting the required material on the conveyor belt.
- Ships arrive at the port according to an Erlang-3 distribution. This distribution is chosen because the interval of arriving ships is expected to be relatively regular. The material is transported by a limited number of shipping agents.
- One ship is served by not more than one ship loader.

The details of the simulation study are described in Annex 3. The results of the simulation study are given in table 4.7. As can be seen from this table the berth occupancy gets higher as the number of berths increases.

Required throughput [M ton/yr]	**Total new quay length [m]**	**Total no of new cranes**	**Average berth occupancy**	**Average waiting time [hr]**
15	340	1	44%	1.23
20	605	2	37%	0.67
30	645	2	52%	0.95
40	810	3	50%	1.48
50	910	3	63%	1.60
60	1190	4	57%	0.50
70	1190	4	66%	1.00
80	1335	5	62%	1.04
90	1395	5	68%	1.01
100	1435	5	77%	1.95

table 4.7 Simulation results aggregates.

The port Authorities have indicated that a ship loader that works from a quay wall is highly preferred over an open or platform construction. A jetty construction will not fit in the port plans since a commodity shift is easer when a quay wall is applied. To make it possible to handle other types of cargo on the quay the main effort will be to change the super structures. Off course the required land behind the quay is less for a ship loader with conveyor belts and stockpiles at some distance from the loading cranes, than for example the land that is required for container storage. This means that the width of the land behind the quay wall should not determined just to fit for conveyor belts but will allow the handling and storage of other materials than aggregates. The port has also negative experience with a ship loader on a jetty and the filling procedure of the vessel.

Additional advantage of a quay wall is the flexibility in which ships can be moored and the fact that if necessary one ship can be served by more than one ship loaders if available.
Disadvantages of a quay wall over a jetty construction are the cost and the influence on the wave climate in the harbour basin. The construction costs of a quay wall are most likely higher than for an open structure. A quay wall has a wave reflection coefficient that is much higher than the coefficient of the slope protection behind an open structure. The negative influence of the quay wall on the wave climate in the harbour basin will be much higher than for an open structure.

The required quay length for the three phases and scenarios does greatly depend on the distribution of vessel sizes. As mentioned, the preferred crane type is a traveling shiploader. This means that the loading point can be varied over the length of the quay. The number of large cape size dry bulk vessels is limited as can be seen in table 4.4. The chance that a cape size vessel arrives while an other large size vessel is being loaded is small. Simulations show that there is hardly any influence on the berth occupancy and waiting times for the same throughput if the quay length for two vessels is reduced such that two cape size vessels can not berth. The port authorities have indicated however that at least in the first phase, they desire a quay that can handle two of the largest size vessels at the same time.

<u>Other dry bulk</u>
The demand for throughput capacity of the dry bulk import terminal is expected to be lower than that of the export terminal. The Port Authorities desire a continuous mechanical device that can handle at least 2000 ton per hour. This ship unloader will be connected by conveyor with the stockpile area. With a simple simulation, waiting times and berth occupancies have been determined using the following parameters:

- The average unloading rate of the cranes is 2,000 ton/hr.
- Arrival pattern of ships is according an Erlang distribution. Since the arrival pattern is expected to be relatively regular an Erlang 3 distribution was chosen..
- Vessel sizes are distributed according to table 4.4.
- Ships are handled according a first in first out system.
- Average idle time is 3 hours
- The facilities in the existing port are not part of the calculation of waiting times for the new port.

For when the demand for throughput capacity is higher than 4 million ton per year, it will be necessary to realize one extra berth to keep waiting times within acceptable limits. Average waiting times with 1 berth and 6 M ton import per year are more than 6.8 hours. With an average service time of 20 hrs, including idle time this is assumed to be unacceptable.
Waiting times and crane occupancies are examined for the situation that both berths can handle ship types of up to 175,000 ton and for the situation that one berth can only handle ships smaller than 100,000 ton. Advantage of this limitation for the second berth is that less quay length is required.

Required import [M ton/yr]	**Total quay length [m]**	**Total no of cranes**	**Average berth occupancy**	**Average waiting time [hr]**
2	280	1	14%	1.45
4	280	1	26%	1.52
6	525	2	20%	0.97
8	525	2	27%	1.23
10	605	2	32%	1.27

table 4.8 Simulation results dry bulk import

For scenario B1, one crane will be sufficient to serve for the demand until the end of phase 1. For phase 2 and 3, a second crane is needed. Scenario B2, representing medium growth, it will be possible to serve for the demand in import capacity for phase 1 and 2, eventually in phase 3, a second crane is needed. In scenario B3, import increases only slightly. It will not be necessary to realize the proposed ship unloader with conveyor belt. In fact, these amounts of material can be handled by ship based crane (lift and grab operation) at an unoccupied quay in the new or existing port.

4.7.3 Liquid bulk

The role of the Port of Fujairah in the oil storage and trading process is primarily to deliver the oil handling facilities for the oil storage and stevedoring companies. Besides the guaranty of safe navigation in and around the port this comprises providing sufficient berths to avoid long waiting times and the ability to reach sufficient loading and unloading discharge rates. Pumps are located at the storage facilities; the Port is responsible for piping and loading arms.
For the planning aspects if the new liquid bulk terminal, it is assumed that the vessel size distribution according to table 4.5 does not represent the distribution of vessel sizes that is expected at the new oil terminal. It would be more appropriate to assume that vessel sizes depend on the function of the delivery. Per storage function and for import and export, an average vessel type is assumed. Material with longer storage times is transported by larger vessels. Material for blending is transported by medium size vessels. Bunker fuel storage is replenished by large size vessels. The bunker vessels are smaller ships. These assumptions will be used for throughput, waiting time and berth occupancy calculations and are summarized in table 4.9. The second and third columns give the percentage of the total storage volume that is used for the specific function. The last to columns give the ship sizes that are used for the specific delivery.

Storage type	Storage dirty [%]	Storage white [%]	Average storage time [yr]	Importing ships [DWT]	Exporting ships [DWT]
Strategic	32.0%	8.0%	2	162,500	162,500
Speculative	16.5%	8.5%	1	162,500	162,500
Blending	0.0%	13.5%	0.08	90,000	90,000
Bunkering	0.0%	13.5%	0.08	162,500	15,000
Break of bulk	0.0%	4.0%	0.08	150,000	15,000
Make of bulk	4.0%	0.0%	0.08	15,000	150,000

table 4.9 Average ship sizes per storage type.

The speed of the load and unload operations of these ships depend on the flow velocities in the pipes, the diameters of loading arms and the number of loading arms per berth. The flow velocities again depend on the onshore pump capacities, the onboard pump capacity of ships and pipe properties. The following average flow velocities for load and unload operations are assumed. (based on VHFL experience and calibrated with VHFL berth occupancy and waiting times)

- Loading of black material: 3 m/s
- Unloading of black material 3.5 m/s
- Loading of white material: 4 m/s
- Unloading of white material 4.5 m/s

The velocities for clean products (white) are higher as these have a lower viscosity and less pipe resistance as a consequence.
The distribution of the inter arrival time of the ships is assumed to be Erlang 3. The arrival pattern is expected to be relatively regular. The idle time is assumed to be 3 hours on every berth and ship size. The system is assumed to be First in First Out. With the parameters described in this paragraph, the throughput capacity of several numbers of berths having several different sizes has been estimated. The current berths OTB1, OTB2 and OTB3, as described in paragraph 2.10.2, are assumed to be part of the total system so they are implemented in the model. The model has been used to estimate the maximum throughput of the OTB's for an average waiting time, not longer than 1 hour. It resulted from this test that the OTB's can handle a total throughput of 16.4 M ton per year. With the distribution of storage times as given in graph 4.1, this means a total storage volume of 2.13 M m^3 can be served with this facility.
The model was calibrated by analysis of the existing VHFL terminal throughput, waiting times and berth occupancy data from 2006. For several storage volumes the required number of berths is determined using all assumptions mentioned in this report. These proposed numbers of berths are given in table 4.10. These figures present the outcome of the simulation study including the OTB's.
OTB 1 and OTB 2 can both be used for one medium size vessel of for two smaller vessels. Since these berths are in the sheltered harbour basin, it is proposed that as they are used for handling the smaller tankers. These tankers will suffer a higher downtime if they are berthed at the more exposed Open Sea Tanker Terminal. The range of bigger tankers will be handled at the new OSTT. These vessels are less sensitive for wave motions.

Storage capacity	Capacity [ton/yr]	Number of new berths	Berth no	Max ship size [DWT]	loading arms	Avg. waiting time [hr]	berth occ.
2 M m^3	15 M	0	0	0	0	0.93	34.5%
4 M m^3	30 M	2	OSTT 1	175,000	4 * 16”	0.42	39.8%
			OSTT 2	175,000	4 * 16”		18.9%
6 M m^3	46 M	3	OSTT 1	90,000	4 * 16”	0.99	21.6%
			OSTT 2	165,000	4 * 16”		54.6%
			OSTT 3	165,000	4 * 16”		36.1%
8 M m^3	62 M	4	OSTT 1	15,000	2 * 12”	2.10	38.4%
			OSTT 2	90,000	4 * 16”		34.8%
			OSTT 3	165,000	4 * 16”		72.1%
			OSTT 4	165,000	4 * 16”		58.1%
10 M m^3	78 M	5	OSTT 1	90,000	4 * 16”	0.61	58.2%
			OSTT 2	90,000	4 * 16”		55.3%
			OSTT 3	150,000	4 * 16”		68.7%
			OSTT 4	165,000	4 * 16”		55.4%
			OSTT 5	165,000	4 * 16”		42.0%
12 M m^3	100 M	5	OSTT 1	150,000	4 * 16”	2.39	78.6%
			OSTT 2	165,000	4 * 16”		83.1%
			OSTT 3	165,000	4 * 16”		77.4%
			OSTT 4	165,000	4 * 16”		70.3%
			OSTT 5	165,000	4 * 16”		60.9%

table 4.10 Number of liquid bulk berths

4.7.4 Containers

The dimensions of the new container terminal is based on assumptions on the following assumptions:

- Container vessel sizes are distributed according to table 4.6 derived from Lloyd’s register vessel statistics. Besides this, growth of vessel sizes is taken into account by allowing the anticipated vessels with sizes of up to 400 m and 11,000 in the new port expansion.
- The TEU factor is assumed to be 1.7. This means that twice as much FEU (Forty feet Equivalent Unit) as TEU are expected in the new port. This TEU factor is determined with the following expression: $f = (N_{20} + 2 \cdot N_{40}) / N_{tot}$.
- The gross production of the cranes is assumed to be 25 TEU moves per hour. The assumed maximum number of cranes is given in the last column of table 4.11.
- The ship sizes as shown in table 4.11 are assumed, taking into account the Lloyd’s register vessel statistics and the assumption that ships will continue to grow in size. For the calculation of waiting times and berth occupancies when a throughput capacity of 0.5 M TEU is required, it is assumed that the largest ships do not call the port of Fujairah.

TEU	Length [m]	Draught [m]	Breadth [m]	% of ships	Max number of cranes
100 – 1000	75 – 185	3 – 10.5	11 – 28	30 %	2
1000 – 2000	145 – 214	8 – 12	23 – 33	32.5 %	3
2000 – 3000	180 – 260	10 – 12.5	29 – 33	15 %	4
3000 – 4000	235 – 285	11.5 – 13	32 – 33	10 %	5
4000 – 5000	250 – 300	12.5 – 14.5	32 – 38	5 %	6
5000 – 7000	265 – 315	12.5 – 14.5	38 - 42	5%	8
7,000 – 11,000	315 - 400	14.0 – 15.5	42 - 56	2.5 %	10

table 4.11 Container vessel size distribution used for simulation

- The number of containers that need to be handled per vessel is 50% to 100% of the total vessel capacity, equally distributed between this maximum and minimum. It is further assumed that import and export of container is according figure 4.2.
- The simulation is carried out using a fixed number of berths. This means that the throughput capacity, berth occupancies and waiting times are not determine for a number of quay lengths. Instead the number of berths, the berth capacity and the number of cranes are varied to find acceptable values for waiting times and occupancy. It is assumed that an average waiting time of 0.5 hours is acceptable.
- For the determination of the waiting time an average downtime of 3 days is assumed. This downtime represents the downtime due to unworkable weather, unusable cranes due to maintenance and downtime due to exceedence of the maximal allowable ship movement. This movement is caused by wave penetration. The wave penetration depends on the layout of the port, the protection of the harbour basin by breakwaters and the reflection coefficient of the quays.
- The total required quay length as given in table 4.12 is determined using [4.7.1].

Using the above mentioned assumptions several number of berths and cranes where tested. The results of these simulations are given in Annex 3.

Required throughput [M TEU/yr]	Total quay length [m]	Total no of cranes	Average berth occupancy	Average waiting time [hr]
0.5	675	9	53 %	0.4
1	1022	15	47 %	0.4
1.5	1432	19	51 %	0.5
2	1702	23	55 %	0.5
2.5	1927	28	57 %	0.5
3	2050	36	60 %	0.5
3.5	2109	40	70 %	0.8

table 4.12 Results from container throughput simulation study

According to the composed scenarios as proposed in paragraph 4.4, it can be seen that for scenario D1, at the end of phase 1 a total quay length of 1432 m is required. For scenario D2 a total quay length of 775 is required at the end of phase 1, 1702 m at the end of phase 2 and finally after phase 3, 2050 m to able to handle 3 M TEU per year. In scenario D3, a total length of 1022 is required to be able to handle the total throughput of 1 M TEU/yr that is anticipated for at the end of phase 2 and 3 in this scenario.

4.7.5 Chemicals

In scenario 1 it is anticipated that there might be an increase in the demand for the handling capacity of chemicals. For this reason one berth for handling of chemicals is considered is the first construction phases and 2 berths in the last construction phase.

4.7.6 Summary berths and quay lengths

The required quay lengths and number of cranes as determined in this chapter are summarized in table 4.13, shown below.

	PHASE 1					
	Scenario 1		Scenario 2		Scenario 3	
	Quay length	No of cranes	Quay length	No of cranes	Quay length	No of cranes
Aggregates	910	3	810	2	810	2
Other dry bulk	280	1	280	1	-	-
Oil	2 berths	-	2 berths	-	2 berths	-
Containers	1432	19	675	9	675	9
Chemicals	1 berth	-	-	-	-	-

	PHASE 2					
	Scenario 1		Scenario 2		Scenario 3	
	Quay length	No of cranes	Quay length	No of cranes	Quay length	No of cranes
Aggregates	1395	5	910	3	810	2
Other dry bulk	525	2	280	1	-	-
Oil	5 berths	-	4 berths	-	3 berths	-
Containers	2110	40	1927	28	1022	15
Chemicals	1	-	-	-	-	-

	PHASE 3					
	Scenario 1		Scenario 2		Scenario 3	
	Quay length	No of cranes	Quay length	No of cranes	Quay length	No of cranes
Aggregates	1435	5	910	3	340	1
Other dry bulk	525	2	525	2	-	-
Oil	6 berths	-	4 berths	-	2 berths	-
Containers	2110	40	2050	36	1022	15
Chemicals	2	-	-	-	-	-

table 4.13 Summary required quay length and number of cranes

4.8 Terminal area

4.8.1 Dry bulk

<u>Area behind quay</u>

The quay behind the aggregate loading berths will only be used for the conveyor systems, and cranes. There is no space required for stockpiling on the quay, since this takes place on the stockpile area outside the port. The loading or unloading of dry bulk vessels in the new port expansion is assumed not to take place by lift and grab operation. The required width behind the quay wall of the aggregate loading berths

therefore depends on the width of aggregate loading cranes, the number of conveyor belts and the width for these conveyor belts. The number of conveyor belts that have to operate next each other both depend on the scenario as on the proposed layout. The required area will therefore be determined per proposed layout.
The current conveyor belt has a capacity of max 2,200 tons per hour. The new conveyor is planned to have almost a doubled capacity of 4,000 tons per hour. The required width for this conveyor is 15 m. The placement of conveyors next to each other is preferred over the placement of one conveyor over each other.

<u>Stockpile area</u>
The current stockpile area is fully occupied by the Fujairah Rock and aggregate which quarry is direct behind the Port of Fujairah. As mentioned, the aggregate from other quarries is supplied at the conveyor feeder point as the vessel is laden. It is possible to feed the conveyor by four trucks simultaneously. With the increase of the exported tonnage of aggregates and the increased export rate however, a more effective approach is required. Instant delivery and filling with the new rates will require a drastic increase in the amount of trucks from the quarries. The design of a new aggregate supply system falls beyond the scope of this study. It is however assumed that more space is necessary to be able to feed vessels with a sufficient rate.

<u>Conveyor belts</u>
For the end of phase 3 in scenario A1 the total export amounts100 M ton. In table 4.13 it is estimated that 5 cranes with an average capacity of 3,300 ton/hr are necessary to load the dry bulk vessels. This means that also 5 conveyor lines will have to connect the stockpile area with the berths. Besides the conveyor belts to the aggregate loading berths, the dry bulk import berths needs to be provided of a transport system from the quay to future users. It is anticipated that this will take place by conveyor belt as well. It is assumed that the maximum number of lines between the quay and the hinterland is 6. For an average width of 10 m per conveyor a total width of 60 m is needed for this transport line.

4.8.2 Liquid bulk

The onshore part of the oil terminal contains the storage tanks, piping, manifolds and control rooms and offices. The required area for this terminal is estimated using the following assumptions.

- Average height of storage tanks is 22 m,
- The average diameter of these tanks is 40 m.
- The average distance between the tanks is 25 m
- The area that is needed for manifolds, piping, roads, offices, control rooms, service and switchgear buildings is 35% of the total area.

With these assumptions, a total amount of 3.5 m^3 can be stored per m^2. These numbers are based on the area that VHFL needs for oil storage. VHFL currently stores 1.1 million m^3 on 32 ha. This includes area for manifolds offices, roads and piping, etc. For long term storage, usually tanks are used with a larger diameter and height than these for blending or make/break of bulk. This means that more oil can be stored on the same area.
For the demand in storage capacity at the end of phase 3 for the scenario 1, the required area for these oil storage terminals according to the above mentioned assumptions is 328 ha. This can never be realized within the existing available port site. For this reason it is anticipated that expansion of the oil storage capacity is realized outside the existing port area. The first expansions will be realized West of the existing port, between the road to Khor Fakkan and the mountains. Later expansions will be realized North of VHFL on a new area reclaimed from the sea.

4.8.3 Containers

The following assumptions where made to calculate the container stacking area.

- The distribution between import/export remains the same over various throughput changes.
- The Apron area has width of 60 m. This width comprises a 4 m service lane, a 24 m crane track, 10 space for hatch covers and 22 m for traffic lanes.
- The maximum dwell time (within 98% of the containers have left the terminal) is assumed to be 15 days, which means that the average dwell time is 5.67
- Because of their relatively low maintenance cost, and relatively long life, RTG will be used in the container stacking area. When RTG are used (rubber tired gantries) it will be possible to apply a stacking height of 4 containers height. (1 over 4). This means that on average 7 m^2 must be taken into account needed per TEU.

The area of the storage yard is determined with formula [4.8.1] for import and export containers and empties.

$$O = \frac{C_i \cdot \bar{t}_d \cdot F}{r \cdot 365 \cdot m_t} \qquad [4.8.1]$$

In which:
O = required area
C_i = number of container movements per year
$\bar{t}_d$ = average dwell time
F = required area per TEU inclusive equipment traveling lanes
r = average stacking height / nominal stacking height
m_i = acceptable average occupancy rate

The area for a container freight station (CFS) is determined using formula [4.8.2].

$$O = \frac{C_i \cdot V \cdot t_d \cdot f_1 \cdot f_{12}}{h_a \cdot 365 \cdot m_i} \qquad [4.8.2]$$

In which:
C_i = number of TEU movements per year through CFS
V = Volume of 1 TEU container (29 m)
f_1 = gross area / net area
f_2 = Bulking factor
h_a = average height of cargo in the CFS (m)

Throughput [M TEU/yr]	Required area for container terminal [m^2]
0.5	228,100
1	429,050
1.5	633,720
2	829,710
2.5	1,022,910
3	1,209,600
3.5	1,392,570

table 4.14 Required area for container terminal

As mentioned the possibility of container transport between Fujairah and Dubai by rail is investigated. This means that not only for a road transfer area but also for a rail transfer space must be available. The connection with the new railway requires that the location of the container terminal can be reached by railway line.

4.9 Elevation levels

4.9.1 Quay walls

The Port Authorities have demanded that elevation level for the new quay walls for the dry bulk terminal and the container terminal should be equal to the existing port. This level is CD +4.75 m. This means that the top of the quay wall is 3.05 m above MSL and 1.6 m higher than extreme high water. The quay walls must be relatively sheltered to avoid damage due to wave overtopping.

4.10 Water areas in the port

4.10.1 Access channel

The access channel links the harbour basin to the open sea. The location and layout of this channel will have an effect on the wave, current and wind conditions met by the ships in the channel. Although Fujairah has a mild wind and wave climate and long shore current velocities are low, a properly lined out access channel remains important.
Further the size of the channel determines the amount of dredged material. In the case of the Port of Fujairah, this will be of minor importance since the access channel does not have to be very long. This is due to the fact that the 20 m depth contour line is relatively close to the harbour entrance.
Since the new port expansion is planned to be realized in between the existing port and the existing VHFL jetty, the approach of ships to these facilities should be taken into consideration with determining the location and layout of the access channel.

<u>Channel depth</u>
The design vessel having the largest draught is the loaded cape size dry bulk vessel. This vessel has a draught of 18 m. In this study it is assumed that no tidal window has to be applied. A tidal window would have an effect on the average waiting time of the largest (and most expensive) vessels. The entrance channel will probably be very short and the amount of soil to be dredged will probably not be large. It is therefore assumed that the cost for deepening the entrance channel will be less than the introduction of a tidal window. Besides this, there is the expectation that there is a large amount of soil required for the land fills of the port expansion and the emphasized reclamation, north of the project location.
The required depth of the access channel is determined with the following expression.

$$d = T + (D + s_{\max} + r) \qquad [4.10.1]$$

In which:

- Tidal level beneath which no entrance is allowed.
  This level is the CD+0 level. This is the lowest astronomical tide. No tidal window is applied.
- D = Draught of the design ship, 18 m.
- s_{max} = Squat
  Squat is the tendency of the design ship to change its under keel clearance as it moves ahead or astern, or is passed by an other vessel close by. The following simple expression is suggested:

$$s = 2.4 \frac{\nabla}{L_{pp}^2} \cdot \frac{F_{nh}^2}{\sqrt{\left(1 - F_{nh}^2\right)}} \qquad [4.10.2]$$

  In which:
  ∇ = volume of displacement (m^3) = $C_b \cdot L_{pp} \cdot B \cdot T$

L_{pp} = length between perpendiculars, 300 m
B = Beam, 48 m
T = draught, 18 m
C_b = block coefficient, 0.9
∇ = 233,280 m^3
F_{nh} = Froude depth number = $V_{crit}/\sqrt{gh}$ = $5/\sqrt{9.81\cdot 18}$ = 0.37
This means that the expected squat is 0.92 m.

- r = Vertical motions due to waves and swell (heave, pitch and roll).
  The vertical motion due to wave response depends on the wave height in front of the port. The risk of a ship touching the channel bottom depends on the occurrence of this wave height, expected number of passages of the design ship, the time that a ship is in the cannel and the time that the water level is very low. To avoid over dimensioning and regarding the fact that the entrance channel will probably be very short, it is assumed that a significant wave height of 0.5 m which is only exceeded for 20% of the time is acceptable to determine the bottom level of the entrance channel.

- m = remaining safety margin, 0.5 m

The required water depth, determined using expression [4.10.1] is 19.9 m.

Channel width

The design vessel with the largest beam is a container vessel having a beam of 56. Container vessels having this beam and a length of almost 400 m do exist, but are not expected to enter the Port of Fujairah very often in the near future. These vessels can handle 11,000 TEU.
Further the width of the channel is greatly dependant on the number of lanes. Since these very large container vessels are not expected to call the Port of Fujairah very often, it will not be necessary to design a two lane access channel for these ships. On the other hand, the frequency of arriving and leaving medium handy size dry bulk vessels might get rather high. For these reasons, the width of the access will be the largest of the one lane channel for the 11,000 container vessel or the two lane channel for the handy size dry bulk vessel. Handysize bulk vessels have breaths up to 30 m.

The required channel width is described by the PIANC rules with equation [4.10.3] for a one way channel.

$$W = W_{BM} + \sum W_i + 2\cdot W_B \qquad [4.10.3]$$

For a two lane channel equation [4.10.4] must be used.

$$W = W_{BM} + \sum W_i + 2\cdot W_B \qquad [4.10.4]$$

It is assumed that the entrance channel will be straight. The width of the entrance channel is built up from a basic width to which are added a number of increments. The basic width is that required by the design ship to move in calm water with no wind.

$$W_{BM} = \begin{cases} 1.6\cdot B & ,1.25\cdot D < d < 1.5\cdot D \\ 1.7\cdot B & , \quad d < 1.25\cdot D \end{cases} \qquad [4.10.5]$$

The draught of the largest expected container vessel is 15.5 m.
The depth of the access channel is set to 20 m. This means that a basic width is used of $1.6\cdot B$.

The factors for additional width $\sum W_i$ are determined according to PIANC (1997) tables. Additional widths for straight channel section depend on wind, wave and current conditions. Prevailing cross winds are described in paragraph 3.2.1. In table 3.1, omnidirectional wind velocities are given. From this table it can be seen that a wind speed of 14 m/s is only exceeded 1.5% of the time. These winds are expected to come from the Northwest. This means that no additional width has to be taken into account for cross winds.

Paragraph 3.3 describes the current velocities near the coast of Fujairah. From table 3.3 it can be seen that 93% of the time, current velocities do not exceed 0.55 m/s. An additional width of $0.3 \cdot B$ is used for channel width.
The only longitudinal currents that are expected are due to the astronomical tide, water flowing in and out of the new harbour basin. The tidal range is in the order of 1 meter and the surface of the existing harbour basin is 1.3 Mm, which means that 1.3 Mm of water is exchanged during each tidal cycle. The flow velocities depend on the width and depth of the access channel. This velocity will never exceed 2.4 m/s which mean that no extra width for longitudinal currents is applied.
Also the wave climate is mild. The daily wave climate is described in 3.4.1. In table 3.4 the exceedence percentages for significant wave heights are shown. It can be seen that 94% of the time, the significant wave height does not exceed 1.0 m. When a moderate vessel speed is assumed, the required additional width is $0.1 \cdot B$.
The aids to navigation are good. An additional width of $0.1 \cdot B$ is applied.
The seabed characteristics are sandy soils which are smooth and soft. Additional width is $0.1 \cdot B$.
Oil tankers do not enter the port via the access channel but stay outside the basin since the tanker terminal is at open sea. Chemical tankers however are expected to enter the basin. These tankers will not have the dimensions of the design vessel. This means that no extra width for hazardous cargo will be taken into account.
Since the access channel runs through two breakwaters, the additional width for bank effects is taken $1.0 \cdot B$.
The additional width for two way traffic depends on the vessel speed and the traffic density. A low vessel speed is assumed (5 – 8 knots) and a moderate traffic density. This means that the additional width increments are $1.6 \cdot B$ for vessel speed and $0.2 \cdot B$ for traffic density.
The width of the one lane channel according to [4.10.3] and the above mentioned additional width increments is 184 m. The width of the two lane channel according to [4.10.4] is 246 m. This means that the channel width will be at least 246 m.

Channel length
The required length of the access channel depends on the stopping length of the largest vessels. Ships need to sail with a certain speed to not lose rudder control. The minimum speed to maintain sufficient rudder control is 3 to 4 kn under mild conditions like the waters in front of Fujairah.
To assist the vessels further to the berthing place, tug assistance is necessary as can be learned from the existing Port of Fujairah operations. On the other hand, the channel length should be the smallest possible, compatible with safety. This minimizes time taken to transit the channel
The following is assumed:

- Max vessel speed to tie up = 5-6kn
- Max wave height to tie up = 1.5 m

Preferred alignment
Ideally prevailing wind, wave and current directions should not lie perpendicular to the channel. Preferably there is a small angle between the access channel and the prevailing wave direction. Concerning the soil and the dredgability of the soil, there is no preferred alignment of the access channel. There are no hard rocks, other obstacles or areas with extreme sediment accretion.
Bends in the access channel need to be avoided for reasons of safe navigation.

4.10.2 Harbour basin

The width of the turning basin should at least be $2 \cdot L_s$. With the largest vessels expected to have a LOA of 400 m, the diameter of the turning basin should be at least 800 m.
Wave penetration in the harbour basin should be minimized to prevent downtime at the quay and to provide good mooring conditions. This should be subject of further study.

Port basin resonance

Critical values for wave periods are described by the following expression.

$$T_{n(open)} = \frac{4 \cdot L_b}{(1+2n)} \cdot \frac{1}{\sqrt{g \cdot D}}$$

Where:

$T_{n(open)}$ = critical wave period

L_b = Length of the basin

For a basin with a length of approximately 1200 m, most problems occur when T_n is close to long swell periods of 10 – 16 seconds or long waves with periods of 30 to 300 seconds. By avoiding regular shapes in the design, harbour resonances can be avoided. Long swell however is not common in the waters in front Fujairah. During severe storms, wave periods up to 6 seconds maximum are observed.

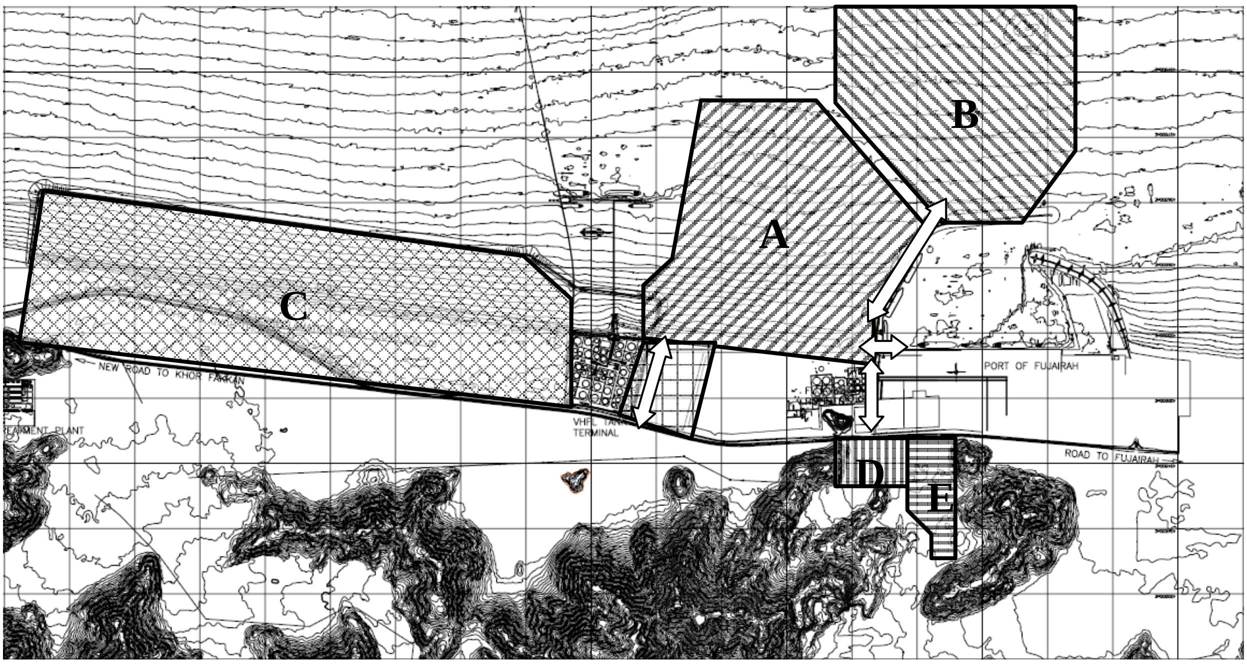
5 New harbour layout

5.1 Introduction

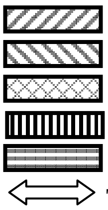
One of the objectives of this masterplan study is to search for a favorable layout for the expansion of the Port of Fujairah. In this chapter several new harbour layout alternatives will be proposed and discussed. For these alternatives, the requirements and data as described in the previous chapters will be the guideline. The main criteria for the development of the layouts will however be geometrical considerations.

The first step will be to search for a final harbour layout, with the requirements of phase 3 of the proposed scenarios. The second step will be to get into detail for phase 1 and 2 for different scenarios this will be done in the next chapter. The Port Expansion will be discussed per separate section. These sections are show in figure 5.1.

The layouts discussed in this chapter are shown on a larger scale in Annex 2 to this report.



5.1 Sections Port Expansion



Section A: Area for dredged harbour basin and quay walls.
Section B: Area for liquid bulk terminal
Section C: Area for storage tanks and other industry
Section D: Area for storage tanks and industry
Section E: Stockpile area aggregates
Transport corridor

5.2 Harbour basin, Section A

5.2.1 Arrangement of commodities

The three commodities that will be handled in a sheltered area behind breakwaters are aggregates loading, handling of other dry bulk and container handling. To arrange these commodities in the new harbour layout, the following aspects need to be considered.

- The dry bulk quays must preferably connected with the stockpile area by short lines.
- The width of the area behind the dry bulk quay can be relatively narrow. The minimum width is discussed in paragraph 4.8.1. However it must be taken into account that it may be necessary to use this area for transport lines for other commodities. The area behind the container quay must be relatively large. The total required area for the container terminal is given in table 4.14.
- Straight quay walls are preferred over quays with bends. On one straight quay, there is more flexibility in mooring the ships. Required quay lengths according to table 4.13.
- The container terminal requires a good connection with road and rail.
- Quays need to be on a sheltered location in the layout especially container handling.
- Quay lengths are according to table 4.13

Cut and fill balance

The construction of the new port will comprise dredging and reclamation works. To prevent that dredging costs reach a very high level, the dredging depth must be minimized. In this way material required for land fills can be dredged with relatively cheap equipment that is available in the area. Besides this it is useful to search for a cut and fill balance. This means that the quantity that must be dredged for the approach channel and the harbour basin equals approximately the required quantity of material for the land fills of the project. In this balance it can be taken into account that a large amount of soil is required for the reclamation project, north of VHFL. This means that preferably a large amount of material is dredged and less material is needed for the new port land fills. This will be very hard to achieve since the available area for port expansion is bordered by FRCL in the West and starts for this reason at the current coast line. This means that all land behind the quay walls must be reclaimed from the sea.
The construction of the land reclamation, north of the VHFL terminal will also require soil material. This must be taken into account with making the soil balance.

Hydraulic requirements

The qualitative hydraulic requirements such as dimensions of access channel and turning circle are described in paragraph 4.10. Further, it is desired that ships can be turned in the basin since the length of the basin will be more than 1000 m.
With the generation of layouts it is taken into account that the manoeuvrability around the VHFL terminal is possible and navigation is safe. For this reason the same relation between turning circle diameter and vessel dimensions that is maintained inside the harbour basin will also be used for the VHFL jetty.

Area for tugs and small crafts

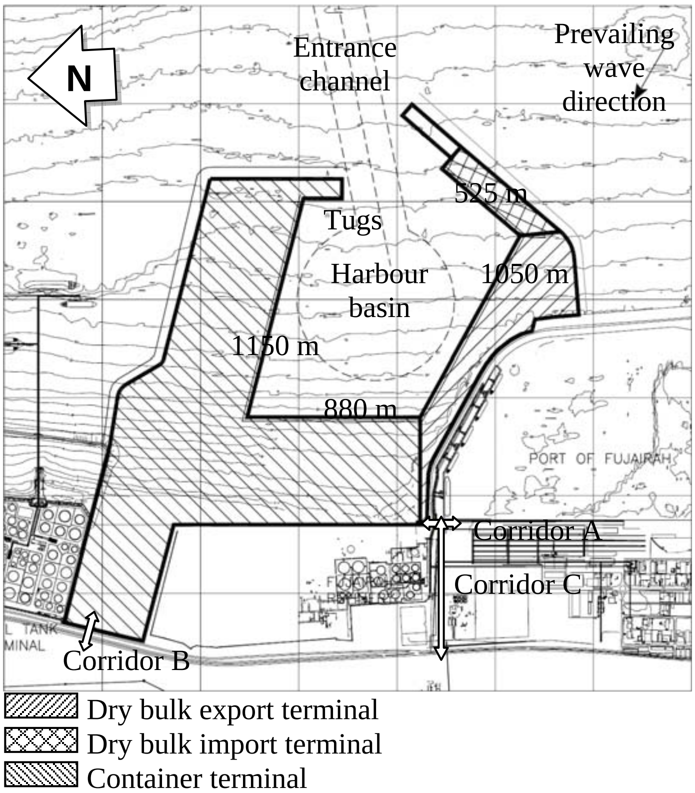
Within the new harbour basin a small area and quay wall will be reserved for tugs and small crafts. The length of this quay wall does not have to be longer than 150 m. Since these vessels are more sensitive for wave agitation, it is preferred that the location of this tugboat quay wall is in a part of the harbour basin with less wave agitation and on the other hand not far from the entrance of the harbour.

Northern boundary
Expansion to the North is restricted by the VHFL terminal. It has been made clear by the Port Authorities that these facilities can not be relocated.

5.2.2 Proposed harbour basin layouts

In this paragraph, three harbour layout alternatives are proposed. These layouts principally differ in size. In the first layout (A1), the maximum quay length is fitted at the proposed location, north of the existing port. The final total quay length in this layout approaches but does not reach the required quay length for phase 3 and scenario 1. The second layout (A2) presents a total quay length that is adequate for phase 3 scenario 3. This layout has the possibility to increase throughput capacity by construction of extra jetties. The third proposed layout (A3) represents the expansion of the port partly south of the existing harbour. However it was preferred that this area would not be part of the Port of Fujairah port expansion project, the feasibility of expansion at this location will be part of the study since the required throughput capacity according to scenario 1 can not be reached with layout 1 and therefore an other solution must be found.

Layout 1
Layout 1 is shown in figure 5.2.



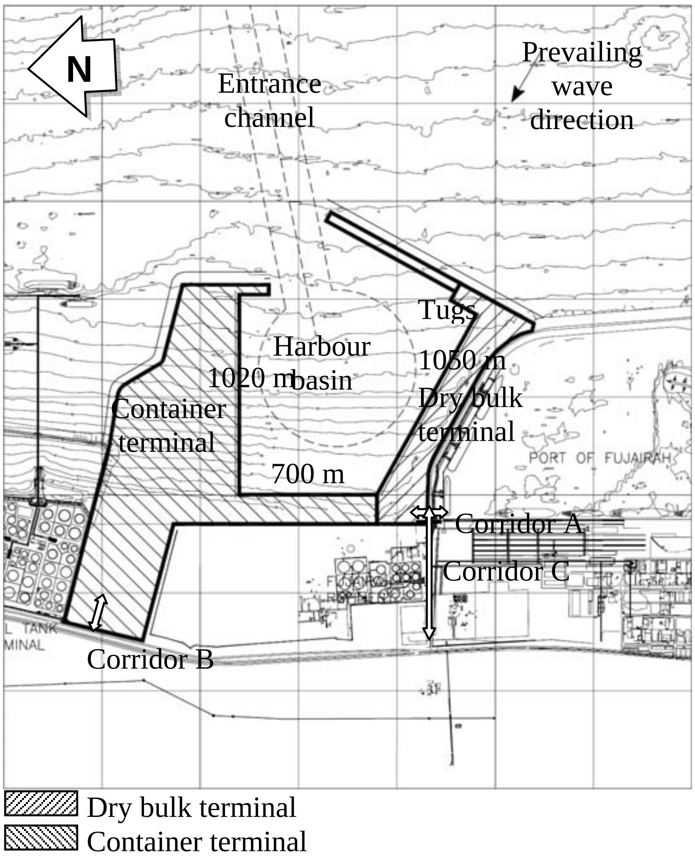
5.2 Sketch of the proposed harbour expansions layout 1

After completion of the port with layout A1, a total quay length of 3605 m is realized at the proposed location, north of the existing port. With this layout the port expands maximal within the boundaries of the proposed location, north of the existing port. The maximum possible throughput that can be achieved with this layout approximates but dos not reach the throughput as describes by scenario 1.
Dry bulk is handled south of the new harbour basin. A 1000 m long dry bulk quay wall is attached to the existing Northern breakwater. Between this new quay wall and the existing northern breakwater, a relatively narrow strip of land is created which will be sufficient for cranes, conveyor belts and a pipe rack to the new OSTT. The dry bulk berths are located directly north of the existing port for several

reasons. The aggregate loading facility has the greatest need to increase in export capacity and will therefore be constructed first. In this layout the dry bulk quay wall is attached to the existing port so that this facility can be connected with the existing port functions. It will also be possible to operate this quay without extensive protection against wave attack. This will be subject of further study. It will be possible to access this quay wall from the existing port thru corridor A as shown in figure 5.2.
Attached to the southern breakwater of the new port expansion, a 700 m long quay wall is planned for handling of dry bulk. This will be loading of aggregates or unloading of clinker. This quay wall can be constructed in a later stage. It will also serve as protection against wave attack for the container quay walls. Since the dry bulk handling requires a relatively narrow strip of land the amount of material for land fill remains within acceptable limits. The coastal protection for this part of the new port will have to be heavy since this section borders deep water and relatively vulnerable structures are present right behind it.

Containers are handled west and north of the new harbour basin. A large strip of land behind the quay is used for container storage. Two quays are planned, having a total length of 2030 m. West from the harbour basin a quay with a length of 880 m and North from the harbour basin a length of 1150 m. The width of the land behind these quays is 550 m (west) and 500 m (north). The total surface of the container terminal is 178.6 ha. The transport of containers over land takes place through corridor B. This corridor links up directly with the road between Fujairah and Khor Fakkan. Since the dominant wave direction is from the southeast, it is expected that wave motion in this part of the basin is less, since it is sheltered by the new southern breakwater.
The entrance channel has a width of 250 m as determined in paragraph 4.10.1. The width or alignment has no effect for the dredging quantity since the harbour entrance is at the 20 m depth. The distance between the breakwater heads however is determined by this width. Since the
With the construction of the existing oil terminal berths, it was foreseen that expansion to the North would take place. The pipe rack for this terminal is supplied with a pipe bridge as a corridor to the new port expansion. Corridor A will be the connection between the existing and the new port. Since the bulk cargo is preferably constructed first, this corridor will serve than as the access for these construction works. Tug facilities are planned to be realized attached to the northern breakwater.

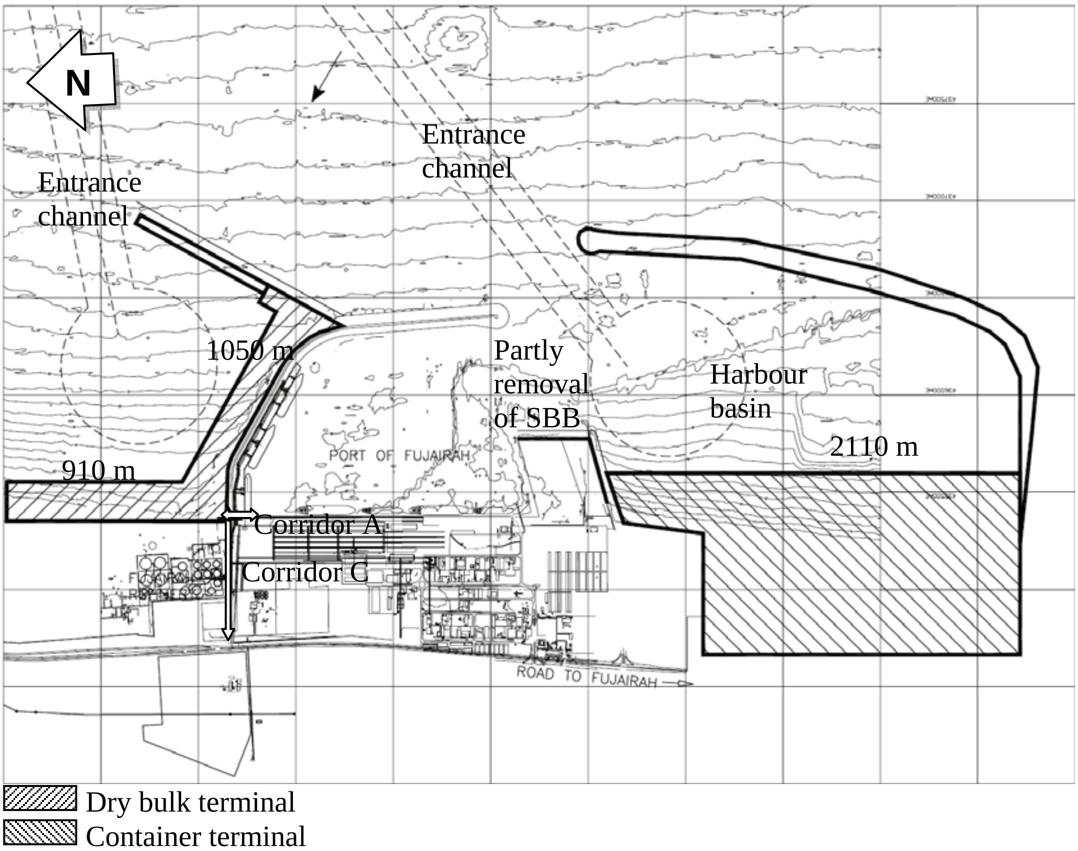
<u>Layout A2</u>
Layout A2 is based on a minimization of the amount of required material for land fills. Within this layout less space is available for quays and terminals. Layout A2 is shown in figure 5.3.



5.3 Sketch of the proposed harbour expansions layout A2

The total quay length after completion of the port expansion with this layout is 2070 m comprising two quays south and north of the harbour basin. This is the required quay length of phase 3 and scenario 3 representing minimum growth in the demand for export capacity. West from the harbour basin, no quay will be constructed. This part of the new port will kept free for dry bulk or for liquid bulk jetties.
The total quay length for handling of dry bulk cargo is 1050. The terminal is located directly north of the existing northern breakwater. As mentioned above, the dry bulk terminal is planned to be constructed first.
The container terminal is located in the northern part of the port expansion. The container quay lies directly north of the harbour basin and has a length of 1020 m. The total area of the container terminal is 102 ha. As in layout 1, the transport of containers over land takes place through corridor B.

Layout A3
With layout A3 all quay length and terminal area can be realized that is required for scenario 1. Since is not possible to realize a port that can reach this throughput at the preferred location, the area south of the port is considered. However other developments where planned in the area south of the existing Port of Fujairah, the feasibility of a container terminal at this location is studied as well. In layout A3 the dry bulk berths are positioned north of the existing port at the original port expansion location. Only the container terminal is shifted to the south. Layout A3 is shown in figure 5.4



5.4 Sketch of the proposed harbour expansions layout A3

The container quay wall has a total length of 2110 m without bends and starts directly south from the existing southern breakwater. The total area of the terminal behind this quay is 165 ha. The container terminal is protected against wave penetration by a breakwater stretching out from the south end of the new quay and encloses the entire terminal. The entrance channel is directed to the Northeast. This will also be the new entrance channel for the existing port. Ships will sail to the turning circle where they will be turned and towed to their berthing position.

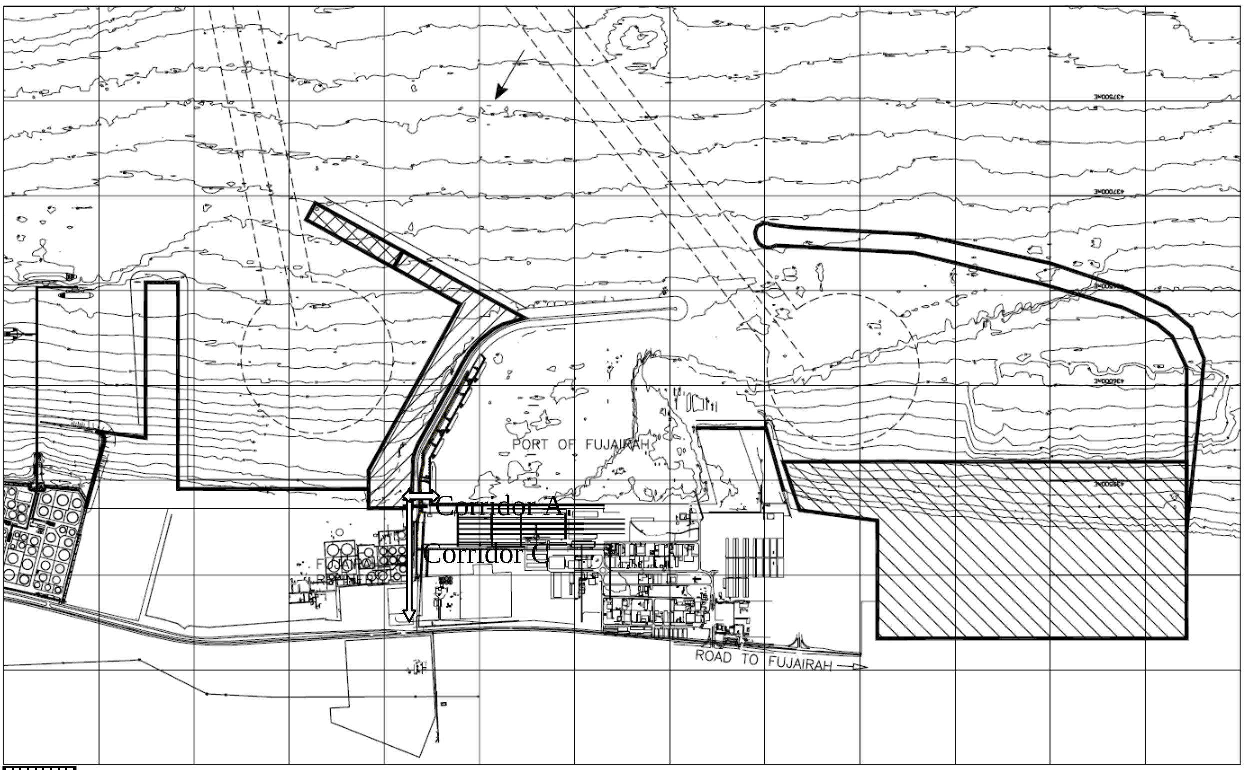
With this port layout it will be necessary to make an adjustment to the existing port and the part of the port that is currently under construction. It is assumed in this part of the study that it is necessary to remove the seaward part of the existing southern breakwater and a part of the new South Breakwater Berth. An advantage of this layout will be the extra protection of the existing port against penetration of swell from southern directions.

The total length of the dry bulk quay walls is 1960 m. The two quays do not form an enclosed basin. It is assumed that one single breakwater, attached to the existing northern breakwater gives sufficient shelter against waves to keep downtime within acceptable limits. The loading of dry bulk vessels has a rather large critical wave height. The downtime due to exceedence of the critical wave height will be investigated in this study.

It must be taken into account with the generation of alternatives for the liquid bulk terminal that the entrance channel for this alternative partly runs through the proposed area for the Open Sea Tanker Terminal. Probably an alternative location will have to be chosen for the new liquid bulk terminal. It may be possible to construct the new terminal directly south of VHFL.

<u>Layout A4</u>

An alternative for the dry bulk terminal for layout A3 is to attach the western quay to the new breakwater. It is expected that wave height at the eastern quay will be less than at the western quay. The required amount of soil material for the reclamation of land in this solution will be higher as well as the amount of material for the coastal protection works. Further, absence of the western quay wall makes it possible to realize the liquid bulk terminal, north of the turning circle.In layout A4 a strip of land is planned at this location. The function of this strip is to partly realize the liquid bulk terminal onshore. The feasibility of reclaiming land in stead of construction of offshore trestle bridges is to be investigated in Annex 8, layout evaluation. Layout A4 is shown in figure 5.5



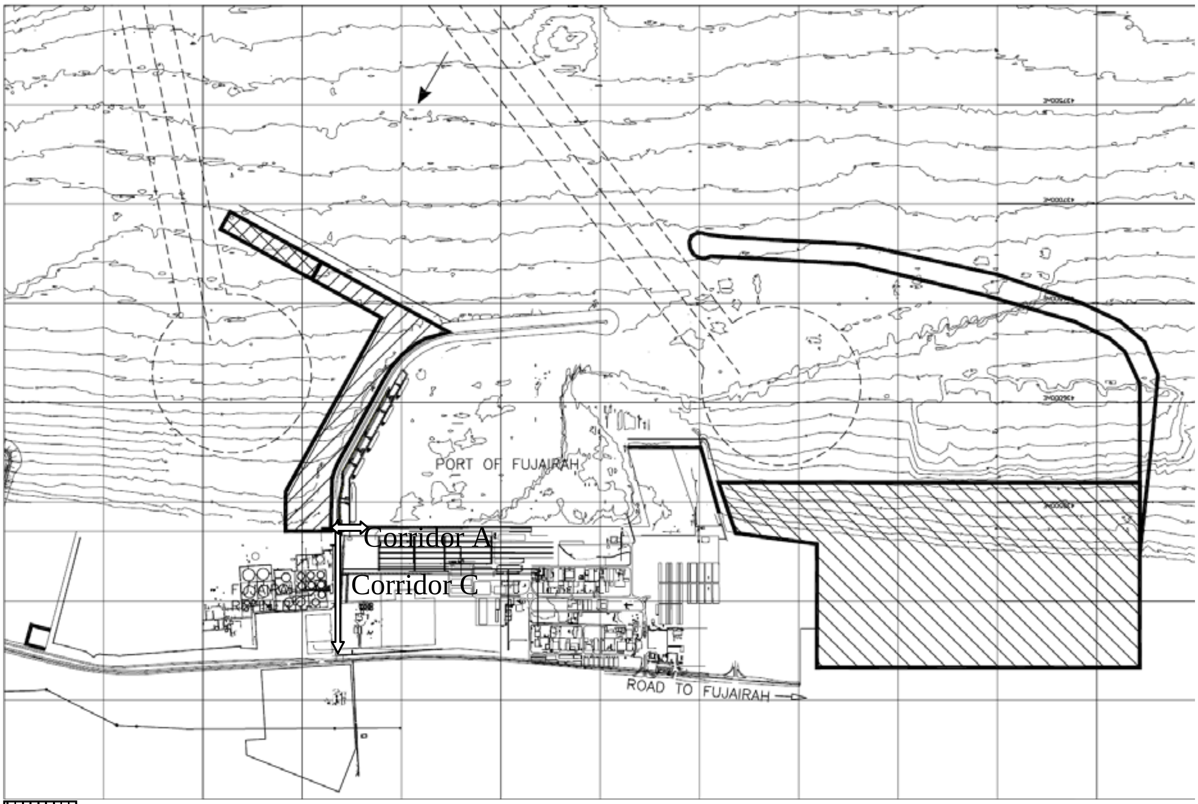
Dry bulk terminal
Container terminal

5.5 Sketch of the proposed harbour expansion layout A4

Additional to the advantage of reduced wave height at the quay, harbour basin layout A4 gives the possibility to realize the liquid bulk terminal, north of the Port.

Layout A5

Harbour basin layout A5 is based on harbour basin layout A4. These layouts differ by the reclaimed strip of land that is proposed in layout A5, directly south of the VHFL terminal. In stead of reclaiming land and using pipe racks, off shore trestle bridges are proposed in this layout.



Dry bulk terminal
Container terminal

5.6 Sketch of the proposed harbour expansion layout A5

5.3 General layout of the Open Sea Tanker Terminal, section B

5.3.1 Introduction

The proposed layout for the Open Sea Tanker Terminal is related to the preferred layout for the harbour basin. The existing OTB has two berths that are able to handle one medium size vessel or two smaller vessels up to 15,000 DWT. It is assumed that the existing OTB will be used for the handling of smaller ships up to 15,000 DWT. In this way the current facilities are able to handle four vessels up to 15,000 and one vessel up to 90,000 DWT simultaneously. The small vessels are more vulnerable for waves. The handling of these vessels in the sheltered harbour basin will minimize downtime due to wave motion. The new terminal will handle the cape size vessels up to 165,000 DWT. These ships are less vulnerable for wave motion and currents. As mentioned in paragraph 4.7.3, five new berths are required to be able to provide the capacity for scenario 1and three new berths for scenario 3.
With the generation of alternatives, the following is taken into account:

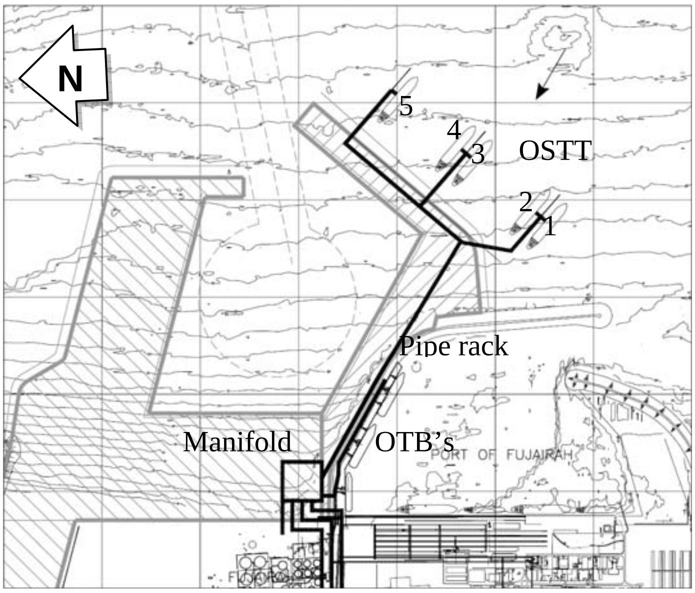
- A short connection to manifold is preferred. The pipeline routing is preferably over land since pipe racks are less expensive than trestle bridges.
- The dominant wave direction is preferably on the heads of the moored ships.

- Access to the berths must be easy with sufficient manoeuvring/turning space. Approach lines should not cross the other harbour entrances.
- The oil terminal is preferred to be located away from other commodities like containers and dry bulk.

5.3.2 Proposed layouts liquid bulk terminal

Layout B1

In layout B1 the liquid bulk terminal is located southeast of the new harbour basin. This location is appropriate for all proposed harbour basin layouts. This location gives a relatively short connection with the new storage facilities. This layout is shown in figure 5.7.

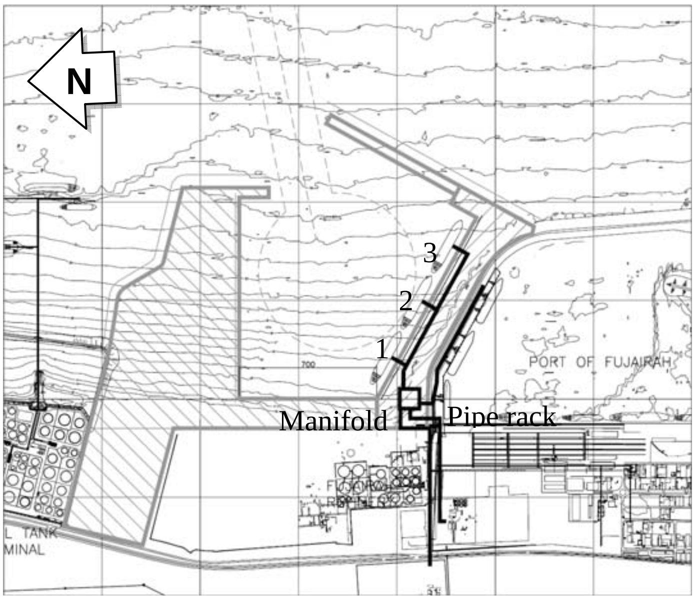


5.7 Sketch of the proposed OSTT layout B1 and harbour basin layout A1

Berths are orientated parallel to the dominant wave direction as preferred. An onshore pipe rack connects the manifold with the new berths. The existing OTB's will be connected to this manifold as well. Three finger piers stretch out perpendicular to the Eastern quay wall. These finger piers are all connected via an abutment to an onshore pipe rack, running parallel to the Eastern dry bulk quay wall. The liquid bulk terminal can be constructed in phases, starting with the first finger pier, berth 1 and 2. This layout provides the possibility to expand the number of new berths to 6 since north of berth 5 an extra berth can be realized if necessary. The construction of a pipe rack is relatively cheap and can be executed quick and simultaneous to the construction of the finger piers. The water depth at the location of the OSTT is between CD-16 m and CD -24 m. This means that some dredging will be necessary to bring the shallow part to the depth required for the larger oil tankers expected in Fujairah.

Layout B2

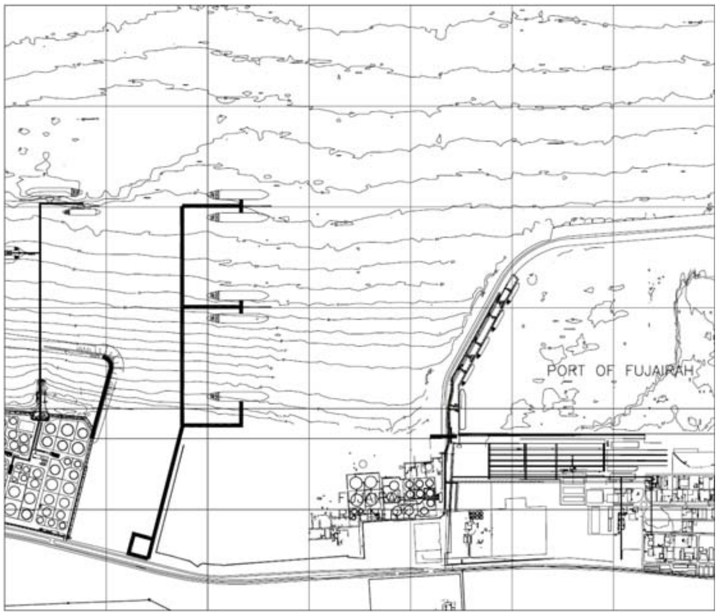
When the demand for storage capacity does not follow the rapid growth as described by scenario 1 and 2, it will possibly not be necessary to build the liquid bulk terminal outside the harbour basin. In this case the dry bulk terminal can be relocated in the new port. For this scenario layout B2 is proposed. This layout is shown in figure 5.8.



5.8 Sketch of the proposed OSTT layout B2 for harbour basin layout A2

In layout B2 the liquid bulk berths take the position of the dry bulk berths at the Southern quay. Dry bulk is handled at the Western quay wall. It may be possible use a jetty at the liquid bulk berths in stead of a quay wall. Besides the fact that the costs of a jetty will possibly be lower than the costs of a quay wall, this has the advantage of a low wave reflection coefficient of the light revetment over the full reflection of a vertical wall. This means that the reflected wave height at the Northern container quay wall will be less which can bring a significant reduction in the downtime on this quay. Waves from the Northeast reflected by the new Southern quay wall, attack container vessels at the Northern quay at the bow. From this angle of attack, vessels are most sensitive.
If the demand for storage and throughput capacity grows significantly, expansion of number of liquid bulk berths is possible by construction of extra berths attached to the Southern breakwater or at open sea as proposed in layout B1.

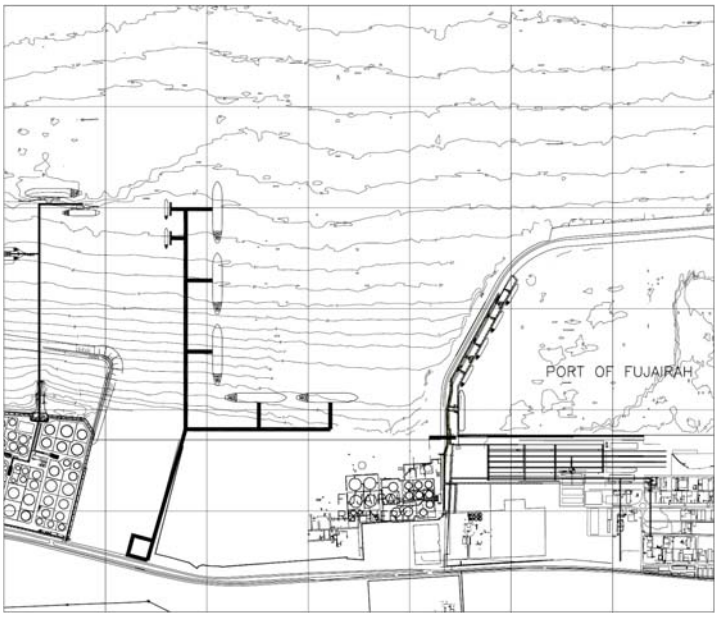
Layout B3
Layout B3 presents the proposed liquid bulk terminal directly south from the VHFL terminal. This location is merely feasible when the container terminal is realized south of the existing port according to layout A3, A4 or A5. The absence of the northern quay of the northern port expansion in this layout provides the possibility to realize the new oil terminal directly south from VHFL. Oil terminal with layout B3 can be realized partly onshore with harbour layout A4 or as a jetty with layout A5. Layout B3 is shown in figure 5.9.



5.9 Sketch of the proposed OSTT layout B3 for harbour basin layout A5

Layout B4

Liquid bulk terminal B4 is located north of the new turning basin. Merely the alignment of the berths differs from layout B3. Layout B4, can only be realized in combination with harbour basin layout A3, A4 and A5. Oil terminal with layout B3 can be realized partly onshore with harbour layout A4 or as a jetty with layout A5. Layout B4 is shown in figure 5.10.



5.10 Sketch of the proposed OSTT layout B4 for harbour basin layout A5

5.4 Land areas

5.4.1 Reclamation project

The main function of the new reclaimed north of the port expansion project land will be to serve the demand for space for oil storage facilities in the vicinity of the Port of Fujairah and the planned Port of Fujairah expansions. Besides for oil storage tanks, the new reclaimed land will also give room for other industrial developments in Fujairah such as the new planned cement factory.

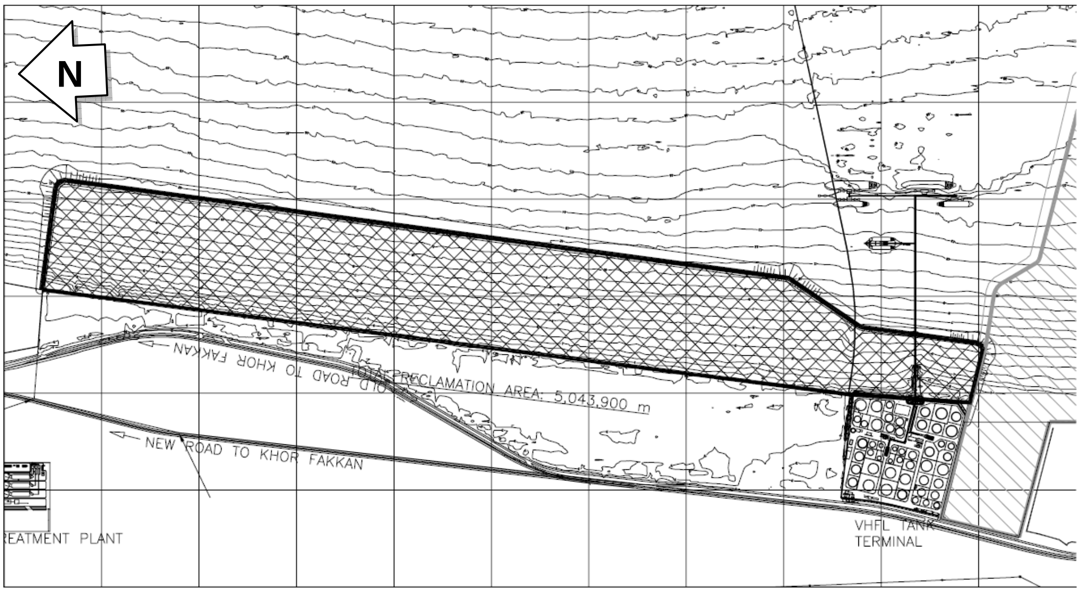
The outer limits of this reclamation project are defined by the Naval base in the North and the Port expansion of the port of Fujairah in the South. The proposed width of the new reclaimed land is 500 m from the existing coastline to the new coastal protection. There are no alternative layouts proposed in this study since this study focuses on the Port Expansion Project. The total surface of the new gained land will be:

- West of existing coast line 500 ha
- East of existing coast line 225 ha

There are two main different approaches to realize this reclamation project;

1) The material with which the new land is reclaimed, is gained by deepening the sea bottom east from the new coast line. This solution is further mentioned in this report as: “dredging solution”.
2) The new reclaimed land is built up from material gained by blasting several parts of the mountainous area west from the road between Fujairah and Khor Fakkan. This solution is further mentioned is this report as “blasting solution”.

The construction will be carried out simultaneously with the construction works of the expansion of the Port of Fujairah. The use of dredged material for the reclamation project will also influence the choice for the layout of the port of Fujairah since a dredging surplus will be used for the reclamation project if the dredging solution is selected.
Study to this subject has made clear that the construction cost for dredging and blasting are comparable. The area of the land that is reclaimed from the mountains is relatively small. Further blasting has the disadvantage that blasting the required material takes roughly twice as long as the dredging construction time. The Municipality of Fujairah has indicated that this factor will be decisive.
The surface level of the new reclaimed land and the rest of the project area are set at CD + 5.0 m. This is the same surface level as the VHFL terrain on the South boundary of the project area.



5.11 Layout Reclamation Project

Figure 5.11 shows the proposed layout of the reclaimed area.

<u>Al Sodha area</u>

The project area lies west from a more or less flat land between the mountainous area and the shore line.
Between these mountains and the shore also lies the road between Fujairah and Khor Fakkan. This road was formerly curving around a small village called Qurayya. Currently construction works are carried out to change this profile into a straighter route. Several houses of the village have already been removed to make this possible.

East from the road, the land is entirely flat without any masses of rock. The main requirement is that available space is utilized as efficient as possible. This means that as much square meters must be gained as possible within the set boundaries. Not only the area East from the road is considered but also the area between the road and the mountains must be taken into account. This will have effect on the choice between the dredging and the blasting solution. If the blasting solution is chosen, the total area will finally be bigger which will be an advantage for this solution.

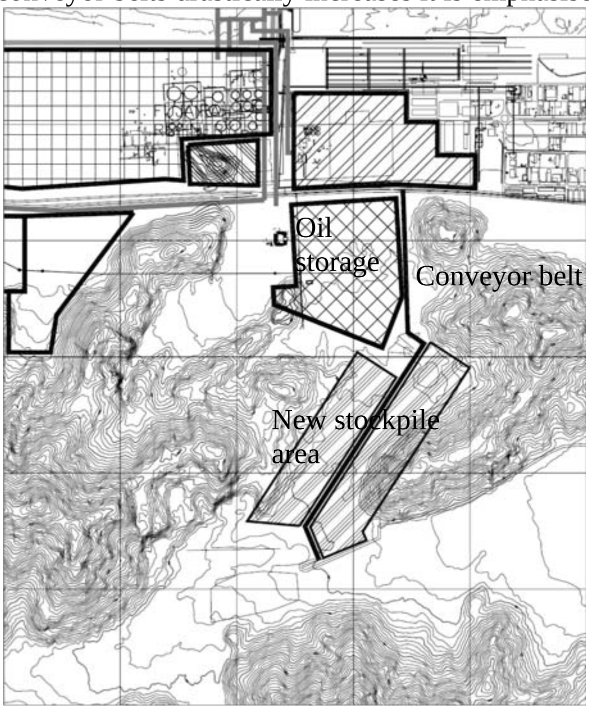
Interaction with VHFL berths

The reclamation project area also covers a strip of land in front of the VHFL terminal. Part of this terminal is an existing jetty for loading and unloading of oil tankers. There is a certain interaction between the reclamation project and the jetty because of the change of the wave climate due to reflection. Currently the coast in front of the VHFL parcel is a beach. Since waves brake on a beach there is no reflection of waves towards the berths on the jetty.

If certain critical wave heights are exceeded it is no longer possible to load or unload vessels on this jetty. If the wave climate at the jetty changes, this may possibly have an effect on the downtime of this jetty. Coastal protection works will reflect a larger part of the waves than a beach. It is therefore necessary to asses the wave climate at the location of the VHFL berths. The proposed layout will therefore have to be evaluated on the effect that it has on the downtime at the VHFL jetty. An other aspect that should be paid attention to is the manoeuvrability around the jetty.

5.4.2 Aggregate stockpile area

The proposed location of the expansion of the aggregate stockpile area is at the location of the existing stockpile area. However the required land for storage of aggregates, space for loading points and conveyor belts drastically increases it is emphasised that there is still enough room for expansion.



5.12 Proposed location of the new aggregate stockpile area

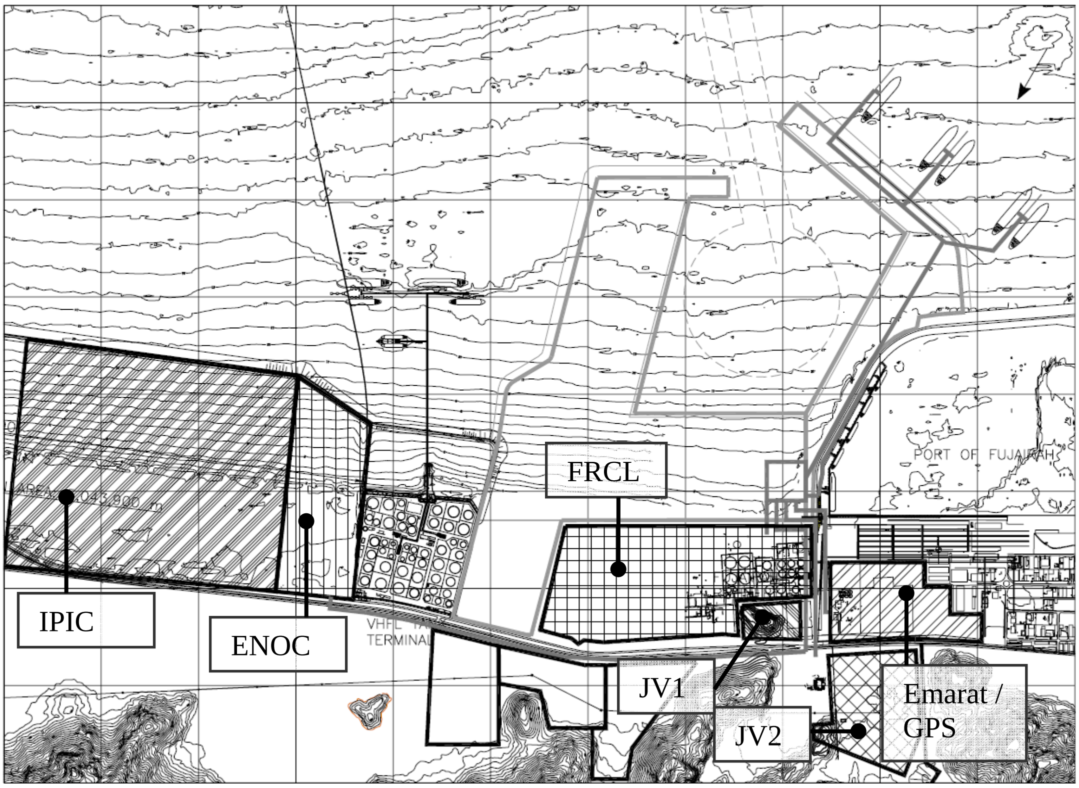
5.4.3 Oil storage areas

Oil storage facilities are planned at several locations in the vicinity of the Port of Fujairah. The total new area available for oil storage is 326 ha, distributed over 6 different locations as shown in figure 5.13. The areas of these locations are given in table 5.1.

FRCL refinery	69 ha
JV1	5.5 ha
JV2	26 ha
Emarat GPS	25 ha
ENOC	40 ha
IPIC	160 ha
Total 165.6	326 ha

table 5.1 Areas oil storage facilities in Fujairah

With the relation of 3.5 m^3/m^2, the assumed possible storage volume on the available area is 11.4 million m^3. This volume can be increased to 12 million m^3 for scenario 1, by using higher tanks or larger diameters.



5.13 Proposed areas for oil storage

To build extra storage facilities west of the road to Khor Fakkan, rock will have to be removed. The feasibility of reclaiming parts of the mountainous area will have to be studied.

5.4.4 Container terminal

In layout A1, the space available for the container terminal is 178 ha. This is sufficient for a container terminal with a yearly throughput of 3 M TEU. The available space in layout A2 for the container terminal is 102 ha. This is more than enough for a container terminal with a throughput of 1 M TEU. In fact it might be possible to increase the throughput of the terminal to approx. 2 M TEU with the available space for storage and quays. This would mean however that the Western quay wall would be used for container handling and the growth of dry bulk throughput capacity is restricted. The available space in layout A3, A4 and A5 for the container terminal is 165 ha which is sufficient for a container terminal with a yearly throughput of 3.5 M TEU.

5.5 Chemical berths

Merely scenario 1 requires berths for handling of chemical. Two berths for vessels up to are planned, north of the reclaimed area behind the new northern quay wall for harbour basin layouts A1 and A2. For harbour basin layouts

6 Selection of most promising alternative

6.1 Introduction

In this chapter the layouts proposed in the previous chapter are evaluated. The large number of different combined throughput scenarios, the number of combination layout alternatives, their limitations and the phasing of the project, make it very complicated to carry out this evaluation. Consequently it is indispensable to simplify the stated problem.
The joint proposed harbour basin layouts and liquid bulk terminal layouts will be evaluated. Several of these combined layouts can not achieve the throughput capacity for the highest growth scenario. As a result no valid comparison can be made between layouts that are capable of providing scenario 1 throughput, and the layouts in which it is not possible to achieve this throughput.
The evaluation of layouts is carried out for three groups of layouts. These are the layouts that can achieve the required throughput for the three scenarios. For each group the layouts are evaluated using two different techniques. A monetary evaluation is performed as well as a multi criteria analysis. The two evaluations are coupled by a cost per value point rating.
The proposed harbour layout combinations including intermediate phasing are shown in Annex 2 to this report. The monetary evaluation, as well as the multi criteria analysis, are described in detail in Annex 8.

6.2 Simplifications

6.2.1 Combination of throughput scenarios

The first simplification is the combination of the composed throughput scenarios. In reality it may be possible that the demand for throughput capacity for one commodity will grow strongly as for other commodities the throughput capacity will lag behind. For a practicable evaluation however this will give too many possibilities. It is assumed that correlated development of demand in throughput capacity is not unrealistic. This simplification results in the reduction of the number of scenarios to the total of 3.

6.2.2 Combination of layouts and phasing

The layouts, as discussed in the masterplan report are combinations of layout alternatives for the new port harbour basin and for the liquid bulk terminal. The liquid bulk terminal is planned to be an open sea terminal. There are five alternatives for the harbour basin and four alternatives for the liquid bulk terminal. Finally nine layout combinations will be discussed in this annex. These are the following combinations:

1) A1 – B1 Harbour layout 1 and liquid bulk terminal layout 1
2) A2 – B2
3) A2 – B1
4) A3 – B1
5) A4 – B3
6) A4 – B4
7) A5 – B1

8) A5 – B3
9) A5 – B4

6.3 Multi criteria analysis

The layout alternatives will be assessed by multi criteria analysis (MCA). A multi criteria analysis is a decision making tool developed for complex problems. It is particularly applicable to cases where a single criterion approach, such as cost-benefit analysis falls short. The MCA will be used to asses the alternatives by a number of unequal validated criteria.

6.3.1 Objectives

To carry out the MCA, clear objectives should be specified. The main objectives for the expansion of the Port of Fujairah are summarized as follows:

- Flexibility in throughput capacity expansion.
- Optimization of handling facilities efficiency
- Optimization or improvement of safety

Costs are not part of this analysis since these are quantitative and the multi criteria analysis uses qualitative criteria. The proposed layout alternatives will be the options for achieving the above mentioned objectives. Each criterion will be given a specific weight.

Flexibility in throughput capacity expresses not only the possibility of the port layout alternative to expand in size, but also to adapt when the relative position of commodities and their throughput changes. This means that this objective gives two criteria that will both be assessed for the terminal area as well as the water area in the port. Further this objective gives the criteria of serving larger ships in the future. Larger vessels will give other requirements for turning basin and channel dimension and water depth of the harbour basin.

- The possibility to expand
- The possibility to adapt
- Possibility of serving larger ships

The objective of handling facility efficiency comprises the following subjects.

- Downtime due to hydraulic effects such as wave penetration and currents.
- Length of transport lines, distances of the berths to stacking areas and storage tanks.

Safety is subdivided into the following two subjects:

- Nautical safety
- Terminal safety

The subject of minimizing or reduction of hazard to the environment is partly classified under the objective of nautical safety, terminal safety. It is assumed that the difference between the considered layouts has no influence on the hazard to the environment or the urban areas.

6.3.2 Criteria validation

Criteria for the MCA are validated as shown in table 6.1.

Criteria	Growth possibilitie	Layout adaptability	Increasing vessel size	Downtime hydraulic ef...	Length of transport l...	Nautical safety	Terminal safety	Total	Weighted score [%]
Growth possibilities	X	1	1	1	1	1	1	6	29%
Layout adaptability	0	X	1	0	0	0	0	1	5%
Increasing vessel size	0	0	X	0	0	0	1	1	5%
Downtime hydraulic effects	0	1	1	X	1	0	1	4	19%
Length of transport lines	0	1	1	0	X	0	0	2	9%
Nautical safety	0	1	1	1	1	X	1	5	24%
Terminal safety	0	1	0	0	1	0	X	2	9%
Total								21	100%

table 6.1 Weighted score criteria

From table 6.1 it can be seen that growth possibilities are the most important criteria. For each layout a score between 0 and 3 will be given for each individual criterion. This score can be explained according to the following list:

- 0: Has effects that are opposite to the objectives
- 1: Hardly any positive or negative influences
- 2: Has a positive effect on achieving the objectives
- 3: Meets the objectives

6.4 Monetary evaluation

Beside the MCA, a monetary evaluation is carried out. In this evaluation, the proposed technical civil and marine designs (discussed in chapter 7 and annexes 4 – 7) are used to determine the project cost for all proposed layout combinations. The construction costs for the final layout are estimated as well as construction the costs for the intermediate phases.
This monetary evaluation is discussed in detail in Annex 8.

6.5 Evaluation scenario 1

6.5.1 Introduction scenario 1

Scenario 1 describes the highest growth in the demand for throughput capacity. Merely the harbour basin layouts A3, A4 and A5 will be part of this evaluation since these are the only layouts that can follow the anticipated growth according to scenario 1. This paragraph describes a monetary evaluation and multi criteria analysis, carried out for the following layout combinations:

4) A3 – B1
5) A4 – B3
6) A4 – B4

7) A5 – B1
8) A5 – B3
9) A5 – B4

6.5.2 Capacity and phasing scenario 1

Since quay length, number of berths is equal for all layouts it is assumed in this paragraph that the throughput capacity of all layout combinations is equal. In reality the capacity will differ somewhat because of different berth configurations. However taking this into account, reaches beyond the scope of this study. This means that the evaluation of these layouts will purely be based on cost and other aspects excluding throughput capacity.
The capacity of these layouts for three construction phases is given in Annex 8. Following the growth according to scenario 1, the following phasing is proposed:

- 2007 - Construction of phase 1:
- 2012 – Construction of phase 2
- 2022 – Construction of phase 3

6.5.3 Cost scenario 1

Costs are given by net present value, at the end of the project span in 2032. For this calculation a discount rate of 7% is taken into account. Only the costs for civil and marine works are taken into account. Since costs for mechanical works, super structures and benefits are assumed to be comparable for all layout alternatives, these are excluded from this calculation. Also the loss of income due to the unavailability of the area south of the port is left out of the NPV calculation since this is equal for all layouts. Merely factors that are unequal are taken into

	A3B1	**A4B3**	**A4B4**	**A5B1**	**A5B3**	**A5B4**
NPV 2032	$ -460.5 M	$ -506.0 M	$ -496.6 M	$ -464.8 M	$ -480.6 M	$ -477.0 M

table 6.2 Net present value 2032, layout alternatives scenario 1

From table 6.2 it can be concluded that the net present value for layout A3B1 in 2032 will be higher than for all other layout alternatives. For the layouts with the liquid bulk terminal north of the harbour basin, layout A5B3 has the highest NPV in 2032. The following conclusions can be drawn:

- It is more economical to realize a new quay wall at the west of the new harbour basin harbour basin (layout A3) than east of the harbour basin (layout A4 and A5)
- It is more economical to realize the liquid bulk terminal, attached to the new southern breakwater than north of the harbour basin.
- Realization of an offshore liquid bulk terminal on trestle bridges is less expensive than an on shore terminal on new reclaimed land. Even when it is taken into account that dredged material from the harbour can be used.

6.5.4 Multi criteria analysis scenario 1

For the proposed layouts, each criterion as described in paragraph **Error! Reference source not found.** will be given a score in this paragraph.

Growth possibilities
Layout A3B1 and A5B1 give the possibility to expand the harbour further in northern direction since the liquid bulk terminal is realized north of the existing port. It would be possible to expand until a harbour layout similar to the proposed layout A2 is reached. This means that roughly 1000 m extra quay length can be realized. The liquid bulk terminal is expandable up to 6 berths very easily. Further expansion of this terminal is possible in southern direction.
The other layouts have less expansion possibilities. It is possible to expand the liquid bulk terminal at the location of layout B1. This however would mean extra investments on pipe racks to this location. Extra quay length will be hard to realize within these proposed layouts. It would be necessary to use the harbour basin of the container terminal, south of the existing port for further expansion.
The expansion possibilities of the container terminal are not evaluated. The container terminal layout is similar for all proposed layouts for scenario 1.

Layout adaptability
Since all layouts have the same quay length distribution, this criterion is of minor importance for the evaluation of the scenario 1 layouts. Each layout will be valued equally.

Increasing vessel size
Increasing design vessel size will have an effect on the radius of the turning basin. The basin radius is critical for the layouts with liquid bulk terminal layout B3 and B4. These layouts will also require deepening of the harbour basin when larger liquid bulk vessels are expected in the port.

Downtime hydraulic effects
The downtime of the liquid bulk terminal due to exceedence of wave height or current velocity is expected to be lower for the liquid bulk terminal layouts inside the harbour basin (B3 and B4) than outside the harbour basin (B1). Further the berths that are aligned parallel to the coastal protection are expected to be more sensitive for wave action than the berths perpendicular to the shore. Further the berths that are aligned parallel to the dominant wave direction are also expected to be more vulnerable for waves. The berths inside the harbour basin are expected to be less sensitive for currents. Especially for layout A4 in which the berths are sheltered by the reclaimed area.
The eastern quay in layout A4 and A5 is more sheltered than the western quay of layout A3. This means that less downtime is expected for these layouts.

Length of transport lines
The length of the conveyor belts for the layouts A4 and A5 is significant longer (1000 m) than for layout A3. The liquid bulk terminal layouts B3 and B4 makes it possible to construct several pipe lines directly to the tank farms on the new reclaimed land, north of the port. The length to the central manifold is the same length as for layout B1.

Nautical safety
The vessel manoeuvring in the turning area in front of liquid bulk terminal layout B1 may hinder the vessels that approach the existing harbour basin. This approach line has turned northward as the existing southern breakwater is reconstructed. On the other hand, the reduction of the amount of vessels in the new harbour basin may create a safer situation in this part of the port.

Terminal safety
With the realization of the liquid bulk terminal north of the new harbour basin (B3 and B4), liquid bulk handling and storage are centered at one location. Layout B1 will require oil handling in the direct vicinity of several dry bulk handling facilities. However this is feasible, separate handling is preferable.

The above mentioned arguments are used to compose an MCA matrix, given in table 6.3. It can be seen that layout alternative A5B1 has the highest score. This can be explained by the good expansion possibilities and low sensitivity for wave action for the dry bulk berths. Layout A3B1 seems to be the second best option close to layout A5B1.

Criteria	Growth possibilities	Layout adaptability	Increasing vessel size	Downtime hydraulic effects	Length of transport lines	Nautical safety	Terminal safety	Weighted score [%]
Weight factor	29%	5%	5%	19%	9%	24%	9%	
A3 – B1	3	1	2	2	3	1	1	2.00
A4 – B3	1	1	0	2	2	1	2	1.32
A4 – B4	1	1	0	2	2	1	2	1.32
A5 – B1	3	1	2	3	1	1	1	2.01
A5 – B3	1	1	0	2	2	1	2	1.32
A5 – B4	1	1	0	1	2	1	2	1.13

table 6.3 Multi criteria analysis

6.5.5 Cost per value point scenario 1

The monetary evaluation is coupled to the multi criteria analysis by composing a cost per value point rating. This rating is given in table 6.4 in which NPV of 2032 is divided by value points. This table shows that layout A3B1 has the lowest cost per value point. It can be concluded that layout A3B1 not only is the cheapest layout that can achieve scenario 1 throughput but also that this layout has good qualitative properties.

A3B1	A4B3	A4B4	A5B1	A5B3	A5B4
$ 230.2 M	$ 383.2M	$ 376.1M	$ 231.2M	$ 364.1M	$ 422.1M

table 6.4 NPV per value point

6.5.6 Conclusion scenario 1

The conclusion can be drawn that if it is desirable that the new port expansion should reach the throughput capacity as described by the combined scenario 1, layout A3B1 would be the most favourable layout followed by layout A5B1. This means that the area south of the existing port should be part of the Port Expansion plans.

6.6 Evaluation scenario 2

6.6.1 Introduction scenario 2

Scenario 2 describes medium growth in the demand for throughput capacity. Layouts A3, A4 and A5 have a comparable throughput capacity. In the previous paragraph, the conclusion was drawn that layout A3 is the most favourable layout. Further evaluation is carried out, only with layout A3. With layout A2 it is not possible to reach throughput capacity for scenario 2. The following layouts will be evaluated in this paragraph:

1) A1 – B1
4) A3 – B1

6.6.2 Capacity and phasing scenario 2

The capacity of the evaluated layouts is not equal over the proposed phasing. To achieve the required capacity for scenario 2, the following phasing is proposed:

- 2007 - Construction of phase 1 for both layouts.
- 2012 – Construction of phase 2 for layout A1B1
- 2022 – Construction of phase 3 for layout AB1, phase 2 for A3B1

6.6.3 Cost scenario 2

Costs are given by net present value, at the end of the project span in 2032. For scenario 2, an equal discount rate of 7% is used as for scenario 1. Only the costs for civil and marine works are taken into account. Since costs for mechanical works, super structures and benefits are assumed to be comparable for all layout alternatives, these are excluded from this calculation.
Since for layout A3B1, the area south of the port is used for the expansion of the container terminal, the loss of income of the lease of this land is included in the NPV calculation. The net present value at the end of 2032 is given in table 6.5. However for layout A3 it is necessary to construct a very costly new breakwater, the cost of the reclamation works that are required for the container terminal of layout A1 exceeds the cost of coastal protection works for layout A3.

	A1B1	**A3B1**
NPV 2032	$ -452.9 M	$ -503.5 M

table 6.5 Net present value 2032, layout alternatives scenario 2

From table 6.5 it can be concluded that the net present value of the civil and marine works, including loss of income due to unavailability of land is highest for layout A1B1.

6.6.4 Multi criteria analysis scenario 2

For both layouts, each criterion will be given a score in this paragraph.

Growth possibilities
The growth possibilities for layout A3B1 are significantly better than for layout A1B1. At the end of phase 2032 layout A1B1 has run out of expansion possibilities as quay walls are constructed at all sides of the harbour basin. Since only phase 1 and 2 of Layout A3B1 need to be realized to achieve the required throughput capacity, growth possibilities are better. When the land south of the port the port is leased out, it is assumed to be impossible to regain this for port expansion.

Layout adaptability
All commodities concentrated around one harbour basin will increase the flexibility of allocating functions to quay walls. This means that layout A3B1 would be less flexible.

Increasing vessel size
The enclosed harbour basin of layout A1B1 is assumed to be less flexible. However for this layout, vessel sizes of up to 400 m are considered. It is expected that for many years, this will be supply for all ships entering the Port of Fujairah.

Downtime hydraulic effects
For both layouts additional study on wave penetration and downtime will have to be executed. It is expected that downtime on the western container quay for layout A1B1 can be significant due to waves from directions 75º – 105 º. The harbour basin is relatively open for waves from these directions. It is advised that only the larger container vessels use this quay. Especially in the intermediate project phases

where the harbour basin is not enclosed by breakwaters, downtime due to wave motion is expected to be high.
Aggregate vessels are less sensitive for wave motion. The open character of the northern expansion is therefore not expected to cause significant downtime.

<u>Length of transport lines</u>
The southern quay wall for layout A1B1 is located 500 m further eastward than the southern quay wall for layout A3B1. This means that the length conveyor belts as well as pipe lines are 500 m longer for layout A1B1 than for layout A3B1.

<u>Nautical safety</u>
Some interference between the vessels, approaching the existing harbour basin and the new liquid bulk terminal is expected. The changed alignment of the approach channel for the existing basin with layout A3B1 has a negative effect on safe navigation.
The approach to the new harbour basin, north of the port according to layout proposal A1B1 will cause interference with ships approaching the VHFL terminal.

<u>Terminal safety</u>
The location of the container terminal in the direct vicinity of petrochemical industry with layout A1B1 might be seen as a disadvantage. Layout A3B1 offers a location for the container terminal, free from other commodities that can threat safety on the terminal.

The above mentioned arguments are used to compose an MCA matrix, given in table 6.6. It can be seen that layout alternative A3B1 has the highest score. This can be explained by the good expansion possibilities for layout A3 and pour possibilities for layout A1 and by the exposure to waves of the intermediate phases of layout A1B1.

Criteria	Growth possibilities	Layout adaptability	Increasing vessel size	Downtime hydraulic effects	Length of transport lines	Nautical safety	Terminal safety	Weighted score [%]
Weight factor	29%	5%	5%	19%	9%	24%	9%	
A1 – B1	0	2	1	0	1	1	1	0.57
A3 – B1	3	1	1	2	2	1	3	1.95

table 6.6 Multi criteria analysis scenario 2

6.6.5 Cost per value point scenario 2

The monetary evaluation is coupled to the multi criteria analysis by composing a cost per value point rating. In table 6.7 the NPV, divided by the number of value points is given.

A1B1	A3B1
$ -794.6 M	$ -258.2 M

table 6.7 NPV per value point scenario 2

6.6.6 Conclusion scenario 2

It can be concluded that layout A3B1 is the most favorable layout although layout A3B1 has higher construction cost. The reduction of the project cost by using dredged material for the Fujairah land

Reclamation project, the lease of the land south of the existing port play an important role in the assessment.

6.7 Scenario 3

6.7.1 Introduction scenario 3

Scenario 3 describes low growth in the demand for throughput capacity. Layouts A3, A4 and A5 have a comparable throughput capacity. In the previous paragraph, the conclusion was drawn that layout A3 is the most favourable of these layouts. The following layouts will be evaluated in this paragraph:

1) A1 – B1
2) A2 - B2
3) A2 – B1
4) A3 – B1

6.7.2 Capacity and phasing scenario 3

The capacity of the evaluated layouts is not equal over the proposed phasing. To achieve the required capacity for scenario 3, the following phasing is proposed:

- 2007 - Construction of phase 1 for all layouts.
- 2008 – Construction of phase 2 for layout A2B2
- 2012 – Construction of liquid bulk terminal phase 2 for layout A1B1 and A3B1 and construction of phase 2 for layout A2B1.
- 2022 – Construction of phase 3 for layout A2B1

It must be noted that achieving the required throughput of scenario 3 for layout A1B1 and A3B1 for the last project will higher berth occupancy and cause longer waiting times with this phasing.

6.7.3 Cost scenario 3

Costs are given by net present value, at the end of the project span in 2032. A discount rate of 7% is used as for scenario 1. Costs for mechanical works, super structures and benefits are assumed to be comparable for all layout alternatives; these are excluded from this calculation. Included in the calculation is the rental rate of the area south of the port for layout A3.

	A1B1	**A2B2**	**A2B1**	**A3B1**
NPV 2032	$ -271.6 M	$ -270.9 M	$ -306.7 M	$ -470.5 M

table 6.8 Net present value 2032, layout alternatives scenario 3

From table 6.5 it can be seen that the cost for layout alternative A3B1 are high. This can be explained by the fact that the initial costs for this alternative are high. For layout A1B1 construction of a breakwater attached to the southern quay is included in the calculation. This breakwater is necessary to keep downtime due to wave motion at the container terminal within acceptable limits.

6.7.4 Multi criteria analysis scenario 3

Growth possibilities
Growth possibilities after 2032 are sufficient for layout A1 and very good for layout A3. Layout A2B1 and especially layout A2B2 have less possibility for expansion.

Layout adaptability
Since expansion is centered north of the existing port for layouts A1 and A2, these alternatives give more possibilities for modification of commodities at the quays. Especially layout A2B2 is very suitable for adjustment of quay length or number of berths per commodity.

Increasing vessel size
This criterion is validated equally for all layouts.

Downtime hydraulic effects
For scenario 3 it will not be necessary to finalize the complete layout A1B1 to reach the required capacity. The first phase does not comprise construction of a breakwater. Container vessels are very sensitive for wave motion and are berthed parallel to the dominant wave direction. This means that additional protection will be necessary. For calculation of project cost, construction of a breakwater in phase 1 is considered. Although this breakwater will reduce downtime, vessels will still be very vulnerable for waves from the Northeast. The liquid bulk terminal layout B2 is sheltered behind breakwaters and will suffer less from waves or currents.

Length of transport lines
Transport lines will be longer for layout A1B1. Piping will be shorter for layout A2B2.

Nautical safety
In layout alternative A2B2, berthing takes place is inside the sheltered harbour basin. The approach line of the VHFL terminal is free for layout A1B1 and A3B1.

Terminal safety
In layout alternatives A1B1, A2B1 and especially A2B2 the container terminal is operated in the direct vicinity of the liquid bulk terminal.

The above mentioned arguments result in the following matrix. It can be seen that the harbour layout A3B1 reaches the highest score.

Criteria	Growth possibilities	Layout adaptability	Increasing vessel size	Downtime hydraulic effects	Length of transport lines	Nautical safety	Terminal safety	Weighted score [%]
Weight factor	29%	5%	5%	19%	9%	24%	9%	
A1 – B1	2	2	1	1	1	2	1	1.34
A2 – B2	0	2	1	3	3	2	1	1.56
A2 – B1	1	1	1	2	2	2	1	1.52
A3 – B1	3	1	1	2	2	1	2	1.95

table 6.9 Multi criteria analysis scenario 3

6.7.5 Cost per value point

The cost per value point rating is given in table 6.10.

A1B1	A2B2	A2B1	A3B1
$ -202.7 M	$ -173.7 M	$ -201.8 M	$ -241.3 M

table 6.10 NPV per value point scenario 3

6.7.6 Conclusion

From table 6.10 it can be seen that the most favorable layout alternative is A2B2 for scenario 3. Layout A3B1 reaches a higher score in the MCA but construction costs are too high to make this layout cost effective, with a low economical growth.

6.8 Most promising alternative

The results of the multi criteria analysis and monetary evaluation can be summarized as follows:

- When it is desired that scenario 1 or scenario 2 throughput can be achieved the most promising layout alternative is harbour basin layout A3 in combination with liquid bulk terminal layout B1.
- When it is desired that only scenario 3 throughput can be achieved, the most promising layout alternative is harbour basin layout A2 in combination with liquid bulk terminal layout B2.

Harbour basin layouts A1, A4 and A4 as well as liquid bulk terminal layout B3 and B4 do not form the most favorable solution in any case. Layouts A3B1 and A2B2 have several elements in common. These are the location and alignment of the southern and western quay walls and the, geometry of the dredged basin for the expansion works, north of the existing port.

7 Technical designs

7.1 Introduction

In this chapter, technical designs of the civil and marine parts of the port expansion are proposed. These designs are not discussed in detail in this report but are further described in Annex 4, Annex 5 and Annex 7 to this report. The designs where used for the cost estimations that where part of the monetary evaluation of the proposed harbour layouts.

7.2 Quay wall design

The technical design of the quay walls is discussed in Annex 4 to this report. For all quay walls in the layout the same design has been considered.

The most favorable type of quay wall cost as well as construction time wise is a combi sheet pile wall. The specific dimensions of this structure are given in table 7.1. The quay wall is designed for a depth of CD – 18.0 m, the surface level of the reclamation (and top of the quay wall is CD + 4.75 m. So the retaining height of the structure is 22.75 m). All the quay wall designs are based upon the same geometry. The quay wall design is assumed to be a combi wall structure.

Tubulars	L = 28.5 m Ø = 1.42 m d = 16 mm
Infill sheeting	Larssen 605 W = 600 mm L = 22 m
Copping beam	$4.0 \cdot 3.5\,m^3$

table 7.1 Specific dimensions quay walls

For the back anchoring of the combi wall structure several systems and options have been looked at. Self drilling anchors with grout cover tie back anchors to a sheet pile wall, both with Dywidag rods or bundled strand tendons.

7.3 Coastal protection works

The design of coastal protection works is discussed in Annex 5 to this report. In this annex a design proposal is given for four main parts of the coastal protection works. These are:

- Revetment section in the exposed areas
- Breakwater part. (water on both sides)
- A breakwater round head and convex bends in the revetment sections.
- Revetment section in the sheltered areas

For both sections the stability of several slopes and stone weights for wave loads with different return periods are tested.

The design of the coastal protection works can be summarized as follows:

Slope: 1:2 on the exposed sections,
1:1.5 on the sheltered sections
1:3 for the breakwater roundhead and convex bends

Crest height: CD + 8.5 m (with crown wall)

Component	Material	Gradation	Thickness (m)
Amour layer	Rock	4 – 7 ton	2.5
under layer	Rock	0.3 – 1 ton	1.25
Toe	Rock	0.3 – 1 ton	3
Core	Quarry run	0 – 1000 kg	

table 7.2 Summary design revetment straight section

7.4 Liquid bulk terminal

The design of the open sea tanker terminal is discussed in Annex 7 to this report. The design of the terminal is assumed to be equal for all finger piers.

The Open Sea Tanker terminal is built up from the following elements:

- Concrete product platforms on steel piles on which the loading arms are installed.
- Concrete breasting platforms founded on steel piles.
- Concrete mooring platforms founded on steel piles.
- Steel catwalks between breasting, mooring and product platforms .
- Steel access bridges from the shore to the product platforms. These access bridges are founded on concrete platforms and steel piles. The length of the bridges is 37.5 m each.

The trestle bridges carry a minimum of 8 pipes with a diameter of 16”.

8 Conclusions and recommendations

8.1 Conclusions

- The current cargo flow and the anticipated growth in the demand for throughput capacity require a throughput capacity that can not be provided by the current facilities of the Port of Fujairah. Especially current dry bulk export facilities are under dimensioned.
- The wave climate of the waters in front of Fujairah is mild. Current velocities are low.
- When it is desirable that the new port expansion should be able to achieve throughput as described by scenario 2 or scenario 1 representing moderate to strong growth, it is indispensable that the area south of the existing Port of Fujairah is part of the expansion project. This means that it is necessary to reserve space for port expansion south of the existing port of Fujairah. The most favorable harbour basin layout to reach the required capacity for moderate or high growth is harbour basin layout A3 and liquid bulk terminal layout B1.
- When economic growth is limited according to scenario 3, describing weak growth the most favorable harbour layout is A2B2. In this layout liquid bulk is handled inside the new harbour basin, north of the existing port. The area south of the port can be used for other purposes.
- The existing aggregate export and liquid bulk handling facilities can remain operational in the Port of Fujairah. Container handling is more efficient when all facilities are concentrated in the new port expansion. The remaining space in the existing port is advised to be utilized for anticipated growth in the number of RoRo vessels, general cargo ships, cruise ship and ship repair facilities.
- The most favorable type of quay wall cost as well as construction time wise is a combi sheet pile wall. The most favorable type of armour for coastal protection is rock.

8.2 Recommendations

- Many assumptions in the basic data where made to be able to carry out this study. The assumptions require changes when more data is available to increase the validity of the outcome of this study.

8.2.1 Further study

It is recommended that further study preformed on the following subjects:

- Wave penetration in the new harbour basins and downtime due to waves and currents at the quays as well as at the liquid bulk terminal.
- Ship manoeuvrability for the proposed harbour layouts. Manoeuvring to new and existing harbour basin, new liquid bulk terminal and the existing VHFL terminal.
- Project cost of super structures (cranes and conveyor belts) and project benefits.
- Channel width and alignment optimization.
- Feasibility of single point mooring buoys in front Fujairah.

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A1 Annex 1: Derivation of boundary Conditions

Masterplan for the port of Fujairah Expansion Project

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A 1.1 General

In this section the site conditions, relevant for the design of elements of the new northern Port of Fujairah expansion, are described. All variables have units according to the international SI conventions. Wave and wind directions refer to the direction from which the waves and winds are coming. The direction is given in degrees, measured clockwise with respect to North.

Wind and wave data are presented in the form of wind and wave roses. Wind and wave roses provide a quick way of summarizing the directional wind and wave conditions statistics. The number in the centre of the rose represents the percentage of the time that calm conditions occur. The direction that the arm points in represents the direction that the winds or waves come from. The length of an arm represents the percentage of the time that winds or waves come from the corresponding direction. This can be seen in the bar (under the roses), which indicates the percentage represented by unit length. The width and pattern of a section of the arm indicate the corresponding speed or height class. The length of each section of the arm represent the percentage of the time that wind or waves come from that direction in a given speed or height class.

A 1.2 Data sources

In this document four different data sources where used to determine the boundary conditions. These sources are:

- Recordings from Port of Fujairah Marine Department;
- Recordings from the VHFL-jetty;
- Ship observations from Hydrobase;
- Satellite observations from Argos.

All to be found in the Data report annex 2 to 07-5211-Ph.1

At a distance of 500 m north of the proposed new port expansion, Vopak Horizon Fujairah Ltd. (VHFL) runs an open sea tanker terminal. At the jetty, measurements are being made on wave heights and directions, wind speeds and directions, water temperatures and current speeds. In this report, the results of these measurements are further mentioned as the records from the VHFL-jetty.

Measurements have been made with an instrument using the Doppler shift principle over orbital motion for wave heights and directions. Recordings are available over a fairly long period and they could have been the most important data source. The placement of the instrument however raises some questions about the reliability of the results. The instrument on the jetty is placed southwest from the largest berth on the jetty. During occupation of this berth, the instrument lies on the lee side of the ship for waves coming from the northeast. Most likely for this reason, waves from the northeast are poorly represented in the measurements results. Wave data from the measurements will be analyzed to check other sources but will not be decisive for the designs.

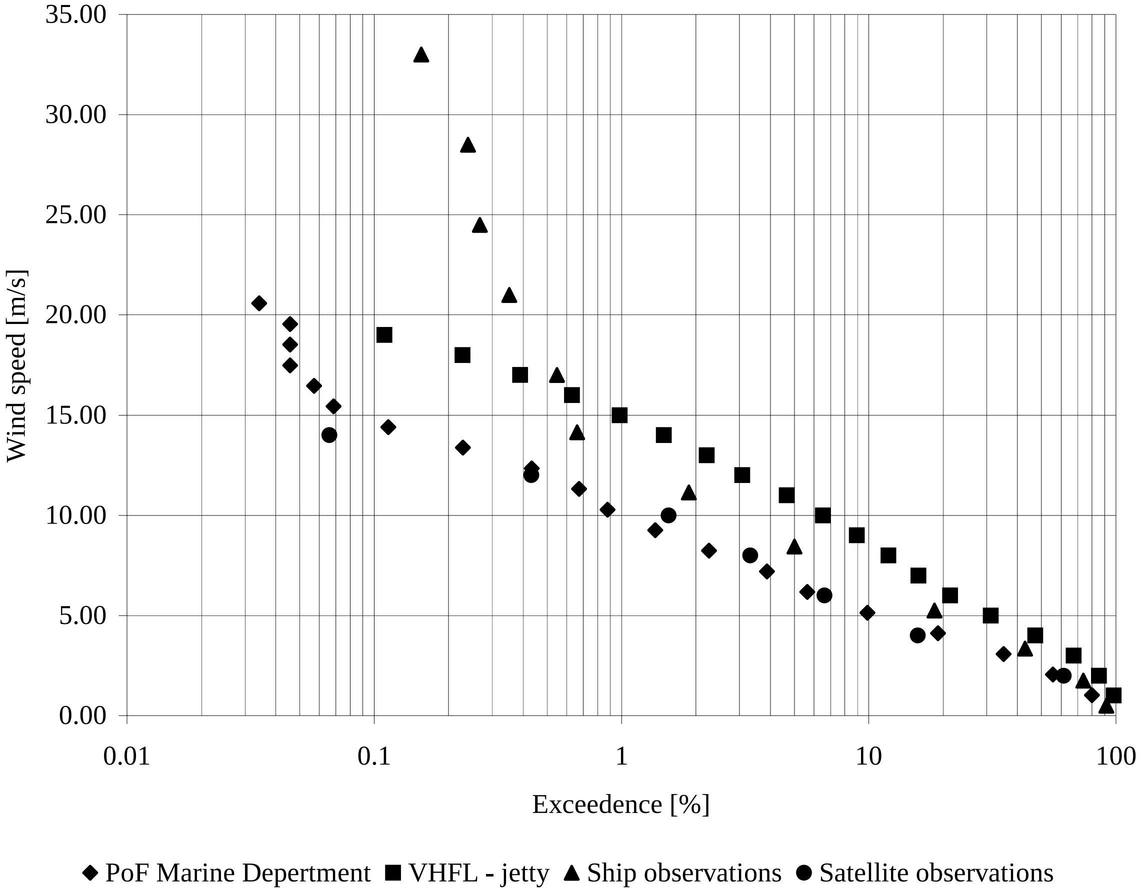
A 1.3 Environmental conditions

For the determination of the environmental boundary conditions, measurements by the Port of Fujairah Marine Department as well as ship and satellite observations are available. Wind and wave data from ship observations are derived from the Hydrobase database. Wind and wave data from satellite observations are derived from the Argoss database.

A 1.3.1 Wind

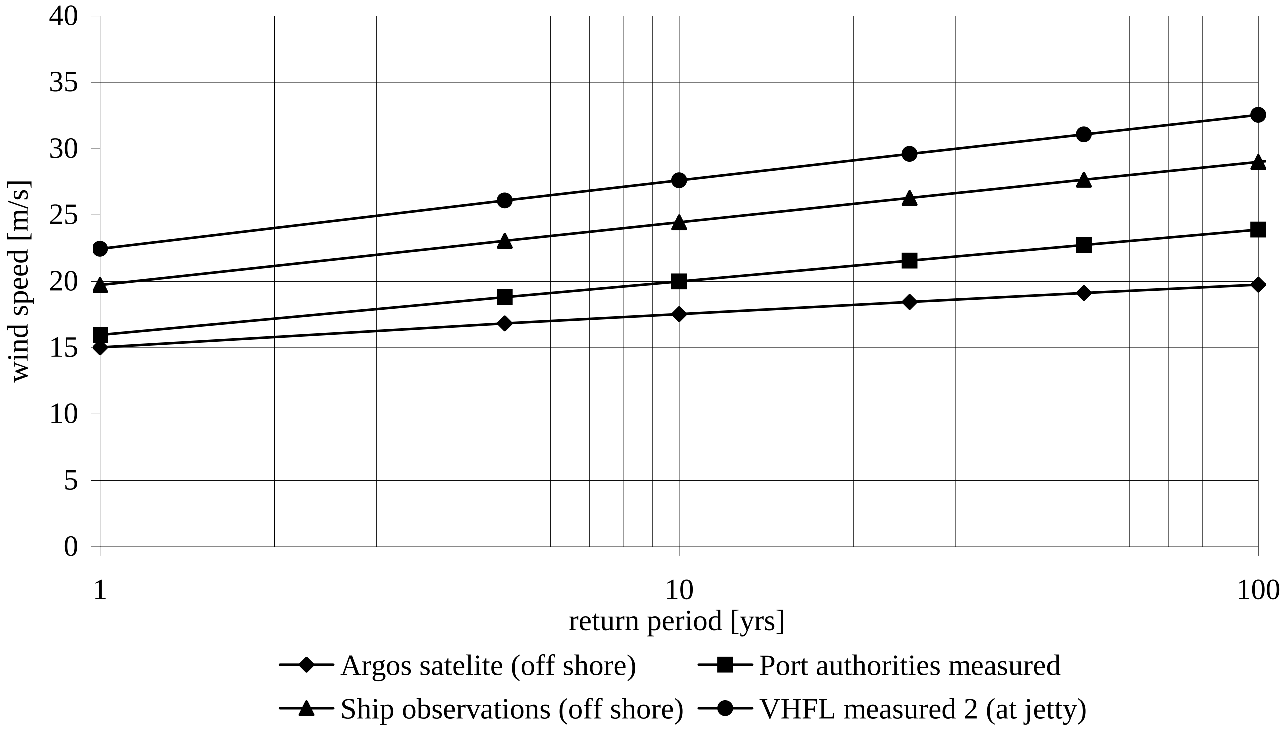
Winds in Fujairah are fairly light. According measurements and ship and satellite observations, wind speeds of 8 m/s are not exceeded 90 % of the time but strong winds from the west do occur. These winds are described as Katabatic winds by the Port Authorities. It is expected that these north-westerly winds are caused by the “Shamal” weather system.

In graph A 1.1, omnidirectional wind speeds according to four data sources are plotted. It can be seen that these sources show fairly consistent wind speeds. As the wind roses in figures1.1 to 1.6 show, wind directions according to available sources differ somewhat. This can be explained by the difference of the location where data is derived from and local influences like obstacles that block winds from certain directions.



graph A 1.1 Wind speed exceedence according to four data sources, omnidirectional.

For the available sources wind data, the extreme values were determined using a Weibull distribution. In graph A 1.2, the extreme omnidirectional values for these four sources are plotted. It can be seen that with a return period of 100 years, wind speeds of 34 m/s can be reached. These winds most likely come from the Northwest.



graph A 1.2 Extreme Wind speeds according to four data sources, omnidirectional.

For the determination of the wind climate, the following data sources where analyzed.

- Recordings from Port of Fujairah Marine Department;
- Recordings from the VHFL-jetty;
- Ship observations from Hydrobase;
- Satellite observations from Argos.

<u>Port of Fujairah Marine Department weather information</u>
According to the Port of Fujairah Marine Department weather information, the maximum wind speed is 37 m/s. This information states that generally, the winds at Fujairah are fairly light. Force 3 – 4 from the East or Southeast between the months of June to November. From November to May, winds are variable with occasional periods of strong winds (up to Force 10) from the West or Northwest. These strong Katabatic winds that occur in the late afternoons and evenings are associated to the nearby mountains.

The Port of Fujairah Marine Department hourly reports the state of the weather. Measurements of wind speeds and directions are part of this weather report. Figure 1.1 shows the annual wind rose of recordings made in the January 2005 to December 2005. This wind rose shows that the most and strongest winds come from the West. Percentages of occurrence of omnidirectional wind speeds according to records made by the Port of Fujairah Marine Department are distributed as shown in table A 1.1.

Wind speed (m/s)	Percentage of occurrence (%)
< 2.0	20.0
< 4.0	44.3
< 6.0	64.9
< 8.0	80.9
< 10.0	90.1
< 12.0	94.4
< 14.0	96.1

table A 1.1 Omnidirectional wind speeds according to records made by the Port of Fujairah Marine Department.

VHFL recordings

The wind data measured at the VHFL jetty was provided in the form of a time series of 10-minute average wind speed and direction (i.e. average taken over the previous 10 minutes) every 10 minutes for the period from April 2001 to January 2004. This series was converted to a time series of hourly averaged wind speed and direction. This was done by averaging the wind speed over one hour. The direction was taken by averaging the x component and the y component of the wind velocity and taking the vectorial direction of these averages.

Figure 1.2 shows the annual wind rose resulting from this analysis. This rose indicates that the wind conditions at the site are very mild, with winds less than 6 m/s for most of the time. For a small part of the time (3.3 %) Shamal winds occur from the Northwest of 6 m/s or more. Only very weak winds (<4 m/s) come from the Northeast. These wind conditions seem to be milder than suggested by the Port Authorities, although the directional characteristics are similar. Percentages of occurrence of omnidirectional wind speeds according to records made at the VHFL-jetty are distributed as follows:

Wind speed (m/s)	Percentage of occurrence (%)
< 2.0	14.6
< 4.0	52.8
< 6.0	78.7
< 8.0	88.0
< 10.0	93.5
< 12.0	96.9
< 14.0	98.5

table A 1.2 Omnidirectional wind speeds according to records made at the VHFL-jetty.

Ship observation

Figure 1.3 shows the annual wind rose for the wind climate based on ship observations. According to these observations, most winds are force 4 or less (less than 8 m/s). Wind speeds, higher than 8 m/s occur about 5% of the time. Most of the winds with these speeds come from westerly directions (i.e. from the land).
From the monthly wind roses, figures 1.4 and 1.5, it can be seen that in the period from December to March the dominant direction is from the West and Northwest. In the period from July to September the dominant direction is from the East and Southeast.

In general it may be expected that winds over open sea are significantly higher than wind over land because of boundary layer effects. Furthermore, if the wind is less than 8 m/s, the wind direction may be considerably different at the coast than on open sea due to the effect of sea breezes. Further, the high wind speeds from the West in the ships observations are also expected to be caused by the same Shamal weather system that causes the winds from Northwest at the coast. Percentages of occurrence of omnidirectional wind speeds according to ship observations are given in table A 1.3.

Wind speed (m/s)	Percentage of occurrence (%)
< .5	91.5
< 1.8	82.4
< 3.3	69.1
< 5.3	75.5
< 8.4	86.6
< 11.1	96.9
< 14.1	98.8

table A 1.3 Omnidirectional wind speeds according ships observations.

Satellite observations

Figure 1.6 shows the annual wind rose for the wind climate based on satellite observations. The centre of the area where this scatterometer data is derived from is at 25° 11'N, 57° 00'E. Data from 1232 passes is derived from an area with size 100 x 100 km.

The wind rose shows the offshore wind climate. The main wind directions are from the West and from the Southeast, where the strongest winds, up to 12 m/s come from the West. According to these satellite observations, most of the time wind speeds stays below 8 m /s. Wind speeds higher than 8 m /s occur about 4 % of the time. Percentages of occurrence of omnidirectional wind speeds according to satellite observations are given in table A 1.4:

Wind speed (m/s)	Percentage of occurrence (%)
< 2.0	61.5
< 4.0	54.4
< 6.0	90.8
< 8.0	96.7
< 10.0	98.2
< 12.0	98.9
< 14.0	99.6

table A 1.4 Omnidirectional wind according to satellite observations.

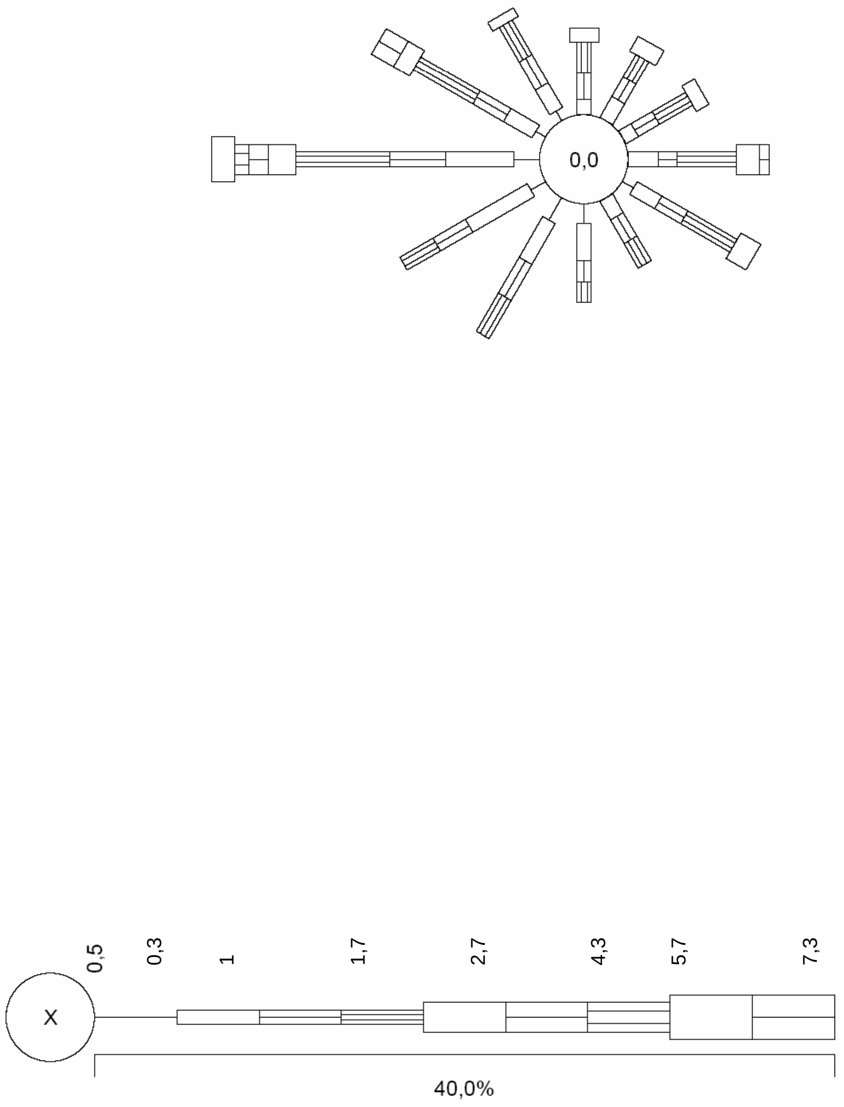


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Figure Title
Wind rose, Fujairah, source: P.o.F. Marine Department

Figure no:
A 1.1

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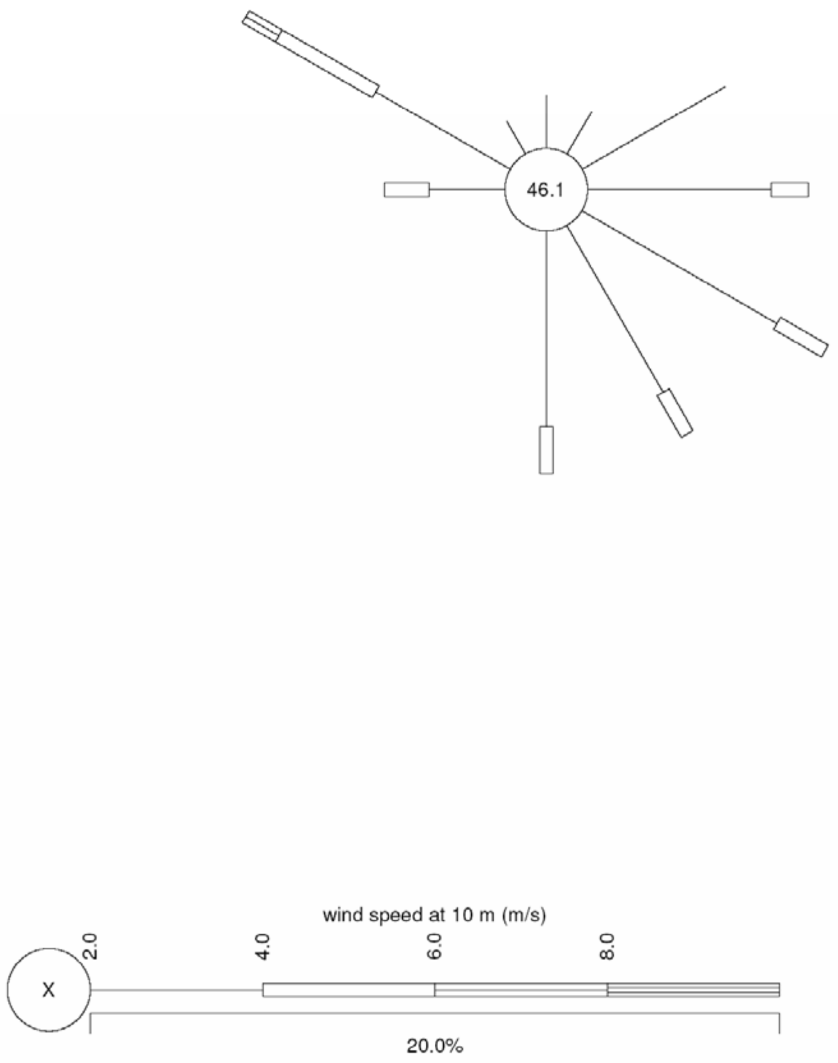

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Figure Title
Wind rose, Fujairah, source: measurements VHFL jetty

Figure no:
A 1.2

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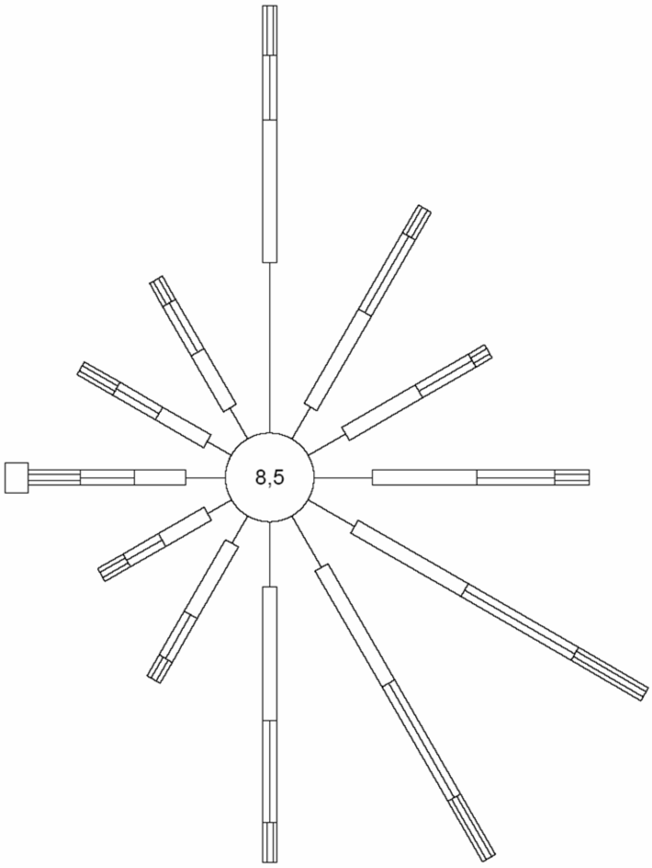

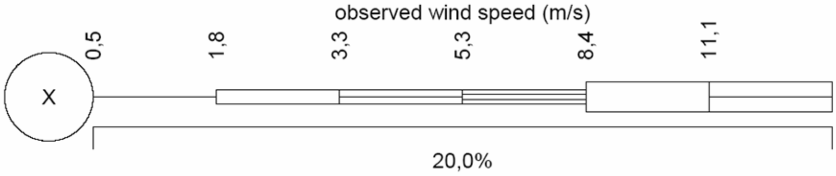

Project Title:
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Figure Title
Wind rose, Fujairah, source: ship observations

Figure no:
A 1.3

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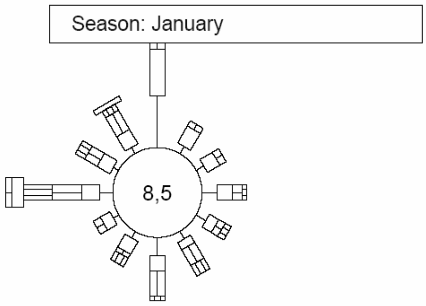

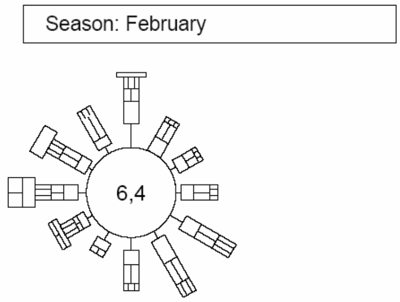

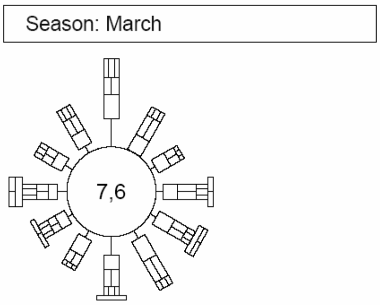

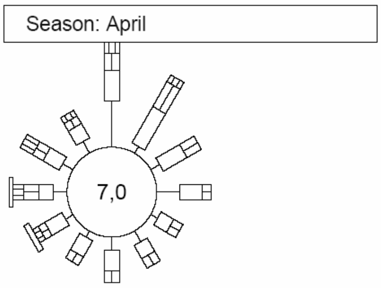

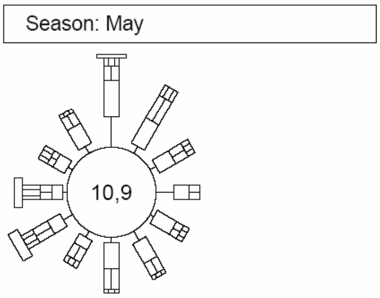

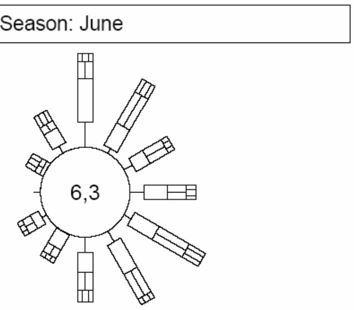

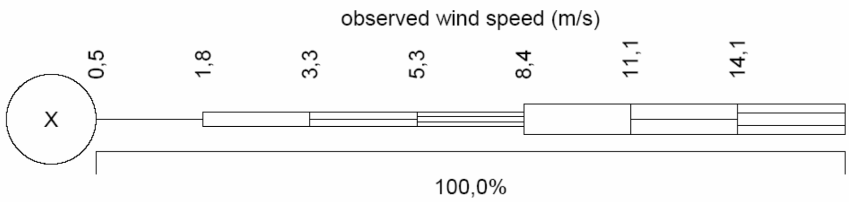

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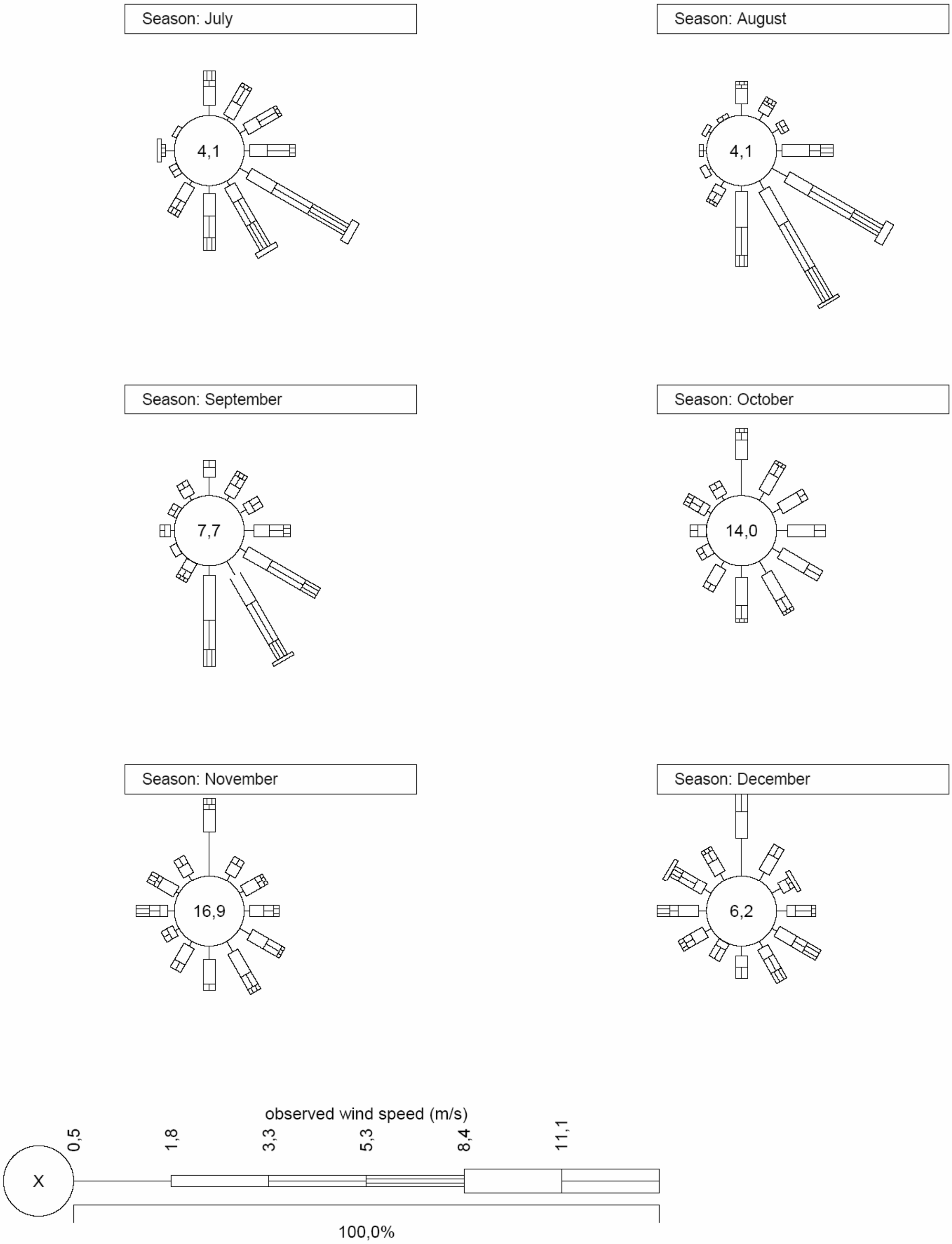
Figure Title
Wind roses seasonal, Fujairah, source: ship observations

Figure no:
A 1.4

M.U.C. Engineering



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Wind roses seasonal, Fujairah, source: ship observations

Figure no:
A 1.5

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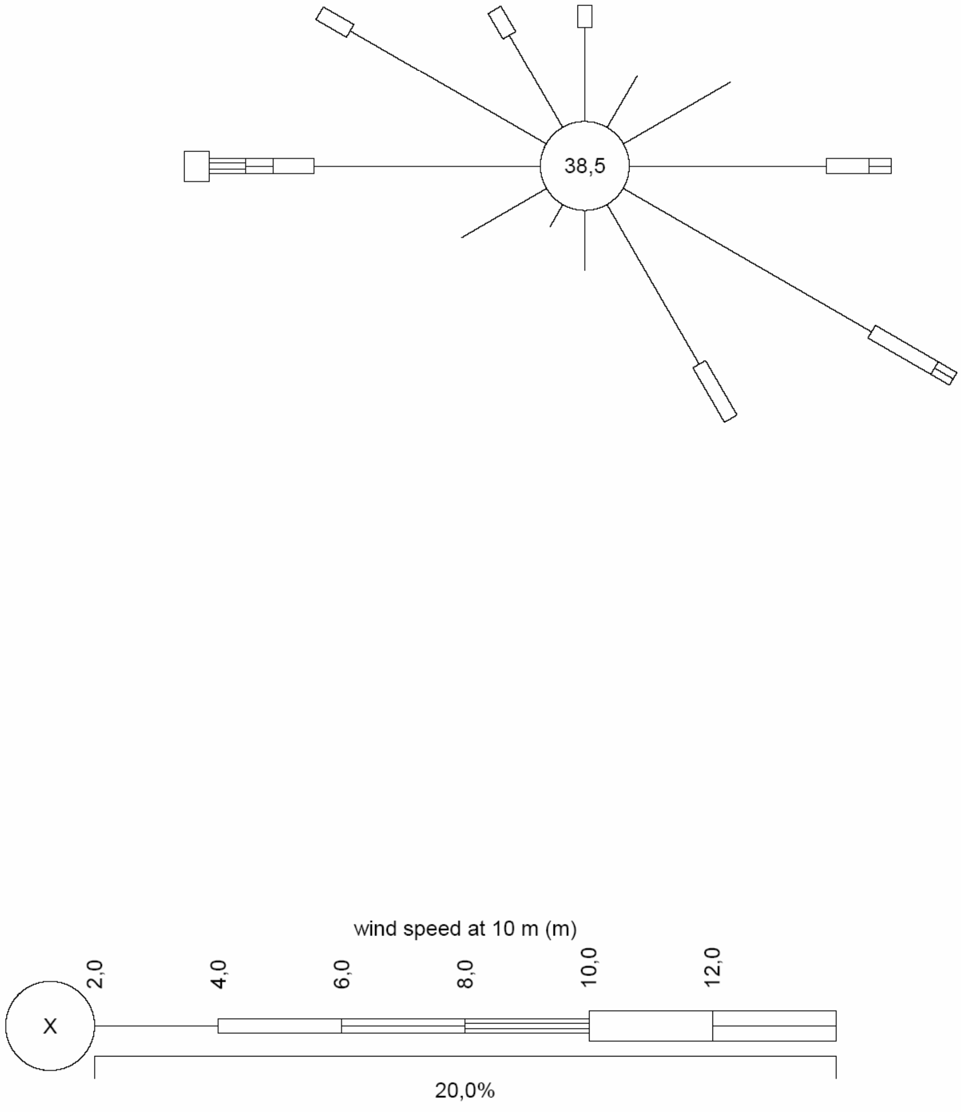


Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Wind rose, Fujairah, source: satellite observations

Figure no:
A 1.6

M.U.C. Engineering

A 1.3.2 Temperature

According to the Port of Fujairah Marine Department weather information, Fujairah has a tropical climate with a daily average temperature of 34.2°C in summer and 17.8°C in winter. Temperatures vary between 12.1°C and 24.5°C in winter and between 27.6°C and 42.3°C in summer.

A 1.3.3 Visibility

According to the Port of Fujairah Marine Department weather information, visibility at Fujairah is generally good but during strong offshore winds, there can be problems with dust. Visibility is still possible over a hundred meters, allowing berthing using modern navigation aids.
The Port of Fujairah Marine Department records weather conditions. According to these recordings the state of the weather for the year 2005 is described as follows:

State of the weather	**Percentage of occurrence (%)**
Cloudy	55.7
Hazy	25.1
Fine	17.4

table A 1.5 Percentage of time that the weather is in the given conditions based on observations by the Port of Fujairah Marine department.

A 1.3.4 Water levels

According to Port of Fujairah tidal information water levels are distributed as shown below:

Extreme High Water		FHD + 3.14 m
Highest Astronomical tide	HAT	FHD + 2.8 m
Mean Higher High Water	MHHW	FHD + 2.6 m
Mean Lower High Water	MLHW	FHD + 2.3 m
Mean Sea Level	MSL	FHD + 1.7 m
Mean High Lower Water	MHLW	FHD + 1.4 m
Mean Lower Low Water	MLLW	FHD + 0.2 m
Lowest Astronomical tide	LAT	FHD - 0.1 m

table A 1.6 Water levels

Water levels are indicated according to Fujairah Harbour Datum (C.D.).
Fujairah Harbour Datum = Admiralty Datum – 0.1 m

A 1.3.5 Sea water density and temperature

The seawater at Fujairah has a density 1024 kg/m^3. This value has been determined by sample analysis. The data report contains a copy of the certificate of this sample analysis. According to the Port of Fujairah weather information, seawater temperatures vary between 22° C and 24° C in winter and between 30° C and 33° C in summer.

A 1.3.6 Sedimentation and maintenance dredging

The harbour master reports that there is no maintenance dredging required in Fujairah. Regarding the current velocities and sediment characteristics not much sedimentation or erosion is expected.

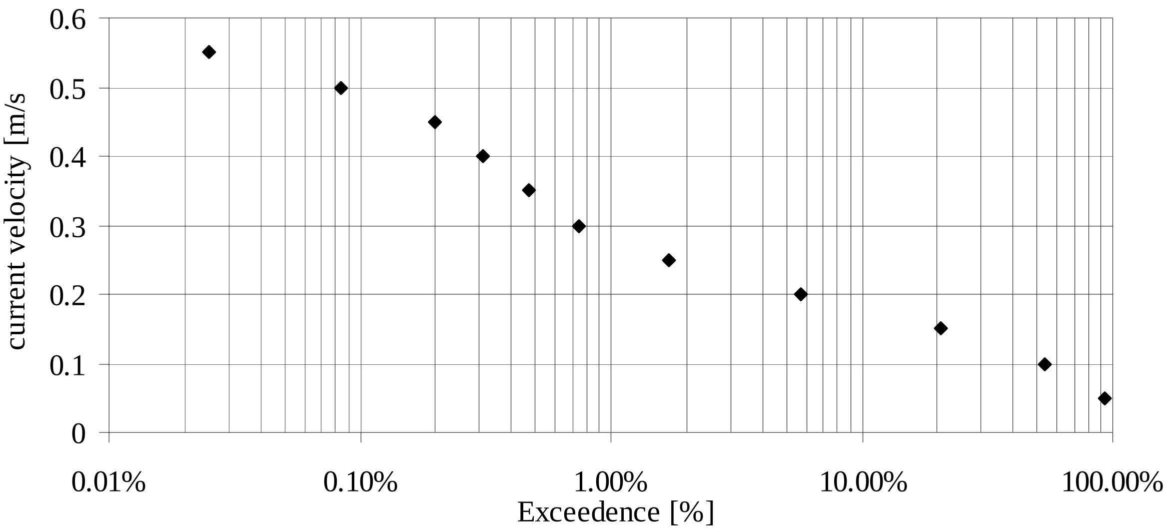
A 1.4 Currents

Current velocities at the location of the proposed Port expansion are relatively low, not exceeding 0.2 m/s most of the time. Currents are aligned parallel to the coast, mainly directed to the North but currents directed to the South do occur a few hours per day during low water and in July, during the Monsoon period.

At the location of the VHFL-jetty, current speeds and directions where measured hourly for several years. These measurements show a north-easterly directed current with velocities that are relatively low and do not exceed 0.18 m/s, 90 % In graph A 1.3 the exceedence of current speeds measured at the VHFL-jetty are plotted.

Current velocity(m)	**Percentage of occurrence (%)**
< 0.05	0.03
< 0.10	0.08
< 0.15	0.20
< 0.20	0.31
< 0.25	0.47
< 0.30	0.74
< 0.35	1.71
< 0.40	5.67
< 0.45	20.59
< 0.50	54.04
< 0.55	93.31

table A 1.7 Current velocities according to measuremtents made at the VHFL-jetty..



graph A 1.3 Exceedence graph of omnidirectional current velocities according to VHFL measurements

According to the Port of Fujairah Marine Department, the Arabian Sea Pilot indicates maximum current velocities of 0.39 m/s occurring during July (The Southwest Monsoon period). This current is aligned parallel to the coast in a Southerly direction. Observations made during the site investigations for the construction of the port showed currents not exceeding 0.26 m/s, with the direction flow being generally to the North and reversing to the South for a few hours during on of the low water periods each days.

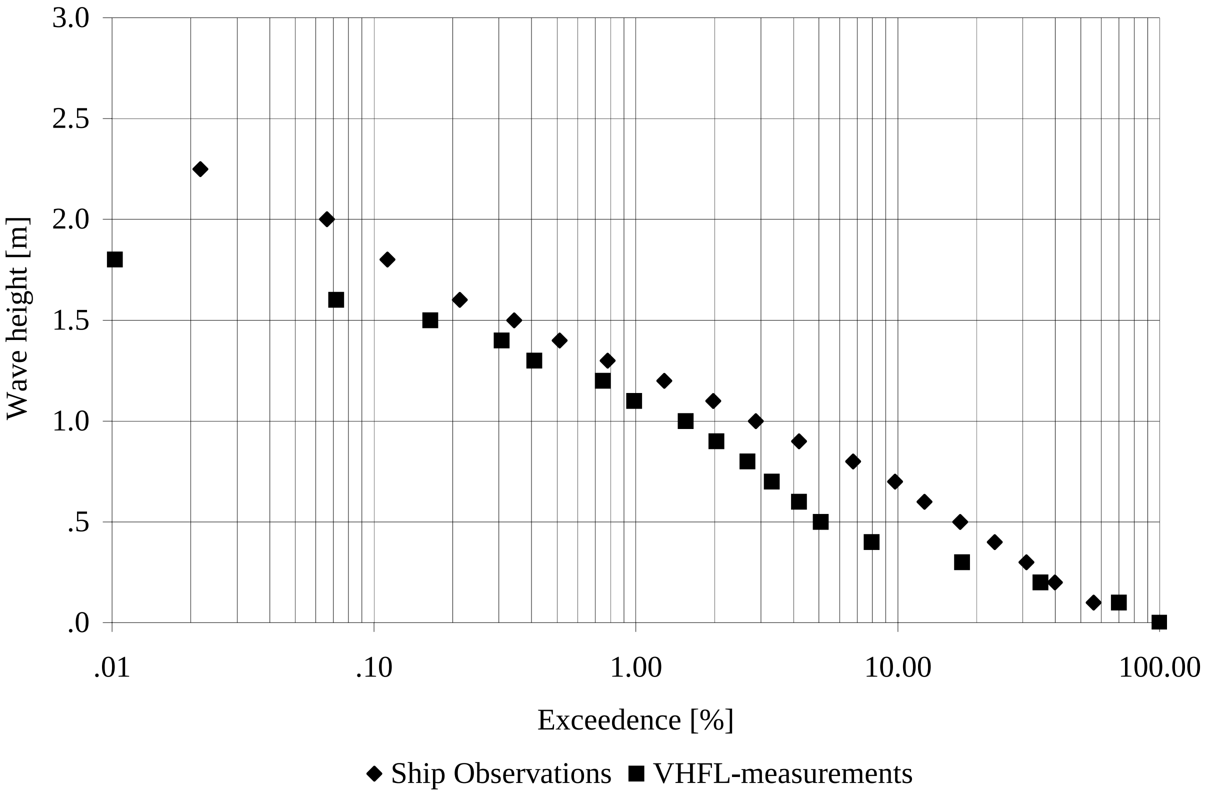
Floater measurements made in April and May 2006 confirm that southerly directed currents do occur and current velocities are relatively low. The average measured current velocity lies at 0.09 m/s and reach a maximum velocity of 1.2 m/s. Measurements are made at different spots at the location of the new port expansion according to the map in. A plot of the floater displacements shows generally southern directed currents. It must be regarded that the results of these measurements must be seen as momentary.

A 1.5 Waves

A 1.5.1 Normal wave climate

<u>Sumary</u>
The normal wave climate at the location of the proposed new Port expansion is mild. Waves are relatively low, only exceeding 1.5 m 0.5% of the time (1.8 days per year). The main wave direction is from the East and Southeast.
Wave data is available from ship and satellite observations and measurements at the VHFL-jetty.

In graph A 1.4 the wave height exceedence statistics for waves at the location of the VHFL terminal derived from ship observations and from measurements made at this location are plotted. It can be seen that the wave height distributions of the two wave climates are rather consistent.



graph A 1.4 Wave height exceedence by Ship observations and VHFL measurements

For the determination of the normal wave climate, both ship observations and measurements at the VHFL-jetty are considered. The wave height distributions of these wave climates agree very well but the wave climate based on ships observations contains significantly more waves from the Northeast than the wave climate according to the measurements at the VHFL-jetty. This can possibly be explained by the location where the measurements have taken place and the possible blocking of waves by moored ships at the VHFL-jetty. The measurement from the VHFL-jetty do also not represent all months. For these reasons, the emphasis is on the wave data from the ships observations as this includes waves from the Northeast and contains data from all months.

Wave heights for different directions at the location of the VHFL-jetty according to the transformed ship observations are distributed according to table A 1.8.

Hs (m)	**15° - 45° [%]**	**45° - 75° [%]**	**75° - 105° [%]**	**105° - 135° [%]**	**135° - 165° [%]**	**165° - 15° [%]**	**Total [%]**
> 0.2	7.86	4.96	7.43	12.67	6.71	.19	39.83
> 0.4	2.93	3.13	5.48	9.02	2.94	.01	23.51
> 0.6	1.03	1.42	3.48	5.53	1.20	.	12.66
> 0.8	.19	.72	2.23	3.23	.39	.	6.76
> 1.0	.06	.25	.96	1.40	.20	.	2.87
> 1.2	.02	.14	.37	.68	.08	.	1.28
> 1.4	.01	.06	.12	.29	.03	.	.51
> 1.6	.	.01	.06	.13	.02	.	.21
> 1.8	.	.	.03	.07	.01	.	.11
> 2.0	.	.	.01	.06	.	.	.07

table A 1.8 Percentages of time that the wave heights in the given direction are exceeded at the location of the VHFL-jetty according to transformed ship observations.

In this table the percentage of time is shown that wave heights are exceeded and come from the given direction and in the last column, the total percentage of time that wave heights are exceeded (joint probability of wave height and direction).

<u>Port of Fujairah Marine Department</u>
The Port of Fujairah Marine Department gives information on the state of the sea. In their record sea states are described in four ways; smooth, slight, moderate and rough.
For the year 2005 the state of the sea is described as follows:

State of the sea	**Percentage of occurrence (%)**
Smooth	65.1
Slight	31.6
Moderate	3.2
Rough	0.05

table A 1.9 Percentage of time that the state of the sea is in the given condition recorded by the Port of Fujairah Marine Department.

The directions of waves are not indicated. As stated, at the moments that rough seas are recorded, also high waves are measured at the VHFL jetty. It shows that the state of the sea is smooth or slight for most of the time. Although these data have a low accuracy and can not be used in further calculations, they are used to verify the moments that high waves are measured at the VHFL-jetty.

Port of Fujairah Marine Department gives information based on a study that has been carried out in 1979 for a location offshore of the harbour. This study can be summarized as follows:

Most severe waves come from the directions between East and Southeast with waves with an Hs of 3.5 m exceeded for 0.1% of the time and waves higher than 1.5 m exceeded for 0.5% of the time.
Moderately high waves also come from the North. East Northeast and South Southeast; where significant wave heights of 2 m are exceeded for 0.1% of the time
It should be born in mind that these wave conditions are offshore and should be expected to be milder close to the coast both due to sheltering and shallow water effects.

Measurements at the VHFL-jetty
Results of wave measurements are available from the period between December 2003 and February 2006. These measurements where made at the location of the VHFL-jetty, North of the proposed Port at a depth of CD -14 m.
These time series included the date, time, significant wave height, and main wave direction given at intervals of 30 minutes. Note that the data are not complete and that some months are poorly represented (March, April and December). However, there are sufficient data to give useful results. Figure 1.7 shows an annual wave rose, figure 1.8 and 1.9 show the monthly wave roses based on the measured wave data. It can be seen that the most severe wave conditions occur in the months January, July and August. Percentage of occurrence of omnidirectional wave heights according to records made at the VHFL-jetty are distributed as follows:

Significant wave height (m)	**Percentage of occurrence ()**
< 0.2	64.9
< 0.4	92.1
< 0.6	95.8
< 0.8	97.3
< 1	98.5
< 1.2	99.2
< 1.4	99.7

table A 1.10 Wave heights according to satellite observations.

It can be seen from figure 1.7 that most of the time waves come from the East and Southeast. Since the measurements are made near the jetty, there is a possible influence of berthed ships on waves from the Northeast. Berthed ships may possibly block waves that come from this direction. The data set with wave measurements from this site contained no information of wave periods.

Ship observations
Offshore wave data from Ship observations are available of observations in the period between 1960 and 1997. A selection of these data was made in a coastal strip of length 100 km (centered on Fujairah) and width 70 km. Figure 1.10 shows the wave rose according to wave data from these ship observations. A standard correction was applied to the observed wave height to get the significant wave height (multiplication by 0.8). The offshore wave conditions from the ship observations (without correction) are broadly consistent with the information given by the harbour master.
The climate based on the corrected ship observations was transformed to the site of the VHFL terminal to account for refraction, shoaling and dissipation by bottom friction. The wave rose of transformed wave data is plotted in figure 1.11.

Shallow water effects
Shoaling and refraction of waves occur when the waves are in shallow water. If the water depth is less than half the wavelength, then the wave is considered to be in shallow water. When waves move into shallow water, they begin feel the bottom.
Refraction is the bending of waves because of varying water depths underneath. The part of a wave in shallow water moves slower than the part of a wave in deeper water. So when the depth under a wave crest varies along the crest, the wave bends. In this case, waves approach a straight shoreline at an angle.

The part of the wave crest closer to shore is in shallower water and moving slower than the part away from the shore in deeper water. The wave crest in deeper water catches up so that the wave crest tends to become parallel to the shore.
Shoaling occurs as the waves enter shallower water. The wave speed and wavelength decrease in shallow water, therefore the energy per unit area of the wave has to increase, so the wave height increases. The wave period remains the same in shoaling.

Percentage of occurrence of omnidirectional wave heights according to ship observations transformed to the location of the VHFL-jetty are distributed as follows:

Significant wave height (m)	**Percentage of occurrence (%)**
< 0.2	60.2
< 0.4	76.5
< 0.6	87.3
< 0.8	93.2
< 1.0	97.1
< 1.2	98.7
< 1.4	99.5

table A 1.11 Wave heights according to off shore Ship observations transformed to the location of the VHFL-jetty.

Distribution of ship observed wave periods are show in table A 1.12. In this table the joint probability of observed wave periods and significant wave heights are shown.

Hs Low	(m) Up	< 5.5	5.5 7.5	7.5 9.5	9.5 11.5	11.5 13.5	13.5 15.5	15.5 17.5	17.5 19.5	19.5 21.5	21.5 >	total
<	.25	42.73	.	.	.65	.	.	.	.	.	.	43.38
.25	.75	33.53	.94	.39	.13	.13	.03	.	.	.	.	35.15
.75	1.25	12.87	1.67	.18	.03	.05	.08	.	.	.	.	14.88
1.25	1.75	3.02	.65	.31	.	.	.03	.	.	.	.	4.01
1.75	2.25	1.28	.42	.08	.05	.03	.	.	.	.	.	1.85
2.25	2.75	.29	.08	.	.03	.	.	.	.	.	.	.39
2.75	3.25	.13	.05	.03	.	.	.	.	.	.	.	.21
3.25	4.25	.	.08	.	.	.	.	.	.	.	.	.08
4.25	5.25	.	.03	.	.	.	.	.	.	.	.	.03
5.25	6.25	.	.	.	.03	.	.	.	.	.	.	.03
Total	93.85	3.91	.99	.91	.21	.13	.	.		.	.	100

table A 1.12 Joint probability of occurrence of wave periods and heights

From table A 1.12 a relation between observed wave period and significant wave height in deep water as given in equation [1.5.1] can be found.

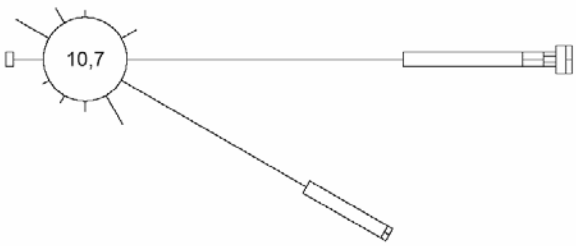
$$T_{obs} = 4.5 \cdot \sqrt{H_s} \qquad [1.5.1]$$

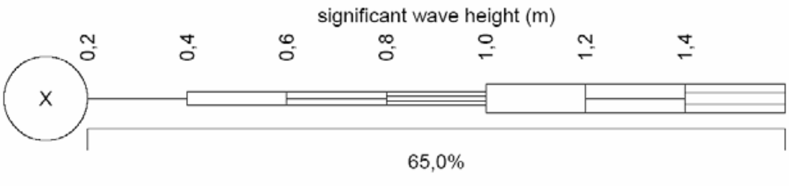
Further the relation between the observed period and peak period based on experience with ship observations is given in equation [1.5.2].

$$T_p = 1.1 \cdot T_{obs} \qquad [1.5.2]$$

Satellite observations

Offshore wave data from satellite observations are available in the form of scatter tables with the occurrence frequency of wave heights versus wind speeds. The directions of the waves are not indicated. These data show wave heights that are larger than the heights from the ship observations database and measurements of the VHFL-jetty. This can be explained by the fact that this dataset contains waves generated by storms with winds that come from the West and the Northwest. These winds generate waves that travel in southern and south-easterly direction. These waves do not arrive at the location of the Port of Fujairah. For this reason the wave heights from the satellite observations are not used to determine the near shore normal wave climate.





Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Wave rose, Fujairah, source: measurements VHFL jetty (Dec 2003 – Feb. 2006)

Figure no:
A 1.7

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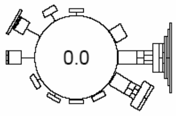
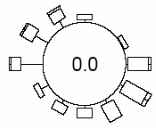
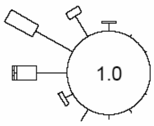


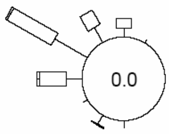
Season: January



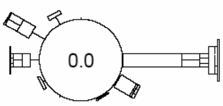
Season: February



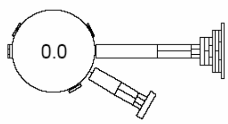
Season: March



Season: April

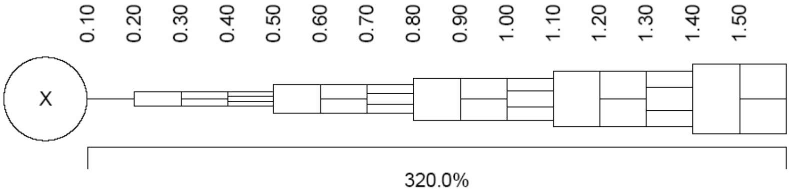


Season: May



Season: June

significant wave height (m)



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Wave roses seasonal. Fujairah, source: measurements VHFL jetty

Figure no:
A 1.8

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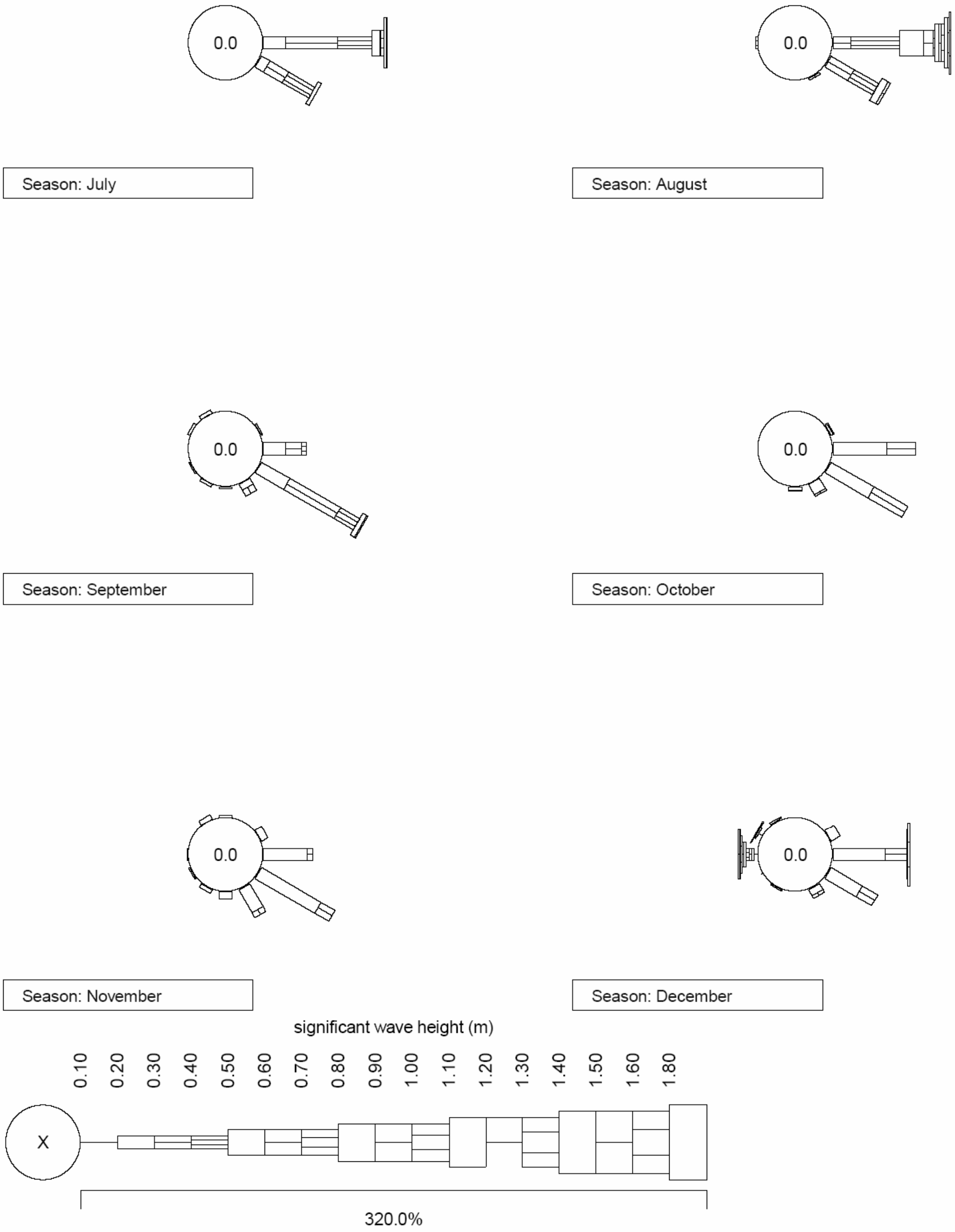

Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Wave roses seasonal. Fujairah, source: measurements VHFL jetty

Figure no:
A 1.9

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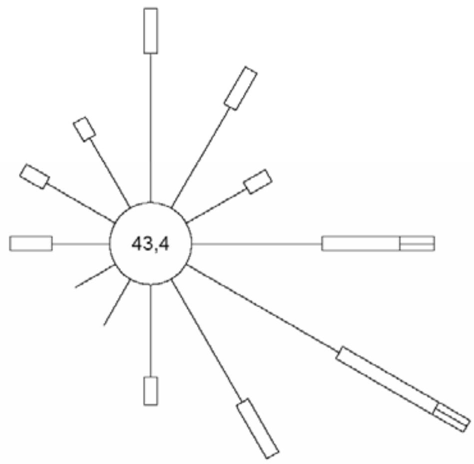

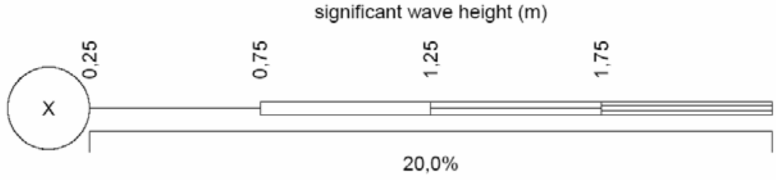

Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Wave rose, Fujairah off shore, source: ship observations

Figure no:
A 1.10

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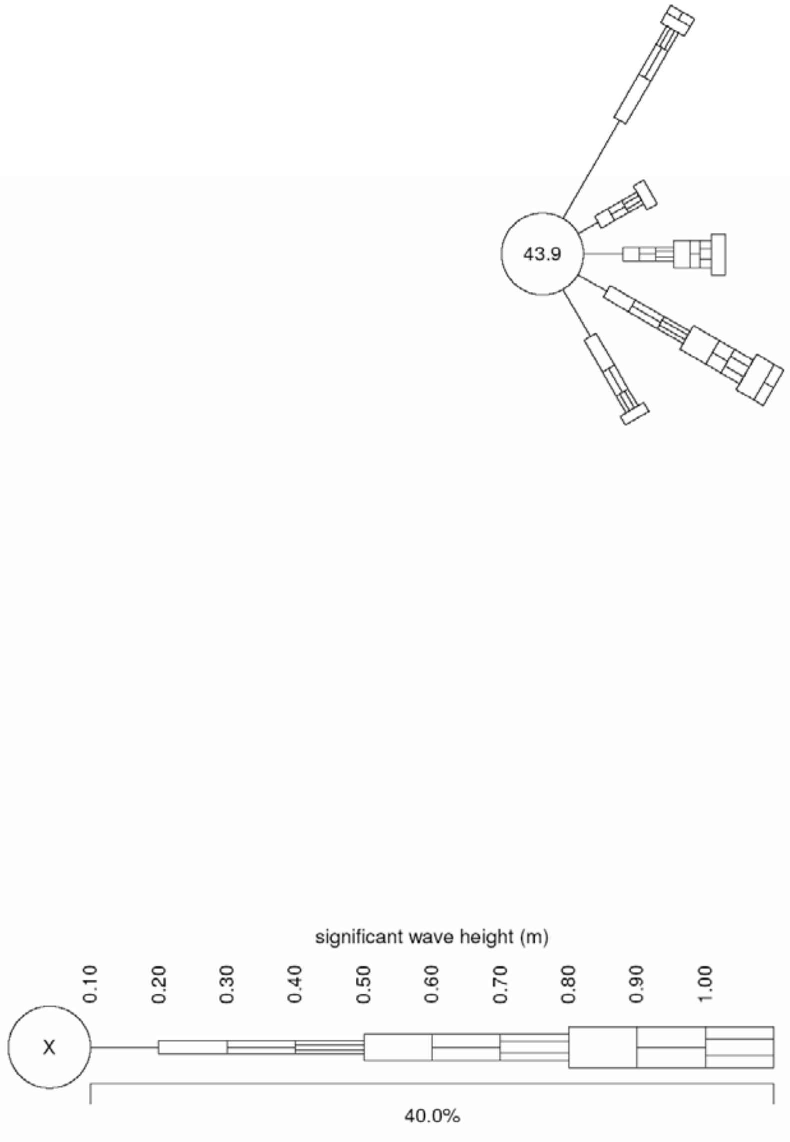

Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Wave rose, Fujairah, source: ship observations

Figure no:
A 1.11

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A 1.5.2 Extreme wave Climate

Extreme wave height and period

For the determination of the near shore extreme wave climate, the data from ship and satellite observations and measurements at the VHFL-jetty are analyzed. The final near shore extreme wave climate is determined by extrapolation of the off shore normal wave data and transformation to near shore values.

The extrapolation is carried out, using a Weibull fit on the frequency distribution of the Hydrobase off shore ship observation and the Argoss off shore satellite observation. The Weibull technique fits a curve to the frequency distribution of the return periods. These Weibull curves are presented in figures 1.12 to 1.17. For this Weibull extrapolation, the full data set of ship observations is used. There is no selection of storms being made to fit these curves on, since other effects than the winds that cause the normal wave climate are not expected. Although the Shamal weather system causes high waves in the region, these winds are directed to the east and will not cause large wave heights near the Fujairah coast.
The numerical results of the Weibull extrapolation of the offshore extreme wave heights are shown in table A 1.13.

Return	**345°-15°**		**15°-45°**		**45°-75°**		**75°-105°**		**105°-135°**		**135°-165°**		**165° - 195°**	
Period	**Hs0**	**T_{obs}**	**Hs0**	**T_{obs}**	**Hs0**	**T_{obs}**	**Hs0**	**T_{obs}**	**Hs0**	**T_{obs}**	**Hs0**	**T_{obs}**	**Hs0**	**T_{obs}**
1 Yr.	2.24	6.7	1.44	5.4	1.73	5.9	1.88	6.2	**2.42**	**7.0**	2.40	7.0	1.95	6.3
5 Yr.	2.85	7.6	1.81	6.1	2.29	6.8	2.25	6.8	3.01	7.8	**3.09**	**7.9**	2.57	7.2
10 Yr.	3.11	7.9	1.97	6.3	2.54	7.2	2.41	7.0	3.26	8.1	**3.38**	**8.3**	2.84	7.6
25 Yr.	3.46	8.4	2.17	6.6	2.86	7.6	2.60	7.3	3.59	8.5	**3.77**	**8.7**	3.19	8.0
50 Yr.	3.73	8.7	2.32	6.9	3.10	7.9	2.75	7.5	3.84	8.8	**4.06**	**9.1**	3.46	8.4
100 Yr.	3.99	9.0	2.48	7.1	3.34	8.2	2.89	7.7	4.09	9.1	**4.36**	**9.4**	3.72	8.7
200 Yr	4.25	9.3	2.62	7.3	3.58	8.5	3.03	7.8	4.33	9.4	**4.65**	**9.7**	3.99	9.0

table A 1.13 Extreme off shore wave heights and periods for given return periods and directions according to corrected ship observations.

The stated wave periods are based on an assumption of constant wave steepness derived from the relation [1.5.1] between significant wave height and observed period. From table A 1.13 it can be seen that the highest waves come from a southeasterly direction between 135° and 165°. The offshore wave heights are translated to near shore conditions (14 m. depth line) taken into account the effects of refraction, shoaling and dissipation due to bottom friction. Additional to these effects, a factor of 10% uncertainty is added to these resulting wave heights. This results in the near shore wave heights and directions as given in table A 1.14.

Return	**345°-15°**		**15°-45°**		**45°-75°**		**75°-105°**		**105°-135°**		**135°-165°**		**165° - 195°**	
Period	**Hs0**	**Dir**	**Hs0**	**dir**	**Hs0**	**dir**	**Hs0**	**Dir**	**Hs0**	**dir**	**Hs0**	**dir**	**Hs0**	**Dir**
1 Yr.	1.14	35.6°	1.34	39.6°	1.81	62.4°	1.96	90.0°	2.41	115.4°	1.97	132.2°	1.04	147.4°
5 Yr.	1.36	40.9°	1.59	43.0°	2.29	64.3°	2.30	90.0°	2.90	113.5°	2.62	129.7°	1.26	141.4°
10 Yr.	1.45	42.7°	1.69	44.5°	2.51	65.0°	2.40	90.0°	3.10	112.6°	2.78	128.1°	1.35	139.2°
25 Yr.	1.59	44.9°	1.82	46.1°	2.77	66.0°	2.61	90.0°	3.38	111.8°	3.01	126.6°	1.48	136.7°
50 Yr.	1.69	46.4°	1.92	47.2°	2.97	66.8°	2.74	90.0°	3.58	111.1°	3.21	125.7°	1.59	135.1°
100 Yr	1.80	47.8°	2.03	48.4°	3.17	67.6°	2.87	90.0°	3.80	110.7°	3.37	124.8°	1.69	133.6°
200 Yr	1.90	49.0°	2.12	49.3°	3.37	68.2°	2.99	90.0°	4.00	110.2°	3.54	123.6°	1.80	132.2°

table A 1.14 Extreme near shore wave (depth line 14) heights and directions for given return period and direction according to corrected ship observations.

It can be seen that the highest waves near shore (at a depth of 14 m) come from a direction between 105° and 135°. This means that although offshore waves from a more southern direction are higher, due refraction waves from a direction between 105° and 135° are decisive.
In figures 1.18 to 1.21, the characteristics of waves from a direction between 105° and 135° are shown for different return periods. From these figures it can be seen that for different water depths, wave characteristics can be summarized according to table A 1.15.

Return period	**off shore**	**d = 22 m**	**d = 18 m**	**d = 14 m**	**d = 10 m**	**d = 6 m**
1 Yr.	2.42 m	2.36 m	2.31 m	2.26 m	2.24 m	2.27 m
10 Yr.	3.26 m	3.08 m	3.03 m	3.01 m	3.05 m	3.07 m
100 Yr.	4.09 m	3.80 m	3.78 m	3.80 m	3.84 m	3.85 m
200 Yr.	4.33 m	4.01 m	4.00 m	4.04 m	4.06 m	4.08 m

table A 1.15 Near shore significant wave heights for different return periods and water depths

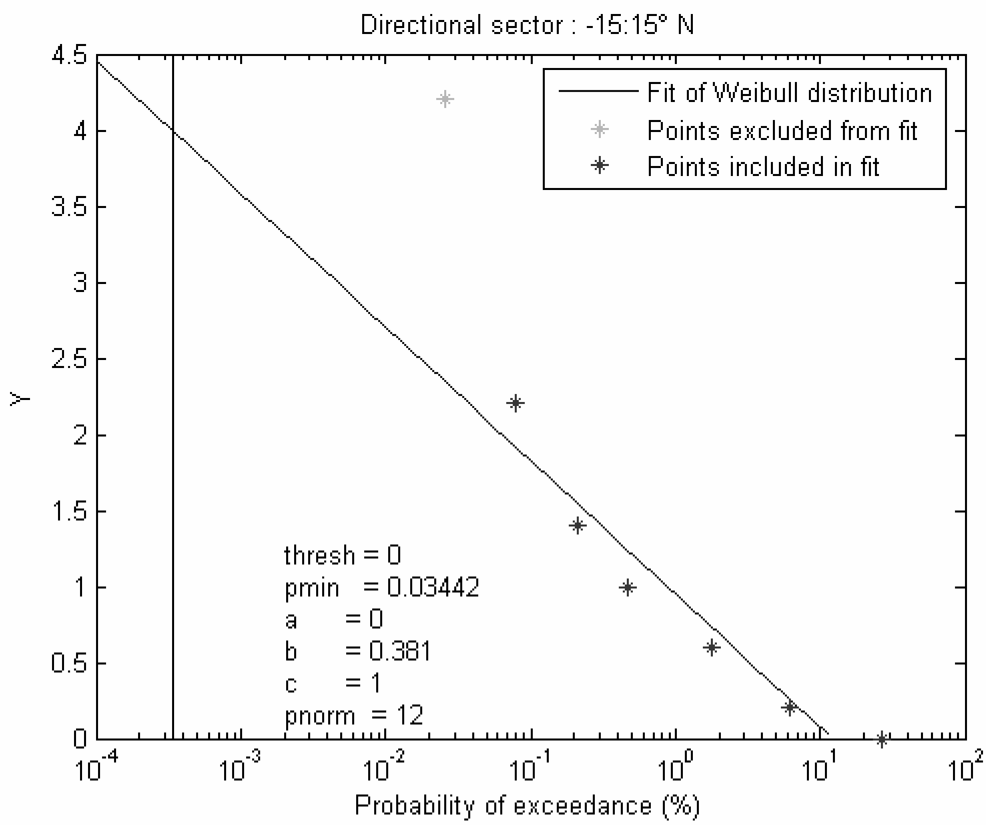
The finals near shore design wave characteristics with a return period of 100 year are:

H_s	3.80 m
T_p	10.0 s
dir	110.7°

The other two sources with wave data, VHFL-jetty measurements and Argoss satellite observations have not been taken into account for the determination of the extreme near shore wave climate.

The extreme wave height that is determined using the Argoss satellite observations data set is 5.8 m. Since only omnidirectional wave heights are available from satellite observations, this is the omnidirectional extreme off shore wave height for a return period of 100 years. Directional information from satellite observations is available through wind data. The wind rose of the extreme values from satellite observations, show that maximum wind speeds are expected to be in a southern direction. Waves generated by these winds are not expected to reach the coast of Fujairah and do therefore not represent the extreme near shore wave climate at the location of the new Port of Fujairah.

The data from the VHFL-measurements is near shore wave data. As stated in the previous paragraph, waves from northern directions are not represented in the data. Since for this reason it would not be correct to determine the extreme wave climate directly from these records, the data is used to check the wave data from ship observations. This is done by determining the omnidirectional extreme wave heights from the VHFL-measurements and from the ship observations transformed to near shore values. These values seem to be consistent.



Project Title: Masterplan for the port of Fujairah Expansion Project	Figure no: A 1.12
Figure Title: Extreme off shore wave height, omnidirectional, source: ship observations	

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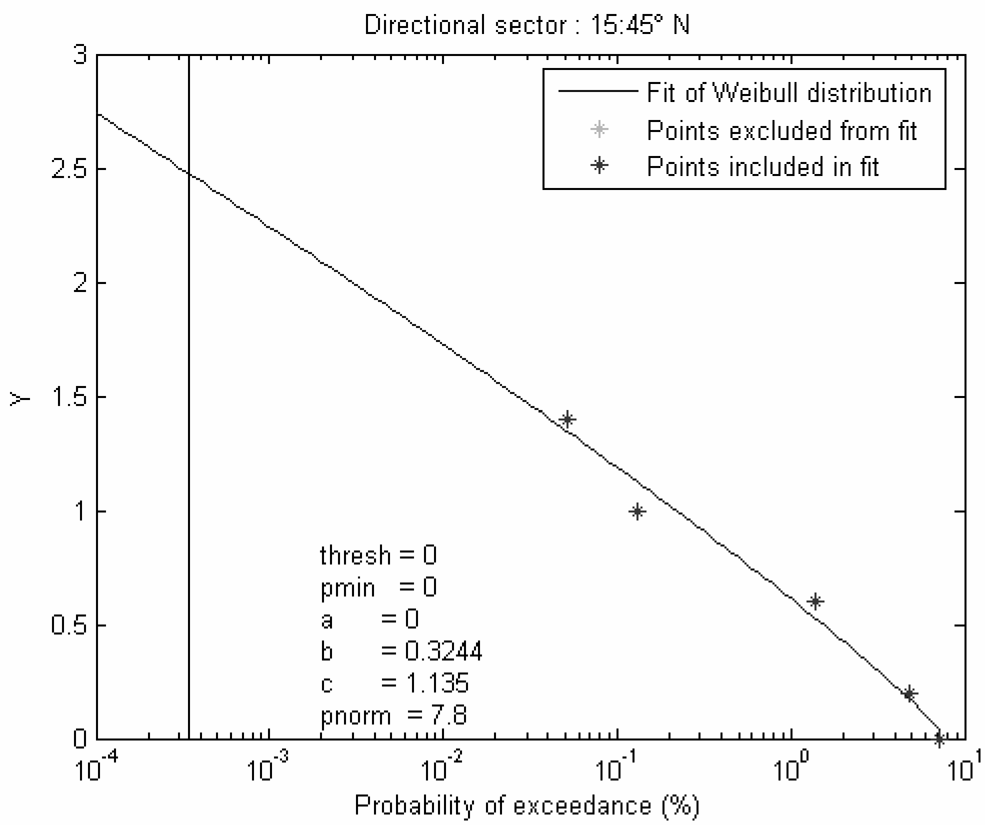

Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Extreme off shore wave height, angle of incidence 15° - 45°, source: ship observations

Figure no:
A 1.13

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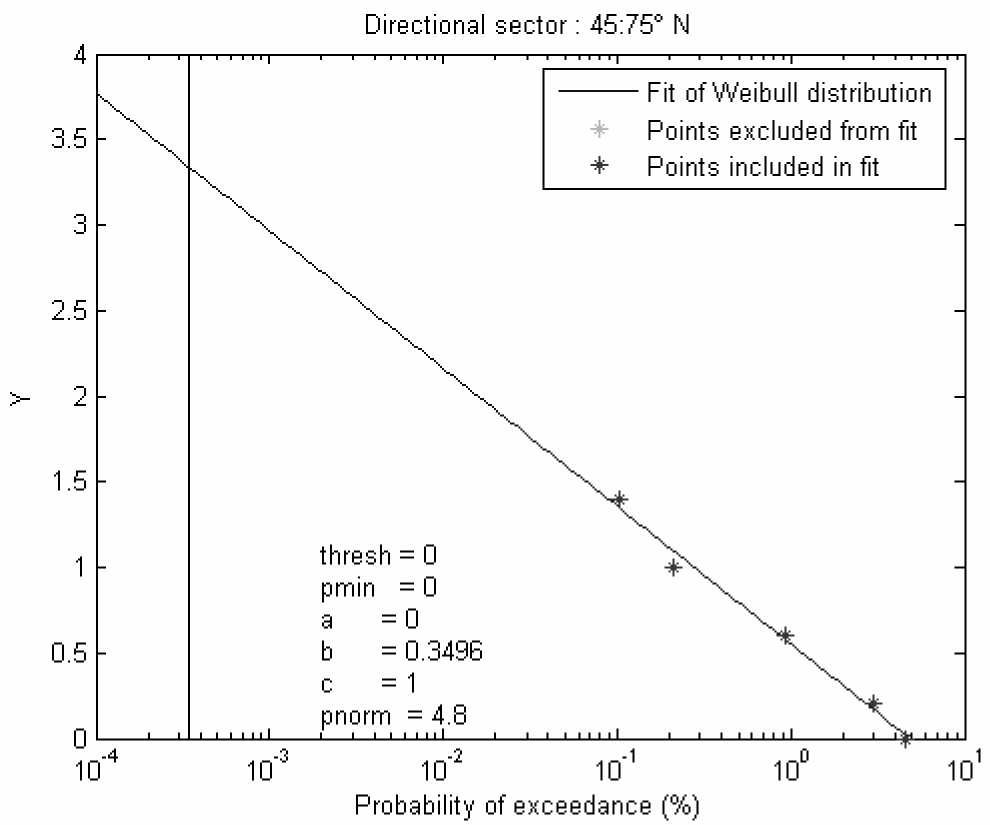

Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure no:
A 1.14

Figure Title
Extreme off shore wave height, angle of incidence 45° - 75°, source: ship observations

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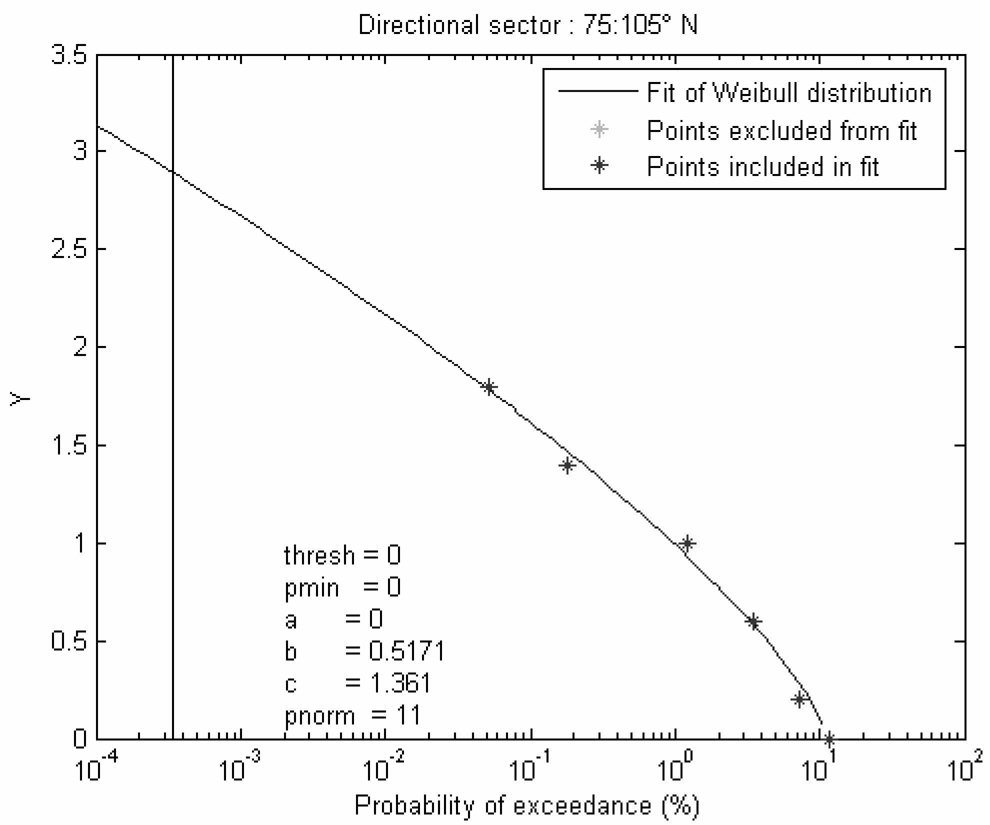

Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Extreme off shore wave height, angle of incidence 75° - 105°, source: ship observations

Figure no:
A 1.15

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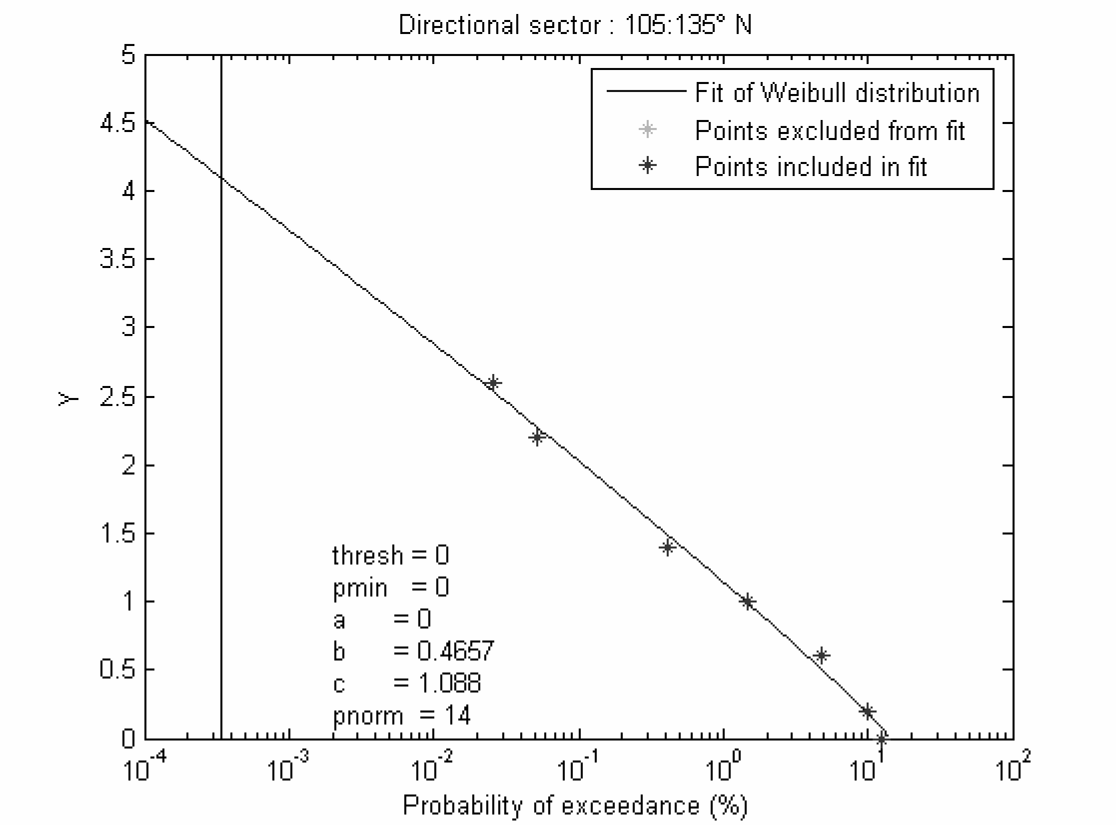

Project Title:	Figure no:
Masterplan for the port of Fujairah Expansion Project	A 1.16
Figure Title Extreme off shore wave height, angle of incidence 105° - 135°, source: ship observations	

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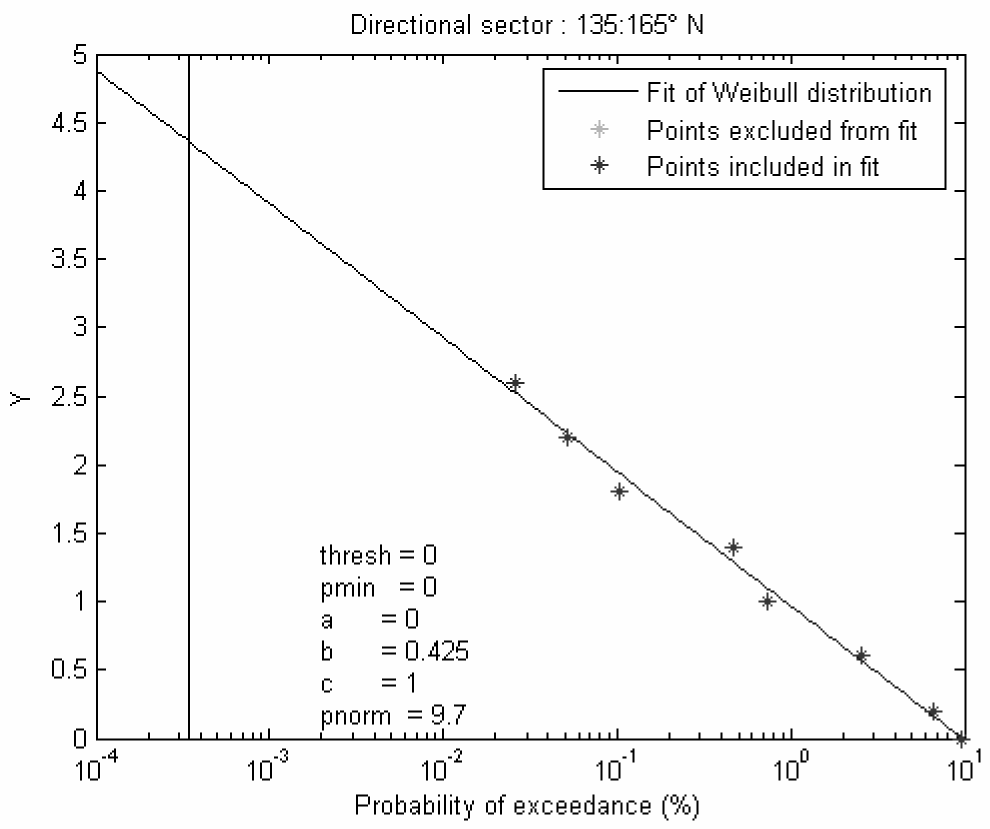
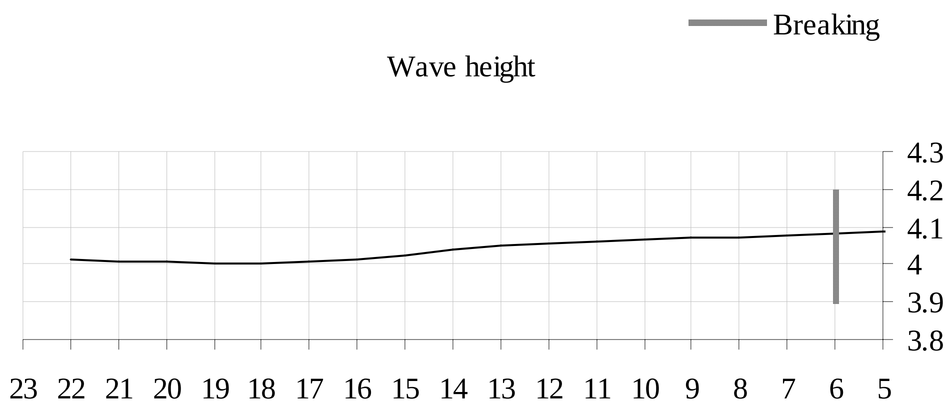


Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Extreme off shore wave height, angle of incidence 135° - 165°, source: ship observations

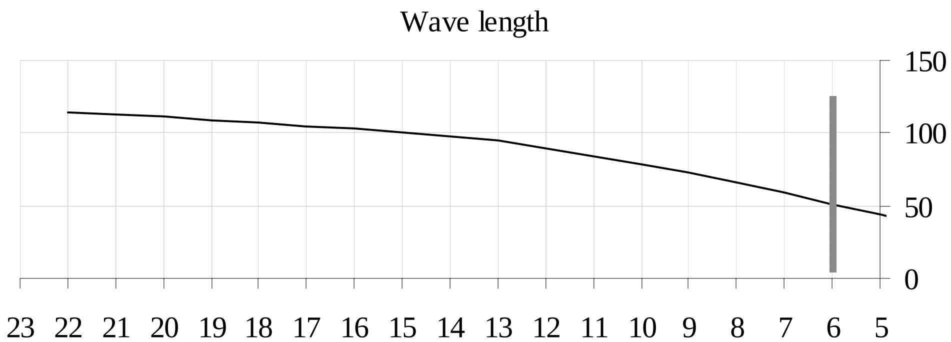
Figure no:
A 1.17

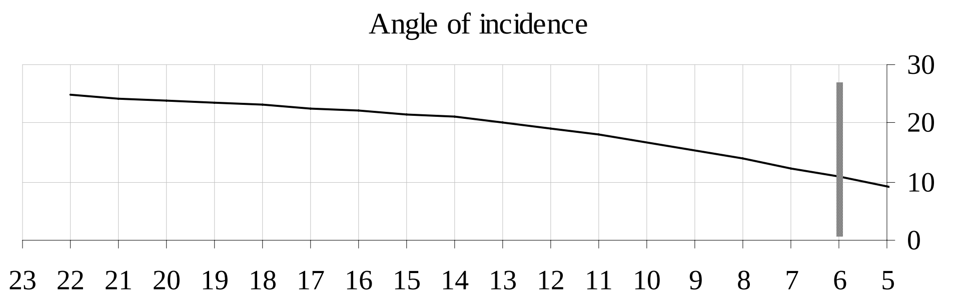
M.U.C. Engineering



$Hs_0 = 4.33$ m

T = 9.4 sec.





(Angle of incidence = angle relative to normal to the shore)

Project Title: Masterplan for the port of Fujairah Expansion Project	Figure no: A 1.18
Figure Title: Near shore wave characteristics R = 200 Yr.	

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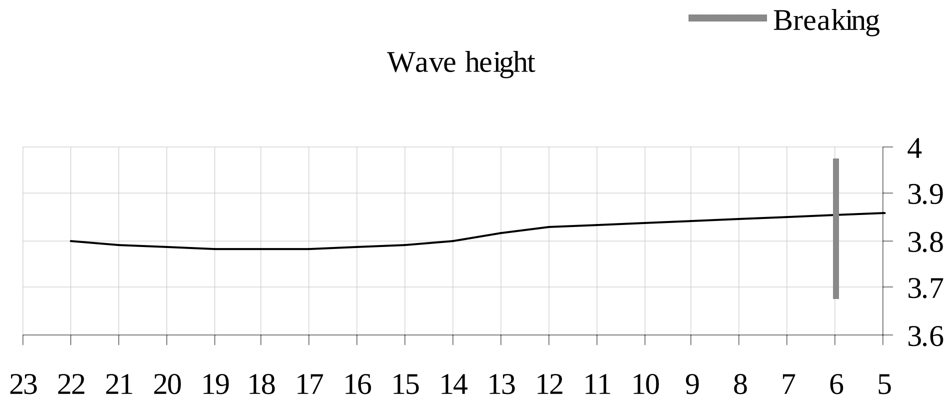
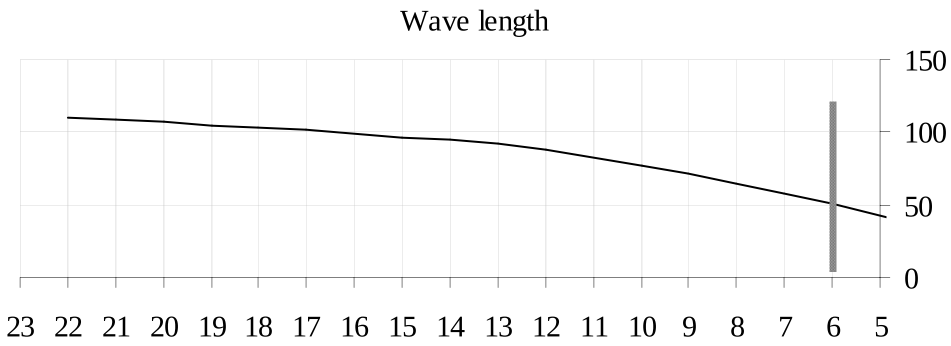
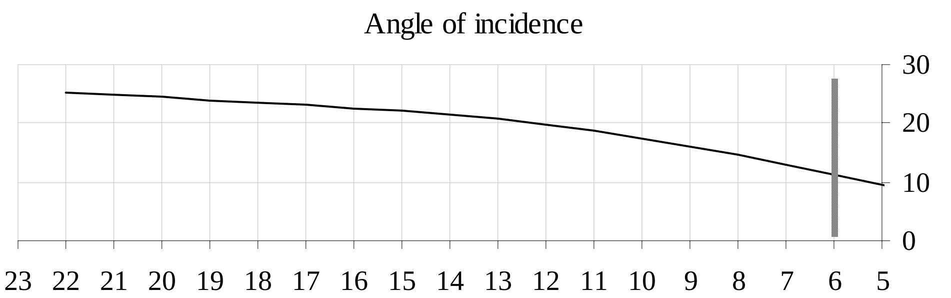


Hs_0 = 4.09 m

T = 9.1 sec





(Angle of incidence = angle relative to normal to the shore)

Project Title: Masterplan for the port of Fujairah Expansion Project	Figure no: A 1.19
Figure Title Near shore wave characteristics R = 100 Yr.	

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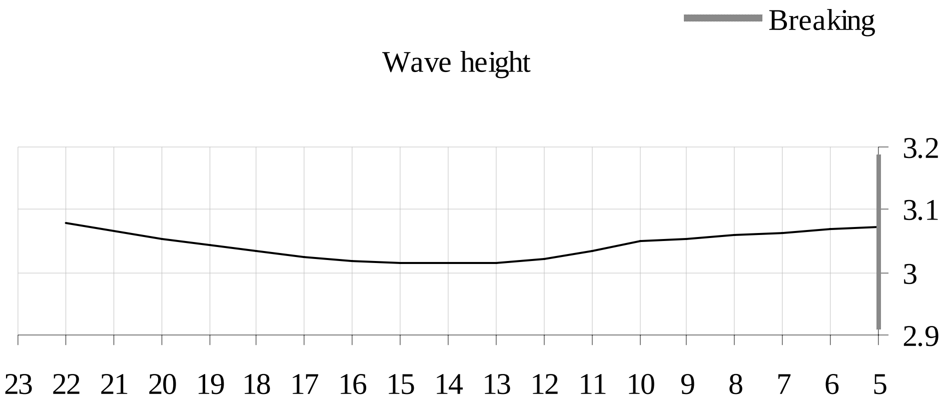
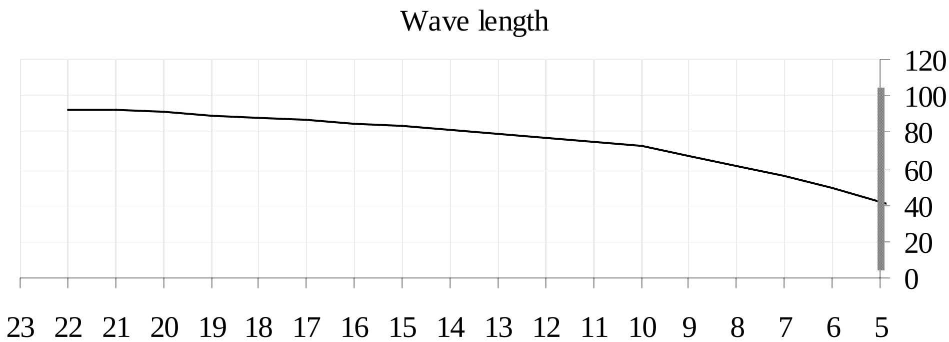
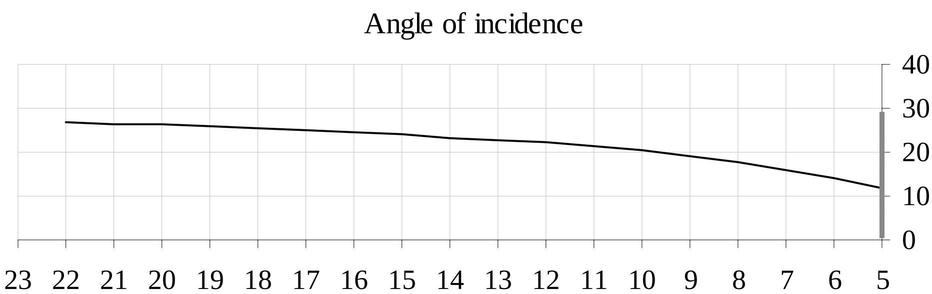


Hs_0 = 3.26 m.

T = 8.1 sec.





(Angle of incidence = angle relative to normal to the shore)

Project Title: Masterplan for the port of Fujairah Expansion Project	Figure no: A 1.20
Figure Title Near shore wave characteristics R = 10 Yr.	
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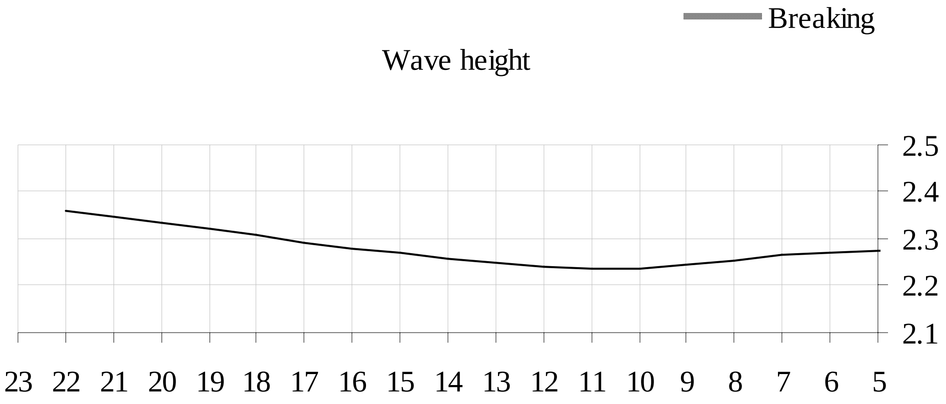
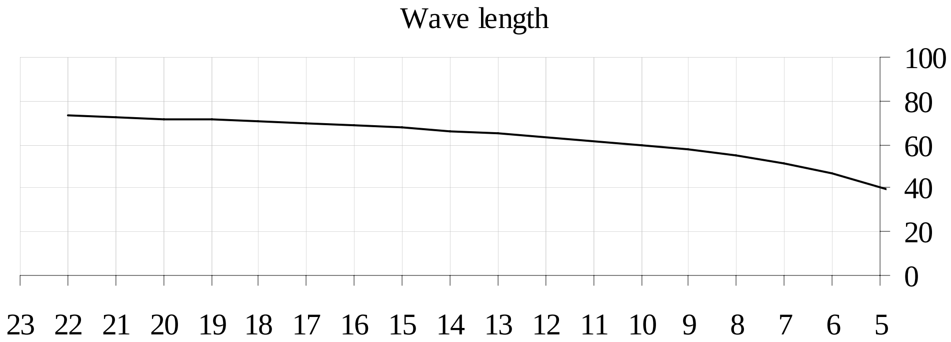


Hs_0 = 2.42 m.
T = 7.0 sec.



(Angle of incidence = angle relative to normal to the shore)

Project Title: Masterplan for the port of Fujairah Expansion Project	Figure no:
Figure Title: Near shore wave characteristics R = 1 Yr.	A 1.21

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A 1.6 Bathymetry

The bathymetry for the present situation is based on a survey carried out in November 2005 from the southern breakwater of the existing port to the southern breakwater of the Naval Base. According to the survey the bottom slope is mild at the location of the proposed new port expansions and is 1:102 with parallel depth contours.

A 1.7 Geotechnical

A 1.7.1 Site investigations

In October 2006, Fugro Middle East performed a near shore geotechnical investigation for the Northern Port Expansion Project. This investigation comprised a complete geotechnical survey of 38 boreholes to various depths, including sampling and coring.

The borehole observations and laboratory tests results indicated that the subsurface is relatively consistent throughout the site, consisting of two main units that are:

- Upper soil sediments
- Underlying bedrock

The upper soil sediments consisted mainly of grey, silty to very silty, medium to fine sand, with varying amounts of shell fragments that reached gravel size. The thickness of this layer varies throughout the site from less than 2.0 m to more than 11.0 m. This unit is observed to thicken mainly in the proposed harbour dredging and landfill area. This phenomenon might be explained by limited sediment transport in this area facing the existing breakwater wall. A thinner seabed sand layer is observed in the proposed berth area, located further south east of the site where sediment transport might be more considerable. Generally, the upper 3 meters of the soil sediments unit were proven to be very loose. Towards the bottom, the unit becomes medium dense.

The underlying bedrock consisted mainly of intercalating layers of siliceous calcarenite, calcareous sandstone and conglomerate. These three sub units are essentially similar, with difference in silt and carbonate content, the sandstone being siltier and less carbonaceous. Limited presence of calcareous siltstones and siliceous calcirudites, most probably in the form of lenses, are encountered within the major bedrock unit. The bedrock extended throughout the site, from beneath the soil unit to the full depth of the boreholes. The overall strength of the bedrock ranged from extremely weak to weak; indicating slightly indurated/cemented rock mass. Fracturing spacing ranged from being wide to medium fractured with occasional presence of zones of very closely fractured, non indurate/cemented rock

A 1.7.2 Seismic

The site is recognized as being in an area with low seismic activity and conservative design values sourced from reference codes and other projects being applied.

A2 Annex 2 Harbour layout alternatives

Masterplan for the port of Fujairah Expansion Project

TUDelft
Technical University of Delft
Faculty of Civil Engineering and Geosciences
Hydraulic and offshore section

B.V. Ingenieursbureau M.U.C.

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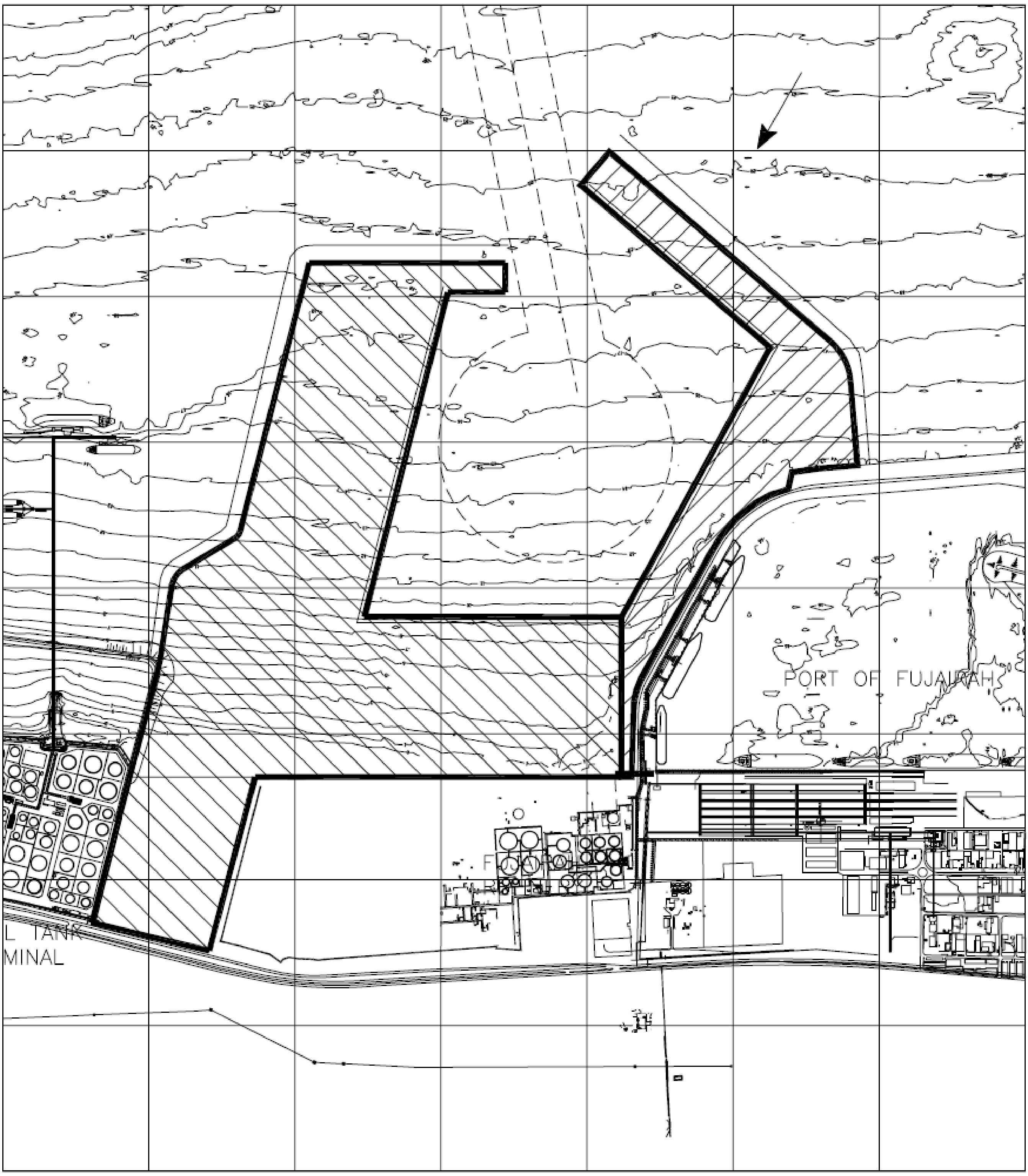
A 2.1 Introduction

This annex to the report Masterplan for the Port of Fujairah Expansion Project gives the proposed harbour layouts and oil terminal layouts that are described in chapter 5 of the report. Further the locations of the oil storage facilities and the aggregate stockpile area are shown
The figures 2.12 to 2.41 show combined proposed harbour basin and liquid bulk terminal layouts.



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Masterplan for the port of Fujairah Expansion Project

Figure no:
A 2.1

Figure Title
Layout A1

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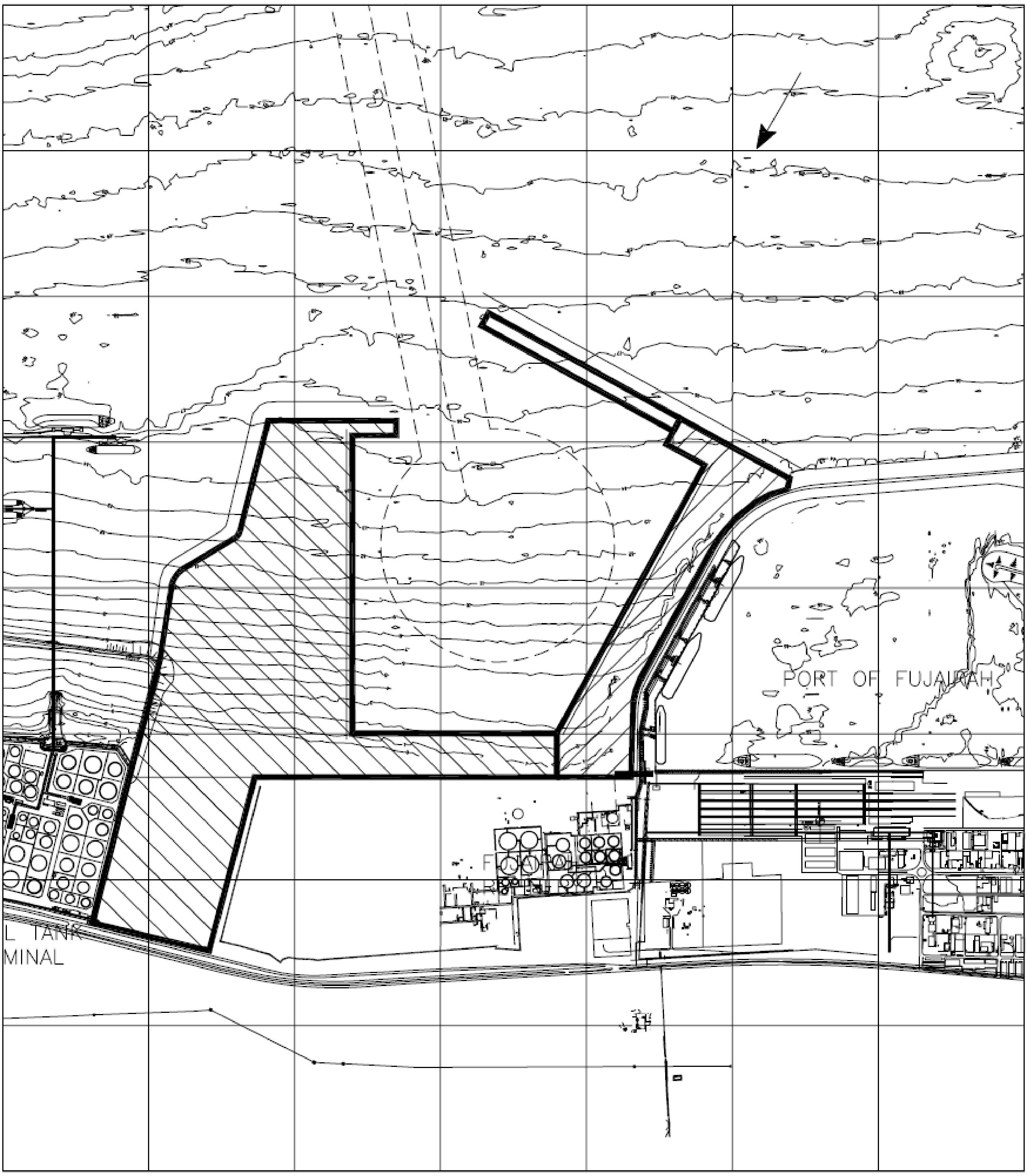

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Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A2

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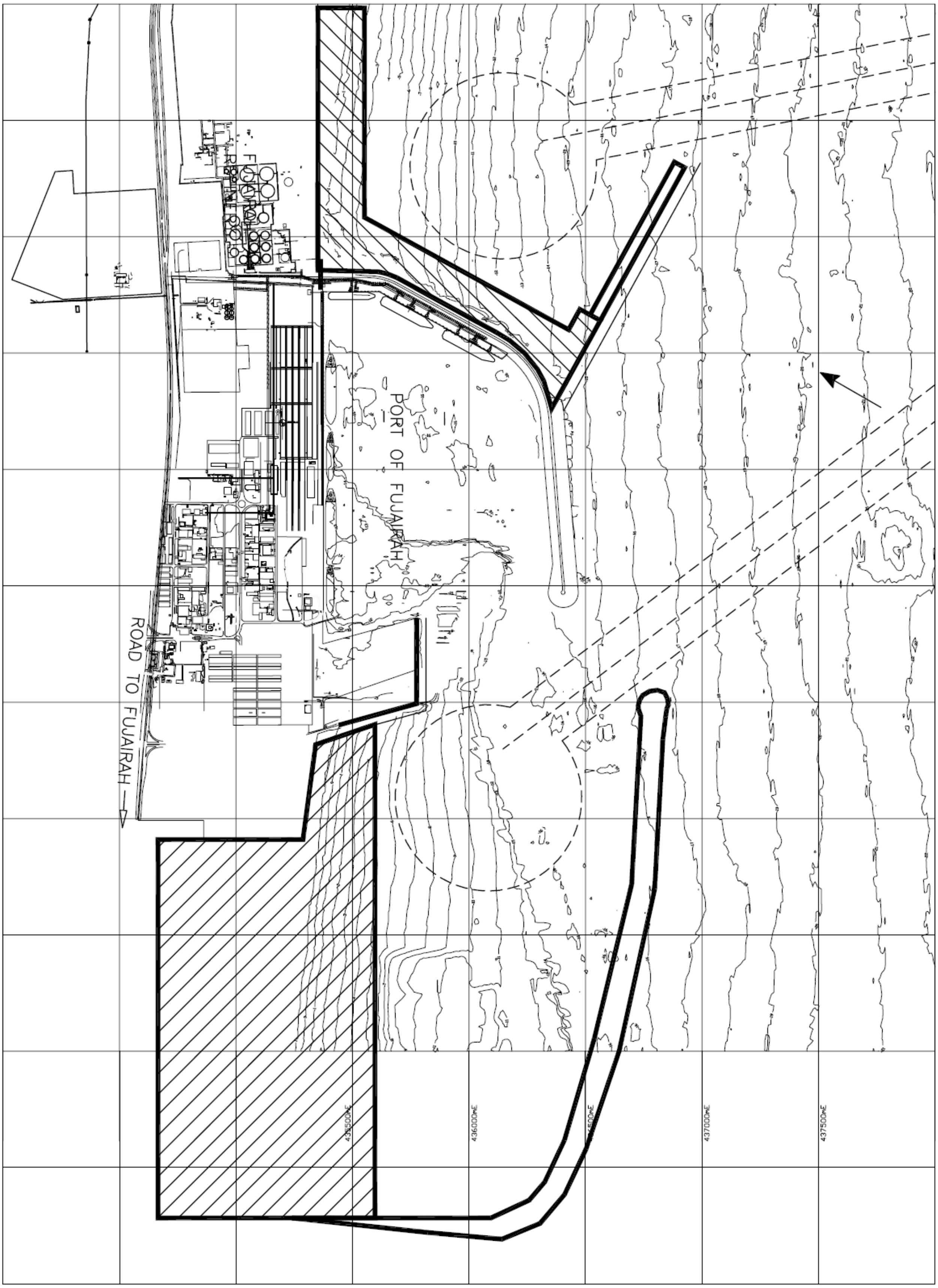

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Figure Title Layout A3	

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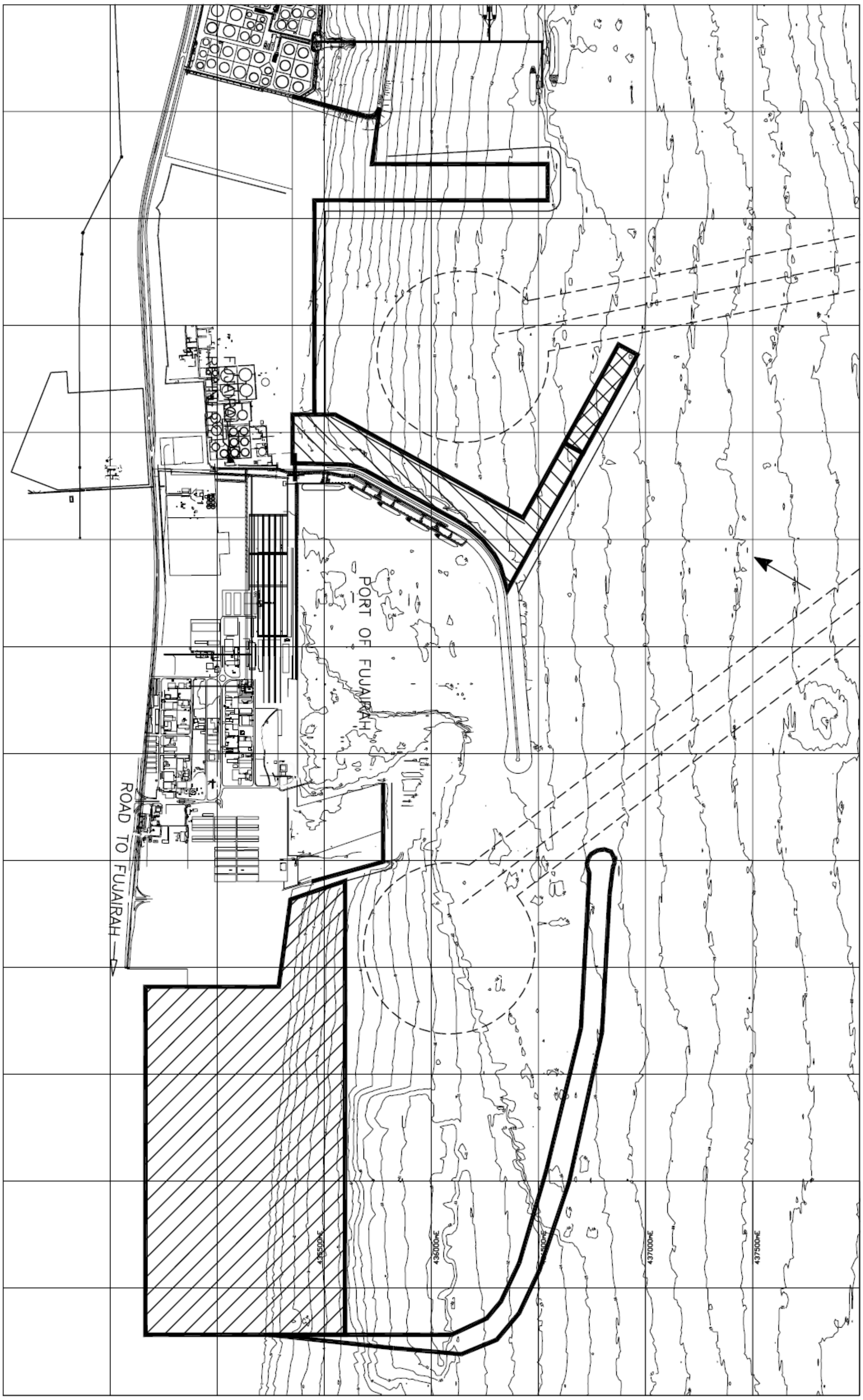

Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A4

Figure no:
A 2.4

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Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A5

Figure no:
A 2.5

M.U.C. Engineering

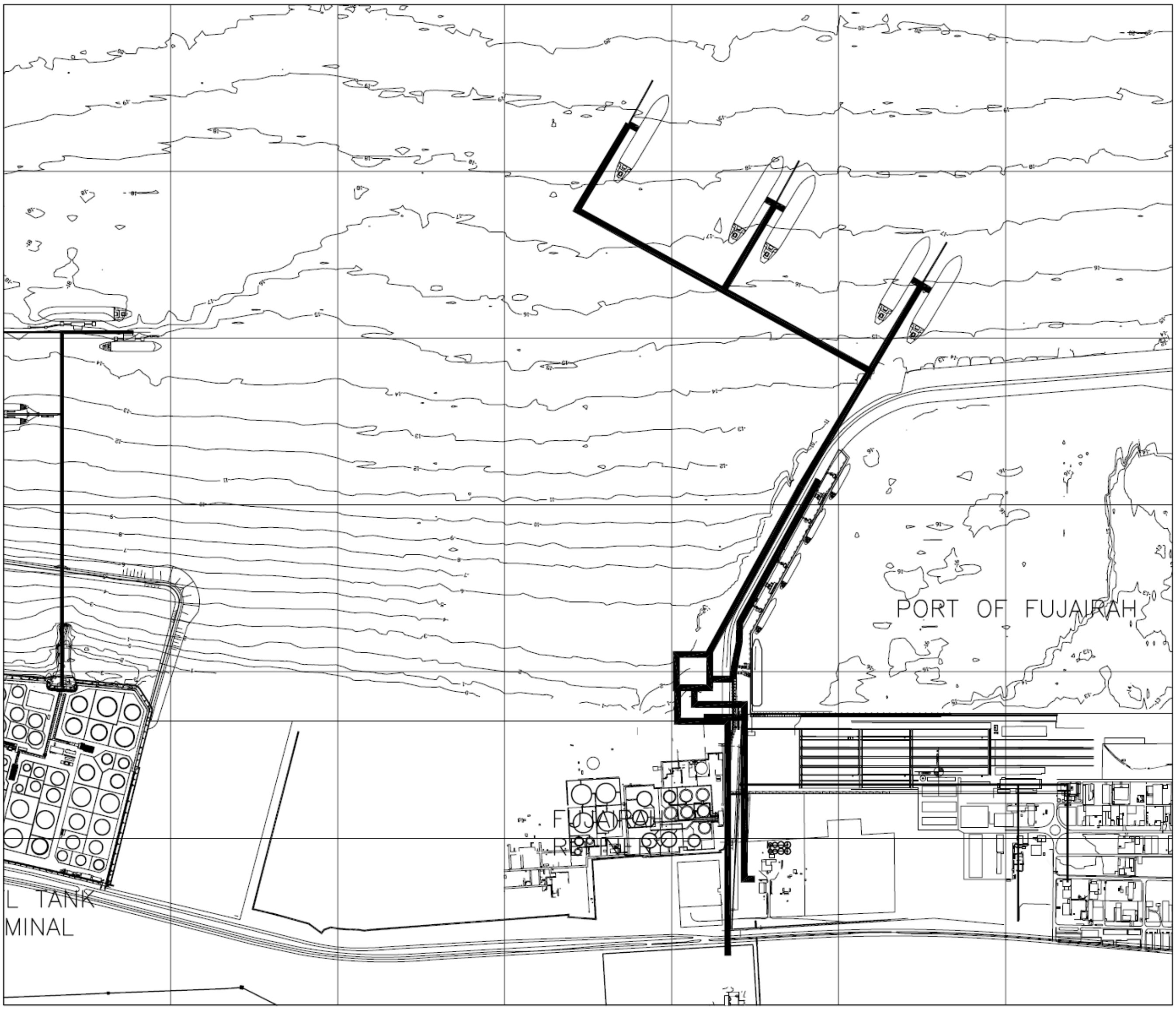

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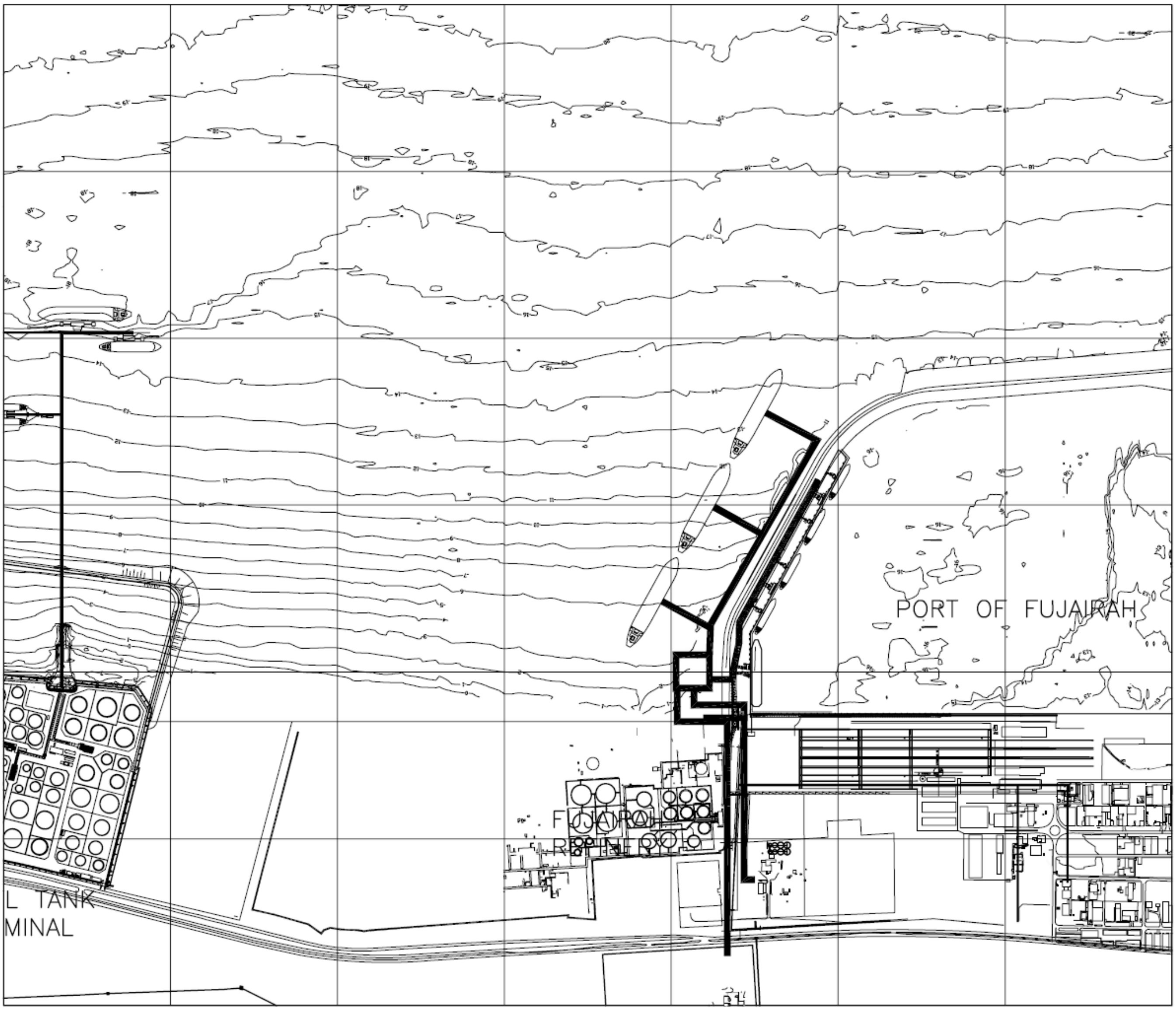
Figure Title
Layout B1

M.U.C. Engineering



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Masterplan for the port of Fujairah Expansion Project

Figure Title
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M.U.C. Engineering

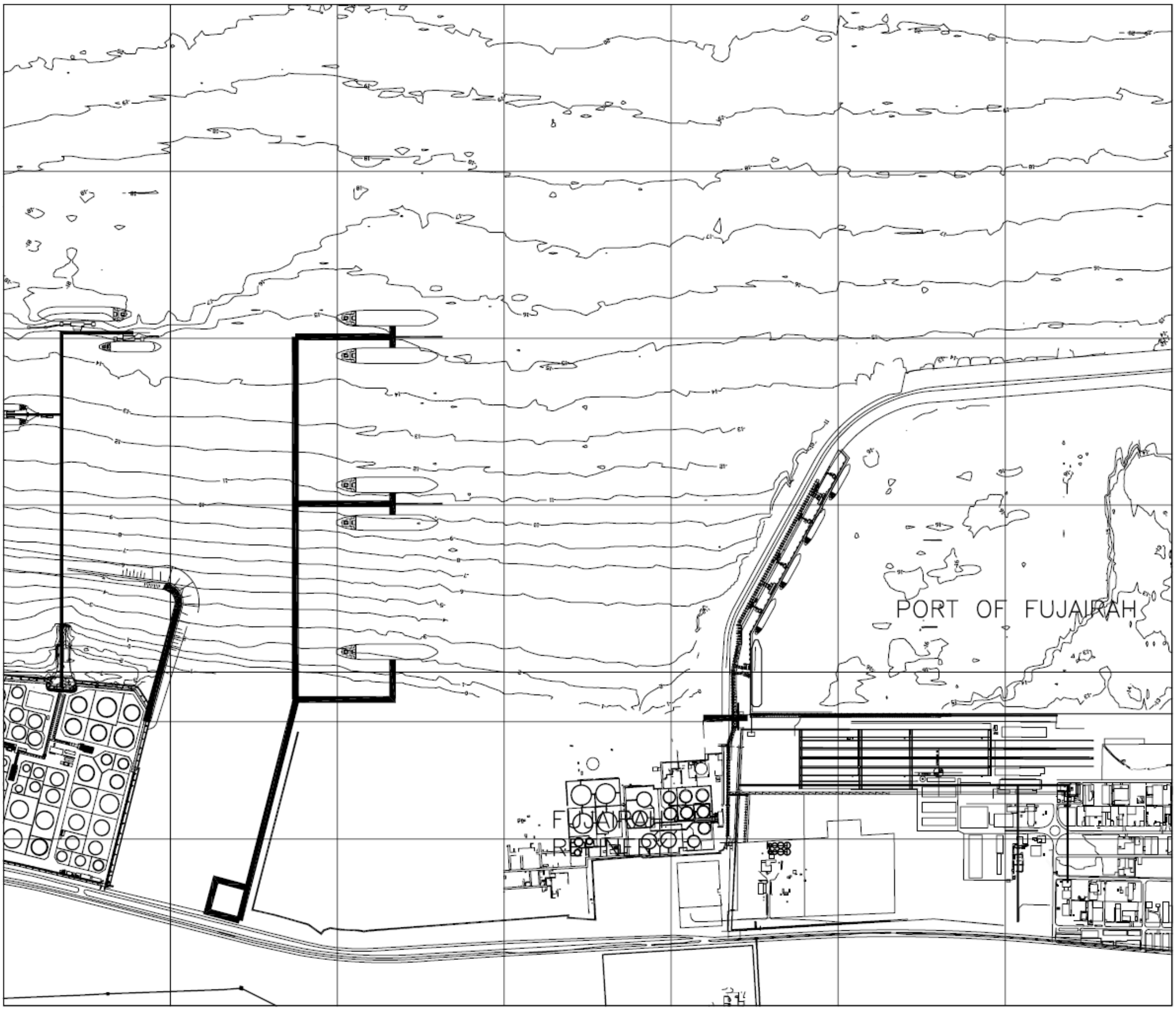

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Figure Title
Layout B3

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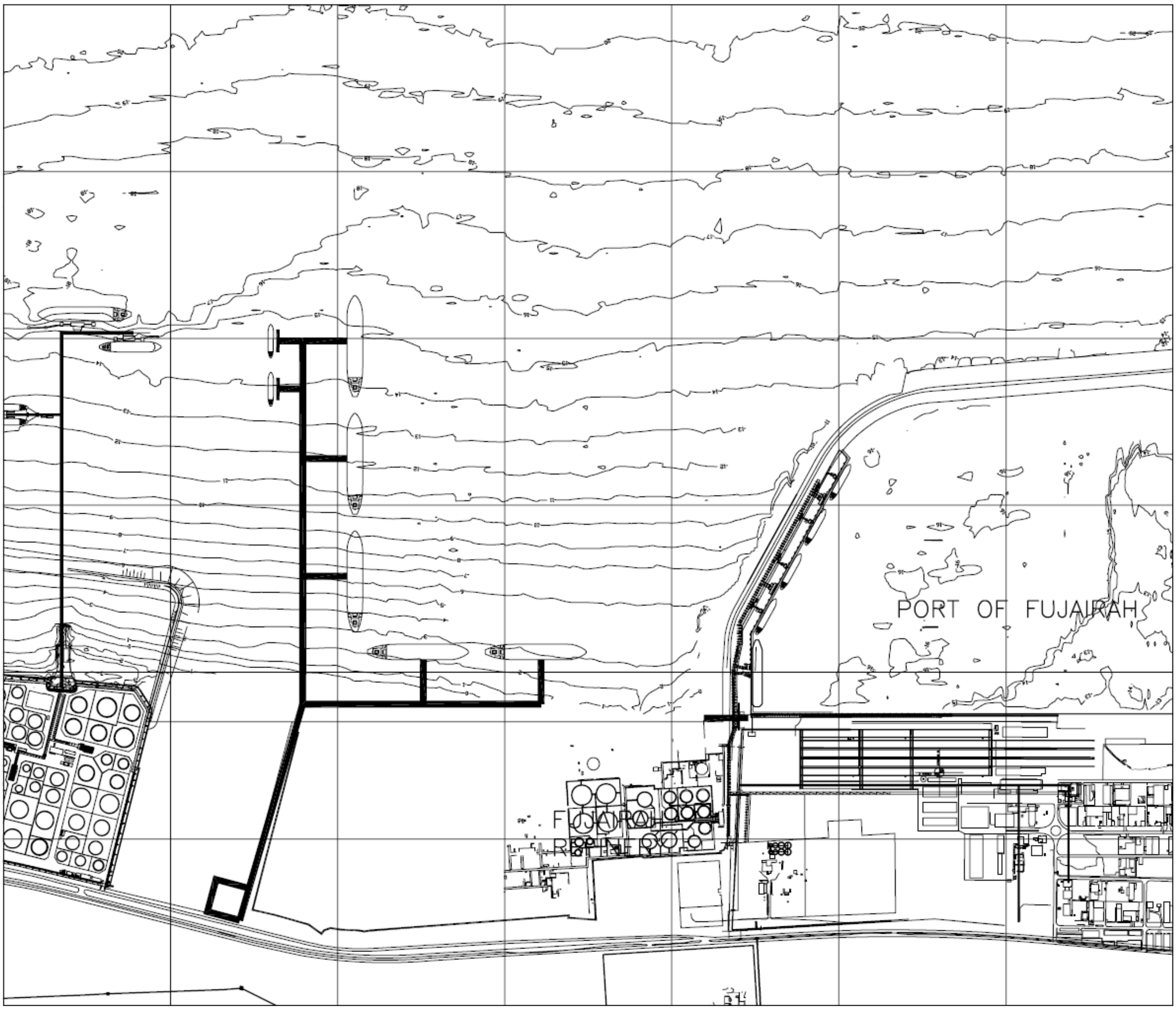

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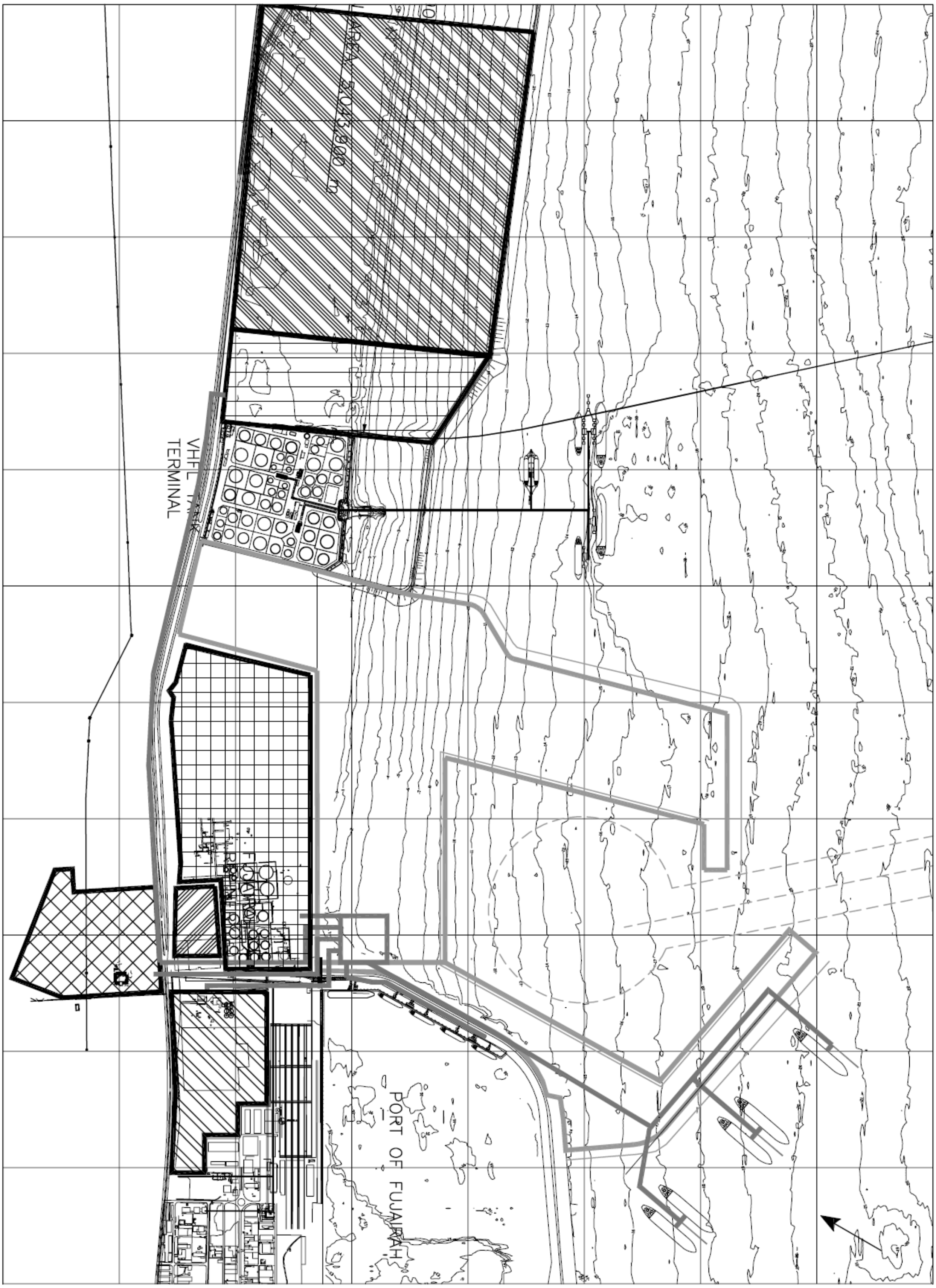
Figure Title
Layout B4

M.U.C. Engineering



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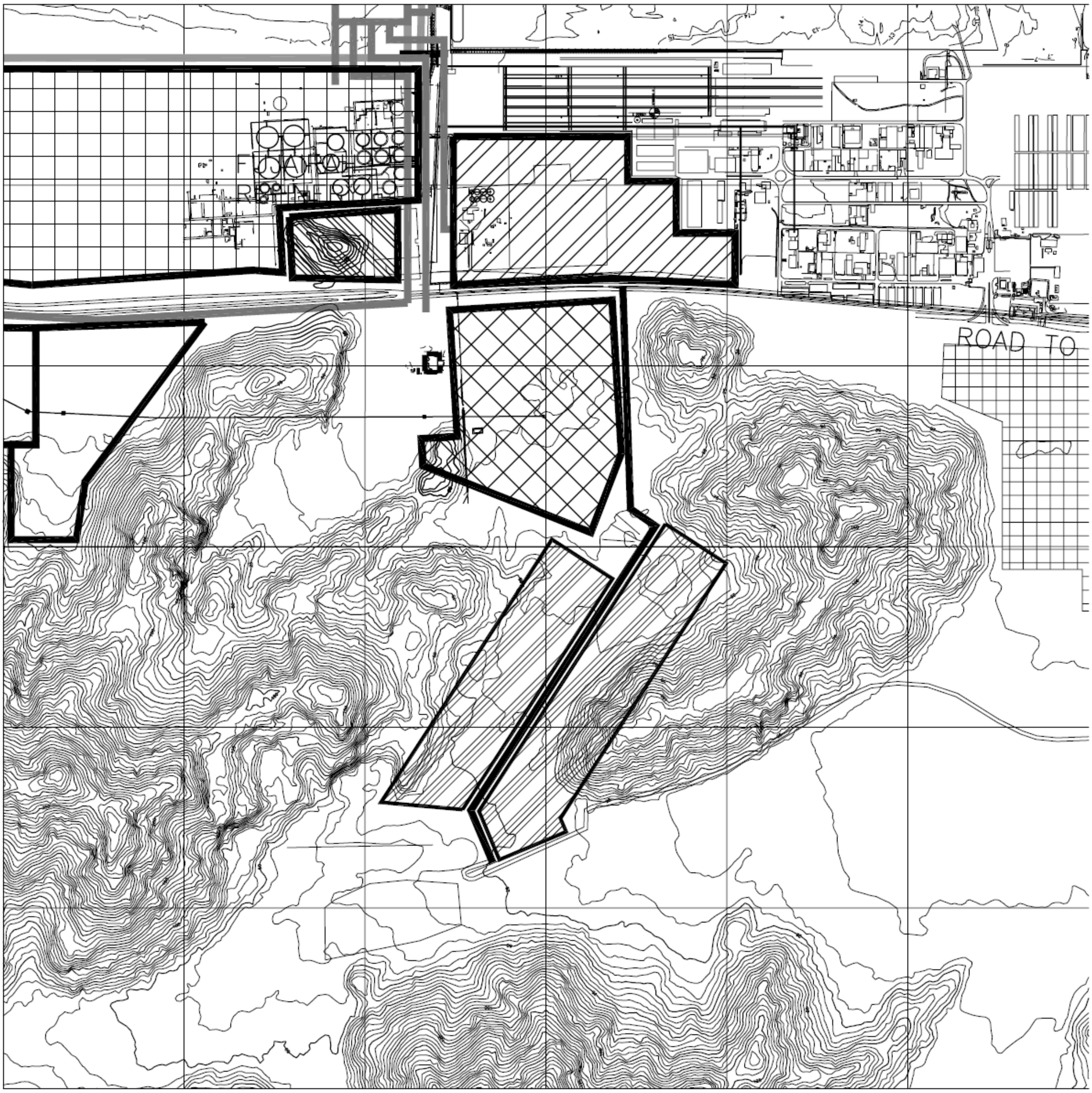
Masterplan for the port of Fujairah Expansion Project

Figure Title
Location of oil storage facilities

Figure no:
A 2.10

M.U.C. Engineering



Project Title:
Masterplan for the port of Fujairah Expansion Project

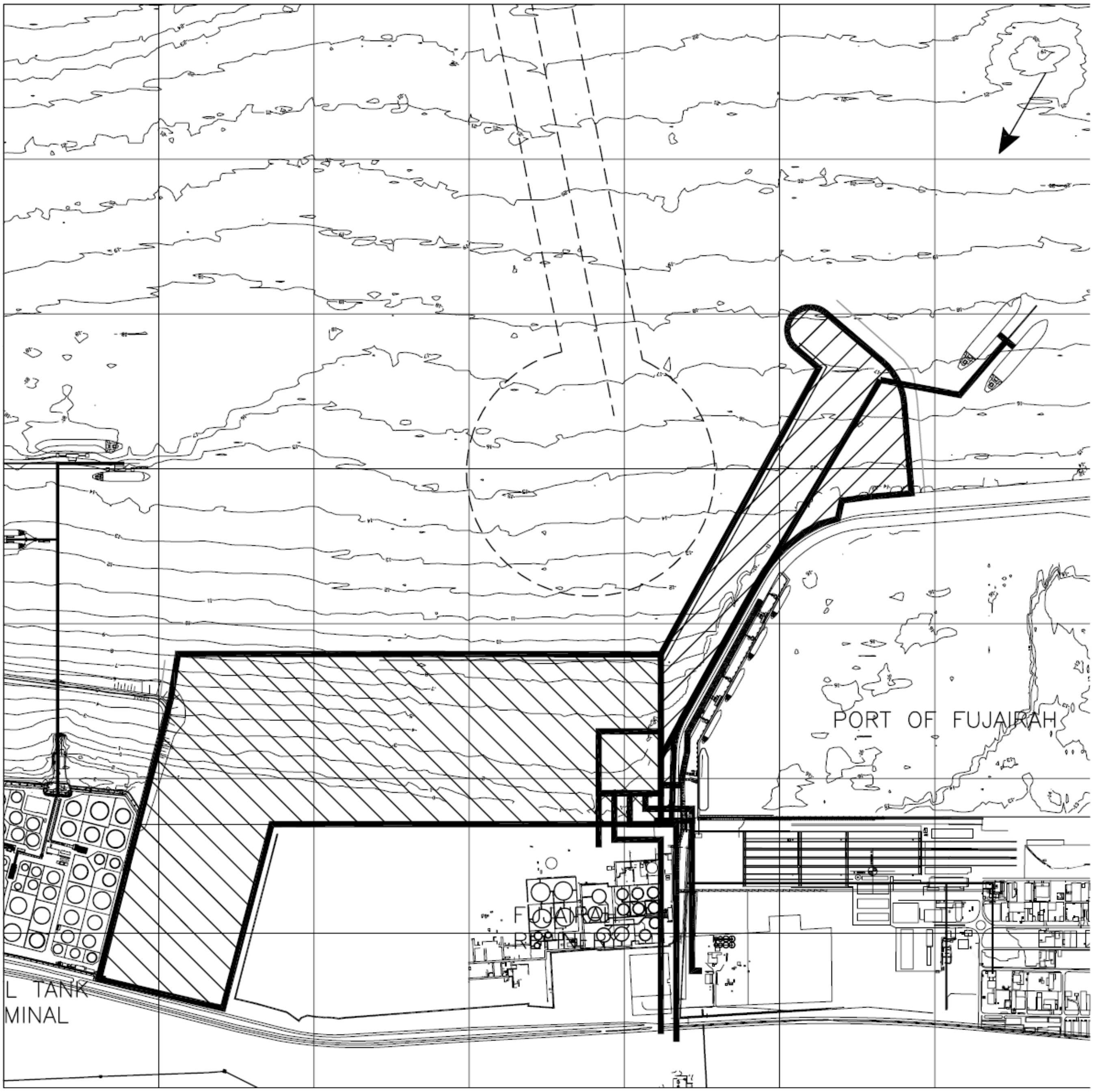
Figure no:
A 2.11

Figure Title
Location of aggregate stockpile areas

M.U.C. Engineering

A 2.2 Combination of layouts and phasing

The following figures show combined harbour basin and liquid bulk terminal layouts.



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Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A1 B1 phase 1 option A

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A 2.12

M.U.C. Engineering

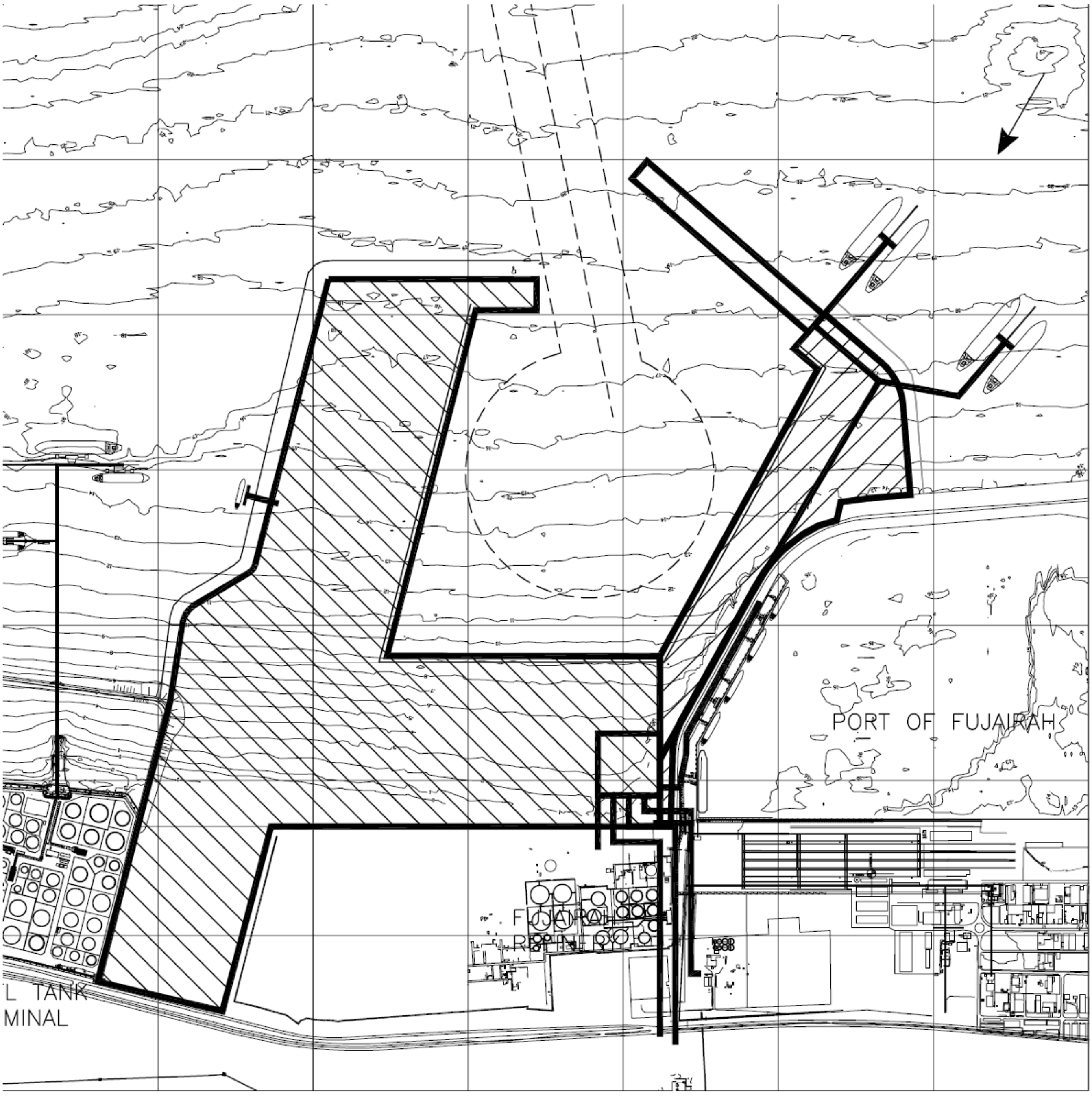

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Figure Title
Layout A1 B1 phase 2 option A

M.U.C. Engineering

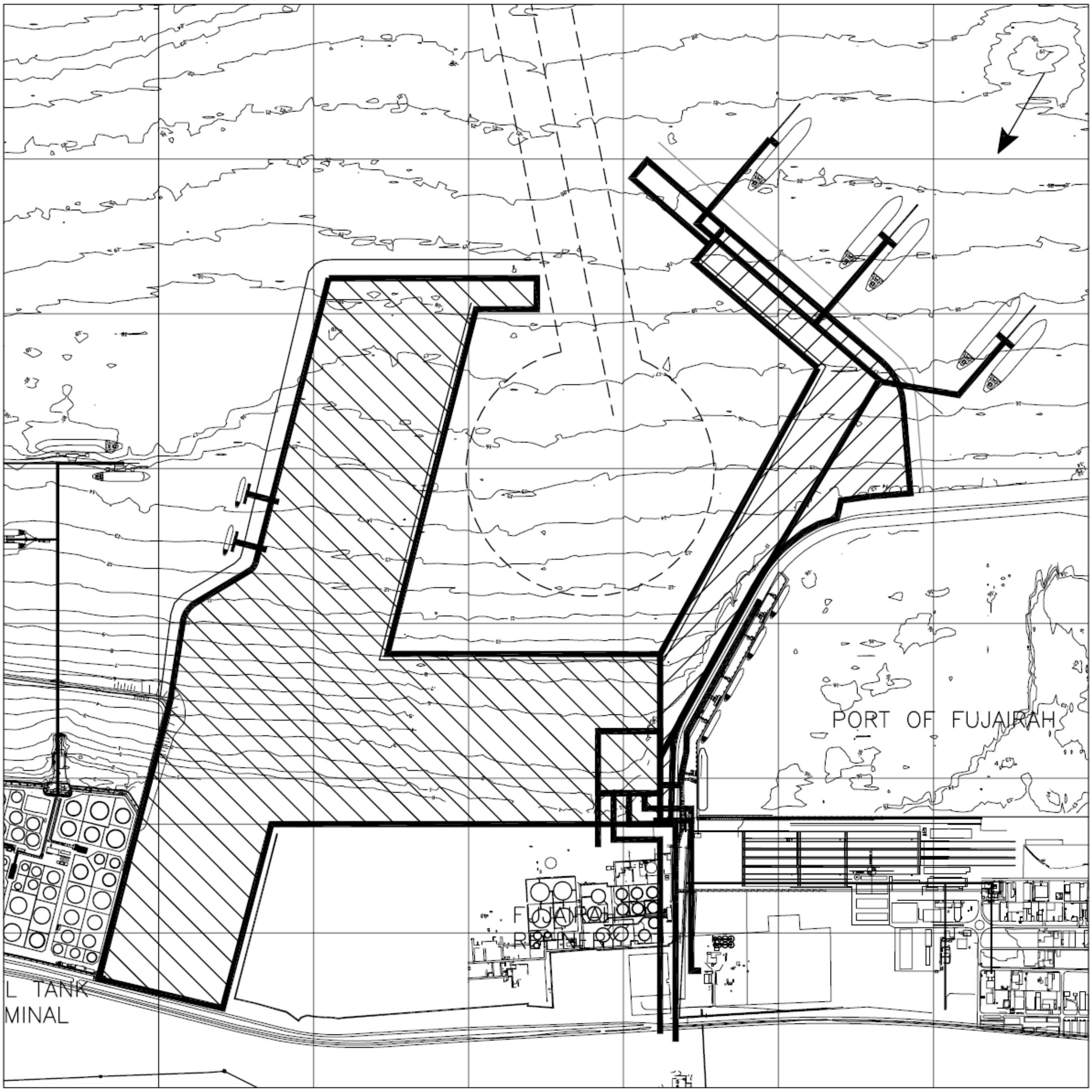

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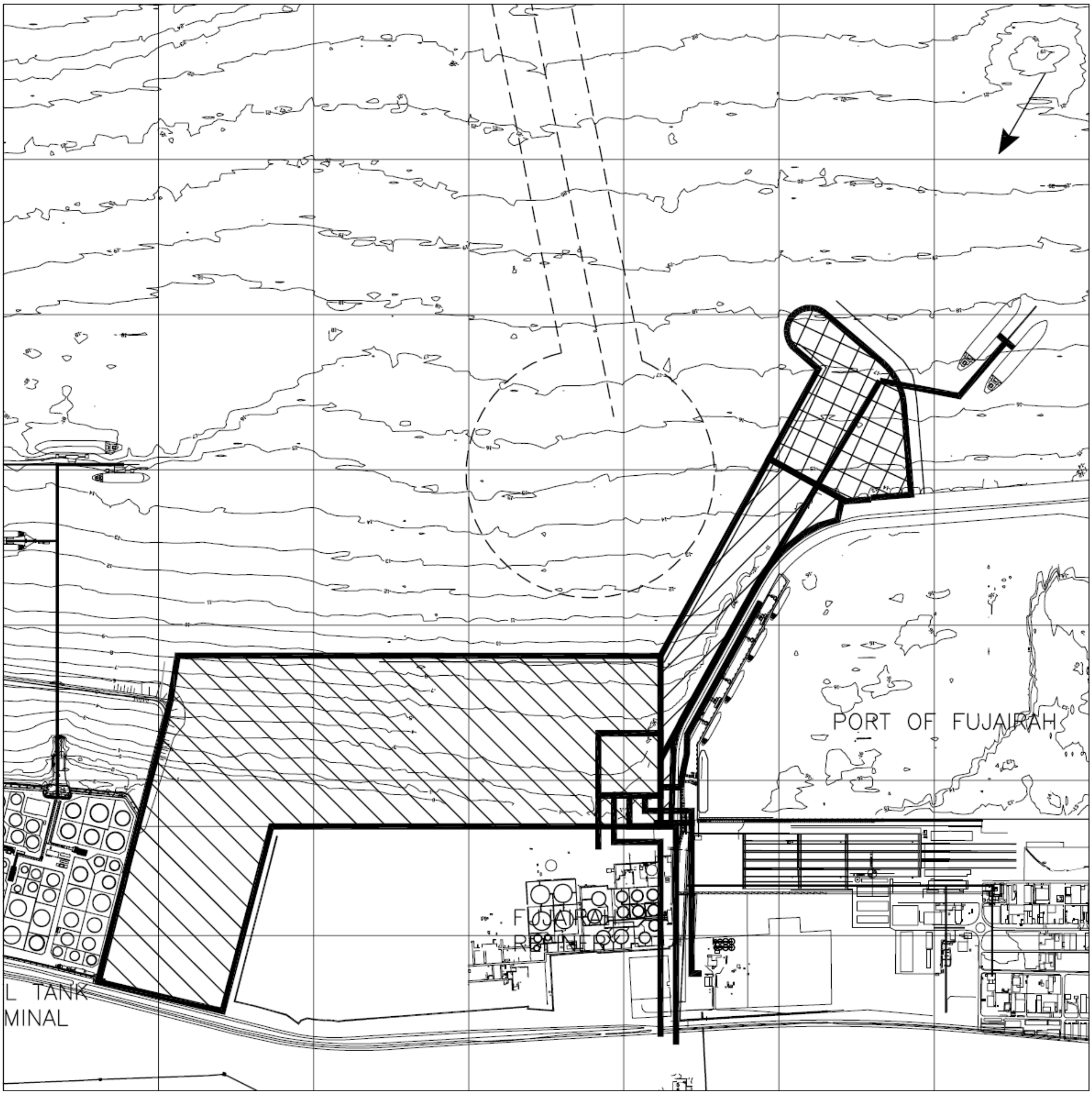
Figure Title
Layout A1 B1 phase 3 option A

M.U.C. Engineering



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Masterplan for the port of Fujairah Expansion Project

Figure Title
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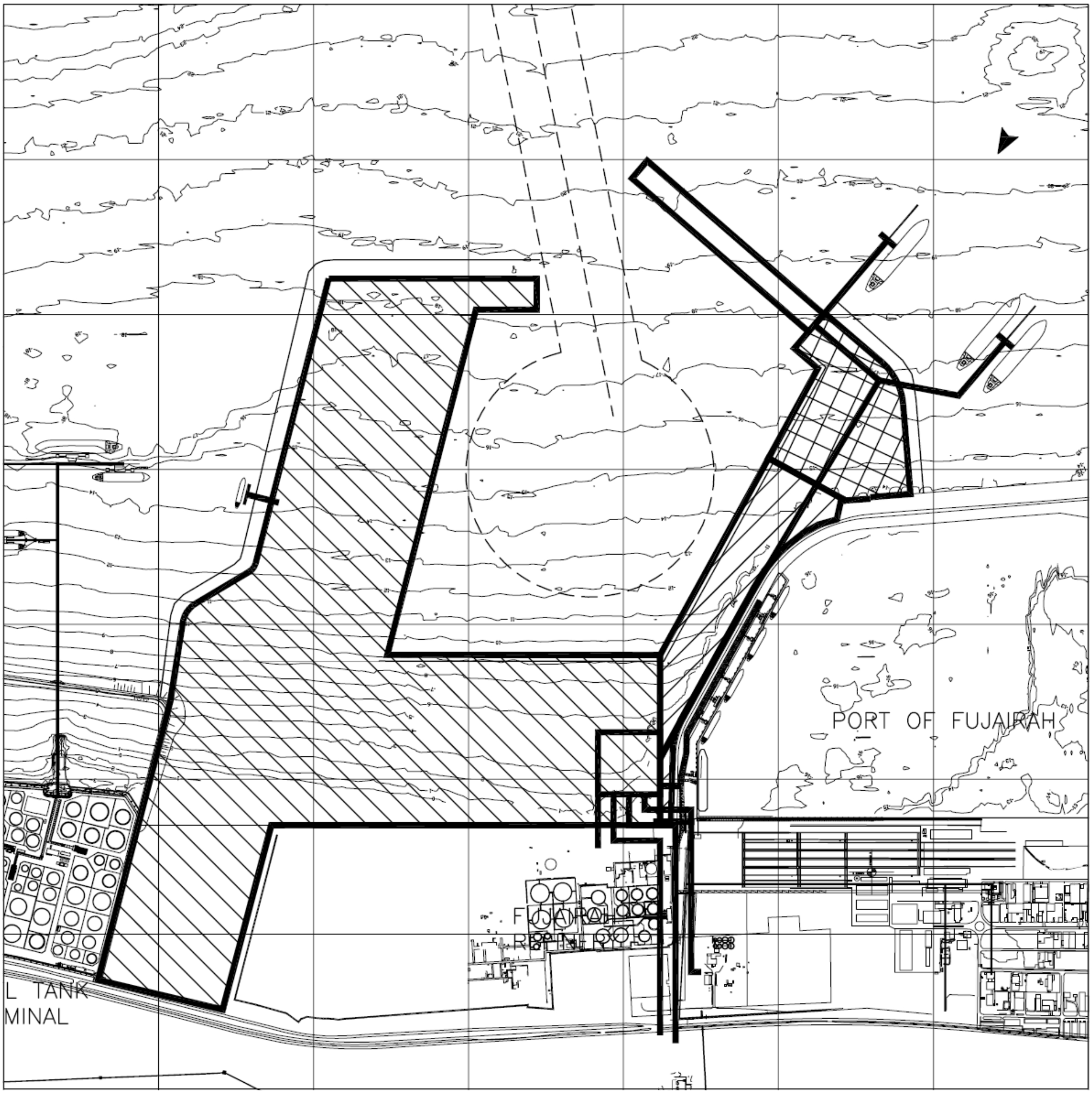
M.U.C. Engineering



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Masterplan for the port of Fujairah Expansion Project

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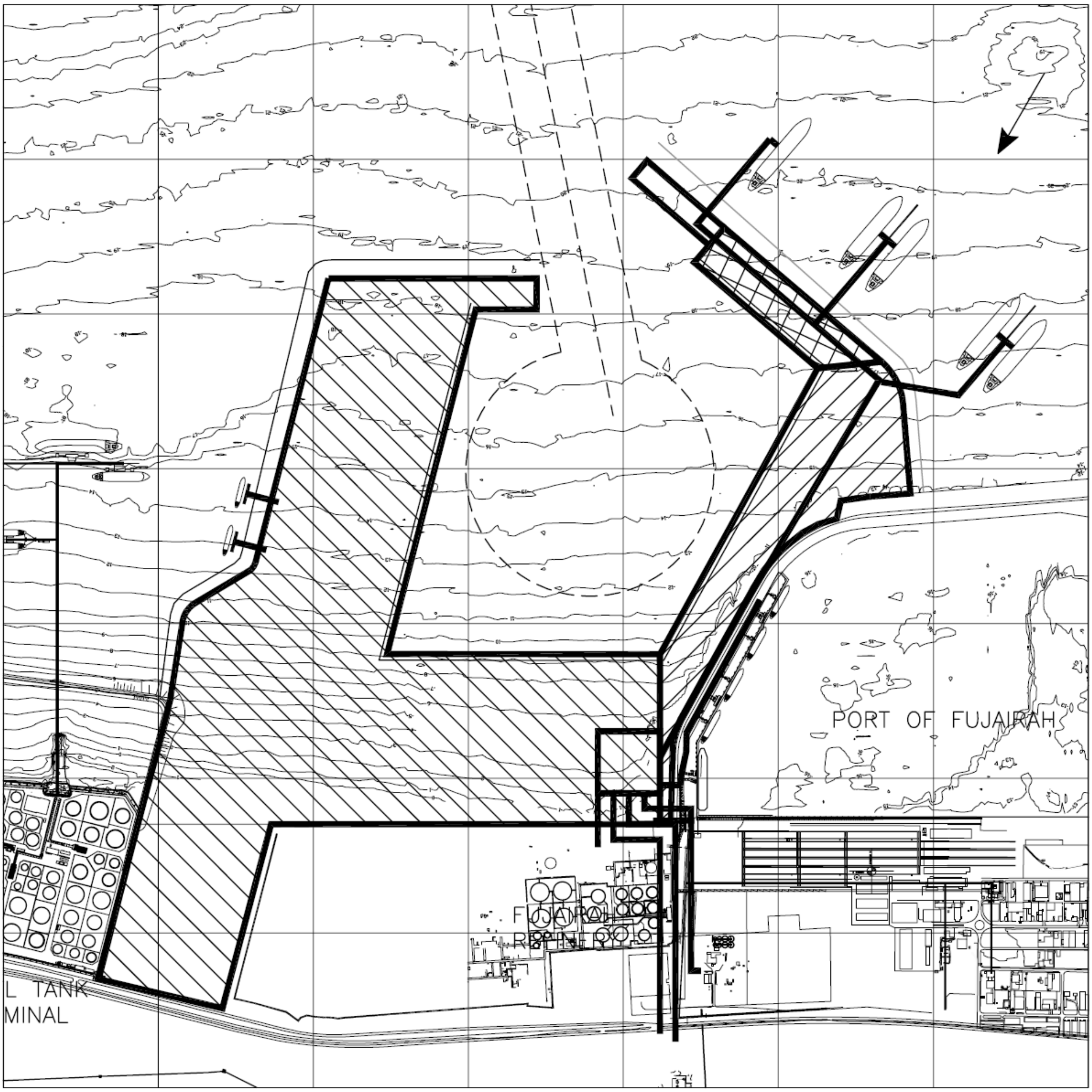
Figure Title
Layout A1 B1 phase 2 option B

M.U.C. Engineering



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Masterplan for the port of Fujairah Expansion Project

Figure no:
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Figure Title
Layout A1 B1 phase 3 option B

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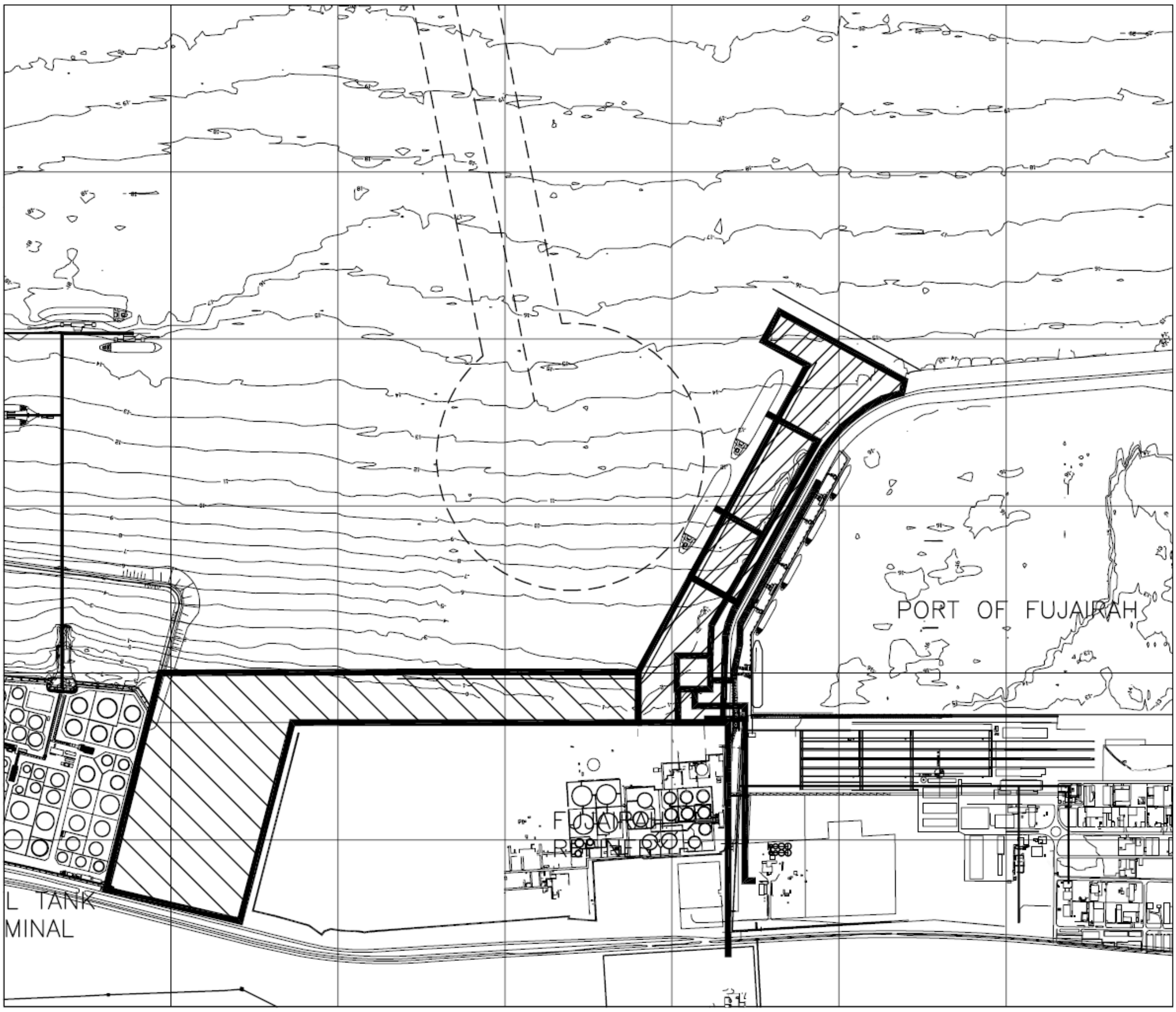

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Masterplan for the port of Fujairah Expansion Project

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Figure Title
Layout A2 B2 phase 1

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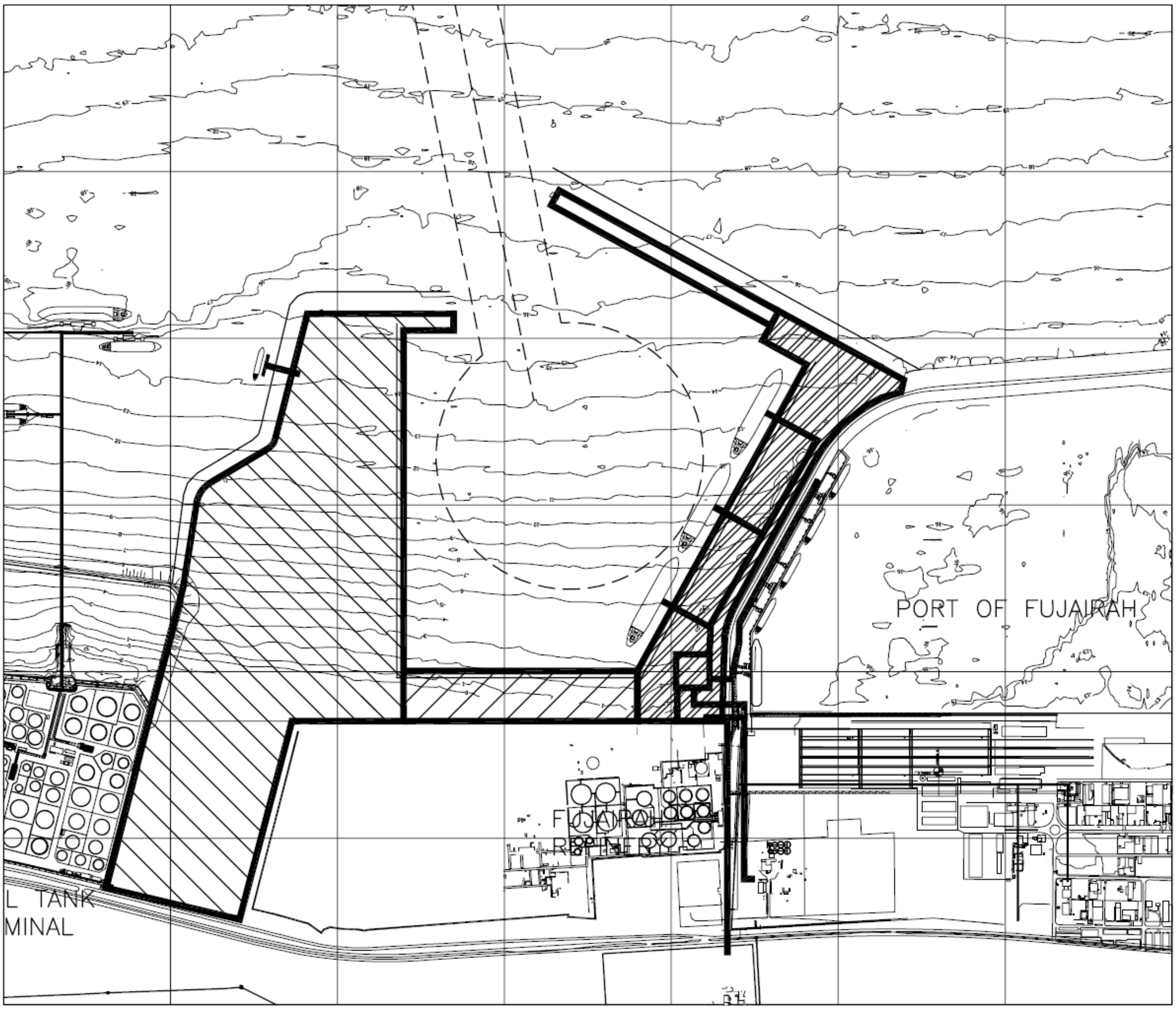

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Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A2 B2 phase 2

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M.U.C. Engineering

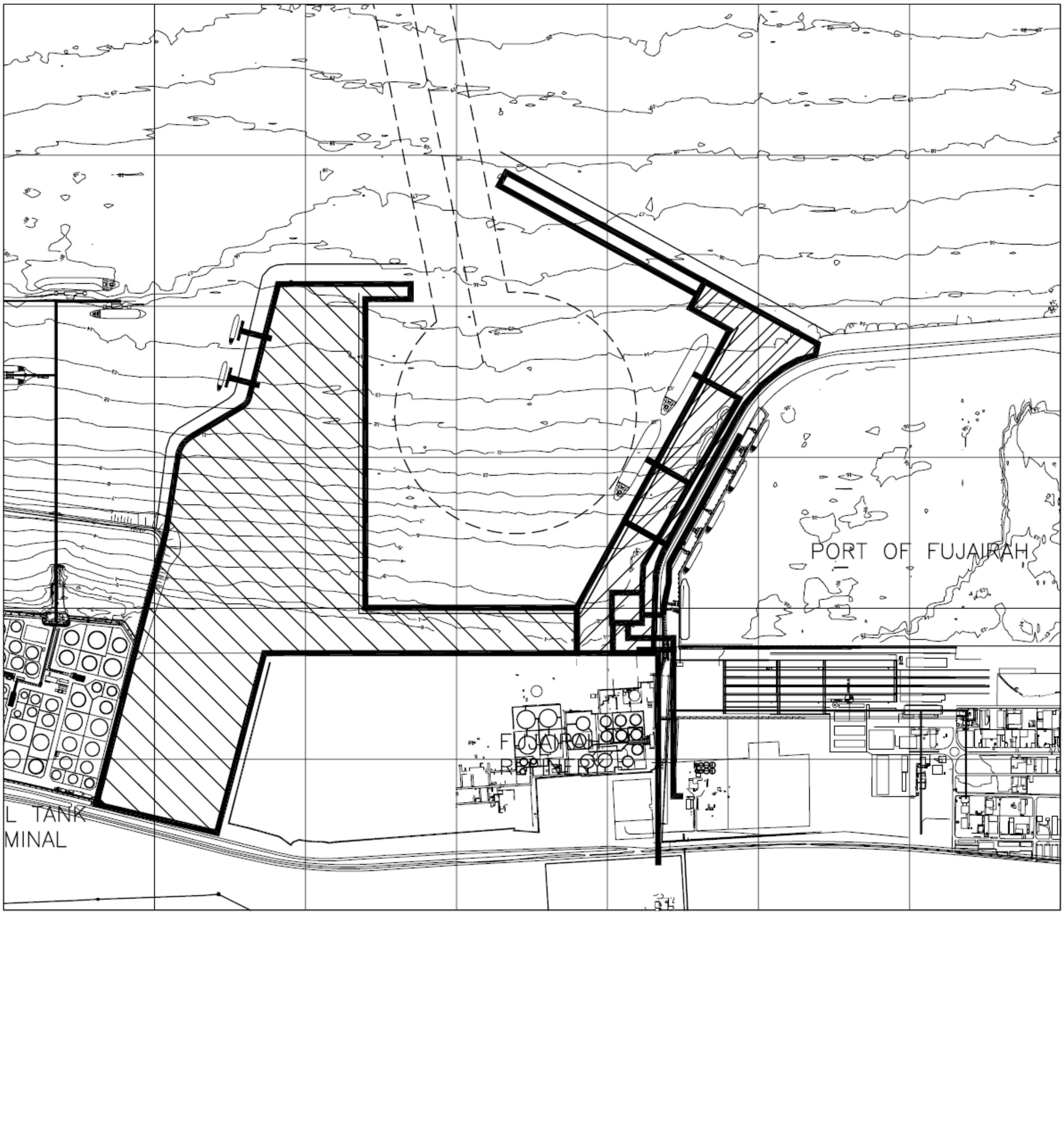

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Figure Title
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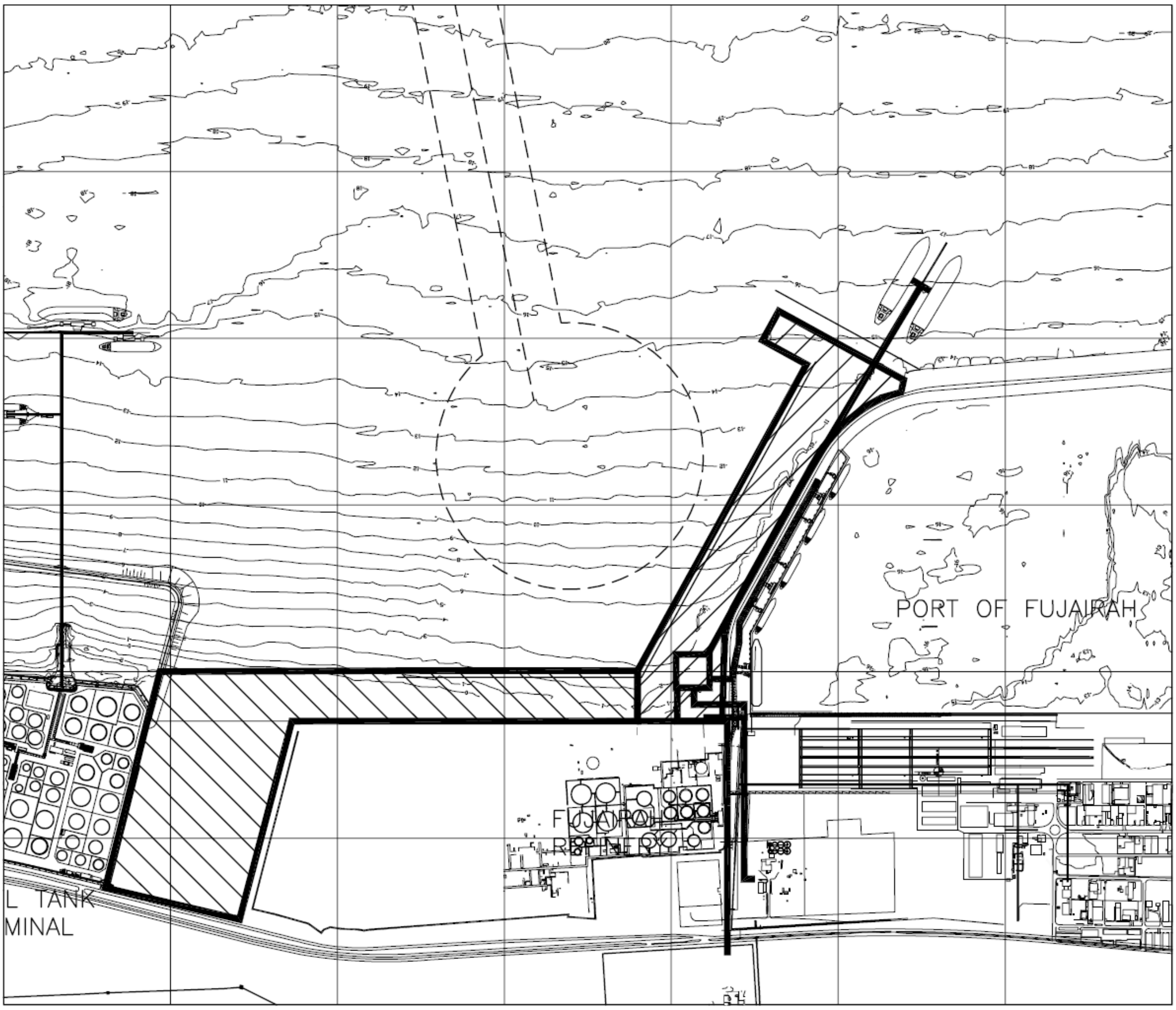

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Masterplan for the port of Fujairah Expansion Project

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Figure Title
Layout A2 B1 phase 1

M.U.C. Engineering

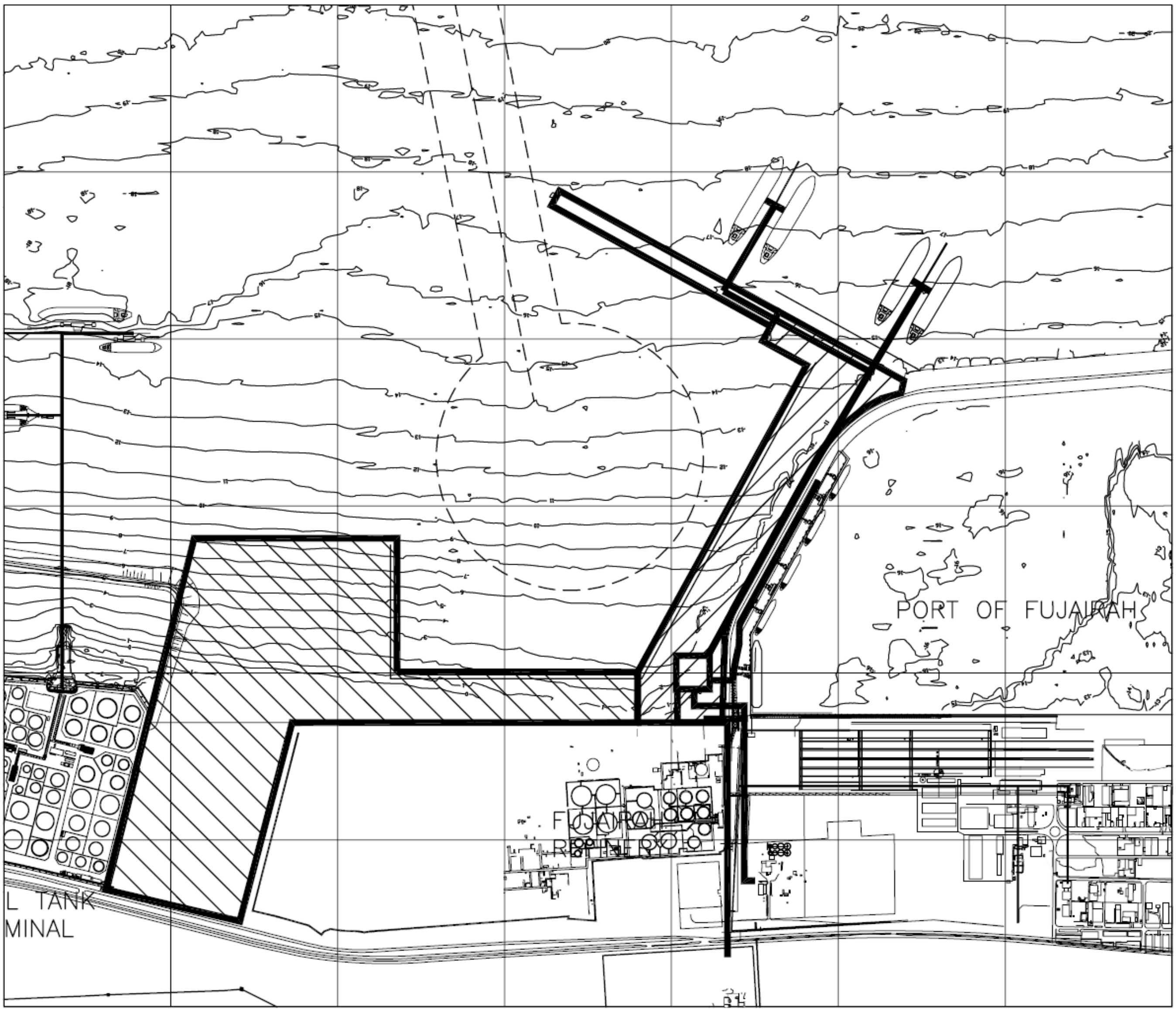

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Figure Title
Layout A2 B1 phase 2

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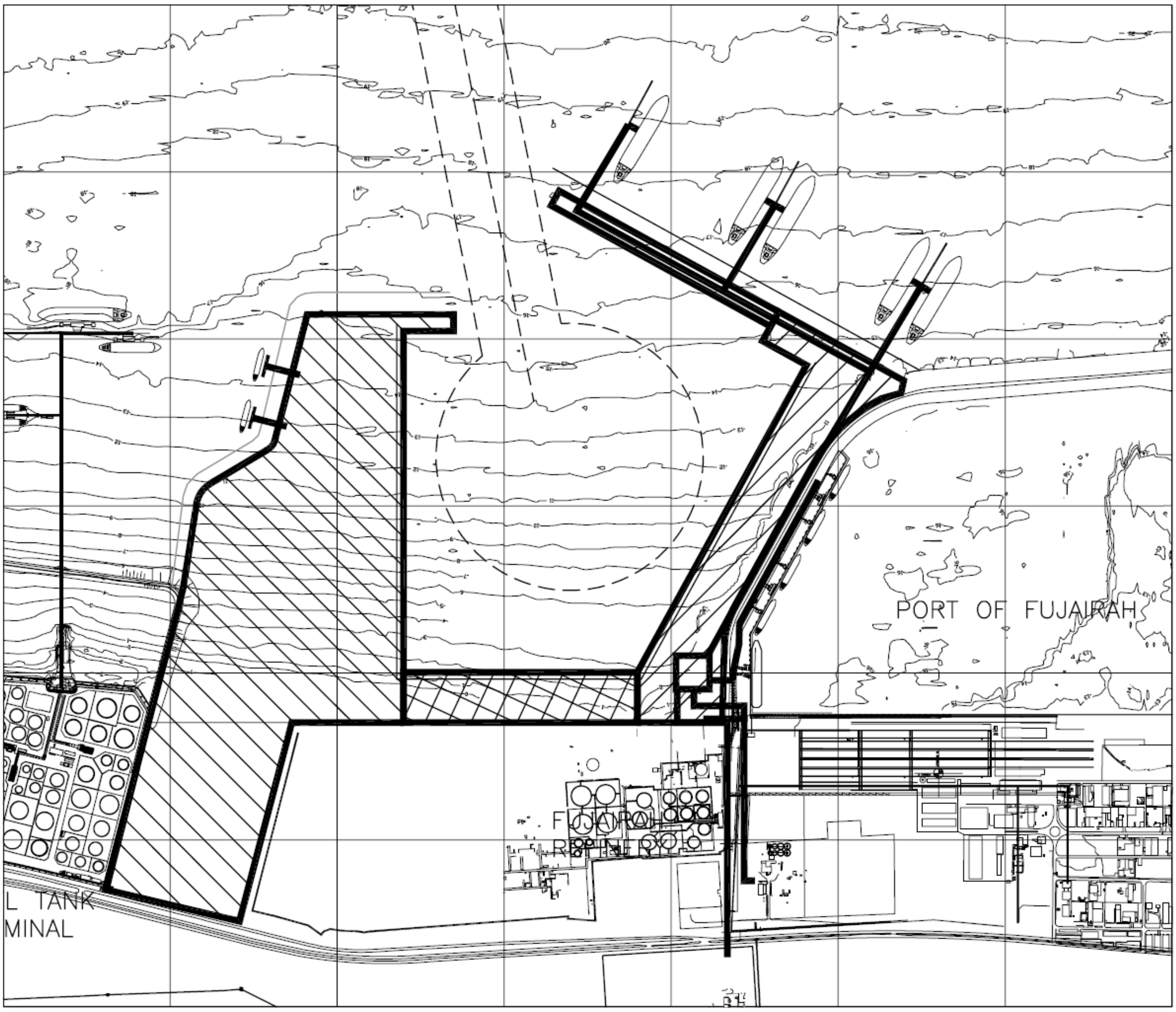

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Masterplan for the port of Fujairah Expansion Project

Figure no:
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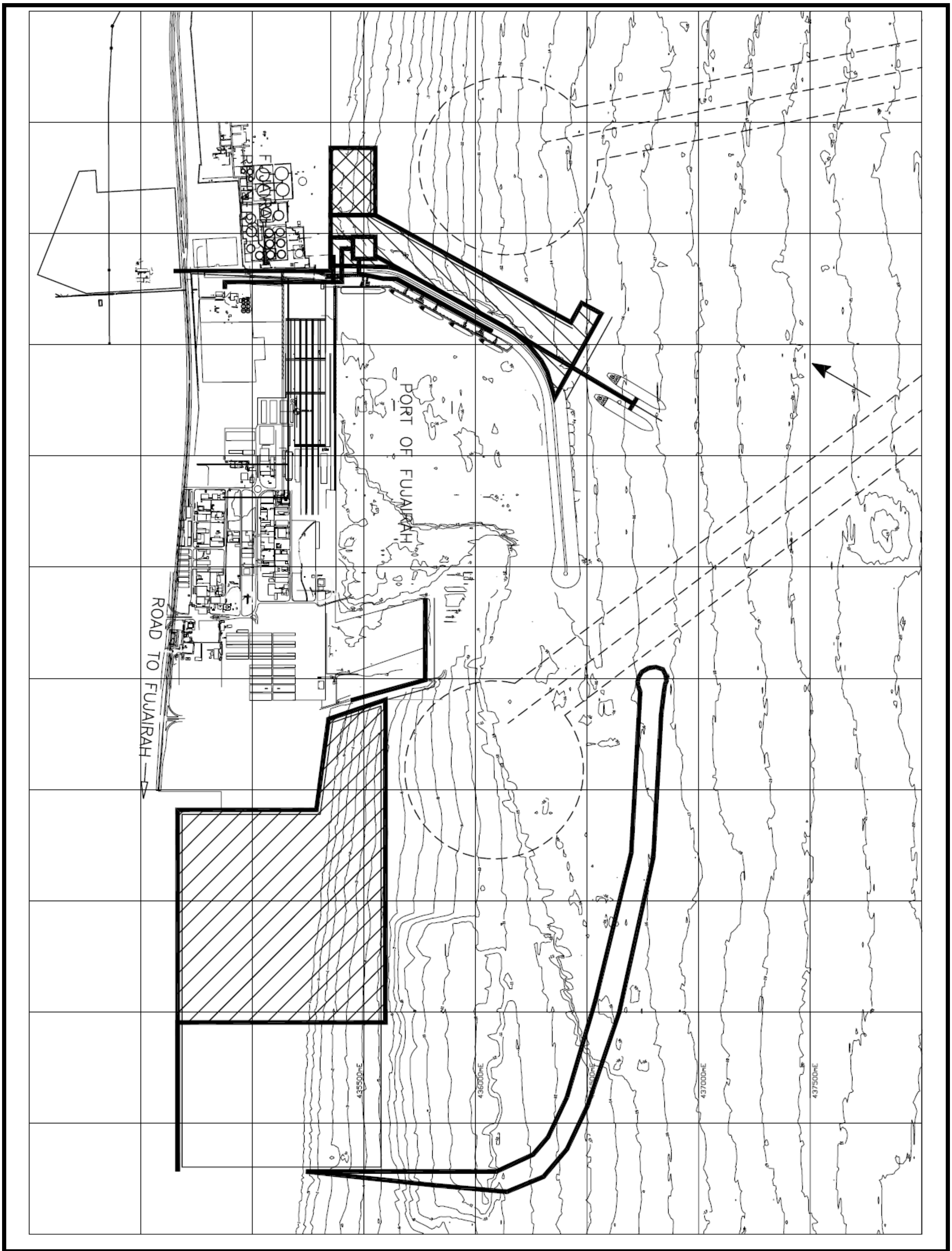
Figure Title
Layout A2 B1 phase 3

M.U.C. Engineering



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Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A3 B1 phase 1

Figure no:
A 2.24

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Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A3 B1 phase 2

Figure no:
A 2.25

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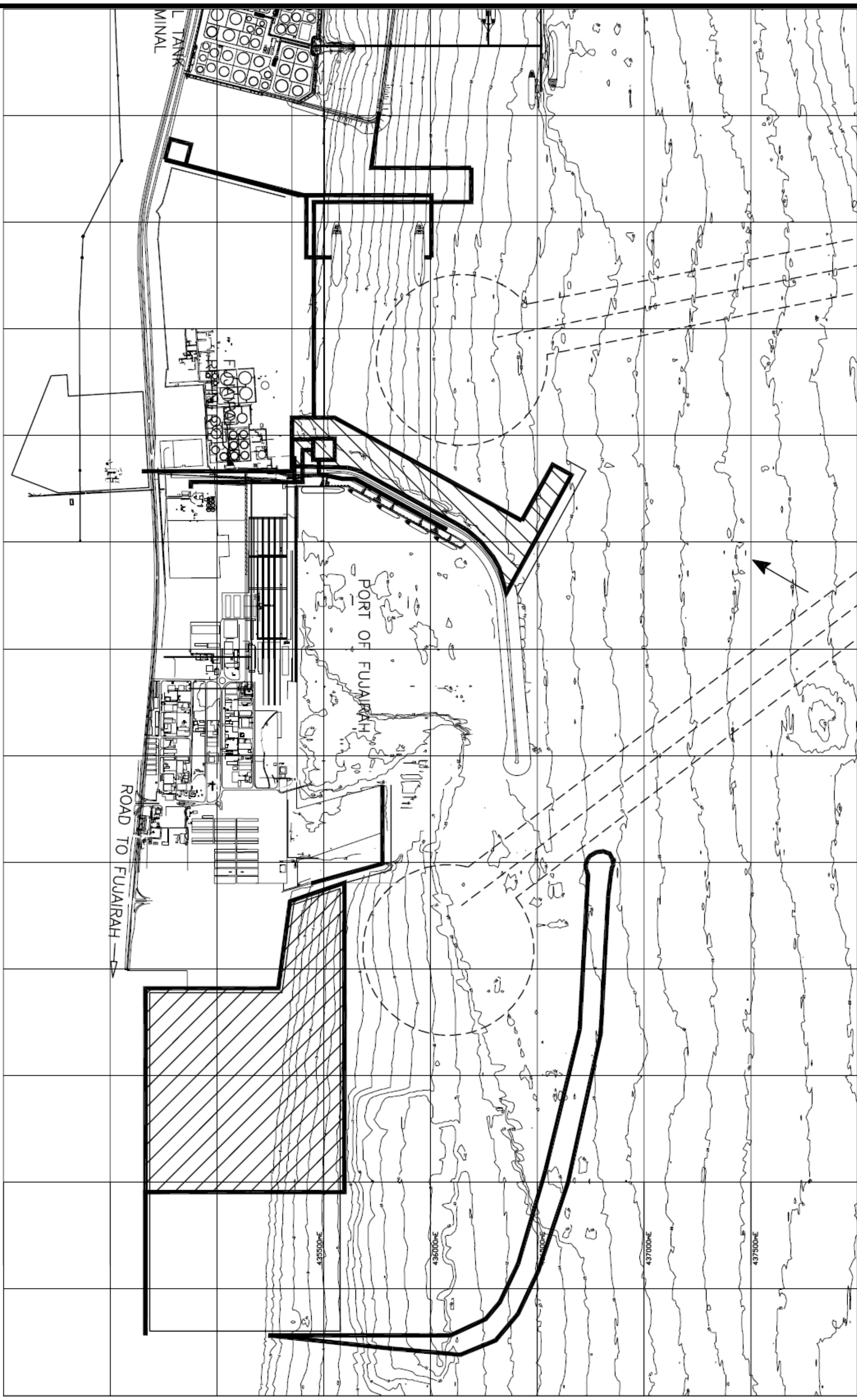
Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure no:
A 2.26

Figure Title
Layout A3 B1 phase 3

M.U.C. Engineering



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Masterplan for the port of Fujairah Expansion Project

Figure no:
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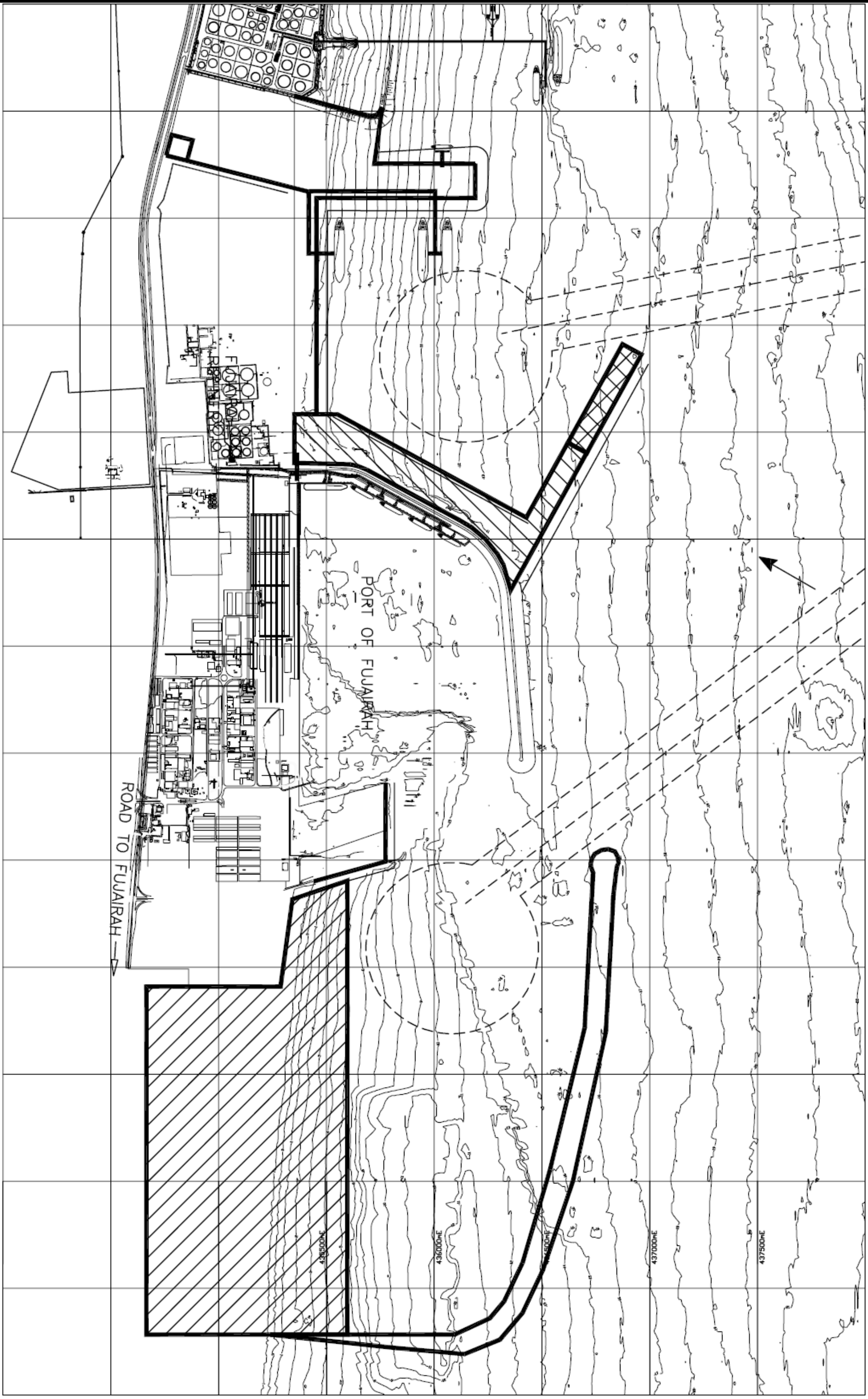
Figure Title
Layout A4 B3 phase 1

M.U.C. Engineering



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Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A4 B3 phase 2

Figure no:
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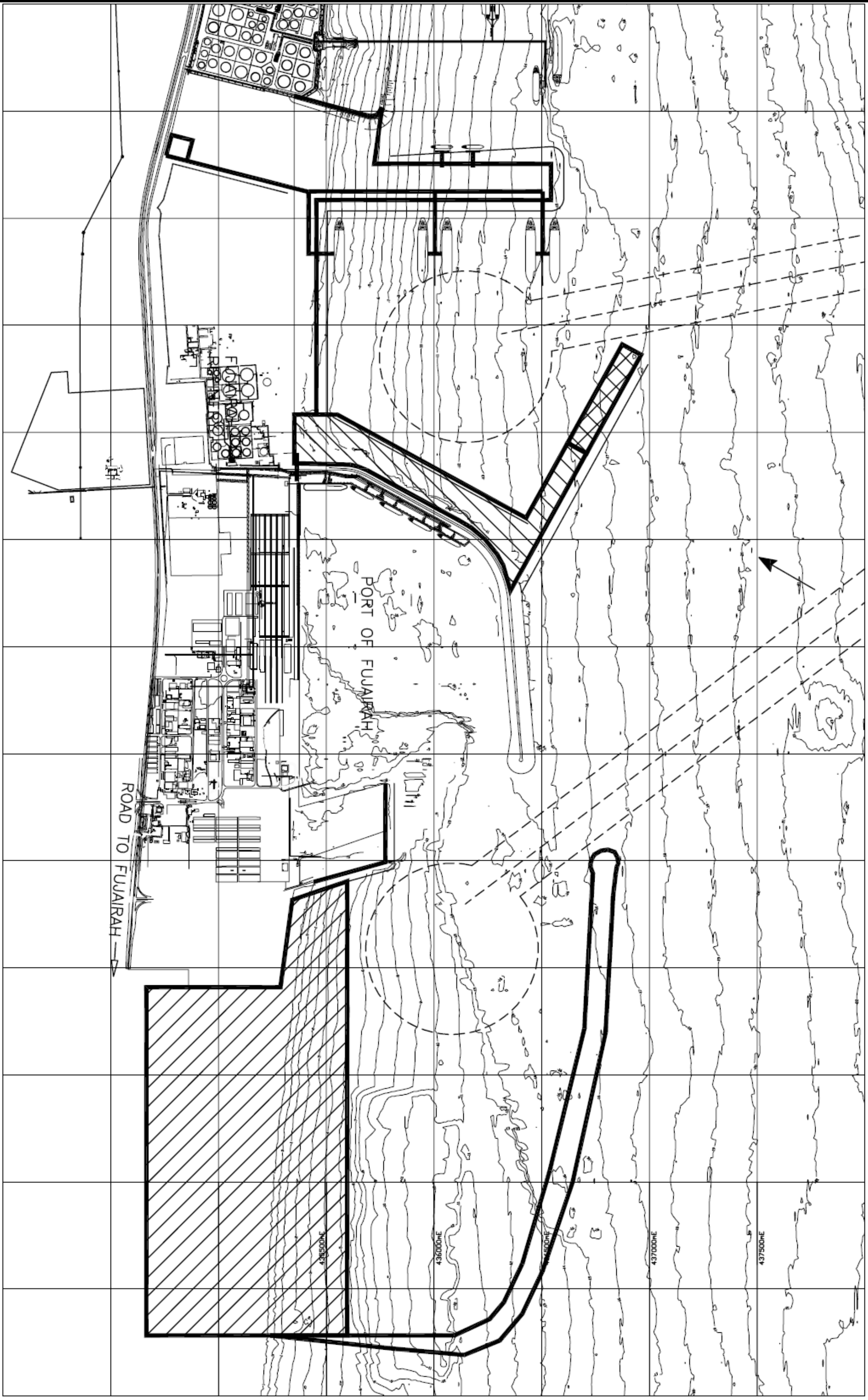
M.U.C. Engineering



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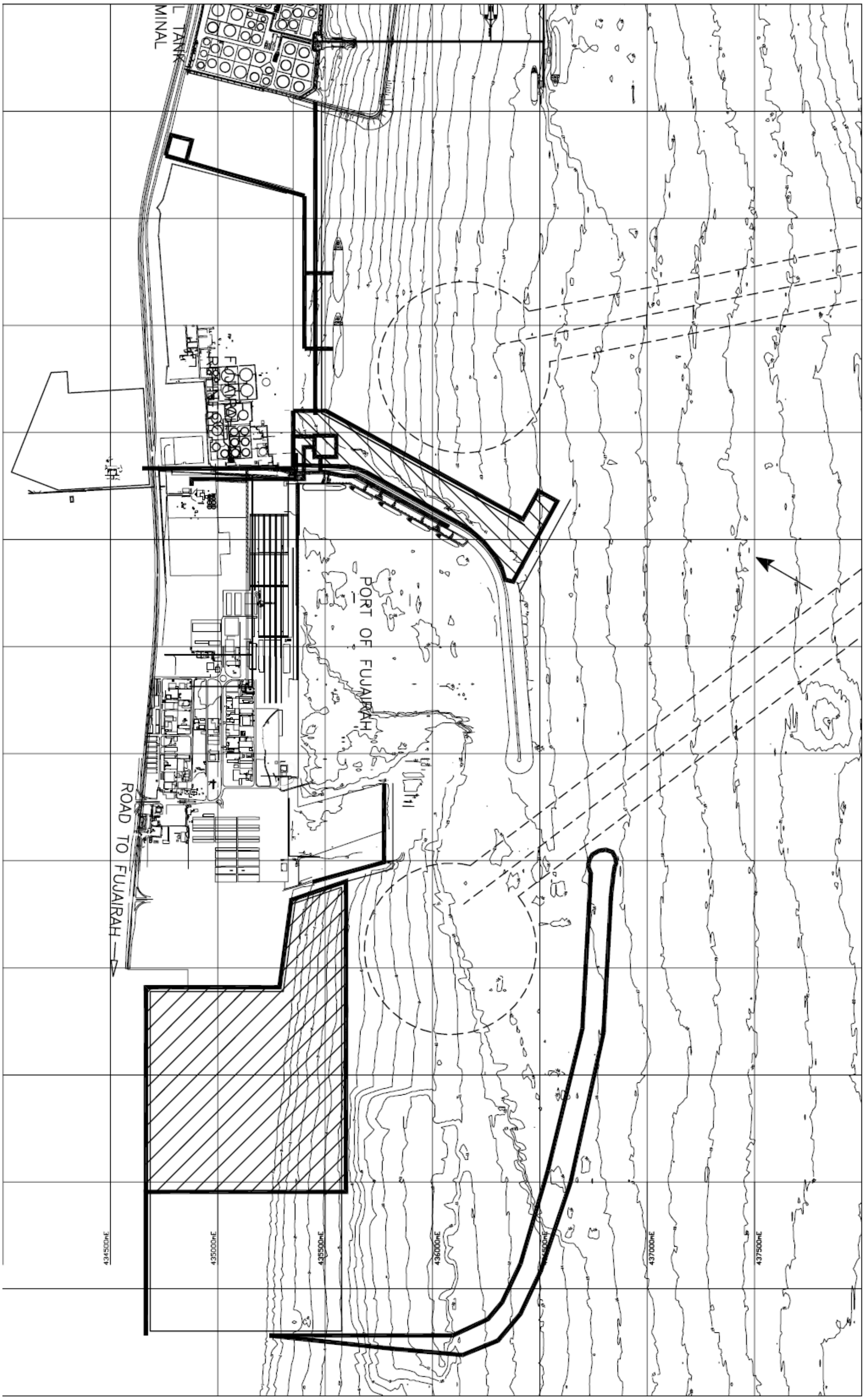
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A4 B3 phase 3

Figure no:
A 2.29

M.U.C. Engineering



Project Title:

Masterplan for the port of Fujairah Expansion Project

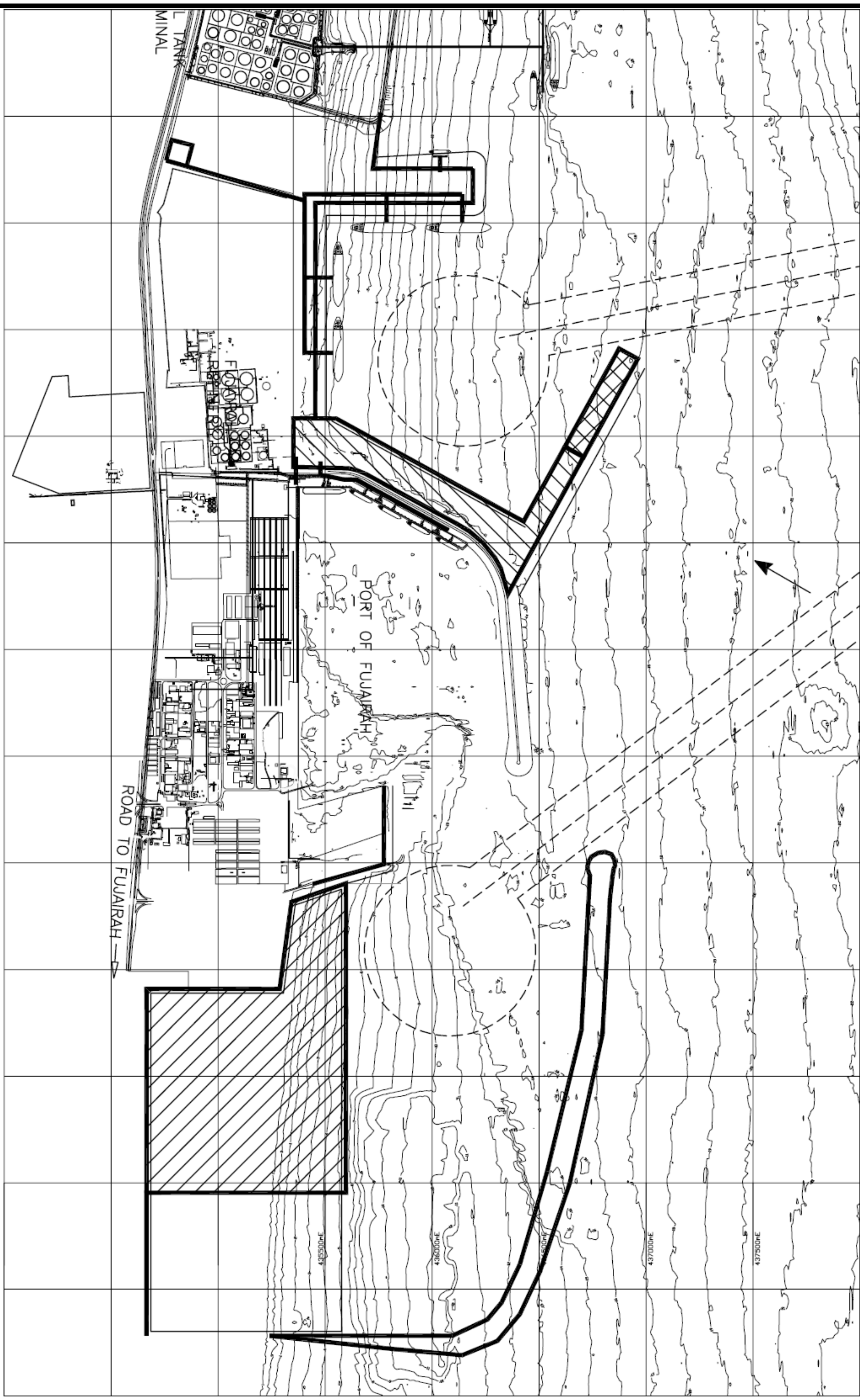
Figure Title

Layout A4 B4 phase 1

Figure no:

A 2.30

M.U.C. Engineering



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A4 B4 phase 2

Figure no:
A 2.31

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Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A4 B4 phase 3

Figure no:
A 2.32

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Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A5 B1 phase 1

Figure no:
A 2.33

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Project Title:

Masterplan for the port of Fujairah Expansion Project

Figure Title

Layout A5 B1 phase 2

Figure no:

A 2.34

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Project Title:

Masterplan for the port of Fujairah Expansion Project

Figure Title

Layout A5 B1 phase 3

Figure no:

A 2.35

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Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A5 B3 phase 1

Figure no:
A 2.36

M.U.C. Engineering

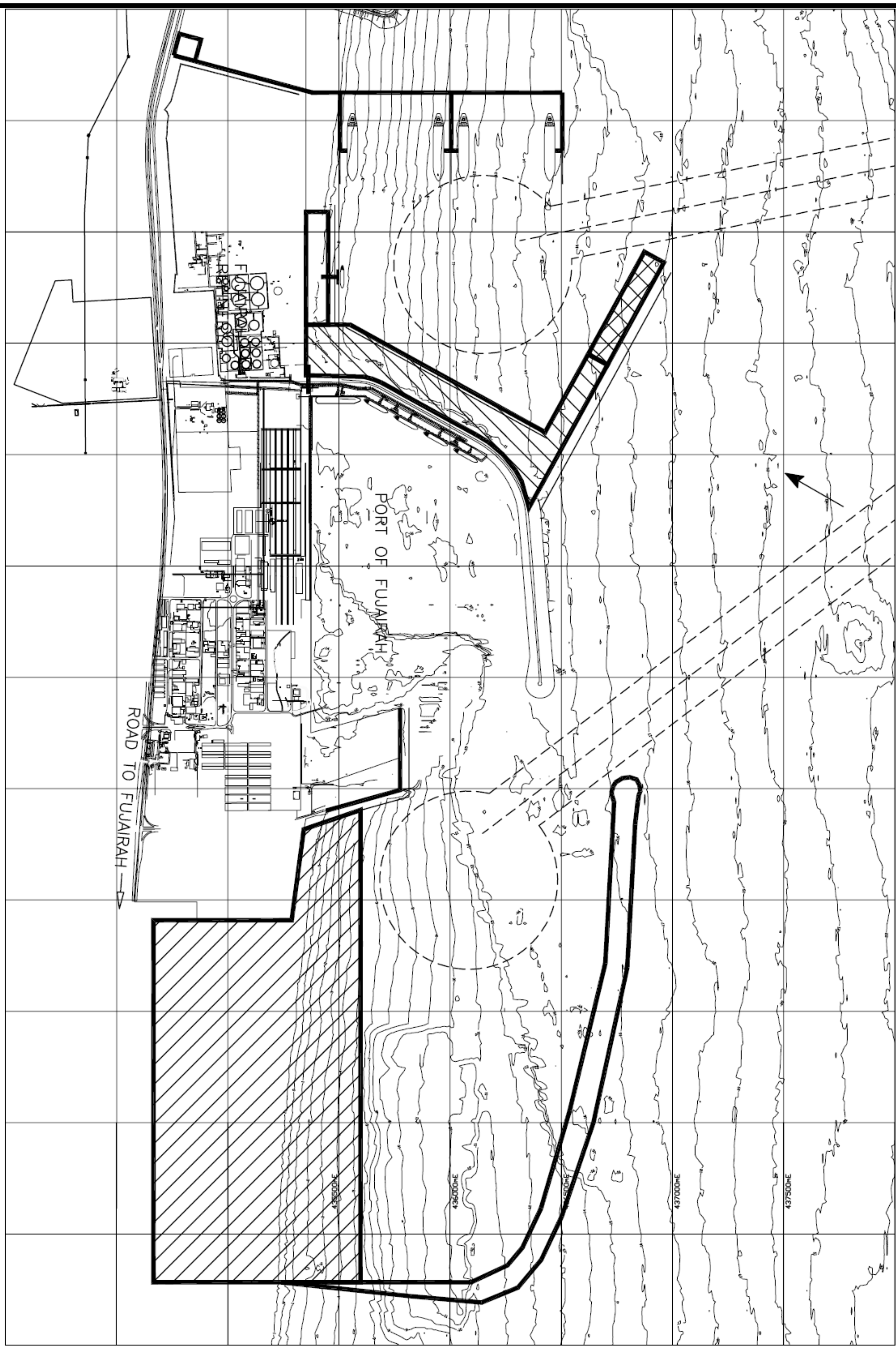

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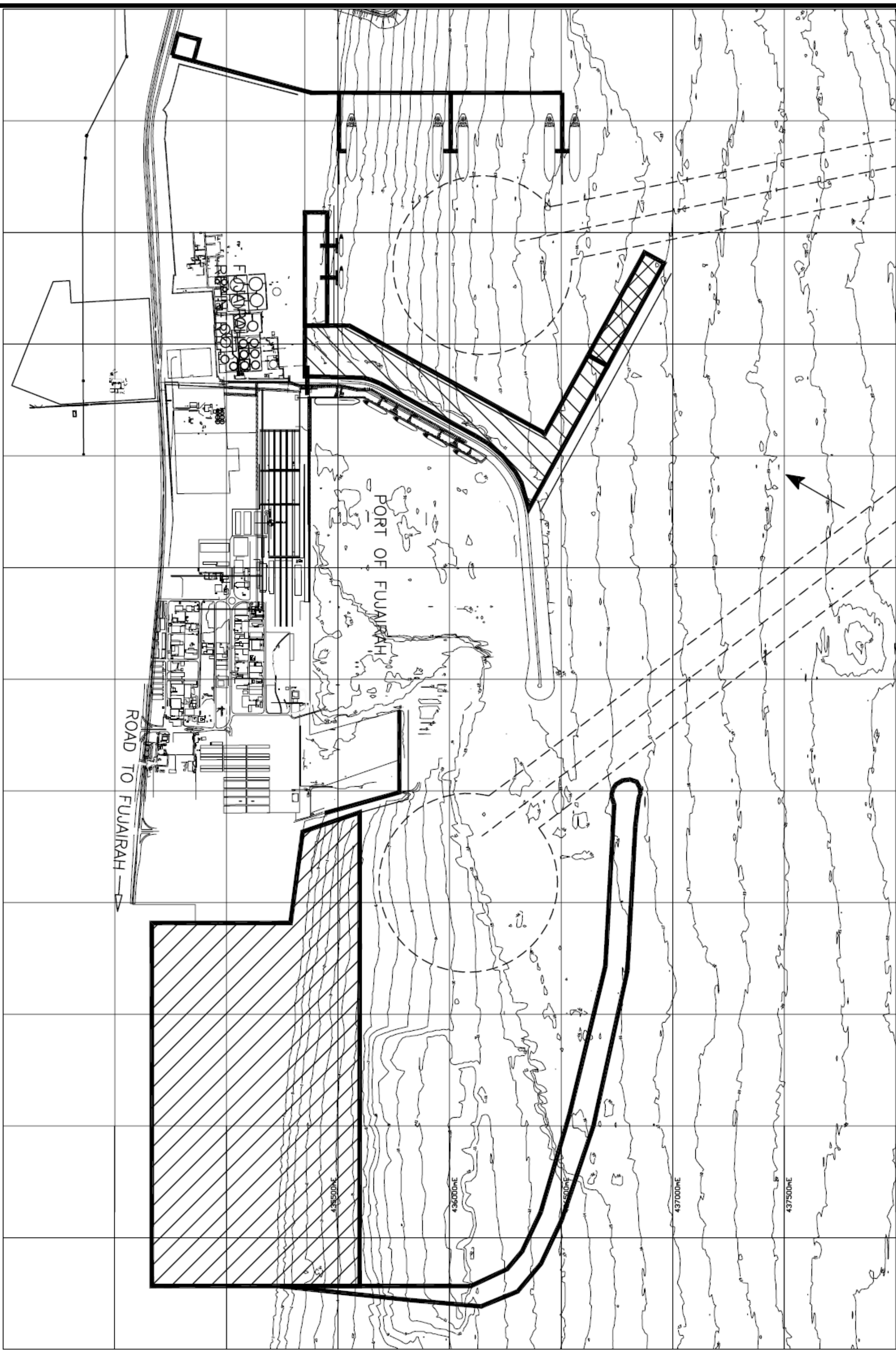
Figure Title Layout A5 B3 phase 2	

M.U.C. Engineering



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Masterplan for the port of Fujairah Expansion Project

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Layout A5 B3 phase 3

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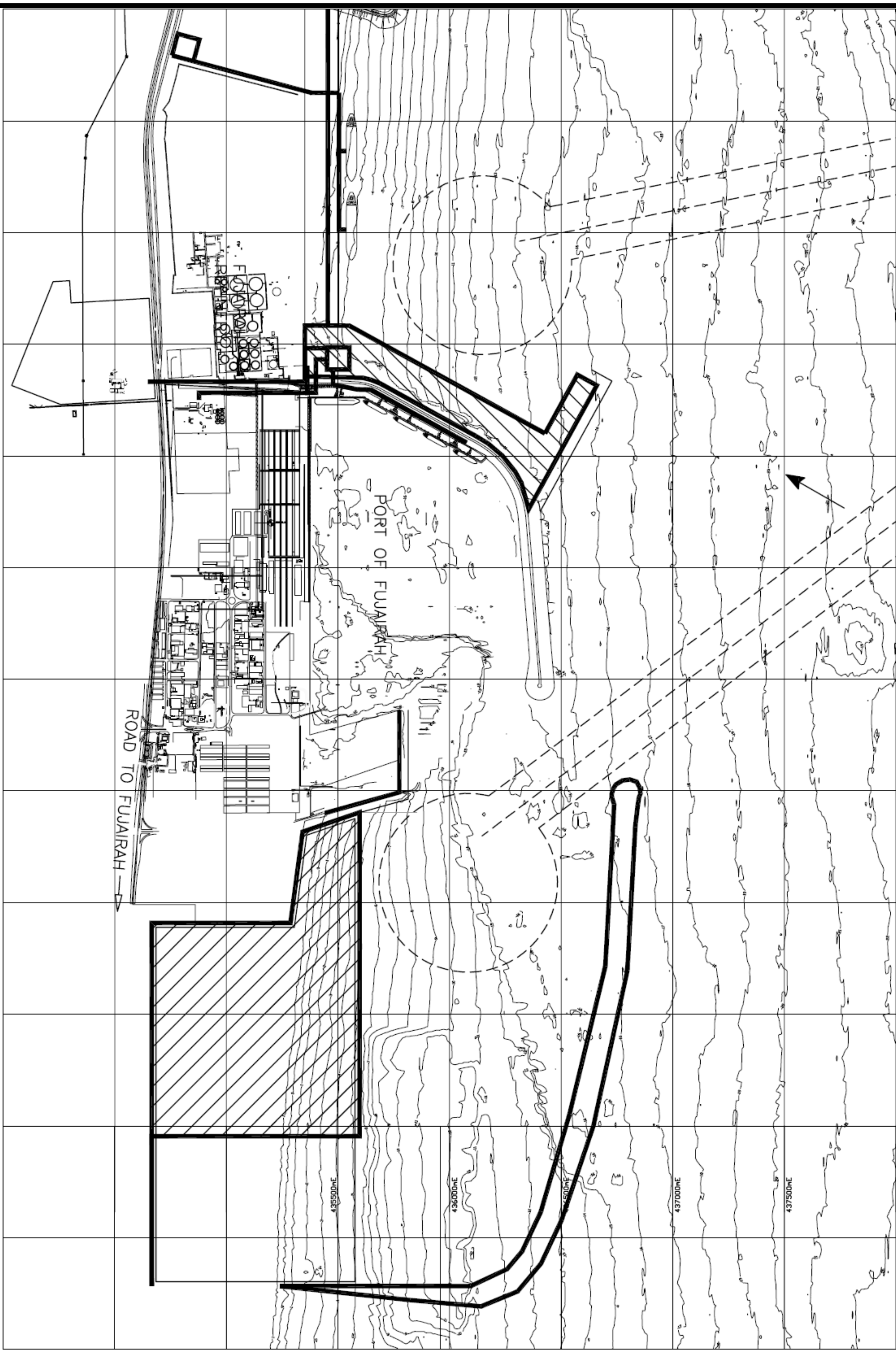
A 2.38

M.U.C. Engineering



Project Title:
Masterplan for the port of Fujairah Expansion Project

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Layout A5 B4 phase 1

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A 2.39

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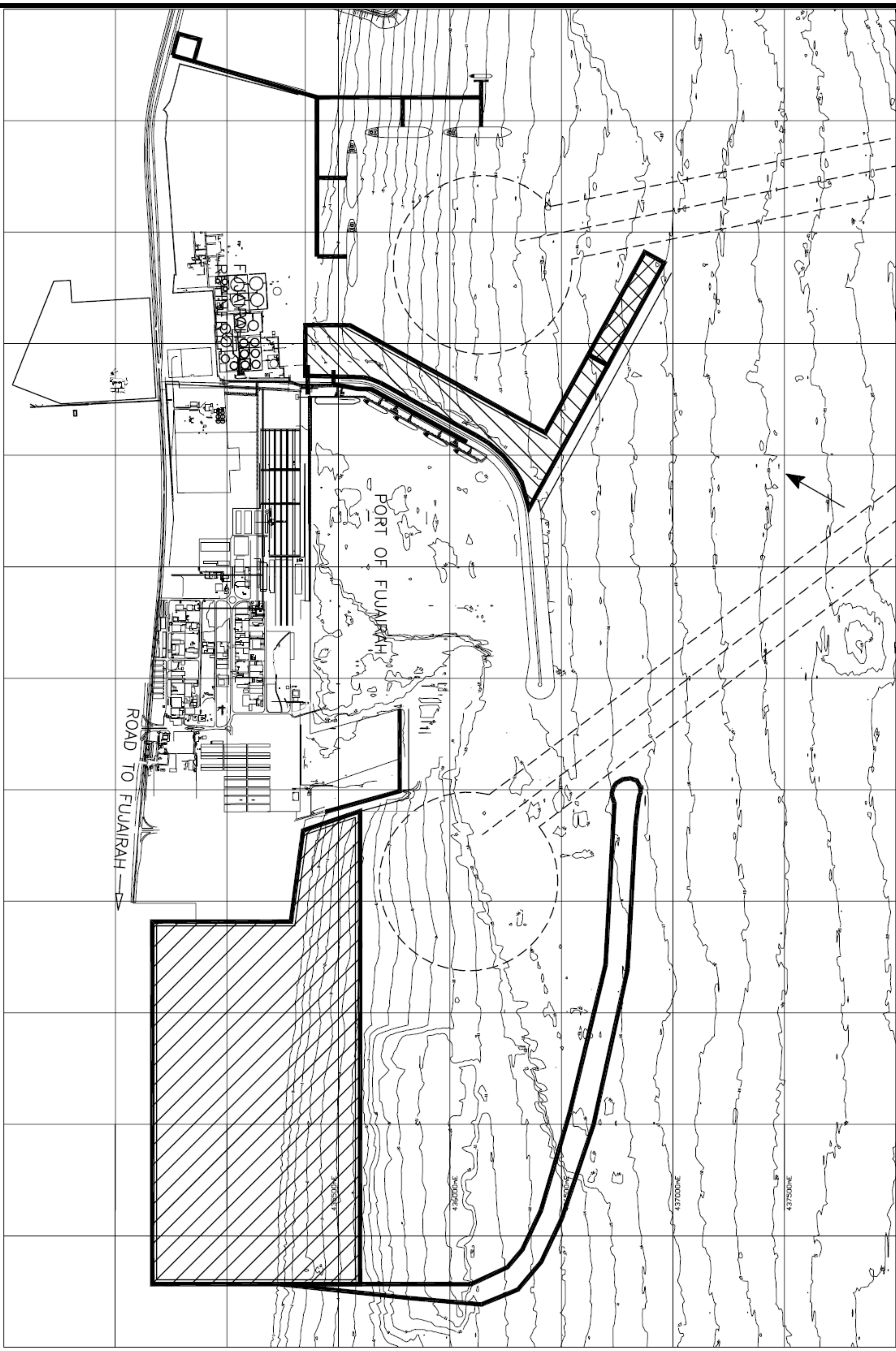

Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Layout A5 B4 phase 2

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Figure Title
Layout A5 B4 phase 3

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A3 Annex 3 Ship simulation model

Masterplan for the port of Fujairah Expansion Project

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A 3.1 Introduction

This annex to the Masterplan for the Port of Fujairah Expansion Project, describes the simulation models developed for the Port of Fujairah Expansion Project. The following sections describe the basic logic of the simulation model and provide details of how the model behaves given specific events.
A standard spreadsheet program was used to develop the – discrete event simulation model. The type of simulation that was used uses the Monte Carlo method, which makes use of random numbers to select model inputs from pre-defined statistical distributions. By repeatedly testing the model, a statistical distribution can be developed for the solution of variables. Monte Carlo methods are suitable for simulation of bulk terminals, due to the complex interaction of random variables.

A 3.2 Scope of the simulation studies

For the Expansion Project of the Port of Fujairah several simulation models where developed.
The main topics that were studied are:

- Throughput capacity of a new dry bulk terminal in combination with the existing dry bulk facilities in the Port of Fujairah.
- Throughput capacity of a new liquid bulk terminal in combination with the existing liquid bulk facilities in the Port of Fujairah.
- Throughput capacity of a new Container terminal.

The throughput capacities of these terminals where tested in two steps. The first step gives an estimate for the quay length, number of berths and number of cranes that is required to reach a certain throughput. The input values for these runs are the proposed throughput scenarios, vessel dimension and assumed capacities of cranes and conveyor belts. The results of this step are used to create layout alternatives. The second step is to estimate the throughput capacities of the proposed layout alternatives. The results of these calculations are used for the evaluation and selection of the proposed layouts.

A 3.3 Model description

A 3.3.1 Model structure

The model generates ships calling the port of Fujairah. The size of the ships and the inter arrival time are according to predefined statistical distributions. The ship enters the port of Fujairah and is served at a free berth that is able to handle the specific ship size. This can be immediately or when all berths are occupied after waiting. The ship that arrives first is being served first. This system is called FIFO (first in first out). The number of berths and the capacity of the berths can be varied.
The model is first used to determine the required quay length and number of berths for several desired throughput capacities. For this purpose, the average inter arrival time for which the desired throughput can be reached is determined. Subsequently the number of berths is varied until average waiting times are at an acceptable level.

The model takes into account:

- Capacity of the current ship loader
- Loading delays
- Varying vessel dimensions

- Variation in filling rates
- Vessel berthing restrictions

The model does not take into account:

- Meteorological conditions (wind speed, wind direction, wave height, current speed, etc)
- Ship traveling time
- Vessel manoeuvring conditions
- Conveyor routing
- Fluctuations in the loading rate due to unavailability of materials

A 3.3.2 Input values

Ship arrival pattern

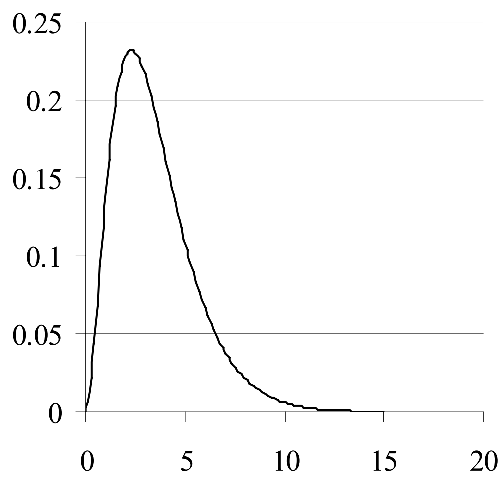
The assumed arrival pattern of ships is according an Erlang distribution. The Erlang distribution is a continuous probability distribution with wide applicability primarily due to its relation to the exponential and Gamma distributions. The Erlang distribution was developed by A. K. Erlang to examine the number of telephone calls which might be made at the same time to the operators of the switching stations. This work on telephone traffic engineering has been expanded to consider waiting times in queuing systems in general. The distribution is now used in the field of stochastic processes.
The probability density function of the Erlang distribution is

$$f(x;k;\lambda) = \frac{\lambda^k \cdot x^{k-1} \exp^{-\lambda x}}{(k-1)!} \text{ for } x > 0 \qquad \text{[Annex 3.3.1]}$$

The parameter k is called the shape parameter and the parameter λ is called the rate parameter. Because of the factorial function in the denominator, the Erlang distribution is only defined when the parameter k is a positive integer. In fact, this distribution is sometimes called the Erlang-k distribution (e.g., an Erlang-2 distribution is an Erlang distribution with $k=2$). The Gamma distribution generalizes the Erlang by allowing its first parameter to be a real, using the gamma function instead of the factorial function. The cumulative distribution function of the Erlang distribution is

$$F(x,k,\lambda) = 1 - \sum_{n=0}^{k-1} e^{-\lambda x} (\lambda x)^n / n! \qquad \text{[Annex 3.3.2]}$$

Te probability density function of the Erlang 3 is shown in graph A 3.1



graph A 3.1 Erlang 3 distributions with average inter arrival time of 3.5 hr.

Average waiting time

Goal of the simulation is to choose the number of berths so that the average waiting does not become too high. The suggested optimum berth utilization according to UNCTAD for container handling:

$$t_{wait} / t_{service} = 0.10 \qquad \text{[Annex 3.3.3]}$$

And for other commodities:

$$t_{wait} / t_{service} = 0.20 \qquad \text{[Annex 3.3.4]}$$

Conformation of these numbers by means of an economic study, does reaches beyond the scope of this study.

Run time of the model

One simulation run comprises 2500 ship movements. The run time of the model therefore depends on the average inter arrival time of the vessels. The results of one simulation will be averaged over a number of runs. The arithmetic mean is used. This is the most common type of average, often referred to simply the "average" or "mean".

$$= \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \text{[Annex 3.3.5]}$$

Where *x* is the set of simulation outputs and *n* is the number of simulation runs. The minimum number of runs to assure that the estimate of the mean lies within 10% of the true mean with $\alpha = 0.05$ is given:

$$n = \frac{(t_{\alpha/2})^2 \cdot \mathrm{var}(X_i) \cdot \left[1 + 2 \cdot \sum_{p=1}^{m} \left\{ \left(1 - \frac{p}{m+1}\right) \cdot \rho_{p_1 x} \right\} \right]}{(d\mu)^2} \qquad \text{[Annex 3.3.6]}$$

Further a basic criteria for the minimum duration of the simulation period is that the queue length at the beginning of the simulation period is independent of the queue length at the end of the period

A 3.4 Simulation dry bulk terminal

A 3.4.1 Introduction

The dry bulk terminal exists of two parts. One part is exclusively used for to the loading of aggregates and one part for the unloading of other dry bulk. This other material will most likely be clinker or bauxite. One of the planned developments in the emirate of Fujairah is the construction of a cement factory. This will be the main reason to make the aggregate unloading facility.

A 3.4.2 Input values

Arrival pattern

Since the arrival pattern is expected to be relatively regular an Erlang 3 distribution was chosen. The average inter arrival time varies for the different required throughput capacities. Ships are handled according a first in first out system.

Vessel dimensions

Dimensions of dry bulk vessels are distributed according to table A 3.1 for dry bulk. These values are derived from Lloyd's register vessel statistics.

Dry bulk vessels	DWT	Length [m]	Draught [m]	Max no of cranes	%
Handysize	6,000 – 50,000	120 – 220	6 – 12.5	1	71 %
Suezmax/Panamax	50,000 – 100,000	200 – 250	10 – 15	1	21 %
Cape size	100,000 – 150,000	240 – 285	15 – 17.5	2	4 %
Cape Size	150,000 – 175,000	265 – 300	17 – 18	2	4 %

table A 3.1 Dry bulk vessel size distribution according to Lloyd's register vessel statistics

Loading rates/loading durations
Assumed average idle time based on the current port operations is 3 hours. The idle time represents the following processes:

- Ship traveling to the berth
- Ship turn and berth
- Ship documentation and loading preparations

The loading commences once these delays have occurred. The difference between the time the ships arrives at the terminal, and the time the vessel starts to load is tracked as the ship quay time for each vessel. The model does not calculate demurrage time.
The vessel loading rate depends on the loading rate of the cranes and the number of cranes. It is assumed that only for the bigger vessels more than one crane is used. For the first estimation of required quay length and number of cranes, on crane per vessel is assumed. It is assumed that when the port expands further, extra cranes can be installed. Of course this must be taken into account with the determination of the width behind the quays. It is assumed that the amount of aggregates to load the vessels can always be supplied for. It must be noted that to realize this in practice, this will be a large task for the quarries and transporters.
The average loading rate of the existing crane is 1,700 ton/hr. The new cranes are assumed to have a rate 3,300 ton/hr. The facilities in the existing port are part of the calculation of waiting times for the new port. This means that the existing ships loader remains in use.

The dry bulk terminal at least for phase 1, will be designed for cape size vessels. (150,000 – 175,000 DWT) and smaller.
The loading of aggregates will be a continuous process where ship loaders will be fed by a conveyor belt system from the stockpile area. The port has ordered cranes that have loading rates of maximum 4.4 ton per hour. The average loading rate of this crane is 3,400 ton per hour. The cranes are capable of loading ships up to 175,000 DWT. These cranes are travelling shiploader types which mean that they can move parallel to the quay.
To determine the required number of cranes for the port expansion and the composed scenario's according to the previous chapter, a basic simulation of the port system has been carried out.
For this simulation the following assumptions have been made:

- Ships sizes of dry bulk vessels that call the future Port of Fujairah are distributed according to table A 3.1. It is also assumed that the average parcel size of these vessels is evenly distributed between half full and full.
- The existing port (only the aggregate ship loader and not lift and grab operation) is part of the system. The average loading rate for this berth is 1,700 ton per hour. Ships calling the Port of Fujairah will be berthed in the existing port first. Since the maximum draft is only 15 m in the existing port, only ships up to 100,000 DWT can be handled in the existing port.
- Ships are handled according to a "first in first out" system. If the size of the vessel admits it, it will first be berthed at the existing port. If this berth is occupied it will be berthed at a quay in the new port expansion.

- The average idle time is 3 hours. This is the time that the berth can not be used by other ship while the ship loader is not operating. This time is used for mooring the ship, administrative processes and for getting the required material on the conveyor belt.
- Ships arrive at the port according to an Erlang-3 distribution. This distribution is chosen because the interval of arriving ships is expected to be relatively regular. The material is transported by a limited number of shipping agents.
- One ship is served by not more than one ship loader.

A 3.4.3 Results

20 M ton yearly

Average inter arrival time	20.5	hr
Simulation time	4.45	yr
No of ship movements	2000	
Average waiting time	0.67	hr
Required quay length	605	m

Occupancy berth 1 (existing)	62.4%
Occupancy berth 2	25.8%
Occupancy berth 3	24.1%

Ship sizes	total	berth 1	berth 2	berth 3
25,000	71.0%	77.1%	77.0%	36.1%
75,000	21.0%	22.9%	23.0%	9.5%
125,000	4.0%	0.0%	0.0%	26.9%
162,500	4.1%	0.0%	0.0%	27.5%
Service time [hr]	21.8	24.4	31.5	31.5

table A 3.2 Simulation results dry bulk export 20 M ton/yr

30 M ton yearly

Average inter arrival time	14.3	hr

Simulation time	3.05	yr

No of ship movements	2000	

Average waiting time	0.95	hr

Required quay length	605	m

Occupancy berth 1 (existing)	71.8%
Occupancy berth 2	47.7%
Occupancy berth 3	35.6%

Ship sizes	total	berth 1	berth 2	berth 3
25,000	71.3%	77.6%	72.0%	58.2%
75,000	20.7%	22.4%	21.0%	16.6%
125,000	3.8%	0.0%	7.1%	4.8%
162,500	4.2%	0.0%	0.0%	20.4%

Service time [hr]	20.7	24.3	23.0	23.0

table A 3.3 Simulation results dry bulk export 30 M ton/yr

40 M ton yearly

Average inter arrival time	10.8	hr

Simulation time	2.24	yr

No of ship movements	2000	

Average waiting time	1.48	hr

Required quay length	807	m

Occupancy berth 1 (existing)	77.4%
Occupancy berth 2	38.0%
Occupancy berth 3	38.5%
Occupancy berth 4	46.6%

Ship sizes	total	berth 1	berth 2	berth 3	berth 4
25,000	71.3%	75.9%	100.0%	49.0%	20.6%
75,000	20.8%	24.1%	0.0%	51.0%	21.9%
125,000	3.9%	0.0%	0.0%	0.0%	28.8%
162,500	3.9%	0.0%	0.0%	0.0%	28.8%

Service time [hr]	19.6	24.8	18.3	18.3	33.5

table A 3.4 Simulation results dry bulk export 40 M ton/yr

50 M ton yearly

Average inter arrival time	8	hr
Simulation time	1.76	yr
No of ship movements	2000	
Average waiting time	1.60	hr
Required quay length	908	m

Occupancy berth 1 (existing)	82.2%
Occupancy berth 2	63.7%
Occupancy berth 3	54.6%
Occupancy berth 4	51.2%

Ship sizes	total	berth 1	berth 2	berth 3	berth 4
25,000	70.8%	77.1%	77.2%	68.2%	48.4%
75,000	21.1%	22.9%	22.8%	20.0%	15.7%
125,000	4.0%	0.0%	0.0%	11.7%	7.8%
162,500	4.1%	0.0%	0.0%	0.0%	28.1%
Service time [hr]	19.4	24.4	17.1	17.1	27.0

table A 3.5 Simulation results dry bulk export 50 M ton/yr

60 M ton yearly

Average inter arrival time	6.8	hr
Simulation time	1.49	yr
No of ship movements	2000	
Average waiting time	0.5	hr
Required quay length	1192	m

Occupancy berth 1 (existing)	83.7%
Occupancy berth 2	52.1%
Occupancy berth 3	68.5%
Occupancy berth 4	51.1%
Occupancy berth 5	32.6%

Ship sizes	total	berth 1	berth 2	berth 3	berth 4	berth 5
25,000	70.8%	75.6%	100.0%	48.8%	48.4%	70.8%
75,000	21.1%	24.4%	0.0%	34.2%	33.5%	21.1%
125,000	4.2%	0.0%	0.0%	8.7%	9.4%	4.2%
162,500	4.0%	0.0%	0.0%	8.4%	8.7%	4.0%
Service time [hr]	24.8	21.8	21.8	21.1	21.6	24.8

table A 3.6 Simulation results dry bulk export 60 M ton/yr

70 M ton yearly

Average inter arrival time	5.85	hr

Simulation time	1.27	yr

No of ship movements	2000

Average waiting time	1.00	hr

Required quay length	1192	m

Occupancy berth 1 (existing)	86.6%
Occupancy berth 2	60.1%
Occupancy berth 3	75.2%
Occupancy berth 4	62.4%
Occupancy berth 5	46.5%

Ship sizes	total	berth 1	berth 2	berth 3	berth 4	berth 5
25,000	71.1%	74.7%	100.0%	51.2%	51.7%	50.2%
75,000	20.9%	25.3%	0.0%	32.4%	32.1%	33.2%
125,000	4.1%	0.0%	0.0%	8.5%	8.3%	7.9%
162,500	4.0%	0.0%	0.0%	7.9%	7.9%	8.7%

Service time [hr]	18.4	25.1	21.3	21.3	20.2	20.6	r

table A 3.7 Simulation results dry bulk export 70 M ton/yr

80 M ton yearly

Average inter arrival time	5.15	hr

Simulation time	1.11	yr

No of ship movements	2000

Average waiting time	1.00	hr

Required quay length	1335	m

Occupancy berth 1 (existing)	88.5%
Occupancy berth 2	61.6%
Occupancy berth 3	44.2%
Occupancy berth 4	60.7%
Occupancy berth 5	67.6%
Occupancy berth 6	52.5%

Ship sizes	total	berth 1	berth 2	berth 3	berth 4	berth 5	berth 6
25,000	70.6%	70.9%	100.0%	100.0%	38.6%	22.6%	21.9%
75,000	21.2%	29.1%	0.0%	0.0%	61.4%	35.1%	35.4%
125,000	4.1%	0.0%	0.0%	0.0%	0.0%	20.9%	21.1%
162,500	4.2%	0.0%	0.0%	0.0%	0.0%	21.4%	21.6%

Service time [hr]	18.2	26.2	10.6	10.6	18.8	30.0	30.2

table A 3.8 Simulation results dry bulk export 80 M ton/yr

90 M ton yearly

Average inter arrival time	4.64	hr
Simulation time	1.01	yr
No of ship movements	2000	
Average waiting time	1.01	hr
Required quay length	1395	m

Occupancy berth 1 (existing)	89.6%
Occupancy berth 2	66.1%
Occupancy berth 3	72.1%
Occupancy berth 4	56.5%
Occupancy berth 5	68.9%
Occupancy berth 6	54.1%

Ship sizes	total	berth 1	berth 2	berth 3	berth 4	berth 5	berth 6
25,000	70.7%	74.0%	100.0%	63.3%	65.8%	38.2%	39.6%
75,000	21.3%	26.0%	0.0%	36.7%	34.2%	19.7%	21.8%
125,000	3.9%	0.0%	0.0%	0.0%	0.0%	20.2%	19.3%
162,500	4.1%	0.0%	0.0%	0.0%	0.0%	21.8%	19.3%
Service time [hr]	18.0	25.2	16.1	16.1	14.7	27.6	26.5

table A 3.9 Simulation results dry bulk export 90 M ton/yr

100 M ton yearly

Average inter arrival time	4.05	hr
Simulation time	0.88	yr
No of ship movements	2000	
Average waiting time	1.95	hr
Required quay length	1436	m

Occupancy berth 1 (existing)	92.4%
Occupancy berth 2	74.6%
Occupancy berth 3	79.7%
Occupancy berth 4	75.6%
Occupancy berth 5	75.3%
Occupancy berth 6	66.2%

Ship sizes	total	berth 1	berth 2	berth 3	berth 4	berth 5	berth 6
25,000	71.0%	73.7%	100.0%	66.1%	58.6%	48.8%	48.1%
75,000	20.9%	26.3%	0.0%	33.9%	29.7%	25.0%	24.4%
125,000	4.0%	0.0%	0.0%	0.0%	11.7%	8.7%	9.4%
162,500	4.1%	0.0%	0.0%	0.0%	0.0%	17.5%	18.2%
Service time [hr]	17.8	25.3	15.7	15.7	17.5	23.2	23.5

table A 3.10 Simulation results dry bulk export 100 M ton/yr

A 3.4.4 Summary

The results of the simulation study are given in table A 3.11. As can be seen from this table the berth occupancy gets higher as the number of berths increases.

Required throughput [M ton/yr]	Total new quay length [m]	Total no of new cranes	Average berth occupancy	Average waiting time [hr]
15	340	1	44%	1.23
20	605	2	37%	0.67
30	645	2	52%	0.95
40	810	3	50%	1.48
50	910	3	63%	1.60
60	1190	4	57%	0.50
70	1190	4	66%	1.00
80	1335	5	62%	1.04
90	1395	5	68%	1.01
100	1435	5	77%	1.95

table A 3.11 Simulation results aggregates.

<u>Other dry bulk</u>

The demand for throughput capacity of the dry bulk import terminal is expected to be lower than that of the export terminal. The Port Authorities desire a continuous mechanical device that can handle at least 2000 ton per hour. This ship unloader will be connected by conveyor with the stockpile area. With a simple simulation, waiting times and berth occupancies have been determined using the following parameters.

- The average unloading rate of the cranes is 2,000 ton/hr.
- Arrival pattern of ships is according an Erlang distribution. Since the arrival pattern is expected to be relatively regular an Erlang 3 distribution was chosen..
- Vessel sizes are distributed according to table A 3.1.
- Ships are handled according a first in first out system.
- Average idle time is 3 hours
- The facilities in the existing port are not part of the calculation of waiting times for the new port.

For when the demand for throughput capacity is higher than 4 million ton per year, it will be necessary to realize one extra berth to keep waiting times within acceptable limits. Average waiting times with 1 berth and 6 M ton import per year are more than 6.8 hours. With an average service time of 20 hrs, including idle time this is assumed to be unacceptable.

Waiting times and crane occupancies are examined for the situation that both berths can handle ship types of up to 175,000 ton and for the situation that one berth can only handle ships smaller than 100,000 ton. Advantage of this limitation for the second berth is that less quay length is required.

A 3.4.5 Results

2 M ton yearly

Average inter arrival time	180	hr
Simulation time	32.55	yr
No of ship movements	2000	
Average waiting time	1.45	hr
Required quay length	279	m
Occupancy berth 1	13.7%	

Ship sizes	total	berth 1
25,000	84.2%	84.2%
75,000	15.8%	15.8%
125,000	0.0%	0.0%
162,500	0.0%	0.0%
Service time [hr]	19.5	19.5

table A 3.12 Simulation results dry bulk import 2 M ton/yr

4 M ton yearly

Average inter arrival time	95	hr
Simulation time	17.26	yr
No of ship movements	2000	
Average waiting time	1.52	hr
Required quay length	279	m
Occupancy berth 1	25.8%	

Ship sizes	total	berth 1
25,000	84.3%	84.3%
75,000	15.7%	15.7%
125,000	0.0%	0.0%
162,500	0.0%	0.0%
Service time [hr]	19.5	19.5

table A 3.13 Simulation results dry bulk import 4 M ton/yr

6 M ton yearly

Average inter arrival time	53.5	hr
Simulation time	9.17	yr
No of ship movements	2000	
Average waiting time	1.23	hr
Required quay length	523	m

Occupancy berth 1	27.7%
Occupancy berth 2	25.4%

Ship sizes	total	berth 1	berth 2
25,000	81.2%	100.0%	34.3%
75,000	14.6%	0.0%	51.0%
125,000	4.2%	0.0%	14.7%
162,500	0.0%	0.0%	0.0%
Service time [hr]	24.6	15.5	43.5

table A 3.14 Simulation results dry bulk import 6 M ton/yr

8 M ton yearly

Average inter arrival time	69	hr
Simulation time	12.21	yr
No of ship movements	2000	
Average waiting time	0.97	hr
Required quay length	523	m

Occupancy berth 1	21.7%
Occupancy berth 2	18.4%

Ship sizes	total	berth 1	berth 2
25,000	81.0%	100.0%	24.8%
75,000	14.5%	0.0%	57.5%
125,000	4.5%	0.0%	17.7%
162,500	0.0%	0.0%	0.0%
Service time [hr]	24.9	15.5	42.8

table A 3.15 Simulation results dry bulk import 8 M ton/yr

10 M ton yearly

Average inter arrival time	45	hr

Simulation time	9.21	yr

No of ship movements	2000

Average waiting time	1.27	hr

Required quay length	604	m

Occupancy berth 1	38.7%
Occupancy berth 2	24.5%

Ship sizes	total	berth 1	berth 2
25,000	71.2%	77.4%	53.7%
75,000	21.0%	22.6%	16.4%
125,000	4.0%	0.0%	15.1%
162,500	3.9%	0.0%	14.7%

Service time [hr]	25.4	21.1	37.2

table A 3.16 Simulation results dry bulk import 10 M ton/yr

A 3.4.6 Summary

Required import [M ton/yr]	Total quay length [m]	Total no of cranes	Average berth occupancy	Average waiting time [hr]
2	280	1	14%	1.45
4	280	1	26%	1.52
6	525	2	20%	0.97
8	525	2	27%	1.23
10	605	2	32%	1.27

table A 3.17 Simulation results dry bulk import

For scenario B1, one crane will be sufficient to serve for the demand until the end of phase 1. For phase 2 and 3, a second crane is needed. Scenario B2, representing medium growth, it will be possible to serve for the demand in import capacity for phase 1 and 2, eventually in phase 3, a second crane is needed. In scenario B3, import increases only slightly. It will not be necessary to realize the proposed ship unloader with conveyor belt. In fact, these amounts of material can be handled by ship based crane (lift and grab operation) at an unoccupied quay in the new or existing port.

A 3.5 Simulation liquid bulk terminal

For the planning aspects if the new liquid bulk terminal, it is assumed that the vessel size distribution according to Lloyd’s vessel statistics does not represent the distribution of vessel sizes that is expected at the new oil terminal. It would be more appropriate to assume that vessel sizes depend on the function of the delivery. Per storage function and for import and export, an average vessel type is assumed. Material with longer storage times is transported by larger vessels. Material for blending is transported by medium size vessels. Bunker fuel storage is replenished by large size vessels. The bunker vessels are smaller ships. These assumptions will be used for throughput, waiting time and berth occupancy calculations and are summarized in table A 3.18. The second and third columns give the percentage of the total storage volume that is used for the specific function. The last to columns give the ship sizes that are used for the specific delivery.

Storage type	Storage dirty [%]	Storage white [%]	Average storage time [yr]	Importing ships [DWT]	Exporting ships [DWT]
Strategic	32.0%	8.0%	2	162,500	162,500
Speculative	16.5%	8.5%	1	162,500	162,500
Blending	0.0%	13.5%	0.08	90,000	90,000
Bunkering	0.0%	13.5%	0.08	162,500	15,000
Break of bulk	0.0%	4.0%	0.08	150,000	15,000
Make of bulk	4.0%	0.0%	0.08	15,000	150,000

table A 3.18 Average ship sizes per storage type.

The speed of the load and unload operations of these ships depend on the flow velocities in the pipes, the diameters of loading arms and the number of loading arms per berth. The flow velocities again depend on the onshore pump capacities, the onboard pump capacity of ships and pipe properties. The following average flow velocities for load and unload operations are assumed. (based on VHFL experience and calibrated with VHFL berth occupancy and waiting times)

- Loading of black material: 3 m/s
- Unloading of black material 3.5 m/s
- Loading of white material: 4 m/s
- Unloading of white material 4.5 m/s

The velocities for clean products (white) are higher as these have a lower viscosity and less pipe resistance as a consequence.

The distribution of the inter arrival time of the ships is assumed to be Erlang 3. The arrival pattern is expected to be relatively regular. The idle time is assumed to be 3 hours on every berth and ship size. The system is assumed to be First in First Out. With the parameters described in this paragraph, the throughput capacity of several numbers of berths having several different sizes has been estimated. The current berths OTB1, OTB2 and OTB3, are assumed to be part of the total system so they are implemented in the model. The model has been used to estimate the maximum throughput of the OTB's for an average waiting time, not longer than 1 hour. It resulted from this test that the OTB's can handle a total throughput of 16.4 M ton per year. With the distribution of storage times as described in the masterplan report, this means a total storage volume of 2.13 M m^3 can be served with this facility.
The model was calibrated by analysis of the existing VHFL terminal throughput, waiting times and berth occupancy data from 2006. For several storage volumes the required number of berths is determined using all assumptions mentioned in this report. These proposed numbers of berths are given in table A 3.19. These figures present the outcome of the simulation study including the OTB's.

OTB 1 and OTB 2 can both be used for one medium size vessel of for two smaller vessels. Since these berths are in the sheltered harbour basin, it is proposed that as they are used for handling the smaller tankers. These tankers will suffer a higher downtime if they are berthed at the more exposed Open Sea Tanker Terminal. The range of bigger tankers will be handled at the new OSTT. These vessels are less sensitive for wave motions.

A 3.5.2 Summary of simulation results

Storage capacity	Capacity [ton/yr]	Number of new berths	Berth no	Max ship size [DWT]	loading arms	Avg. waiting time [hr]	Avg. service time [hr]	berth occ.
2 M m^3	15 M	0	0	0	0	0.93	32.6	34.5%
4 M m^3	30 M	2	OSTT 1	175,000	4 * 16”	0.42	34.1	39.8%
			OSTT 2	175,000	4 * 16”			18.9%
6 M m^3	46 M	3	OSTT 1	90,000	4 * 16”	0.99	33.4	21.6%
			OSTT 2	165,000	4 * 16”			54.6%
			OSTT 3	165,000	4 * 16”			36.1%
8 M m^3	62 M	4	OSTT 1	15,000	2 * 12”	2.10	32.5	38.4%
			OSTT 2	90,000	4 * 16”			34.8%
			OSTT 3	165,000	4 * 16”			72.1%
			OSTT 4	165,000	4 * 16”			58.1%
10 M m^3	78 M	5	OSTT 1	90,000	4 * 16”	0.61	29.3	58.2%
			OSTT 2	90,000	4 * 16”			55.3%
			OSTT 3	150,000	4 * 16”			68.7%
			OSTT 4	165,000	4 * 16”			55.4%
			OSTT 5	165,000	4 * 16”			42.0%
12 M m^3	100 M	5	OSTT 1	150,000	4 * 16”	2.39	27.4	78.6%
			OSTT 2	165,000	4 * 16”			83.1%
			OSTT 3	165,000	4 * 16”			77.4%
			OSTT 4	165,000	4 * 16”			70.3%
			OSTT 5	165,000	4 * 16”			60.9%

table A 3.19 Number of liquid bulk berths

A 3.5.3 Containers

The simulation of the container terminal is carried out using the following assumptions:

- Container vessel sizes are distributed according to Lloyd’s register vessel statistics. Besides this, growth of vessel sizes is taken into account by allowing the anticipated vessels with sizes of up to 400 m and 11,000 in the new port expansion.
- The TEU factor is assumed to be 1.7. This means that twice as much FEU (Forty feet Equivalent Unit) as TEU are expected in the new port. This TEU factor is determined with the following expression: $f = (N_{20} + 2 \cdot N_{40}) / N_{tot}$.
- The gross production of the cranes is assumed to be 25 TEU moves per hour. The assumed maximum number of cranes is given in the last column of table A 3.20.
- The ship sizes as shown in table A 3.20 are assumed, taking into account the Lloyd’s register vessel statistics and the assumption that ships will continue to grow in size. For the calculation of waiting times and berth occupancies when a throughput capacity of 0.5 M TEU is required, it is assumed that the largest ships do not call the port of Fujairah.

TEU	Length [m]	Draught [m]	Breadth [m]	% of ships	Max number of cranes
100 – 1000	75 – 185	3 – 10.5	11 – 28	30 %	2
1000 – 2000	145 – 214	8 – 12	23 – 33	32.5 %	3
2000 – 3000	180 – 260	10 – 12.5	29 – 33	15 %	4
3000 – 4000	235 – 285	11.5 – 13	32 – 33	10 %	5
4000 – 5000	250 – 300	12.5 – 14.5	32 – 38	5 %	6
5000 – 7000	265 – 315	12.5 – 14.5	38 - 42	5%	8
7,000 – 11,000	315 - 400	14.0 – 15.5	42 - 56	2.5 %	10

table A 3.20 Container vessel size distribution used for simulation

- The number of containers that need to be handled per vessel is 50% to 100% of its total capacity, equally distributed between this maximum and minimum. It is further assumed the number of imported containers is equal to the number of exported containers.
- The simulation is carried out using a fixed number of berths. This means that the throughput capacity, berth occupancies and waiting times are not determine for a number of quay lengths. Instead the number of berths, the berth capacity and the number of cranes are varied to find acceptable values for waiting times and occupancy. It is assumed that an average waiting time of 0.5 hours is acceptable.
- For the determination of the waiting time an average downtime of 3 days is assumed. This downtime represents the downtime due to unworkable weather, unusable cranes due to maintenance and downtime due to exceedence of the maximal allowable ship movement. This movement is caused by wave penetration. The wave penetration depends on the layout of the port, the protection of the harbour basin by breakwaters and the reflection coefficient of the quays.

Using the above mentioned assumptions several number of berths and cranes where tested. The results of these simulations are given in table A 3.21.

Required throughput [M TEU/yr]	Total quay length [m]	Total no of cranes	Average berth occupancy	Average waiting time [hr]
0.5	675	9	53 %	0.4
1	1022	15	47 %	0.4
1.5	1432	19	51 %	0.5
2	1702	23	55 %	0.5
2.5	1927	28	57 %	0.5
3	2050	36	60 %	0.5
3.5	2109	40	70 %	0.8

table A 3.21 Results from container throughput simulation study

According to the composed scenarios, it can be seen that for scenario D1, at the end of phase 1 a total quay length of 1432 m is required. For scenario D2 a total quay length of 775 is required at the end of phase 1, 1702 m at the end of phase 2 and finally after phase 3, 2050 m to able to handle 3 M TEU per year. In scenario D3, a total length of 1022 is required to be able to handle the total throughput of 1 M TEU/yr that is anticipated for at the end of phase 2 and 3 in this scenario.

A 3.5.4 Summary berths and quay lengths

The required quay lengths and number of cranes as determined in this chapter are summarized in table A 3.22, shown below.

Phase 1	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	Quay length	**No of cranes**	**Quay length**	**No of cranes**	**Quay length**	**No of cranes**
Aggregates	910	3	810	2	810	2
Other dry bulk	280	1	280	1	-	-
Oil	2 berths	-	2 berths	-	2 berths	-
Containers	1432	19	675	9	675	9
Chemicals	1 berth	-	-	-	-	-

Phase 2	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	Quay length	**No of cranes**	**Quay length**	**No of cranes**	**Quay length**	**No of cranes**
Aggregates	1395	5	910	3	810	2
Other dry bulk	525	2	280	1	-	-
Oil	5 berths	-	4 berths	-	3 berths	-
Containers	2110	40	1927	28	1022	15
Chemicals	1	-	-	-	-	-

Phase 3	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	Quay length	**No of cranes**	**Quay length**	**No of cranes**	**Quay length**	**No of cranes**
Aggregates	1435	5	910	3	340	1
Other dry bulk	525	2	525	2	-	-
Oil	6 berths	-	4 berths	-	2 berths	-
Containers	2110	40	2050	36	1022	15
Chemicals	2	-	-	-	-	-

table A 3.22 Summary required quay length and number of cranes

A4 Annex 4 Principle quay wall design

Masterplan for the port of Fujairah Expansion Project

TUDelft
Technical University of Delft
Faculty of Civil Engineering and Geosciences
Hydraulic and offshore section

B.V. Ingenieursbureau M.U.C.

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A 4.1 Introduction

This annex describes a principle design for the quay walls in the Port of Fujairah Expansion Project. The quay wall design was not carried out as a part of this study but is carried out by B.V. Ingenieursbureau M.U.C.

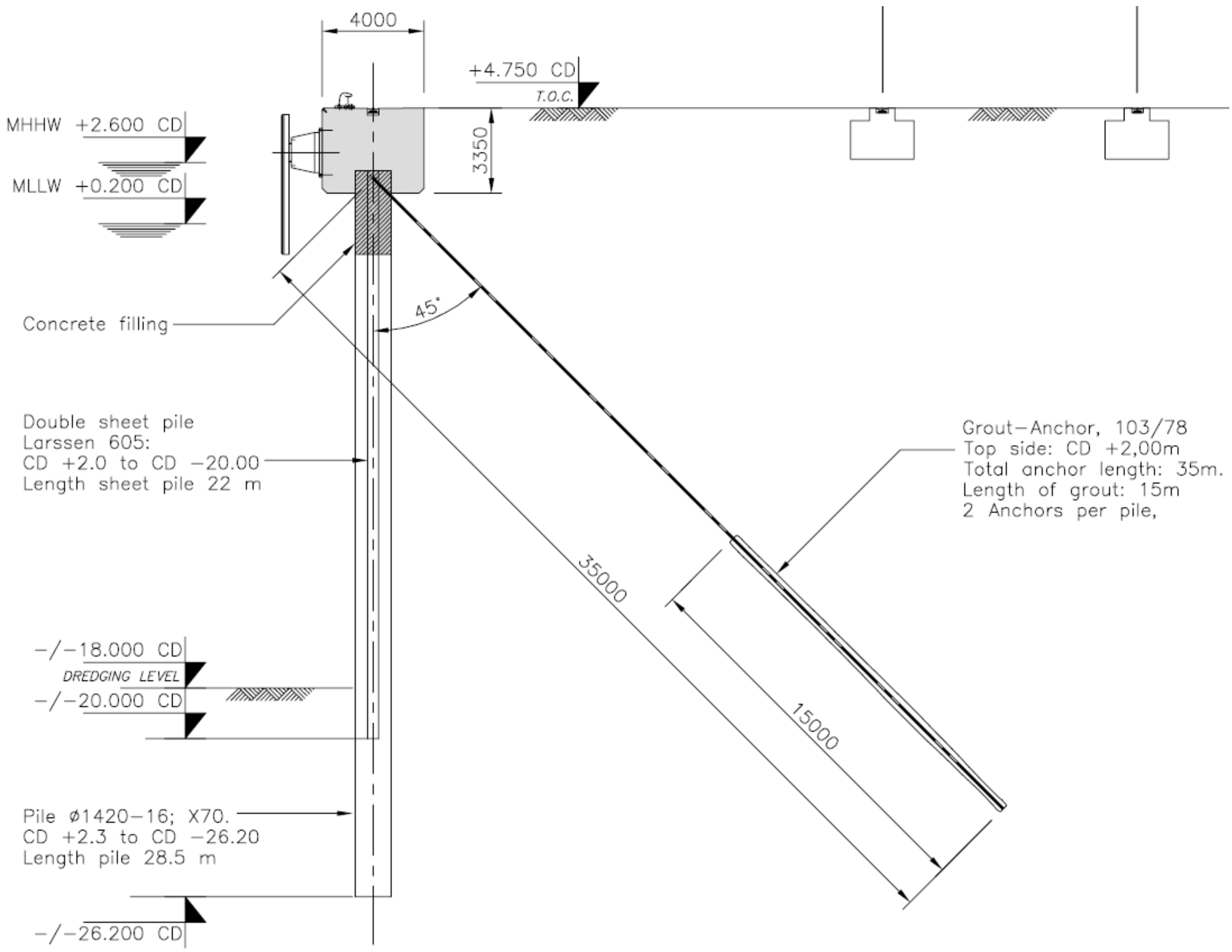
A 4.2 Design of quay wall

The most favorable type of quay wall cost as well as construction time wise is a combi sheet pile wall. The specific dimensions of this structure are given in table A 4.1. The quay wall is designed for a depth of CD – 18.0 m, the surface level of the reclamation (and top of the quay wall is CD + 4.75 m. So the retaining height of the structure is 22.75 m). All the quay wall designs are based upon the same geometry. The quay wall design is assumed to be a combi wall structure.

Tubulars	L = 28.5 m Ø = 1.42 m d = 16 mm
Infill sheeting	Larssen 605 W = 600 mm L = 22 m
Copping beam	$4.0 \cdot 3.5\,m^3$

table A 4.1 Specific dimensions quay walls

For the back anchoring of the combi wall structure several systems and options have been looked at. Self drilling anchors with grout cover tie back anchors to a sheet pile wall, both with Dywidag rods or bundled strand tendons.
A vertical cross section of the proposed design is shown in figure 4.1, a horizontal cross section is shown in figure 4.2.



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Principle quay wall design cross section

Figure no:
A

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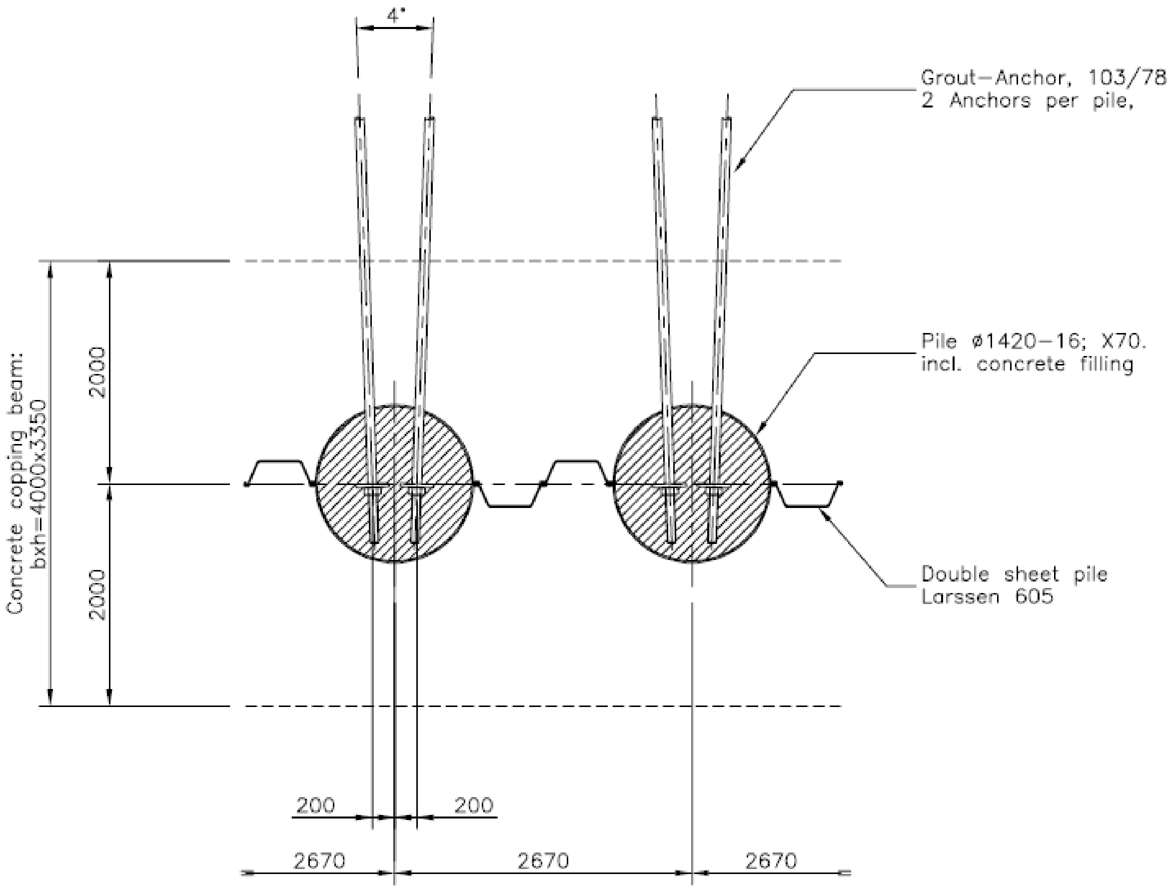

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A5 Annex 5 Principle design Coastal Protection works

Masterplan for the port of Fujairah Expansion Project

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Technical University of Delft
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A 5.1 Introduction

A 5.1.1 General

In this annex to the report “Masterplan for the expansion of the Port of Fujairah” the technical design of coastal protection works is described in detail.

The coastal protection will mainly consist of four parts:

1. Revetment section in the exposed areas
2. Breakwater part. (water on both sides)
3. A breakwater round head and convex bends in the revetment sections.
4. Revetment section in the sheltered areas

This study contains the design calculations for the cross sections of the coastal protection works of the Port Expansion Project. In chapter A 5.2 of this report, the design criteria and applied equations for armour stability, overtopping, etc. are lined out. In chapter A 5.3 the boundary conditions are summarized. With these boundary conditions and equations, the designs for the coastal protection works are made in chapter A 5.4.

A 5.1.2 Description of the existing coastal protection works

Fujairah harbour is built on the gulf of Oman coast. This coast runs North South and is almost straight except for a bay further north at Khorfakkan. The harbour is entirely artificial, being formed by a pair of rubble mound breakwaters, armoured on the outside with pre-cast concrete Dolos armour units and otherwise constructed from locally quarried rock.

The breakwaters curve out from the shoreline and overlap so that the entrance faces South-southeast. This produces generally calm conditions in the port, particularly at the south end where a floating jetty is operated.

The original design of the breakwaters is based on a wave analysis performed on the basis of hind casting from local wind conditions. But wave recordings carried out during the construction of the port, demonstrated that the main wave action originated well out in the Gulf of Oman and that local wind had little effect. One result of this is that the design of the Fujairah breakwaters is conservative and they suffer no significant overtopping. The other result is that at certain times there is significant penetration of southerly waves into the harbour. Local reporting indicates that these events are rare and that the maximum local wave action near the root of the north breakwater has amplitude of less than one meter.

The breakwaters are founded onto the original seabed and the area within the harbour basin was then dredged according to the requirements for each zone of the harbour. The soils are generally sandy becoming more cemented with depth until they can be classified as rock.

A 5.2 Design criteria

A 5.2.1 Project design life

The project design life is set at 50 years. The average return interval for design meteorological and oceanographic events is 100 years. The probability of occurrence of a particular single event (for example a storm with a certain wave height) in a given time period is shown in table A 5.1. From this table it may seem that a 100 year event has a 39% probability of occurring in 50 years and a 10% probability of occurring in 10 years.

return period Years	**Design life**					
	1	**5**	**10**	**20**	**50**	**100**
2	50%	97%	100%	100%	100%	100%
5	20%	67%	89%	99%	100%	100%
10	10%	41%	65%	88%	99%	100%
50	2%	10%	18%	33%	64%	87%
100	1%	5%	10%	18%	39%	63%
225	0%	2%	4%	9%	20%	36%
495	0%	1%	2%	4%	10%	18%
990	0%	1%	1%	2%	5%	10%

table A 5.1 Occurrence probabilities

It should be noted that combined probabilities of multiple events will be less. Where the events are independent, the combined probability is the product of the individual probabilities.
In reality, events related to marine design conditions are rarely totally independent. An example of this is the water level is not independent of wave conditions (since the storm surge component is related to the wave). For these events the combined probability is intermediate between the probability of the single events and their product. For partially dependent events (waves and water levels), the assessment of the combined probability is less easy. The combination of a 100 yr water level wit a 100 yr wave has a combined return which is less than the value corresponding to totally independent events (10,000 years) but much more than the value of 100 years, corresponding to totally dependent events.
The designs that are proposed in this report will be reviewed on effects due to conditions with varying return periods. Each of these effects will be treated in a separately way. For effects of combined events, such as overtopping (dependant on wave height and water level), reasonable assumption will be made for both values.

A 5.2.2 Structural

Although there are many options for the structural type of revetments that can be applied in the new Port of Fujairah (mound types, monolithic types, composite types or unconventional types), the choice for a mound type is quickly made due to the wide availability of rock in Fujairah.
In many cases, the mayor costs of revetments are determined by the price of the rocky material. In areas where rock is not available, it is being shipped in from mountainous regions. In these situations, the purchase and transport cost of rocky material can exceed the cost of the construction of a monolithic or other unconventional structure. Fujairah though, is a mayor supplier of rock for the use of breakwaters. As the rocky material is produced in quarries, only several kilometers from the New Port, transport costs are very low.
An advantage of the rubble revetment other than cost is the interaction between the structure and the subsoil and the behavior at failure. The rubble types are more or less flexible and can even follow uneven

settlements of the foundation layers. Monolithic structures require a solid foundation that can cope with high and often dynamic loads.
The behavior of the structure close to failure is also quite different. When a critical load value is exceeded, a monolithic structure will lose stability at once, whereas a mound type of structure will fail more gradually as elements from the amour layer disappear one after another.
For the reason mentioned above, rubble-mound breakwaters are the most commonly applied types of breakwater in the area of Fujairah. In fact, all coastal structures from the northern, to the southern Oman border are rubble mound.
For these reasons further study on the application of monolithic, composite or unconventional revetments for the first phase of the New Northern Port Expansion of the Port of Fujairah is not carried out.

A 5.2.3 Armour

For the type of armour it is assumed that rock, available from the mountainous area in Fujairah is cheaper than the application of new cast concrete armour units. Concrete armour units are not only more expensive due to material and fabrication cost but will also demand extra skills and equipment for placement which are cost increasing. Concrete armour units are generally applied when the wave climate demands a slope stability that can not be reached with rock armour.
An other choice that must be made is whether to make the breakwater with or without crown wall. With applying a crown wall it is possible to reduce the height of the revetment, while overtopping still remains within the limits. Though a concrete wall is an expensive structure, it is still possible to reduce cost because less rocky material is required. In this report both a design proposal is given for a revetment with and without crown wall.

A 5.2.4 Overtopping

Where berths reclaimed areas, roads, buildings, etc are located behind and close to breakwaters and revetments, overtopping may cause inconvenience or problems. The amount of allowable overtopping therefore depends on the function of the particular structure. If the function is to protect an area with relatively vulnerable structures, lower overtopping discharges are allowed.
Besides the structures behind the revetment, the stability of the inner slope and the transition of the armoured part of the revetment with the pavement of the land fills, depends on the load of overtopping waves. Since the reclaimed areas contain roadways, storage areas, and buildings located just behind the revetments, the allowable amount of overtopping is restricted to a certain limit. Standard references for commonly accepted damage levels for different overtopping discharges are those indicated in the (CIRIA-CUR 1991, C5) and are presented in the figure 5.1. The maximum values for return periods of 1, 10 and 100 yr are chosen, taken into account the vulnerability of the structures behind the revetment (cranes and conveyors). Besides this, the design philosophy is such that preventing is damage is more important than finding an optimum between maintenance and construction cost.
The estimation of the mean overtopping over the breakwaters and revetments is based on the equation by Van der Meer and Janssen’s (1995) for run-up and overtopping [Annex 5.2.1] and [Annex 5.2.2]. The resulting overtopping discharge from wind-generated waves is very unevenly distributed in time and space because the amount varies considerably from wave to wave. The major part of the overtopping discharge during a storm is due to a small fraction of the waves. In fact the local overtopping discharge from a single wave can be more than 100 times the average overtopping discharge during the storm peak.

Overtopping is calculated for the situation with and without crown wall. For these two situations, different equations are used. With the calculation of overtopping discharges for both situations, Mean Lower High Water level is used (CD +2.3 m). Additional to this level, a height of 0.50 m is used for global sea level rise.

Overtopping for situation without crown wall

The overtopping discharges for the revetment design without crown wall are evaluated based on the equation by Van der Meer and Janssen (1995) for straight and bermed impermeable slopes, including the influence of surface roughness, shallow foreshore, oblique, and crested waves.

For $\xi_{op} < 2$

$$\frac{q}{\sqrt{q \cdot H_s^3}} \cdot \sqrt{\frac{s_{op}}{\tan\alpha}} = \exp\left(-5.2 \frac{R_c}{H_s} \frac{\sqrt{s_{op}}}{\tan\alpha} \frac{1}{\gamma_r \gamma_b \gamma_h \gamma_\beta}\right) \qquad \text{[Annex 5.2.1]}$$

For $\xi_{op} > 2$

$$\frac{q}{\sqrt{q \cdot H_s^3}} = 0.2 \exp\left(-2.6 \frac{R_c}{H_s} \frac{1}{\gamma_r \gamma_b \gamma_h \gamma_\beta}\right) \qquad \text{[Annex 5.2.2]}$$

Where:

R_c = the height of the crest with respect to the water level.

A 5.2.5 Overtopping equation for the situation with crown wall

For the situation with crown wall, the overtopping discharges are determined, using the equation by Bradbury and Allsop (1988)

$$\frac{q}{g \cdot H_s \cdot T_{om}} = a\left[\left(\frac{R_c}{H_s}\right)^2 \sqrt{\frac{s_{om}}{2\pi}}\right]^{-b} \qquad \text{[Annex 5.2.3]}$$

The coefficients *a* and *b* have been determined with physical model testing. For these coefficients, the values determined by Aminti and Franco (1988) where used.

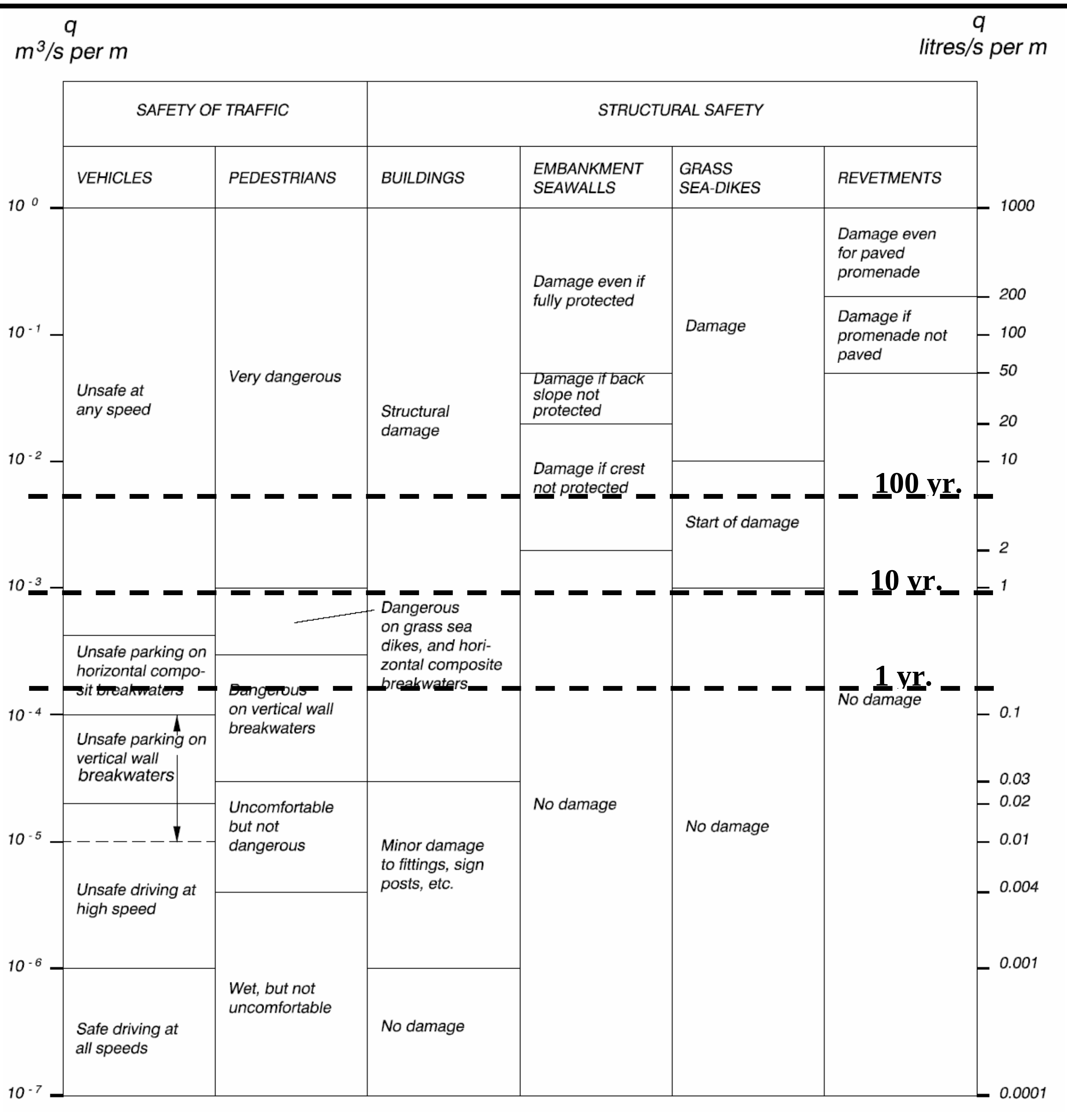

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Figure Title
Critical values of allowable overtopping discharges

Figure no:
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A 5.2.6 Stability of rock amour layer

Applied equation
The stability of the rock amour layer of all breakwater and revetment sections is determined with the equation by Van der Meer (1988). Van der Meer's equation resulted from extensive experimental investigations consisting of about 300, 2D stability tests performed in 1988 at Delft Hydraulics. It is now very commonly used in the conceptual design of natural rock breakwaters.
Van der Meer's equation (1988) for two layered, rock-armoured non-overtopped slopes, in which a distinction must be made between plunging and surging waves:

For plunging waves where $\xi_m < \xi_{mc}$:

$$\frac{H_s}{\Delta \cdot D_{n50}} = 6.2 \cdot S^{0.2} \cdot P^{0.18} N_z^{-0.1} \xi_m^{-0.5} \qquad \text{[Annex 5.2.4]}$$

For surging waves where $\xi_m > \xi_{mc}$:

$$\frac{H_s}{\Delta \cdot D_{n50}} = 1.0 \cdot S^{0.2} P^{-0.13} N_z^{-0.1} (\cot\alpha)^{0.5} \xi_m^{P} \qquad \text{[Annex 5.2.5]}$$

Where:

$$\xi_m = s_m^{-0.5} \tan\alpha \qquad \text{[Annex 5.2.6]}$$

$$\xi_{mc} = (6.2 \cdot P^{0.31} (\tan\alpha)^{0.5})^{1/(P+0.5)} \qquad \text{[Annex 5.2.7]}$$

Where:

α = Angle of the seaward slope of the structure.
The stability on a slope with an angle of 1:2, 1:1.5 and 1:2.5 is investigated.

P = Permeability coefficient
Van der Meer's equation takes into account the permeability of the slope design calculations through a notational permeability parameter. (*P*). This will be taken here as 0.4 for breakwater design and 0.3 for revetment sections.

s_m = Wave steepness (H_s/L)
Van der Meer assumed the effect of the wave period to be connected with the shape and intensity of breaking waves. He therefore used the Irribarren parameter. (ξ_m)

The relative density of rock is:

$$\Delta = (\rho_s / \rho_w) - 1 \qquad \text{[Annex 5.2.8]}$$

D_{n50} = Equivalent cube length of median rock. $= (W_{50} / \rho_s)^{1/3}$

Van der Meer takes into account the duration of the sea state thru an *n* number of waves. This will is taken here as 2000 waves.

S = Relative eroded area. (= A_e / D_{n50}^2)

Damage classification
For two-layer rock amour, the damage level *S* classified as follows (Van der Meer 1988):

For a slope angle of 1:2:

- $S = 4 – 6$: Intermediate damage
- $S = 8$: Failure

For a slope angle of 1:1.5:

- $S = 2$: Initial damage
- $S = 3 – 5$: Intermediate damage
- $S = 8$: Failure

These damage classifications can be described as follows:

- No damage: No unit displacement. Note that S might not be equal to zero due to settlement.
- Initial damage: (ranging from moderate to severe damage) Few units are displaced. This damage level corresponds to the no damage level used in the shore Protection manual 1977 and 1984 in relation to the Hudson equation stability coefficient. In this equation the “no damage” level is defined as 0-0.5 displaced units within the zone extended from the middle of the crest height down to the seaward face to depth of SWL equal to a H_S – value which causes the damage 0-0.5.
- Intermediate damage: Units are displaced but without causing exposure of the under or filter layer to direct wave attack.
- Failure: The under layer or filter layer is exposed to direct wave attack.

The criteria for damage levels of the armour layer set for this project for storms with varying return periods are given in table A 5.2.

Return period [yr]	Damage level
1	0.5
10	1
100	2

table A 5.2 Criteria damage levels armour layer

A 5.2.7 Head section stability

Under similar wave conditions the round head of a rubble-mound structure normally sustains more extensive and more frequent damage than the structure trunk. One reason is the very high cone-overflow velocities, sometimes enhanced in certain areas by wave refraction. Another reason is the reduced support from neighboring units in the direction of wave overflow in the lee side of the cone.
Carver and Heimbaugh (1989) investigated the head stability of rock. Model tests resulted in the following stability equation:

$$\frac{H}{\Delta \cdot D_{n50}} = A \cdot \xi^2 + B \cdot \xi + C_c \qquad \text{[Annex 5.2.9]}$$

Where H = Characteristic wave height.

$$\xi = \frac{\tan \alpha}{\sqrt{H / L}} \qquad \text{[Annex 5.2.10]}$$

Where L = Local wave length at the structure toe. For the determination of the wave length, the peak period is used.

A, B, C_c = Empirical coefficients dependant on the type of amour unit and the slope.

According to the Coastal Engineering Manual, the armouring of the head of the breakwater should be the same on the lee side slope as on the seaside slope for a distance of about 15 to 45 m from the structure end.

A 5.2.8 Stability of the toe

Van der Meer, 'd Angremond and Gerding investigated the relation between the unit weight of toe elements, toe level and damage (N_{od}). They derived the following relation.

$$\frac{H_s}{\Delta \cdot D_{n50}} = \left(0.24 \cdot \frac{h_b}{D_{n50}} + 1.6\right) N_{od}^{0.15} \qquad \text{[Annex 5.2.11]}$$

The validity range is:

a) $0.4 < h_t / h < 0.9$

b) $3 < h_t / D_{n50} < 25$, where:

N_{od} = Character of damage

- $N_{od} = 0.5$: Start of damage
- $N_{od} = 1.0$: Acceptable damage
- $N_{od} = 4.0$: Severe damage (Failure)

h_b = Water depth at top of the toe berm.
D_{n50} = Equivalent cube length of median stone

The criteria for damage levels of the toe structure for storms with varying return periods are give in table A 5.3

Return period [yr]	Damage level
1	0.1
10	0.2
100	0.5

table A 5.3 Criteria damage levels toe structure

A 5.2.9 Under layers

The filter criteria between the amour and the under layer (from CIRIA-CUR 1991):

$$\frac{W_{15a}}{W_{85u}} \leq 5 \qquad \text{[Annex 5.2.12]}$$

$$10 \leq \frac{W_{50a}}{W_{50u}} < 15 \qquad \text{[Annex 5.2.13]}$$

The filter criteria between the under layers are respectively:
(From British Standards BS6349-7 1991)

$$\frac{D_{15(larger)}}{D_{85(smaller)}} \leq 5 \qquad \text{[Annex 5.2.14]}$$

$$4 \leq \frac{D_{15(larger)}}{D_{15(smaller)}} \leq 25 \qquad \text{[Annex 5.2.15]}$$

$$\frac{D_{50(larger)}}{D_{50(smaller)}} \leq 25 \qquad \text{[Annex 5.2.16]}$$

Where:

D is the nominal size of the units considering and the suffixes “15”, “50”and “85” refer to the percentages of material not exceeding that size. For criteria between the under layer and the core (from CIRIA-CUR, 1991). Migration between under layer and core:

$$\frac{D_{15u}}{D_{85c}} \leq 5 \qquad \text{[Annex 5.2.17]}$$

$$5 \leq \frac{D_{50u}}{D_{50c}} \leq 60 \qquad \text{[Annex 5.2.18]}$$

With the suffixes “u” and “c” referring to under layer and core respectively.

A 5.2.10 Layer under rock amour

The CEM advises that the first under layer should weigh about one tenth of the weight of the overlying amour layer units if the first under layer and the cover layer are both quarry stones.
Layer thickness

The thickness *r* of a layer must be the greater of either 0.3 m, or one of the following, whichever of the three is the greatest:

$$r = 2.0 \cdot \left(\frac{W_{50}}{w_a}\right)^{1/3} \qquad \text{[Annex 5.2.19]}$$

Where W_{50} is the weight of the 50-percent size in the gradation, or:

$$r = 1.25 \cdot \left(\frac{W_{\max}}{w_a}\right)^{1/3} \qquad \text{[Annex 5.2.20]}$$

Where W_{max} is the heaviest stone in the gradation.

A 5.2.11 Construction requirements

Fujairah is one of the most important sources of rock and aggregates in the region. This is due to the high quality of the rocky material (high density and strength) and the wide availability. Although the main products of quarries in Fujairah are aggregates, there is a lot of experience with the production and transportation of large blocks for breakwaters and revetments.
Quarries can produce and transport every desired gradation up to approx. 10 tons. However blocks up to 10 ton can be produced, handling of these blocks is difficult and time consuming. Experience learns that stones with a weight up to 7 tons can be handled relatively easy. The produced material has a high

density, which varies between 2800, and 3000 kg/m^3. For the stability calculations, a material density of 2800 kg/m^3 is applied.

A 5.2.12 Equipment

For the design of the breakwaters and revetments, the use of rolling equipment is taken into account. Floating equipment requires unnecessary load and unload activity that will increase the construction cost of the project. It is assumed that the material of the core will therefore simply be brought in by dump trucks that also pick up the material at the quarry. The major advantages of this construction method are the potential use of cheap local equipment and the independence of working conditions at sea (fog, waves, swell and currents).
Since rolling equipment can be used, the dam is built out with a work front in several phases, for core, under layer, toe. The crest of the core is used as main supply road. Therefore this crest must be high enough above high water level to guarantee the safety of equipment and personnel.

A 5.2.13 Protection of the breakwater during construction

In general the problem of breakwater construction is to build out the core and cover layers consecutively in such a manner that the parts that are not yet stabilized by its cover is not damaged by the environmental conditions during construction. All damage which occurs during construction has to be repaired according to the prescribed layer profile, as the functioning of the breakwater depends on the filter design rules. Therefore it is necessary to consider tolerances and to maintain a very strict position control during construction.
Since the wave climate in Fujairah is mild however, damage to the unprotected core is not expected to be excessive. Other projects in the area of Fujairah have been constructed in the same way and have not experienced high erosion of the unprotected slope.

A 5.3 Boundary conditions

Hydraulic boundary conditions are described in detail in Annex 1 to the masterplan report.

A 5.4 Proposed design

A 5.4.1 Introduction

In this chapter a design proposal is given for four main parts of the coastal protection works. These parts are:

1. Revetment section in the exposed areas
2. Breakwater part. (water on both sides)
3. A breakwater round head and convex bends in the revetment sections.
4. Revetment section in the sheltered areas

For both sections the stability of several slopes and stone weights are tested for wave loads with different return periods are tested. For the revetment section the both a design with and without crown wall is proposed.

A 5.4.2 Revetment design (straight section)

Functional requirements

The main function of the revetment, West of the landfill made in phase 1 is the protection against erosion due to wave and current attack, and to provide a sheltered area for the moored ship on the new southern quay wall. Additional to the demands of stability of the amour layer material and toe, the protection of the structures behind this revetment requires a maximum limit on the allowable overtopping as stated in figure 5.1.

Amour layer

The selected gradation for the amour layer of the revetment is 4 to 7 tons. This gradation has a median stone weight of 5.5 tons. For quarries in Fujairah, this is a convenient stone size to produce and transport. For the stability calculations, wave heights according to table A1.15 in Annex 1 and the relation between wave height and period where used. Further the following parameter where applied.

$P_{breakwate}$	0.4	-	Permeability breakwaters
$P_{revetments}$	0.3		Permeability revetment sections
N_z	2000	-	Number of waves
s_m	0.0367	-	Wave steepness
ρ_s	2800	kg/m3	Mass density of the rock
ρ_w	1024	kg/m3	Mass density of water
Δ	1.73	-	Relative density
$W_{50(al)g}$	5500	Kg	Medain stone weight of selected gradation
D_{n50}	1.25	M	Median stone diameter

table A 5.4 Parameters stability calculation armour layer

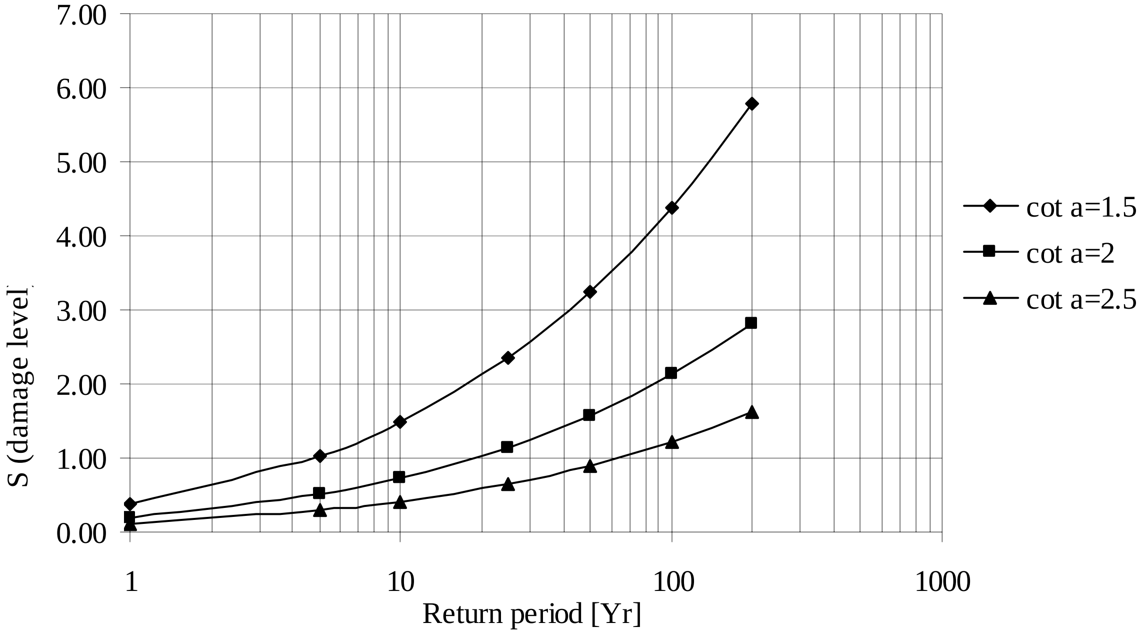
For three slopes, respectively 1:1.5, 1:2 and 1:2.5 the damage levels under varying wave attack are calculated. With equations [Annex 5.2.6] and [Annex 5.2.7] the values for ξ_{m1} and ξ_{mc1} are calculated to determine if waves are plunging or surging for each of these slopes.

	cot α=2	*cot α=3*	*cot α=4*		
ξ_{m1}	2.61	1.74	1.30	-	Surf similarity parameter
ξ_{mc1}	3.77	3.01	2.56	-	Combined parameter
Wave	plunging	plunging	plunging	-	Plunging or surging waves

table A 5.5 Surf similarity parameter

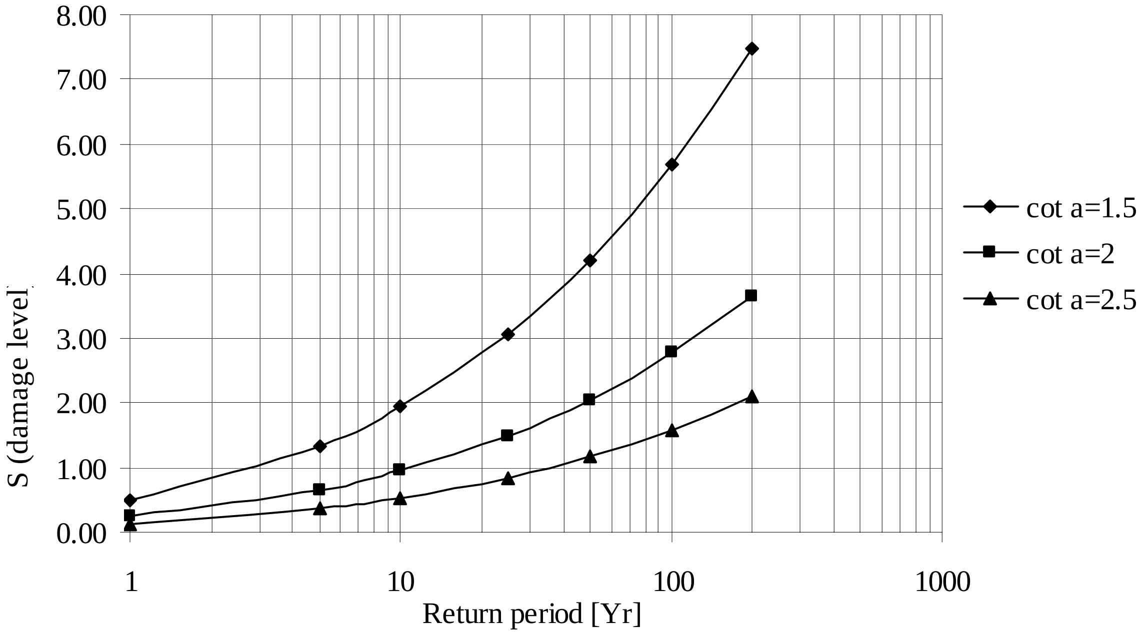
From table A 5.5 it can be seen that waves are plunging. This means that for all stability calculations equation [Annex 5.2.4] will applied using waves conditions with varying return periods of 1 to 200 years according to table A1.15.

The resulting damage levels of these calculations are shown in graph A 5.1. It can be seen that for return periods up to 200 year and slope angles less steep than 1:2, the damage level *S* does not exceed 3.0, which means that damage would remain in the range, classified as intermediate damage.



graph A 5.1 Damage level of the selected gradation for wave load with different return periods according to stability equation of Van der Meer (1988) with a slope of 1:1.5, 1:2 and 1:2.5 for breakwater sections (P=0.4)

It can be seen that a slope angle of 1:5 immediately results in larger values for the damage level. The difference between a slope of 1:2 and 1:2.5 is less. For this reason a slope of 1:2 is chosen. With this median stone weight, the thickness of the amour layer is 2.5 m, which is two times the nominal diameter of the rock in this layer.

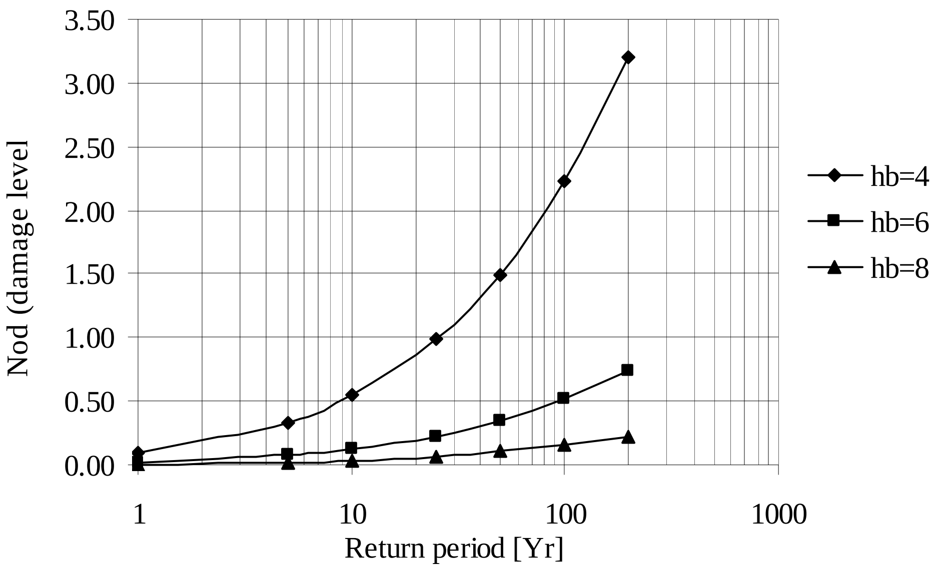


graph A 5.2 Damage level of the selected gradation for wave load with different return periods according to stability equation of Van der Meer (1988) with a slope of 1:1.5, 1:2 and 1:2.5 for revetment sections (P = 0.3)

From graph A 5.2 it can be seen that for the reduced permeability higher damage levels are expected. For the 100 year return period wave characteristics, the expected damage level is 2.77 which still is acceptable.

<u>Under layer</u>
For the under layer a gradation of 300 – 1000 kg is chosen. The rock material for this layer has a median weight of 650 kg. With this median weight, the thickness of the under layer is 1.23 m, which is two times the nominal diameter of this layer.

<u>Toe</u>
For the toe, the material of the under layer with a gradation of 300 – 1000 kg is extended over the berm of the breakwater. The damage levels for the toe material for wave loads with return periods between 1 and 200 years and water depths of 4, 6 and 8 m are determined using the equation of Van der Meer, d'Angremond and Gerding for toe stability [Annex 5.2.11]. This water depth is the depth from mean lower low water to the top of the toe. The same parameters as in table A 5.4 where used for these calculations.
The results of the calculations are plotted in graph A 5.3. For a return period of 200 year and water depths of 6 and 8 m, it can be seen that the damage level (N_{od}) does not exceed 1, which represents "acceptable damage". For a water depth of 4 m, this damage level exceeds 3 for the wave load with a return period of 200 years.

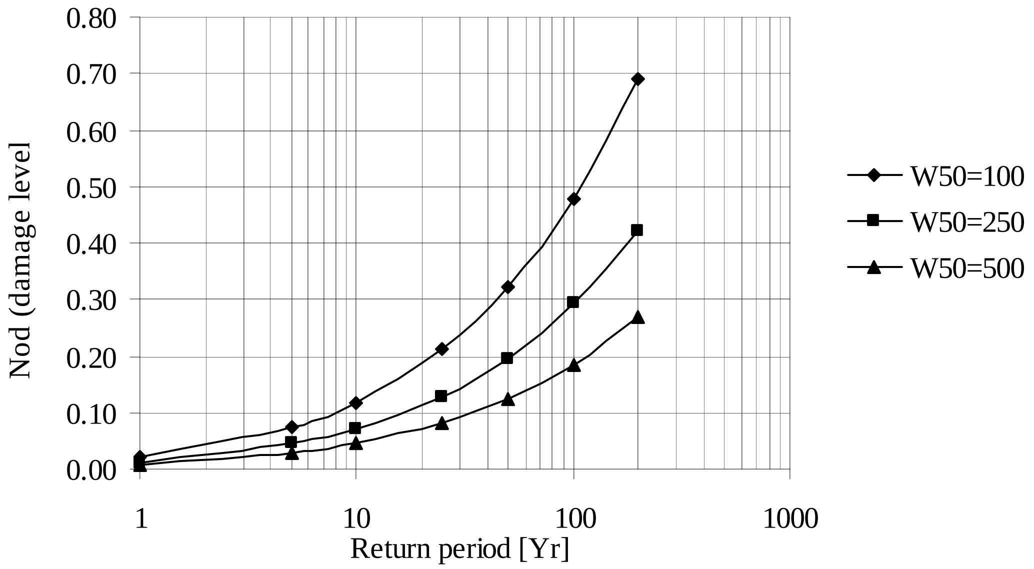


graph A 5.3 Damage level of the toe of the revetment for wave load with return periods varying between 1 and 200 years and for different depths.

The top of the toe will be constructed at a water depth of 6 m since damage stays within the acceptable range for this depth and waves with a return period of 200 years.

<u>Core</u>

The core is build up from quarry run. A quarry run gradation from 0 – 1000 kg is proposed. The sea side of the under water slope of the breakwater will not be armed with a selected heavy stone gradation but will be extended over 4 meters. During a heavy storm, the lighter material will be washed away so that the heavier material remains on the slope. The stability of this material, having a median stone weight of 500 kg is calculated using the toe stability equation of Van der Meer [Annex 5.2.11].
The wave parameters according to Annex 1 table A1.15 and the relation [Annex1, 1.5.1] where used to determine the damage levels for the different water depths.



graph A 5.4 Damage level of material of material on the front side of the toe

Crest height

The crest height of the revetment depends on the maximum allowable average overtopping discharge. Limits for return periods of 1, 10 and 100 years are given in figure 5.1.

Overtopping of the revetment is analyzed for the situation with and without crown wall and for crest heights varying between 7.5 m and 10.5 m relative to chart datum. For these calculations the equation of Van der Meer and Janssen [Annex 5.2.1]and the equation of Bradbury and Allsop [Annex 5.2.3] have been used.

For the stability calculations, wave heights according to Annex 1 table A1.15 an relation [Annex1, 1.5.1] where used. Further the following parameter where applied.

H_w	2.3	m	Water Level
SLR	0.50	m	Sea level rise in the next 100 years
$\cot\alpha$	2	-	Slope angle
s_{op}	0.026	m	Deep water steepness of the peak period
ξ_{op}	3.09	-	surf similarity parameter
$r_{(a+1)}$	2.50	m	Reduction functional crest height (permeability)
γ_r	0.5	-	reduction factor for surface roughness
γ_b	1	-	reduction factor for berm structures
γ_h	1	-	reduction factor for shallow for shore
γ_b	1	-	reduction factor for oblique wave attack

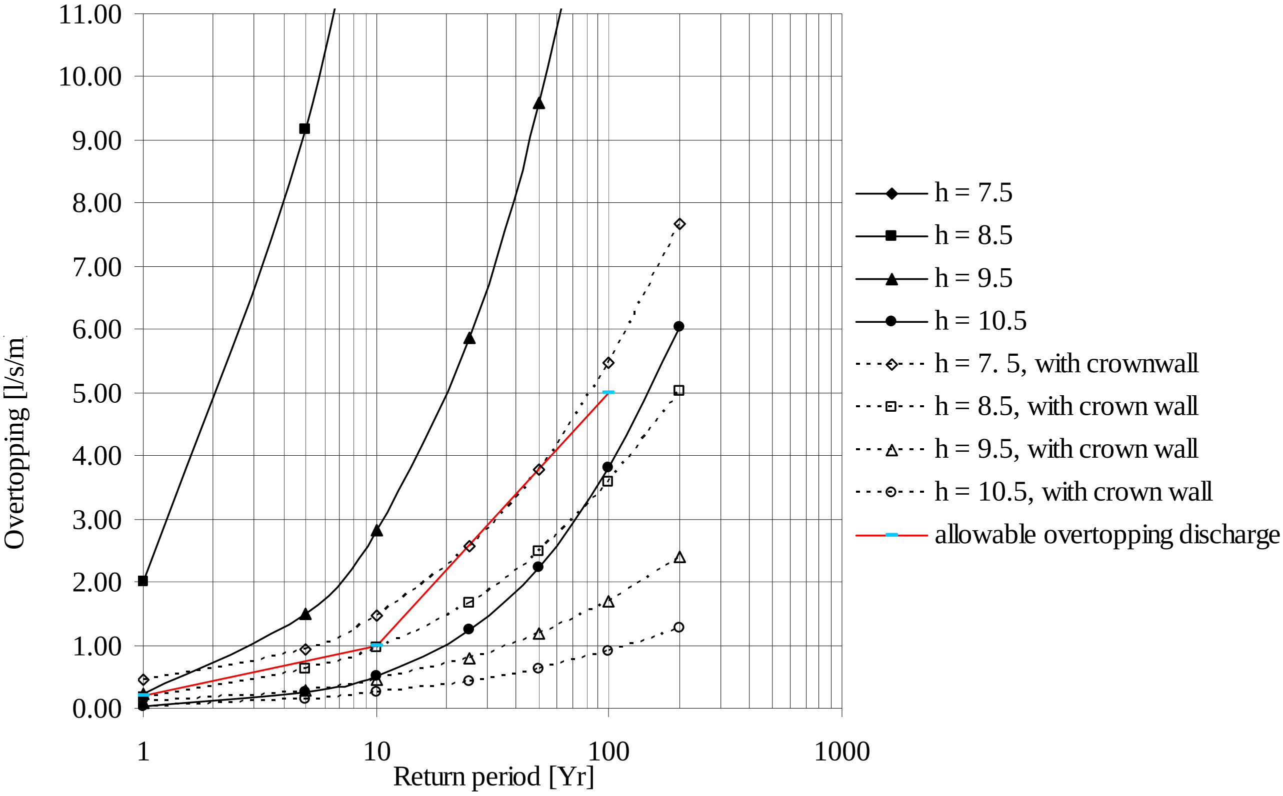
table A 5.6 Parameters average overtopping discharge estimation

For the calculation of the average overtopping discharges for the revetment type without crown wall, the permeability of the armour layer is taken into account. This layer consists of large blocks thru which still large discharges are possible. To calculate the discharge using the top of this layer would be optimistic and not right. For this reason, a crest height reduction is applied with the thickness of the armour layer.

	H_{crest1}	H_{crest2}	H_{crest3}	H_{crest4}		
H_{crest}	7.5	8.5	9.5	10.5	m	Crest height
R_c	4.7	5.7	6.7	7.7	m	Relative freeboard

table A 5.7 Crest heights and relative freeboards used for average overtopping discharge estimation

The results of the calculations have been plotted out in graph A 5.5. It can be seen that the overtopping of the revetment for a design without crown wall is very high. In fact, only with a crest height of 10.5 meters, the overtopping stays within acceptable limits. The overtopping of the revetment with crown wall is already within acceptable limits for a height of 8.5 m. Since both solutions are possible, construction cost will determine which option is preferred.



graph A 5.5 Average overtopping discharges of the revetment with different heights, with and without crown wall.

<u>Geotextile</u>
To prevent loss of stability of the inner slope of the revetment by migration of dredged material thru the armour layers, a geotextile is to be applied between the quarry run core and the dredged material and between the quarry run core and the under layer on the top of the revetment. This geotextile does not need to be extended over the full cross section but from a depth of 2 m below top level of hydraulic fill to the seaward end of the crest of the quarry run core.

<u>Summary</u>
The design of the revetment can be summarized as follows and is shown in figure 5.2:

Slope: 1:2
Crest height: CD + 8.5 m (with crown wall)
CD +10.5 m (without crown wall)

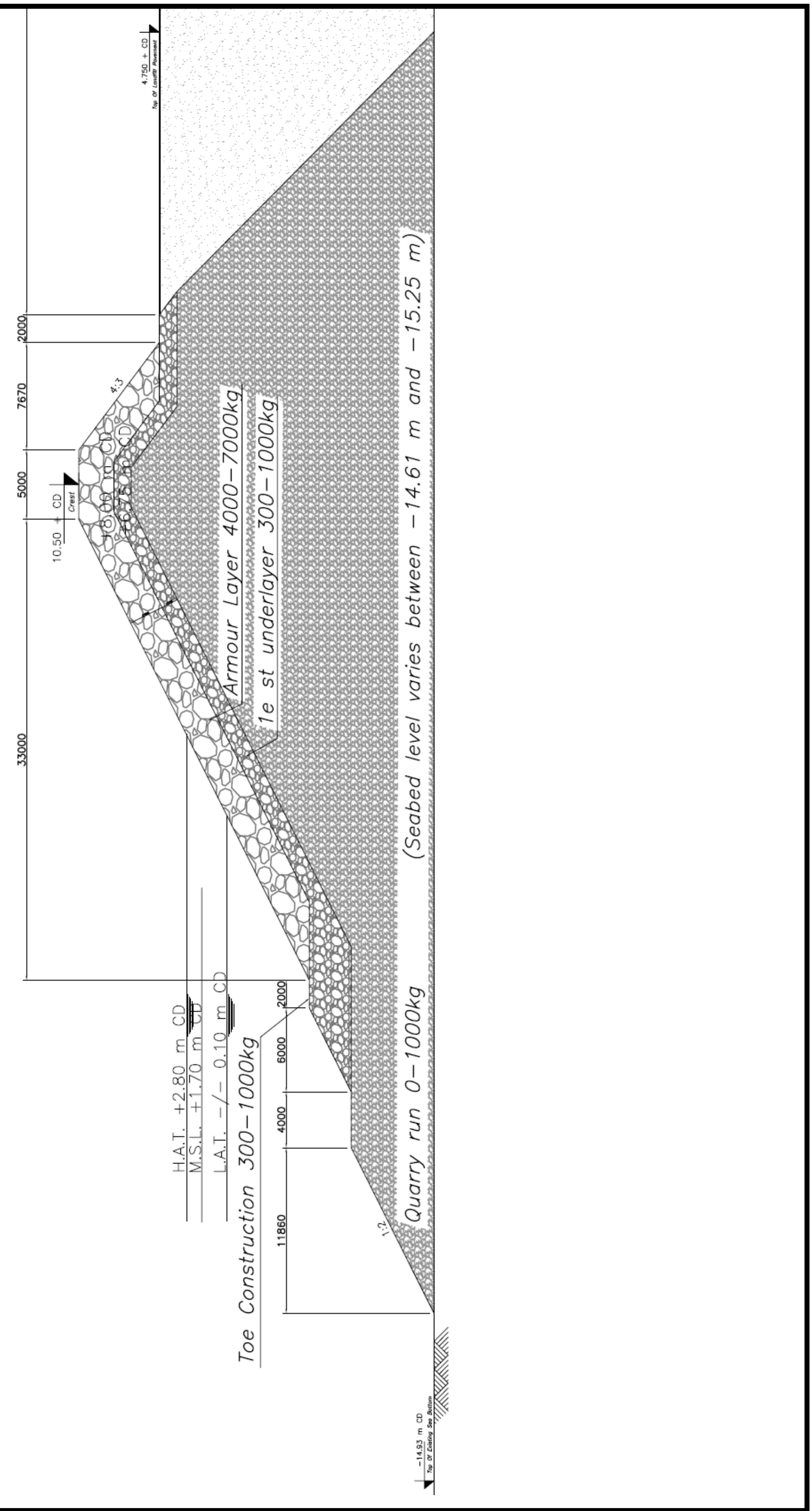
Component	**Material**	**Gradation**	**Thickness (m)**
Amour layer	Rock	4 – 7 ton	2.5
under layer	Rock	0.3 – 1 ton	1.25
Toe	Rock	0.3 – 1 ton	3
Core	Quarry run	0 – 1000 kg	

table A 5.8 Summary design revetment straight section

<u>Material quantity</u>
The amount of material in the cross section is given in table A 5.9

Component	Quantity [m^3/m]
Amour layer 4 – 7 ton	86
under layer and toe	68
Quarry run core	796
Concrete crown wall	7

table A 5.9 Amount of material in the revetment cross section



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure no:
5.2

Figure Title
Cross section revetment design phase 1 (straight part) without crown wall

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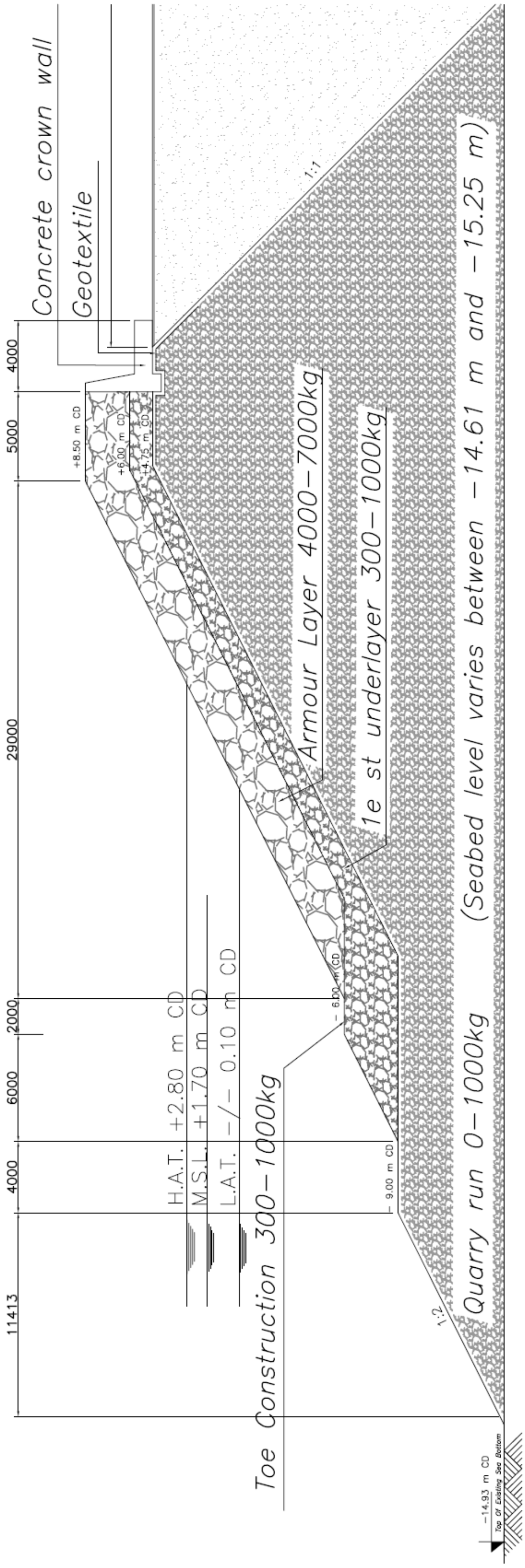

Project Title: Masterplan for the port of Fujairah Expansion Project	Figure no: 5.3
Figure Title: Cross section revetment design phase 1 (straight part) with crown wall.	

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A 5.4.3 Breakwater section

Functional requirements
The function of the new breakwater is to prevent waves from penetrating the harbour basin. There are no criteria for the overtopping discharge other than that no significant wave transmission is allowed. This means that the breakwater crest can be lower than the crest of the revetment. Since overtopping will be heavier with a low crest, special attention must be paid to the rear side of the breakwater.
The preferred construction method is by building out the work front by dumper trucks. This dry construction method is assumed to be less expensive than using ship born equipment. To secure safe working in the dam a certain core height is necessary. It is assumed that a height of CD +4 m, which is 1.2 m above HAT is sufficient for safe working during normal conditions.

Amour layer
The armour layer as present in the cross section of the proposed design for the revetment will be continued on the breakwater. The stability criteria and the load on the breakwater armour layer are similar to that of the revetment.

Crest height
The breakwater has no overtopping criteria. Its height is determined by the height of the core. As mentioned this will be built out from the shore. For this reason the height of the crest of the breakwater head is set at CD + 7.75, which is the top core plus the layer thickness of the amour layer.

Summary
The design of the breakwater section can be summarized as follows and is shown in figure

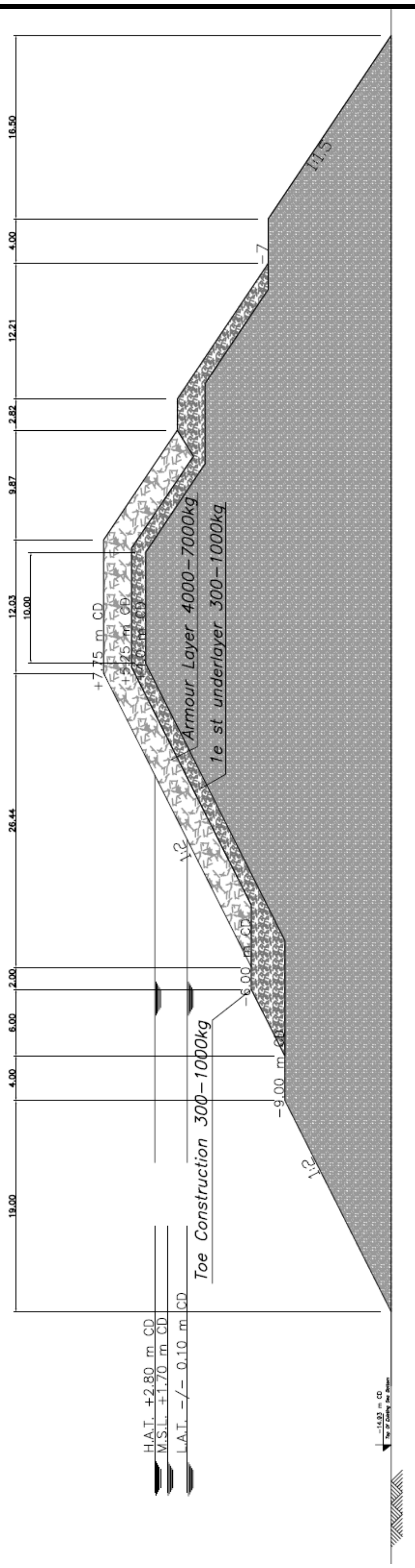
Slope: 1:2
Crest height: CD +7.75 m

Component	**Material**	**Gradation**	**Thickness (m)**
Amour layer	Rock	4 – 7 ton	2.5
under layer	Rock	0.3 – 1 ton	1.25
Toe	Rock	0.3 – 1 ton	
Core	Quarry run	0 – 1000 kg	

Material quantity
The amount of material in the cross section is given in table A 5.10

Component	**Quantity [m^3/m]**
Amour layer 4 – 7 ton	122
under layer and toe	114
Quarry run core	1391

table A 5.10 Amount of material in the breakwater cross section



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Cross section breakwater sections

Figure no:
5.4

M.U.C. Engineering

A 5.4.4 Breakwater round head

Functional requirements

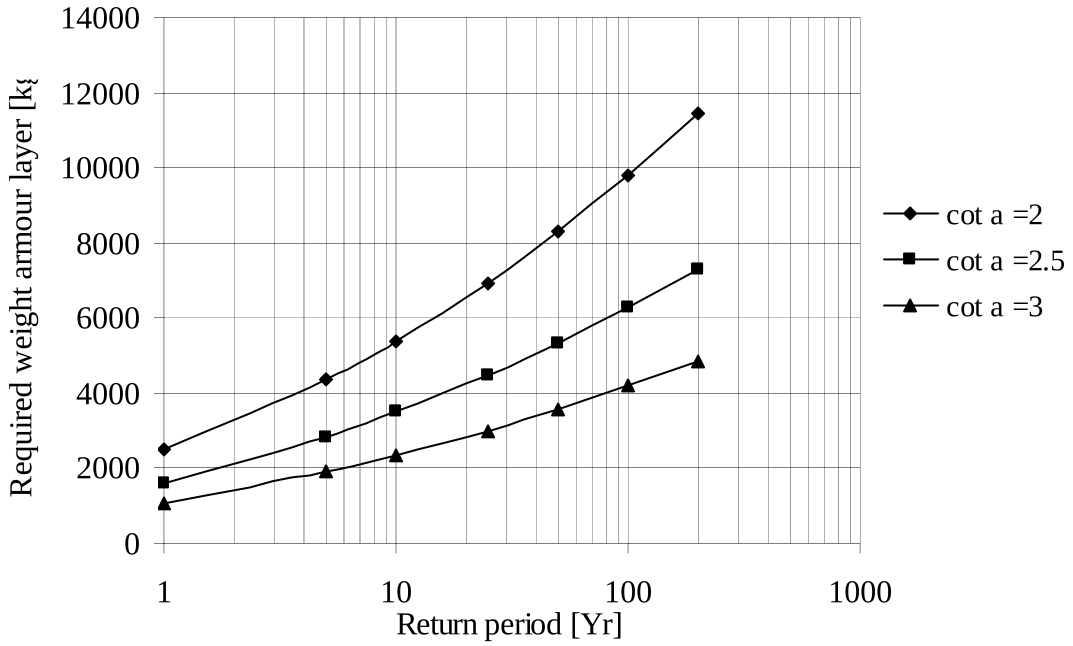
The main function of the temporary breakwater head is to protect the outer end breakwater against erosion due to wave and current attack.

Amour layer

For this breakwater head, slopes of 1:2, 1:2.5 and 1:3 have been evaluated using equation [Annex 5.2.9]. The required median stone weights for these slopes according to the equation of Carver and Heimbough (1989) are given in graph A 5.6.

A	0.272
B	-1.749
Cc	4.179

table A 5.11 Empirical coefficients of Carver and Heimbough



graph A 5.6 Required weight of armour layer for head section

The selected gradation for the amour layer of the breakwater round head is 4 to 7 tons. This gradation has a median weight of 5.5 tons. For the design of the head section, the wave with a return period of 10 years is used. From graph A 5.6 it can be seen that for the wave load with a return period of 100 years and a slope of 1:3, the required median stone weight is 4.90. This means that the amour layer from the revetment section with a median stone weight of 5.50 ton can safely be continued over the temporary head section.

The fact that the radius of this breakwater head is relatively large (50 to 75 m) is positive for the stability of the material in the armour layer.

Crest height

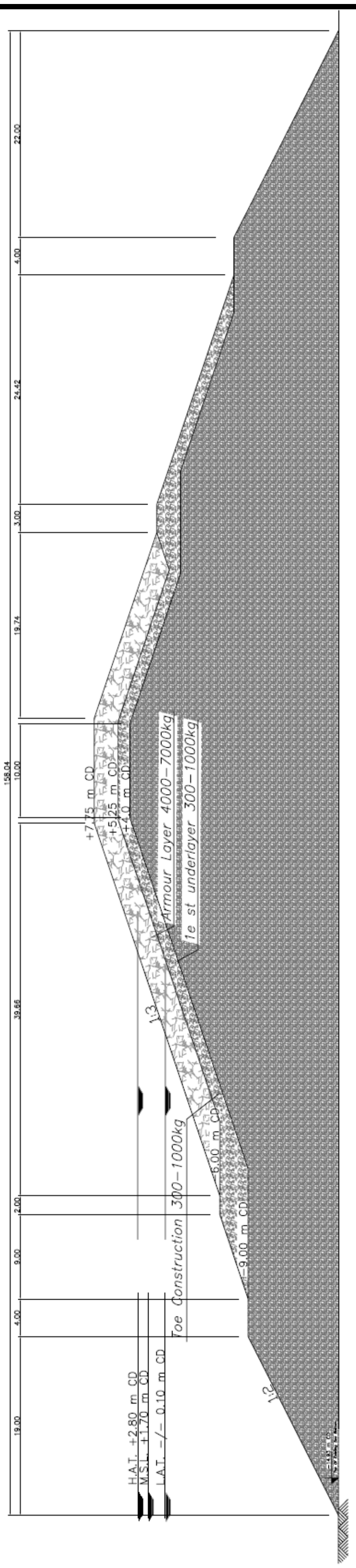
The breakwater head has no overtopping criteria. Its height is only determined by its earth retaining function. For this reason the height of the crest of the breakwater head is set at CD + 7.25, which is the top of the landfill plus the layer thickness of the amour layer. Since overtopping can be significant with this height, special attention should be paid on the protection of the inner slope. The under layer is therefore extended over the entire area of the head section.

Summary
The design of the temporary breakwater round head is equal to the breakwater cross section and is shown in figure 5.5:

Material quantity
The amount of material in the cross section is given in table A 5.10

Component	**Quantity [m^3]**
Amour layer 4 – 7 ton	21,000
under layer and toe	18,000
Quarry run core	65,000

table A 5.12 Amount of material in the breakwater cross section



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Cross section permanent round head design

Figure no:
5.5

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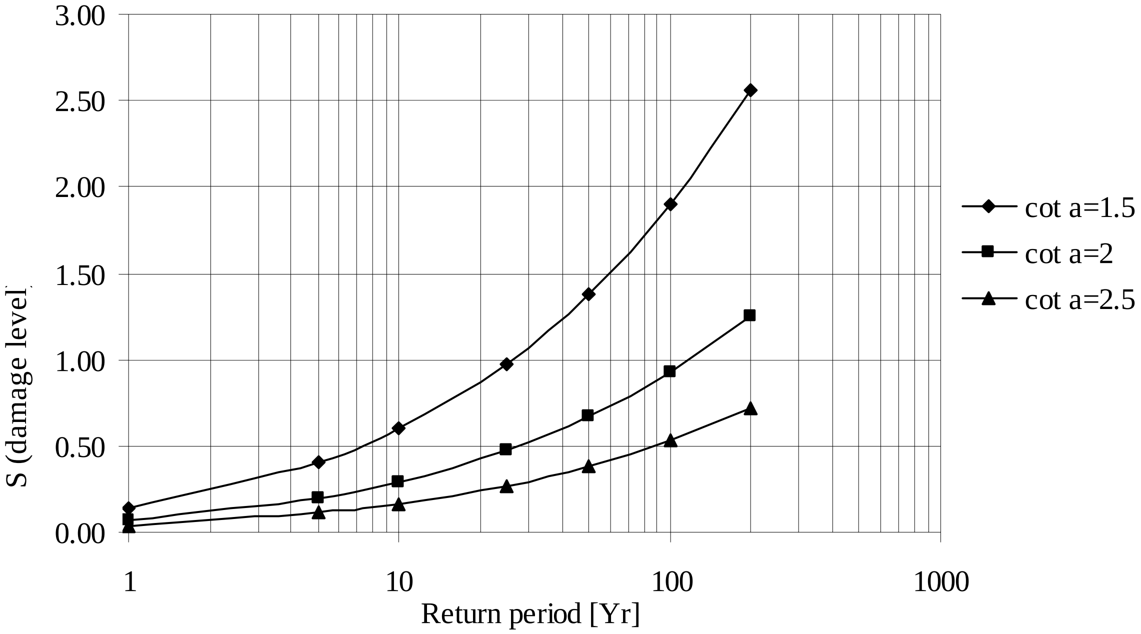
A 5.4.5 Revetment section sheltered

The revetment on the northern part of the new port (in layout 1 and layout 2) is sheltered from the dominant wave direction by the container terminal. It is assumed that the wave height reduces by 80% on these revetment sections.



graph A 5.7 Stability of the armour layer of the sheltered revetments

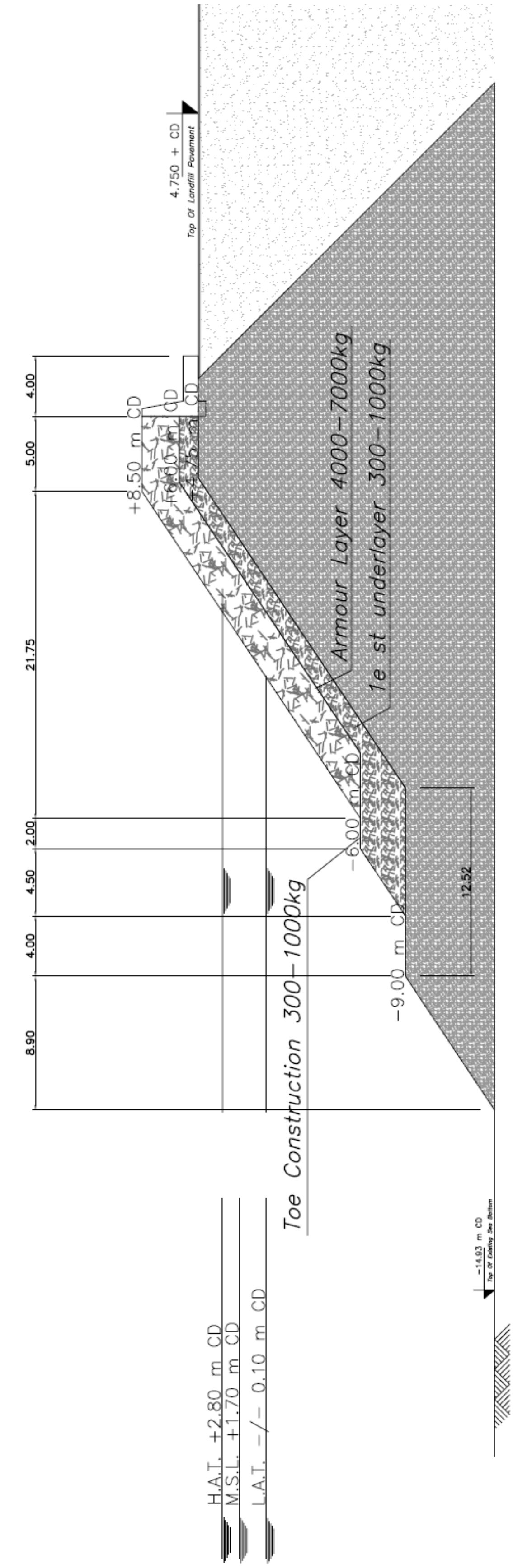
For practical reasons the height of the revetment is kept constant.

Material quantity

The amount of material in the cross section is given in table A 5.13

Component	Quantity [m^3/m]
Amour layer 4 – 7 ton	69
under layer and toe	58
Quarry run core	688
Crown wall	7

table A 5.13 Amount of material in the sheltered revetments



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Masterplan for the port of Fujairah Expansion Project

Figure Title
Cross section breakwater sections

Figure no:
5.4

M.U.C. Engineering

A6 Annex 6 Dredging quantities

TUDelft
Technical University of Delft
Faculty of Civil Engineering and Geosciences
Hydraulic and offshore section

B.V. Ingenieursbureau M.U.C.

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A 6.1 General

A 6.1.1 Introduction

This annex describes the dredging and reclamation works for the Port of Fujairah expansion project. It focuses on the proposed alternative harbour basin layouts 1 – 5. Attention is paid to the Fujairah Land Reclamation project which is planned to be realized north of the Port. Goal of this part if the masterplan study is to estimate the dredging and reclamation cost of the different layouts.
The following assumptions where made:

- The dredged material can be used for hydraulic fill of the land behind the new quays.
- The surplus of material can be used for the Fujairah land reclamation project. Costs saved for this project are reduced from the dredging cost of the Port Expansion Project.
- If not enough material is available for filling of land behind quay walls, quarry run produced in Fujairah is used.

A 6.1.2 Dredgability

The material in the designated dredge area is believed to be suitable for the land reclamation works. Details of the soil composition are given in annex 2 of the masterplan report.

A 6.1.3 Phasing

For each layout a project phasing is proposed. The quantities given in this annex are given per phase.

A 6.2 Quantities

A 6.2.1 Introduction

The layouts that where used for calculation of the dredging and land fill quantities, are shown in figures attached to this annex. The bulking factor is assumed to be 10%. The bulking factor comprises the material volume increase after dredging and includes compaction after hydraulic fill. In fact it represents the relation between fixed volume in situ before excavation and fixed volume in site after hydraulic fill. The estimated amount of material that comes free by dredging the entire harbour basin and entrance channel of the proposed layout is given in the following paragraphs:

A 6.2.2 Layout A1

Phase 1

Layout 1 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-3	-1	395,037	0	0	0	2,271,463	0
-3	-5	-4	165,788	0	0	0	1,450,645	0
-5	-7	-6	183,288	0	0	0	1,970,346	0
-7	-9	-8	190,102	0	0	0	2,423,801	0
-9	-11	-10	25,269	0	110,476	0	372,718	-994,284
-11	-13	-12	37,444	0	177,651	0	627,187	-1,243,557
-13	-15	-14	97,211	0	250,326	0	1,822,706	-1,251,630
-15	-17	-16	112,932	0	368,512	0	2,343,339	-1,105,536
-17	-19	-18	0	0	327,725	0	0	-327,725
-19	-21	-20	0	0	213,974	0	0	213,974
							13,282,204	**-4,922,732**

table A 6.1 Dredging and reclamation quantities layout A1, phase 1

Phase 2

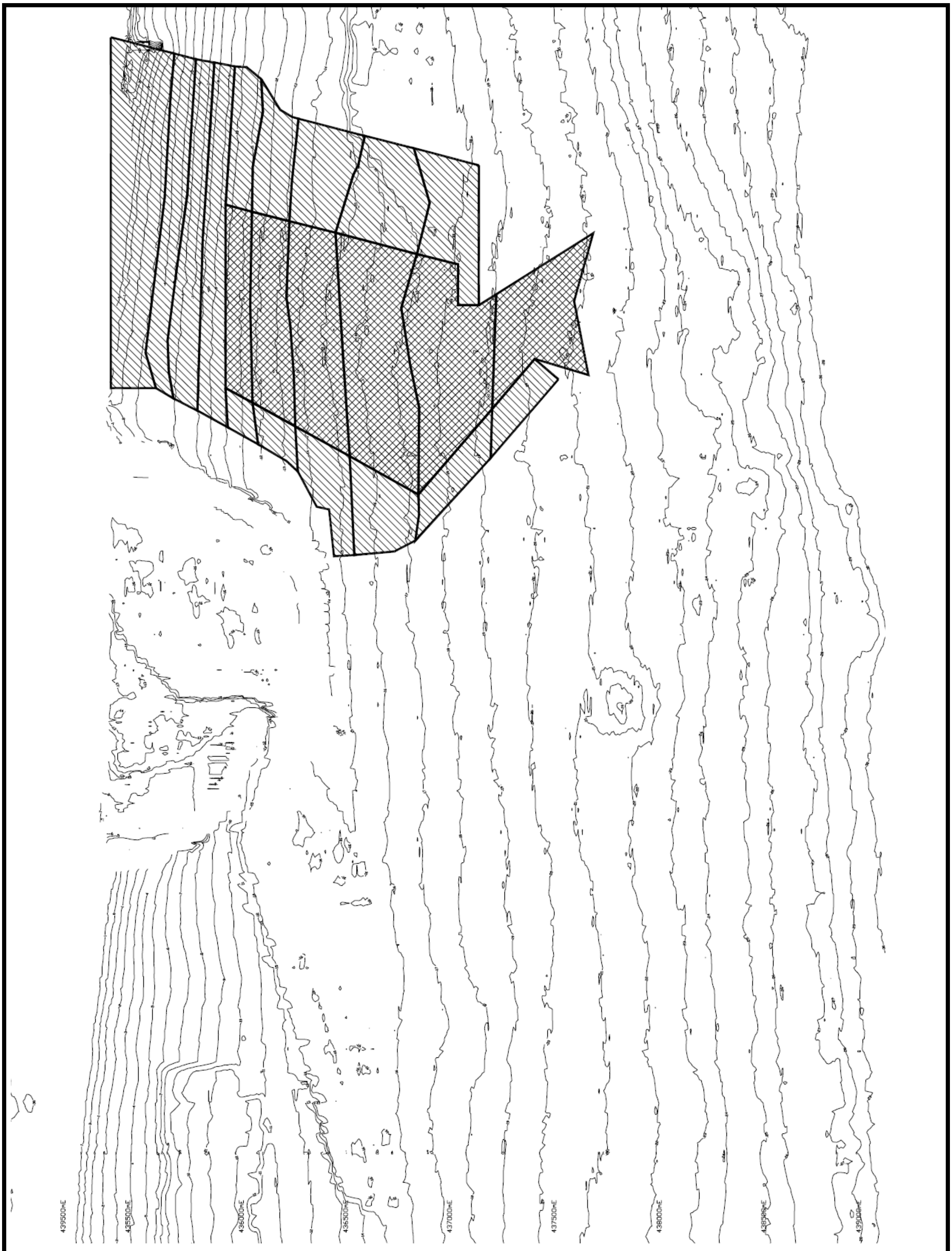
Layout 1 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-3	-1	0	0	0	0	0	0
-3	-5	-4	0	0	0	0	0	0
-5	-7	-6	0	0	0	0	0	0
-7	-9	-8	0	0	0	0	0	0
-9	-11	-10	0	86,838	0	0	1,280,861	0
-11	-13	-12	0	98,683	0	0	1,652,940	0
-13	-15	-14	0	137,601	0	0	2,580,019	0
-15	-17	-16	0	173,123	0	0	3,592,302	0
-17	-19	-18	0	153,847	0	0	3,500,019	0
-19	-21	-20	0	0	0	0	0	0
							12,606,141	**0**

table A 6.2 Dredging and reclamation quantities layout A1, phase 2

Phase 3

Layout 1 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-3	-1	0	0	0	0	0	0
-3	-5	-4	0	0	0	0	0	0
-5	-7	-6	0	0	0	0	0	0
-7	-9	-8	0	0	0	0	0	0
-9	-11	-10	0	0	0	0	0	0
-11	-13	-12	0	0	0	0	0	0
-13	-15	-14	0	0	0	0	0	0
-15	-17	-16	0	0	0	0	0	0
-17	-19	-18	76,084	0	0	0	1,730,911	0
-19	-21	-20	60,435	0	0	0	1,495,766	0
							1,730,911	**0**

table A 6.3 Dredging and reclamation quantities layout A1, phase 3



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Dredging and reclamation areas layout A1

Figure no:
A 6.1

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A 6.2.3 Layout A2-B2

Phase 1

Phase 1 Layout A2 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-1	0	219,565	0	0	0	1,042,934	0
-1	-3	-2	137,135	0	38,112	0	925,661	-647,904
-3	-5	-4	17,803	0	81,795	0	155,776	-1,226,925
-5	-7	-6	20,576	0	94,302	0	221,192	-1,225,926
-7	-9	-8	22,829	0	109,864	0	291,070	-1,208,504
-9	-11	-10	25,269	0	116,415	0	372,718	-1,047,735
-11	-13	-12	37,444	0	194,534	0	627,187	-1,361,738
-13	-15	-14	58,838	0	318,621	0	1,103,213	-1,593,105
-15	-17	-16	0	0	242,845	0	0	-728,535
-17	-19	-18	0	0	200,511	0	0	-200,511
-19	-21	-20	0	0	250,396		0	250,396
							4,739,750	**-8,990,487**

table A 6.4 Dredging and reclamation quantities Layout A2 – B2, phase 1

Phase 2

Layout 2 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-1	0	0	0	0	0	0	0
-1	-3	-2	0	0	0	0	0	0
-3	-5	-4	0	72,422	0	0	633,693	0
-5	-7	-6	0	58,426	0	0	628,080	0
-7	-9	-8	0	62,379	0	0	795,332	0
-9	-11	-10	0	79,729	0	0	1,176,003	0
-11	-13	-12	0	81,028	0	0	1,357,219	0
-13	-15	-14	0	113,552	0	0	2,129,100	0
-15	-17	-16	0	0	0	0	0	0
-17	-19	-18	0	0	0	0	0	0
-19	-21	-20	0	0	0		0	0
							6,719,426	**0**

table A 6.5 Dredging and reclamation quantities Layout A2-B2, phase 2

Phase 3

No dredging is required in phase 3 for layout 2A-B2

Layout A2-B1

Phase 1

Layout 2 d1	**d2**	**avg**	**4.75 area [m2]**	**4.75 area [m2]**	**-19 area [m2]**	**-16 area [m2]**	**Land fill vol [m3]**	**dredging vol [m2]**
1	-1	0	219,565	0	0	0	1,042,934	0
-1	-3	-2	137,135	0	38,112	0	925,661	-647,904
-3	-5	-4	17,803	0	81,795	0	155,776	-1,226,925
-5	-7	-6	20,576	0	94,302	0	221,192	-1,225,926
-7	-9	-8	22,829	0	109,864	0	291,070	-1,208,504
-9	-11	-10	25,269	0	116,415	0	372,718	-1,047,735
-11	-13	-12	37,444	0	194,534	0	627,187	-1,361,738
-13	-15	-14	58,838	0	318,621	0	1,103,213	-1,593,105
-15	-17	-16	0	0	242,845	0	0	-728,535
-17	-19	-18	0	0	200,511	0	0	-200,511
-19	-21	-20	0	0	250,396		0	250,396
							4,739,750	**-8,990,487**

table A 6.6 Dredging and reclamation quantities Layout A2-B1, phase 1

Phase 2

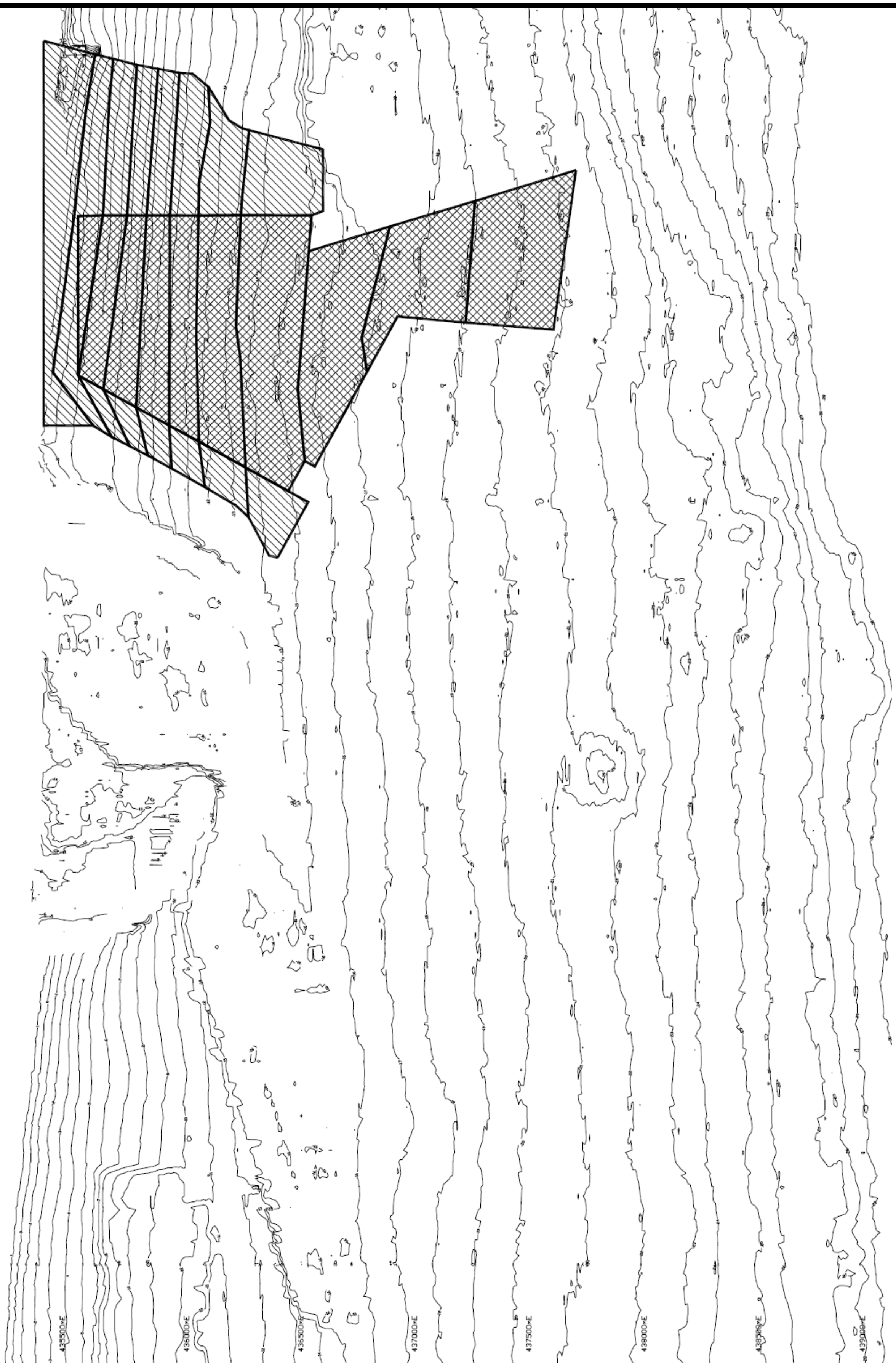
Layout 2 d1	**d2**	**avg**	**4.75 area [m2]**	**4.75 area [m2]**	**-19 area [m2]**	**-16 area [m2]**	**Land fill vol [m3]**	**dredging vol [m2]**
1	-1	0	0	0	0	0	0	0
-1	-3	-2	0	0	0	0	0	0
-3	-5	-4	0	72,422	0	0	633,693	0
-5	-7	-6	0	58,426	0	0	628,080	0
-7	-9	-8	0	62,379	0	0	795,332	0
-9	-11	-10	0	0	0	0	0	0
-11	-13	-12	0	0	0	0	0	0
-13	-15	-14	0	0	0	0	0	0
-15	-17	-16	0	0	0	0	0	0
-17	-19	-18	0	0	0	0	0	0
							2,057,104	**0**

table A 6.7 Dredging and reclamation quantities Layout A2-B1, phase 2

Phase 3

Layout 2 d1	**d2**	**avg**	**4.75 area [m2]**	**4.75 area [m2]**	**-19 area [m2]**	**-16 area [m2]**	**Land fill vol [m3]**	**dredging vol [m2]**
1	-1	0	0	0	0	0	0	0
-1	-3	-2	0	0	0	0	0	0
-3	-5	-4	0	0	0	0	0	0
-5	-7	-6	0	0	0	0	0	0
-7	-9	-8	0	0	0	0	0	0
-9	-11	-10	0	79,729	0	0	1,176,003	0
-11	-13	-12	0	81,028	0	0	1,357,219	0
-13	-15	-14	0	113,552	0	0	2,129,100	0
-15	-17	-16	0	0	0	0	0	0
-17	-19	-18	0	0	0	0	0	0
-19	-21	-20	0	0	0		0	0
							4,662,322	**0**

Dredging and reclamation quantities Layout A2-B1, phase 3



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Dredging and reclamation areas layout A2

Figure no:
A 6.2

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A 6.2.4 Layout A3

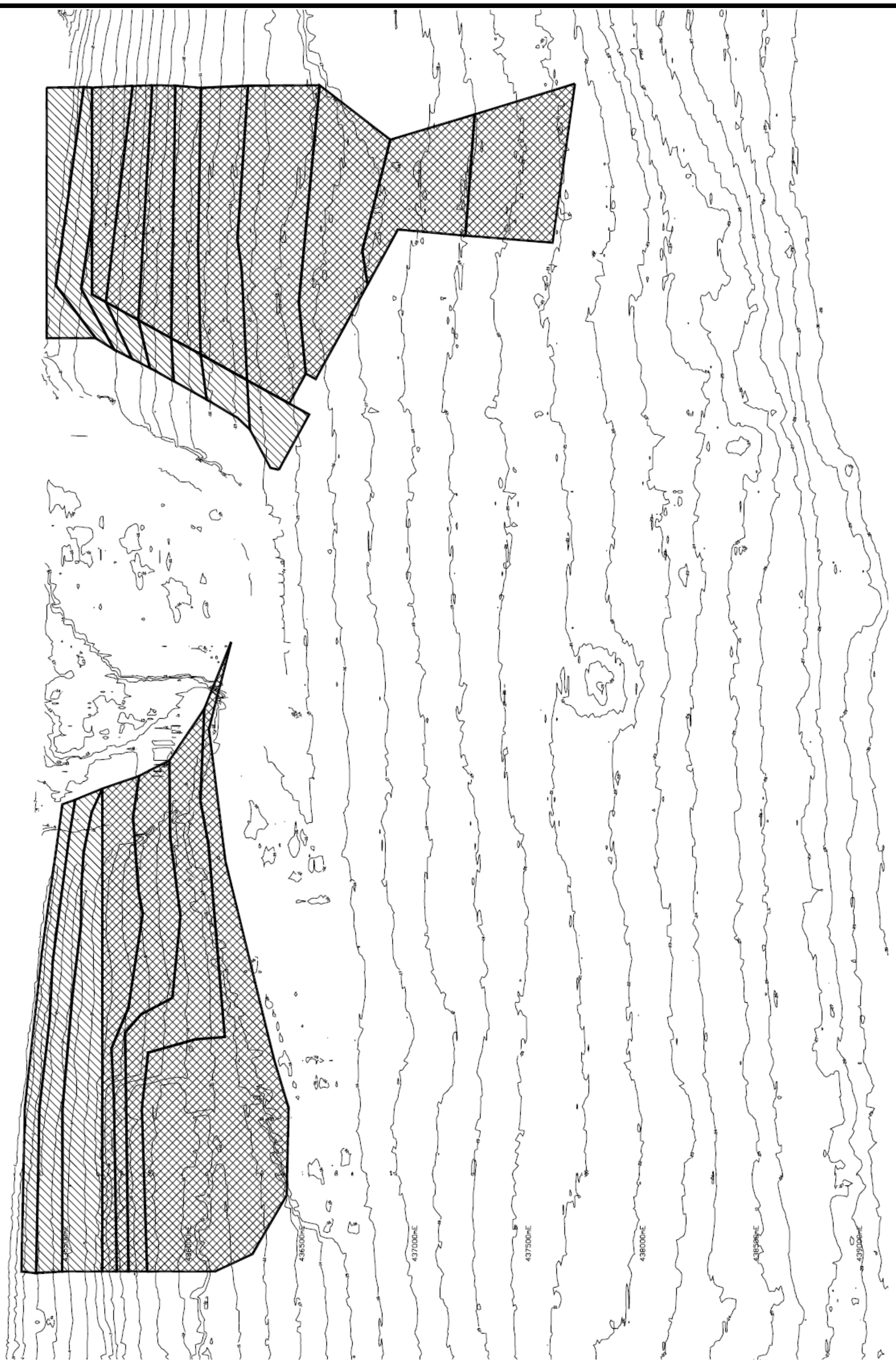
Phase 1

Layout 3 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-1	0	117,967	123,218	0	0	1,145,629	0
-1	-3	-2	98,380	205,619	0	0	2,051,993	0
-3	-5	-4	26,096	280,127	112,441	0	2,679,451	-1,686,615
-5	-7	-6	20,675	0	117,100	215202	222,256	-3,674,320
-7	-9	-8	22,829	0	133,617	235628	291,070	-3,354,811
-9	-11	-10	25,269	0	131,837	337458	372,718	-3,211,281
-11	-13	-12	37,444	0	234,700	732685	627,187	-4,573,640
-13	-15	-14	58,838	0	380,063	0	1,103,213	-1,900,315
-15	-17	-16	0	0	297,319	0	0	-891,957
-17	-19	-18	0	0	200,511	0	0	-200,511
-19	-21	-20	0	0	250,396	0	0	250,396
							8,493,517	**-19,243,054**

table A 6.8 Dredging and reclamation quantities Layout A3, phase 1

Phase 2
No dredging and reclamation works in phase 2 of layout A3.

Phase 3
No dredging and reclamation works in phase 3 of layout A3.



Project Title:

Masterplan for the port of Fujairah Expansion Project

Figure Title

Dredging and reclamation areas layout A3

Figure no:

A 6.3

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A 6.2.5 Layout A4

Phase 1

Layout 4 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-1	0	309,661	123,218	0	0	2,056,175	0
-1	-3	-2	73,152	205,619	134,935	0	1,881,704	-2,293,895
-3	-5	-4	84,607	280,127	82,078	0	3,191,423	-1,231,170
-5	-7	-6	38,072	0	124,390	215202	409,274	-3,769,090
-7	-9	-8	44,068	0	143,092	235628	561,867	-3,459,036
-9	-11	-10	51,809	0	143,948	337458	764,183	-3,320,280
-11	-13	-12	37,444	0	238,639	732685	627,187	-4,601,213
-13	-15	-14	58,838	0	385,416	0	1,103,213	-1,927,080
-15	-17	-16		0	289,717	0	0	-869,151
-17	-19	-18		0	183,449	0	0	-183,449
-19	-21	-20		0	250,396	0	0	250,396
							10,595,025	**-21,403,968**

table A 6.9 Dredging and reclamation quantities Layout A4, phase 1

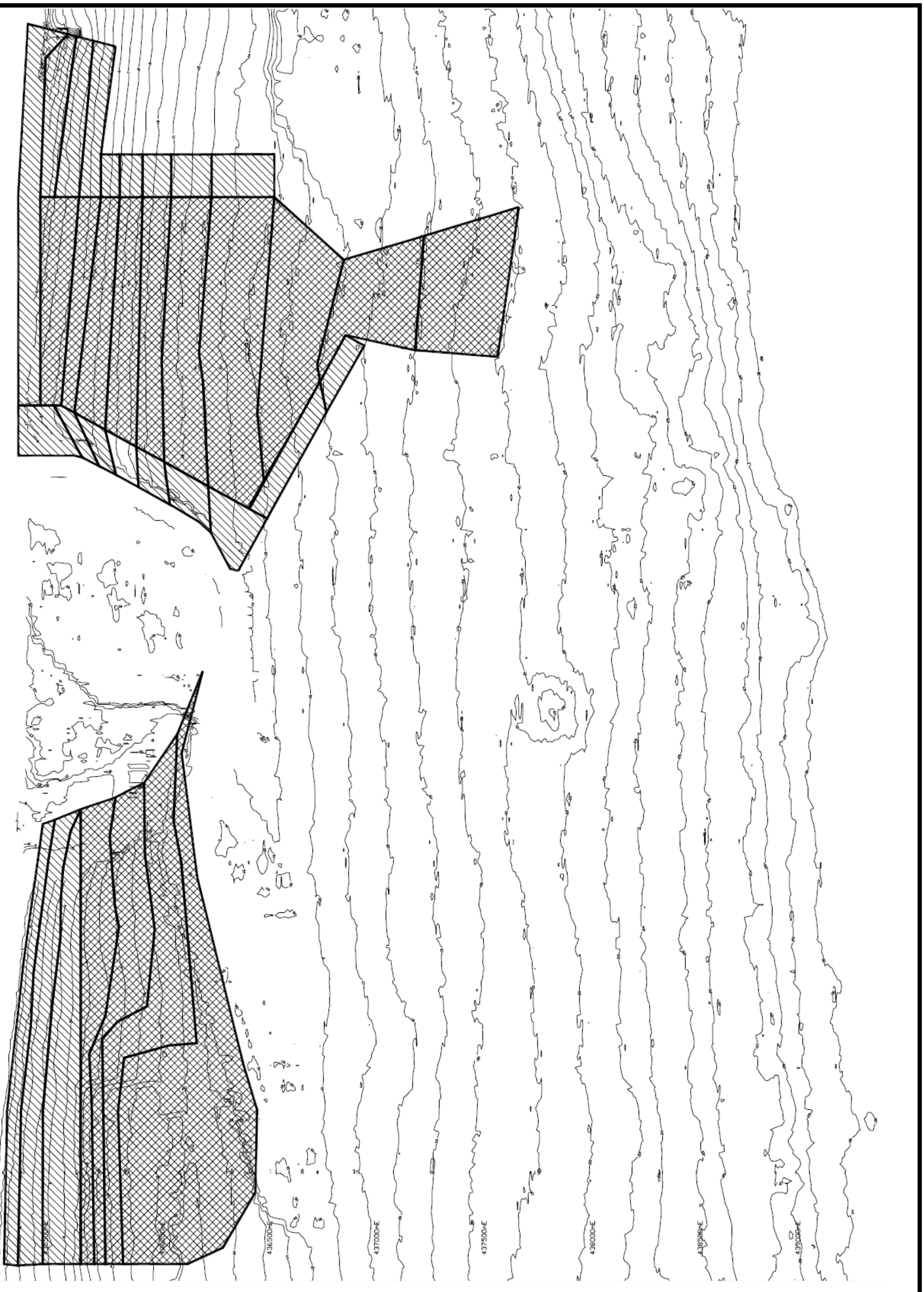
Phase 2

Layout 4 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-1	0	0	0	0	0	0	0
-1	-3	-2	0	0	0	0	0	0
-3	-5	-4	0	0	0	0	0	0
-5	-7	-6	0	0	0	0	0	0
-7	-9	-8	0	0	0	0	0	0
-9	-11	-10	0	0	0	0	0	0
-11	-13	-12	37,531	0	0	0	628,644	0
-13	-15	-14	58,363	0	0	0	1,094,306	0
-15	-17	-16	0	0	0	0	0	0
-17	-19	-18	29,506	0	0	0	671,262	0
-19	-21	-20	0	0	0	0	0	0
							2,394,212	**0**

table A 6.10 Dredging and reclamation quantities Layout A4, phase 2

Phase 3

No dredging and reclamation works in phase 3 of layout A4.



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Dredging and reclamation areas layout A4

Figure no:
A 6.4

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A 6.2.6 Layout A5

Phase 1

Layout 4 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-1	0	53,686	123,218	0	0	840,294	0
-1	-3	-2		205,619	134,935	0	1,387,928	-2,293,895
-3	-5	-4	17,347	280,127	82,078	0	2,602,898	-1,231,170
-5	-7	-6	20,576	0	124,390	215202	221,192	-3,769,090
-7	-9	-8	22,829	0	143,092	235628	291,070	-3,459,036
-9	-11	-10	25,269	0	143,948	337458	372,718	-3,320,280
-11	-13	-12	37,444	0	238,639	732685	627,187	-4,601,213
-13	-15	-14	58,838	0	385,416	0	1,103,213	-1,927,080
-15	-17	-16		0	289,717	0	0	-869,151
-17	-19	-18		0	183,449	0	0	-183,449
-19	-21	-20		0	250,396	0	0	250,396
							7,446,499	**-21,403,968**

table A 6.11 Dredging and reclamation quantities Layout A4, phase 1

Phase 2

Layout 4 d1	d2	avg	4.75 area [m2]	4.75 area [m2]	-19 area [m2]	-16 area [m2]	Land fill vol [m3]	dredging vol [m2]
1	-1	0	0	0	0	0	0	0
-1	-3	-2	0	0	0	0	0	0
-3	-5	-4	0	0	0	0	0	0
-5	-7	-6	0	0	0	0	0	0
-7	-9	-8	0	0	0	0	0	0
-9	-11	-10	0	0	0	0	0	0
-11	-13	-12	0	0	0	0	0	0
-13	-15	-14	0	0	0	0	0	0
-15	-17	-16	0	0	0	0	0	0
-17	-19	-18	29,506	0	0	0	671,262	0
-19	-21	-20	0	0	0	0	0	0
							671,262	**0**

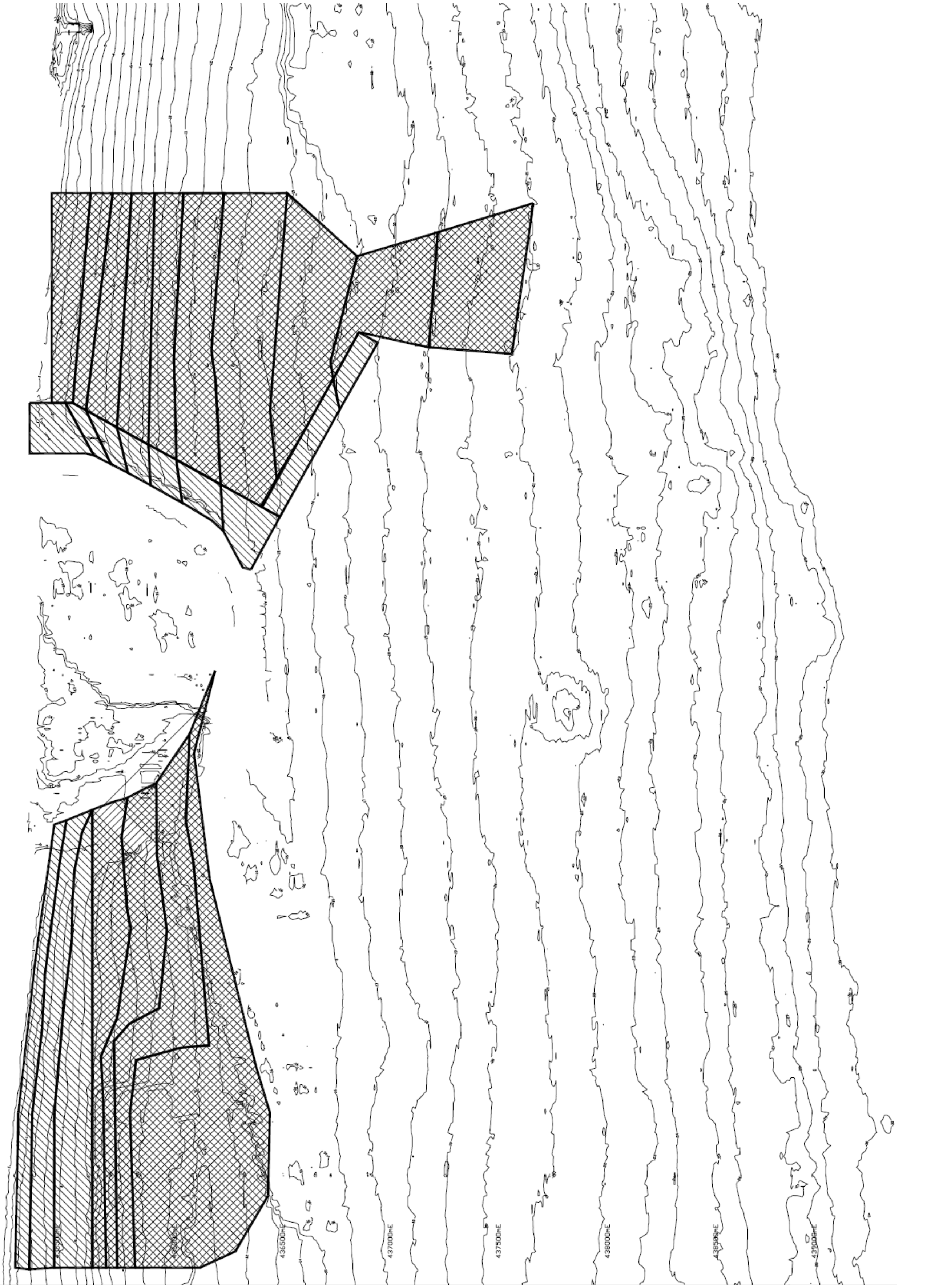
table A 6.12 Dredging and reclamation quantities Layout A4, phase 2

Phase 3

No dredging and reclamation works in phase 3 of layout A4.

A 6.3 Fujairah Land Reclamation Project

The amount of soil required in situ for the Fujairah Land Reclamation Project is 28.7 M m^3. This means that all material that comes free from the Port Expansion Project can be used for the reclamation project



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Dredging and reclamation areas layout A5

Figure no:
A 6.5

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A7 Annex 7 Principle Tanker Terminal design

Masterplan for the port of Fujairah Expansion Project

TUDelft
Technical University of Delft
Faculty of Civil Engineering and Geosciences
Hydraulic and offshore section

B.V. Ingenieursbureau M.U.C.

10/29/2007

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A 7.1 Introduction

This annex describes the principle design of the Open Sea Tanker Terminal in the Port of Fujairah Expansion Project. The designs for this part of the project where not carried out as a part of this study but where carried out by B.V. Ingenieursbureau M.U.C.

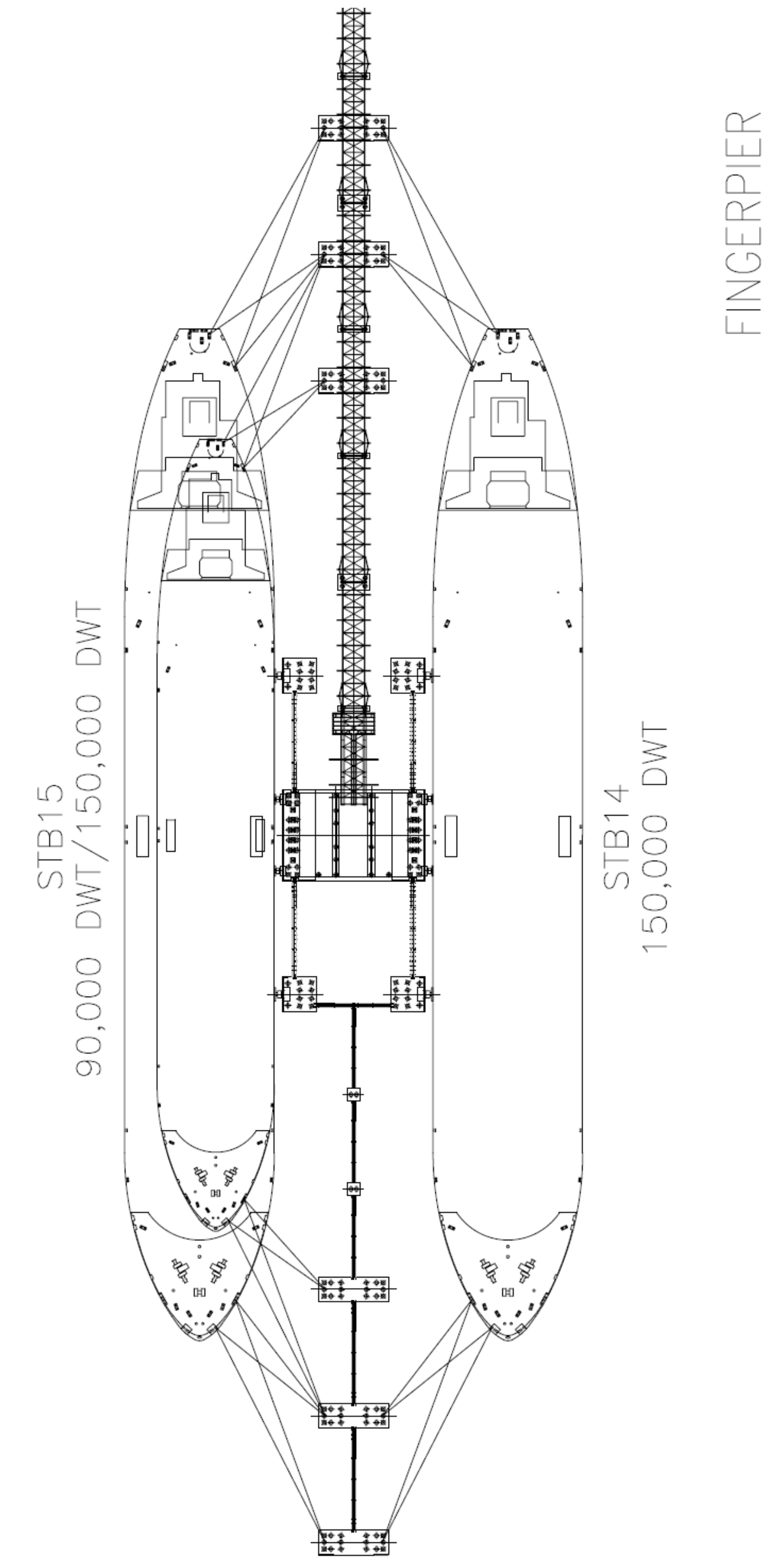
A 7.2 Design of Open Sea Tanker Terminal

The general layout of the Finger piers is shown in figure 7.1.

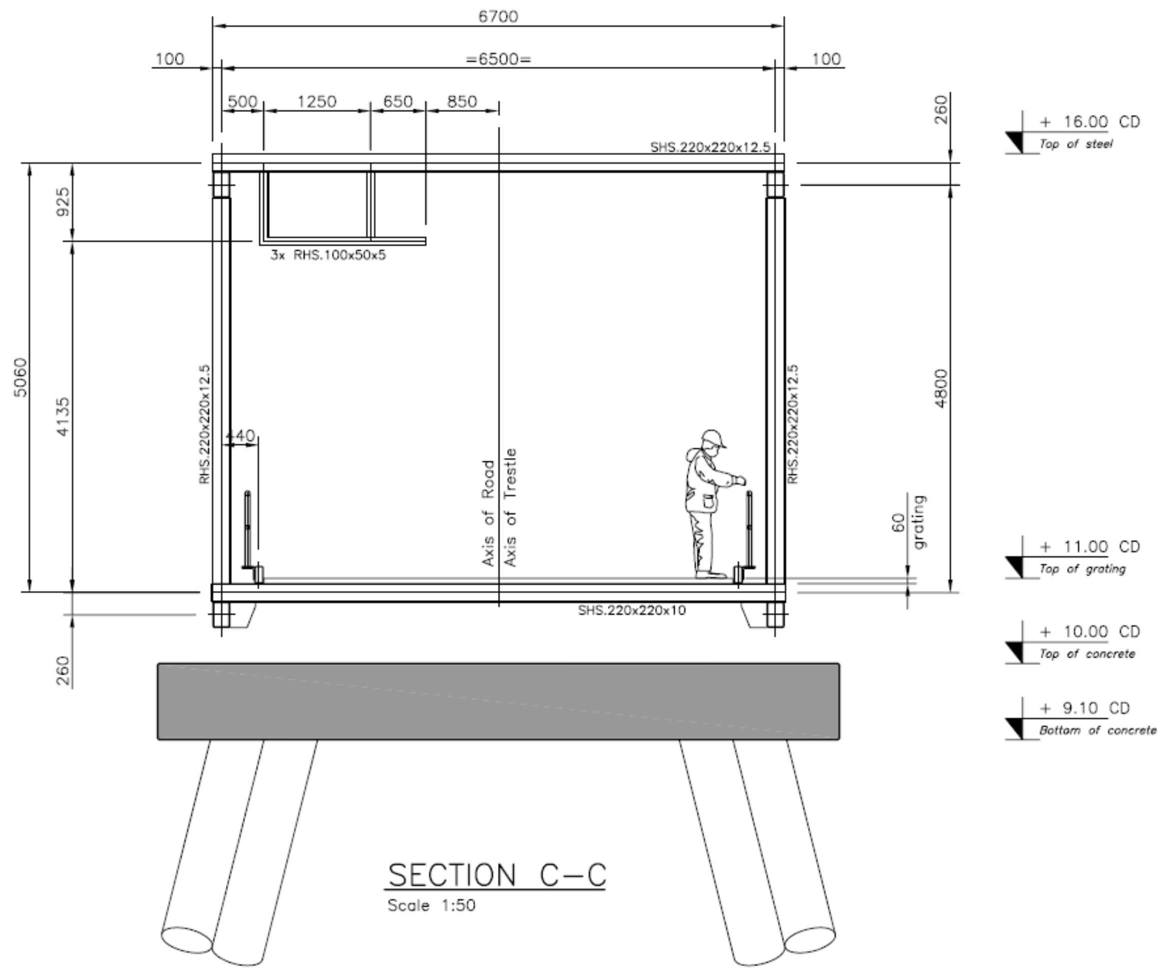
The Open Sea Tanker terminal is built up from the following elements:

- Concrete product platforms on steel piles on which the loading arms are installed.
- Concrete breasting platforms
- Concrete mooring platforms
- Steel catwalks between breasting, mooring and product platforms
- Steel access bridges from the shore to the product platforms. These access bridges are founded on concrete platforms and steel piles. The length of the bridges is 37.5 m each.

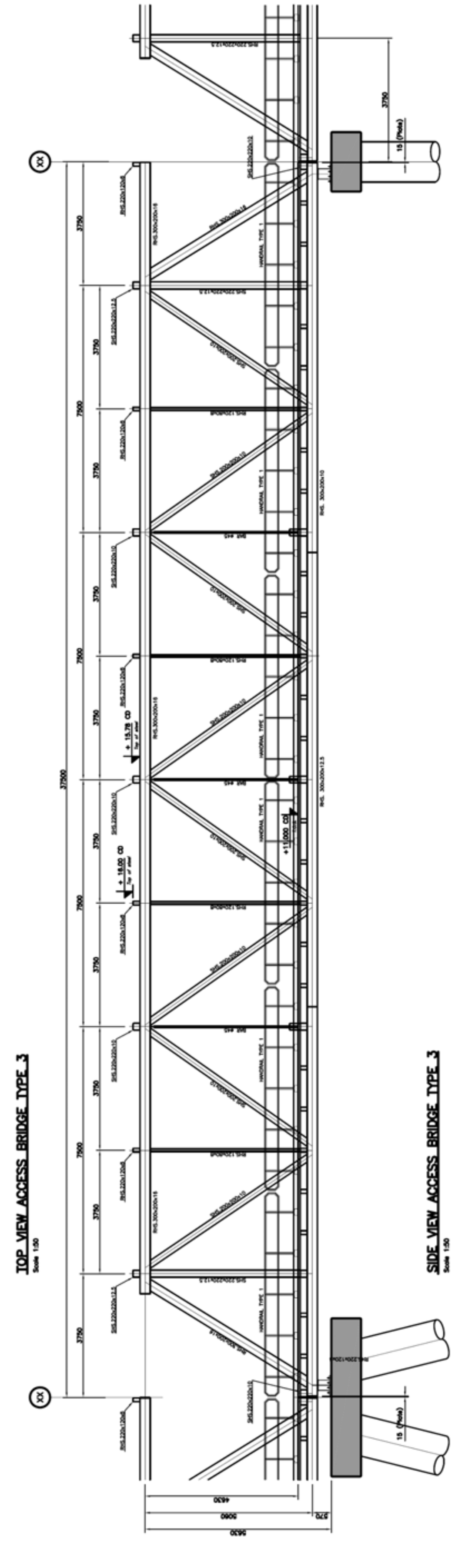
Cross section and side view of the access bridge is shown in figures 7.2 and 7.3.



Project Title: Masterplan for the port of Fujairah Expansion Project	Figure no: A
Figure Title Overview finger pier	
M.U.C. Engineering	



Project Title: Masterplan for the port of Fujairah Expansion Project	Figure no: A	
Figure Title Cross section standard trestle bridge		
M.U.C. Engineering		



Project Title:
Masterplan for the port of Fujairah Expansion Project

Figure Title
Side view standard trestle bridge.

Figure no:
A

M.U.C. Engineering

A8 Annex 8 Layout evaluation

Masterplan for the port of Fujairah Expansion Project

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A 8.1 Introduction

In this annex to the report Masterplan for the Port of Fujairah, several layout alternatives for the expansion of this port will be analyzed. These layouts, including intermediate phasing and are shown in Annex 2 to the masterplan report.

The objective of this evaluation is to asses the feasibility of several proposed layout alternatives based on monetary and other criteria.

In the masterplan report, several scenarios are composed for the demand in throughput capacity for different commodities. Not all layouts are capable of supplying for the required capacity for the highest growth scenario. This obstructs a straightforward monetary evaluation or multi criteria analysis. The capability of realizing the required throughput capacity is assumed to be so important, that a separate evaluation is carried out for the different scenarios. This means that first the layouts are separately evaluated that are capable of supplying for the highest growth scenario. Subsequently the layouts are tested that can supply for the demand according to scenario 2 and for scenario 3.

A 8.2 Pricing assumptions

A 8.2.1 Introduction

In this paragraph the construction cost of the layouts are estimated. These construction cost are estimated, based on project cost of other comparable projects in the Fujairah region. The cost estimations are rough and not suitable for tendering phase.

A 8.2.2 Cost estimation

The costs of four main parts of the port expansion construction works are taken into account. These are:

- Dredging and reclamation
- Construction of quay walls
- Coastal protection
- Construction of the Open Sea Tanker Terminal

A 8.2.3 Pricing assumptions dredging and reclamation works

For the proposed layouts, dredging and land fill volumes have been determined. Detailed results of this study are shown in Annex 6 “Dredging quantities”. For several layout alternatives there is a dredging surplus. Although a dredging surplus would increase the total project cost of the Port Expansion Project, it would be favorable to reduce the project cost of the reclamation project, north of the Port expansion. This project is not owned by the Port of Fujairah Authorities but by the Fujairah Municipality. Both projects however are on behalf of His Highness Sheikh Saleh bin Mohammad Al Sharqi and the Government of Fujairah. For further cost estimations it is assumed that a possible dredging surplus, soil material can be sold to the Municipality of Fujairah for reclamation purposes.
Dredging costs are estimated by using a fixed price per m^3 in situ to be dredged, based on other comparable dredging projects in the region. The price of quarry run is based on several comparable reclamation projects in the region.

The depth of the new harbour basin does not make it necessary to use very large dredging equipment. In fact the equipment that it is necessary for dredging the harbour basin to the desired depth is currently presently in the region. In the pricing assumptions it is not taken into account that the dredging can be executed in combination with the gaining of the material for the Fujairah Land Reclamation Project. Combining these projects would further decrease the dredging price since mobilization and demobilization costs are less. It is however unsure if both projects can be executed simultaneous.

Dredging	**price**	**unit**
Dredging and hydraulic fill	5.50	[$/m^3]
Quarry run material	9.00	[$/m^3]
Refund from reclamation	-4.00	[$/m^3]

table A 8.1 Unit prices dredging and reclamation works

Further a net bulking factor of 10% is assumed. This factor represents the volume gain of soil, subtracted from the sea bottom compacted used for landfill.

A 8.2.4 Pricing assumptions quay walls

The design of the quay wall is described in Annex 4 “Design of quay wall” to this report. In this annex, the conclusions was drawn that the most favorable type of quay wall cost as well as construction time wise is a combi sheet pile wall. In this paragraph several pricing assumptions will be made. These assumptions are given in table A 8.2.
These assumptions where used to estimate the cost of a 1,000 m quay wall. This resulted in a price per m which is used for estimation of construction cost for quay walls per m.

Piles	**quantity**	**unit**	**price per unit**	**cost**
Purchase of material				
Purchase of tubes	375	pc	$ 18,200	$ 6,824,989
Purchase of sheet piles (infill)	374	pc	$ 5,984	$ 2,238,141
Cathodic protection (purchase and installation)	375	pc	$ 250	$ 93,750
Transport				
Transport of tubes	375	pc	$ 6,256	$ 2,345,881
Transport of infill elements	374	pc	$ 610	$ 228,030
Local transports	749	pc		$ 176,000
Installation				
Installation of tubes	375	pc	$ 3,395	$ 1,273,002
Installation of infill	374	pc	$ 905	$ 338,562
Additional time, startup, unworkable weather, cool down	5	wks	$ 81,472	$ 407,361
Mobilization and demobilization				$ 147,800
Lump sum items pile installation				$ 75,000
Total				$ 14,148,515

Anchoring				
Purchase of anchor material	750	pc	$ 5,513	$ 4,134,375
Transport of anchor material	750	pc	$ 135	$ 101,501

Additional installation cost of anchor material	750	pc	$ 254	$ 190,249
Additional installation cost of anchor material				$ 91,094
Total				$ 4,517,219

Additionals				
Filling of piles with sand	4157	m3	$ 10	$ 41,572
Concrete plugs	1366	m3	$ 350	$ 478,072
Concrete copping beam	13400	m3	$ 235	$ 3,149,000
Fenders (purchase and installation)	42	pc	$ 10,127	$ 425,351
Bollards (purchase and installation)	42	pc	$ 5,051	$ 212,140
Stairs (steel purchase)	6.3	ton	$ 2,451	$ 15,439
Stairs installation	21	pc	$ 154	$ 3,226
Front rail purchase	1000	m	$ 512	$ 511,875
Front rail installation	1000	m	$ 18	$ 17,739
Total				$ 4,854,414

Rear crane rail (2 tracks)				
Concrete rail foundation	8713	m3	$ 185	$ 1,611,813
Rear crane rail purchase	2050	m	$ 512	$ 1,049,344
Rear rail installation	2050	m	$ 18	$ 36,365
Total				$ 2,697,521

Foundation conveyor belts				
Concrete footing foundation	856	m3	$ 185	$ 158,360
Total				$ 158,360

Soilworks and pavement				
Soilworks	160000	m2	$ 2	$ 320,000
Rear rail installation	2000	m	$ 18	$ 35,478
Total				$ 2,697,521

Utilities	Lump sum			$ 500,000
Site offices, workshops, etc.	Lump sum			$ 150,000
Engineering cost by contractor	Lump sum			$ 100,000
Third party inspections	Lump sum			$ 100,000
Management fees and overhead	0.05			$ 1,549,801

Total cost	**$ 32,745,831**

Insurance and finance cost and profit/risk		
CAR insurance	1.0%	$ 309,960
Financial cost for contractor	1.5%	$ 464,940
Profit and risk	6.0%	$ 1,859,762
Overall total for 1000 m		**$ 35,380,494**

table A 8.2 Construction cost 1000 m quay wall.

The price assumptions from table A 8.2 lead to a quay wall price per 1,000 m of $ 35,280,494 and a price per m quay wall of $ 35,280

A 8.2.5 Pricing assumptions coastal protection works

The technical design of coastal protection is discussed in Annex 5 "principle design coastal protection works". This annex gives a principle design for five main parts of the coastal protection of the port project. These parts are:

- Revetment section exposed
- Revetment section sheltered
- Breakwater section
- Breakwater round head.
- Coastal protection inside the harbour basin

The proposed coastal protection is carried out as rubble mound with large rock armour layer on a slope of 1:2. Since Fujairah is an important producer of rock in the region, it seems obvious that rock is used as armour on the coastal protection. The proposed revetments have a concrete crown wall to reduce overtopping discharges.
In 0 unit price assumptions are used to estimate costs per m coastal protection works for the different parts. Additional to these costs are general overhead and preliminaries and cost for survey and inspection works.
A constant water depth representative for the specific part of the coastal protection is assumed.

Revetment exposed	**Price per m^3**	**Quantity per m**	**Price per m**	**Price per m incl.**
Armour rock	$34	86	$2,924	$3,845
Under layer	$19	68	$1,292	$1,699
Core Material	$16	796	$12,736	$16,748
Concrete crown wall	$850	7	$5,950	$7,824
Total				**$30,116**

Revetment sheltered				
Armour rock	$34	69	$2,346	$3,085
Under layer	$19	58	$1,102	$1,449
Core Material	$16	688	$11,008	$14,476
Crown wall	$850	7	$5,950	$7,824
Total				**$26,834**

Breakwater				
Armour rock	$34	122	$4,148	$5,455
Under layer	$19	114	$2,166	$2,848
Core Material	$16	1391	$22,256	$29,267
Total				**$37,570**

Breakwater roundhead

Armour rock	$34	21000	$714,000	$938,910
Under layer	$19	18000	$342,000	$449,730
Core Material	$16	65000	$1,040,000	$1,367,600
				$2,756,240

Protection inside harbour basin				
Armour rock 300 - 1000 kg	$19	28	$532	$700
Core Material	$16	682	$10,912	$14,349
				$15,049

General overhead and preliminaries	30%
Survey and inspection works	1.50%

table A 8.3 Cost estimations coastal protection works

A 8.2.6 Pricing assumptions liquid bulk terminal

The technical design of the open sea tanker terminal is discussed in Annex 7 “design liquid bulk terminal” to this report. The onshore part of the OSTT consists of a manifold and a pipe rack between the manifold and the jetty. The jetty is build op from steel trestle bridges founded on concrete footings on steel piles. Standard trestle bridges are used for all offshore parts of the OSTT.
In table A 8.4 pricing assumptions are given that are used for cost estimation of the various layouts of the liquid bulk terminal.

Piles per 100	**quantity**	**unit**	**price per unit**	**cost**
Purchase of tubes	100	pc	$24,563	$2,456,286
Cathodic protection (purchase and installation)	200	pc	$250	$50,000
Transport of tubes	100	pc	$6,256	$625,568
Local transports				$300,000
Installation of tubes	100	pc	$11,991	$1,199,143
Additional time, startup, unworkable weather, cool down.	6	wks	$162,550	$975,303
Mobilisation and demobilsation				$292,800
Lump sum items pile installation				$400,000
Total				$18,147,011
Price per pile				$181,470

Berth for two 175,000 DWT vessels				
Piles	124	pc	$181,470	$22,502,294
Concrete platform	1625	m3	$450	$731,250
Miscellaneous steelworks for OSTT STB 1 and 2	560	ton	$2,723	$1,524,880
Offshore handling of STB materials (steel and concrete)	52	wks	$55,000	$2,860,000
Miscellaneous steelworks (grating, anchorbolts, ertalon, etc.)				$210,000
Mobilisation and demobilsation of equipment				$160,000
Electrical	Lump sum			$675,000

Electrical	Lump sum			$675,000
Storage containers on	2	pc	$30,000	$60,000
Gang ways for	Lump sum			$630,000
Quick release hooks	Lump sum			$441,000
Loading arms for (8 x 16")	Lump sum			$2,016,000
Fenders	Lump sum			$630,000
Slob tank + gutter on main platform	2	pc	$10,000	$20,000
Total				$33,135,424

Piperack per m				
Steelworks for onshore piperack	0.5	ton	$2,451	$1,225
Concrete sleepers for onshore piperack	0.7	m3	$500	$350
Total				$1,575

Trestle bridges per m				
Piles	0.05333	pc	$181,470	$9,678
Steelworks for trestle bridge (49 bridges, length: 37,5 m each)	1.2	ton	$2,723	$3,268
Gratings for Trestle bridges	6.5	m2	$50	$325
Onshore handling of trestle bridges (Kamags)	0.05	wks	$5,000	$250
Offshore handling of trestle bridges (sheer legs)	0.015	wks	$15,000	$225
Electrical supply on the trestle	Lump sum			$950
total per m				$14,696

Piping				
Purchase and installation 16" piping per m				$175

Trestle abutment				
Trestle abutment				$150,000

Miscellaneous items for Open Sea Tanker Terminal				
Sea water fire pump platform + pump	Lump sum			$1,500,000
Fire fighing facilities	Lump sum			$300,000
12" fire fighting line from SWFP platform	Lump sum			$300,000
Concrete foundation slab for trestle bridge construction	Lump sum			$500,000
Special lifting device	Lump sum			$500,000
Site offices, workshops, etc.	Lump sum			$150,000
Total				$3,250,000

Management fees and overhead	5%
CAR insurance	1%
Financial cost for contractor	2%
Profit and risk	6%

table A 8.4 Pricing assumptions liquid bulk terminal

The design of the chemical berths is not discussed in detail in this document. The berths consist of a concrete platform connected to the shore by a concrete bridge. An overall impression is given in Annex 7 to this report. The berths will be equipped with four 10” loading arms.
A price of $ 16 M is assumed for these berths. Including overhead this is $ 18.3 M. Since all layouts have two chemical berths, operating under comparable conditions, these costs are of minor importance.

A 8.2.7 Relation to Dirham

Costs are given in American Dollars. Since November 1997, the dirham has been pegged to the U.S. dollar (1 US dollar is 3.6725 dirhams, which translates to approximately 1 dirham = 0.272294 dollar).

A 8.3 Cost estimation

Cost estimations of the proposed layouts combinations are based on pricing assumptions described in the previous paragraph and quantity calculations. In this paragraph, quantities and costs of the different layouts are summarized per construction phase.

The following layouts are considered:

1) A1 – B1 Harbour layout 1 and liquid bulk terminal layout 1
2) A2 – B2
3) A2 – B1
4) A3 – B1
5) A4 – B3
6) A4 – B4
7) A5 – B1
8) A5 – B3
9) A5 – B4

First quantities for each layout and phase are determined, subsequently construction are determined.

The area south of the existing port was planned to be leased out for other developments. The proposed lease price per m^2 for this area would be 25 Dhs/m^2 year which is $ 6.08. The specific area that is used for the container terminal is 164. This means that the yearly loss of income due to the unavailability of this area would be $ 10 M.

A 8.3.1 Quantities

Dredging		**A1-B1**	**A2-B2**	**A2-B1**	**A3-B1**	**A4-B3**	**A4-B4**	**A5-B1**	**A5-B3**	**A5-B4**
Dredging	m3	4,922,732	8,990,487	8,990,487	19,243,054	21,403,968	21,403,968	21,403,968	21,403,968	21,403,968
Quarry run fill	m3	7,867,199	0	0	0	0	0	0	0	0
Reclamation red.	m3	0	5,149,785	5,149,785	12,673,843	15,050,848	15,050,848	16,097,866	16,097,866	16,097,866
Quay wall										
Quay wall	m	1935	1750	1750	2750	2750	2750	2750	2750	2750
Coastal protection										
Revetment exposed	m	330	430	430	430	631	631	631	631	631
Rvtm. sheltered	m	0	0	0	0	830	0	0	0	0
Breakwater	m	0	0	0	3775	3775	3775	3775	3775	3775
Brkw. roundhead	-	1	1	1	2	2	2	2	2	2
Harbour basin	m	0	0	0	0	1,700	1,300	0	0	0
OSTT										
Berths	-	2	2	2	2	2	2	2	2	2
Trestle bridges	m	350	0	270	270	400	200	270	1150	620
Trestle abutment	-	1	0	1	1	2	2	1	1	1
Piperack	m	1460	950	960	960	1550	1400	960	650	750
Piping	m	11680	4640	9840	9840	12195	10744	9840	12195	10744

table A 8.5 Quantities proposed layouts phase 1

Dredging		**A1-B1**	**A2-B2**	**A2-B1**	**A3-B1**	**A4-B3**	**A4-B4**	**A5-B1**	**A5-B3**	**A5-B4**
Dredging	m3	0	0	0	0	0	0	0	0	0
Quarry run fill	m3	12,606,141	6,719,426	2,057,104	0	2,394,212	2,394,212	671,262	671,262	671,262
Reclamation red.	m3	0	0	0	0	0	0	0	0	0
Quay wall										
Quay wall	m	1150	1020	400	1295	1295	1295	1295	1295	1295
Coastal protection										
Revetment exposed	m	670	445	0	0	750	750	750	750	750
Rvtm. sheltered	m	1520	940	760	0	0	830	0	0	0
Breakwater	m	750	750	750	750	0	0	0	0	0
Brkw. roundhead	-	2	1	1	1	1	1	1	1	1
Harbour basin	m	0	0	0	0	0	732	500	500	500
OSTT										
Berths	-	2	1	2	2	2	2	2	2	2
Trestle bridges	m	250	0	250	250	120	260	250	760	970
Trestle abutment	-	1	0	1	1	1	2	1	0	0
Piperack	m	275	0	500	500	380	350	500	0	0
Piping	m	16280	0	14640	14640	12200	12316	14640	13984	12316
Chemical berths	-	1	1	1	1	1	1	1	1	1

table A 8.6 Quantities proposed layouts phase 2

Dredging		**A1-B1**	**A2-B2**	**A2-B1**	**A3-B1**	**A4-B3**	**A4-B4**	**A5-B1**	**A5-B3**	**A5-B4**
Dredging	m3	0	0	0	0	0	0	0	0	0
Quarry run fill	m3	1,730,911	0	4,662,322	0	0	0	0	0	0
Reclamation red.	m3	0	0	0	0	0	0	0	0	0
Quay wall										
Quay wall	m	525	0	620	0	0	0	0	0	0
Coastal protection										
Revetment exposed	m	525	0	440	0	160	160	0	0	0
Rvtm. sheltered	m	0	0	840	0	380	380	0	0	0
Breakwater	m	0	0	0	0	0	0	0	0	0
Brkw. roundhead	-	0	0	1	0	0	0	0	0	0
Harbour basin	m	0	0	0	0	380	380	0	0	0
OSTT										
Berths	-	1	0	1	1	1	1	1	1	1
Trestle bridges	m	250	0	250	250	290	130	250	0	480
Trestle abutment	-	1	0	1	1	1	1	1	0	0
Piperack	m	500	0	500	500	495	352	500	0	0
Piping	m	23080	0	21440	21440	8210	1890	21440	8140	7500
Chemical berths	-	2	2	2	2	2	2	2	2	2

table A 8.7 Quantities proposed layouts phase 3

A 8.3.2 Cost estimation

Dredging	**A1-B1**	**A2-B2**	**A2-B1**	**A3-B1**	**A4-B3**	**A4-B4**	**A5-B1**	**A5-B3**	**A5-B4**
Dredging	$27,075,026	$49,447,679	$49,447,679	$105,836,797	$117,721,824	$117,721,824	$117,721,824	$117,721,824	$117,721,824
Quarry run fill	$70,804,791	$0	$0	$0	$0	$0	$0	$0	$0
Reclamation red.	$0	-$20,599,142	-$20,599,142	-$50,695,372	-$60,203,393	-$60,203,393	-$64,391,464	-$64,391,464	-$64,391,464
Total	$97,879,817	$28,848,537	$28,848,537	$55,141,425	$57,518,431	$57,518,431	$53,330,360	$53,330,360	$53,330,360
Quay wall									
Quay wall	$69,273,000	$62,650,000	$62,650,000	$98,450,000	$98,450,000	$98,450,000	$98,450,000	$98,450,000	$98,450,000
Coastal protection									
Revetment exposed	$9,938,323	$12,949,936	$12,949,936	$12,949,936	$19,003,278	$19,003,278	$19,003,278	$19,003,278	$19,003,278
Rvtm. sheltered	$0	$0	$0	$0	$22,272,129	$0	$0	$0	$0
Breakwater	$0	$0	$0	$141,825,051	$141,825,051	$141,825,051	$141,825,051	$141,825,051	$141,825,051
Brkw. roundhead	$2,756,240	$2,756,240	$2,756,240	$5,512,480	$5,512,480	$5,512,480	$5,512,480	$5,512,480	$5,512,480
Harbour basin	$0	$0	$0	$0	$25,583,062	$19,563,518	$0	$0	$0
Total	$12,694,563	$15,706,176	$15,706,176	$160,287,467	$188,612,938	$166,340,809	$166,340,809	$166,340,809	$166,340,809
OSTT									
Berths	1	0	1	1	1	1	1	1	1
Trestle bridges	250	0	250	250	290	130	250	0	480
Trestle abutment	1	0	1	1	1	1	1	0	0
Piperack									
Piping									
Lump sum									
Overhead	500	0	500	500	495	352	500	0	0
Total	23080	0	21440	21440	8210	1890	21440	8140	7500
TOTAL	**$229,132,528**	**$114,066,449**	**$153,895,981**	**$360,570,161**	**$395,133,978**	**$368,969,448**	**$364,812,438**	**$379,404,284**	**$370,454,499**

table A 8.8 Cost estimation phase 1

Dredging	**A1-B1**	**A2-B2**	**A2-B1**	**A3-B1**	**A4-B3**	**A4-B4**	**A5-B1**	**A5-B3**	**A5-B4**
Dredging	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quarry run fill	$113,455,269	$60,474,834	$18,513,938	$0	$21,547,908	$21,547,908	$6,041,354	$6,041,354	$6,041,354
Reclamation red.	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total	$113,455,269	$60,474,834	$18,513,938	$0	$21,547,908	$21,547,908	$6,041,354	$6,041,354	$6,041,354
Quay wall									
Quay wall	$41,170,000	$36,516,000	$14,320,000	$46,361,000	$46,361,000	$46,361,000	$46,361,000	$46,361,000	$46,361,000
Coastal protection									
Revetment exposed	$20,177,807	$13,401,678	$0	$0	$22,587,098	$22,587,098	$22,587,098	$22,587,098	$22,587,098
Rvtm. sheltered	$40,787,513	$25,223,857	$20,393,756	$0	$0	$22,272,129	$0	$0	$0
Breakwater	$28,177,163	$28,177,163	$28,177,163	$28,177,163	$0	$0	$0	$0	$0
Brkw. roundhead	$5,512,480	$2,756,240	$2,756,240	$2,756,240	$2,756,240	$2,756,240	$2,756,240	$2,756,240	$2,756,240
Harbour basin	$0	$0	$0	$0	$0	$11,015,766	$7,524,430	$7,524,430	$7,524,430
Total	$94,654,962	$69,558,937	$51,327,159	$30,933,403	$25,343,338	$47,615,466	$25,343,338	$25,343,338	$25,343,338
OSTT									
Berths	$33,135,424	$1,950,000	$33,135,424	$33,135,424	$33,135,424	$33,135,424	$33,135,424	$33,135,424	$33,135,424
Trestle bridges	$3,674,002	$0	$3,674,002	$3,674,002	$1,763,521	$3,820,962	$3,674,002	$11,168,965	$14,255,126
Trestle abutment	$150,000	$0	$150,000	$150,000	$150,000	$300,000	$150,000	$0	$0
Piperack	$433,221	$0	$787,675	$787,675	$598,633	$551,373	$787,675	$0	$0
Piping	$2,849,000	$0	$2,562,000	$2,562,000	$2,135,000	$2,155,300	$2,562,000	$2,447,200	$2,155,300
Lump sum	$975,000	$975,000	$975,000	$975,000	$975,000	$975,000	$975,000	$975,000	$975,000
Overhead	$5,564,247	$394,875	$5,573,354	$5,573,354	$5,232,273	$5,526,638	$5,573,354	$6,443,089	$6,820,315
Total	$46,780,894	$3,319,875	$46,857,454	$46,857,454	$43,989,851	$46,464,696	$46,857,454	$54,169,678	$57,341,165
Chemical berths	$18,250,000	$18,250,000	$18,250,000	$18,250,000	$18,250,000	$18,250,000	$18,250,000	$18,250,000	$18,250,000
TOTAL	**$314,311,126**	**$188,119,646**	**$149,268,551**	**$142,401,857**	**$155,492,096**	**$180,239,070**	**$142,853,145**	**$150,165,369**	**$153,336,856**

table A 8.9 Cost estimation phase 2

Dredging	**A1-B1**	**A2-B2**	**A2-B1**	**A3-B1**	**A4-B3**	**A4-B4**	**A5-B1**	**A5-B3**	**A5-B4**
Dredging	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quarry run fill	$15,578,199	$0	$41,960,896	$0	$0	$0	$0	$0	$0
Reclamation red.	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total	$15,578,199	$0	$41,960,896	$0	$0	$0	$0	$0	$0
Quay wall									
Quay wall	$18,795,000	$0	$22,196,000	$0	$0	$0	$0	$0	$0
Coastal protection									
Revetment exposed	$15,810,968	$0	$13,251,097	$0	$4,818,581	$4,818,581	$0	$0	$0
Rvtm. sheltered	$0	$0	$22,540,468	$0	$10,196,878	$10,196,878	$0	$0	$0
Breakwater	$0	$0	$0	$0	$0	$0	$0	$0	$0
Brkw. roundhead	$0	$0	$2,756,240	$0	$0	$0	$0	$0	$0
Harbour basin	$0	$0	$0	$0	$5,718,567	$5,718,567	$0	$0	$0
Total	$15,810,968	$0	$38,547,805	$0	$15,015,459	$15,015,459	$0	$0	$0
OSTT									
Berths	$33,135,424	$0	$33,135,424	$33,135,424	$33,135,424	$33,135,424	$33,135,424	$33,135,424	$33,135,424
Trestle bridges	$3,674,002	$0	$3,674,002	$3,674,002	$4,261,842	$1,910,481	$3,674,002	$0	$7,054,083
Trestle abutment	$150,000	$0	$150,000	$150,000	$150,000	$150,000	$150,000	$0	$0
Piperack	$787,675	$0	$787,675	$787,675	$779,798	$554,523	$787,675	$0	$0
Piping	$4,039,000	$0	$3,752,000	$3,752,000	$1,436,750	$330,750	$3,752,000	$1,424,500	$1,312,500
Lump sum	$650,000	$0	$650,000	$650,000	$650,000	$650,000	$650,000	$650,000	$650,000
Overhead	$5,941,054	$0	$5,900,874	$5,900,874	$5,657,934	$5,142,365	$5,900,874	$4,929,389	$5,901,281
Total	$48,377,155	$0	$48,049,975	$48,049,975	$46,071,748	$41,873,543	$48,049,975	$40,139,313	$48,053,288
Chemical berths	$36,500,000	$36,500,000	$36,500,000	$36,500,000	$36,500,000	$36,500,000	$36,500,000	$36,500,000	$36,500,000
TOTAL	**$135,061,322**	**$36,500,000**	**$187,254,675**	**$84,549,975**	**$97,587,207**	**$93,389,002**	**$84,549,975**	**$76,639,313**	**$84,553,288**

table A 8.10 Cost estimation phase 3

A 8.3.3 Summary cost estimation

Dredging	A1-B1	A2-B2	A2-B1	A3-B1	A4-B3	A4-B4	A5-B1	A5-B3	A5-B4
Phase 1	$229,132,528	$114,066,449	$153,895,981	$360,570,161	$395,133,978	$368,969,448	$364,812,438	$379,404,284	$370,454,499
Phase 2	$314,311,126	$188,119,646	$149,268,551	$142,401,857	$155,492,096	$180,239,070	$142,853,145	$150,165,369	$153,336,856
Phase 3	$135,061,322	$36,500,000	$187,254,675	$84,549,975	$97,587,207	$93,389,002	$84,549,975	$76,639,313	$84,553,288
TOTAL	**$678,504,975**	**$338,686,095**	**$490,419,208**	**$587,521,993**	**$648,213,282**	**$642,597,520**	**$592,215,558**	**$606,208,966**	**$608,344,642**

table A 8.11 Summary cost estimation per phase

Dredging	**A1-B1**	**A2-B2**	**A2-B1**	**A3-B1**	**A4-B3**	**A4-B4**	**A5-B1**	**A5-B3**	**A5-B4**
Dredging	$27,075,026	$49,447,679	$49,447,679	$105,836,797	$117,721,824	$117,721,824	$117,721,824	$117,721,824	$117,721,824
Quarry run fill	$199,838,259	$60,474,834	$60,474,834	$0	$21,547,908	$21,547,908	$6,041,354	$6,041,354	$6,041,354
Reclamation red.	$0	-$20,599,142	-$20,599,142	-$50,695,372	-$60,203,393	-$60,203,393	-$64,391,464	-$64,391,464	-$64,391,464
Total	$226,913,285	$89,323,371	$89,323,371	$55,141,425	$79,066,339	$79,066,339	$59,371,713	$59,371,713	$59,371,713
Quay wall									
Quay wall	$129,238,000	$99,166,000	$99,166,000	$144,811,000	$144,811,000	$144,811,000	$144,811,000	$144,811,000	$144,811,000
Coastal protection									
Revetment exposed	$45,927,098	$26,351,614	$26,201,033	$12,949,936	$46,408,956	$46,408,956	$41,590,376	$41,590,376	$41,590,376
Rvtm. sheltered	$40,787,513	$25,223,857	$42,934,224	$0	$32,469,007	$32,469,007	$0	$0	$0
Breakwater	$28,177,163	$28,177,163	$28,177,163	$170,002,214	$141,825,051	$141,825,051	$141,825,051	$141,825,051	$141,825,051
Brkw. roundhead	$8,268,720	$5,512,480	$8,268,720	$8,268,720	$8,268,720	$8,268,720	$8,268,720	$8,268,720	$8,268,720
Harbour basin	$123,160,494	$85,265,113	$105,581,140	$191,220,870	$228,971,734	$228,971,734	$191,684,147	$191,684,147	$191,684,147
Total	$45,927,098	$26,351,614	$26,201,033	$12,949,936	$46,408,956	$46,408,956	$41,590,376	$41,590,376	$41,590,376
OSTT									
Berths	$99,406,272	$5,037,000	$99,406,272	$99,406,272	$99,406,272	$99,406,272	$99,406,272	$99,406,272	$99,406,272
Trestle bridges	$12,491,605	$0	$11,315,925	$11,315,925	$11,903,765	$8,670,644	$11,315,925	$28,069,372	$30,420,733
Trestle abutment	$450,000	$0	$450,000	$450,000	$600,000	$750,000	$450,000	$150,000	$150,000
Piperack	$3,520,907	$1,496,583	$3,087,686	$3,087,686	$3,820,224	$3,311,386	$3,087,686	$1,023,978	$1,181,513
Piping	$8,932,000	$812,000	$8,036,000	$8,036,000	$5,705,875	$4,366,250	$8,036,000	$6,005,825	$5,348,000
Lump sum	$2,275,000	$1,625,000	$2,275,000	$2,275,000	$2,275,000	$2,275,000	$2,275,000	$2,275,000	$2,275,000
Overhead	$17,367,411	$1,211,029	$17,027,815	$17,027,815	$16,903,072	$16,218,895	$17,027,815	$18,661,660	$18,946,265
Total	**$144,443,196**	**$10,181,611**	**$141,598,698**	**$141,598,698**	**$140,614,208**	**$134,998,447**	**$141,598,698**	**$155,592,106**	**$157,727,782**
TOTAL	**$678,504,975**	**$338,686,095**	**$490,419,208**	**$587,521,993**	**$648,213,282**	**$642,597,520**	**$592,215,558**	**$606,208,966**	**$608,344,642**

table A 8.12 Cost estimation total project

A 8.4 Capacity of the proposed layouts

The capacity of the proposed layouts is determined by using the simulation models that are described in annex 3 to the masterplan report. The first objective of this simulation study was to determine the required quay length and number of berths for the composed scenarios. The second objective is to test the capacity of the proposed layout alternatives. The results of the last study are given in the following tables.

For layouts A1 – B1, there are two options proposed. In the first option, the full quay length of the dry bulk terminal is utilized for loading of aggregates. In this way it is possible to reach the throughput as required for scenario 1. In the second option, this layout has two berths for import of dry bulk.

	Phase 1																			
	A1B1 - A		A1B1 - B		A2B2		A2B1		A3B1		A4B3		A4B4		A5B1		A5B3		A5B4	
	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms
Aggregates	1050	3	725	2	325	1	1050	3	910	3	910	3	910	3	910	3	910	3	910	3
Other dry bulk	0	0	325	1	0	0	0	0	280	1	280	1	280	1	280	1	280	1	280	1
Oil	2	8	2	8	725	8	725	8	2	8	2	8	2	8	2	8	2	8	2	8
Containers	880	12	880	12	700	9	700	9	1450	19	1450	19	1450	19	1450	19	1450	19	1450	19
Chemicals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

table A 8.13 Available quay length, phase 1

It can be seen that the quay lengths and number of berths do not differ for layouts A3, A4 and A5. These layouts supply for the highest growth scenario.

	Phase 2																			
	A1B1 - A		A1B1 - B		A2B2		A2B1		A3B1		A4B3		A4B4		A5B1		A5B3		A5B4	
	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms
Aggregates	1050	3	725	2	700	2	1050	3	1395	5	1395	5	1395	5	1395	5	1395	5	1395	5
Other dry bulk	0	0	325	1	0	0	0	0	525	2	525	2	525	2	525	2	525	2	525	2
Oil	4		4	0	1055	3	4	0	5		5		5		5		5		5	
Containers	2030	30	2030	30	1022	15	700	15	2110	40	2110	40	2110	40	2110	40	2110	40	2110	40
Chemicals	1	0	1	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0

table A 8.14 Available quay length, phase 2

	Phase 1																			
	A1B1 - A		A1B1 - B		A2B2		A2B1		A3B1		A4B3		A4B4		A5B1		A5B3		A5B4	
	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms	Quay length / berths	No of cranes / loading arms
Aggregates	1575	5	1050	3	1050	3	1050	3	1435	5	1435	5	1435	5	1435	5	1435	5	1435	5
Other dry bulk	0	0	525	2	0	0	525	2	525	2	525	2	525	2	525	2	525	2	525	2
Oil	6	0	6	0	2	0	6	0	6	0	6	0	6	0	6	0	6	0	6	0
Containers	2030	30	2030	30	1022	15	1022	15	2110	40	2110	40	2110	40	2110	40	2110	40	2110	40
Chemicals	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0

table A 8.15 Available quay length, phase 3

The capacity of the proposed layouts is determined by using the simulation models that are described in annex 3 to the masterplan report. The first objective of this simulation study was to determine the required quay length and number of berths for the composed scenarios. The second objective is to test the capacity of the proposed layout alternatives. The results of the last study are given in the following tables.

	Phase 1										
	A1B1 - A	A1B1 - B	A2B2	A2B1	A3B1	A4B3	A4B4	A5B1	A5B3	A5B4	
Aggregates	50	30	15	50	50	50	50	50	50	50	[M ton/yr]
Other dry bulk	0	4	0	0	4	4	4	4	4	4	[M ton/yr]
Oil	30	30	30	30	30	30	30	30	30	30	[M ton/yr]
Containers	0.75	0.75	0.5	0.5	1.5	1.5	1.5	1.5	1.5	1.5	[M TEU/yr]
Chemicals	-	-	-	-	-	-	-	-	-	-	[M ton/yr]

table A 8.16 Maximum throughput phase 1

	Phase 2										
	A1B1 – A	A1B1 - B	A2B2	A2B1	A3B1	A4B3	A4B4	A5B1	A5B3	A5B4	
Aggregates	50	30	30	50	90	90	90	90	90	90	[M ton/yr]
Other dry bulk	0	4	0	0	8	8	8	8	8	8	[M ton/yr]
Oil	62	62	46	62	78	78	78	78	78	78	[M ton/yr]
Containers	2.5	2.5	1	0.5	3.5	3.5	3.5	3.5	3.5	3.5	[M TEU/yr]
Chemicals	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	[M ton/yr]

table A 8.17 Maximum throughput phase 2

	Phase 3										
	A1B1 – A	A1B1 - B	A2B2	A2B1	A3B1	A4B3	A4B4	A5B1	A5B3	A5B4	
Aggregates	100	50	50	50	100	100	100	100	100	100	[M ton/yr]
Other dry bulk	0	8	0	8	8	8	8	8	8	8	[M ton/yr]
Oil	100	100	30	100	100	100	100	100	100	100	[M ton/yr]
Containers	2.5	2.5	1	1	3.5	3.5	3.5	3.5	3.5	3.5	[M TEU/yr]
Chemicals	1	1	1	1	1	1	1	1	1	1	[M ton/yr]

table A 8.18 Maximum throughput phase 3

A 8.4.2 Net present value calculation

Discount rate: 7%

	A3 - B1 [$M]	**A4 - B3 [$M]**	**A4 - B4 [$M]**	**A5 - B1 [$M]**	**A5 - B3 [$M]**	**A5 - B4 [$M]**
2007	-$360.6	-$395.1	-$369.0	-$364.8	-$379.4	-$370.5
2008	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2009	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2010	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2011	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2012	-$142.4	-$155.5	-$180.2	-$142.9	-$150.2	-$153.3
2013	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2014	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2015	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2016	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2017	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2018	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2021	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2022	-$84.5	-$97.6	-$93.4	-$84.5	-$76.6	-$84.6
2023	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2024	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2025	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2026	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2027	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2028	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2029	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2030	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2031	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2032	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
NPV	-$460.5	-$506.0	-$496.6	-$464.8	-$480.6	-$477.0

table A 8.19 NPV Scenario 1

Discount rate: 7%

	A1 – B1 [$M]	**A3 – B1 [$M]**
2007	-$229.1	-$370.6
2008	$0.0	-$10.0
2009	$0.0	-$10.0
2010	$0.0	-$10.0
2011	$0.0	-$10.0
2012	-$314.3	-$10.0
2013	$0.0	-$10.0
2014	$0.0	-$10.0
2015	$0.0	-$10.0
2016	$0.0	-$10.0
2017	$0.0	-$10.0
2018	$0.0	-$10.0
2019	$0.0	-$10.0
2020	$0.0	-$10.0
2021	$0.0	-$10.0
2022	-$86.7	-$152.4
2023	$0.0	-$10.0
2024	$0.0	-$10.0
2025	$0.0	-$10.0
2026	$0.0	-$10.0
2027	$0.0	-$10.0
2028	$0.0	-$10.0
2029	$0.0	-$10.0
2030	$0.0	-$10.0
2031	$0.0	-$10.0
2032	$0.0	-$10.0
NPV	-$452.9	-$503.5

table A 8.20 NPV Scenario 2

Discount rate: 7%

	A1 - B1 [$M]	A2 - B2 [$M]	A2 - B1 [$M]	A3 - B1 [$M]
2007	-$257.3	-$114.1	-$153.9	-$360.6
2008	$0.0	-$188.1	$0.0	-$10.0
2009	$0.0	$0.0	$0.0	-$10.0
2010	$0.0	$0.0	$0.0	-$10.0
2011	$0.0	$0.0	$0.0	-$10.0
2012	-$46.8	$0.0	-$149.3	-$46.9
2013	$0.0	$0.0	$0.0	-$10.0
2014	$0.0	$0.0	$0.0	-$10.0
2015	$0.0	$0.0	$0.0	-$10.0
2016	$0.0	$0.0	$0.0	-$10.0
2017	$0.0	$0.0	$0.0	-$10.0
2018	$0.0	$0.0	$0.0	-$10.0
2019	$0.0	$0.0	$0.0	-$10.0
2020	$0.0	$0.0	$0.0	-$10.0
2021	$0.0	$0.0	$0.0	-$10.0
2022	$0.0	$0.0	-$187.3	-$10.0
2023	$0.0	$0.0	$0.0	-$10.0
2024	$0.0	$0.0	$0.0	-$10.0
2025	$0.0	$0.0	$0.0	-$10.0
2026	$0.0	$0.0	$0.0	-$10.0
2027	$0.0	$0.0	$0.0	-$10.0
2028	$0.0	$0.0	$0.0	-$10.0
2029	$0.0	$0.0	$0.0	-$10.0
2030	$0.0	$0.0	$0.0	-$10.0
2031	$0.0	$0.0	$0.0	-$10.0
2032	$0.0	$0.0	$0.0	-$10.0
NPV	-$271.6	-$270.9	-$306.7	-$470.5

table A 8.21 NPV Scenario 3