Masterplan of Jebel Ali Port

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Preface

This is the final report of the Master of Science thesis titled "Masterplan of Jebel Ali Port". This thesis is part of my master program at the faculty of Civil Engineering and Geosciences, Delft University of Technology.

This study has been performed in the office and under the supervision of Maritime Rotterdam, Royal Haskoning.

This thesis work has been assessed and supported by the graduation committee, which consist of the following members:

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By this means I would like to thank all the graduation committee for guidance and advices. And I also want to all colleagues of Royal Haskoning who gave their support during my thesis work.

Zhuoyi Wang

AM Rotterdam, June 2008

Summary

Jebel Ali Port situated at 35 kilometers southwest of the city of Dubai, in the United Arab Emirates (UAE). It experienced a rapid development in its history, and already becomes an essential part to Dubai Emirate and to the UAE. Now Jebel Ali Port is the world's largest man-made harbor and the biggest port in the Middle East. It is also the largest container port between Rotterdam & Singapore.

Dubai Ports (Jebel Ali Port together with Port Rashid) is operated by DP World, which is the flagship facility of DP world with averaged annual growth over 20% for the past four years. Because of the rapid cargo volumes growth in Dubai Ports and desired closure of nearby Port Rashid for new developments, Jebel Ali Port will not have sufficient capacity for handling containers and other cargos in the future. Thus an expansion plan is necessary to meet the handling capacity requirement and maintain the high level of service in Jebel Ali Port.

The objective of this study is the development of a masterplan for the new Jebel Ali Port by 2030, including landform alternatives, evaluation of the most promising alternative, cost estimation, computer model simulation and quay wall design.

Because of the land scarcity along the coastline, the new Jebel Ali Port will be constructed as a set of reclaimed offshore islands to the north of, and connected, to the existing port. An entire floating terminal is unfavorable for this project, which is not comparable to a land reclamation project. The main reason is a floating terminal must locate at least 26 km offshore, which leads to relatively high cost and difficulties with transportation.

Based on the spatial constraints and the requirements according to the cargo and port facilities analysis, three landform alternatives have been proposed. A monetary evaluation as well as a multi criteria analysis finally resulted in the selection the most promising alternative. The most promising landform alternative provides an attractive and competitive port, with acceptable waiting time, ample storage area and good accessibility.

An own developed computer simulation tool “free-quay model” is used for analysis the behavior of container quay operation and determination of the required quay length together with number of cranes.

Different types of quay wall are considered for this project. Concrete block wall and caisson wall are further designed, taking into account the earthquake condition. The most favorable type of quay wall cost as well as construction time wise is a concrete block wall.

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1. Introduction

1.1. General information about the UAE and Dubai

The United Arab Emirates (UAE) is a Middle Eastern federation of seven states situated in the southeast of the Arabian Peninsula in Southwest Asia on the Arabian Gulf, bordering Oman and Saudi Arabia. The seven states, termed Emirates, are Abu Dhabi, Ajman, Dubai, Fujairah, Ras al-Khaimah, Sharjah, and Umm al-Quwain.

The UAE has an area of approximately 83,600 km², with the population of 4.59 million in 2006. The capital of the UAE is Abu Dhabi and Dubai is the largest city in the country.

Figure 1.1 Location of the UAE

Figure 1.2 Map of the UAE

Dubai can either refer to one of the seven Emirates that constitute the United Arab Emirates, or that emirate's main city, sometimes called "Dubai city" to distinguish it from the Emirate. The Emirate of Dubai shares borders with Abu Dhabi in the south, Sharjah in the northeast, and the Sultanate of Oman in the southeast. Dubai Emirate is positioned at 25.2697° N 55.3095° E and covers an area of 4,114 km² (1,588 mi²).

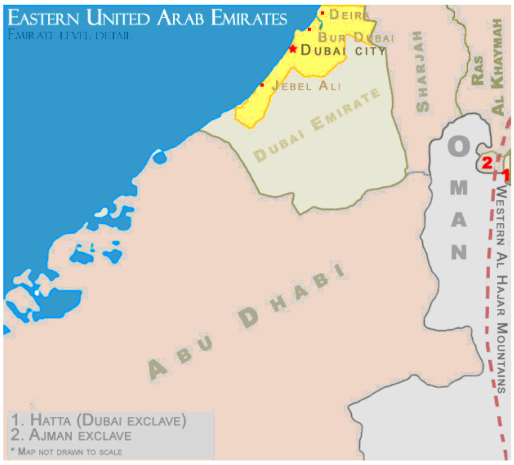


Figure 1.3 Location of Dubai Emirate

The modern Emirate of Dubai was created with the formation of the United Arab Emirates in 1971. However, written accounts documenting the existence of the city go back at least 150 years prior to the formation of the UAE. Dubai shares legal, political, military and economic functions with the other Emirates within a federal framework, although each Emirate has jurisdiction over some functions such as civic law enforcement and provision and upkeep of local facilities.

Dubai has the largest population (1.4 million in 2006) and is the second largest Emirate by area, after Abu Dhabi. Dubai has been ruled by the Al Maktoum dynasty since 1833. The Emirates' current ruler, Mohammed bin Rashid Al Maktoum, is also the Prime Minister and Vice President of the UAE.

2. Dubai ports

2.1. History of Dubai Ports

Dubai Ports (Jebel Ali Port and Port Rashid), is the busiest port in the Middle East. Dubai ports experienced a rapid development in its history, and it already becomes an essential part to Dubai Emirate and to the UAE.

Figure 2.1 Jebel Ali Port

Figure 2.2 Port Rashid

Port Rashid was completed in 1972. The port's location near to the city center, its all-new infrastructure and Dubai's thriving business community made it an instant success. By 1978 the number of berths was increased to 35, including five berths large and deep enough to handle the largest container vessels at that time.

In 1976, the late ruler of Dubai, Sheikh Rashid, gave instructions for an even more ambitious project: the construction of the world's largest man-made harbor at Jebel Ali, and it was completed in 1979.

Jebel Ali (also written as "Jabal Ali") is a port town, located thirty-five kilometers southwest of the city of Dubai. The port began to be constructed in the late 1970's along with Jebel Ali Village, which was used, initially, for the construction workers of the port.

1977 **1978** **1983** **2005**

Figure 2.3 Development of Jebel Ali Port

Jebel Ali Port is the world's largest man-made harbor and the biggest port in the Middle East. It is also the largest container port between Rotterdam & Singapore and was awarded the title of 'Best Seaport- Middle East' for the 13th consecutive year at the Asian Freight and Supply Chain Awards (AFSCA) 2007.

Jebel Ali Port and Jebel Ali Free Zone (JAFZA) merged with Port Rashid in May 1991 to form Dubai Ports Authority (DPA). Because of the strong marketing power and good port facilities, it led to a dramatic increase in throughput to exceed one million TEUs. In 2007, Dubai ports ranked as 7th top container terminal in the world with yearly throughput of 10.65 million TEU.

2.2. DP World

Dubai Ports is operated by DP World, which is the flagship facility of DP world with averaged annual growth over 20% for the past four years.

DP World was formed in September 2005 with the integration of Dubai Ports Authority (DPA), which was focused on the UAE ports of Port Rashid and Jebel Ali Port, and DPI (Dubai Ports International) which had been set up to export the success internationally.

Nowadays, DP World is part of a larger group that includes P&F World, Nakheel, Istithmar and the holding company Dubai World. It is one of the largest marine terminal operators in the world with 43 terminals and 13 new developments across 28 countries. The total throughout of 2007 is approximately 43.3 million TEU.

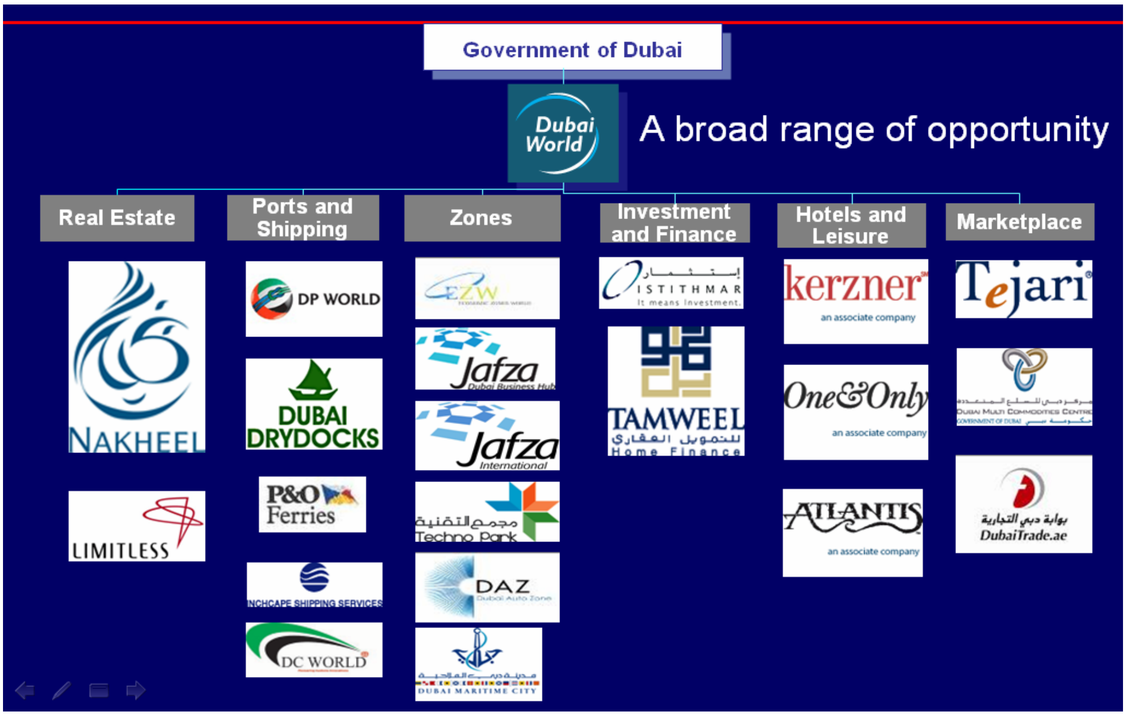


Figure 2.4 Group structure of Dubai World

2.3. Dubai Ports

Jebel Ali Port is situated 35 km SW of the city of Dubai. The position of the Port Control Tower is 24˚59'04"N and 55˚02'09"E.

Port Rashid is situated in the city of Dubai. The position of the Port Control Tower is 25˚15'33"N and 55˚16'09"E. The distance between Jebel Ali Port and Port Rashid is about 38 km.

Figure 2.5 Dubai Ports

2.3.1. Jebel Ali Port

The buoyed Jebel Ali approach channel starts 24 km (13 nautical miles) offshore. It has a depth of 17 m and width of 320 m. Vessels should meet or wait for the pilot in the area north of the seaward end of the channel.

The 14-16m outer basin is 2.3 km long and 600 m wide. The inner basin is 3.7 km long and 425 m wide, with different depths of 11.5 m, 16 m and 17 m. The main axis of both basins is 047º - 227º. All channel and basin bottoms are sandstone. As the holding ground is poor, vessels are recommended to use more chain than usual.

There are 71 berths (16 container vessels berths) in the existing Jebel Ali Port, which can provide services for container vessels, tankers, LPG, bulk cargos and Ro/Ro vessels. The container terminal in inner harbor area is termed as Terminal 1 to be distinguished from other new container terminals.

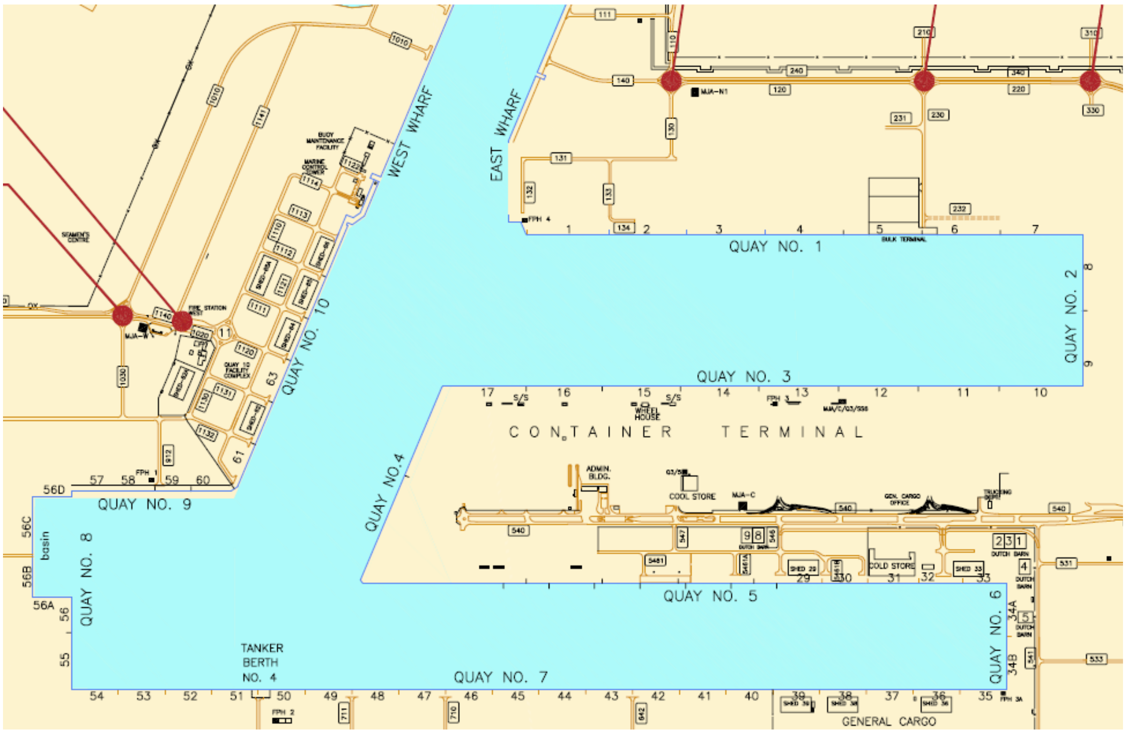


Figure 2.6 Berths in Jebel Ali Port

2.3.2. Port Rashid

Dubai approach buoy is 6 miles from Port Rashid entrance at 25˚21'N and 55˚14'E. Port Rashid has no approach channel and entry should be made between the breakwaters from the north-west. The entrance has a width of 190 m and minimum depth of 13 m.

The inner basin turning radius is 160 m, with a minimum depth of 11.5m. Vessels of up to 230 m overall length are allowed entry. The holding ground is also poor and it is recommended that vessels use more chains than usual. There are 35 berths (5 container vessels berths) in Port Rashid, which is mainly for container vessels and tankers.

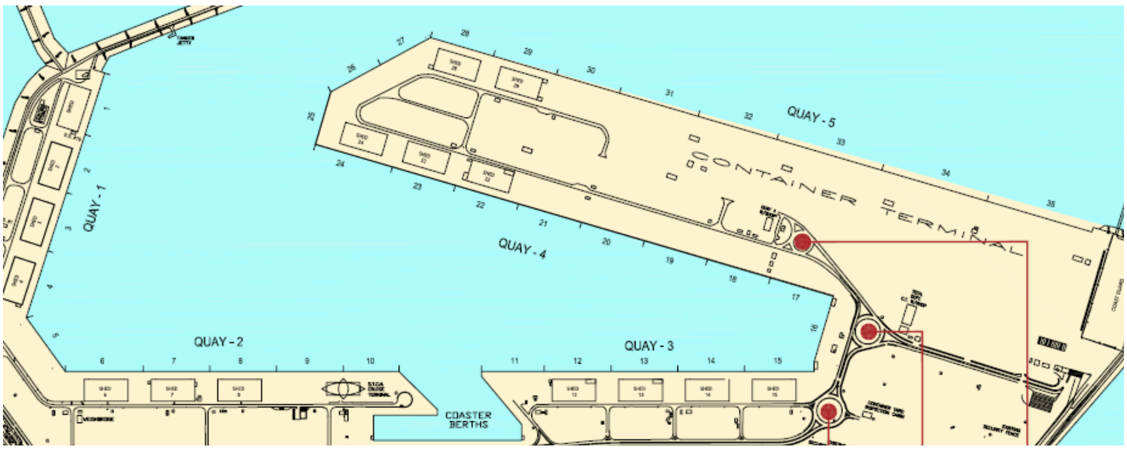


Figure 2.7 Berths in Port Rashid

2.3.3. New development in Jebel Ali Port

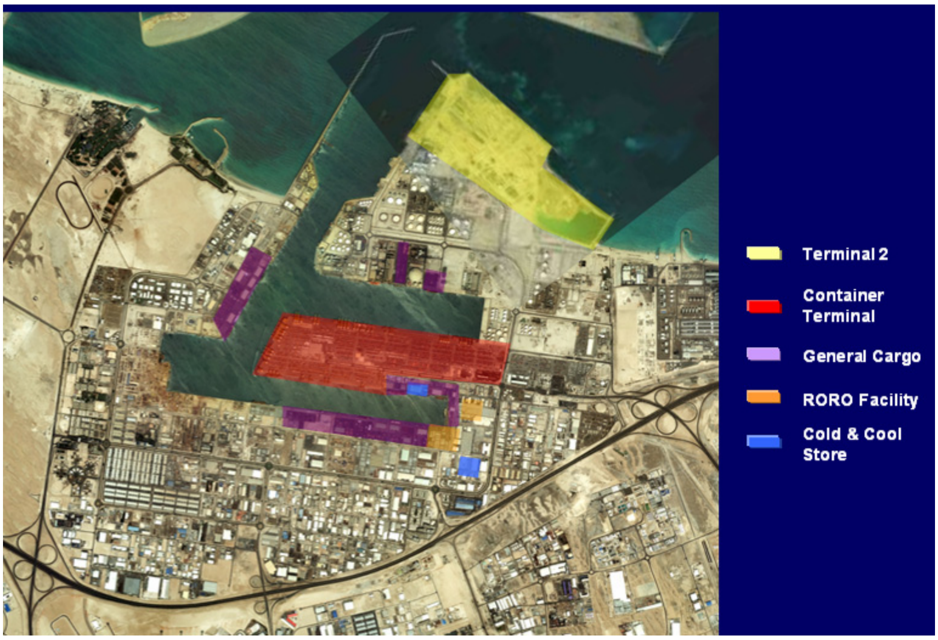


Figure 2.8 New Jebel Ali Port

To provide additional capacity for container vessels, a new outer container terminal (Terminal 2) is currently under construction. With total investment of US$1.5 billion (Dh5.5 bn), Terminal 2 will be able to handle additional 5 million TEUs per year.

Phase 1 consists of 1.2 km quay, 4 berths, 17 m depth alongside, 2.5 million TEUs capacity, which started operation in August, 2007; Phase 2 consists of additional 1.3 km quay, 3 berths, 17 m depth alongside, 3.0 million TEUs capacity, which is expected to be completed in mid 2008.

	PHASE 1	***PHASE 2 (including phase1)***
Quay Length (m)	1200	2500
Gantry Cranes	8	29
RMG's	18	46
Terminal Tractors	84	209
Trailers	94	244
ECH	7	15
Total Terminal Area (ha)	180	250

Table 2.1 Description of Terminal 2

Figure 2.9 Aerial View of Terminal 2 Phase 1
(Source: www.choppershot.com)

3. Scope of the study

3.1 Problem assessment

The rapid growth of Dubai Ports and development of Dubai city require a long term expansion plan of Jebel Ali Port.

On one hand, the outstanding growth of Dubai Ports container and general cargo volumes over the last 3 years (an average growth of 23%) and a continuous fast growth predicted in the future will lead to insufficient capacity of the existing port.

Type of Vessels	Jebel Ali Port	Port Rashid	Jebel Ali T2
Container Vessels (MTEUs)	7.5	1.5	2.5 (5.5)
Break Bulk (MMT)	11.0	4.0	-
Ro/Ro Vessels (kVeh)	132	508	-

Table 3.1 Capacities of container, break bulk and Ro/Ro vessels (2007)

On the other hand, because of the development of Dubai city, local authorities are considering closing Port Rashid for years and all cargoes are planned to move to Jebel Ali Port. Because of insufficient capacity of Jebel Ali Port, Port Rashid is still operating busily and new development of that area is delayed for years. However, local authorities want to close Port Rashid after 2008.

Container	2008	2013*	2018	2023	2030
Predicted Throughput	11.7	19.2	28.9	40.0	56.2
Present Capacity	13.0+1.5	13.0	13.0	13.0	13.0

Table 3.2 Predicted Throughput V.S. Present Capacity
*(Million TEUs, *Assume Port Rashid will be closed after 2008)*

It is concluded that the throughput will exceed present capacity around 2010, thus further expansion is necessary to meet the requirement and maintain the high level of service at Jebel Ali Port. However, even a short term expansion will take about 3 years, so it should be realized that existing port may not have enough capacity for the next a few years.

3.2 Problem definition

Because of the rapid growth of Dubai Ports and desired closure of Port Rashid, Jebel Ali Port will not have sufficient capacity for containers and other vessels in the future. Thus further expansion of Jebel Ali Port is necessary.

DP World wants a new masterplan of Jebel Ali Port by 2030, which should provide enough capacity (Container, Ro/Ro, Bulk, etc.) and should allow for future development. Considering the nearby Palm Islands Project and Waterfront Project, the environmental impacts are an important issue in this project.

Figure 3.1 Big projects along Dubai coast

Because of lack of available land along the coastline, except for the initial stage (Terminal 2) that is constructed primarily on the existing landfill, the others will probably be constructed as a set of offshore islands to the north of, and connected to, the existing Jebel Ali Port.

3.3 Objectives of study

The objective of the study is the development of a masterplan for Jebel Ali Port until 2030, which meets the future throughput figures in the various conditions.

This masterplan should take into account the existing port facilities, hinterland connection, industrial area and environmental constraints. Detailed objectives include:

- Collect economical, environmental, nautical information
- Analysis of port layout
- Study feasibility for floating container terminals
- Propose layout alternatives
- Select the most promising layout alternative
- Develop free-quay simulation tool
- Design hydraulic structures

4. Data collection

4.1. Landside area

Landside areas along Dubai coastline are already densely developed. Several industry companies located northeast of Jebel Ali Port, which also have ambitious expansion plans, including:

- Emirate National Oil Co. Jebel Ali Refinery (ENOC Jebel Ali Refinery)
- Dubai Electricity and Water Authority (DEWA)
- Dubai Natural Gas Co. Ltd. (DUGAS)
- Dubai Aluminum Co (DUBAL)

Figure 4.1 Landside NE of Jebel Ali Port

Obviously, these companies prohibit the future expansion of Jebel Ali Port to the northeast on existing land. It is also difficult for further reclamation along the northeast coastline. Mainly, there are two reasons:

Firstly, there are four very long pipe lines coming from DUGAS to offshore area. The cost of relocating these pipelines is quite high.

Secondly, there are several intakes/outfalls for DUBAL and DEWA along the coastal line, which are also quite difficult and expensive to be relocated.

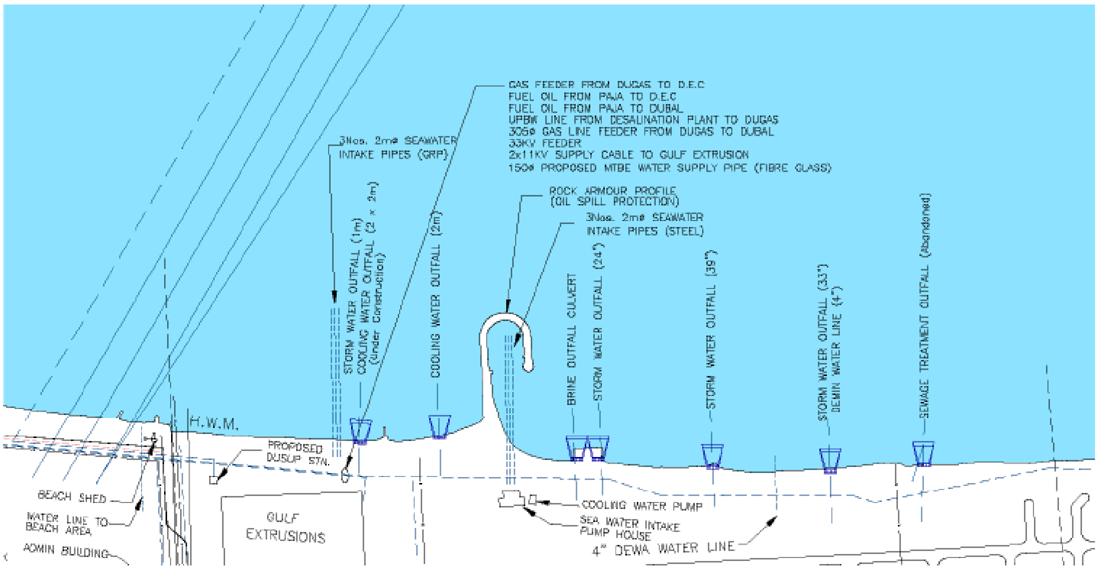


Figure 4.2 DUBAL intakes/outfalls

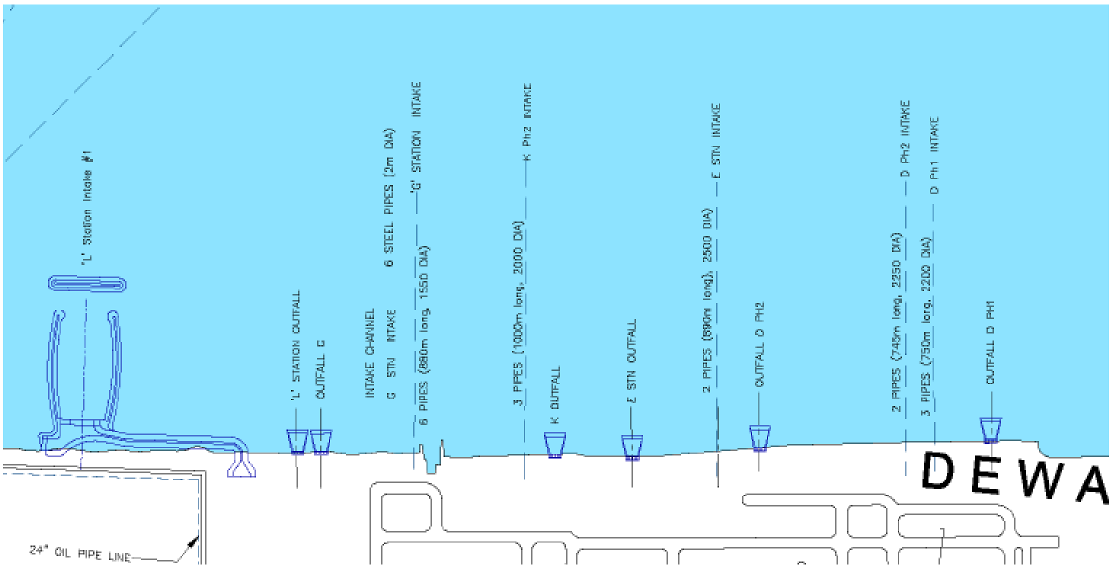


Figure 4.3 DEWA intakes/outfalls

In the area southwest to Jebel Ali Port, projects of Palm Jebel Ali and Waterfront are under construction, leaving no space for future development of new Jebel Ali Port.

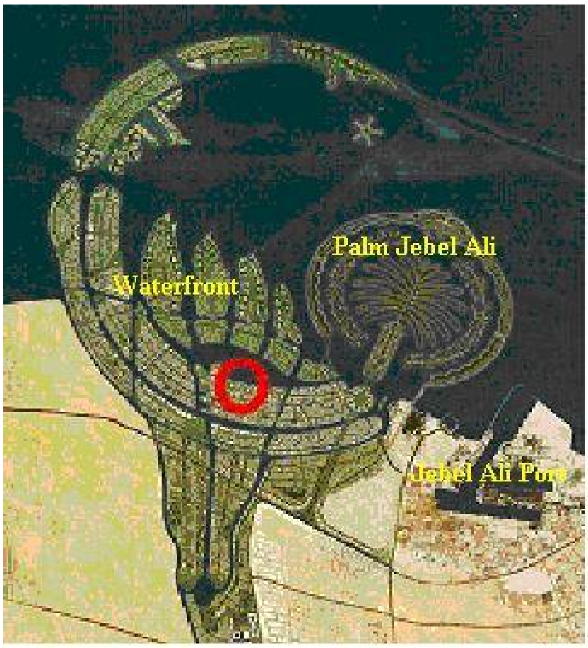


Figure 4.4 Landside SW of Jebel Ali Port

4.2. Capacity information

4.2.1. General information

The Dubai Ports experienced a rapid growth in 2007, and rose up to the 7th top container terminal (8th in 2006 and 9th in 2005) in the world with total throughput of 10.65 million TEUs.

Types	Throughput/Calls	Growth Rate
Container throughput (M TEUs)	8.92	+17%
Container vessel calls	7226	+4%
Ro/Ro (KVeh)	394	+7%
Ro/Ro vessel calls	742	+10%
Bulk cargo (M MT)	9.60	+44%
Break bulk (M MT)	8.56	+13%
General cargo vessel calls	1504	+9%

Table 4.1 Dubai Terminal Traffic-2006
(Source: DP World Presentation 17th May. 2007)

It is noticed that the Dubai Ports' throughput in 2006 almost reached the capacity. Even with the completion of Jebel Ali Terminal 2, it may still have the insufficient capacity problem for the near future.

Type of Vessels	Jebel Ali T1	Port Rashid	Jebel Ali T2
Container (MTEUs)	7.5	1.5	2.5 (5.5)
Break Bulk (MMT)	11.0	4.0	-
Ro/Ro (KVeh)	132	508	-

Table 4.2 Capacities for container, break bulk and Ro/Ro vessels

4.2.2. Storage area

The Dubai Ports offers ample storage areas in both Jebel Ali Port and Port Rashid. It covers container yard, general cargo storage and specialized storage. Specialized storage is available for sensitive commodities such as synthetic resins, heat-sensitive laminates, glass and paper in various stages of refinement.

Container Yard Area	
Jebel Ali Port	Port Rashid
1,006,050 m^2	615,000 m^2

Table 4.3 Container Yard Area

General Cargo Storage Area			
Jebel Ali Port		Port Rashid	
7 Dutch Barns	18,900m^2	13 Warehouses	96,655m^2
12 Fully Covered Sheds	90,535m^2	-	-
Total covered storage	109,435m^2	Total covered storage	96,655m^2
Open Storage	959,604m^2	Open Storage	307,810m^2

Table 4.4 General Cargo Storage

Container Freight Station (CFS) facilities, together with advanced cargo handling equipments, provide an efficient service to LCL (Less than container load) consolidators.

CFS Area			
Jebel Ali Port		Port Rashid	
Covered storage	17,400m^2	Covered storage	22,295m^2
Open storage	201,000m^2	Open storage	48,600m^2
Total storage	218,400m^2	Total storage	70,895m^2

Table 4.5 CFS Area

The Conditioned Storage can accommodate chilled perishables such as dairy products and chocolates, or semi-perishables including pharmaceuticals and tobacco. Inventory and delivery procedures are fully computerized.

Area (sq.m)	Temperature Range	Pallet Capacity (Approx.)
2,695	+5º C / +22º C	1,400

Table 4.6 Conditioned Storage at Jebel Ali Port

4.3. Environmental data

In this section, 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 the North.

4.3.1. Bathymetry

An important source for bathymetric data is Admiralty Chart ("Admiralty Chart #3789, Jebel Ali and Approaches," Admiralty 1998 *MINA JABAL ALI and APPROACHES*). It is noticed that depth information in nearshore area can be changed significantly because of reclamations of Palm Islands and the World.

For this reason, bathymetry information provided by WL | Delft Hydraulics (*WL stands for Waterloopkundig Laboratorium*) and HPA (*Han-Padron Associates*) is also taken into account.

The bathymetry output by HPA [Ref.1] is presented in following figures:

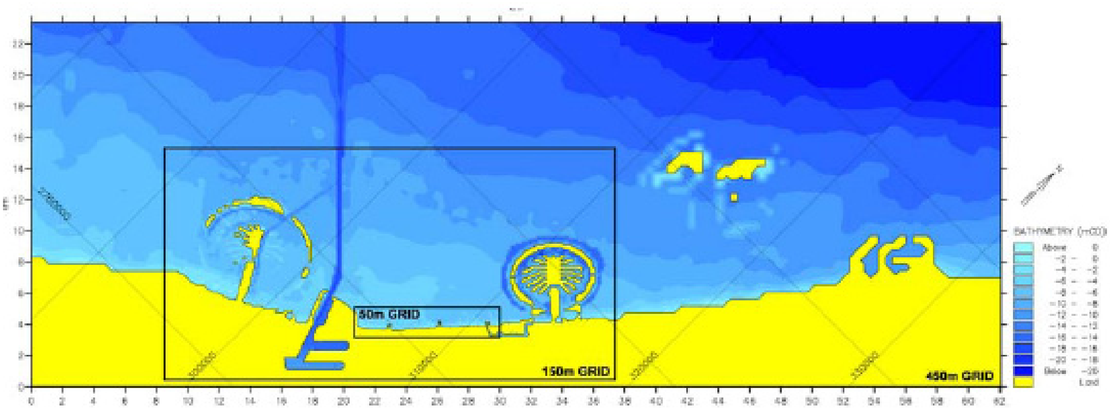


Figure 4.5 Bathymetry of 2004

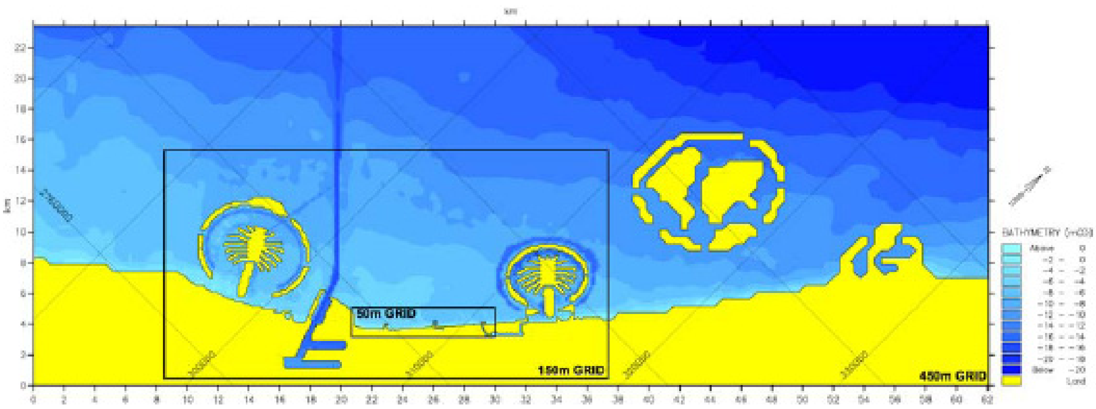


Figure 4.6 Future bathymetry
(with completion of Palm Islands and the World)

4.3.2. Oceanographic data

4.3.2.1. Tide and water level

Water level conditions in the Dubai area are dominated by tidal fluctuations, which propagate from the Strait of Hormuz and produce complex interaction within the largely enclosed Gulf geometry, with following characteristics:

- The tide is mixed semi-diurnal with a strong diurnal component;
- There are only small variations of the tidal range between Port Rashid and Jebel Ali Port. The levels of HAT and LAT at Port Rashid are about 0.1 to 0.15 m less than that at Jebel Ali Port;
- The tide propagates from the Northeast to the Southwest;
- There is a phase difference of about 15-30 minutes between Port Rashid and Jebel Ali Port;
- There is a seasonal tidal effect (because of seasonal variations in atmospheric pressure) which results in a 20 cm higher mean level in the summer (July to August) than in the winter.

<u>Tidal levels</u>
Characteristic tidal levels for the Dubai coast were determined by WL | Delft Hydraulics in the study for Palm Jumeirah [Ref.5] and are summarized in the following table, which is coincident with HPA's study [Ref.1].

Item	Tidal Levels	Design Value, (m, ACD)
1	Highest Astronomical Tide (HAT)	+2.20
2	Mean Higher High Water (MHHW)	+1.60
3	Mean Lower High Water (MLHW)	+1.30
4	Mean Sea Level (MSL)	+1.00
5	Mean Higher Low Water (MHLW)	+0.80
6	Mean Lower Low Water (MLLW)	+0.40
7	Lowest Astronomical Tide (LAT)	-0.20
8	Admiralty Chart Datum (ACD)	±0.00
9	Dubai Municipality Datum (DMD)	-0.097

Table 4.7 Characteristic Tidal Levels at Dubai Coast

It is noticed that two vertical datum levels are used in Dubai: Admiralty Chart Datum (ACD) and Dubai Municipality Datum (DMD). The relationship between two datum were established by Nortech in 2005 based on a leveling survey.

<u>Water levels</u>

Due to strong onshore winds, low short-term atmospheric pressures and wave setup, water levels can be expected to rise above the normal tidal water levels. Extreme surge heights and total water levels (joint probability of tidal water levels and surge heights) were predicted by WL | Delft Hydraulics for Palm Jebel Ali project. However, it gives lower values (about half meter lower) than water levels estimated by HPA. Because little is known about approaches of HPA and the updated data used by WL | Delft Hydraulics, the extreme water levels established by WL | Delft Hydraulics will be applied to later design.

Three selected locations were chosen for output of surge height and water level. JA01 located at the top of crescent breakwater of Palm Jebel Ali; JA02 and JA03 located at the southwest and northeast tip of crescent breakwater, respectively [Ref.5].

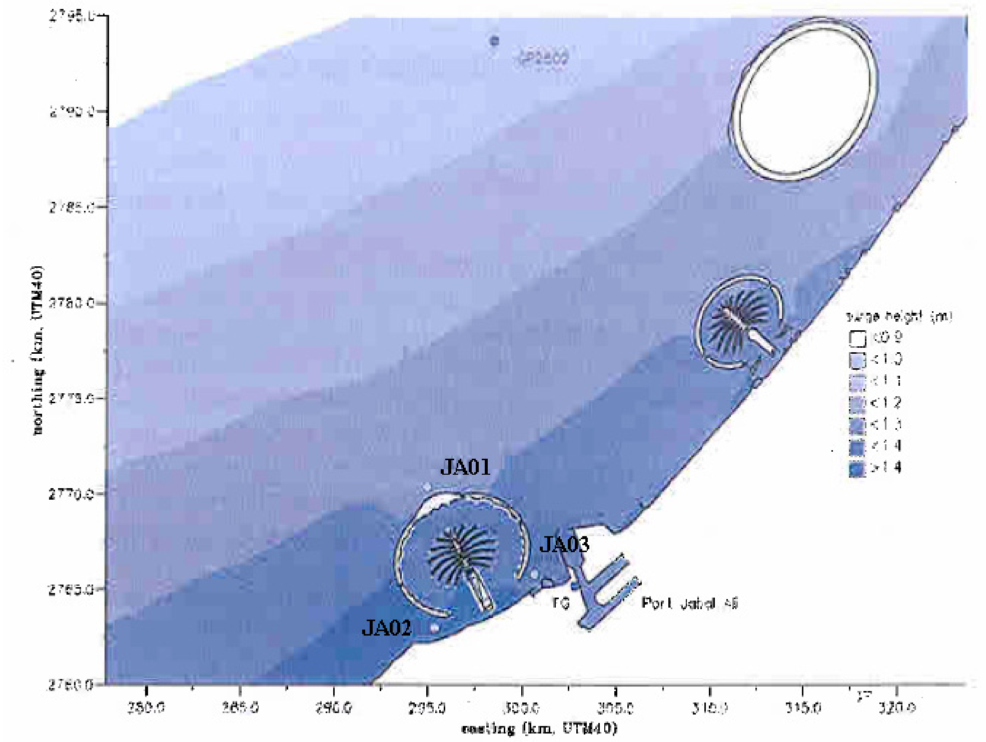


Figure 4.7 Surge heights for different locations [Ref.5]

Return Period (years)	Surge (m)			Water Level (m, ACD)		
	JA01	JA02	JA03	JA01	JA02	JA03
1	0.35	0.35	0.35	2.20	2.20	2.20
5	0.50	0.60	0.55	2.30	2.30	2.30
10	0.60	0.70	0.65	2.35	2.35	2.35
25	0.75	0.85	0.80	2.45	2.50	2.45
50	0.85	1.00	0.90	2.50	2.60	2.45
100	0.95	1.10	1.05	2.60	2.75	2.70
250	1.10	1.25	1.20	2.75	2.90	2.85
1000	1.30	1.50	1.40	2.95	3.15	3.05

Table 4.8 Extreme surge heights and water level for various return periods at selected locations [Ref.5]

<u>Sea level rise</u>

The latest estimation of the sea level rise by the Intergovernmental Panel on Climate Change (IPCC) is approximately 25 cm over the next 50 years and it is not included in above water levels.

4.3.2.2. Wave climate

Sources of wave climate are *'Palm Jebel Ali, Updated wave and water level study' [WL | Delft Hydraulics, 2005]* and *'JANCT Master Plan Report' [Han-Padron Associates, 2005]*.

Offshore wave conditions

The resulting extreme wave conditions in deep water near Dubai (approx. 75 km offshore) of the Shamal direction are summarized in following table.

Return Period [year]	Wave Conditions		
	H_s [m]	T_p [s]	Direction [ºN]
1	4.0	9.1	300
5	4.6	9.6	300
10	4.9	9.8	300
25	5.2	10.0	300
50	5.4	10.2	300
100	5.8	10.4	300

Table 4.9 Extreme Offshore Wave Conditions for Shamal direction

Results for various wave direction and return periods, based on extrapolation by means of probability density functions, are summarized in following table.

Direction [ºN]	Return Period [year]		
	1	10	100
0	1.7	2.0	2.3
30	2.0	2.6	3.1
60	2.3	2.8	3.3
90	2.1	2.6	3.0
120	2.0	2.3	2.6
150	1.8	2.2	2.6
180	1.6	2.1	2.5
210	1.4	2.1	2.8
240	1.4	2.0	2.7
270	3.0	3.6	4.5
300	**4.0**	**4.9**	**5.8**
330	2.1	3.2	4.4

Table 4.10 Significant wave height in deep water near Dubai

Nearshore wave conditions

SWAN is used to predict nearshore wave conditions by WL | Delft Hydraulics. Detail information can be found in the report *'Palm Jebel Ali, Updated wave and water level study' [WL | Delft Hydraulics, 2005]*.

Wave rose
Long-term wave roses are drawn with data from different locations [Ref.2]. Inspection of these wave roses reveals the general wave climate conditions offshore of Jebel Ali. The wave roses from different locations indicate very similar conditions.

Waves occur most frequently from 285º to 300º. Similarly, the largest wave heights, near 4 m, occur from 285º to 300º. Waves propagating from other directions towards the study area are much smaller and less frequent.

The station OWI 2260, located in 16 m depth of water, is the nearest one to the Jebel Ali Port. The wave rose from OWI 2260 is shown below:

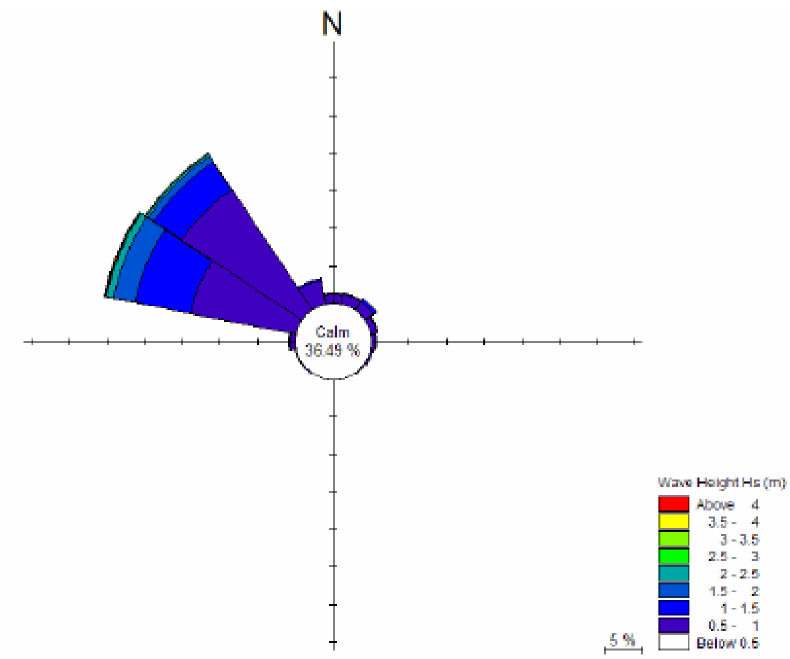


Figure 4.8 Wave Rose of OWI 2260

4.3.2.3. Wind conditions

Long-term wind roses are drawn with data from DM JOB station, DPA station and Fateh platform, respectively [Ref.1]. The general information of these observation sites is:

- The DPA Jebel Ali meteorological tower located at the top of the marine traffic control tower. The DPA tower has been reported by DPA to be located at 67 m above ground elevation.
- The DM Jumeirah (JOB) met station, which has been reported by DM to be located approximately 10 m above ground.
- The offshore Fateh Platform is located at about 90 km offshore from coastal line.

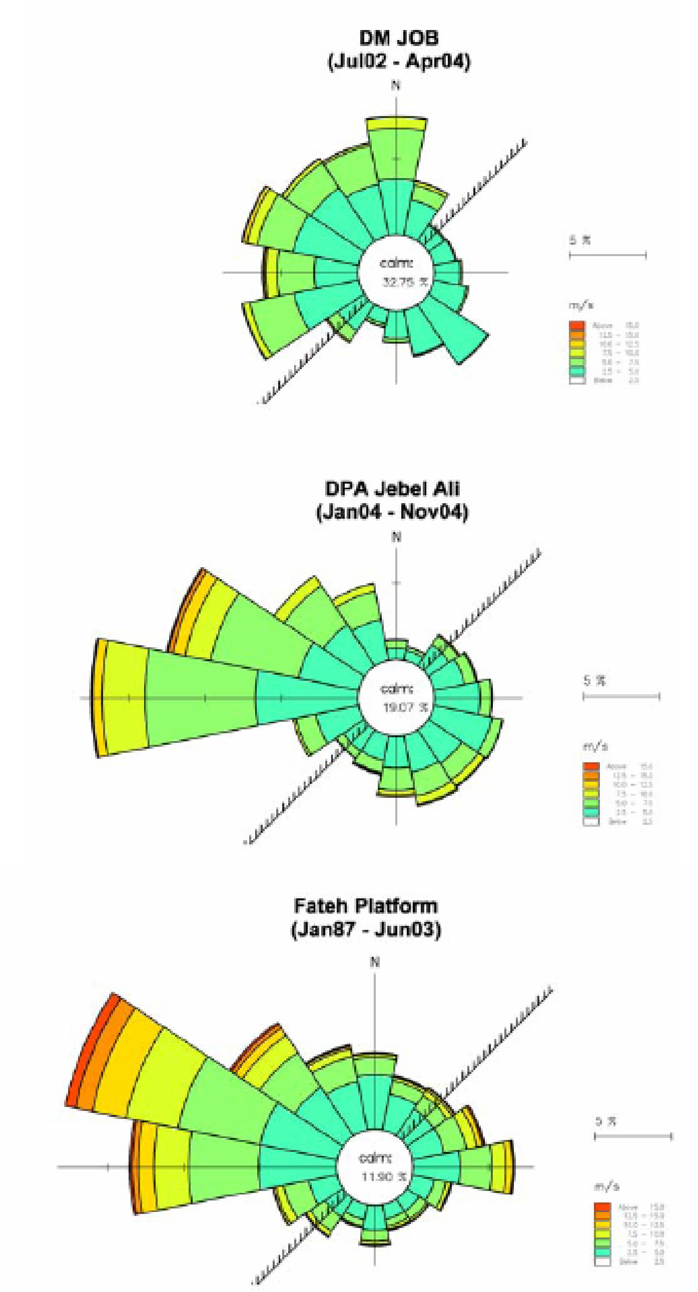


Figure 4.9 Wind roses

Several conclusions can be drawn from these observations:

- Wind climate is strongly affected by diurnal “sea breeze” effects due to the differential heating of the water relative to the desert located inland;
- The diurnal effect is strong enough that, with the exception of strong storms, the passage of regional weather systems tends to modify the diurnal signal rather than obscure it;

- The DM JOB station shows a much more diffuse signal in terms of wind direction;
- The DPA gauge shows more similarities with the offshore Fateh record in terms of winds approaching from a near-westerly direction.

In general, the wind climate can be characterized as relatively mild and dominated by the diurnal sea breeze signal. Winds occur most frequently from 255 to 300º. Wind speeds measured at the DPA station are on average approximately 25 percent higher than wind speeds measured at the other nearshore stations. This is a result of the higher elevation of the DPA anemometer.

4.3.2.4. Currents

Currents in the vicinity area of Jebel Ali Port are tidally dominated, with an underlying signal of reversing shore-parallel residual currents which are largely meteorologically forced. The currents are relatively weak (typically in the order of 0.1 - 0.2 m/s). During the field data gathering period [Ref.1], the residual current, which is believed to be a regional feature, flowed predominantly from east to west at an average speed in the order of 0.04 m/s in the offshore areas, although at times speeds in the order of 0.10 m/s were recorded.

4.3.2.5. Salinity and temperature

From records of DUBAL and DEWA intakes, the salinity is much less variable than the temperature, typically lying within the range from 39 to 42 PSU (Practical Salinity Units). This is also consistent with the range observed during the HPA campaign [Ref.2].

With the exception of the region in proximity to the intakes and outfalls, little or no stratification was observed. However, strong stratification was observed near intakes and outfalls. According to a field study conducted by HPA in 2004 [Ref.2], the highest water temperature recorded was approximately 39°C and was measured near the seabed in proximity to DEWA intakes. In general, the highest water temperatures were recorded near intakes and outfalls. The sea temperature offshore of Dubai ranges between 31° and 33°C, and varied little throughout the water column.

Away from the DUBAL and DEWA mixing zones, both salinity and temperature were well mixed in the vertical during the HPA field data gathering campaign. Furthermore, horizontal variations were also small if areas away from the influence of DUBAL and DEWA are considered.

4.3.2.6. Climate and visibility

Dubai has a sub-tropical, arid climate, with temperature ranging from a 14 °C to 39 °C. Rainfall is infrequent, irregular and falling is mainly in winter.

Month	Min (°C)	Max (°C)	Record High (°C)	Record Low (°C)	Average Number of Days of Rain
January	14	22	32	8	5
February	15	23	31	7	9
March	17	27	38	11	7
April	20	31	41	9	4
May	24	36	45	18	1
June	27	38	45	22	0
July	29	39	47	25	1
August	30	39	47.3	25	1
September	27	38	44	22	0
October	23	34	40	16	1
November	19	30	41	13	2
December	16	25	31	6	7

Table 4.11 Temperature and rain days in Dubai
(Source: Online Weather Portal. UAEInteract.com.)

Visibility at Dubai is generally good but during strong offshore winds, there can be problems with dusts (sometimes sand storms). Fogs can also be a problem in Dubai, and the visibility is less than 50 meters under fog conditions.

Fogs occur because the warm, moist winds from the Gulf comes inland and sometime remains there, and there is no dry breeze from the mountains to push it back out to sea. The moisture sits there in the atmosphere and is turned to fog because of colder temperatures at night. However, with modern navigation aids, berthing is still possible during fogs.

Figure 4.10 Dubai in fog

4.3.3. Geotechnical data

In 2005, Fugro Middle East was commissioned by Dubai Ports Authority to perform a geotechnical investigation in Jebel Ali Port area [Ref.3,4]. The geotechnical investigation includes two parts:

1) onshore geotechnical investigation areas located adjacent to the tanker berth area;
2) nearshore geotechnical investigation located along the north of existing east breakwater and extended to the east towards Dubai plant shoreline.

4.3.3.1. Geology of the region

The UAE occupies a corner of the Arabian Platform, a body of continental rock that has remained relatively stable since the Cambrian Period more than 500 million years ago.

Dubai is located in a relatively inactive seismic region. The region is categorized as UBC Zone 2A earthquake with a magnitude not exceeding 6.5 on the Richter scale.

Quote:

The geology of the UAE and the Arabian Gulf area has been substantially influenced by the deposition of marine sediments associated with numerous sea level changes during relatively recent geological time. With the exception of mountainous regions shared with Oman in the north-east, the country is relatively low-lying, with near-surface geology dominated by Quaternary to late Pleistocene age, mobile Aeolian dune sands, and sabkha/evaporate deposits.

The geologically stable Arabian Plate is separated from the unstable Iranian Fold Belt by the Arabian Gulf. It is believed that a tilting of the entire Arabian Plate occurred during the early Permian period, resulting in uplift in southern Yemen and depression to the north-east. Crustal deformations and igneous intrusions occurred in the north-east as a result of this movement. Subsequent tectonic movements, peripheral to the folding of the Iranian Zagros Range, during the Plio-Pleistocene epoch, probably contributed to the formation of both the Arabian Gulf depression, and the mountainous regions shared by the UAE and Oman in the north-east.

The near-surface geology of the Dubai region is dominated by Aeolian dune sand deposits of Holocene to Pleistocene age. These deposits typically comprise fine grained, silty, calcareous sand, which is commonly dense and variably cemented beneath a shallow, loose, normally consolidated mobile layer. Although variable, the degree of cementation generally increases with depth, such that the variably cemented sand grades to predominantly calcareous sandstone. In the near shore coastal zone the superficial deposits are generally relatively thin and typically consist of shelly, silty sands, which can contain random bands/ lenses of sandy silt and localized moderately strongly to strongly cemented layers, commonly referred to as caprocks.

4.3.3.2. Soil conditions

Along the north of existing east breakwater and extended to the east towards Dubai plant shoreline, a total of eighteen nearshore boreholes were completed to the predetermined termination elevation. The results of soil survey are presented in Fugro's report [Ref. 3,4]:

Quote:

The boreholes revealed a thin layer of slightly sandy silt/ silty sand extending to 0.5m to 3.5m below the existing seabed level for different locations.

Underlying this layer, slightly weathered, light grey, fine to medium grained, weak to very weak calcarenite was encountered extending to 1.0 to 6.9m below the existing seabed level. Below these layers, slightly to moderately weathered, light grey to light brown, thinly laminated, weak to very weak, calcareous sandstone was encountered to a depth varying from 5.5m to 11.3m below the existing seabed.

A layer of light brown to grayish blown, weak gypsum nodules in matrix of very silty sand varying in thickness from 1.2m to 2.0m at a depth varying form 5.4m to 9.5m below the seabed level was encountered in several boreholes.

Underlying these layers alternating layers of slightly to moderately weathered, grayish brown to greenish grey, weak to very weak conglomeratic siltstone and conglomerate and occasionally siltstone/calcisiltite was encountered to the termination depth of the boreholes.

5. Cargo and port facilities analysis

5.1. Competing ports

There are several competing ports in the UAE and in Arabian Sea area: Abu Dhabi, Khor Fakkan, Fujairah (Fujarah), Muscat, Salalah, Aden and Colombo.

5.1.1 Competing ports within the UAE

Main deepwater ports in other Emirates are Abu Dhabi, Khor Fakkan and Fujarah, which are potential alternative gateways for the UAE and other GCC countries.

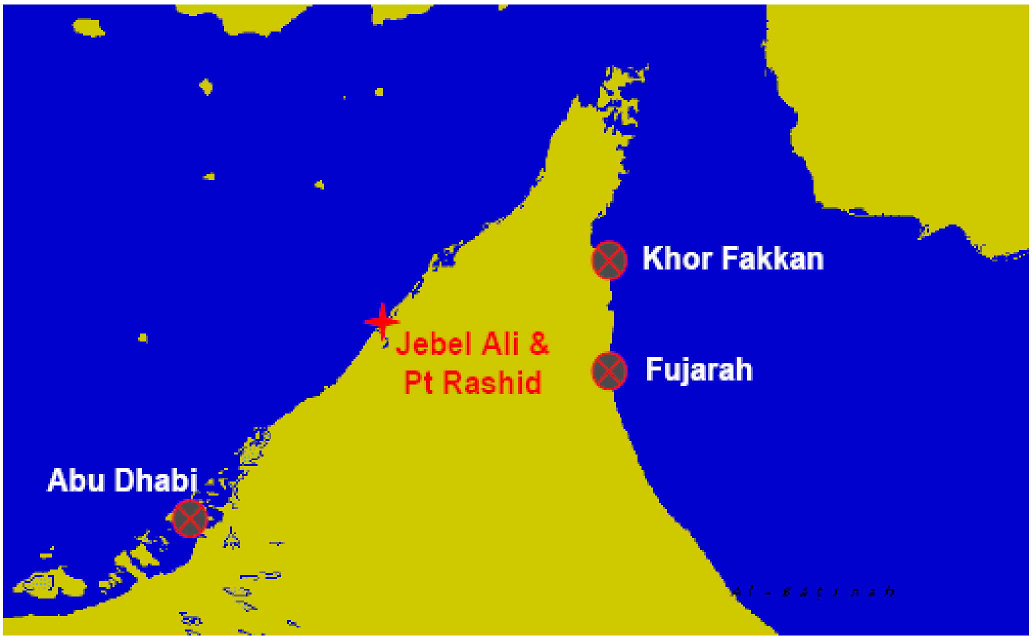


Figure 5.1 Competing ports in the UAE [Ref.1]

<u>Abu Dhabi Ports</u>
Abu Dhabi Ports comprises of three main ports, Mina Zayed, Musaffah and Freeport. Mina Zayed is the main terminal for container and general cargo vessels, while Musaffah and Freeport are catering for smaller vessels, tugs, barges and service crafts. Abu Dhabi Ports is managed by DP World.

Mina Zayed is located in the northeast part of Abu Dhabi. It covers an area of 510 hectares and contains 21 berths (4 container vessel berths) with depths ranging from 6 to 15 meters and a total berth length of 4,375 meters.

ADPC (Abu Dhabi Ports Company) is developing a new port at Khalifa, together with the development of Khalifa Port & Industrial Zone (KPIZ).

The future Khalifa Port is notably closer to Jebel Ali Port than the existing one of Mina Zayed. Taking its location and competing hinterland market into account, it could be an important competing port in the future. However, it is noticed that DP World will also manage Khalifa port through a joint venture with ADPC.

<u>Sharjah Ports</u>
Sharjah Ports comprises of twins ports Mina Khalid and Khor Fakkan, which locates in the Emirate Sharjah, at west coastline of Gulf of Oman and outside the Strait of Hormuz.

Khor Fakkan container terminal (KCT) is an important container terminal within the UAE and it is the only natural deepwater port in Middle East. It contains 4 container vessel berths with depth raging from 12.5m to 15m.

<u>Fujairah Port</u>
Fujairah Port is situated on the eastern coast of the UAE, approximately 70 nautical miles south from the Strait of Hormuz. Its strategic position has proved to be an attractive port for numbers of vessels.

In addition, Fujairah along with Singapore and Rotterdam ranks as one of the top three bunkering points in the world.

Several parties are involved in the operation of this port, and DP World is currently operating the container terminal of Fujairah Port.

5.1.2 Competing ports in Arabian Sea

There are five important ports in the area of Arabian Sea: Muscat, Sohar, Salalah, Aden and Colombo, besides Khor Fakkan and Fujarah. These ports are competing with Dubai Ports mainly for transshipment business.

Figure 5.2 Competing ports in Arabian Sea

Port Muscat (Port Sultan Qaboos)
Port Muscat is Oman's premier maritime gateway, situated in 250 km south of the Strait of Hormuz on the Indian Ocean coast of the Arabian Peninsula. It is operated and managed by Port Services Corporation S.A.O.G. from November 1976.

Port Muscat plans to build a new deepwater container berth, which would be at least 650 meters long and dredged to a depth of 15 meters.

Port Sohar
Port of Sohar is situated just outside the Strait of Hormuz and is 240 km northwest of Muscat. It is managed by Sohar Industrial Port Company (SIPC) S.O.A.C., which is a joint venture of Oman government and the Port of Rotterdam with 50 percent share held by each.

The Port of Sohar is developing into a world class port, which is capable of receiving ships up to 16.5 m draught (18 m after 2008), and handling all types of cargo. The quay length of Oman International Container Terminal (OICT) will increase to 1500m in 2008.

Port Salalah
Port Salalah is situated in the southern region of Oman, located 15 km south of Salalah city and it can accommodate vessels up to 16m draught. It is operated by Salalah Port Services S.A.O.G (SPS).

In May 2007, Port Salalah opened its 5^{th} berth, and the 6^{th} berth will follow in 2008. Construction of berth 6 will increase the port's capacity to approximately 4.5 million TEUs and increase the total berth length to 2,200 m. The total yard area after the expansion will be 765,000 m^2.

Port Aden
Aden, at the south-west corner of the Arabian Peninsula, in mid-way between Europe and the Far East, lies on a major world trading route through the Suez Canal. It is a large natural harbor with an area of about 70 km^2 of sheltered water surrounded by Jebel Shamsan. Overseas Port Management (OPM) has been running the Aden Container Terminal after the government bought the terminal back from PSA in 2003,

A joint Yemeni-UAE company will be founded for the operation and development of an Aden container port with 50 percent share held by each, according to a memorandum which was signed November 27^{th}, 2007 in Dubai between Yemen and DP World.

The port consists of container terminals (Ma'alla container terminal and Aden container terminal), oil harbor, fishing harbor and other facilities. Water depth in outer harbor is between 11 m to 16 m, and in inner harbor is between 5.5 m to 11.9 m.

Port Colombo

Located at the west coast of Sri Lanka Island, the crossroad to the East and the West, Port Colombo has been used by merchants since 14th Century (know as Port Kolomtota).

Container terminals in Port Colombo comprise of Jaya container terminal, Unity container terminal and South Asia Gateway terminal, with 9 container berths in total. The water depth is between 9 m to 15 m for different locations. This port is operated by Sri Lanka Ports Authority (SLPA), which was set up in 1979. SLPA administers and operates all specified commercial Ports in Sri Lanka, including Colombo, Galle, Trincomalee, Kankasanturai and Point Pedru.

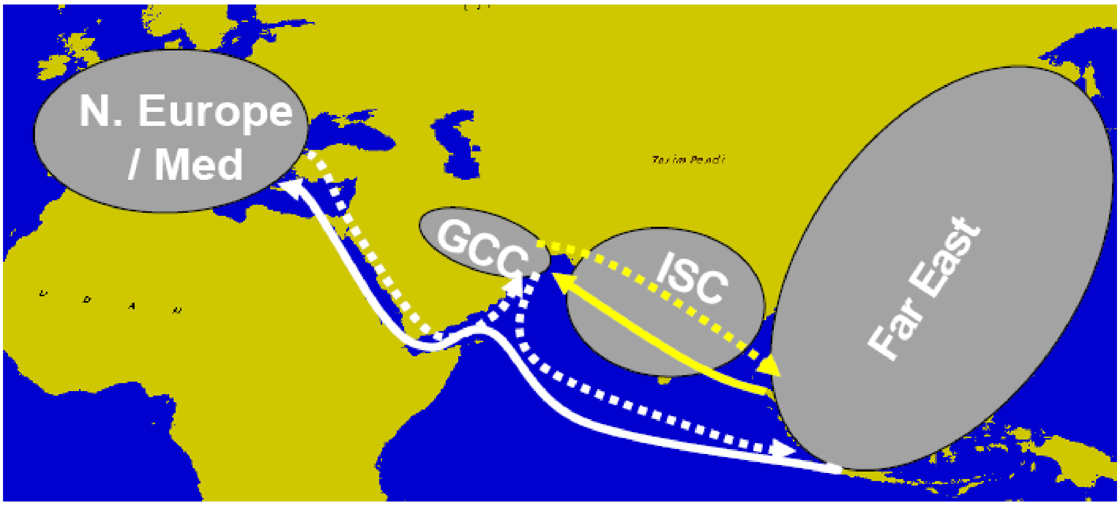


Figure 5.3 Map of routes [Ref.1]

5.1.3. Conclusion

Jebel Ali Port has the largest and most capable facilities, among Middle East container ports, to function simultaneously as a transshipment hub and as the primary gateway to the UAE and GCC countries.

It is also noticed that DP World are also involved in the operation and management of several competing ports, for instances, Abu Dhabi Ports, Fujairah Port and Port Aden. These ports are possible to cooperate rather than compete with Jebel Ali Port.

The new port at Khalifa, Abu Dhabi could handle the overflow traffic at Jebel Ali Port in a short term. Indeed, the relationship between the two ports could be further strengthened if a proposed rail link between Jebel Ali and Khalifa goes ahead as planned.

5.2. Containerized cargo analysis

The Dubai Ports ranked the 8th largest container terminal in 2006 and is the largest one between Rotterdam and Singapore.

Rank	Port	Region	Throughput (million TEUs)
1st	Singapore	South East Asia	24.80
2nd	Hong Kong	East Asia	23.23
3rd	Shanghai	East Asia	21.72
4th	Shenzhen	East Asia	18.47
5th	Busan (Pusan)	North East Asian	12.03
6th	Kao-hsiung	East Asia	9.77
7th	Rotterdam	North Europe	9.60
8th	**Dubai**	**Middle East**	**8.92**
9th	Hamburg	North Europe	8.86
10th	Los Angeles	North America	8.47

Table 5.1 Top 10 Container Terminals in the World (2006)

This section presents results of the analysis of containerized cargos. The forecasts are developed for four periods to project annual volumes in 2013, 2018, 2023 and 2030 and the 5-year increments is applied in order to smooth year over year variations. The design periods are coincided with HPA' report for the reason of comparisons.

5.2.1. Historical profile

Historical data of containers throughput from 1991 to 2006 is shown in the figure below. It shows a rapid growth after 2001, when DPA, JAFZA & Customs merged to form Ports, Customs & Free Zone Corporation.

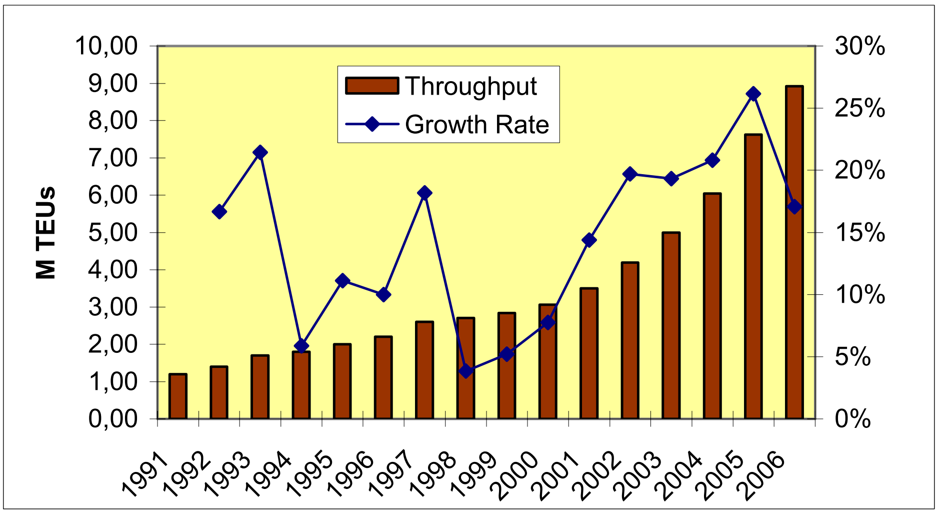


Figure 5.4 Containers throughput (1991 to 2006)

A detailed examination of container volumes comprises of local market volume and transshipment volume. This detail information is presented in HPA's report [Ref.1], but it only covers data from 1998 to 2003.

Because the examination was used in the scenario analysis conducted by HPA and it gives a close view of container business in Dubai Ports, several key points are summarized and presented below:

1) Transshipment volumes were slightly more than local volumes and the percentage of transshipment in total volume is 56% in 2003;
2) Local volume grew faster than transshipment volume with CAGR of 16% in contrast to 9% for the latter;
3) For local volumes, imported loaded containers had twice amount of exported loaded containers. Thus, the long-term growth for imported loaded containers would have more influence on the total volume of local market segment;
4) The main segment of Dubai Ports' transshipment volumes were either destined to or originating from other Middle East ports or from Far East ports.

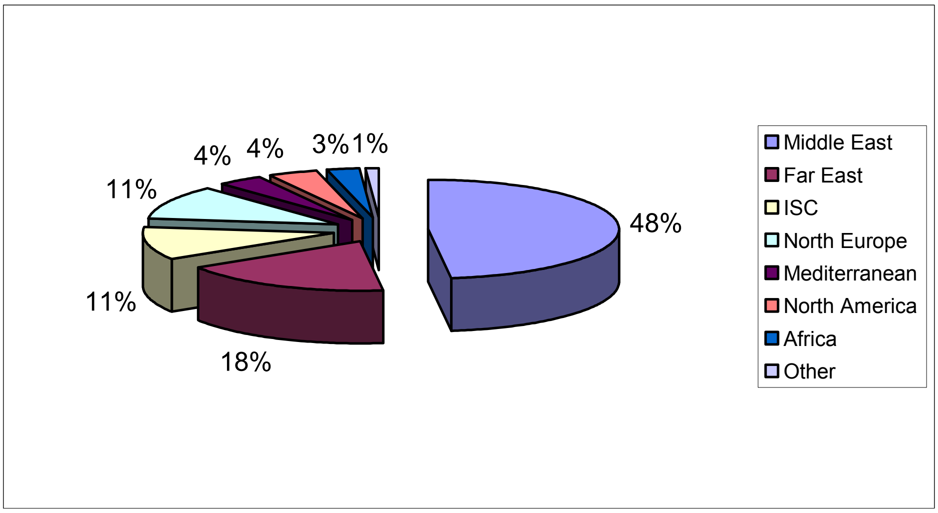


Figure 5.5 Transshipment volumes by region (2003) [Ref.1]

5.2.2. Throughput forecast

Trend-line forecast

A simple forecast method is firstly applied to predict throughputs by 2030. With container throughput data from 1991 to 2006, different trend-lines are drawn to find the most reasonable forecast result.

Year	Throughput	Growth rate
1991	1,20	-
1992	1,40	17%
1993	1,70	21%
1994	1,80	6%
1995	2,00	11%
1996	2,20	10%
1997	2,60	18%
1998	2,70	4%
1999	2,84	5%
2000	3,06	8%
2001	3,50	14%
2002	4,19	20%
2003	5,00	19%
2004	6,04	21%
2005	7,62	26%
2006	8,92	17%

Table 5.2 Containers throughput

After several trials, a second order polynomial trend-line with coefficient of determination (R^2) of 0.968 is found with reasonable results, which are shown below:

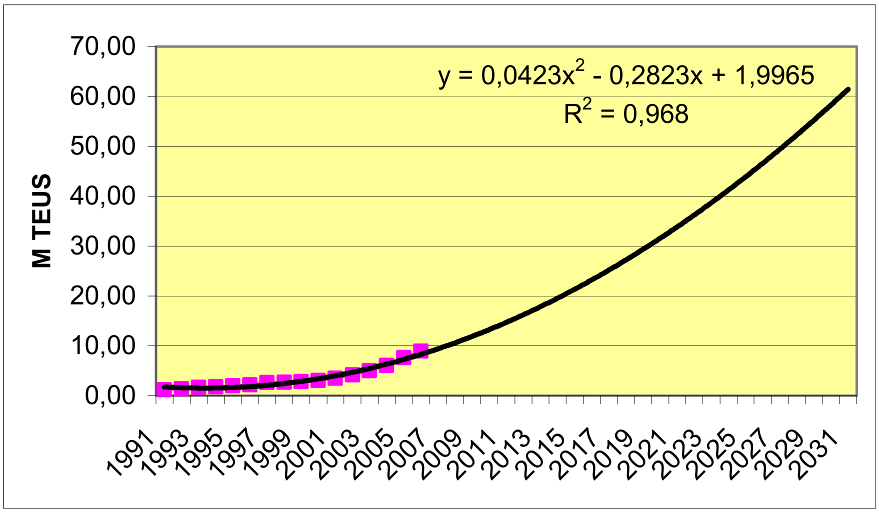


Figure 5.6 Polynomial trend-line forecast

Predicted throughputs for 2013, 2018, 2023, and 2030 can be got either from the figure or from the equation above.

	Throughput (million TEUs)	CAGR
2006	8,92	-
2008	10,62	9,1%
2013	17,88	11,0%
2018	27,26	8,8%
2023	38,75	7,3%
2030	58,38	6,0%

Table 5.3 Predicted throughput

According to the study carried out by Containerization International in 2006, the container volume growth in the world will be around 10% for the next ten years. Although other studies give lower growth rate around 8% for the same period, it is expected container throughput in Dubai Ports will experience a fast growth because of following reasons:

Firstly, population in Dubai and in the UAE has experienced and will still experience strong growth. It is expected that population of Dubai Emirate will double within the next ten years [Ref.13].

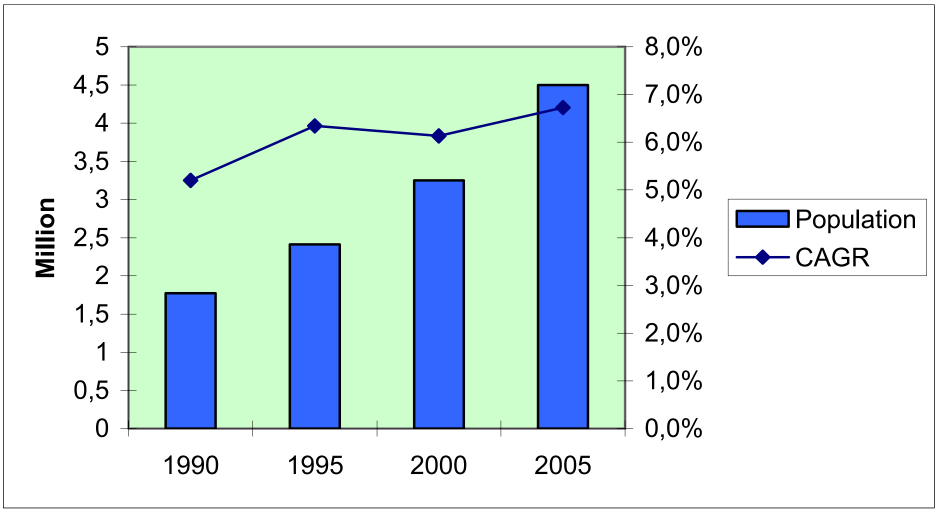


Figure 5.7 Historical review of population in the UAE

Secondly, both Dubai and the UAE economies (as measured by GDP growth) show robust outlook for the future. According to IMF (International Monetary Fund), the UAE is expected to grow by 7.7% in 2007. For Dubai in particular, JAFZA, tourist industry, and real estate business will contribute to the fast economic growth.

Thirdly, because of resurgence of the GCC countries' economies, the Far East–Arabian Gulf trade has expanded in volume by approximately 25% per year for last 5 years. And it will also boost container volume growth in Dubai Ports, because Dubai Ports is an important gateway for these countries.

Finally, Jebel Ali Port has the largest and most capable facilities, among Middle East container ports (as mentioned above), to function simultaneously as a transshipment hub and as the primary gateway.

Thus, it is concluded that the predicted throughput by the trend-line analysis gives reasonable estimation, and the final results are compared with results from the scenarios analysis.

Forecast results

The results from trend-line analysis are compared with results from scenarios analysis. The scenario analysis was conducted by HPA in 2005 and it should be noticed that data after 2003 is not taken into account in that report. Detailed information can be found in *appendix B.*

In principle, scenario analysis gives more accurate results than trend-line analysis but trend-line analysis requires less work and is easier to be conducted. At the same time, it should be realized that the accuracy of data inputted can be more important than the forecast method used and the data of recent years are usually more important than earlier years.

	Trend-line		**Scenarios**	
Year	**Throughput**	**CAGR**	**Throughput**	**CAGR**
2003	5.00		5.00	
2008	10,62	16.3%	11,70	18,5%
2013	17,88	11,0%	19,20	10,4%
2018	27,26	8,8%	28,90	8,5%
2023	38,75	7,3%	40.00	6,7%
2030	58,38	6,0%	56,20	5,0%
Total		9.5%		9.4%

Table 5.4 Comparison between Trend-line forecast and Scenarios forecast (in million TEUs)

A comparison shows only a little difference between these two methods. Because the trend-line analysis included data of recent years, it is decided to use results from the trend-line analysis for later design.

	Throughput (million TEUs)	CAGR
2006	8,92	-
2008	10,62	9,1%
2013	17,88	11,0%
2018	27,26	8,8%
2023	38,75	7,3%
2030	58,38	6,0%

Table 5.5 Final forecast results

5.2.3. Vessel dimensions forecast

Vessel dimensions are determining factors for port design, which influence navigation channel, turning circle, water depth, etc. This section presents the analysis of future containership deployment patterns relevant to Jebel Ali Port [Ref.1].

Intermediate forecast
By 2018, several ship lines will likely operate ultra-large container ships (ULCS) of 10,000-12,000 TEUs capacity, in the Far East – North Europe trade line, with 6 to 10 weekly-frequency deployments. But this scenario would be highly contingent on the fleet and network strategies of a few carriers.

Long term forecast
By 2030, most ship lines will likely operate ULCS in the Far East – North Europe trade. A few of these ULCS deployments will probably deviate to Jebel Ali or a competing nearby hub port.

Design vessel
The new Jebel Ali Port should be able to handle the ULCS in the future, so it is recommended that the design vessel for the Jebel Ali New Container Terminals have the following characteristics:

- Size: 10,000 to 12,000 TEUs
- LOA: 370 to 397 m
- Beam: 50 to 56 m
- Draught: 15.0 to 15.5 m

It should be noticed that economies of scale have dictated an upward trend in sizes of container ships in order to reduce costs. It is possible that larger vessels than the design vessel will call at Jebel Ali Port by 2030, so the flexibility of new terminals will be considered.

5.2.4. Capacity analysis

With predicted capacity and existing capacity, the required capacity can be calculated as:

Predicted Capacity – Existing Capacity = Required Capacity

It should be noticed that existing capacity includes capacities after expansion of inner harbor area and the completion of Terminal 2. The Terminal 2 is still under construction but should be completed before 2009.

The detail information of container terminals in Dubai Ports is presented Chapter 2 and Chapter 3, and the capacity information after completion of Jebel Ali Terminal 2 can be summarized as:

Container	Capacity (Million TEUs)
Jebel Ali T1	7.5
Port Rashid	1.5
Jebel Ali T2	5.5
Total	14.5 (13.0)

Table 5.6 Container capacity in Dubai Ports

The required capacity is summarized as follows:

Year	Predicted throughput (M TEUs)	Existing capacity (M TEUs)	Required capacity (M TEUs)
2008	10.62	14.5	-
2013	17.88	13.0	4.88
2018	27.26	13.0	14.26
2023	38.75	13.0	25.75
2030	58.38	13.0	45.38

Table 5.7 Container capacity analysis

5.3 Non-containerized cargo analysis

This section presents an analysis of non-containerized cargo volumes for four main types of cargos: Ro/Ro, break bulk, dry bulk and liquid bulk. The analysis for non-container vessels is mainly based on the report conducted by HPA [Ref.1].

5.3.1. Ro/Ro cargos

Ro/Ro traffic in Dubai Ports is dominated by automobiles and light trucks, with the volume of used vehicles handled slightly exceeding that of new-assembled vehicles. Imports significantly exceed re-exports for most commodities in this sector.

Dubai Ports is a key port of calls for all of the world's leading Ro/Ro operators, because:

1) It has a sizable local market for imports of new cars and light trucks;
2) It is the port preferred by the carriers for serving the other Emirates (except Abu Dhabi);
3) Auto manufacturers can use JAFZA for receiving/processing/staging new cars and light trucks, which then move to neighboring GCC countries;
4) Trading companies can use DUCAMZ (Dubai Customs Automobile Zone) or JAFZA for receiving, processing, staging, and eventually re-exporting used vehicles to less developed markets;
5) Dubai has accordingly developed a significant business in importing used cars primarily from Japan, North Europe, and its GCC neighbors, and re-exporting them to various African and Asian countries;
6) With its multiple industrial, commercial, and residential construction projects, Dubai also has a sizable local market for imports of heavy machinery and equipment;
7) Manufacturers also use JAFZA for staging machinery and equipment for re-export to other countries in the region.

5.3.1.1. Historical profile

The volume of Ro/Ro cargos, both imports and exports, in Dubai Ports has increased dramatically during the recent 8 years. Imports accounted for approximately 90% of the total volume. Expansion of the local UAE and broader Gulf markets for new vehicles, along with the simultaneous enlargement of Dubai's involvement as a regional hub for used vehicles, has caused Ro/Ro throughput to grow by an average of 28% annually during this period.

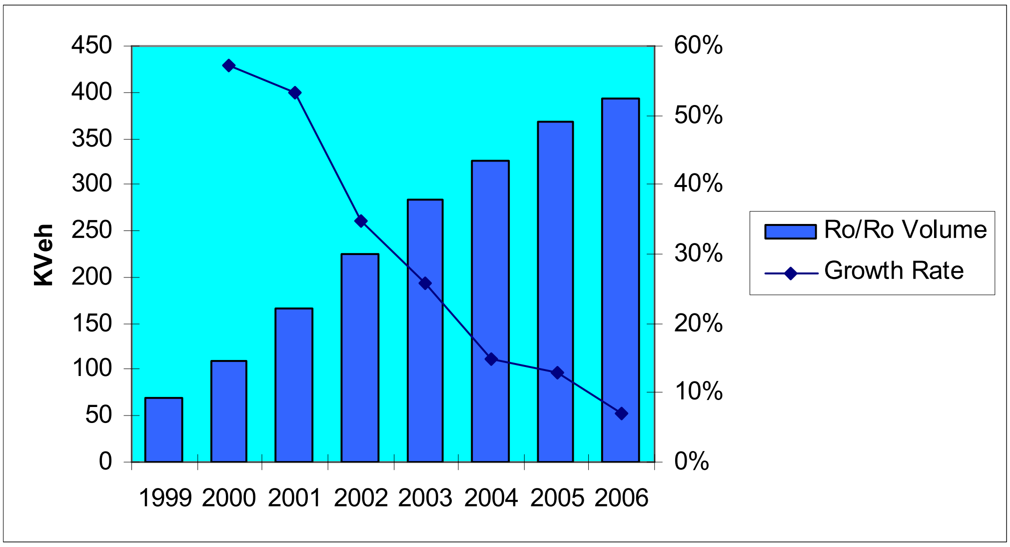


Figure 5.8 Ro/Ro volume and growth rate

5.3.1.2. Throughput forecast

Ro/Ro volumes in Jebel Ali Port are expected to rise by *17-22%* annually from 2003 to 2008 and the growth will slow down after 2008 [Ref.1].

The rapid volumes growth is driven by following factors:

- Increases in population size and average disposable income for Dubai and the UAE, for both the indigenous and expatriate segments of the population;
- Rapid expansion of Dubai and the UAE tourist industries, with corollary impacts for the local car rental market;
- Increases in population size and average disposable income for the neighboring GCC countries and the Asian and African countries for which Dubai serves as a conduit of both new and used vehicles;
- Current and additional large-scale industrial, commercial, and residential development projects in the UAE (and especially Dubai), with corollary impacts for the construction machinery and transportation equipments;
- Lack of significant competition either from other UAE ports or Ro/Ro facilities elsewhere in the Middle East and Subcontinent region.

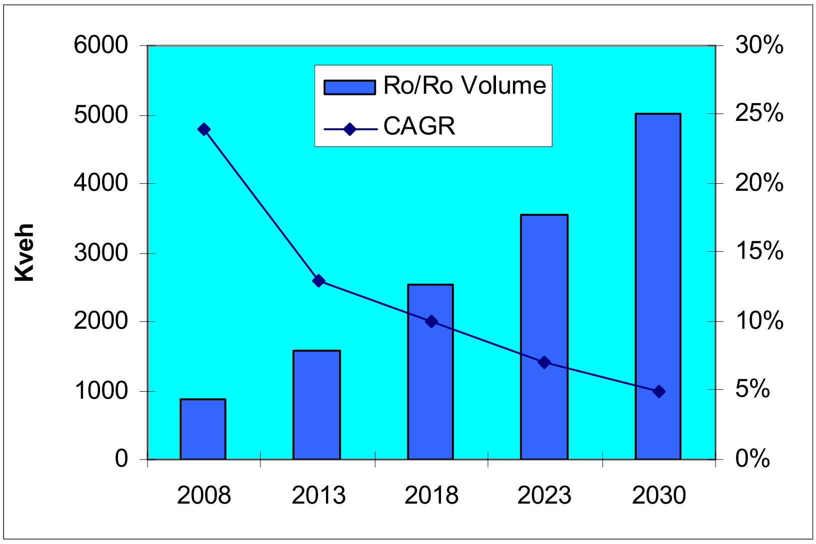


Figure 5.9 Ro/Ro volumes forecast by HPA

It should be noticed that the growth rate dropped down significantly after 2003. Thus, the growth rates between 2003 and 2013 predicted by HPA are too optimistic. However, the predicted growth rates after 2013 seems still reasonable.

It is decided to decrease the CAGR between 2006 and 2013 to 11.6%, which is the actual growth rate between 2003 and 2006. After 2013, the same growth rates predicted by HPA are applied. Finally, it gives 53.8% volume of that predicted by HPA and results can be summarized as:

Year	KVeh	CAGR
2006	393.6	-
2013	848.6	11,6%
2018	1366.7	10,0%
2023	1916.9	7,0%
2030	2697.2	5,0%
Total		8,3%

Table 5.8 Final forecast of Ro/Ro volume

5.3.2 Break bulk cargos

Dubai Ports is handling a substantial and expanding volume of traditionally-stevedored cargos, like break bulk. The main reasons are:

- The construction industry of Dubai (as well as other Emirates), imports basic building materials for an array of development projects;
- The manufacturing industry of Dubai and other Emirates, imports steel products, other metal products, resins, and various production materials;
- Trading companies use Dubai terminals and free zones as staging, trans-loading, and relay centers for supplying steel products and other industrial items to smaller markets around the Arabian Gulf and Indian Ocean;
- Exports from the Al Khaleej Sugar refinery.

5.3.2.1. Historical profile

Dubai's break bulk traffic is dominated by importing of iron and steel products and forest products. Bagged sugar and re-exporting of iron and steel products are the most significant export commodities.

Dubai Ports' total importing tonnage of break bulk cargoes nearly doubled from 1999 to 2006, while exporting tripled during the same period.

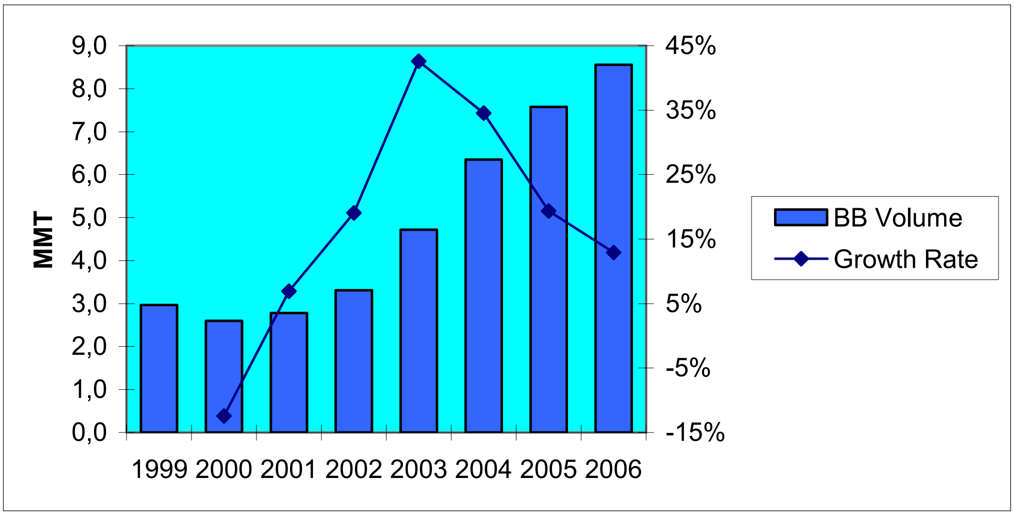


Figure 5.10 Break Bulk volume and growth rate

5.3.2.2. Throughput forecast

According to analysis of regional distribution patterns of key commodities, along with feedbacks from representatives of shipping agents and forwarders, BB volumes forecast is constructed.

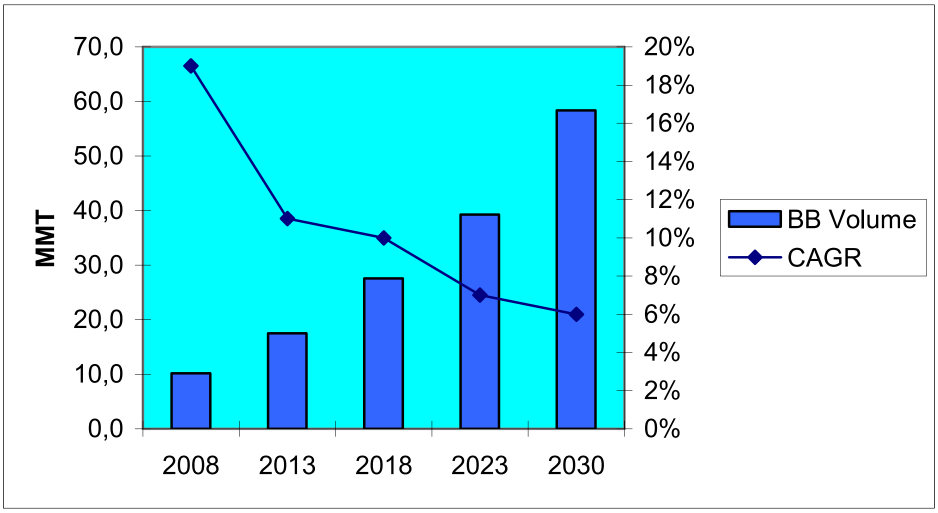


Figure 5.11 BB volumes forecast by HPA

The same growth scenario happened to BB volume as to Ro/Ro volume. The growth rate also dropped down significantly after a high growth rate of 43% in 2003. However, it is found that forecast carried out by HPA in 2005 gives reasonable results, which shows the decrease of growth rate sufficiently in advance. So the same volumes will be used for later design.

5.3.3 Dry Bulk cargos

Dubai Ports handles a number of distinct bulk solids, primarily at Jebel Ali Port, and the commodities that generate the majority tonnage comprise followings:

- Cement clinker imports for local construction projects
- Raw sugar imports for the Al Khaleej Sugar refinery
- Alumina imports for the smelters of Dubai Aluminum Company

In addition, relatively smaller volumes of wheat, silica sand, and other mineral products move through Jebel Ali Port.

Based on the future demand analysis of the cement clinker, sugar, and alumina flows, two alternative growth scenarios were studied by HPA. Given a base volume of 4.6 million tons of dry bulk tonnage in 2003, Dubai Ports could expect to handle between 18.9 and 29.7 million tons per year by 2030 [Ref.1], assuming there are sufficient facilities to accommodate the various commodities.

According to discussions between DP World and HPA, the high growth scenario was finally chosen, which leads to 29.7 million tons by 2030. The results can be summarized as:

Year	Volume (MMT)
2013	10.4
2018	14.9
2023	19.9
2030	29.7

Table 5.9 Long-term dry bulk volume forecast

5.3.4 Liquid Bulk cargos

Although the oil sector’s contribution to Dubai’s GDP has declined from nearly 25% to 5% during 1993-2006 period, it still provides substantial tonnage for Dubai Ports, only less than the container traffic. Some key generators are:

- A condensate refinery of the Emirates National Oil Company, imports condenses and produces jet fuel, LPG, gas oil, and bunker fuel for local consumption, along with naphtha for export;
- An oil processing plant of Star Energy Corporation, imports petroleum and produces products and additives;
- Crude oil imports by EPPCO and Emarat, and exports of petroleum products by EPPCO;
- Imports and exports of Dubai Natural Gas Company.

Dubai Ports' liquid bulk traffic is dominated by oil products. Comparing to other commodities, the volume increased modestly during the past twelve years, with CAGR of 5%.

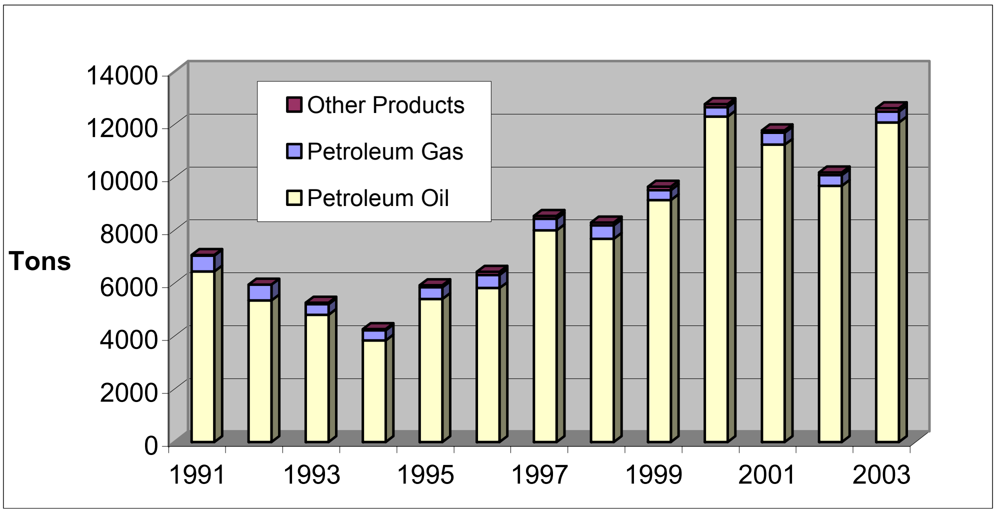


Figure 5.12 LB volume (1991 to 2003) [Ref.1]

It is concluded that liquid bulk volume will still increase modestly for the next 20 years, leading to projected tonnage around 48 millions tons per year by 2030. For different periods, the volumes can be summarized as:

Year	Volume (MMT)
2013	24.8
2018	30.2
2023	36.7
2030	48.3

Table 5.10 Long-term liquid bulk volume forecast

5.3.5. All non-containerized cargos forecast

Based on above analyses and DP World's requirements, the consolidated forecast presented is constructed (an average tons per unit conversion ratio is 2.6 for Ro/Ro units/vehicles).

Cargo Type	2013	2018	2023	2030
Ro/Ro	2.2	3.6	5.0	7.0
Break Bulk	17.4	27.6	39.2	58.4
Dry Bulk	10.4	14.9	19.9	29.7
Liquid Bulk	24.8	30.2	36.7	48.3
Total	**54.8**	**76.3**	**100.8**	**143.4**

Table 5.11 Non-containerized cargo volume forecast (MMT)

As indicated, substantial traffic increases are projected for Dubai Ports of all types of cargo mentioned.

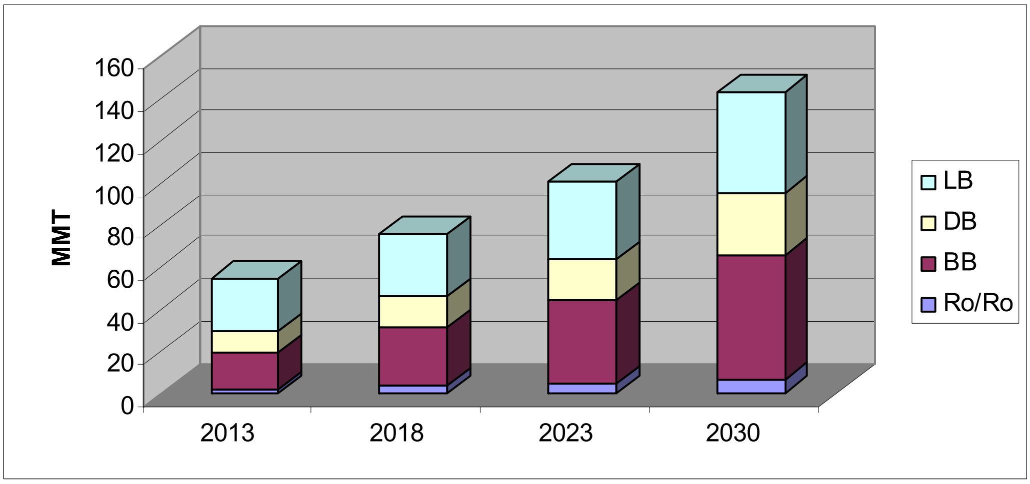


Figure 5.13 Non-containerized cargo volume forecast

5.3.6. Capacity analysis

The detail information about non-containerized cargo facilities in Dubai Ports in 2005 is presented below.

Jebel Ali Port	**No.of Terminals**	**Terminal Area (ha)**	**Berth Length (m)**	**No.of Berth**	**Avg. Berth Length (m)**	**Outdoor Storage Area (m^2)**	**Covered Storage Area (m^2)**
Break Bulk	8	110.7	3,880	22	181.1	721,413	95,635
Ro/Ro	1	11	370	1	152.9	110,000	-
Dry Bulk	4	81.5	1,617	6	279.6	unknown	unknown
Petroleum	10	241.3	1,856	10	194.6	unknown	unknown
Other Liquid Bulk	2	14.8	370	2	92.5	unknown	unknown
Port Rashid							
Break Bulk	5	39.5	4,311.6	25	168.7	524,600	119,416
Ro/Ro	4	42.4	522.4	6	143.0	424,000	-
Dry Bulk	-	-	-	-	-	-	-
Petroleum	-	-	-	-	-	-	-
Other Liquid Bulk	-	-	-	-	-	-	-
Dubai Ports							
Break Bulk	13	150.2	8,191.6	47	174.9	1,246,013	215,051
Ro/Ro	5	53.4	892.4	7	147.9	534,000	-
Dry Bulk	4	81.5	1,617	6	279.6	unknown	unknown
Petroleum	10	241	1,856	10	194.6	unknown	unknown
Other Liquid Bulk	2	15	370	2	92.5	unknown	unknown

Table 5.12 Dubai Ports non-containerized cargo facilities (2005)

Non-containerized cargo capacities are estimated with capacities in 2005 and capacities after two expansion projects. Port Rashid will be closed in 2008 at the latest, so capacities of Port Rashid will not be considered after 2008. At the same time, productivity improvements are also taken into consideration.

Year	Predicted throughput (MMT)	Productivity estimate (MT/ha)	Existing capacity (MMT)	Required capacity (MMT)
2008	10.2	120,000	17.0	-
2013	17.4	120,000	17.2	0.2
2018	27.6	136,000	26.0	1.6
2023	39.2	136,000	26.0	13.2
2030	58.4	136,000	26.0	32.4

Table 5.13 Break bulk capacity analysis

Year	Predicted throughput (Veh)	Productivity estimate (Veh/ha)	Existing capacity (Veh)	Required capacity (Veh)
2008	490,215	12,000	956,000	-
2013	848,609	12,000	1,788,000	-
2018	1,366,694	12,000	2,454,000	-
2023	1,916,859	12,000	2,454,000	-
2030	2,697,213	12,000	2,454,000	243,213

Table 5.14 Ro/Ro capacity analysis

The storage capacity and operational information for dry and liquid bulk terminals are not available, so the report carried out by HPA is consulted [Ref.1]. Assumptions based on empirical observations of Jebel Ali terminal facilities and from other international terminals are developed. It is found that existing Jebel Ali Port already has enough capacity to handle the dry and liquid bulk throughput by 2030, and results can be summarized as:

Types of cargo	No.of berth	Throughput/ Berth (MMT)	Constrained capacity (MMT)	Required capacity (MMT, 2030)
Dry bulk	8	4.38	35.04	29.70
Liquid bulk	11	8.96	98.56	48.30

Table 5.15 Dry and liquid bulk capacity analysis

5.4. Port facilities analysis

Main port facilities are discussed and determined in this section, including the required quay length, number of cranes, storage area and the total area.

		Year			
Cargo Type		2013	2018	2023	2030
Non-Containerized (MMT)	Ro/Ro	2.2	3.6	5.0	7.0
	Break Bulk	17.4	27.6	39.2	58.4
	Dry Bulk	10.4	14.9	19.9	29.7
	Liquid Bulk	24.8	30.2	36.7	48.3
	Total	54.8	76.3	100.8	143.4
Containers (M TEUs)		17.88	27.26	38.75	58.38

Table 5.16 Summary of volumes forecast

5.4.1. Facilities for containerized cargos

Facilities for containerized cargos, including required quay length, number of cranes, storage area and gross total depth will be discussed here.

Quay length

A standard spreadsheet program is used to perform simulations using the Monte Carlo method. In the model, processes of berthing, loading, waiting and leaving can be simulated for a certain period. By repeating simulations, average values of required facilities can be determined with a critical criteria “$t_{waiting}/t_{service}<10\%$”.

It is noticed that number of cranes has a large influence on the required quay length, and the cost for a crane is almost as expensive as the cost for 100 to 150 m length of quay (with a depth of 20 m).

For most ports, cranes are deployed every 100m, on average. For some busy ports, like Hong Kong and Shanghai, the distance is about 80 to 90m and this rule of thumb is applied to Jebel Ali Port.

Results from simulations show that one million TEUs throughput requires 520m of straight quay and 6.5 cranes. So an estimation of required quay length and number of cranes can be made for different periods.

Year	Required throughput (M TEUs)	Total quay length (m)	No. of cranes
2013	4.88	2,540	32
2018	14.26	7,410	92
2023	25.75	13,390	167
2030	45.38	23,600	295

Table 5.17 Facilities for container terminals

Apron area
An apron is an area on the waterfront side of a wharf or pier, usually an area where cargo is prepared for loading/unloading. The apron area has a depth of 80m. It comprises a 5 m service lane, 30 m crane tracks, 15 m hatch covers and a 30 m traffic lane.

The width of traffic lane depends on the traffic system adopted. A width of 30 m is sufficient for normal systems, but an automatic system (for example, AGV) requires wider lanes. However, extra depth is considered at the end to provide more flexibility.

Storage yard
The overall storage yard is usually divided into the normal container yard (CY) and container freight station (CFS).

The CY and CFS apply to the manner and the location of the cargo delivery and receipt in a container service. The CY is the delivery (or receipt) of a whole container from (or at) the shipper's or the forwarder's (or the consignee's) cargo yard or premises. The CFS is the delivery (or receipt) of loose cargo from (or at) the carrier's container freight station. In other words, CFS is where one imported container has different destinations, or stuffs from different origins are loaded into one container for export.

Because CFS of large container terminals is generally off-dock, surface areas of the storage yard are calculated for normal container yard as follows [Ref.6]:

$$O = \frac{C_i \cdot \overline{t}_d \cdot F}{r \cdot 365 \cdot m_i}$$

where:
O : surface area required (m^2)
C_i : number of container movements per type of stack in TEUs
$\overline{t}_d$: average dwell time (days)
F : required area per TEU inclusive of equipment traveling lanes
r : average stacking height/nominal stacking height
m_i : acceptable average occupancy rate

The overall storage area is divided into separate stacks for different types of containers, which are Import Loaded (Import LD), Export Loaded, Transshipment Loaded (TS LD), Import Empty (Import MT) and Transshipment Empty (TS MT).

For a first estimation, it is assumed that all storage areas are normal container yard, which means surface area for CFS is not considered. The calculation for storage areas for one million TEUs capacity can be summarized as:

Types	% of lifts	Dwell time (day)	F (m^2)	r	mi	O (m^2)
Import LD	19.6%	7.8	9	0.7	0.7	76,931
Export LD	10.8%	8.1	8	0.8	0.7	34,239
TS LD	43.0%	7.4	8	0.8	0.8	62,270
Import MT	8.6%	8.0	7	0.9	0.8	18,326
TS MT	17.8%	16.0	7	0.9	0.8	37,930
Total						229,696

Table 5.18 Storage yard area

The results show that a throughput of one million TEUs requires a total storage area of 22.97 ha, which means the depth of storage area is about 440m.

<u>Gross total depth</u>
The depth for container operations comprises depths of apron and storage yard, which is 520m in total. The depth for service area and road is estimated to be 120 m. Thus, a gross depth of 640m is required for the new terminals.

5.4.2. Facilities for non-containerized cargos

For non-containerized cargos, effective operating capacities are estimated by HPA [Ref.1], based on field observation, study and experiences gained from other international ports, as follows:

- Ro/Ro:
  Berth length 585 KVeh/km
  Area 12.0 KVeh/ha
- Break Bulk:
  Berth length 4.8 MMT/km (before 2013)
  5.4 MMT/km (after 2013)
  Area 0.12 MMT/ha (before 2013)
  0.14 MMT/ha (after 2013)

Thus, the required berth length and areas for Ro/Ro and Break Bulk can be calculated:

Year	Required Capacity		Required Berth Length		Required Area	
	BB (MMT)	Ro/Ro (KVeh)	BB (km)	Ro/Ro (km)	BB (ha)	Ro/Ro (ha)
2013	0.2	-	0.04	-	1.6	-
2018	1.6	-	0.29	-	11.5	-
2023	13.2	-	2.42	-	96.8	-
2030	32.4	243.2	5.95	0.42	236.0	20.3

Table 5.19 Summary of required facilities

5.4.2. Summary

The required quay length and areas for main types of cargos as determined in this section are summarized in following table, and shown below:

Year	Required Capacity			Required Quay Length			Required Area		
	Containers (M TEUs)	BB (MMT)	Ro/Ro (KVeh)	Containers (km)	BB (km)	Ro/Ro (km)	Containers (ha)	BB (ha)	Ro/Ro (ha)
2013	4.88	0.2	-	2.54	0.04	-	162.4	1.6	-
2018	14.26	1.6	-	7.41	0.29	-	474.6	11.5	-
2023	25.75	13.2	-	13.39	2.42	-	857.0	96.8	-
2030	45.38	32.4	243.2	23.60	5.95	0.42	1510.2	236.0	20.3

Table 5.20 Summary

It is decided that the required area for Ro/Ro vessels will not be taken into account in the later design, for two reasons:

Firstly, the required capacity is only 9.9% of current capacity, and it is reasonable to assume the current productivity can be improved in the future with better management, more advanced equipment and skilled workers. Thus, the existing capacity may be sufficient by 2030.

Secondly, according to the forecast, the existing capacity is sufficient at least by 2023. So it should be possible to exam the result in the later phase. If new Ro/Ro area is found to be necessary, a possible solution is to gain space from that for container vessels or break bulk vessels. Because the required area for Ro/Ro vessels is only 1.2% of areas for container vessels and break bulk vessels, it would be possible to built several Ro/Ro berths in the future.

6. Landform alternatives

6.1. Location

The new Jebel Ali Port will be constructed as a set of offshore islands to the north of, and connected to, the existing Jebel Ali Port. These islands could be either reclaimed land or floating structures.

Two boundaries for the new port are the existing approach channel in the south and four main pipelines in the north.

Although these pipelines will probably be out of use in the future, it is decided to keep them as a boundary for this masterplan.

There is a spoil ground in the southwest of existing approach channel. It locates approximately 13 km (7 nautical miles) offshore, with the area of 23 km^2 and depth of 6 to 7 m.

6.2. Dimensions of nautical areas

The nautical areas comprise of approach channel, turning circle and harbor basin, and dimensions of these areas are presented below.

6.2.1. Design vessel

The design vessels for Jebel Ali new container terminals have following characteristics:

- Size: 12,000 TEUs
- LOA: 397 m
- Beam: 56 m
- Draught: 15.5 m

6.2.2. Approach channel

The approach channel connects the open sea to the harbor basin, which should provide enough safety for navigation. Following parameters will be determined here: length of the channel, alignments, channel width and channel depth.

The International Navigation Association (PIANC) guidelines are widely accepted for the planning and designing of navigation channels, so there guidelines are applied to this project. Detailed calculations are conducted in a spreadsheet, which can be found in *appendix D*.

6.2.2.1. Channel length and alignment

Designing of alignment of channel should take these factors into account: minimize the channel length, minimize cross current and winds, small angle with dominant wave direction and minimize the bends. The length of channel is determined by stop length and the length over which dredging is required.

Several assumptions are made for the later design:

1. Service speed is 20 knots in deep water.
2. Vessel speed is designed to 8 knots in outer channel and 6 knots in inner channel.
3. Minimum vessel speed for sufficient rudder control is 5 knots.
4. Vessels larger than 50,000 DWT need tugboats for control during the stopping maneuver
5. Maximum vessel speed for tugboat to tie up is 6 knots, and maximum wave height is 1.5 m.

6.2.2.2. Channel depth

The channel depth can be determined as follows:

$$d = D - T + s_{max} + r + m$$

where: D Draught
T Tidal elevation below which no entrance is allowed
$s_{\max}$ Maximum sinkage due to squat and trim
r Vertical motion due to wave response
m Safety margin

The bow squat can be determined with the equation by ICORELS (1980):

$$S = 2.4 \frac{\nabla}{L_{pp}^2} \frac{F_{nh}^2}{\sqrt{1 - F_{nh}^2}}$$

$$F_{nh} = v / \sqrt{gh}$$

6.2.2.3. Channel width

Considering the large amount of vessels calling at Jebel Ali Port, a single one-way channel can't fulfill safety and operational requirements. So a two-way approach channel is preferred, and the channel width can be calculated as follows:

$$W = 2(W_{BM} + \sum W_i + W_B) + W_p$$

where: W_{BM} Basic width
W_i Additional width
W_B Bank clearance
W_p Separation distance

The existing Jebel Ali Port has one approach channel, which starts 24 km (13 nautical miles) offshore. It has a depth of 17m and width of 320 m.

It is preferred that new terminals can use the whole or part of the existing approach channel. Although further deeping and widening of the channel is required, it is still an economical solution.

The results can be summarized as:

	Outer channel	Inner channel
Channel depth (m)	18.5	17.5
Two-way channel width (m)	610	450

Table 6.1 Channel depth and width

Because of the small tidal range in Dubai coast, the SWL (Still Water Level) is defined as the MLW (Mean Low Water) level, which gives enough safety and entrance time. So the bottom of outer channel is DMD-17.6 m.

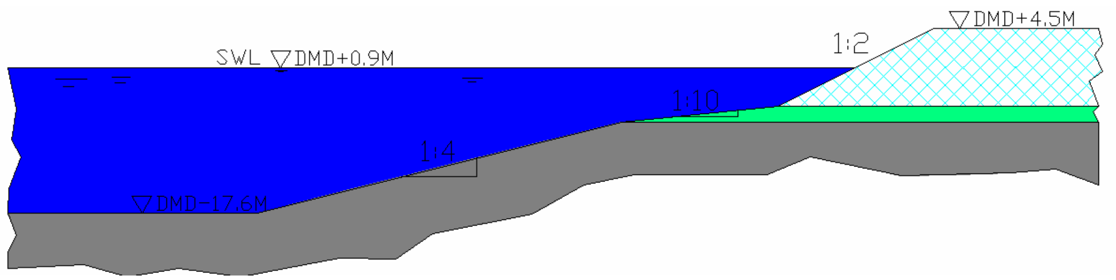


Figure 6.1 Channel side detail

6.2.2.4. Bend design

For an approach channel, it is better to minimize the number of bends and avoid bends close to port entrance. The length of straight channel needed before the actual entrance depends on current, wind and wave conditions.

In the port of Rotterdam, a length of 6000 m is adopted, but in other ports this length is smaller. For Jebel Ali Port, a length of 4500 m is assumed.

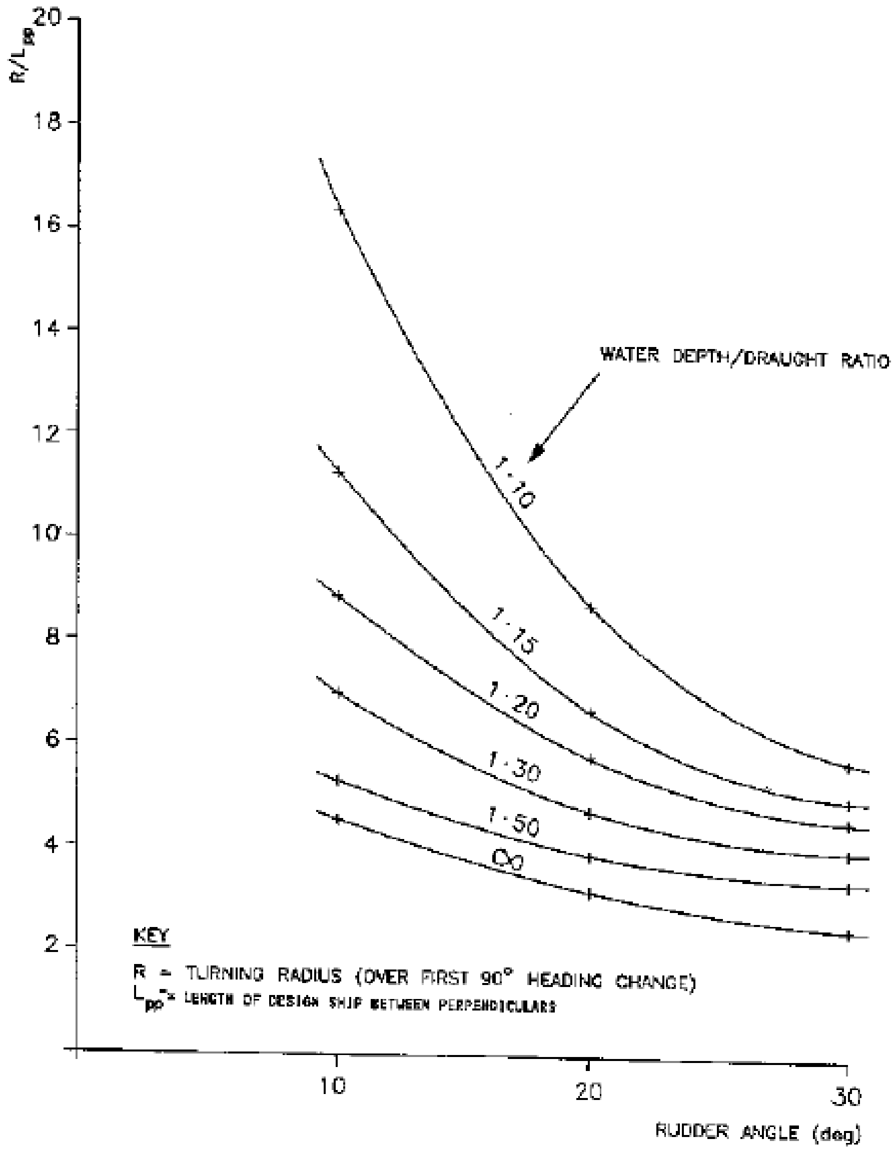


Figure 6.2 Turning radius

As long as vessels have no tug assistance, the radius of bends depends on the maneuverability of the design vessel. According to PIANC, the turning radius can be determined as a function of rudder angle and water depth/draught ratio.

For outer channel, the water depth/draught is about 1.20 and a rudder angle of 20° is assumed for initial design, leaving some margin of safety [Ref.6]. Thus, the turning radius of design vessel is about 2200 m.

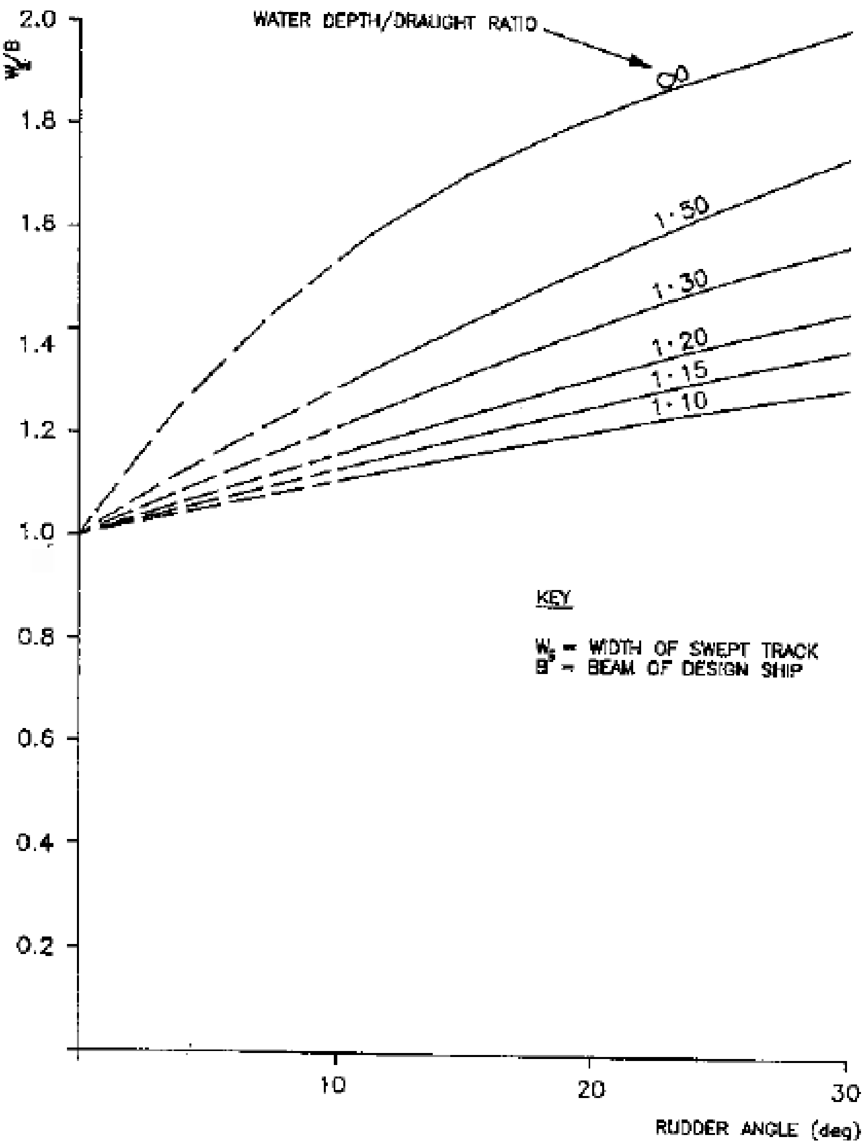


Figure 6.3 Width of swept track in a turn

A vessel sideslips as it turns and sweeps out a path which is wider than its beam. This excess depends on the rudder angle and water depth/draught ratio, which gives 30% of the beam for additional width.

Two continuous bends should be avoided, and the recommended length of a straight channel between two bends is 5*L_{OA} in minimum [Ref.6]. For this project, a length of 2500 m is applied, which is about 6* L_{OA}.

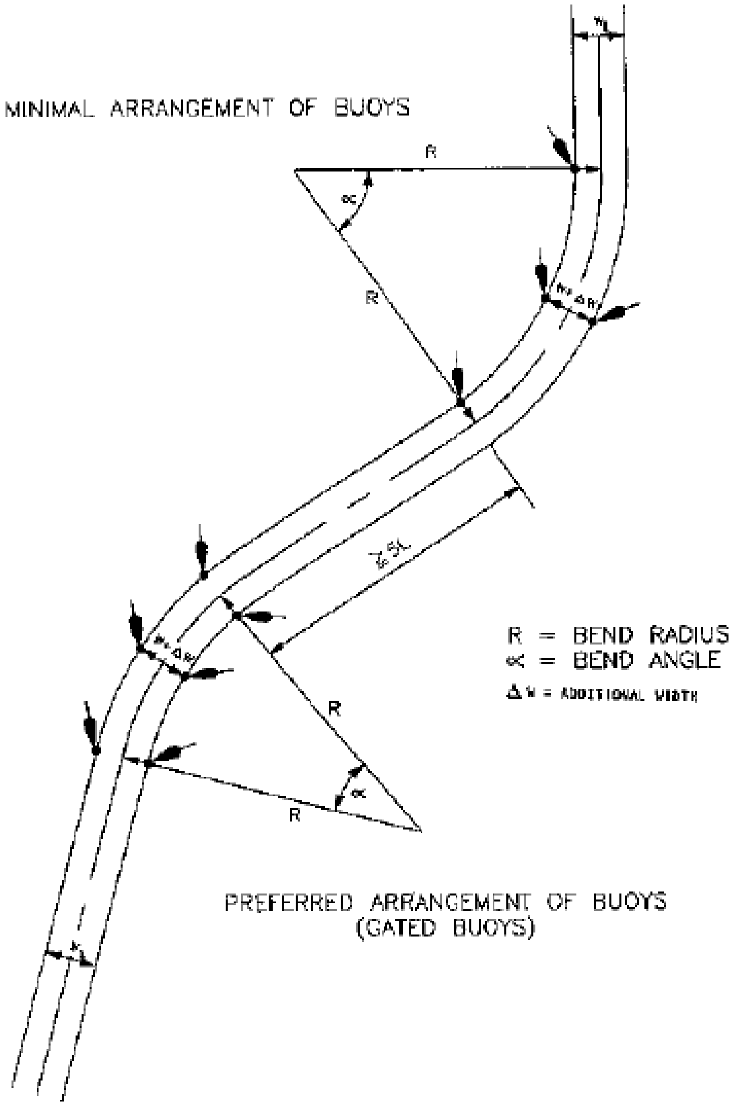


Figure 6.4 Suggested bend markings & definitions

6.2.2.5. Turning circle

Usually, the approach channel ends in a (or some) turning basin(s) or circle(s), where vessels are towed by tugboats to their respective berths. The diameter of this turning circle should at least be 2*L_{OA} for most cases. With the designed L_{OA} of 397 m, the diameter of the turning basin should be at least 795 m.

6.2.3. Harbor basin

6.2.3.1. Basin width

Port basins should provide a sufficient width for the safe towing in and towing out of vessels, whilst other berths are occupied. In case of very long basins (more than 1000m), it is desirable that ships can be turned in most place of the basin with the helps of tugboats. The required width is about *L+B+50* or *8B+50* [Ref.6], which means a basin width of 503m or 498m, respectively.

It is found that current practice at Jebel Ali is for vessels to sail to any location within the harbor basins and to turn around; even quays on both sides of the basins are occupied.

This practice provides an alternative for harbor basin. In detail, the turning circle will not be located at a fixed place but the basin is wide enough for vessels to turn around at any location within the basin, without interrupting vessels berthed alongside. The minimum width for the basin will be $2*L_{OA}+2*B$, which means a width of 906m.

6.2.3.2. Basin depth

A standard practice is to provide an underkeel clearance within a harbour of approximately 10% of the draught of the largest design vessel [Ref.1]. For the largest draught of 15.5 m, the recommended design depth of the basin is 17.0m. So the nominal bottom level will be DMD-16.1 m.

It should be noticed that when dredging is carried out in front of quay walls, the dredging must be deeper than the planned nominal level. The additional depth includes the thickness of maintenance zone and minimum tolerance. The additional depth is about 1.0 m for this project [Ref.12].

6.2.3.3. Basin resonance

In case the period of the incident waves equals or approximates the natural period of oscillation of a harbor basin, resonance phenomena can be expected. This may lead to locally much greater wave heights and, consequently, to more severe problems for ships at berths. If a harbor basin has a more or less uniform depth and rectangular shape, the natural periods of oscillation T_n are as follows:

closed basin:

$$T_n = \frac{2L_B}{n}\frac{1}{\sqrt{gD}}, \text{ with n=1, 2, 3…}$$

open basin:

$$T_n = \frac{4L_B}{(1+2n)}\frac{1}{\sqrt{gD}}, \text{ with n=1, 2, 3…}$$

Because of the very long basin length, wave resonances could occur in the basin, and thus the operation and safety will be affected. Usually, the best approach is to avoid regular shapes, but rectangular shaped basins are planned for this project. The main reason for this decision is the convenience for construction and operation.

To minimize the phenomenon, damping boundaries could be introduced at the end of basin and the impermeable breakwater is preferred. A large entrance is also helpful to reduce the wave resonance.

6.2.4. Ancillary vessel marina

Ancillary vessel marina is a boat basin that has docks, moorings, supplies, and other facilities for small boats. The layout criteria of ancillary marina are briefly described below, which mainly provides mooring facilities for tugboats, pilot boats and line boats here.

The design tugboats have following characteristics:

- LOA: 35 m
- Beam: 10 m

It is designed that a single berthing slip could accommodate 2 tugboats or 1 tugboat and 2 small ancillary boats, or 4 small ancillary boats. Thus, a single typical slip is 25 m in width and 40 m in length. In addition, the minimum distance between a slip and a solid object is 75 m and the width of the marina entrance is 50 m in minimum.

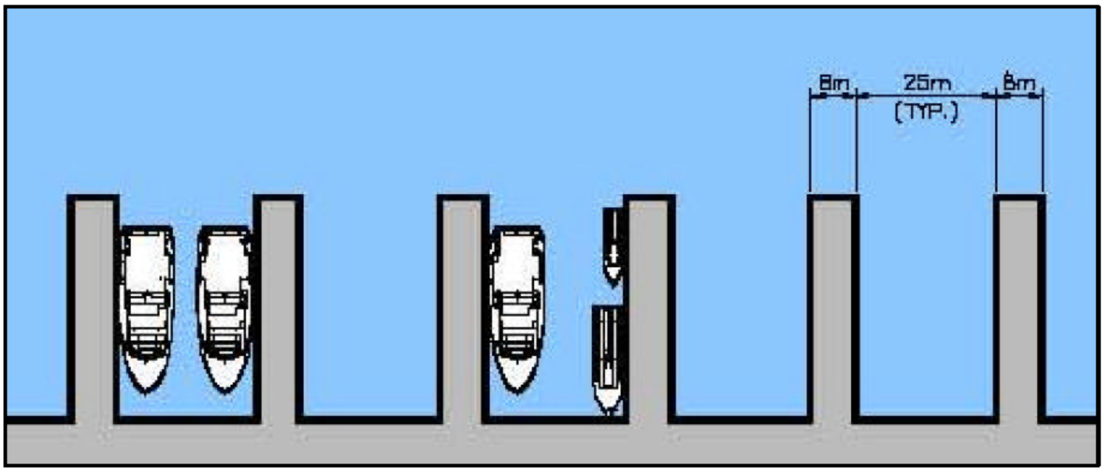


Figure 6.5 Dimensions of typical berthing slips

A preliminary analysis of berthing capacity conducted by HPA showed that 60 typical elements are required by 2030, approximately [Ref.1].

6.3. Landform alternatives

6.3.1. General overview of alternatives

In this section, three different landform alternatives are proposed. These alternatives principally differ in the size of basin and location of channels. Floating container terminals are considered to be unfavorable for this project, and a feasibility study can be found in *appendix A*.

Mainly, these alternatives are carried out with considerations of following issues:

1. Possibility of relocating pipelines;
2. Possibility of using the existing approach channel;
3. Location of turning circles;
4. Possibility of a new approach channel.

Due to the high cost and uncertainty of relocating pipelines, it is not considered for all alternatives. And it is decided to use the existing approach channel as much as possible to minimize the total cost. So areas between the existing channel and pipelines are planned to be the possible new terminal areas.

Two different locations of turning circles are considered: within the basin or in the channel. The former provides more safety but requires larger port areas; the latter saves port areas but causes safety problems.

A new approach channel helps reduce the traffic density and provides more safety. To reduce the cost for the new channel, it is better combined with part of the existing channel and a new dredged channel.

It should be mentioned that the length and location of breakwater are estimated after completion of all terminals. However, a later phase terminal area can act as breakwater for the former terminal; so more breakwaters are needed during the construction.

The basic requirements are the same for alternatives, and they are mentioned in previous sections. The general information of three alternatives can be summarized as:

	A1	A2	A3
Land area (ha)	1,820	1,960	1,900
Quay length (m)	28,670	29,760	29,700
Bridge length (m)	1,000	3,840	4,860
Breakwater length (m)	6,470	7,080	2,920
Reclamation volume (m^3)	227,037,300	261,204,200	254,223,800
Dredging volume (m^3)	126,289,500	172,815,600	218,170,110
Volume difference (m^3)	100,747,800	88,388,600	36,053,690

Table 6.2 General information of alternatives

6.3.2. Alternative 1

The main idea behind this alternative is to minimize the total area and the distance from the mainland. New terminal areas are parallel to the existing Terminal 2, and water areas between terminals are used as harbor basins.

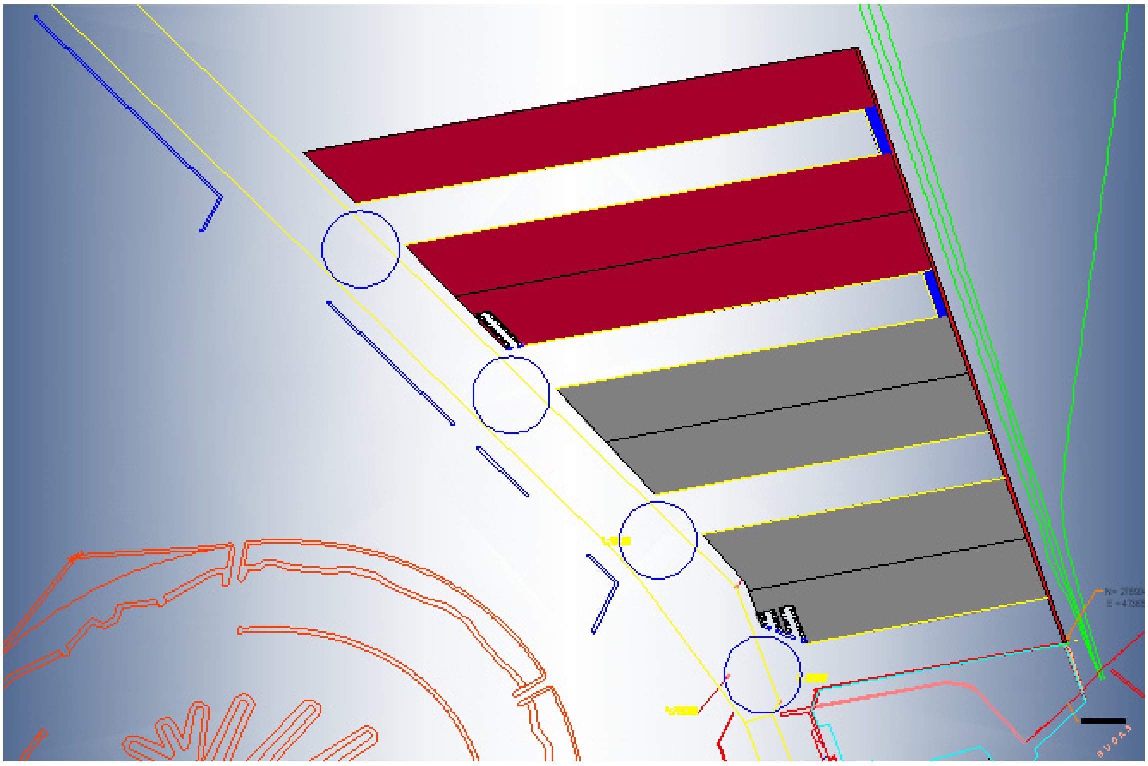


Figure 6.6 Landform Alternative 1

Approach channel
Because water depth at the start point of existing channel is only 17 m, the new channel needs to be further extended into the sea. The new approach channel will starts 26 km (14.7 nautical miles) offshore, with a depth of 18.5 m and width of 610 m. Except for the new extended part of 3 km, the existing channel also needs further widening and deeping.

Turning circle
Turning circles will be located at the approach channel, in order to minimize areas of harbor basin. Each harbor basin has its own area for turning circles before the entrance. For safety consideration, an additional distance between the circumference of turning circle and structures is applied as the beam width of the design vessel.

Harbor basin
Harbor basins are located to the east of the channel with a width of 500 m. Vessels can berth at both sides of the basin. Two bridges will connect the first two reclaimed land to mainland. And, causeways will be constructed for other terminals. These two land-strips also provide space for quays.

Breakwater
Four separated breakwaters are required, with a total length of 6,470 m. Additional distance is designed between the breakwaters and the approach channel, which allows future widening of the planned channel.

Ancillary marina
The tug marina is located near the entrance of harbor basin, which can reduce the turning time for vessels.

6.3.3. Alternative 2

This alternative allows vessels turning around within the basin, which required larger area but provides more safety. Another difference is that the main axis of terminal areas is rotated to reduce the wave penetration into basins.

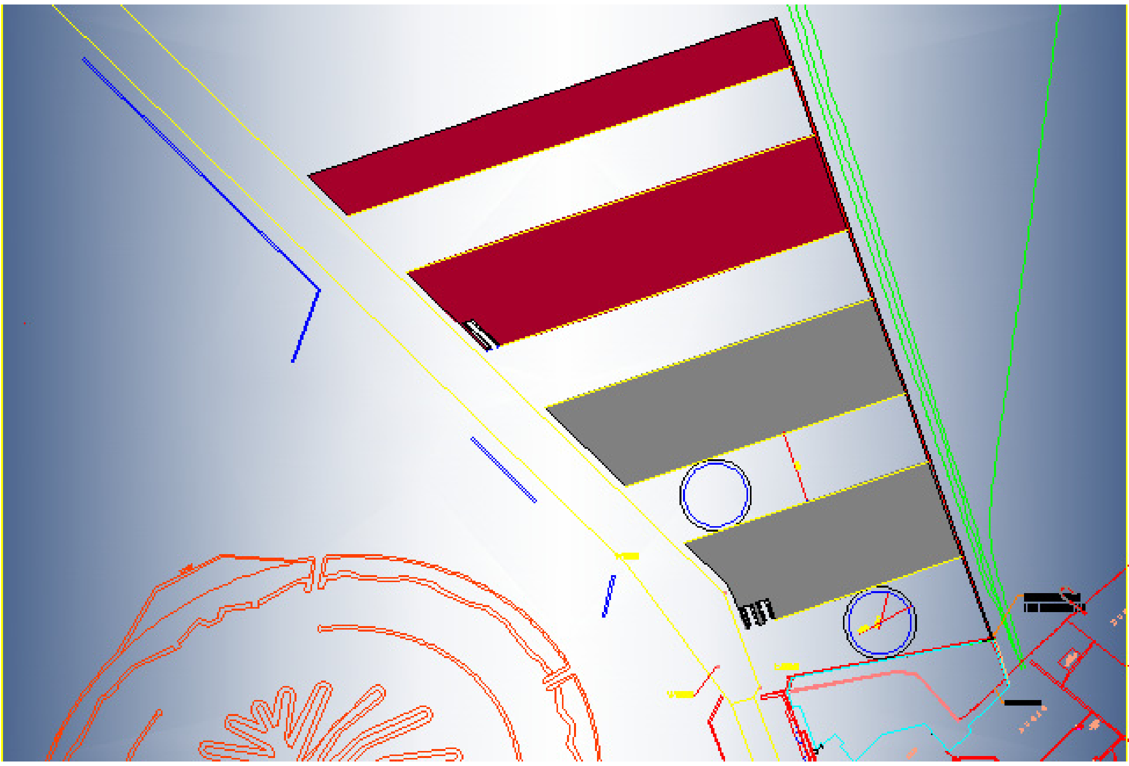


Figure 6.7 Landform Alternative 2

Approach channel
The same approach channel is adopted as the alternative 1.

Turning circle
Vessels can turn around within the basin, which is the current practice at Jebel Ali Port.

Harbor basin

Harbor basins are located to the east of the channel with a width of 906 m. Vessels can berth at both sides of the basin. The basin is designed to be wide enough for vessel turning around even if quays at both sides of the basin are occupied.

In the future, larger vessels can still turn around at a certain location where the side quay is not occupied. For a preliminary design, bridges are adopted between terminals, which allow a good water circulation.

Breakwater
Three separated breakwaters are required, with a total length of 7,080 m. Additional distance is designed between the breakwaters and the approach channel, which allows future widening of the planned channel.

Ancillary marina
The tug marina is also located near the entrance of harbor basin, which can reduce the turning time for vessels.

6.3.4. Alternative 3

This alternative is quite different from other two alternatives. A new approach channel is considered and six reclaimed islands will be constructed instead of four.

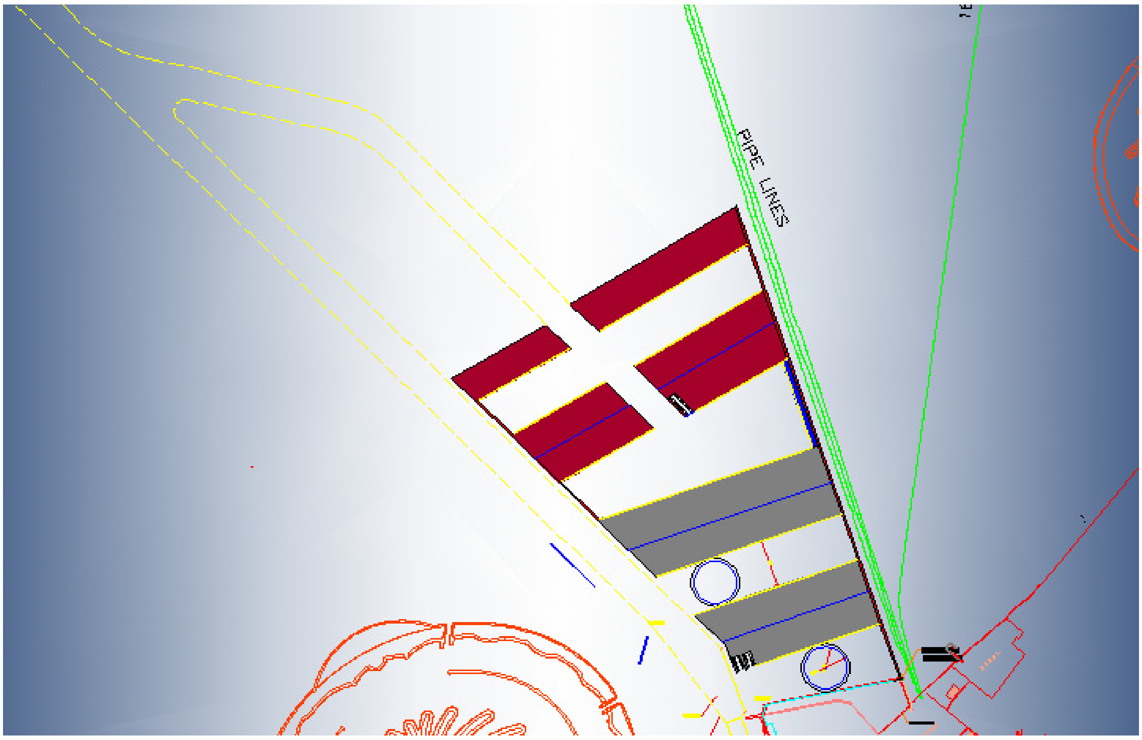


Figure 6.7 Landform Alternative 3

Approach channel

Another channel provides access for other new terminals with a total quay length of 20 km. It shares the first 10 km channel with the main approach channel and the additional 10 km approach channel comprise of two bends and two straight channels.

Turning circle

Vessels can turn around within the basin, which is the current practice at Jebel Ali Port.

Harbor basin

The first two harbor basins are located to the east of the main approach channel and other basins are at the end of the new approach channel.

Breakwater

Two separated breakwaters are required, with a total length of 2920 m. Additional distance is designed between the breakwaters and the approach channel, which allows future widening of the planned channel.

Ancillary marina

The first tug marina is located near the entrance of harbor basin, which can reduce the turning time for vessels. The second one is located in the inside basin, where is well protected from wave penetrations.

7. Multi criteria analysis

These landform alternatives are evaluated by a Multi Criteria Analysis (MCA). On one hand, different aspects with criteria are expressed in scoring pints. On the other hand, gross costs of main elements are estimated. Then the highest value-cost ratio comes to the most promising alternatives.

7.1. Value of the MCA

Main aspects that all alternatives are valued have a weight factors, because one aspect may be more important than the other. The range of score is from 1 to 5, and the score is multiplied by the weight factor. The sum of the results is the total score of the alternative.

7.1.1. Aspects of the MCA

Capacity
The throughput capacity is an important criterion for terminals and it is determined by total length of quay and port areas.

Accessibility of harbour
Oceanographic conditions in the approach channel, including wave, wind and current, can influence the accessibility of the harbor basin.

Nautical safety
The objective of minimizing of hazard is partly classified under the aspects of nautical safety. The safety involves risks of collisions of vessels with other vessels and with structures.

Future expansion
This is the possibility to expand the port in the future to meet a higher throughput requirement.

Environment impact
The new terminals will influence the residence in this area (noise, smell, night light, etc.) and the marine ecosystem. The environmental impact should be reduced, or compensated, if possible.

Maintenance
From a view of life span, enough attentions should be paid to maintenance aspect. Frequent maintenance could influence the operation of terminals and increase the cost. Here, only the maintenance dredging of channels and harbor basins is considered.

Flexibility

The flexibility expresses not only possibilities of rearrange elements without large changes, but also the possibilities of serving larger ships.

Transportation
The complexity and total length of transport lines will influence the efficiency of operation. Only transport lines between terminals are considered here.

7.1.2. Scores of aspects

Scores of different aspects for alternatives are given below, with the range of 1 to 5. A score of 1 is bad and a score of 5 is good. It is intended to give different scores for different alternatives, although the differences between alternatives may be not as big as scores show.

Capacity
Alternative 2 scores best because of the longest quay length and largest terminal areas. Alternative 3 follows with slightly smaller numbers for both aspects.

Accessibility of the harbour
The channel directions are the same for all alternatives; hence the accessibility is evaluated with the protected area of approach channel and location of turning circles.

Alternative 2 scores 5 in this aspect. Because it allows vessels turning around in the sheltered harbour basin, and provides the longest length of breakwater along the approach channel. In general, alternative 1 and alternative 3 provides the same accessibility, but alternative 1 scores a little better with more breakwaters along the channel.

Nautical safety
Alternative 3 scores 5 in this aspect. Because it reduces the traffic density with an additional approach channel and the safety is also increased with large basins.

Alternatives 1 scores the worse for nautical safety. Because vessels will block the channel when turning around and the harbor basin is the smallest. It should be noticed that existing Dubai Ports allows vessel to turn around within the basin. So they don’t have much experience for vessels turning around in the main channel, which also increases the uncertainty for nautical safety.

Harbor expansion
The future expansion of alternatives 3 has more limitations with a new channel. Alternative 1 and alternative 2 can go further freely, but alternative 1 is better because it is closer to the mainland.

Environment impact
The environment impact is simply judged based on the total area of new port (land areas and water areas). Thus alternative 1 scores 5 while alternative 3 scores 1.

Maintenance
Alternative 1 performs the best because of the smallest basin area while alternative 3 is the worst because of the additional channel and large basin area.

Flexibility
Alternative 2 has the best flexibility, because the area between each terminal could be used as quays if necessary. And its wide basin can serve larger vessels in the future. However, alternative 1 has little flexibility because of the fixed smaller basin and some areas between terminals are already used as quays.

Transportation
Alternative 1 is considered to be the best with the smallest length of access road. And alternative 3 only scores 1 point, because of the complexity and total length of transport lines.

It should be mentioned that the downtime is also an important aspect for ports, which is mainly determined by wave penetrations. For these alternatives, it is assumed that the planned breakwater should provide enough protection against wave penetrations and the downtime is the same for all alternatives.

	A1	*A2*	*A3*
Capacity	3	5	4
Accessibility	4	5	3
Safety	1	3	5
Expansion	5	3	1
Environment	5	3	1
Maintenance	5	3	1
Flexibility	1	5	3
Transport	5	3	1
Total score	**29**	**30**	**19**

Table 7.1 Scores table

7.1.3. Weight factor

Now weight factors are give to each aspect, in order to show the importance of different aspects. There is no special requirement for new terminals, so the operational function is considered to be the most important.

The environmental requirement is satisfied as long as the neighborhoods are not against the plan. Mainly, the influence on cooling system of DEWA should be minimized.

To determine weight factors, each aspect is compared to others in following tables. A score of 1 means the item in the row is more important than the item in the column, and a score of 0 means the item in the row is less important than item in the column. According to the ranking, the most important aspect is given the weight factor of 8, while the least important one is given the weight factor of 1.

Aspects	Capacity	Accessibility	Safety	Expansion	Environment	Maintenance	Flexibility	Transport	Total	Weight
Capacity	-	1	1	1	1	1	1	1	7	8
Accessibility	0	-	1	1	1	1	1	1	6	7
Safety	0	0	-	1	1	1	1	1	5	6
Expansion	0	0	0	-	0	0	0	1	1	2
Environment	0	0	0	1	-	1	1	1	4	5
Maintenance	0	0	0	1	0	-	0	1	2	3
Flexibility	0	0	0	1	0	1	-	1	3	4
Transport	0	0	0	0	0	0	0	-	0	1

Table 7. 2 Weight factors set A

The scores in *table 7.1* are multiplied by the weight factor in table 7.2. The sum of the results is the total score of the alternative.

	Weight	Alternative 1		Alternative 2		Alternative 3	
Capacity	8	3	24	5	40	4	32
Accessibility	7	4	28	5	35	3	21
Safety	6	1	6	3	18	5	30
Expansion	2	5	10	3	6	1	2
Environment	5	5	25	3	15	1	5
Maintenance	3	5	15	3	9	1	3
Flexibility	4	1	4	5	20	3	12
Transport	1	5	5	3	3	1	1
Total score		29	117	30	146	19	106

Table 7.3 Total scores table A

7.1.4. Sensitivity analysis

Now different weight factors are applied to see how the total scores fluctuate with different sets. The first set consists of equal weight factors and the second set has emphasis on safety and flexibility aspects.

Aspects	Capacity	Accessibility	Safety	Expansion	Environment	Maintenance	Flexibility	Transport	Total	Weight
Capacity	-	1	1	1	1	1	1	1	7	1
Accessibility	1	-	1	1	1	1	1	1	7	1
Safety	1	1	-	1	1	1	1	1	7	1
Expansion	1	1	1	-	1	1	1	1	7	1
Environment	1	1	1	1	-	1	1	1	7	1
Maintenance	1	1	1	1	1	-	1	1	7	1
Flexibility	1	1	1	1	1	1	-	1	7	1
Transport	1	1	1	1	1	1	1	-	7	1

Table 7.4 Weight factors set B (equal weight)

	Weight	Alternative 1		Alternative 2		Alternative 3	
Capacity	1	3	3	5	5	4	4
Accessibility	1	4	4	5	5	3	4
Safety	1	1	1	3	3	5	5
Expansion	1	5	5	3	3	1	1
Environment	1	5	5	3	3	1	1
Maintenance	1	5	5	3	3	1	1
Flexibility	1	1	1	5	5	3	3
Transport	1	5	5	3	3	1	1
Total score		29	29	30	30	19	20

Table 7.5 Total scores table B

Aspects	Capacity	Accessibility	Safety	Expansion	Environment	Maintenance	Flexibility	Transport	Total	Weight
Capacity	-	1	0	1	1	1	0	1	5	6
Accessibility	0	-	0	1	1	1	0	1	4	5
Safety	1	1	-	1	1	1	1	1	7	8
Expansion	0	0	0	-	0	0	0	1	1	2
Environment	0	0	0	1	-	1	0	1	3	4
Maintenance	0	0	0	1	0	-	0	1	2	3
Flexibility	1	1	0	1	1	1	-	1	6	7
Transport	0	0	0	0	0	0	0	-	0	1

Table 7.6 Weight factors set C (Safety and Flexibility)

	Weight	**Alternative 1**		**Alternative 2**		**Alternative 3**	
Capacity	6	4	24	3	18	5	30
Accessibility	5	4	20	5	25	4	20
Safety	8	1	8	3	24	5	40
Expansion	2	3	6	3	6	5	10
Environment	4	5	20	3	12	1	4
Maintenance	3	5	15	3	9	1	3
Flexibility	7	1	7	5	35	3	21
Transport	1	5	5	3	3	1	1
Total score		28	105	28	132	25	129

Table 7.7 Total scores table C

It is clear that alternative 2 has the highest scores in all cases, but for the equal weight set the difference between alternative 2 and alternative 3 is quite small. This means alternative 2 scores higher for important aspects and lower for less important aspects.

7.2. Cost estimation

The total costs are determined by estimations of costs for main elements. Part of the unit cost is based on the report by HPA in 2005 [Ref.1]. Taking the inflation into account, it is assumed the unit cost increases 20% from 2005.

For this cost estimation, no construction phases are taken into account. It is in contradiction with the real situation. However, for a consideration of time limitation, the influence is neglected.

Dredging and reclamation

The cost depends on the volume of material to be dredged and reclaimed. For this project, the reclaimed volume is much larger than the dredged volume. It is noticed that the reclamation material for nearby Palm Islands was dredged from 20 miles away from the coast and the same practice is assumed for Jebel Ali Port.

Usually, the unit cost is lower when dredged materials can be used for reclamation in nearby areas. In order to show this balance, a unit cost of the dredging & reclamation volume is €2.5/m^{3}and it increases to €3.0/m^3 for extra reclamation volumes.

Approach channel

The cost of approach channel includes costs for dredging, navigation aids (maintenance cost is not considered here). The unit cost for dredging is the same as described above.

The navigation aids system includes buoys, fog signals, leading lights, lightships, radio beacons, radio navigation system, tidal gauges, etc. Usually, the cost for navigation aids system is lower than 3% of the total cost for approach channel. For this project, it is assumed to be 3% of dredging cost.

Sea defense and shore protection

The cost of sea defense is estimated with the length of breakwater and the cost for mobilization. Because the water depth varies slowly in the construction site, it is assumed an average unit cost of €150,000/m for all breakwaters.

Quay structures

The cost for quay wall varies with different types of structures. Usually, the concrete blocks quay structure is an economical alternative, while the caisson quay structure and piles quay structure are more expensive. So it is assumed to use concrete blocks quay for a first estimation. The unit cost is approximately €40,000/m without fenders and crane rails. Additional €5,000/m is applied for these facilities.

Access road

The cost is determined by the mobilization cost and the total length of access road. For a first estimation, a bridge road way is assumed with the unit cost of €60,000/m, while the unit cost for causeway is €25,000/m.

In the end, 15% of the total cost is assumed for the contingency cost. The results can be summarized as:

	A1	*A2*	*A3*
Main elements (€)	2,262,625,860	2,545,508,510	2,609,037,306
Contingency (€)	339,393,879	381,826,277	391,355,596
Total (€/AED)	**2,602,019,739** (AED 14,455,665,217)	**2,927,334,787** (AED 16,262,971,036)	**3,000,392,902** (AED16,668,849,453)

Table 7.8 Cost estimation

7.3. Most promising alternative

The most promising alternative follows from the value-cost ratio of all alternatives; the higher the ratio, the better the alternative.

7.3.1. Values-cost ratio

It is evident that Alternative 2 has the highest value-cast ratio, and thus it becomes the most promising alternative. It is also noticed that Alternative 1 and Alternative 2 are comparable with close rank values.

	A1	*A2*	*A3*
Value	117	146	106
Cost (Billion €)	2.60	2.93	3.00
Ratio	44.97	48.84	35.33
Rank (max=10)	**9.2**	**10.0**	**7.2**

Table 7.9 Value-cost ratio

7.3.2. Recommendation

The cost difference is not as big as the value difference. A main reason is the cost for quay structures accounts for about 45% of the total cost and the quay length is similar for all alternatives.

Because of the small grade of seabed, a larger basin or terminal area doesn't increase the total cost remarkably, but it provides more safety and flexibility for port operations. Actually, more dredging volume is appreciated for compensating dredging/reclamation difference.

It is recommended that a causeway between the first two terminals should be avoided. Because it is close to the cooling system of DEWA, and a free water circulation in this area is important for the running of that system. Further research/simulation for the water circulation and temperature changing is necessary for detail design.

8. Simulation model

As described in Chapter 5, required facilities of container terminals are determined with simulation models and detailed information will be presented in this chapter.

8.1. Introduction

For the preliminary design, a simple standard spreadsheet is used for determining facilities of container terminals. This simulation model is already developed by a colleague in Royal Haskoning.

At the same time, another computer simulation model is developed by the author. This model simulates the behavior of a free quay where vessels can be moored freely instead of fixed berths quay. It's used to perform simulations for the most promising alternative and examine the results from the early design.

The main simulation program is written with *Microsoft Visual C++ 2005 Express Edition*.

This simulation study should provide following information of required facilities for container terminals:

- Required quay length
- Number of required cranes

8.2. Basic theories

Monte Carlo method
The term Monte Carlo was coined in the 1940s by physicists working on nuclear weapon projects in the Los Alamos National Laboratory. The Monte Carlo method is a computational algorithm which relies on repeated random sampling to compute its results. Monte Carlo methods are often used when simulating physical and mathematical systems. It tends to be used when it is infeasible or impossible to compute an exact result with a deterministic algorithm.

Erlang distribution
Usually, the arrival distribution of container vessels is sujected to the Erlang distribution (Erlang 2 or Erlang 3). 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:

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

where e is the base of the natural logarithm and ! is the factorial function. The parameter k is called the shape parameter and the parameter λ (1/θ) is called the rate parameter.

In the queuing theory, the Erlang distribution with parameter k is often written as E_k. When k equals to 1, it gives the same distribution as negative exponential distribution (also written as M distribution).

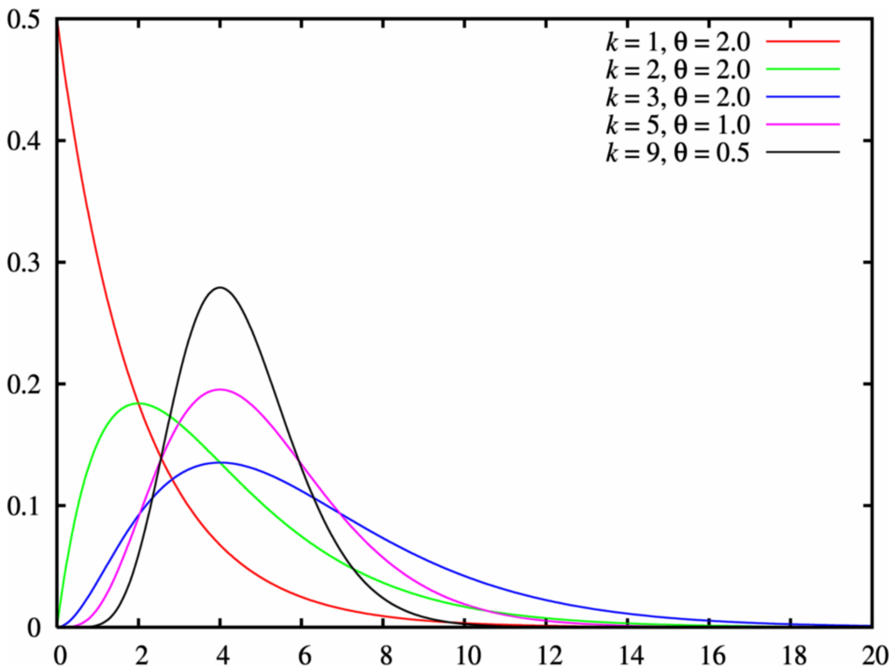


Figure 8.1 Probability density functions for Erlang distribution

Running time

As a good rule of thumb, the maximum lag for which auto-correlation is computed should be approximately 10% of the number of n observations. Thus lag coefficients are used to determine minimum sample sizes. Geisler (1962) shows the minimum sample size to assure that the estimation of the mean lies within 10% of the true mean with probability α=0.05:

$$n=\frac{t_{\alpha/2}^2\cdot \mathrm{var}(X_i)\cdot[1+2\sum_{p=1}^{m}\{(1-\frac{p}{m+1})\cdot\rho_{p,x}]\}}{(d\mu)^2}$$

Queue discipline

In situation where a queue of several customers has been formed there must be some way of deciding which one is to be served. The determining rules are called the queue discipline.

The queue discipline can be described as [Ref.7]:

1. Dependent on the arrival time in the queue
   i. FIFO (First in First out) or FCFS (First Come First Served)
   ii. LIFO (Last in First out)
   iii. Random

2. Dependent on the service time
   i. SPT (Shortest Processing Time First)

3. Dependent on the priority

FIFO is an abstraction in ways of organizing and manipulation of data relative to time and prioritization. This expression describes the principle of a queue processing technique or servicing conflicting demands by ordering process by first-come, first served (FCFS) behaviors: what comes in first is handled first, what comes in next waits until the first is finished.

8.3. Free-quay model

8.3.1. Introduction

Vessels are berthed according to available space and other constraints as number and size of bollards, number and location of main pieces of handling equipment, nautical constraints etc. Among these, available space and number of gantry cranes are the governing parameters, which can be determined by this simulation model.

Generally, there are two types of quay models regarding to the berth arrangement. One is fixed-berths model, where every berth has its own fixed length and boundaries. The other one is free-quay model, where no fixed boundaries exist between berths. The former is usually used for general cargos and the latter is usually used for container vessels. The process of berthing, loading/unloading, waiting and leaving for a free-quay is more complicated than a fixed-berths-quay.

This free-quay model includes two elements, a standard spreadsheet and an executable file (.exe file). The spreadsheet is used for generating vessels arrival information. In case this information can be obtained from other sources, only the executable file is needed.

User defined parameters and vessels arrival information can be generated in the standard spreadsheet. Then user defined parameters should be copied and pasted to a notebook file, and the suffix name should be changed to *.udp*(the default one is *.txt*). The same procedure is required for vessels arrival information, and the suffix name should be *.vai*. It should be mentioned that these two files must have the same file name (for example, *simulation.udp and simulation.vai*).

Then the executable file reads input data from these two files and the simulation is performed. When a simulation is completed, three output files are generated with the same file name as input file, but with different suffix names.

8.3.2. Basic assumptions

The required facilities are determined in regard to waiting time of vessels. Here some assumptions are made:

- An idle time of 3 hours is considered for every vessel, which includes the sailing time from the waiting area to berths, berthing time and unberthing time.
- The container vessels' arrival pattern is Erlang 3 distribution, which means relatively regular arrival time.
- According to UNCTAD, 10% of waiting time ($t_{waiting}/t_{service}$=10%) is acceptable for container terminals and the criteria is applied to determine facilities.
- It is assumed that all berths are not occupied and no vessel is waiting at the beginning of simulation. However, with a long duration of the simulation period, the results are independent of conditions at the beginning.
- The required quay length of each vessel is determined with LOA and additional 25 meters between two berths.
- The number of cranes is unrestricted in this model. And the downtime of cranes is not considered.
- It is assumed that cranes can move immediately and freely along the quay to the destination, which means cranes can even move across other cranes (it is obviously impossible for practical operations).
- Berthing and unberthing of vessels can influence the operation of nearby berths, but this model doesn't take it into account.

8.3.3. Model input

Sizes of container vessels

The sizes information of container vessels is only available for a peak week in 2003 (from 18, Oct. 2003 to 24, Oct. 2003). The result is summarized as:

Length (m)	75-185	145-214	180-260	235-285	250-300	265-315	315-400
No.	23	10	6	5	5	4	-

Table 8.1 Vessels length distribution [Ref.1]

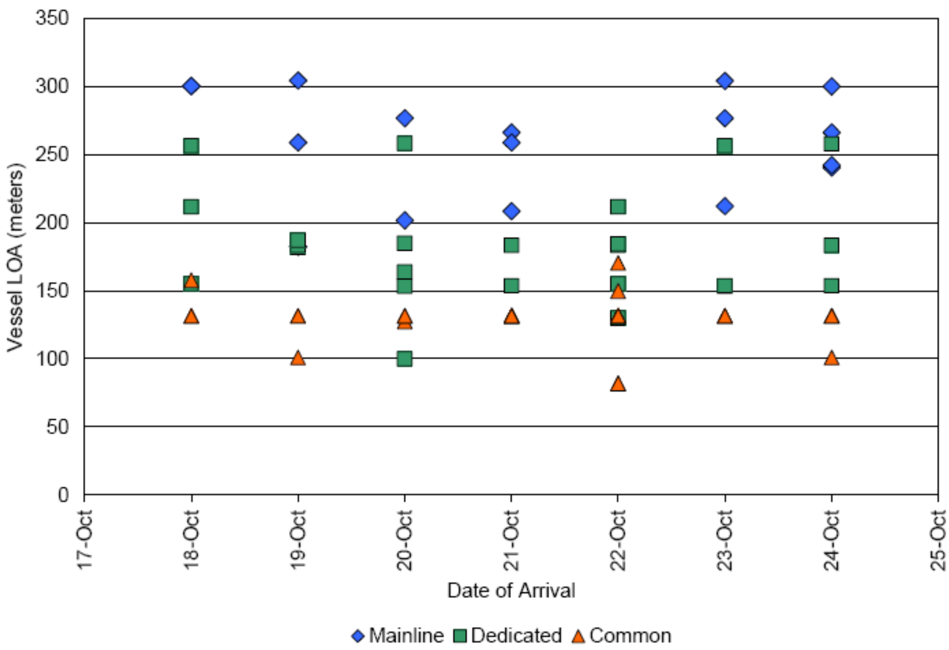


Figure 8.2 Vessel length distribution during a peak week [Ref.1]

The sizes distribution is determined with considerations of the peak distribution, the distribution of Lloyd's registered vessels statistics and future analysis of vessel sizes conducted by HPA.

Capacity (TEUs)	Length (m)	Draught (m)	Breadth (m)	Percentage	Max number of cranes
100-1,000	75-185	3.0-10.5	11-28	35%	2
1,000-2,000	145-214	8.0-12	23-33	25%	3
2,000-3,000	180-260	10.0-12.5	29-33	10%	4
3,000-4,000	235-285	11.5-13.0	32-33	10%	5
4,000-5,000	250-300	12.5-14.5	32-38	10%	6
5,000-7,000	265-315	12.5-14.5	38-42	8%	8
7,000-11,000	315-400	14.0-15.5	42-56	2%	10

Table 8.2 Container vessels distribution for simulation

Arrival pattern

The arrival pattern is assumed to be Erlang 3 distribution, because of regularly scheduled calls for container vessels in Jebel Ali Port. Historical data shows that 40% of feeder vessels and 65% of mainline vessel arrive on time.

Containers information
The TEU factor is assumed to be1.5, which means the same amounts of FEU (Forty feet equivalent Unit) and TEU (Twenty feet Equivalent Unit) are handled in the terminal.

A statistical analysis of distributions of containers' exchanges per ship was conducted by *Hans Agerschou* for 20 international container terminals in 2000. For import/export terminals, he believes that exchange distribution conforms to the theoretical normal distribution with small length range of calling vessels. But no theoretical distribution was found for transshipment or mixed terminals [Ref.9].

Thus it is simply assumed that the amount of containers that need to be handled is between 50% and 100% of the vessel's capacity, with uniform distribution between the minimum and the maximum. However, this assumption will be examined with the simulation model.

Crane productivity
Most container gantry cranes have a theoretical output of 35 to 40 moves per hour or more. The commercial output, depending on local conditions, varies usually from 15 to 35 in average, with peak performance nearing theoretical performance.

According to the study by HPA, quay crane productivity is designed to be 28.6 lifts/hour and crane interference is assumed to 20%, on average [Ref.1]. Thus the crane productivity equals to 34.3 TEUs/hour/crane or 0.57 TEU/min/crane.

Downtime
The downtime is assumed to be 3 days. Accurate downtime estimation should be based on the analysis of wave penetration, which is beyond scopes of this study.

8.3.4. Input & Output

8.3.4.1. General information

The input includes user defined parameters, vessel length distribution, average inter arrival time and the Erlang parameter.

The output includes three reports: Summary (*.sum*), Vessel Units Information (*.vui*), Run-Time Information (*.rti*).

The Summary report contains basic results for the simulation, which are used for the determination of quay length and number of cranes, including:

- Length of run
- Total movements
- Yearly throughput
- Required number of cranes

- Quay occupancy rate
- Crane occupancy rate
- Average waiting rate
- Number of vessels without waiting
- No waiting rate

The Vessel Units Information report includes detailed information for every vessel and the detailed information of every time step is contained in the Run-time Information report. These reports are mainly used for testing.

8.3.4.2. Parameters definition

Required number of cranes (RNC):
The maximum number of operating cranes for all time stamps.

No waiting vessels (NWV):
Number of vessels can be served without waiting.

Quay occupancy rate (QOR):

$$QOR = \frac{\sum (Occupied\_Length * Occupancy\_Time)}{Total\_Length * Time\_Span} * 100\%$$

Crane occupancy rate (COR):

$$COR = \frac{\sum (Operating\_Crane\_No. * Operation\_Time)}{RNC * Time\_Span} * 100\%$$

Average waiting rate (AWR):

$$AWR = \frac{\sum (Waiting\_Time / Service\_Time)}{Total\_Movements} * 100\%$$

No waiting rate (NWR):

$$NWR = \frac{NWV}{Total\_Movements} * 100\%$$

8.3.5. Standard spreadsheet

A standard spreadsheet is mainly used to generate database files for simulation program, which means the program can just read a database file with information of all vessels (including arrival time, LOA, exchanged containers and number of cranes) and perform berthing procedures, rather than generating information of each vessel itself.

The standard spreadsheet includes four work sheets: INPUT&OUTPUT, VAI, VS and Erlang. The information of arrival time and number of exchanged containers are generated in the VAI sheet, and vessel sizes information is generated in the VS sheet. As mentioned above, these data are copied to two text files, UDP file and VAI file.

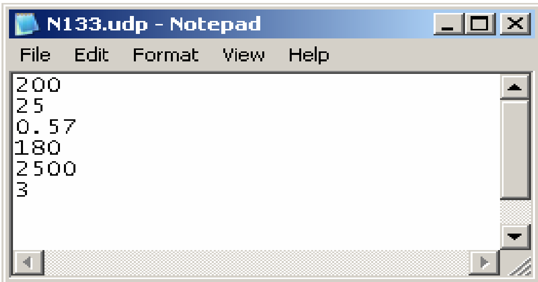
The UDP file should contain information of Quay length, Space between vessels, Loading/unloading rate, Idle time and Number of calls/movements. And the VAI file should include information about Serial number of vessels, LOA, Exchanged container, Assigned cranes and Arrival time.

It is assumed that the number of crane for loading/unloading is determined by the size of vessel, and different values can be defined by user. However, the number must be smaller than the maximum allowable number.

An example follows (one the left side is data in the standard spreadsheet and on the right side is the corresponding text file):

*.udp

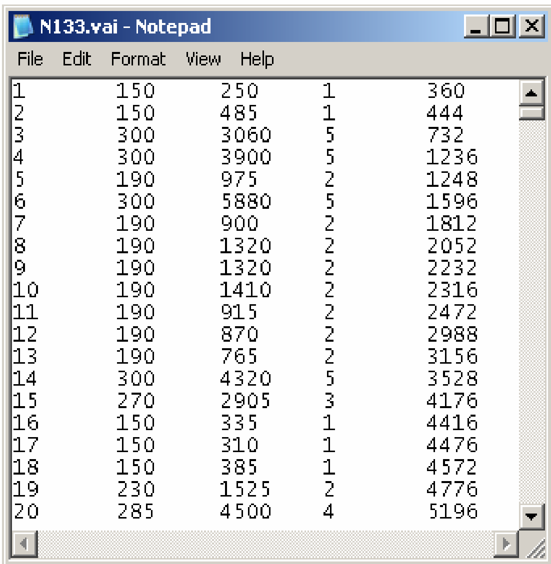
Quay length	2000	m
Space between vessels	25	m
Loading/unloading rate	0.57	TEU/min
Idle time	180	mins
No. of vessels	2500	units
Downtime	3	day/year



```
N133.udp - Notepad
File  Edit  Format  View  Help
200
25
0.57
180
2500
3
```

*.vai

No.	LOA (m)	TEU	Cranes	Arrival Time
1	150	250	1	360
2	150	485	1	444
3	300	3060	5	732
4	300	3900	5	1236
5	190	975	2	1248
6	300	5880	5	1596
7	190	900	2	1812
8	190	1320	2	2052
9	190	1320	2	2232
10	190	1410	2	2316
11	190	915	2	2472
12	190	870	2	2988
13	190	765	2	3156
14	300	4320	5	3528
15	270	2905	3	4176
...	...	...	...	...



```
N133.vai - Notepad
File  Edit  Format  View  Help
1    150   250    1    360
2    150   485    1    444
3    300   3060   5    732
4    300   3900   5    1236
5    190   975    2    1248
6    300   5880   5    1596
7    190   900    2    1812
8    190   1320   2    2052
9    190   1320   2    2232
10   190   1410   2    2316
11   190   915    2    2472
12   190   870    2    2988
13   190   765    2    3156
14   300   4320   5    3528
15   270   2905   3    4176
16   150   335    1    4416
17   150   310    1    4476
18   150   385    1    4572
19   230   1525   2    4776
20   285   4500   4    5196
```

8.3.6. Simulation program

8.3.6.1. General process

At the beginning, the program reads data from UDP and VAI files, and a database with these information is generated. Then two other databases are generated, which are Vessel information and Run-time information.

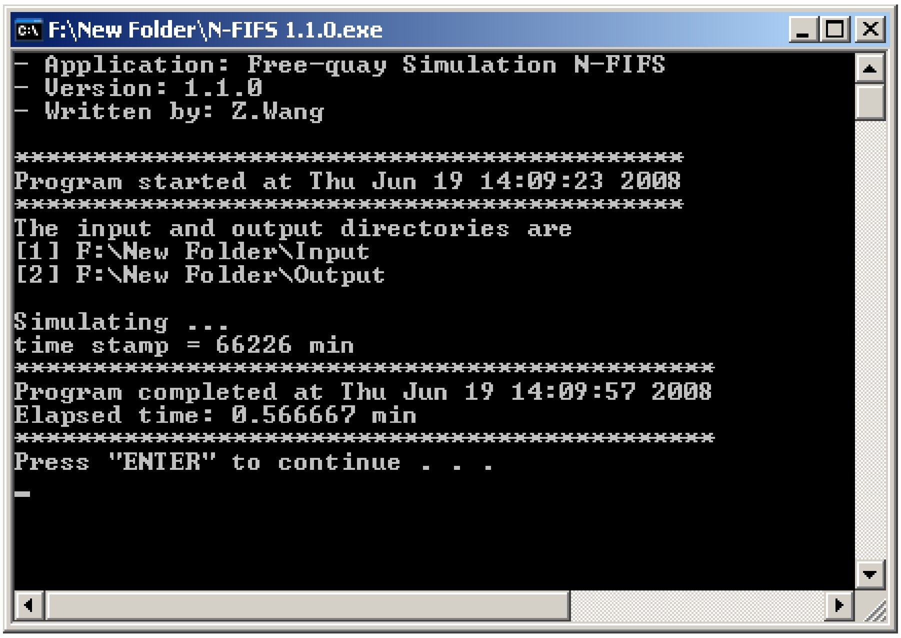
Vessel information database contains the arrival time, start time, complete time, leaving time, waiting time, service time, idle time, total time and vessel state (incoming, waiting or completed) of each vessel.

Run-time formation database contains the crane in use and number of incoming vessels, waiting vessels service vessels, idle vessels and completed vessels for each time stamp.

For every time step, three databases are loaded and renewed. The default time step is 1 minute. At the end of a simulation, output parameters will be calculated according to data stored in three databases.

VESSEL INFORMATION (mins)								
No.	Arrival Time	Start Time	Complete Time	Leaving Time	Waiting Time	Service Time	Idle Time	Total Time
1	132	132	982	1162	0	850	180	1030
2	336	336	1296	1476	0	960	180	1140
3	552	552	1302	1482	0	750	180	930
4	912	912	1780	1960	0	868	180	1048
5	1092	1092	1592	1772	0	500	180	680
6	1464	1464	2244	2424	0	780	180	960
7	1788	1788	3282	3462	0	1494	180	1674
8	2064	2064	2520	2700	0	456	180	636
9	2580	2580	3816	3996	0	1236	180	1416
10	3156	3156	4377	4557	0	1221	180	1401
11	3612	3612	4414	4594	0	802	180	982
12	3804	3804	5909	6089	0	2105	180	2285
13	3900	3900	4755	4935	0	855	180	1035
14	4548	4548	6682	6862	0	2134	180	2314
15	4968	4968	5875	6055	0	907	180	1087
16	5364	5364	5986	6166	0	622	180	802
17	5916	5916	6407	6587	0	491	180	671
18	6240	6240	7906	8086	0	1666	180	1846
19	6528	6528	7199	7379	0	671	180	851
20	6804	6804	7365	7545	0	561	180	741
21	6936	6936	8220	8400	0	1284	180	1464
22	7176	7176	8215	8395	0	1039	180	1219
23	7344	7344	8330	8510	0	986	180	1166
24	7608	7608	9306	9486	0	1698	180	1878
25	7956	8086	9533	9713	130	1447	180	1757
26	8064	8086	9445	9625	22	1359	180	1561
27	8364	8395	9513	9693	31	1118	180	1329
28	8952	8952	10364	10544	0	1412	180	1592
29	9336	9486	11528	11708	150	2042	180	2372
30	9432	9486	10100	10280	54	614	180	848

Figure 8.3 Vessel information file imported in Excel

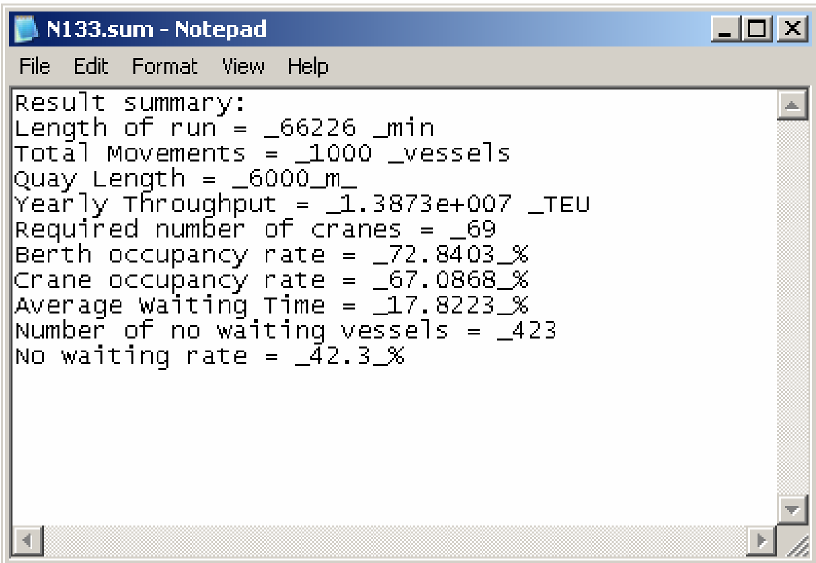


```
F:\New Folder\N-FIFS 1.1.0.exe
- Application: Free-quay Simulation N-FIFS
- Version: 1.1.0
- Written by: Z.Wang

*******************************************
Program started at Thu Jun 19 14:09:23 2008
*******************************************
The input and output directories are
[1] F:\New Folder\Input
[2] F:\New Folder\Output

Simulating ...
time stamp = 66226 min
*********************************************
Program completed at Thu Jun 19 14:09:57 2008
Elapsed time: 0.566667 min
*********************************************
Press "ENTER" to continue . . .
_
```

Figure 8.4 Simulation program



```
N133.sum - Notepad
File Edit Format View Help
Result summary:
Length of run = _66226 _min
Total Movements = _1000 _vessels
Quay Length = _6000_m_
Yearly Throughput = _1.3873e+007 _TEU
Required number of cranes = _69
Berth occupancy rate = _72.8403_%
Crane occupancy rate = _67.0868_%
Average Waiting Time = _17.8223_%
Number of no waiting vessels = _423
No waiting rate = _42.3_%
```

Figure 8.5 An example of output Summary file

A flow chart could be helpful to understand the process:

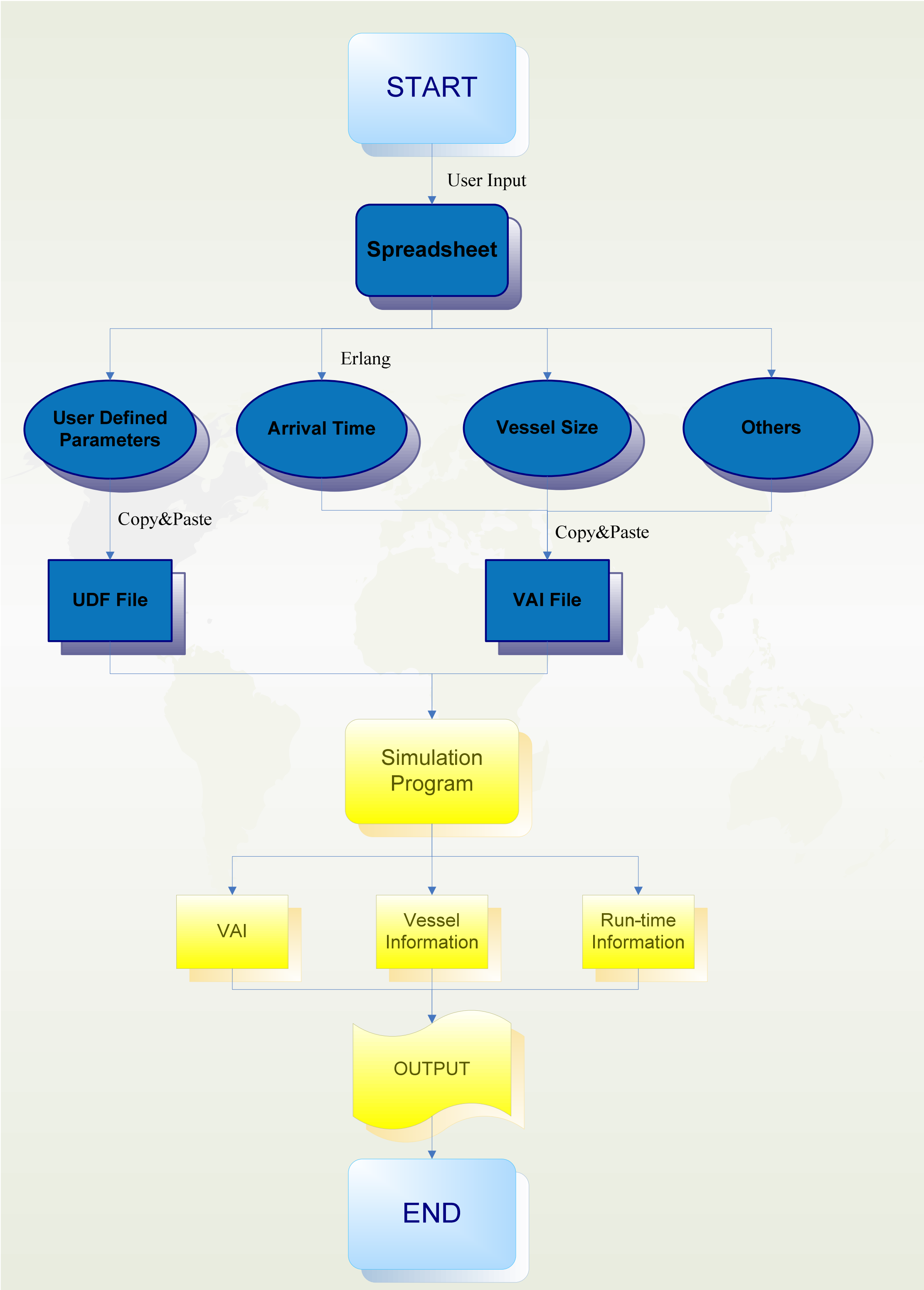


Figure 8.6 Simulation flow chart

8.3.6.2. Simulation process

The main idea behind the model is coloring and searching for continuous available elements. A straight quay and each vessel are divided into many elements, and each element has a length of one meter.

The simulation program first reads database from two text files and all quay elements are marked with ‘0’ at the beginning, which means available. Then the program starts simulation from time stamp 0 until all vessels leave the quay. For every time stamp, the program searches for arrival vessels according to the arrival time stored in the database.

If one arrival vessel found, it will be firstly put into the waiting list. After searching for arrival vessels, the program starts searching in the waiting list, for a required number of continuous ‘0’ in the quay elements, which is determined by the LOA and distance between vessels.

The program searches along the quay, and the length of every suitable berth will be compared. Then the berth with the minimum length will be assigned to the vessel.

Each vessel has its own serial number, which starts from 1 to the number of total calls/movements. If an available berth is found, these continuous quay elements will be marked with the serial number of the vessel, and the vessel will be kicked out of the waiting list. Then, the service time is calculated with exchanged containers divided by the total crane productivity. And the leaving time is determined by adding service time, idle time and waiting time to the arrival time.

The waiting time is calculated by (service) start time minus arrival time. Although every vessel has to go to the waiting list, the waiting time is 0 if the vessel successes to find a berth at one time stamp.

The program also searches for leaving vessel at every time stamp according to the leaving time stored in the database. When a vessel leaves, all the occupied quay elements will be marked with 0 and they become available again.

Another thing to be mentioned is that the number of operating cranes along the quay is recorded for every time stamp, which is used for required number of cranes.

It should be mentioned that vessels on the waiting list is sorted according to the arrival time (the serial number). When the FCFS principle is applied, if the first vessel on the list can’t find a berth, the program will stop the arranging for other vessels.

For example, there are two vessels on the waiting list; the first one requires a berth length of 200 m while the second one requires 150 m. At a certain moment, a vessel leaves, and a berth length of 180 m is available. Although the second one could fit into the berth, both of them will stay on the waiting list.

Finally, the required quay length and number of cranes for one TEU throughput is reached with the principle of approximately 10% of waiting rate. Results of ten simulations are arithmetically averaged for the final values. The arithmetic average should be used for linear distributions between the waiting rate and other parameters, which is not the case. To minimize the influence, only the results of waiting rate between 9% and 11% are averaged for the final results.

A flow chart follows:

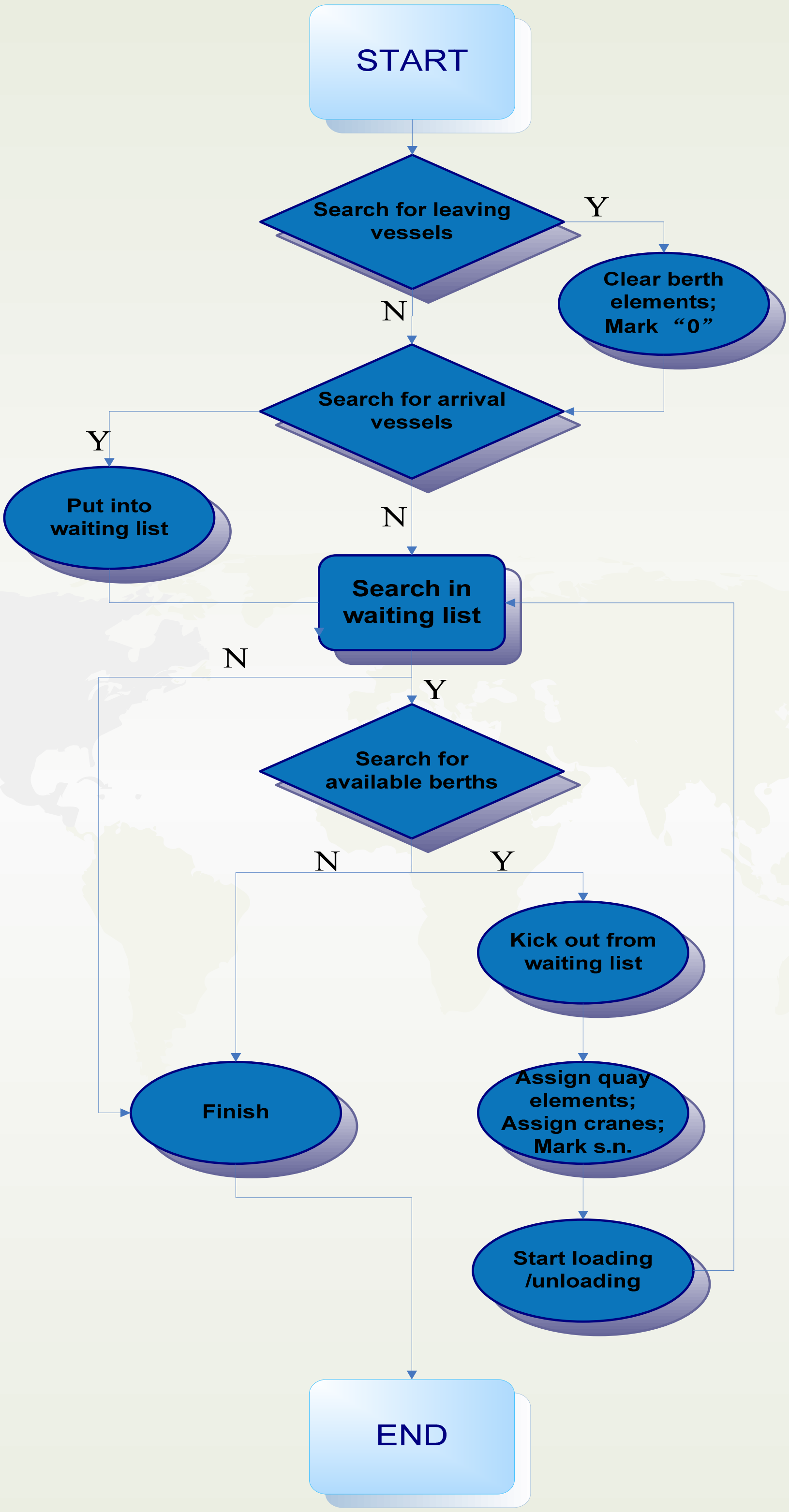


Figure 8.7 Flow chart for one time step with FCFS

8.3.7. Model validation

The simulation model is validated with results from queuing theory.

A quay of 2000 m is simulated with N-FCFS principle, Erlang 2 distribution, and 50% to 100% exchange rate. Simulation results are compared with results of the queuing theory ($E_2/E_2/8$).

The simulation model gives similar number of quay productivity and number of cranes, but the berth occupancy rates/utilizations for the same waiting rate are somehow different. Thus, the relationship of waiting rate and BOR is further studied.

8.3.7.1. Waiting rate & BOR

The relationship between waiting rate and berth occupancy rate is studied and results from the model and queuing theory are compared.

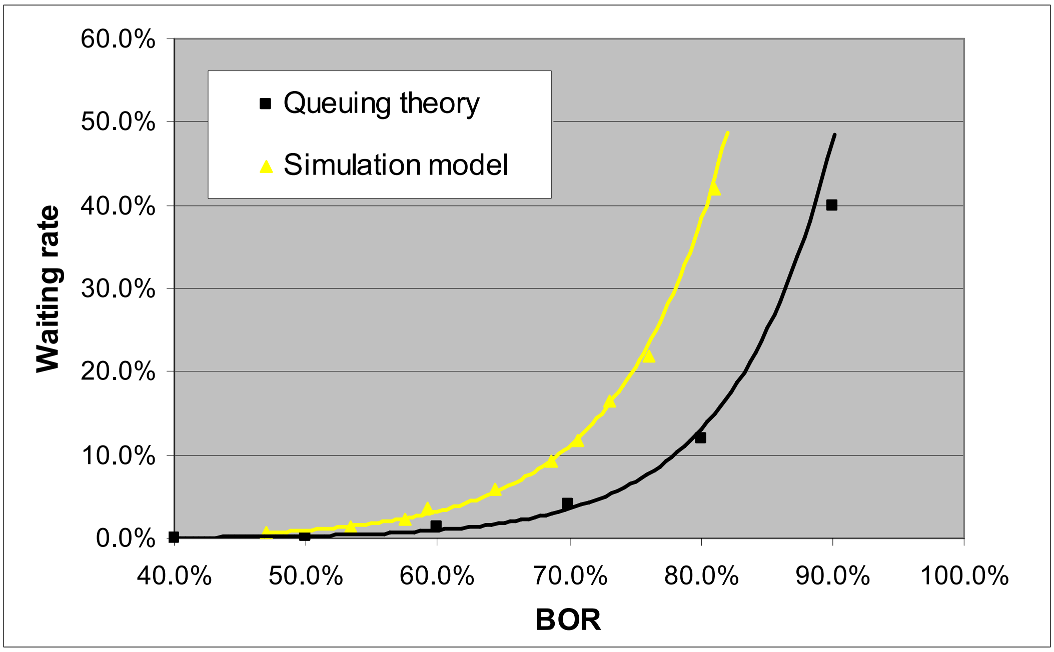


Figure 8.8 Waiting rate & BOR

There is a difference between results of simulation model and queuing theory. A liner relationship exists and results of the new model are 9% lower than queuing theory, on average.

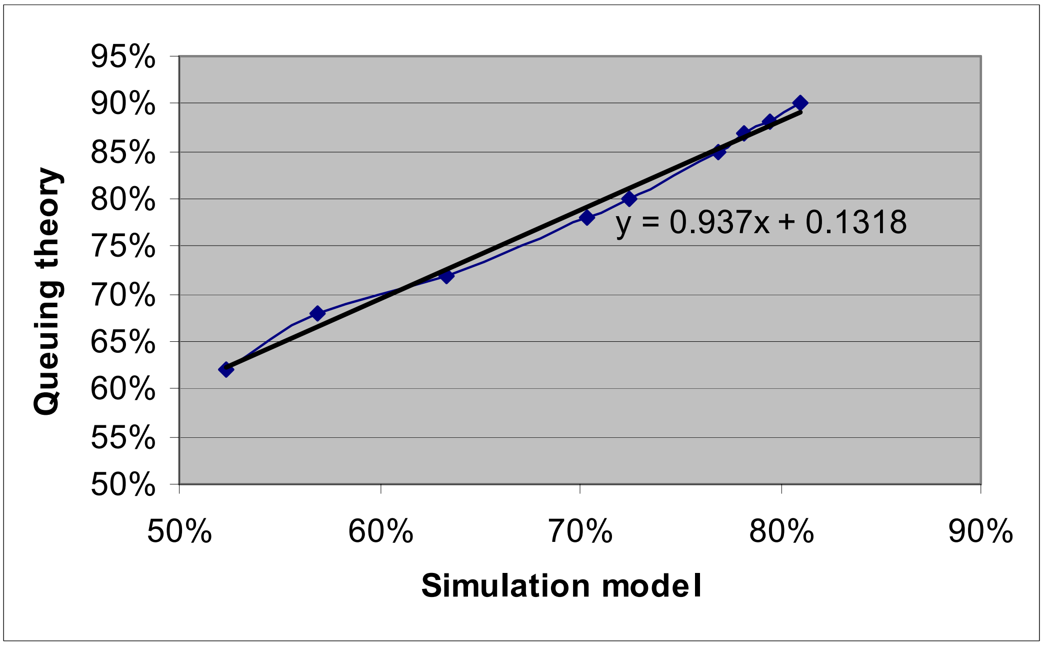


Figure 8.9 Relationship of BOR between simulation model and queuing theory

The different units used for calculating BOR/utilization is considered to be a reason of this difference. BOR of queuing theory is based on the unit of one berth, while the simulation model is based on the unit of one meter length of berth.

For example, a berth of 300m is available for a certain moment. A vessel of 200 m is berthed within that space and it occupied the space for a time of T (distance between vessels is not considered here).

The model calculates the total occupancy time as 200*T, while the queuing theory gives 300*T. So the berth occupancy time is higher according to queuing theory than that of this model.

If this assumption is correct, the berth occupancy rate should be the same without this unit difference. Thus a simple case is made to examine this model.

A total length of 2400 m is simulated and all vessels have the same length of 300 m. Idle time and distance between vessels are not considered. This quay has exactly 8 berths with length of 300 m. Thus, there should be no difference of units. Other assumptions are the same.

Results are summarized in the following figure:

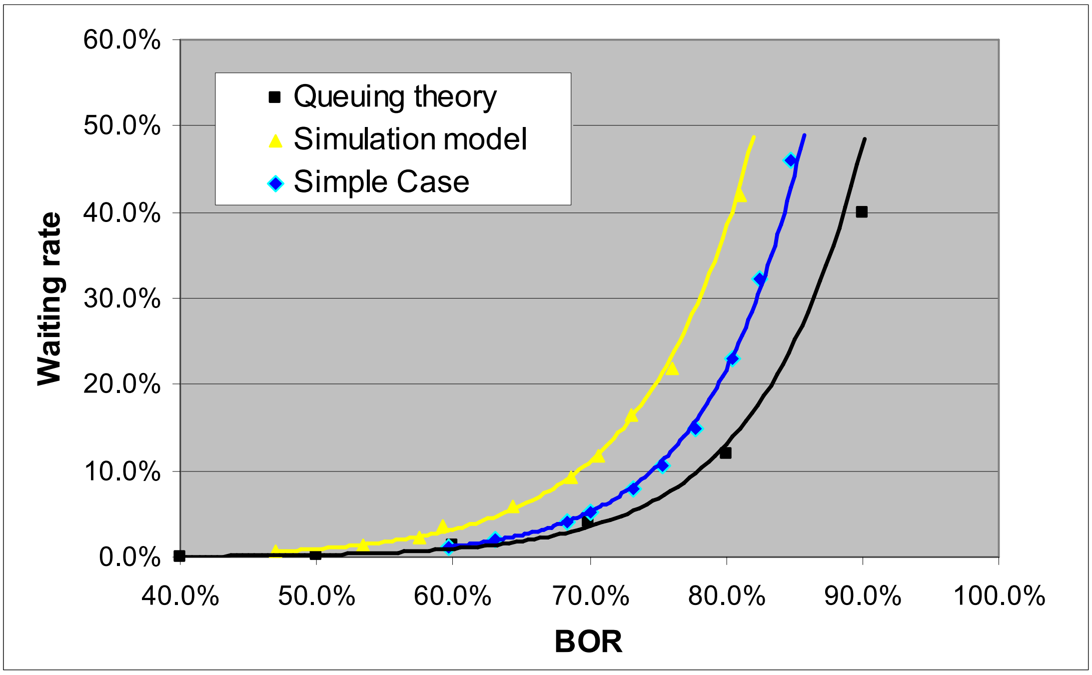


Figure 8.10 Results of the simple case

The result proved that units difference does influence the BOR. It is noticed that for a low waiting rate, the difference of BOR is negletable.

It is noticed that the waiting time increase very rapidly after the BOR reaching 80%, which is different from the queuing theory. Different assumptions of service pattern, exchange rate, and number of cranes may be the reason of this difference. Further studies will be helpful to examine reasons of this difference.

8.3.8. Model analysis

8.3.8.1. FCFS (First Come First Served)

FCFS is widely used for queuing models and the application of FCFS for this free-quay model is firstly examined.

Ten same input files are used for simulations with and without the principle of FCFS. These simulations are based on 2500 calls, 2000 m straight quay, and 50%-100% exchange rate. The results of waiting rate and NWR are compared.

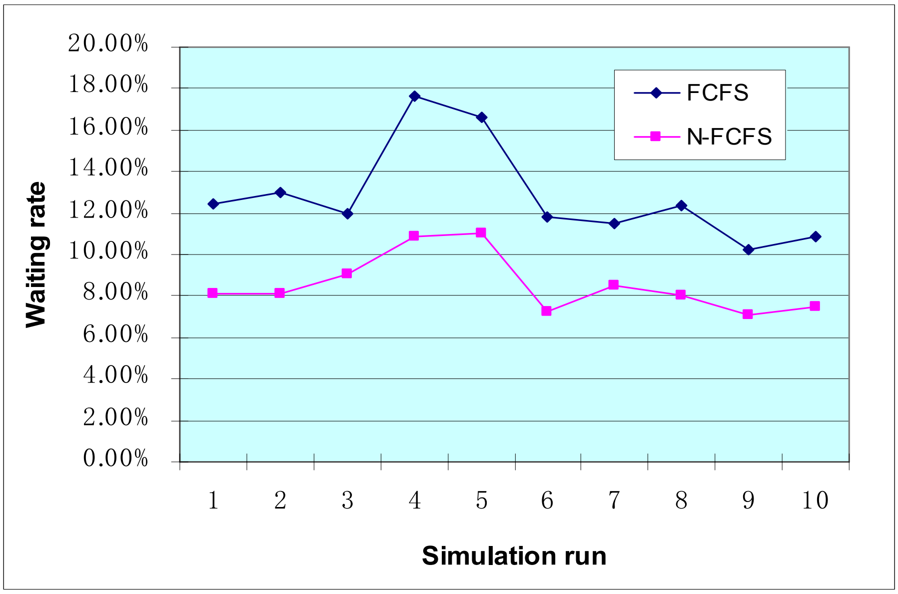


Figure 8.11 Waiting rate for ten simulations

This model shows that FCFS leads to higher waiting rate and lower NWR. The main reason is that more small vessels have to wait if a large vessel can't find a berth; even berths for small vessels are actually available. Based on previous experience of port operations, the N-FCFS gives reasonable results of quay productivity and BOR, so the FCFS principle will not be applied to this model.

It should be noticed that N-FCFS allows small vessels jumping the queue, so the waiting time of large vessel can be long. And these large vessels are usually the mainline vessels, which have some priorities over feeder vessels.

	Waiting rate (%)		NWR (%)	
	FCFS	**N-FCFS**	**FCFS**	**N-FCFS**
Ave	**12,84%**	**8,55%**	**63,3%**	**72,5%**
1	12,45%	8,13%	67,8%	76,8%
2	13,00%	8,09%	62,6%	73,3%
3	11,97%	9,05%	63,4%	70,7%
4	17,61%	10,83%	58,4%	68,8%
5	16,62%	11,05%	57,7%	68,4%
6	11,82%	7,24%	63,6%	72,5%
7	11,51%	8,50%	63,9%	73,0%
8	12,35%	8,02%	62,2%	71,6%
9	10,26%	7,08%	68,0%	75,2%
10	10,84%	7,51%	65,2%	74,7%

Table 8.3 Simulation results

8.3.8.2. Exchange rate/call size

At the beginning, it is assumed that the amount of containers that need to be handled is between 50% and 100% of the vessel's capacity, with uniform distribution between the minimum and the maximum.

This assumption is not the case for practical operations, so the sensitivity of exchanged rate is analyzed here.

Exchanged rates are designed to differ as 30-80%, 40-90% and 50-100%, with equal distribution between the minimum and the maximum. Ten simulations are performed for each exchanged rate. The required quay length for one TEU throughput is reached with the principle of approximately 10% of waiting rate.

The required quay lengths of one million TEU throughputs are drawn in the following figure. The results are sorted from the minimum to the maximum, in order to avoid intersecting of three lines.

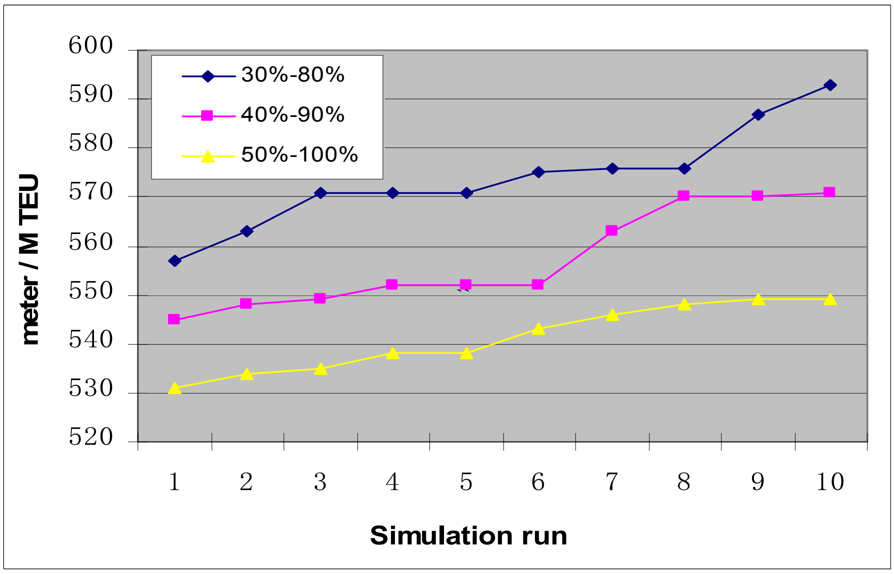


Figure 8.12 Required quay lengths of different exchange rates

	Yearly Throughput	Waiting Rate	NWR	Average Length	Average Cranes
Exchange rate	(M TEU/Year)	(%)	(%)	(m/M TEU)	(units/M TEU)
30%-80%	3.48	9.81%	70.1%	574	7.0
40%-90%	3.59	9.84%	69.6%	557	7.0
50%-100%	3.68	9.87%	69.9%	543	6.8

Table 8.4 Simulation results of different exchange rates

The average required quay length increases with low exchange rate. It can be explained that lower exchange rate requires more vessel calls to achieve the same throughput and it takes each vessel some time (berthing, custom, etc.) before loading/unloading starts. So a low exchange rate decreases the quay productivity.

However, the influence of different exchange rates on required quay length is limited in this model. As shown in *Table 8.4*, if the average exchange decreases for 10%, NWR and average crane numbers are almost the same, while the average required quay length only increases for 2.5%.

Thus, it is conclude that exchange rate is not a sensitive parameter for the required quay length and number of cranes in this model, so the assumption made at the beginning will be used for the final simulation.

8.3.8.4. Long straight quay

The new Jebel Ali Port will have very long straight quays (more than 6 km), which are very unusual in other container terminals. Whether a very long straight quay can bring a “scale effect” is an interesting topic.

Straight quays with different total length are simulated to study the scale effect. Vessel calls are increased for longer length simulation, in order to provide sufficient simulation running time.

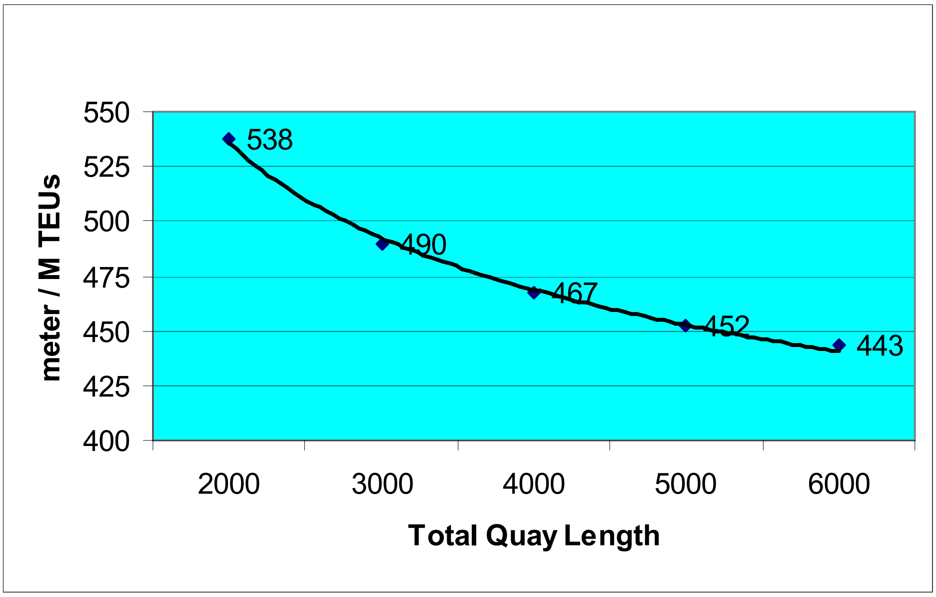


Figure 8.13 Required quay lengths of different total quay lengths

According to the results presented in *Figure 8.13*, the “scale effect” helps increase the quay productivity. The average required quay length is reduced for about 100 m from a straight quay of 2000 m to a straight quay of 6000 m. However, the marginal effect is decreasing with increasing total quay length. Thus, the effect is limited for very long straight quays (more than 5 km), even under the assumption of unrestricted cranes.

According to the queuing theory, the BOR of longer quay (more berths) is increased for the same waiting rate, and it is validated by the model. In other words, longer quays can be used more effectively without influencing the service level.

The decreasing marginal effect can also be explained by *figure 8.14*. For a waiting rate of 8%, the increase of berth occupancy rate is 10% from 2000 m to 4000 m; while the increase is only 4% from 4000 m to 6000 m.

It should be mentioned that more cranes and higher crane occupancy rate are also reasons of higher productivity, but a higher berth occupancy rate is a governing factor.

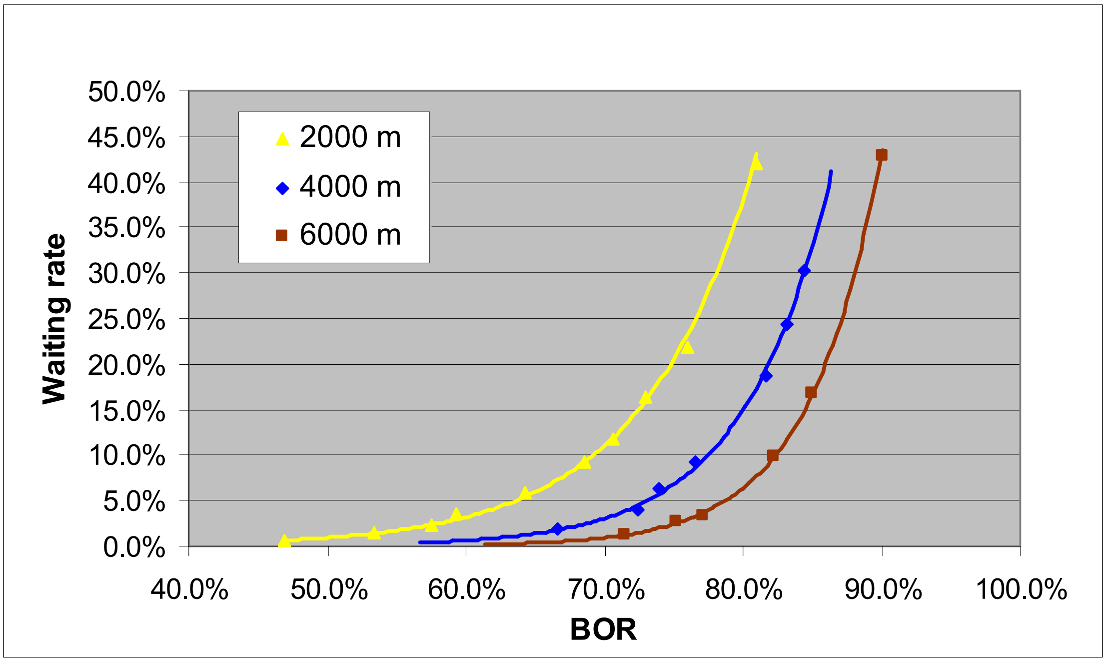


Figure 8.14 Waiting rate & BOR of different quay lengths

The model also shows average crane number is also reduced considerably, but it should be noticed that this model gives lower crane numbers than the real situation. It will be discussed later.

8.3.8.5. Close view of long straight quay

Results of 2000 m and 6000 m long quays are further studied to gain a close view of behaviors of long straight quay.

	Yearly Throughput	Waiting Rate	BOR	COR	NWR	Average Length	Average Cranes
	(M TEU/Year)	(%)	(%)	(%)	(%)	(m/M TEU)	(units/M TEU)
Ave	**13.54**	**9.89%**	**82.10%**	**65.83%**	**58.8%**	**443**	**5.1**
1	13.50	9.05%	82.00%	67.25%	61.3%	444	5.0
2	13.73	10.59%	82.13%	66.41%	57.4%	437	5.0
3	13.37	8.43%	80.54%	66.59%	61.3%	449	5.0
4	13.70	9.33%	82.79%	64.39%	56.4%	438	5.2
5	13.45	9.41%	81.90%	67.99%	60.0%	446	4.9
6	13.64	12.02%	83.28%	68.98%	51.8%	440	4.8
7	13.60	10.49%	83.02%	68.78%	57.1%	441	4.9
8	13.64	9.60%	82.72%	59.10%	59.2%	440	5.6
9	13.61	11.47%	82.17%	63.07%	58.8%	441	5.3
10	13.20	8.53%	80.30%	65.74%	64.8%	455	5.1

Table 8.5 Results of 6000 m long quay

From the results in *Table 8.5* and *Table 8.7*, it is noticed that the BOR and COR increase about 10% and 15% respectively, comparing to 2000 m long straight quay. However, the high productivity also brings negative influences to the terminal operation.

As the top 7 container terminal in the world, Jebel Ali Port is an important stop for liner-ships. It is should be noticed that liner-ships have to comply with a precise schedule. If no berth is available at the time of arrival, the call may be canceled, the cargo shifted to another port or waiting for the next call. Although the averaged waiting rate is acceptable, a berth occupancy rate of 82% is too high to maintain a high level service for liner-ships at Jebel Ali Port.

At the same time, the terminal is running very busily under the high productivity, which means more staff, less maintenance time, short life span of port facilities and possibly more accidents.

In conclusion, even the planned 6000 m quay can reach that high productivity at real operation; it is still unwise to operate terminals under that condition. The productivity predicted by this model should be considered as an upper limit for very long quays.

8.3.8.6. Arrival pattern

The arrival pattern (inter arrival time) is assumed to be Erlang 3 (E3) distribution, because of regularly scheduled calls for container vessels in Jebel Ali Port. Two other arrival patterns are also studied with this model: Erlang 2 (E_2) distribution and negative exponential (M) distribution.

The Erlang 2 distribution is also used for container vessels, which is less regular than the Erlang 3 distribution. The negative exponential distribution is usually used for simulation of general cargos and it is also applied to terminals of a wide range of vessels with irregular arrival time.

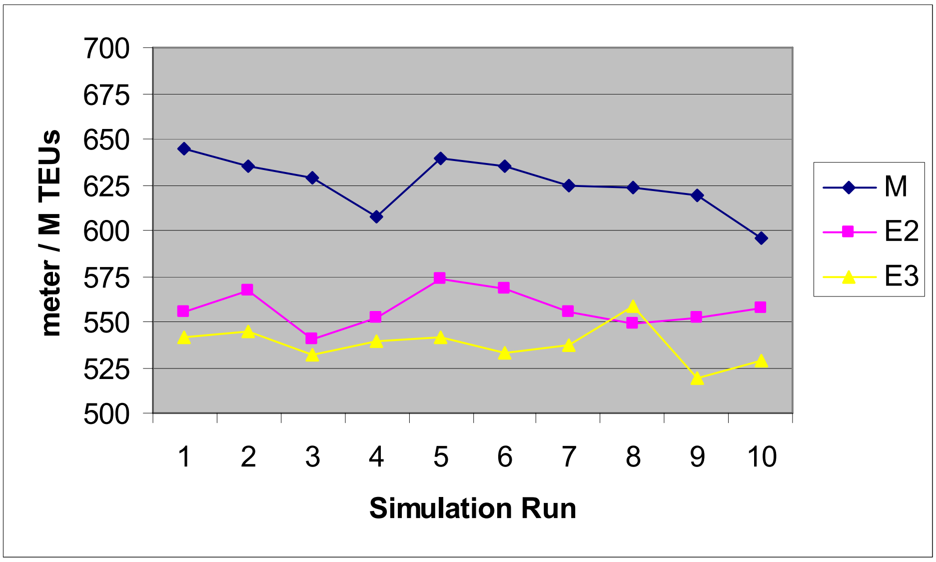


Figure 8.15 Required quay length of different arrival pattern

As shown in *Figure 8.15*, to achieve the same yearly throughput, E_3 distribution requires the shortest quay length, while M distribution requires the longest quay length.

The difference between E_3 and E_2 is small, but the required quay length increases significantly if arrival patterns are subjected to a negative exponential distribution.

Arrival pattern	Quay length	Yearly Throughput	Waiting Rate	NWR	Average Length
	(m)	(M TEU/Year)	(%)	(%)	(m/M TEU)
M	2000	3,20	9,88%	75,4%	625
E_2	2000	3,59	9,89%	71,9%	557
E_3	2000	3,72	9,90%	70,1%	538

Table 8.6 Results for different arrival pattern

The results show that regularly scheduled calls of container vessels are effective to increase the quay productivity. Irregular arrival pattern requires more berths reserved for peak periods, so the average length is longer and the BOR is lower than regular arrival patterns.

Mainline vessels usually call more regularly than feeder vessel, so it is important to attract more mainline container vessels for a higher productivity.

8.3.8.7. Number of cranes

As defined in the previous section, the required number of crane listed above is the maximum number of operating cranes for all time stamps (unrestricted number of cranes). However, it should be noticed that some cranes are only used for very little time and it is unnecessary to have the maximum number of cranes.

Thus, the probability of crane shortage (probability of exceedance) is introduced to further examine the required number of cranes. The horizontal axis indicates the number of available cranes, and the vertical axis indicates the probability that demand will exceed the available number of cranes.

For a certain probability of crane shortage, the corresponding number of cranes can be found from the figure below.

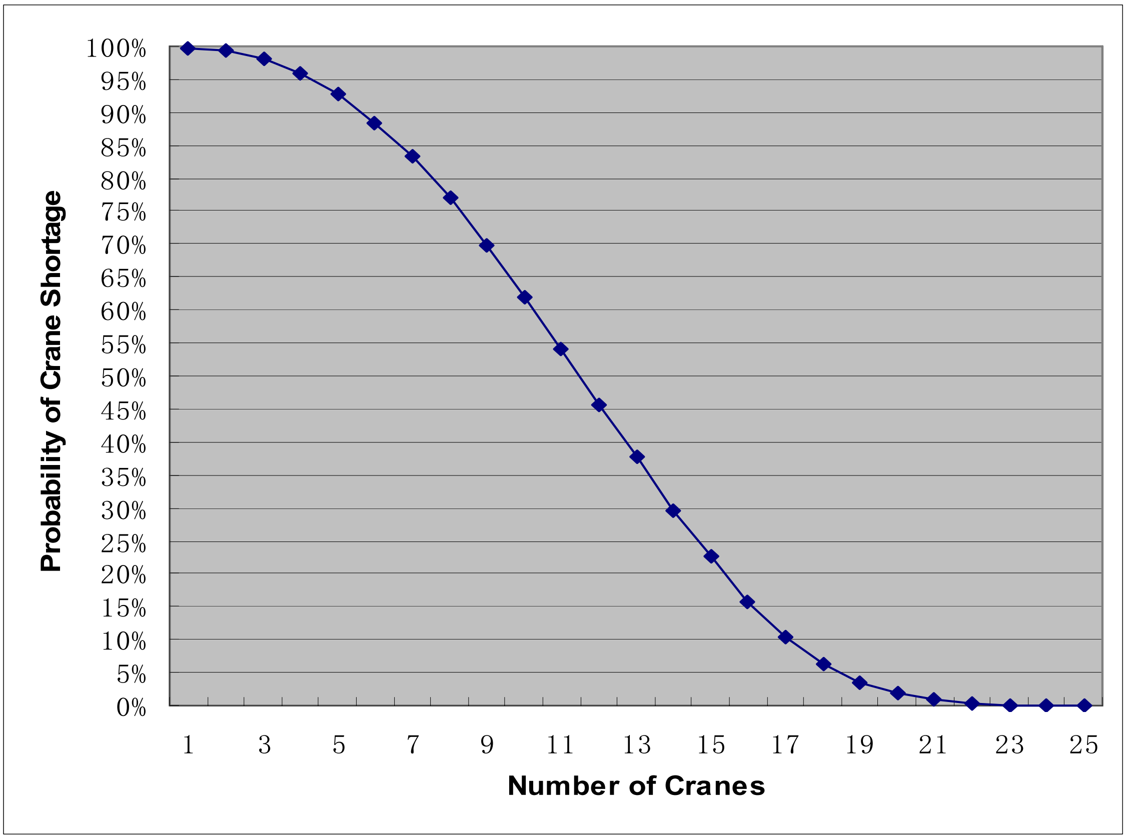


Figure 8.16 Probability of crane shortage for 2000 m quay

Based on experience at other terminals, 5%-10% of probability of crane shortage is about as much as terminal operators and shipping lines can tolerate in a major port.

However, this model assumes that cranes can be moved to other berths freely and immediately. Actually, cranes can not be moved if there are other cranes between departure and destination, and the allowable moving distance is also limited by cables. So this model underestimates required number of cranes.

Because of this limitation, the probability of crane shortage is determined to 1% to compensate for the negative effect of “free moves”. With probability of crane shortage of 1%, the required number of crane is about 21 for 2000 m long quay, which is reasonable based on experience at other terminals operation.
For a very long quay, this effect is significant in reducing number of cranes, because these “free moves” are performed frequently. It is believed that required numbers of cranes for 6000 m long straight quay are away from the real situation.

8.3.9. Simulation results

The final simulations are performed with N-FCFS principle, Erlang 3 distribution, 2000 m long straight quay, and 50% to 100% exchange rate. The results are summarized as:

	Simulation Time	Yearly Throughput	Waiting Rate	BOR	COR	NWR	Average Length
	(weeks)	(M TEU/Year)	(%)	(%)	(%)	(%)	(m/M TEU)
Ave	**59,86**	**3,72**	**9,90%**	**71.72%**	**49,22%**	**70,1%**	**538**
1	61,55	3,69	9,95%	71.03%	49,30%	70,2%	542
2	60,68	3,67	8,83%	70.30%	45,44%	73,4%	545
3	60,20	3,76	8,86%	71.96%	50,13%	71,1%	532
4	59,64	3,71	10,68%	71.56%	45,79%	68,7%	539
5	59,56	3,69	8,87%	71.76%	49,32%	70,9%	542
6	59,20	3,75	10,34%	72.28%	50,75%	70,0%	533
7	60,31	3,72	10,05%	71.43%	49,62%	69,4%	538
8	59,86	3,58	8,47%	70.01%	49,82%	75,1%	559
9	58,78	3,85	13,00%	73.73%	53,48%	64,3%	519
10	58,78	3,78	9,94%	72.83%	48,50%	68,2%	529

Table 8.7 Final results

The simulation shows that one million TEU throughputs require approximately 540 m of straight quay and 5.7 cranes (every 95 m per crane).

8.3.10. Recommendation

8.3.10.1. About the simulation

Firstly, the FCFS principle is widely used for simulations, but it gives relatively higher waiting time and lower quay productivity in this model.

Without this assumption, it is found that some large vessels have to wait very long time before they can be served. Because small vessels are earlier to find available berths, they can always jump the queue. This behavior makes it difficult for quay-side to keep long berths available for large vessels.

Further examinations show that the waiting time of large vessels is long for short quays (less than 2 km) without FCFS. But the waiting time for large vessels decreases for long straight quays (4 to 6 km). However, the best operation criteria vary for different terminals.

Secondly, although the model shows that a very long straight quay has significant "scale effect", the application to practical operation still needs further study.

Common practices in major container terminals haven't proved such high quay productivity. But it should be noticed that very long straight quays (more than 3 km) are very uncommon in the world and a straight quay of 6 km has not been built. Thus, it will be an interesting subject to study the practical behavior of the very long quays in Jebel Ali Port.

Moreover, the quay productivity is also limited by the transportation system and effectiveness of hinterland linkage. Even if the quay operation productivity reaches a very high level, the land transportation can become the bottleneck.

According to this model, a straight quay of length between 3000 m and 4000 m could be a reasonable range for high productivity. Long quays of more than 4 km don't bring proportional high productivity. It should be noticed that the length of straight quay is usually limited by location conditions, and it is the reason why long straight quays are uncommon in the world.

Thirdly, all the exchange rates studied are subjected to a uniform distribution, and other distributions could be also studied to examine the sensibility.

Finally, the approach of determining required number of cranes can still be improved. In this model, it is assumed that cranes are assigned according to the size of vessels (container capacity) automatically. But the number of operating cranes is actually related to the vessel size, number of exchanged containers, available cranes and level of management.

The number of cranes assigned to a vessel is not always the same during the operation period. It is possible that a few cranes operate at the beginning, and more cranes come later; or many cranes operate at the beginning and some leave for other vessels later. The "free moves" also influence the accuracy of the final results and it is compensated by choosing a low probability of crane shortage in this model.

8.3.10.2. About the program

This model is time-driven, which means the same operations are performed for every step. It makes the structure of this model relatively simple. But it increases the amount of calculations, simulation time and computer memory requirements. Furthermore, it is found that simulation time span have larger influence on real time cost than the number of movements/vessels (because this model is time-stimulated).

The overflow is not a problem for this model, but the simulation time can be very long for long time span simulations. For example, a four-year time span, 10,000 calls simulation takes more than 40 minutes.

One solution is the optimization of the structure, which could reduce the amount of calculation. Another solution is to use an event-stimulated model. Operations are only implemented when certain events occur, and different operations are implemented for different events. If no event occurs for a time stamp, the program just comes to the next time stamp.

This event-stimulated model could reduce the amount of operations/calculations significantly. But the structure of program becomes more complicated, and thus more time is required on writing and testing the program.

8.4. Conclusion

The simulation shows that one million TEU throughputs require approximately 540 m of straight quay and 5.7 cranes (every 95 m per crane).

So the container throughput of Alternative 2 (the most promising one) will be about 44 million TEUs per year, and the required number of cranes is about 250. The existing Jebel Ali Port can handle 13 million TEUs per year by 2030. So the total capacity of new Jebel Ali container terminals will be about 57 million TEUs per year by 2030.

The required capacity is about 58.4 million TEUs per year by 2030 according to the forecast. However, the 57 million TEUs capacity is achieved without considering the scale effect of very long straight quay in new Jebel Ali Port.

Because the difference is only 3% of the capacity of Alternative 2, it is believed that it can be compensated by taking the scale effect into account.

Therefore, the final conclusion comes that the new Jebel Ali Port will have enough capacity to meet the container throughput requirement by 2030.

9. Quay wall design

9.1. Introduction

Usually, quay walls are defined as earth retaining structures, which separate the land from the water, for the mooring of ships. The main functions of quay walls are: retaining soil and water; transfer loads to the subsoil; and provide a safe mooring place for vessels.

With the development of new quay structures, a floating structure without earth retaining walls can also become a quay structure.

In this chapter, different types of quay walls are introduced, including some new developments of quay structures. Then, one type of quay walls is developed, which suits the location condition of Jebel Ali Port.

9.2. Types of quay walls

9.2.1 Normal quay walls

There are several types of normal quay walls, which can be divided into three main groups: gravity structures, embedded structures with/without relieving floor and platform/open berth structure.

<u>Gravity structures</u>
Gravity structures are characterized by the way stability of the structure is achieved. The deadweight of the structure is large, so the gravity structure is usually used where the seabed is of good quality. They may therefore be considered where the foundation near dredged level is of rock, dense sand or stiff clay. Some types may be founded on weaker soils if the resulting movements are acceptable, or if the soil is dredged and replaced with a granular material or rubble.

Gravity walls used in maritime works are generally required to retain reclaimed ground, the quality of which can be selected. It is usual to use rubble or a free-draining granular fill immediately behind a quay wall so that the effects of tidal lag are minimized and earth pressures are reduced.

There are different types of gravity structures: block walls, L-wall, caisson wall, cellular wall, etc.

<u>Embedded structures</u>
The embedded structure is a wall consisting of sheets driven into the subsoil. The penetration of the sheet into the subsoil generates a fixed-end moment that secures the stability of the wall.

A relieving floor or platform is an L-wall that is placed on top of a wall structure, which can be a sheet pile wall, a combi-wall, a diaphragm wall or other types of wall structure. The relieving floor reduces the horizontal load on the wall structure, which makes it possible to use a lighter wall profile and to reduce the embedded length of the wall structure. But it increases the vertical load on the wall structure, so a higher bearing capacity is sometimes required.

Platform structures

Platform structure is a jetty like structure. The difference in height between the harbor bottom and ground level is overcome by a slope instead of a vertical retaining wall. This type of structures can be applied when the bearing capacity of the subsoil is limited and when there is a protected slope.

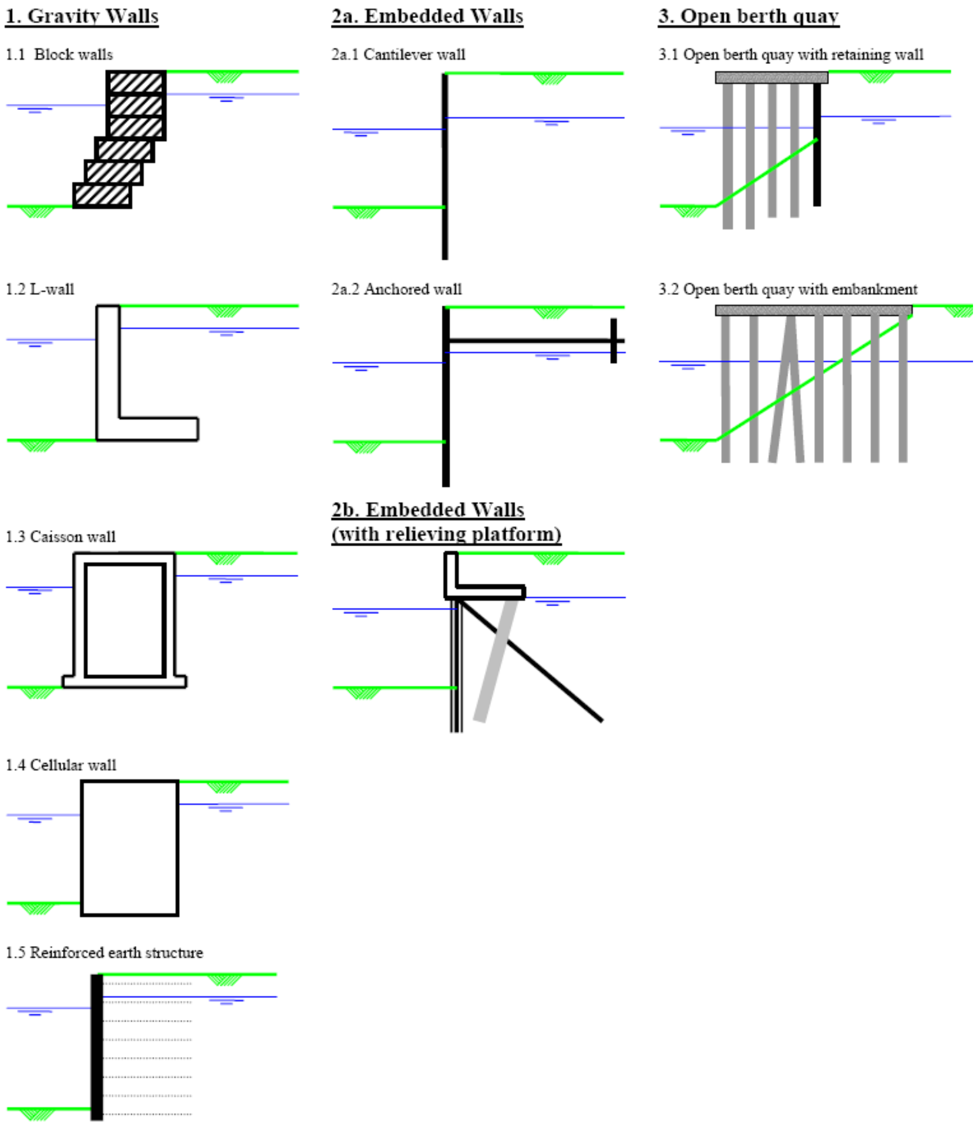


Figure 9.1 Different types of quay wall structures (by: Priscilla Bonte, 2007)

9.2.2. New developments of quay walls

These normal quay walls have a long history of application and are still widely constructed all around the world. At the same time, new types of quay walls are also developed to suit the new development of container operation business.

Several new quay wall concepts are introduced below, including floating quay wall, sandwich quay wall, frozen quay wall, container land and secant quay wall.

Floating quay wall
A floating quay consists of a hollow concrete or steel structure, which is able to move in vertical direction, along with the water level. There can be a sloping bed under the floating structure, or the structure can be connected to an existing retaining wall.

The main problem of fixed structure is the large horizontal load, resulting from large retaining heights of soils. In case of a floating structure the load due to retained soil is absent, which makes it a very attractive solution.

Another advantage of floating quay is a good possibility to serve larger vessels, which is also a main disadvantage of normal fixed structures.

The structure must be anchored to the harbor bottom to secure the positions of the quay. This can be realized with, for example, suction anchorage or spud legs. A connection between floating structure and main land has to be realized which allows vehicles to access the quay.

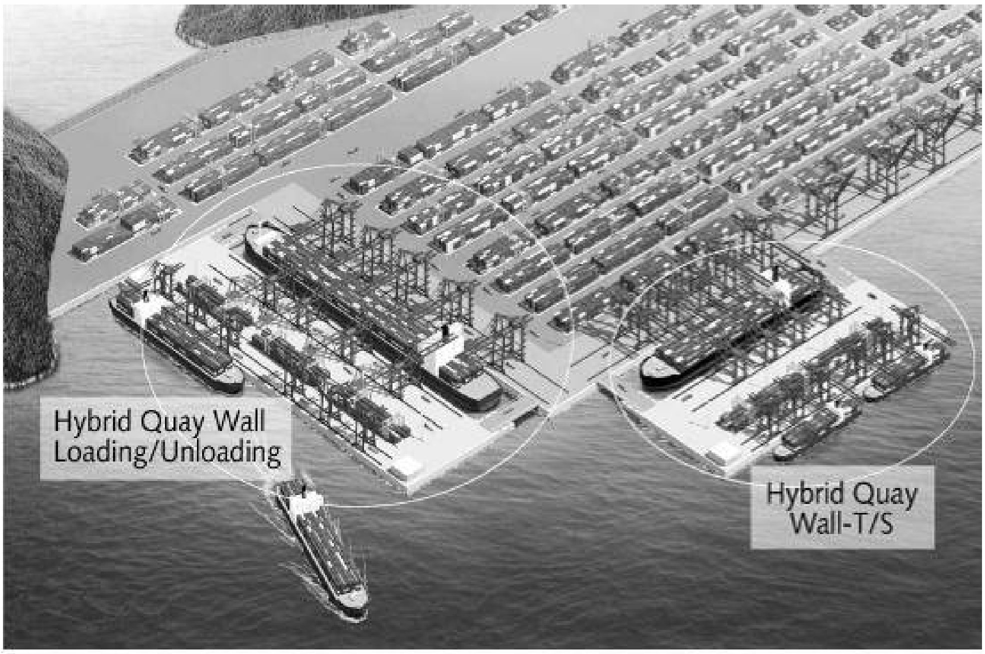


Figure 9.2 Floating quay concept
(by: Korea Ocean Research & Development Institute)

Sandwich quay wall

A sandwich wall consists of two rows of Tubex piles and a grout mass between the two rows of piles [Ref.16]. It can be combined with a relieving floor structure and as a result the embedded length of the wall can be smaller and a more slender design can be made.

The advantage of a sandwich wall is that the steel in the structure is used very efficiently. Due to the composite action the steel piles are loaded mainly by normal forces rather than by bending. Relatively little steel is needed to take up a certain bending moment, this is favorable with respect to the current high steel prices.

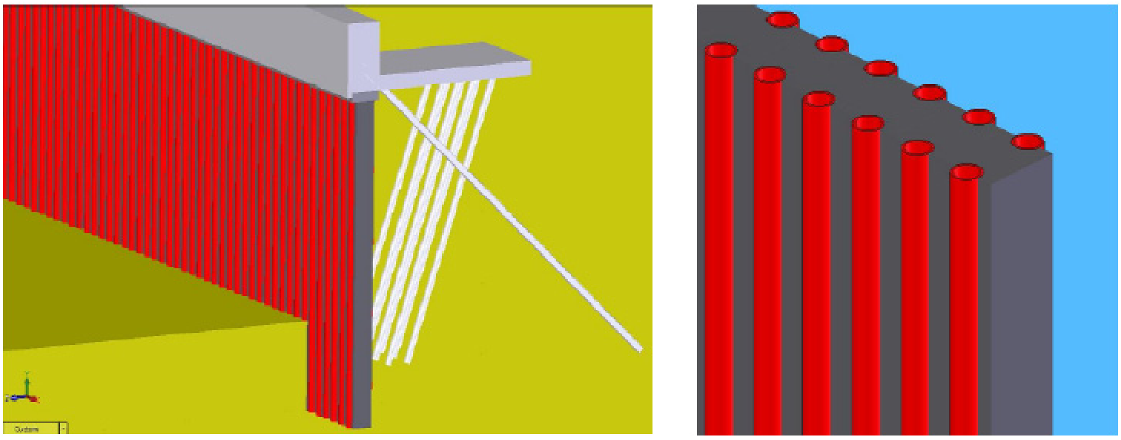


Figure 9.3 Sandwich quay wall concept (by: Priscilla Bonte)

Frozen quay wall

A very innovative concept is creating a vertical quay wall by freezing the ground water in the subsoil. In the ground a pipeline system is installed through which the cooling liquid flows to freeze the ground water. Frozen soils are created around these cooling pipes columns.

As the temperature of the soil decreases the diameter of these ice columns increases until a solid frozen soil mass is created. Once the total soil mass is frozen less energy is needed to maintain the low soil temperature.

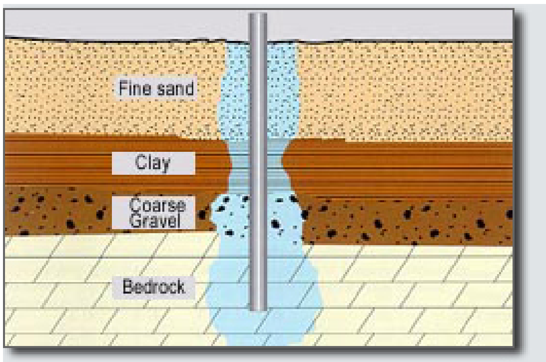


Figure 9.4 Freezing pipe

This type of quay wall requires little construction materials, but it is a very expensive solution in the long run.

Container land

In case of temporary need of extra space, the container land can be an attractive and cheap solution. It consists of packages of several stacked and vertically connected containers. On top of the upper container and underneath the lowest container a concrete slab is placed. This slab leads the loads to the corners of the containers, which are the strongest elements of a container.

Figure 9.5 Container land

This new concept has a very temporary character and the advantage of this concept is the short construction time and low cost. Containers can be obtained which are no longer suitable for transportation purposes. The concept of container land is already well developed.

Secant quay wall

Secant pile walls are also an innovative way to build retaining walls. They are formed by a series of interlocking drilled shafts used primarily where there is a high water table or unsuitable ground conditions.

Prestressed concrete cylinders are penetrated into sea bottom and are filled with soil. Grout columns are positioned between them to fill the gaps and to secure the sand tightness of the wall.

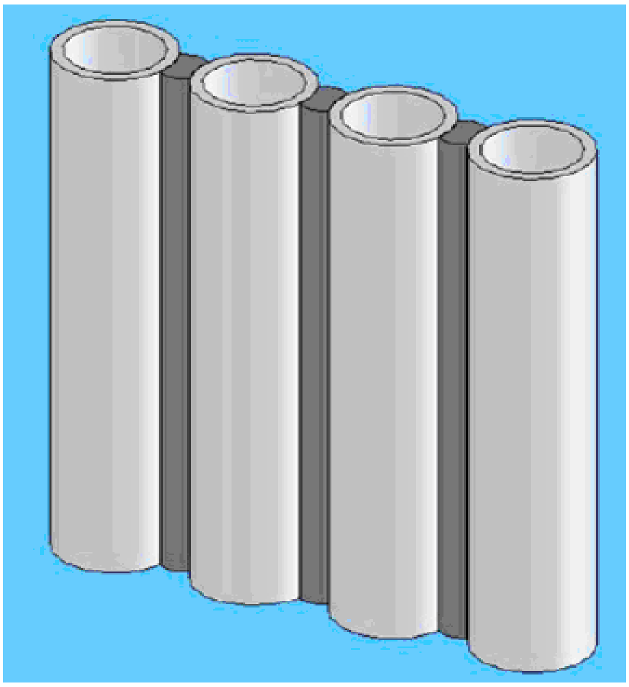


Figure 9.6 Secant wall

9.3. Selection type of quay wall

Different types of quay walls are evaluated based on geotechnical conditions, total costs, construction time and designed method.

Pile structures are not considered to be the best choice for this project. In one hand, because of the existing rock layer under sea bottom, the difficulty and high cost of piles drilling makes pile structures unfavorable. In the other hand, the cast-situ concrete deck also increases the total cost significantly. Besides, the increasing steel price makes pile structures even more expensive.

Container land is only a temporary method and the life time is quite limited. Frozen quay wall is abandoned because of extremely high cost and little applications to big container quay wall construction.

Floating quay wall can be an option. As mentioned above, the main advantage is the absence of retaining soil force and the good possible for serving larger vessels. However, there are little applications in container terminals and the construction method is expected to be more complicated than normal quay structure.

Finally, gravity structure is considered to be the best option for this project. The geotechnical conditions at project location favor gravity walls and the cost is relatively lower. In conclusion, a concrete block wall and a caisson wall are further developed for new Jebel Ali Container Terminals.

9.4. Basic information

9.4.1. Design life and hydraulic design conditions

The design life for the quay wall structure is 50 years. The hydraulic design conditions are the 50-year return period wave and water level conditions in combination with the expected sea level rise after 50 years.

9.4.2. Design vessel

The designed vessel is super-post-Panamax with following characteristics:

- Size: 12,000 TEUs
- LOA: 397 m
- Beam: 56 (22 rows across on the deck) m
- Draught: 15.5 m
- Tonnage: 175,000 tons

9.4.3. Sea bottom and deck level

As described in chapter 6, the bottom level in front of quay walls should be DMD-18.1 m for this design vessel.

However, it is expected that the vessel size will keep increasing and Malaccamax container vessel with 18,000 TEUs capacity may call at Jebel Ali Port in the future. So a buffer depth of one meter is considered for the quay wall design, which leads to the bottom level of DMD-19.1m.

The quay deck level is determined as DMD+4.00m.

9.4.4. Crane

Rail mounted Super-Super-Post Panamax (SSPP) gantry cranes with an outreach of approximately 65 m, and a rail gage of 30.48 m. The waterside crane rail is located 7.25 m from the face of the quay wall.

9.5. Concrete block wall

9.5.1. Design philosophy

The quay wall is designed to meet the required factors of safety for the different load combinations and it is assessed according to the British Standards and Eurocode 8 for earthquakes. The representative values of all related parameters are used and the overall safety factors against the sliding and overturning are taken into account. For abnormal conditions, reduced safety factors are applied.

Safety factors	Sliding		Overturning	
	Block-Block	Block-Foundation	Block-Block	Block-Foundation
NTC	1.75	1.75	1.50	3.00
ATC	1.50	1.50	1.50	1.50

Table 9.1 Required safety factors

9.5.2. Block wall design

The concrete block wall concept is illustrated in *Figure 9.7* and a detailed design report can be found in *appendix C*.

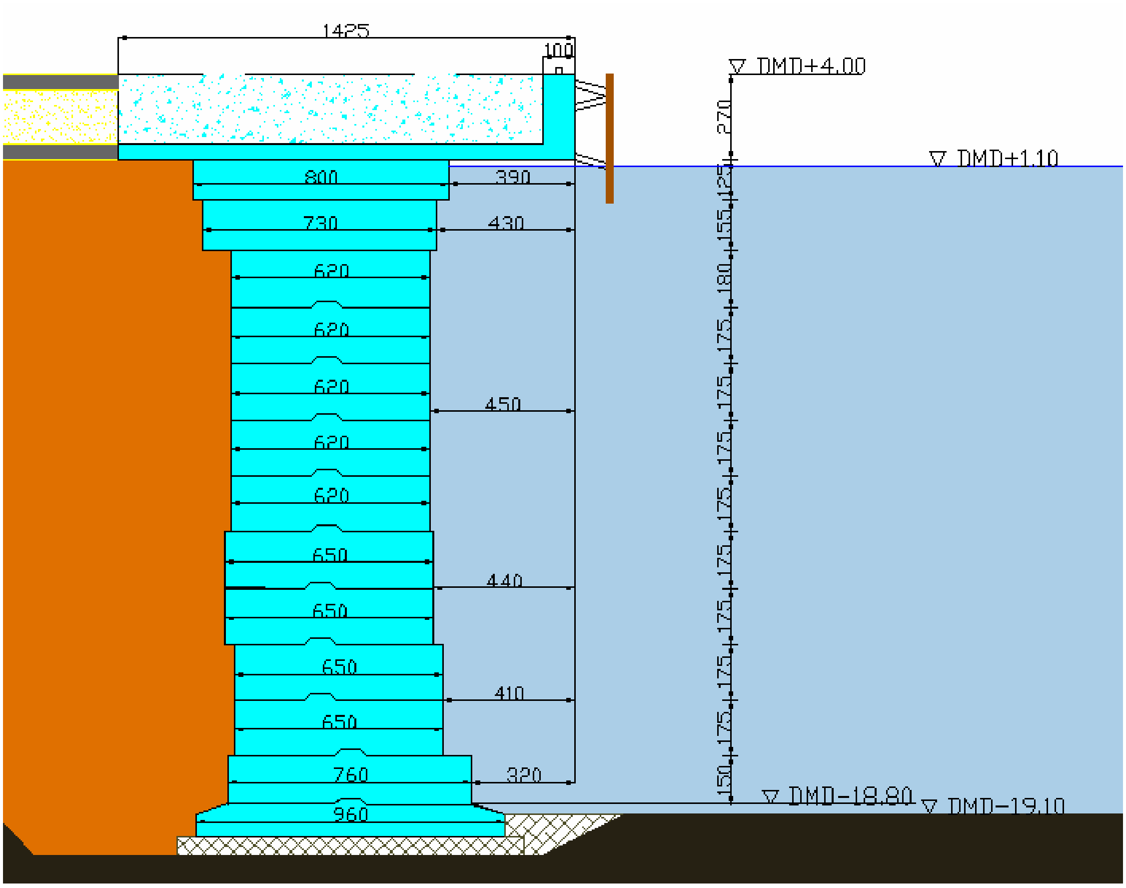


Figure 9.7 Concrete block wall (in cm)

A gravel foundation is required to be placed on top of dredged sea bottom, in order to provide sufficient bearing capacity. Scour protection at the toe would be provided.

The prefabricated concrete blocks are installed using heavy cranes. For preliminary design, concrete blocks are limited to a maximum weight of approximately 70 tons.

However, the selected contractor will have the option to fabricate larger, heavier blocks to suit the capacity of his construction equipment.

After backfilling and compaction of filled material, the top of the block units would be fabricated with reinforced cast-in-place concrete, followed by the crane rail support beam.

The capping blocks need to have a serrated finish and the underlying blocks shall have a rough finish to achieve good friction.

9.6. Caisson wall

9.6.1. Design philosophy

The general design philosophy is the same as block wall. In addition, the floatability and floating stability are taken into account during the transportation stage.

9.6.2. Caisson wall design

Construction method
Two construction methods are considered for this project:

1) Construct small caissons; place them with cranes; and filled with sand.
2) Construct large caissons in docks; tow to the location by tug boats; lower into location by controlled flooding; and filled with sand.

Preliminary design shows that the self weight of concrete caisson is approximately 90 ton/m, which is too heavy for cranes. So the second construction method is chosen.

Dimensions
The determination of dimensions is an iterative process, with the consideration of following aspects:

1 floatability
2 floating stability
3 sliding stability
4 overturning stability

The caisson wall concept is illustrated in *Figure 9.8* and a detailed design report can be found in *appendix C*.

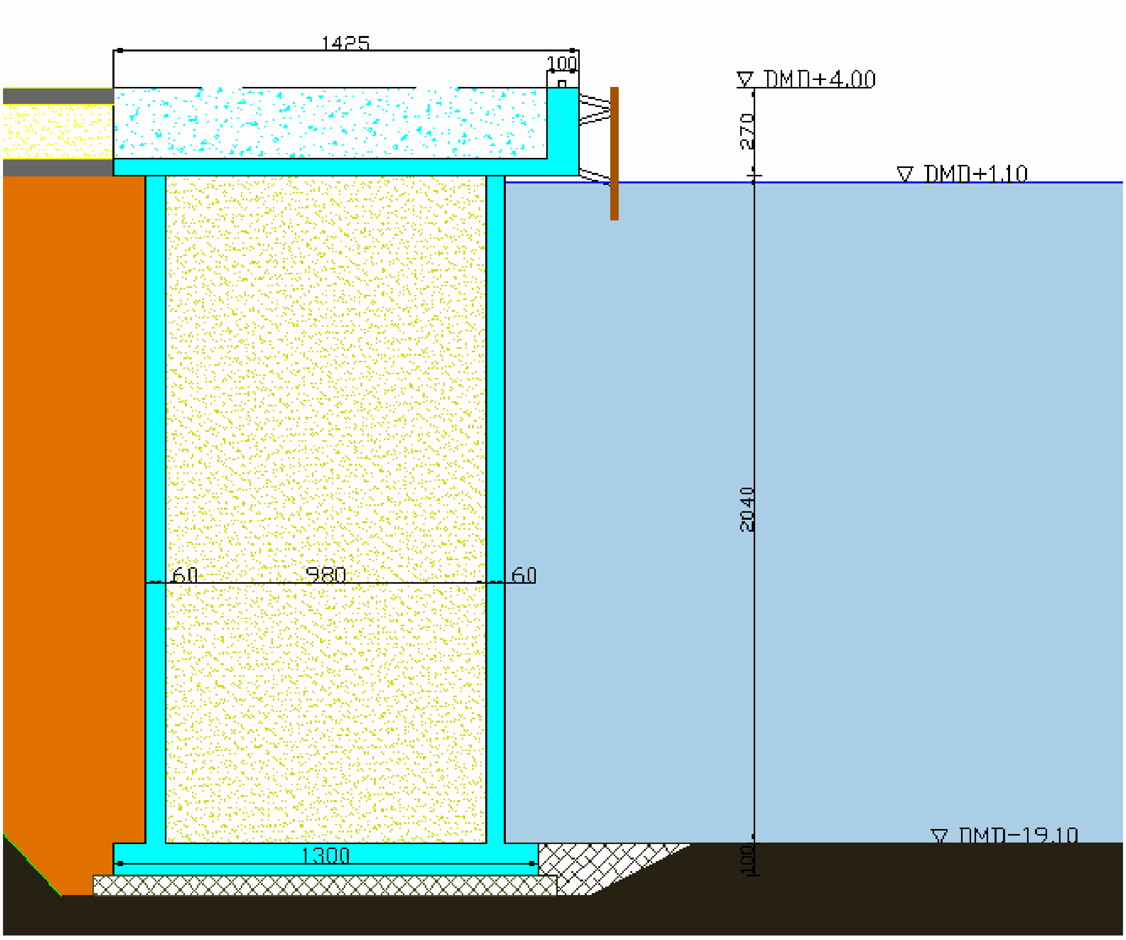


Figure 9.8 Caisson wall (in cm)

9.7. Conclusion

The concrete block wall is recommended for following reasons:

Comparing to caisson wall, the transportation of concrete blocks is easier; the total cost is lower and the time constraints of the construction are smaller.

It is also noticed that concrete block quay walls are widely constructed in Dubai area. So it is familiar to contractors operating in the general vicinity of this project.

In addition, the block wall construction maximizes the use of local materials and minimizes the need to rely on imported material.

In conclusion, suitable geotechnical conditions, relatively low cost, wide applications in Dubai together make the block wall the best option.

10. Conclusions and recommendations

10.1. Conclusions

- Based on the construction time and predicted future cargo volumes, it is expected that the existing port may not have enough capacity around 2012, even under the current expansion project.

    - A more aggressive expansion project should be carried out. Otherwise, either Dubai Ports will have insufficient handling capacity or the closure of Port Rashid will be delayed.

- The New Jebel Ali Port will be constructed as a set of offshore islands to the north of, and connected to, the existing port because of the land scarcity along the coastline.

    - An entire floating terminal is not preferred for this project, which is not comparable to a land reclamation project.

    - Alternative 2 is chosen as the most promising on, which has the largest value and medium cost. Vessels can turn around within the harbor basin.

    - To minimize resonances, damping boundaries could be introduced at the end of basin and impermeable breakwaters are preferred. A large entrance is also helpful to reduce the wave resonance.

    - The reclaimed volume is much larger than the dredged volume. So extra dredging work is necessary and it is noticed that the reclamation sand for nearby Palm Islands was dredged from 20 miles away from the coast.

- A long straight quay has the “scale effect” to increase the quay productivity. However, the marginal effect is decreasing with increasing quay length.

- The most favorable type of quay wall cost as well as construction time wise is a concrete block wall.

10.2. Recommendations

- More detailed information should be collected. A bathymetry and soil survey should be conducted to obtain a detailed and accurate bottom profile.

- A detailed phasing of the masterplan is very helpful to determine the total cost as well as evaluate the best alternative.

- Research has to be conducted on harbor resonance. Because of the very long basin length, wave resonances could occur in the basin, and the operation and safety will be affected.

- Construction costs are based on very rough element designs. In a further stage, when more information is available, the more accurate cost estimations should be made.

- The wave penetration into the harbors basin should be studied for determining the downtime. And sediment transport processes at Jebel Ali Port after expansion projects is needed.

- In a later stage, a more detailed design of berths should be conducted and the accurate number of cranes can be determined.

- A more detailed vessel information and exchange rate are helpful to determine more accurate number of required quay length and number of cranes.

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Appendix A: Feasibility study of floating container terminals

A1. Introduction

With the fast population growth and urban development, land scarcity becomes a severe problem for new developments. So people resort to land reclamation to ease the stress on existing land and underground space. Many countries are expanding their land area by aggressive land reclamation, for examples, the Netherlands, Japan and Singapore.

However, land reclamation is limited to shallow water area (usually less than 20 m) and a good soil condition of seabed is preferred. Otherwise, the land reclamation becomes no longer cost effective. Moreover, land reclamation destroys the marine habitat and may even cause ecological disaster.

Fortunately, large floating structures were proved technically possible, and it becomes an attractive alternative for new land area.

A1.1. Advantages of floating structures

In principle, floating structures have advantages over the traditional land reclamation solution in the following respects:

- They are cost effective when the water depth is large;
- They are environmental friendly as they minimize impacts to the marine eco-system;
- They are easy and fast to construct and therefore sea-space can be speedily exploited;
- They can be easily removed or expanded;
- The facilities and structures are protected from seismic shocks;
- They do not suffer from differential settlement due to reclaimed soil consolidation;
- Their positions with respect to the water surface are constant and thus facilitate small boats and ship to come alongside when used as piers and berths.

A1.2. Types of floating structures

There are basically two types of floating structures, namely the semi-submerged structure and pontoon-shaped structure. Two other types are also mentioned: Mega-Float and tension leg floating structure. However, they can be considered as a special type of semi-submerged structure and pontoon-shaped structure, respectively.

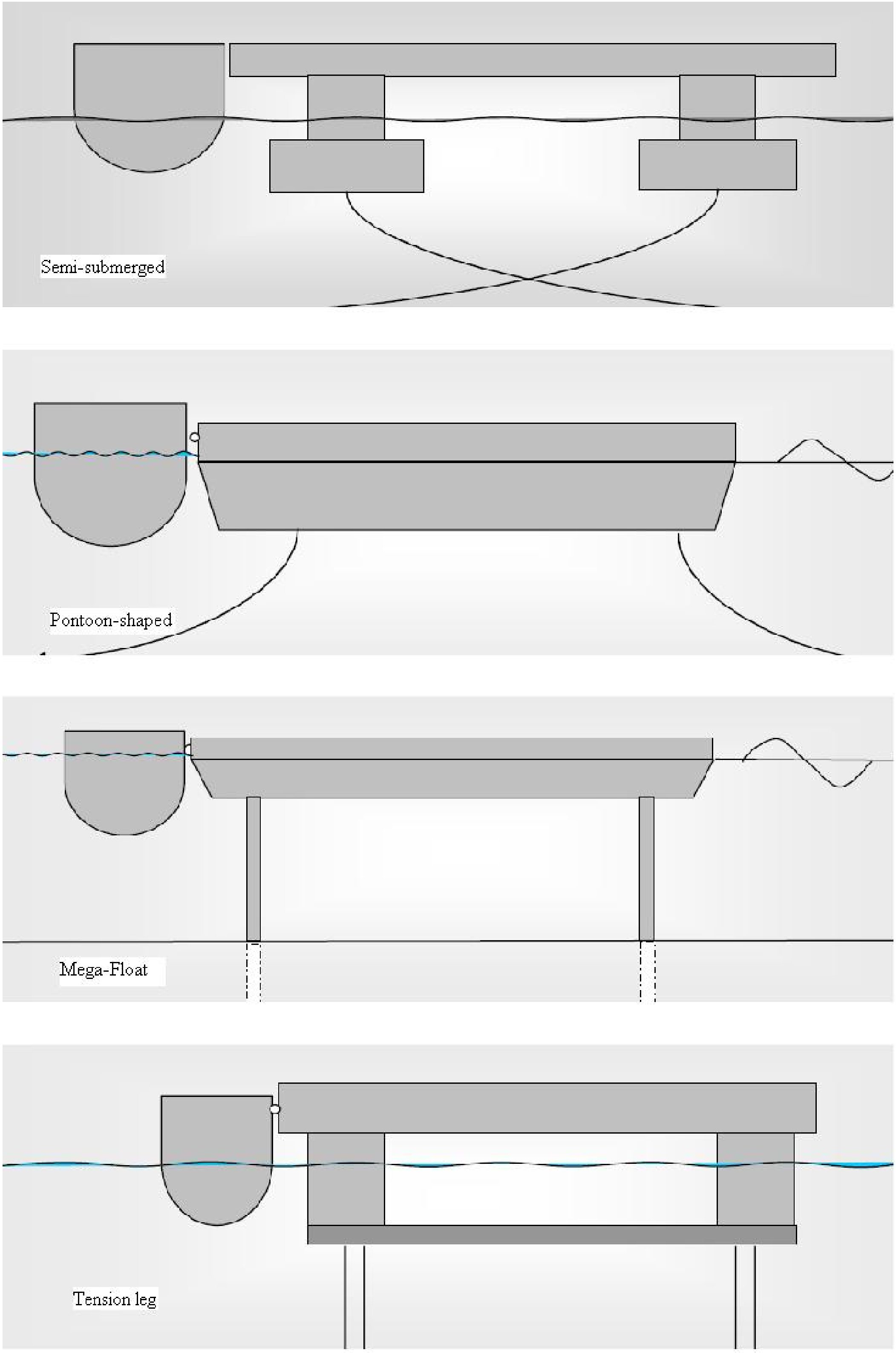

Figure A1.1 Types of floating structures [Ref.14]

Semi-submerged structures are raised above the sea level using column tubes or ballast structural elements. They can minimize the effects of waves while maintaining a constant buoyancy force, so it is favorable from a hydrodynamic point of view. Therefore they are usually deployed in deep water with large waves, for example, floating oil drilling platform.

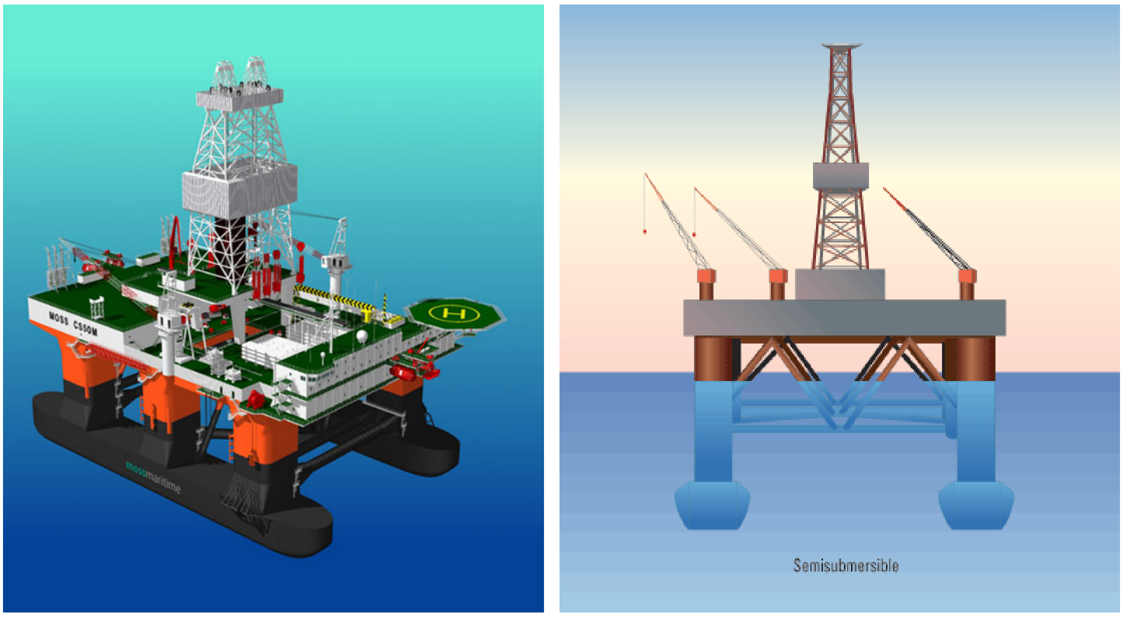

Figure A1.2 Floating oil drilling platform

When a semi-submerged structure are attached to the seabed using vertical tethers with high pretension as provided by additional buoyancy of the structure, they are referred to as tension-leg floating structure.

Pontoon-type floating structures lie on the sea level like a giant plate floating on water. Because wave energy is easier to penetrate under the structure, they are suitable for calm waters, often inside a cove or a lagoon and near the shoreline.

Figure A1.3 Mega-Float in Tokyo Bay, Japan

Figure A1.4 Proposed Floating Runway at Tokyo International Airport

Large pontoon-type floating structures have been termed as Mega-Floats by Japanese engineers. As a general rule of thumb, Mega-Floats are floating structures with at least one of its length dimensions greater than 60 m.

A2. Floating container terminal

A2.1. General information

A floating container terminal can be considered as a very large floating structure with many superstructures on top of it. It is connected to land with access bridge or causeway.

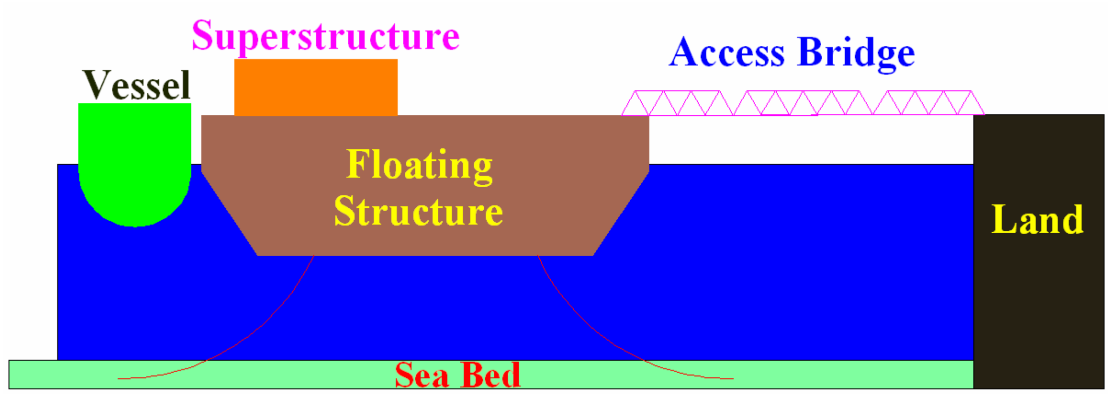

Figure A2.1 Floating terminal

In principle, floating terminals are preferred for these conditions:

- A large tidal range influences loading and unloading activities;
- Earthquake and tsunamis may occur in the area, which endanger the offshore structures;
- Soft soil layers exist below the seabed, which requires soil improvements or foundation structures for land-based structures;
- The local environment will be largely affected by land reclamation;
- The land reclamation can be only conducted in deep water, which leads to high cost.

In general, a floating terminal is more expensive than land-based one. But it provides the possibility for relocating/reusing, so the economic life of a floating structure is longer. Besides, it's easier to reach by larger vessels. Usually, vessels should berth at shelter area and floating breakwater can be applied.

Furthermore, a floating terminal in deep water reduces the traffic density significantly, which could be a problem for big ports. Another function of an offshore terminal could be an additional security for metropolitan cites; dangers to civilians caused by accidents or even terrorism can be minimized.

Because of the high cost, a floating container terminal should focus on the function as transshipment terminal. It requires relatively small terminal area and can reduce transportations to the mainland.

A2.2. Water depth requirement

Usually, floating container terminals are considered for deep sea, where water depth is quite enough for floating structures. But it is not the case for Dubai area. The slope of Dubai seabed is less than 0.1 degree; in other words, the natural 20 m water depth area is at least 25 km away from the mainland.

Because of the shallow water near Dubai coast, the minimum water depth for a floating container terminal is an important criterion for this feasibility study. The minimum water depth includes draught of floating structure, depth of mooring system and safety margin.

A2.2.1. Weight

The weight of a floating container terminal is estimated according to a guide written by CMPT (Centre for Marine and Petroleum Technology).

The weight is divided into permanent weight (deadweight) and variable weight (lightweight). The deadweight includes weights of hull, buildings, containers, ballast water and fuel. The lightweight comprises of the machinery, outfit items, personnel, mooring system and equipment.

Although a steel structure has smaller self weight than concrete structures for the same design loads, it is not preferred for following reasons:

- The material steel is much more expensive than concrete;
- From a view of a life span, a steel structure requires more maintenance cost;
- Steel structures behave less rigid than concrete structures;
- Steel structures with smaller weight and thus smaller draught, are less favorable for vessels' operations;
- For a floating structure, the corrosion of steel could be a big problem.

So following draught calculations are carried out for concrete structures.

Structural weight
CMPT recommends a method for estimations of structural weight at a preliminary stage. The structural weight is estimated in the ratio of a total displacement.

	TLP	Semi-submersible	FPSO
Payload/Displacement	0.25	0.15	0.7
Payload/Structural weight	0.45	0.35	3.5
Structural weight/Displacement	0.60	0.40	0.2
Mooring load/Displacement	0.20	0.05	0.1
Storage/Displacement	-	0.40	0.6

Table A2.1 Weight ratio [Ref.20]

A floating container terminal is similar to a FPSO (Floating Production Storage and Offloading). From the table, it is found the ratio of structural weight/displacement is 0.2.

Buildings and facilities
Here, it is simply assumed that the total weight of buildings and facilities is 20% of the displacement (total weight).

Container weight
A 20-foot-container has a maximum gross weight of 24 tons, with the empty weight of 2.2 tons, so the average weight for per TEU is assumed to be 14 tons.

For the maximum container weight, it is assumed that the storage areas are filled with container with the stack height of 4. The average load for container can be calculated as:

$$\text{Container weight} = 4*14/\ (6.1*2.4) = 3.8\ \text{ton/m}^2$$

Ballast water/sand
Ballast water/sand has following functions:
1) to maintain a constant draught and compensate the weight difference at both sides;
2) to reduce the rotation of floating structures and maintain a even keel

It is assumed that the amount of ballast water should be adequate to compensate for 80% of the maximum containers weight.

Variable weight
It is assumed that variable weight is 20% of the displacement (total weight).

Safety factor
Safety factors for permanent weight and variable weight are 1.0 and 1.2, respectively.

A2.2.2. Draught

The calculation for draught follows:

$$1.0 * W_{dead} + 1.2 * W_{live} = D_{displacement}$$

By the equating the total weight to the displacement, a minimum draught under the designed loads is found to be 14.9 m.

A2.2.3. Minimum water depth

Additional depth is required for the vertical movement, anchor system and safety margin, which lead to a gross water depth of 20 m.

A3. Local conditions in Dubai

In this chapter, local conditions are briefly described, with regards to general principles and water depth requirement for floating terminals.

A3.1. Environmental conditions

Water depth
The seabed near the Dubai coast slopes very gently (less than 0.1°), and thus the required 20m-depth-area is about 25 km (13.9 nautical mile) away from the existing port.

Wave and tidal climate
The significant wave height is about 6 m in the area 25 km away and the tidal range is about 1.2 m in that area.

Foundation layer
The land reclamation in this area can be conducted without soil improvements or additional foundation structures, but these improvements are necessary for quay foundations.

Earthquake and tsunami
The geologically stable Arabian Plate is separated from the unstable Iranian Fold Belt by the Arabian Gulf. Dubai is located in a relatively inactive seismic region. The region is categorized as UBC Zone 2A earthquake with a magnitude not exceeding 6.5 on the Richter scale. The seismic hazard in Dubai is moderate.

A tsunami is not likely to attack Dubai coast in the future, because the water depth of the Arabian Gulf is not deep enough to trigger a tsunami.

A3.2. Construction

Construction method
According to early calculation, the final floating terminal should have a length of several kilometers and a width of several hundred meters. One method for constructing such large floating structure follows these procedures:

1) Construct small elements in dry docks;
2) Elements are towed to the destination;
3) Assemble elements;
4) Build superstructures and facilities.

Construction site
The elements should be firstly constructed in a dry dock. So the dimensions of each element are determined by the dimensions of the dock.

Because the total cost is highly related to the location and rent of the dock, the construction site is also important factor for the final decision.

The big Dubai Dry Dock locates next to the Port Rashid, which can serve as the construction site.

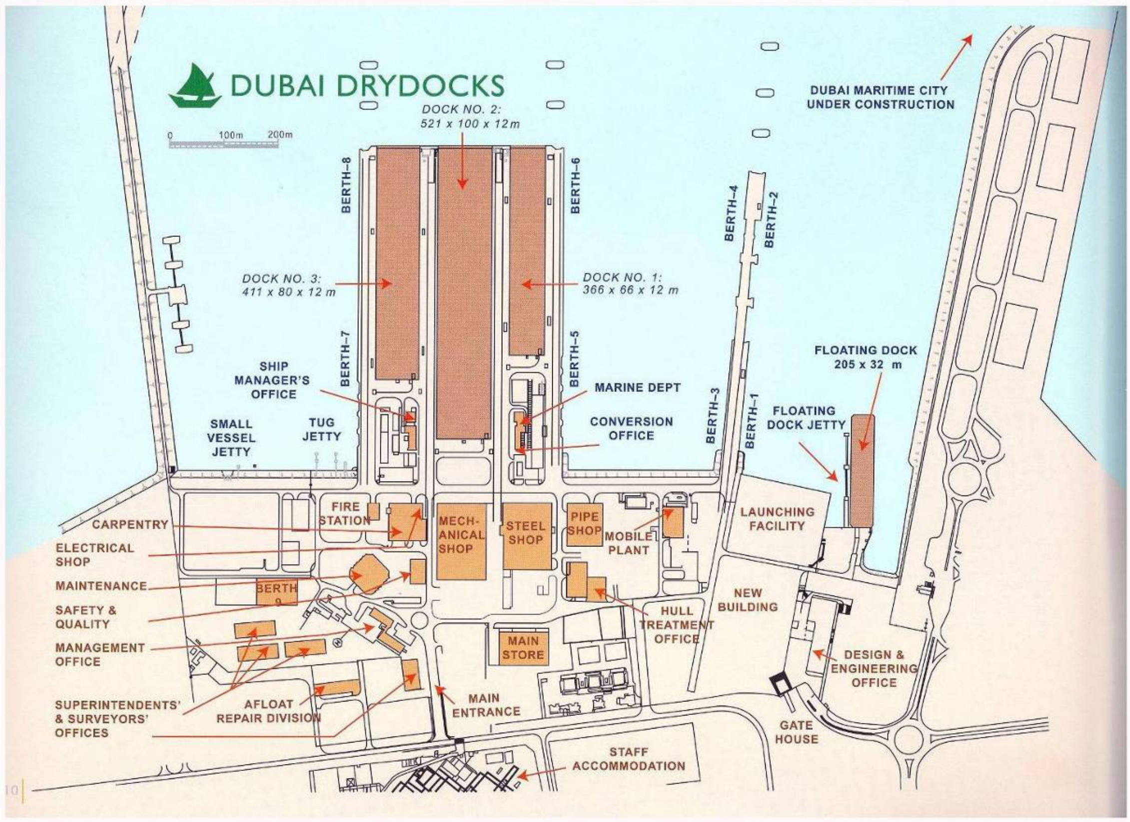

Figure A3.1 Map of Dubai Dry Dock

The dimensions of docks are summarized in following table:

	Length (m)	Breadth (m)	Depth (m)	DWT
Dock 1	366	66	12	350,000
Dock 2	521	100	12	1,000,000
Dock 3	411	80	12	500,000
Dock 4	205	32	7	40,000

Table A3.1 Dimensions of docks

A4. Conclusions

Based on the above information, it is concluded that an entire floating terminal is not preferred for the new Jebel Ali Port. Although the Dubai Dry Dock offers good construction condition for concrete elements, a floating terminal is not comparable to a land reclamation alternative.

Firstly, the final stage of land-based terminal requires land reclamations in 6-7 km offshore areas with an average water depth of 10 m. Both the distance from the mainland and the average water depth are acceptable. But a floating terminal must locate at least 25 km offshore, which leads to difficulties with transportation and managements.

Secondly, soil improvements and foundation structures are not necessary for land reclamations. It makes a floating structure even more expensive in contrast to land-based one.

Thirdly, it should be noticed that a very long bridge is required to connect floating terminal to the mainland, which further increases the total cost. Theoretically, it is possible to construct self-dependent transshipment terminal, which means all the containers follow “Sea-in & Sea-out” principle, but it does require a high level of management and reduce the efficiency of terminal operation.

Fourthly, both the wave climate and geotechnical condition are not in favor of a floating container terminal. Usually, a tidal range of 4 m could lead to remarkable problems for operation activities, but the tidal range is Dubai is only 1.2 m. Furthermore, both the earthquake and tsunamis are not critical problem for the Dubai area.

Finally, although a floating container terminal is more environmental friendly than land-based one, the effect should be further studied for this case. Because only the minimum water depth is considered, the water depth between the bottom of floating structure and sea bed is small. Thus, the effect of allowing good water circulation and minimizing environmental damage is still suspicious. A deeper water location could be preferred, but it will definitely increase the cost further.

Appendix B: Scenario analysis

B1. Introduction

Scenarios analysis is a process of analyzing possible future events by considering alternative possible outcomes/scenarios. The analysis is designed to allow improved decision-making by allowing more complete consideration of outcomes and their implications.

Although it has a lot of advantages, it can be difficult to foresee what the scenarios are, and how to assign probabilities to them. In other words, a scenario analysis usually requires much more information and experience.

B2. General information

A scenario analysis of throughput forecast was conducted by HPA in 2005 and it is summarized in this appendix. It should be noticed that that study was based on historical data up to 2003.

The scenario analysis divided the total throughput into local volume and transshipment volume. The segment of stevedoring volume base comprised of containers imported into and/or exported from the UAE is known as the "local" volume; and the segment of volume base comprised of containers relayed from one ship to another, without exiting the landside perimeter of the port is known as the "transshipment" volume.

Two growth conditions are considered for both local volume and transshipment volume: high growth condition and low growth condition. Then these two conditions together with two parts of volumes are combined into four scenarios for 2008, 2013, 2018, 2023, and 2030, respectively.

B3. Scenario analysis

B3.1. Local volume

As described above, the forecast of local volume took two growth conditions into account, which are high growth condition and low growth condition.

B3.1.1. High growth condition

In the report, HPA analyzed the historical performance of Dubai Ports, Dubai/UAE macro-economic development/outlook, prospects for key Dubai/UAE industries and the competitive position of Dubai Ports within the UAE.

These growth rates were derived according to these analyses, and then were applied to the local volume, considering the logistical requirements of its shipline customers for equipment balancing over each twelve-month period.

With very strong growth expected in those sectors of Dubai and the UAE economies that stimulate containerized imports, and with minimal risk of its local market share being eroded, Dubai Ports can consequently expect its local container stevedoring volumes to rise significantly over the next twenty years.

Movement Type	2003	2008	2013	2018	2023	2030	CAGR
Inbound	1,100	2,737	4,824	7,769	11,415	16,062	
Outbound	1,100	2,737	4,824	7,769	11,415	16,062	
Local Volume	2,200	5,474	9,648	15,538	22,830	32,124	
CAGR		20%	12%	10%	8%	5%	10%

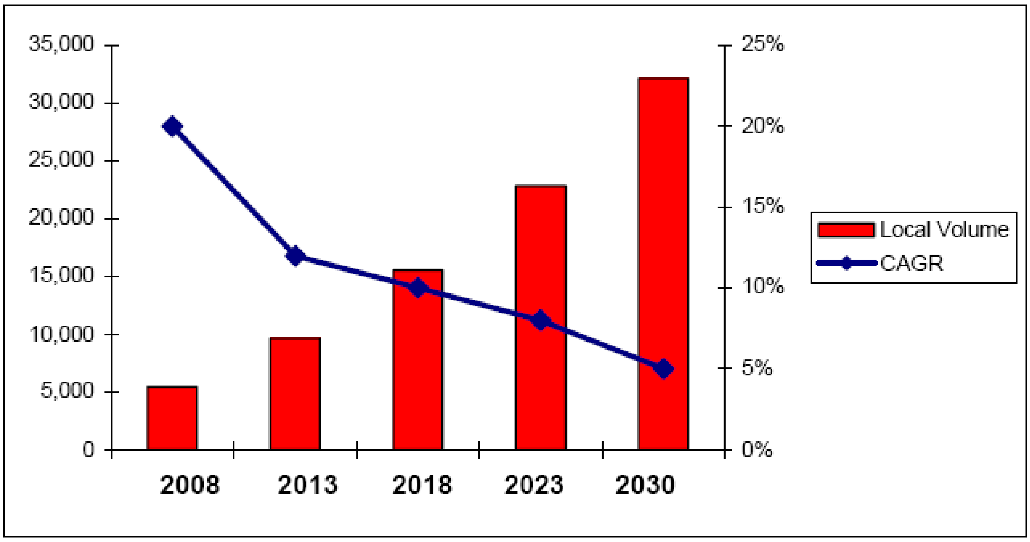

Figure B3.1 Local volume forecast (high growth rate)

In an absolute sense, the growth rate for 2003 to 2008 is high, but HPA considered it is consistent with results of the past two years (2002 and 2003).

For the periods beyond 2013, consecutive decreases in the average annual growth rate were forecasted, reflecting expectations for maturing regional trades and the inherent difficulties of sustaining high growth rates on a constantly-expanding volume base. With the strong but declining growth rates projected until 2023, the incremental volume generated in each of the five-year periods will be quite substantial.

B3.1.2 Low growth condition

An alternative forecast of local market volumes was also constructed. This forecast was developed using a near-term growth rate closer to the one exhibited in the 1998-2003 period, and then using long-term rates closer to those experienced in other importoriented trade lanes of importance in the global liner industry. Even under this alternative low growth scenario, the future volumes of containers were projected to rise dramatically.

Movement Type	2003	2008	2013	2018	2023	2030	CAGR
Inbound	1,100.0	2,327.4	3,921.8	5,762.4	7,711.4	10,850.7	
Outbound	1,100.0	2,327.4	3,921.8	5,762.4	7,711.4	10,850.7	
Local Volume	2,200.0	4,654.8	7,843.6	11,524.8	15,422.8	21,701.5	
CAGR		16%	11%	8%	6%	5%	9%

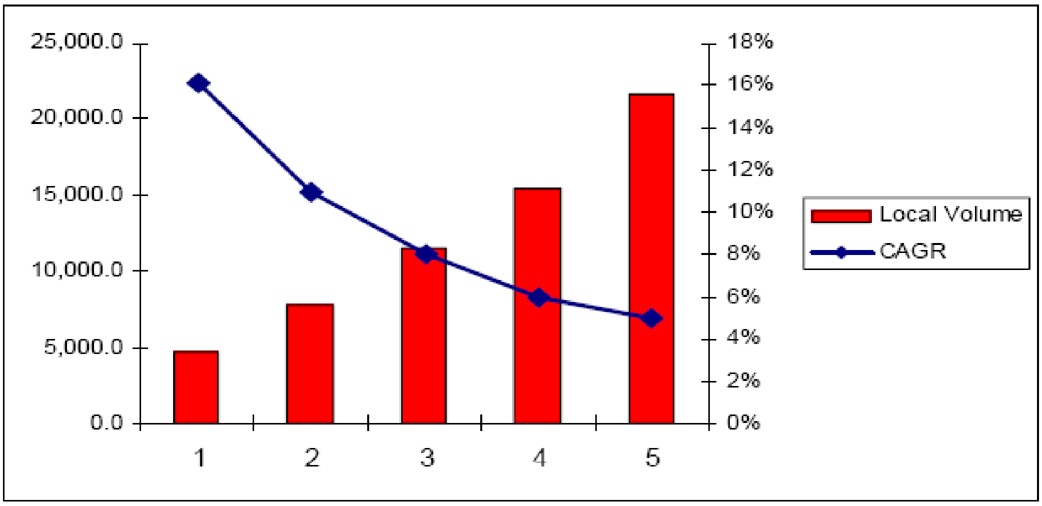

Figure B3.2 Local volume forecast (low growth rate)

B3.2. Transshipment volume

The forecast of transshipment volume were also analyzed for two growth conditions: high growth condition and low growth condition.

B3.2.1. High growth condition

Based upon the growth prospects for the major trades of the Arabian Gulf, the likelihood that most of the deployments in these major trades will continue to minimize the number of direct calls within the Gulf, and the dynamics of the competition between Dubai and other regional ports for Gulf transshipment business, a rapid expansion of Dubai Ports' relay volumes were projected.

Movement Type	2003	2008	2013	2018	2023	2030	CAGR
T/S Volume	2,800.0	7,262	11,696	17,186	25,251	35,531	
CAGR		21%	10%	8%	8%	5%	10%

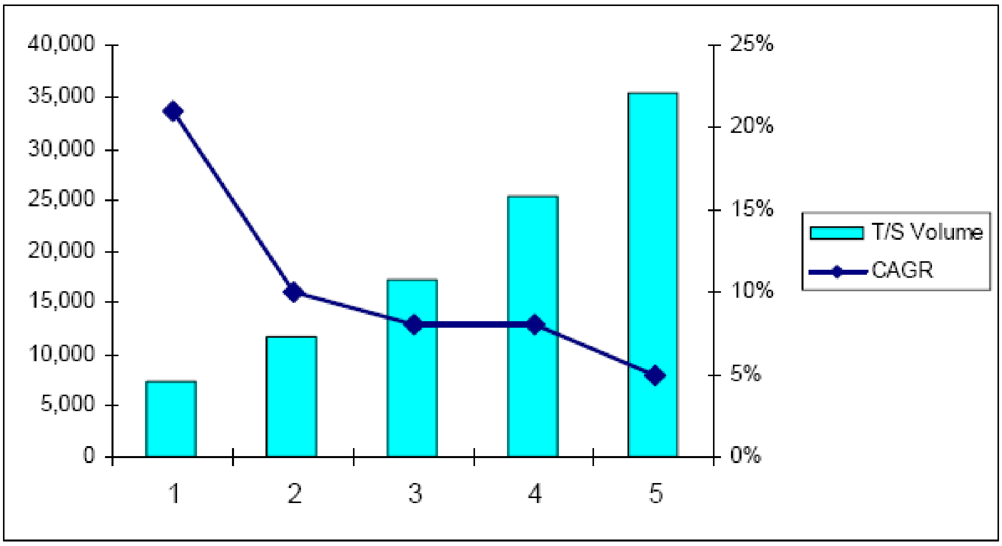

Figure B3.3 Local volume forecast (high growth rate)

B3.2.2 Low growth condition

An alternative forecast for the transshipment business was also constructed, using more conservative growth rates across the entire period to reflect the higher level of risk in this market segment. This was done to reflect the fact that volume generation is a function not only of the expansion of the regional economy and associated liner trades, but also of the network designs and container routing decisions of a relatively small number of shipping lines.

Movement Type	2003	2008	2013	2018	2023	2030	CAGR
T/S Volume	2,800	6,231	9,587	13,446	17,161	24,147	
CAGR		17%	9%	7%	5%	5%	8%

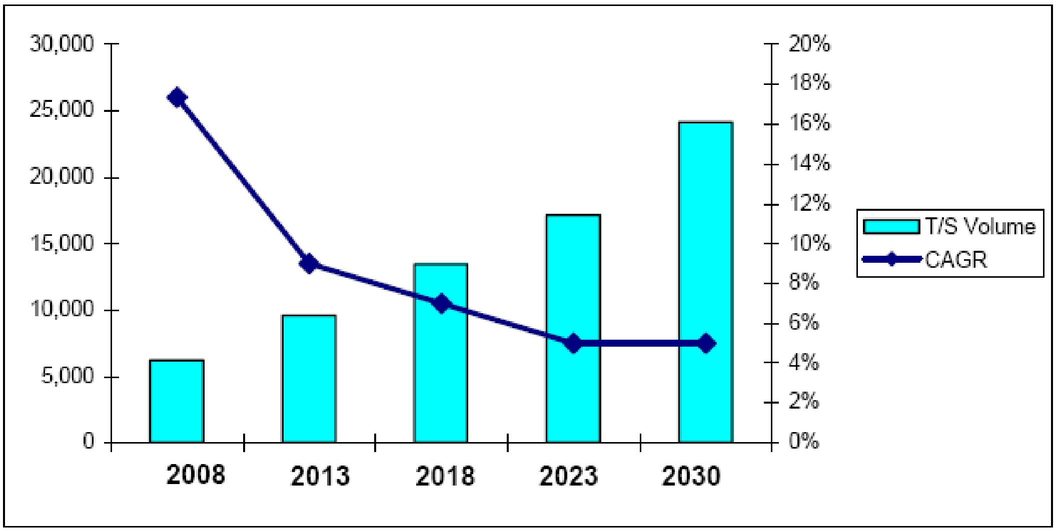

Figure B3.4 Local volume forecast (low growth rate)

The lower growth rate was forecasted for the periods beyond 2008, because of following reasons:

- Import volumes from the Far East to Dammam, Iraq, and Iran will increase to levels warranting direct calls by selected carrier-groups.
- Port facilities and operations in Iraq and Iran will be improved to make direct calls of 3,000-4,000 TEU ships feasible.
- Carriers in the Far East – Gulf trade will deploy additional strings (either independently or in alliances) to increase sailing frequencies and to increase port coverage on each end, instead of just upsizing existing services.
- Higher proportions of India's exports/imports will be routed directly, rather than via Gulf ports or other regional hubs.
- Aden and especially Salalah will capture more of the East Africa transshipment business.

B3.3. Identification of the Most Likely Scenario

In order to identify the most likely growth scenario, forecasts for four growth scenarios were developed. The results can be summarized as:

	Year	Scenarios			
		Low Growth	CAGR	High Growth	CAGR
Local Volume	2003	2,2	-	2,2	-
	2008	4,6	15,9%	5,5	20,1%
	2013	7,8	11,1%	9,6	11,8%
	2018	11,5	8,1%	15,5	10,1%
	2023	15,4	6,0%	22,8	8,0%
	2030	21,7	5,0%	32,1	5,0%
Transshipment Volume	2003	2,8	-	2,8	-
	2008	6,2	17,2%	7,2	20,8%
	2013	9,6	9,1%	11,7	10,2%
	2018	13,4	6,9%	17,2	8,0%
	2023	17,2	5,1%	25,3	8,0%
	2030	24,1	4,9%	35,3	4,9%

Table B3.1 Container throughput forecast by HPA (million TEUs)

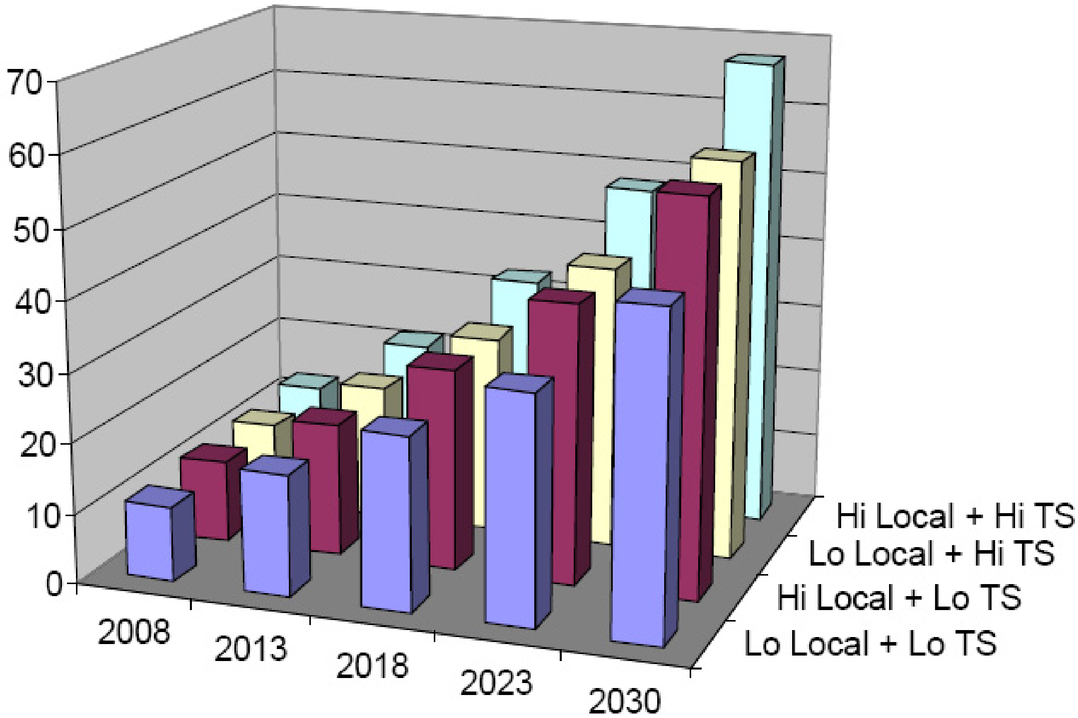

Figure B3.5 Summary of container volume forecast (M TEUs/year)

In review of the four scenarios, it is concluded that the most likely forecast scenario is the one combined by high growth rate for local market and low growth rate for transshipment business. The main reasons behind this are the inherently higher risks associated with the transshipment business and the expected long-term increasingly diversified economy of Dubai and the UAE.

B4. Conclusion

Dubai ports’ container volumes were derived by adding local volume of high growth scenario to transshipment volume of low growth scenario. This combination leads to a total volume of approximately 56.2 million TEUs by 2030.

	Throughput (million TEUs)	**CAGR**
2003	5.00	-
2008	11.70	18.5%
2013	19.20	10.4%
2018	28.90	8.5%
2023	40.00	6.7%
2030	56.20	5.0%

Table B4.1 Results from scenarios analysis (M TEUs/year)

Appendix C: Quay wall design

C1. General information

C1.1. Introduction

This appendix presents the quay wall design for new Jebel Ali Port. This quay wall is designed as part of container terminals, and thus quay walls for other cargos are not considered in this report.

This report addresses:

- Location and datum
- Geotechnical data
- Hydrographical data
- Structural requirements
- Design loads
- Design philosophy
- Block wall design
- Caisson wall design
- Conclusion

Because of insufficient data and time limitation, the detailed geotechnical designs are not considered.

C1.2. Codes and standards

The following design codes and standards are used for the design of the quay wall structures:

- BS 6349 Maritime Structures
- BS 8002 Code of practice for Earth Retaining Structures
- BS 8004 Code of practice for Foundations
- BS 8110 Structural use of concrete, Code of practice for design and construction
- Eurocode 8 Earthquake engineering
- EAU 2004

Where none of the above standards cover a design aspect then these aspects is designed in accordance with the relevant British / European Standard.

C1.3. Location and datum

<u>Location</u>
The layout is defined by the setting-out line provided in the Masterplan (refer to the main report section 6.3). For quay walls the setting-out line defines the front side (sea) of the capping beam.

It is assumed that the design conditions and requirements are the same for all locations. This assumption is based on very gentle slope near Dubai coast, well protected harbor basins, small tidal range, weak currents and the same designed water depth.

<u>Datum</u>
It is noticed that two vertical datum levels are used in Dubai: Admiralty Chart Datum (ACD) and Dubai Municipality Datum (DMD). The relationship between two datum were established by Nortech in 2005 based on a leveling survey (*Nortech, 2005*):

DMD±0.00m = ACD-0.10m

C1.4. Geotechnical data

<u>Ground characteristics</u>
Refer to the main report section 4.3.3.

<u>Seismic conditions</u>
Dubai is located in a relatively inactive seismic region. As advised by the Client, the region is categorized as UBC Zone 2A earthquake with a magnitude not exceeding 6.5 on the Richter scale.

Horizontal peak ground accelerations of 0.15g apply at the surface of the existing caprock. For the seismic quay wall design Eurocode 8 is integrally applied, including the definition of amplification factors in relation to the soil conditions. The reclaimed soil on top of the caprock will be removed and replaced by quarried rock.

The horizontal peak ground acceleration of 0.15g is the basis for the evaluation of the design parameter to be applied for design of the quay wall structure in accordance with Eurocode 8. In Eurocode 8 the amplification factor is represented by the soil factor S (Eurocode 8, Part 1, Section 3). Since the soft soil is completely replaced by quarried rock, the soil factor S may be 1.0.

C1.5. Hydrographic data

<u>Sea water density</u>
The density of the sea water is taken as 1,025 kg/m^3 or 10.1kN/m^3.

<u>Tidal elevations</u>

Item	Tidal Levels	Design Value, (m, DMD)
1	Highest Astronomical Tide (HAT)	+2.30
2	Mean Higher High Water (MHHW)	+1.70
3	Mean Lower High Water (MLHW)	+1.40
4	Mean Sea Level (MSL)	+1.10
5	Mean Higher Low Water (MHLW)	+0.90
6	Mean Lower Low Water (MLLW)	+0.50
7	Lowest Astronomical Tide (LAT)	-0.10

Table C1.1 Characteristic Tidal Levels at the Dubai Coast

Extreme water level

Return Period (years)	Elevation (m, DMD)
1	1.9
5	2.3
10	2.5
25	2.8
50	3.0
100	3.3

Table C1.2 Extreme water level

Sea level rise
The latest estimation of the sea level rise by the Intergovernmental Panel on Climate Change (IPCC) is approximately 25 cm over the next 50 years and it is will be included for later design.

Wave and current conditions
Refer to the main report section 4.3.2.

C2. Structural requirements

C2.1. Design life and hydraulic design conditions

The design life for the quay wall structure is 50 years. The hydraulic design conditions are the 50-year return period wave and water level conditions in combination with the expected sea level rise after 50 years.

C2.2. Quay structure

The required quay wall structure is a gravity structure. Two types of quay wall structures for this project have been developed: concrete block wall and caisson wall.

The dimensions of the blocks are limited to a maximum weight of approximately 70 tons and the dimensions of caissons are depended on construction methods.

C2.3. Structure levels

The quay deck level is determined as DMD+4.00m.
The designed sea bottom level is DMD-19.1m.

C2.4. Design water level

The stability of the quay wall is assessed for a high water level and a low water level.

- For non-earthquake conditions the design high water level is taken as the 1/50 year water level and the expected sea level rise after 50 years (2.80m DMD + 0.25m = 3.05m DMD).

- For earthquake conditions the design high water level is taken as Highest Astronomical Tide including 50 years of sea level rise (2.30m DMD + 0.25m = 2.55m DMD).

- The design low water level for earthquake and non-earthquake conditions is taken as Lowest Astronomical Tide (-0.1m DMD).

A maximum tidal lag of 0.50 m is considered, resulting in the following levels:

	Sea side (m, DMD)	Land side (m, DMD)
HWL	+3.55	+3.05
LWL	-0.10	+0.40

Table C2. 1 Normal condition

	Sea side (m, DMD)	Land side (m, DMD)
HWL	+2.05	+2.55
LWL	-0.10	+0.40

Table C2.2 Earthquake conditions

C2.5. Design vessel

The designed vessel is super-post-Panamax with following characteristics:

- Size: 12,000 TEUs
- LOA: 397 m
- Beam: 56 (22 rows across on the deck) m
- Draught: 15.5 m
- Tonnage: 175,000 tons

C3. Design loads

The quay structure is designed to resist the design loads defined in this section.

C3.1. Dead weight of structures

The deadweight of the structure includes the weight of all structural components. For pre-cast and in-situ concrete a mass density of 24.5kN/m^3 will be used for design.

C3.2. Buoyancy loads

Buoyancy loads include the uplift due to submergence in sea water considering a mass density for sea water of 10.1kN/m^3.

C3.3. Soil and differential water loads

The quay wall is designed to resist the following loads:

- Horizontal active earth pressures developed by the weight of the soil
- Hydrostatic pressure due to a difference in water levels across the wall

The capping beam is designed to resist horizontal at rest pressures.

The backfill and foundation bund consist of quarry run material, and at the capping beam level sand is applied as backfill. The bulk density varies with the quarry mass density and the porosity in situ. *Table C3.1* summarizes the adopted average properties, which are used as characteristic design parameters:

	γ_{dry} [kN/m^3]	γ_{wet} [kN/m^3]	c [kPa]	φ [º]
Sand fill	18.0	20	0	30
Quarry run	17.5	21.5	0	40

Table C3.1 Adopted properties backfill material

C3.4. Surcharge loads

Between the waterside of the quay wall and the landward side of the railway, the quay is loaded by general traffic for container transport and storage of containers to be transported. It is assumed that no containers will be stacked in this area. For temporary storage, only 2 layers of full containers will be assumed. It gives a load of 35 kN/m^2, recommended by the EAU 2004.

The area behind the landward railway could be used for storage. The container in this area can be stacked higher. The EAU 2004 recommends full container, stacked 4 high with a load of $55kN/m^2$.

C3.5. Mooring and berthing loads

For a container vessel with displacement about 175,000 tons, the line pull force is approximately 1400kN. Normally, this load will redistribute over an angle of 45º troughs the superstructure to a line load. The bollard is placed in the centre of the width of the superstructure. This results in a horizontal line load of approximately 280kN/m.

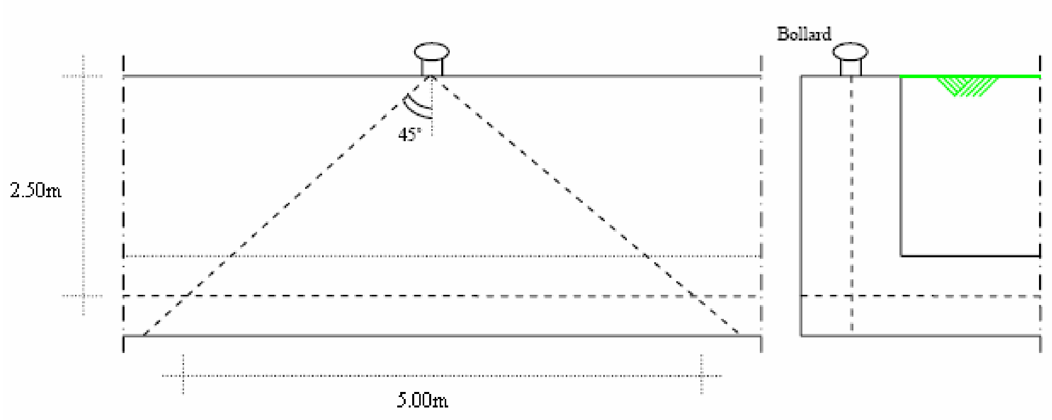

Figure C3.1 Load redistribution

C3.6. Crane loads

Super-Super-Post Panamax (SSPP) cranes will be employed to serve the designed vessels. The cranes require twin-lift capability with an outreach of approximately 65 m, and a rail gage of 30.48 m. The waterside crane rail is located 7.25 m from the face of the quay wall.

The vertical operational crane loads at both waterside and landside are 1100 kN/m and the horizontal loads perpendicular and parallel to rails are 10% of vertical load.

C3.7. Wave loads

Wave loads are considered negligible in the final location for both block wall and caisson wall.

For caisson wall, during the towing journey the caisson will be subjected to wave loads.

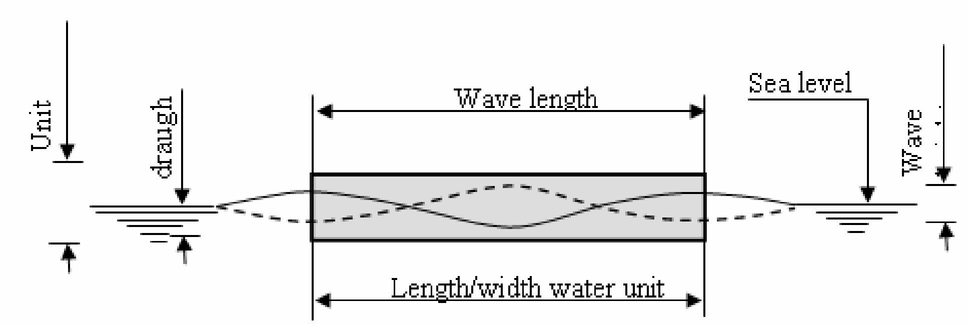

Figure C3.2 Caisson subjected to wave load

Within the criteria of this case it is sufficient to suppose a maximum wave load imposed by a sinus-shaped wave with a wave length (L) equal to length respectively width of the caisson and a wave height (H) equal to 4 meter.

C3.8. Current loads

Currents are weak in the project area, so current loads are considered negligible.

C3.9. Seismic loads

The earthquake loading on the quay wall is determined in accordance with Section 7.3.2 of Eurocode 8, Part 5.

The horizontal (k_h) and vertical (k_v) seismic load coefficients are calculated as:

$$k_h = \alpha \frac{S}{r}$$

$$k_v = \pm 0.5 k_h$$

with:
α = ratio of the design ground acceleration to the acceleration of gravity = 0.15
S = soil factor = 1.0
r = reduction factor

Considering the soil conditions and the type of retaining structure, the values S = 1.0 and r = 2.0 apply. According to Eurocode 8, part 5, table 7.1, this may lead to displacements up to 300*α*S = 45mm. This is considered repairable damage.

The following earthquake load coefficients are therefore adopted:
k_h = 0.075
k_v = +/- 0.0375

The increased active soil load behind the quay wall is combined with a hydrodynamic water force and a hydrodynamic pressure on the outer face of the wall, according to Eurocode 8, part 5, Annex E.

C4. Design philosophy

C4.1. Load combination

Loads are combined according BS 6349 Part 2. Normal load combinations are assessed with the full live loads. Earthquake loads are combined with 50% of the live loads.

The following loads are considered:

- Dead load D
- Earth pressure E
- Hydrostatic pressure H_{hwl} or H_{lwl} (including tidal lag)
- Surcharge loads S
- Mooring loads B
- Seismic load G
- Wave loads W
- Crane loads C
- Fender loads F

C4.1.1. Block wall

The following load combinations are used for the design:

Normal: NTC1: $D + E + H_{hwl} + S + B$
NTC2: $D + E + H_{lwl} + S + B$

Earthquake: ATC1: $D + E + H_{hwl} + G + S_{50\%}$
ATC2: $D + E + H_{lwl} + G + S_{50\%}$

C4.1.2. Caisson wall

1) Transportation stage
The following load combinations are used for the design:

Normal: NTS1: $D + H_{hwl} + W$
NTS2: $D + H_{lwl} + W$

2) Operation stage
The following load combinations are used for the design:

Normal: NTC1: $D + E + H_{hwl} + S + B$
NTC2: $D + E + H_{lwl} + S + B$

Earthquake: ATC1: $D + E + H_{hwl} + G + S_{50\%}$
ATC2: $D + E + H_{lwl} + G + S_{50\%}$

In which:
NTS Normal Transportation Stage
NTC Normal Transient Case
ATC Abnormal Transient Case

C4.2. Failure mechanisms

The quay wall is designed to meet the required factors of safety for the different load combinations and it is assessed according to the British Standards and Eurocode 8 for earthquakes. The representative values of all related parameters are used and the overall safety factors against the failure mechanisms are taken into account. For abnormal conditions, reduced safety factors are applied.

C4.2.1. Block wall

1) Sliding
Sliding of the individual blocks and the complete quay wall is checked, using the following formula:

$$\gamma_S = \frac{f * V_{total}}{H_{total}}$$

with: γ_S = safety factor
f = friction coefficient
V_{total} = resultant vertical load
H_{total} = resultant horizontal load

The following safety factors against sliding are required:

Block – block:
γ_S = 1.75 for normal conditions (NTC)
γ_S = 1.50 for abnormal conditions (ATC)

Block – foundation:
γ_S = 1.75 for normal conditions (NTC)
γ_S = 1.50 for abnormal conditions (ATC)

2) Overturning
Overturning of the individual blocks and the complete quay wall are checked, using the following formula:

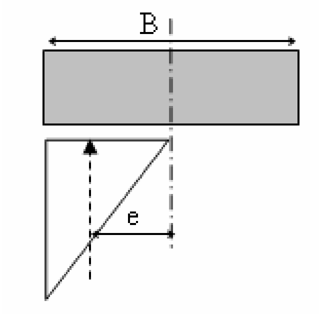

Figure C4.1 Overturning stability

$$\gamma_S = \frac{0.5 * B}{e}$$

with: γ_S = safety factor
B = width of block
e = eccentricity of resultant vertical force (= Moment / Vertical force)

The following safety factors against overturning are required:

Block – block:
γ_S = 1.50 for normal conditions (NTC)
γ_S = 1.50 for abnormal conditions (ATC)

Block – foundation:
γ_S = 3.00 for normal conditions (NTC)
γ_S = 1.50 for abnormal conditions (ATC)

In addition the bearing capacity of the foundation is checked.

<u>3) Foundation failure (BS 6949-2 5.3.1.5)</u>
The maximum pressure under the wall should not exceed the allowable bearing pressure in the underlying material.

C4.2.2. Caisson wall

<u>1) Stability requirements</u>
Refer to 4.2.1.

<u>2) Floating conditions</u>
The stability of a caisson should be checked for all conditions such as casting (if over water), launching, towing and sinking. The effect of waves, especially those of long period, should be considered. In the static and sinking conditions, the trim of a caisson may be readily adjusted by ballasting

Elements must be designed or equipped in such a way that a rotation, caused by external factors, is corrected by an opposing moment, which returns the element to its original position.

Figure C4.2 shows three points, which are of importance in the evaluation of the stability.

G is the centroid, the centre of gravity of the element.

B is the centre of pressure, the point of application of the buoyancy force in state of equilibrium (the state in which the axis of symmetry of the element is vertical).

M is the meta-centre; the point of intersection between the axis of symmetry, the z axis, and the buoyancy force with a rotation, which is not shown in *Figure C4.2*. For small rotations (<10°) the meta-centre is a fixed point.

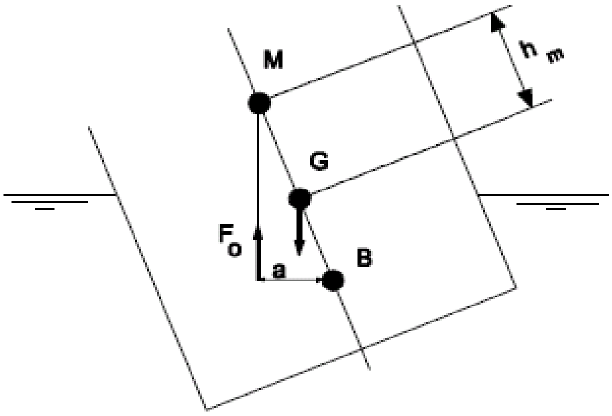

Figure C4.2 Stabilizing moment

The distance between the centre of pressure and the meta-centre is:

$$\overline{BM} = \frac{I}{V}$$

where: I: moment of inertia
V: displacement

For static stability, *M* must be above *G*: the line segment *GM,* also known as the meta-centric height h_m, must be positive. If *M* is positioned above *G,* a corrective moment is created, which tries to return the element to its rest position. The meta-centric height h_m can be calculated as:

$$h_m = \overline{BM} - (\overline{OG} - \overline{OB})$$

For the caisson, an h_m of at least 0.50 m is required.

C5. Block wall design

C5.1. Overturning and sliding

Based on the required factors of safety against overturning and sliding, the structure cross-section is presented below.

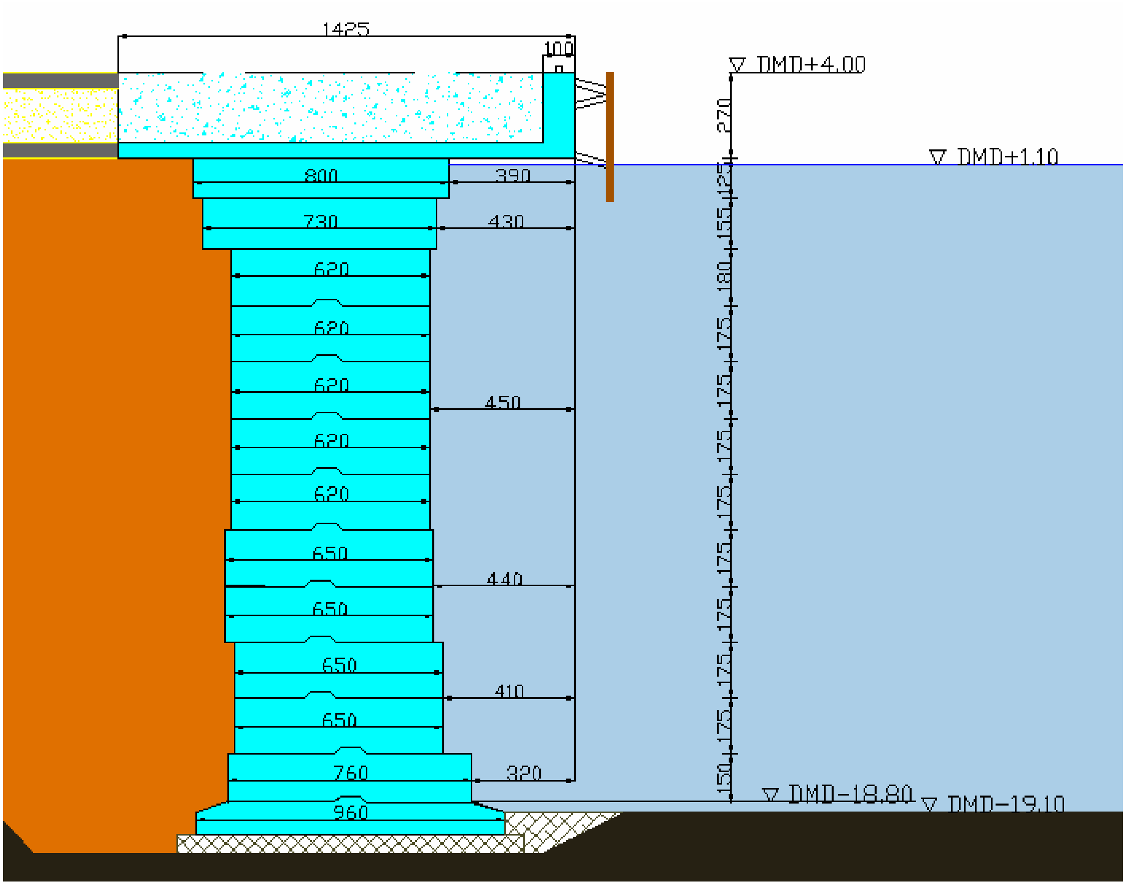

Figure C5.1 Concrete block wall

The detailed calculations are performed in Excel files, and the results are summarized here. The safety factors for all load combinations of sliding are presented in *Table C5.1*.

Safety factors	Sliding			
Elements	**NTC1**	**NTC2**	**ATC1**	**ATC2**
Capping	15,5	25,45	14,45	17,99
A1	12,2	19,23	10,15	11,94
A2	9,75	12,59	7,36	7,49
B1	7,81	9,06	4,97	5,24
B2	6,58	7,21	4,30	4,05
B3	5,7	6,03	3,53	3,31
B4	5,05	5,21	2,99	2,79
B5	4,53	4,60	2,58	2,41
B6	4,13	4,14	2,26	2,12
B7	3,8	3,77	2,02	1,90
B8	3,52	3,47	1,82	1,71
B9	3,27	3,22	1,66	1,56
C1	2,99	2,98	1,57	**1,50**
C2	3,27	3,17	1,59	1,51

Table C5.1 Safety factors of sliding

Calculation shows the overturning stability of the whole structure is governing, instead of each concrete blocks.

	Overturning			
	NTC1	NTC2	ATC1	ATC2
Safety Factor	3,99	4,05	1,58	1,57

Table C5.2 Safety factors of overturning

The block details, including dimensions and weights, are presented in *Table C5.3*.

	Width (m)	Length (m)	Height (m)	Volume (m^3)	Weight (app. Tons)	Top level (DMD,m)	Bottom level (DMD,m)
Capping	2,49	14,25	2,70	95,80	234,72	4,00	1,30
A1	2,49	8,00	1,25	24,90	61,01	1,30	0,05
A2	2,49	7,30	1,55	28,17	69,03	0,05	-1,50
B1	2,49	6,00	1,80	26,89	65,89	-1,50	-3,30
B2	2,49	6,00	1,75	26,15	64,06	-3,30	-5,05
B3	2,49	6,00	1,75	26,15	64,06	-5,05	-6,80
B4	2,49	6,00	1,75	26,15	64,06	-6,80	-8,55
B5	2,49	6,00	1,75	26,15	64,06	-8,55	-10,30
B6	2,49	6,50	1,75	28,32	69,39	-10,30	-12,05
B7	2,49	6,50	1,75	28,32	69,39	-12,05	-13,80
B8	2,49	6,50	1,75	28,32	69,39	-13,80	-15,55
B9	2,49	6,50	1,75	28,32	69,39	-15,55	-17,30
C1	2,49	7,50	1,50	28,01	68,63	-17,30	-18,80
C2	2,49	9,60	1,00	23,90	58,56	-18,80	-19,80

Table C5.3 Detail information of blocks

C5.2. Capping beam

The precast capping blocks are to be placed after levelling of the underlying blocks with cement mortar. The capping blocks need to have a serrated finish and the underlying blocks shall have a rough finish to achieve good friction.

The front edge of the capping beam blocks is placed 110mm offset from the setting out line to compensate for inaccuracies in the placement of the underlying blocks.

C5.3. Toe block

For the toe block, a serrated bottom is required to improve the friction coefficient between the toe block and the underlying bedding layer. The grooves are required to be 50mm.

The toe block is longer than the upper blocks, causing a bending moment at the front of the block. The tensile stress caused by the bending moment is within tolerable limits for the different loading cases.

C6. Caisson quay wall design

C6.1. Construction method

Two construction methods are considered for this project:

1) Construct small caissons; place them with cranes; and filled with sand.
2) Construct large caissons in docks; tow to the location by tug boats; lower into location by controlled flooding; and filled with sand.

Preliminary design shows that the self weight of concrete caisson is approximately 90 tons/m, which is too heavy for cranes. So the second construction method is developed further.

C6.2. Dimensions

The determination of dimensions is an iterative process, with the consideration of following aspects:

- floatability
- floating stability
- sliding stability
- overturning stability

The requirements of sliding and overturning stability under earthquake condition are governing, so the preliminary dimensions are determined with these requirements. After that, these dimensions are evaluated with floatability and floating stability.

The structure dimensions are presented below.

	Width (m)	Length (m)	Depth (m)
Main caisson	11	23.5	20.4
Bottom slab	13	23.5	1.0

Table C6.1 Caisson dimensions

C6.2. Floatability and stability

The floatability and stability are two important checks for transportation stage. The calculations are performed in Excel files and the results can be summarized as follows:

Alternatives	$\overline{D}$ (m)	$\overline{OG}$ (m)	$\overline{OB}$ (m)	I_{tank} (m^4)	V_{water} (m^3)	$\overline{BM}$ (m)	h_m (m)
without ballast water	9.38	7.89	4.69	2607	2472	4.69	**-2.14**
with ballast water	13.73	6.52	6.87	732	3597	0.20	**0.55**

Table C6.2 Floatability and stability

The floatability requirement is satisfied for both cases with and without ballast water. But the static stability requirement is not satisfied without ballast water. So ballast water with a depth of 5 m is used during transportation.

C6.3. Sliding and overturning

The safety factors for all load combinations of sliding and overturning stability are presented in *Table C6.3*.

Elements	**Sliding**				**Overturning**			
	NTC1	NTC2	ATC1	ATC2	NTC1	NTC2	ATC1	ATC2
Capping	15,5	25,5	10,9	14,2	3,54	3,78	1,72	1,80
Caisson	3,17	3,24	1,53	**1,51**				

Table C6.3 Safety factor of caisson wall

C6.4. Cross section

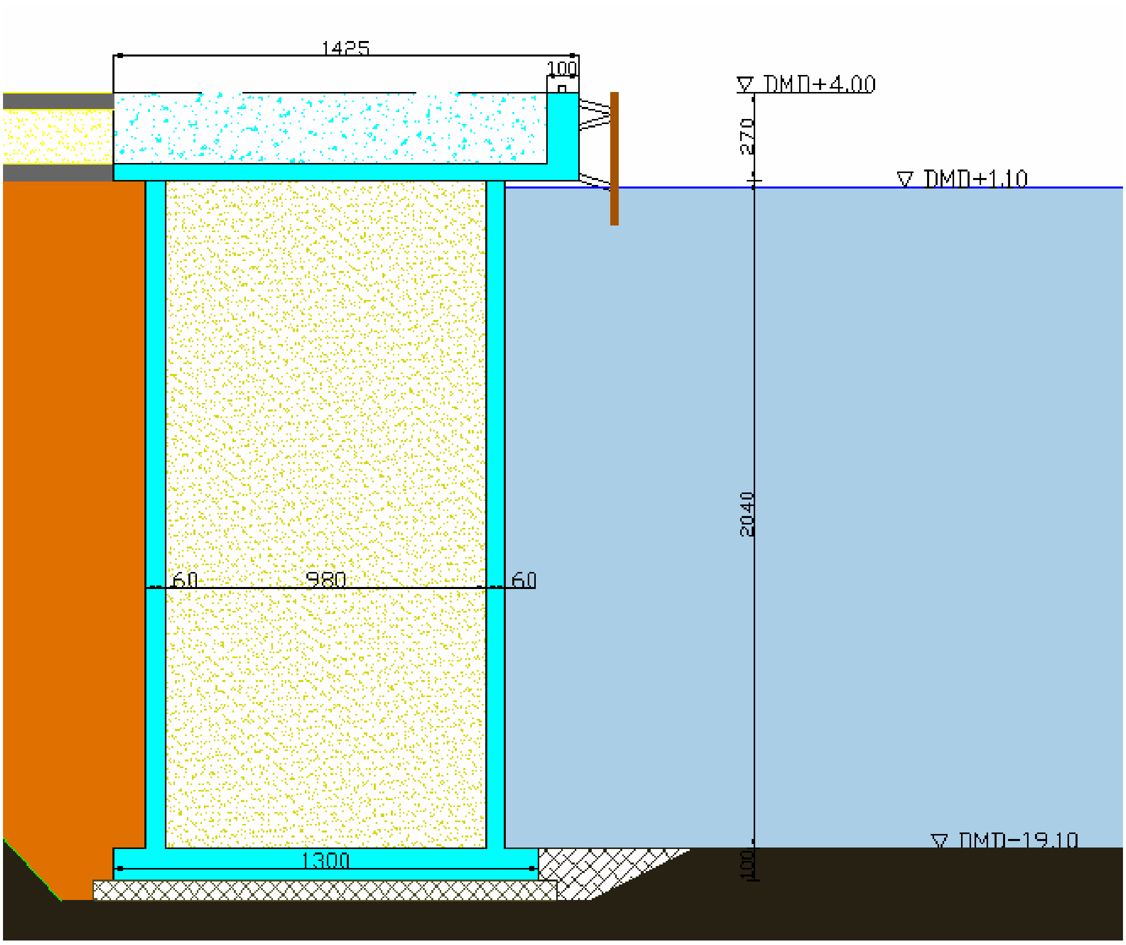

Figure C6.1 Caisson wall

C7. Conclusion

The concrete block wall is recommended for following reasons:

Comparing to caisson wall, the transportation of concrete blocks is easier; the total cost is lower and the time constrains of the construction is smaller.

It is also noticed that concrete block quay walls are widely constructed in Dubai area. So it is familiar to contractors operating in the general vicinity of this project.

In addition, the block wall construction maximizes the use of local materials and minimizes the need to rely on imported material.

In conclusion, suitable geotechnical conditions, relatively low cost, wide applications in Dubai are together makes block wall the best option.

Appendix D: Channel width

Channel Width		**Outer channel**			**Inner channel**		
	Two-way		***610,4***	m		***448,0***	m
	Three-way		***963,2***	m		***711,2***	m
Basic maneuvering lane	**W_{bm}**		***72,8***	m		***72,8***	m
	good	1,3B	*72,8*	m	1,3B	*72,8*	m
	moderate	1,5B		m	1,5B		m
	poor	1,8B			1,8B		
Additional width	**W_i**		***157***	m		***84***	m
Vessel speed (knots)							
	fast>12	0,1B			0,1B		
	moderate>8-12	0			0		
	slow 5-8	0	**0**	m	0	**0**	m
Cross wind (knots)							
	mild<15	0			0		
	moderate>15-33	0,5B	**28**	m	0,5B	**28**	m
	severe>33-48	1,0B			1,0B		
Cross current (knots)							
	negligible<0,2	0			0		
	low 0,2-0,5	0,3B	**16,8**	m	0,2B	**16,8**	m
	moderate>0,5-1.5	1,0B		m	0,8B		m
	strong>1,5-2,0	1,3B		m	-		m
Longitudinal current (knots)							
	low<1,5	0	**0**	m	0	**0**	m
	moderate>1,5-3	0,2B			0,2B		
	strong>3	0,4B			0,4B		
Hs and λ							
	Hs≤1 λ≤L	0				**0**	m
	3>Hs>1 λ=L	0,5B					m
	Hs>3 λ>L	1,5B	**84**	m			m
Aids to navigation							
	Excellent	0			0		
	Good	0,1B	**5,6**	m	0,1B	**5,6**	m
	Moderate with infre poor visibility	0,2B			0,2B		
	Moderate with fre poor visibility	0,5B			0,5B		

	Bottom surface d<1,5T							
		Smooth and soft	0,1B			0,1B		
		Smooth and hard	0,1B			0,1B		
		Rough and hard	0,2B	**11,2**	m	0,2B	**11,2**	m
	Depth of waterway							
		d<1,5T	0,2B	**11,2**	m	0,4B	**22,4**	m
	Cargo hazard level							
		low	**0**	**0**	m	**0**	**0**	m
		medium	0,5B			0,4B		
		high	1,0B			0,8B		

Bank clearance		**W_b**		***28***	m		***28***	m
	Sloping channel							
		fast	0,7B			0,7B		
		moderate	0,5B			0,5B		
		slow	0,3B			0,3B		
	Steep and hard embankments							
		fast	1,3B			1,3B		
		moderate	1,0B			1,0B		
		slow	0,5B	**28**	m	0,5B	**28**	m

Seperation distance		**W_p**		**95,2**	m		**78,4**	m
	Vessel speed							
		fast	2,0B			-		
		moderate	1,6B			1,4B		
		slow	1,2B	**67,2**	m	1,0B	**56**	m
	Traffic density							
		ligh	0			0		
		moderate	0,2B			0,2B		
		heavy	0,5B	**28**	m	0,4B	**22,4**	m