CTwa4330

Ports and Terminals

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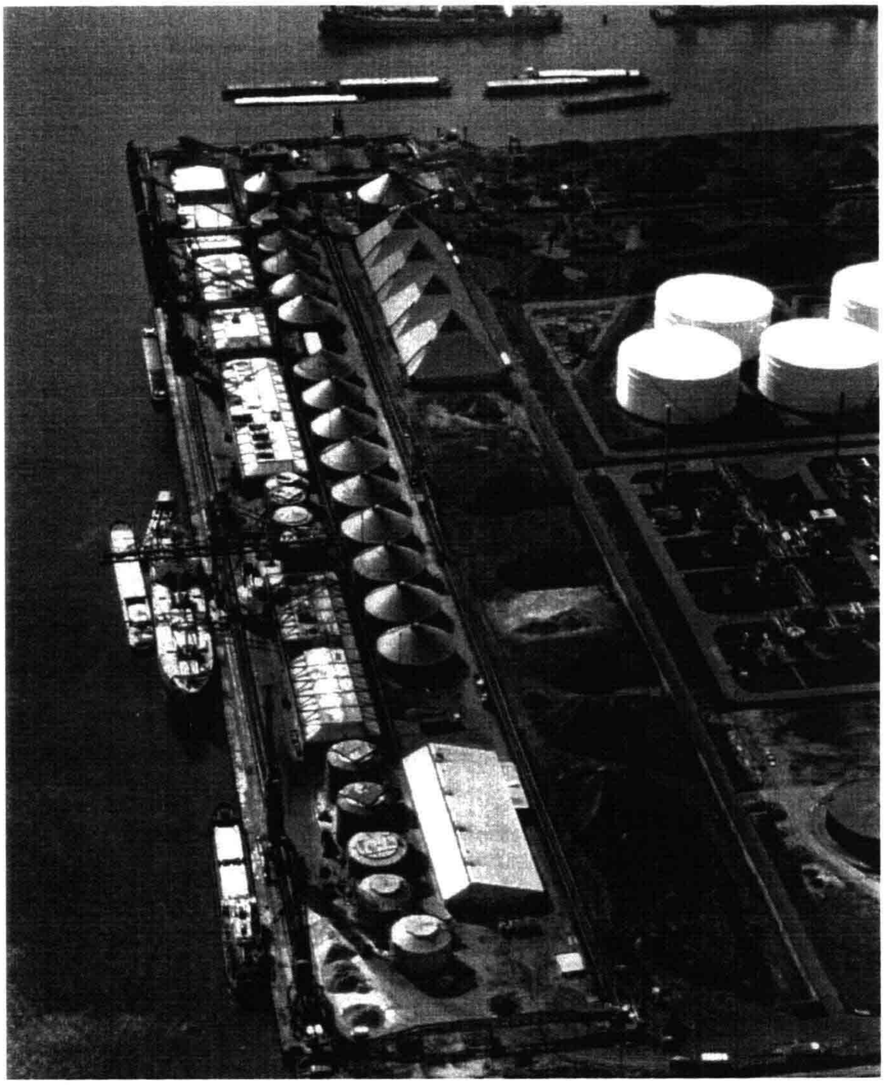

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CTwa4330 Ports and Terminals

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PORTS AND TERMINALS

PLANNING AND FUNCTIONAL DESIGN

prof. ir. H. Ligteringen

Contents

Chapter

1. Introduction
2. Maritime transport
3. Port functions
4. Principles of integrated port planning
5. Planning and design of a port's water areas
6. Landside planning and design
7. Container terminals

Chapter 1. Introduction

This chapter is usually skipped by the student, when going through the lecture notes in preparation of the examination. It is true that in most cases the introductory remarks are not being tested. Yet by doing so, those students will miss the message, one could say the essence of what port planning is all about. Therefore: continue reading this chapter, grasp the message and see if you are taken by it. If so, it will make the entire subject more interesting, the subsequent chapters more easy to digest and the examination easier to pass. It may make you a very good port planner indeed.

By nature port planning is a multi-disciplinary activity. It involves expertise in the field of transport-economics, shipping, nautical matters, safety and logistics. But also knowledge of waves and currents, sediment transport and coastal morphology, dredging and land reclamation, and design of breakwaters and quays. Hence port planning is teamwork. But within this team the port planner plays a central role in developing the concepts and obtaining the required expertise at the right time. Most port planners are civil engineers with hydraulic engineering training and experience. But they need to have two important qualities in addition to that:

i. a basic understanding of the other disciplines involved
ii. creativity

The first quality is needed to direct the work done by these experts and to integrate the results into a balanced design of the port lay-out. The integration process itself is the creative part of the work: after having determined the basic dimensions of approach channel and turning basins, of quays and terminals and of the corridors for hinterland connections, there are often many ways how to physically arrange them into a port lay-out. Here the second quality mentioned above plays a crucial role in developing the right one.

The first part of these lecture notes (Chapter 1 through 6) are aimed at providing the basic elements to perform this planning process. The individual case study, which is part of the curriculum, allows the students to test their creativity. Those who have it, qualify to play the central role of port planner in future projects. Others should not be discouraged: the port planning team needs also specialists in coastal engineering, breakwater- or quay design.

In chapter 7 the detailed planning of container terminals is treated, including the logistic process. Further attention is paid to design aspects, which are typical for such terminals and therefore not treated in other courses. The target is to provide the basis for an all-round port engineer, somebody who can participate in the design of any given type of port or terminal.

Chapter 2. Maritime transport

2.1. INTRODUCTION 2-2

2.2. SPECIFIC DATA OF MERCHANT SHIPS 2-3

2.2.1. TRANSPORT CAPACITY 2-3
2.2.2. VERTICAL DIMENSIONS 2-6
2.2.3. HORIZONTAL DIMENSIONS 2-7
2.2.4. OTHER RELEVANT DATA 2-8

2.3. COMMODITIES AND TYPES OF VESSELS 2-9

2.3.1. INTRODUCTION 2-9
2.3.2. BREAKBULK OR CONVENTIONAL GENERAL CARGO 2-9
2.3.2.1. General cargo ship 2-9
2.3.2.2. Multipurpose ship 2-11
2.3.2.3. Refrigerated general cargo ship (reefer) 2-13
2.3.3. CONTAINER VESSELS 2-14
2.3.4. RO/RO VESSELS 2-18
2.3.5. CAR CARRIERS AND OTHER SPECIAL VESSELS 2-20
2.3.6. BULK CARGO 2-27
2.3.6.1. Introduction 2-27
2.3.6.2. Liquid bulk carriers 2-28
2.3.6.3. Dry bulk carriers 2-33
2.3.6.4. Combined bulk carriers 2-35
2.3.7. SHORT SEA TRADER 2-37

2.4. TRAMP AND LINER TRADE 2-38

2.4.1. LINER TRADE 2-38
2.4.2. TRAMP TRADE 2-39

2.5. GRAPHS 2-40

2.6. REFERENCES 2-46

Chapter 2. Maritime transport

2.1. Introduction

Maritime transport is (in terms of tonkilometers) the most important of the 6 transportmodes, the other five being Inland Water Transport, Road-, Rail and Air transport and transport by pipeline. It is relevant to make the distinction between intercontinental maritime transport and that within a continent, because of the different competitive position. For the intercontinental shipping air transport is the only alternative, but not really a competitor because of the great difference in freight rates (see Table 2-1). Broadly speaking only passengers and high-value goods are carried by plane and this share of the market for transportation is well defined.

Table 2- 1: Freight rates across the Atlantic Ocean

Transport mode	Door-to-door time (days)	Freight rate (US$/kg)
Priority air	2-3	3.30
Standard air	4-7	1.00-1.90
Direct ocean	14-28	0.13-0.26

Maritime transport within a continent has many competitors, road transport being the most important one. Again the air transport mode is quite distinct from the others in terms of freight rate. But maritime transport, road, rail and inland water transport are in the same cost range and therefore in fierce competition. Maritime transport used to be at a disadvantage compared with roads for two reasons:

(i) it often needs additional transport between seaport and final destination. This creates two extra links in the chain, which increases costs, time and unreliability (see *Figure 2- 1*)

(ii) ports presented an uncertain element, due to the conventional custom procedures and the frequent labour strikes, which could cripple transport for weeks.

Both the intercontinental and the continental maritime transport volumes are increasing. The former due to the steady growth of world trade, the latter also because sea transport is becoming more attractive. Customs procedures can be shortened by modern technology such as Electronic Data Interchange (EDI) and "Smart Card". The connections between Short Sea lines and land transport become better by fixed routes and schedules and in many parts of the world the ports become more 'business oriented' and provide faster and more reliable services.

Containerisation in particular represents a major factor in the growth of cargo volume and hence in the increase of port capacity required. The average growth rate of container terminal capacity in the period 1990-1997 was around 9% per year. This is to accommodate partly the absolute growth of (general) cargo volume, partly also the shift of conventional general cargo to containerised cargo. But it means new terminal capacity, cranes and other equipment. This is illustrative of the present trend in port development world-wide: after a period of relative slow-down, even overcapacity in some countries, quite a number of ports are now reaching saturation and make plans for expansion. Examples nearby are Rotterdam (Maasvlakte 2), Antwerp and Le Havre. But also in the Far East Singapore and Hongkong are showing steady growth rates and ongoing port expansion.

Port development depends on the development of maritime transport, both in terms of volumes per commodity and in relation to types and sizes of vessels. For port planning a good understanding of these developments is mandatory. The following sections present data on ship design and cargo handling (as far as relevant for port planning) and some trends.

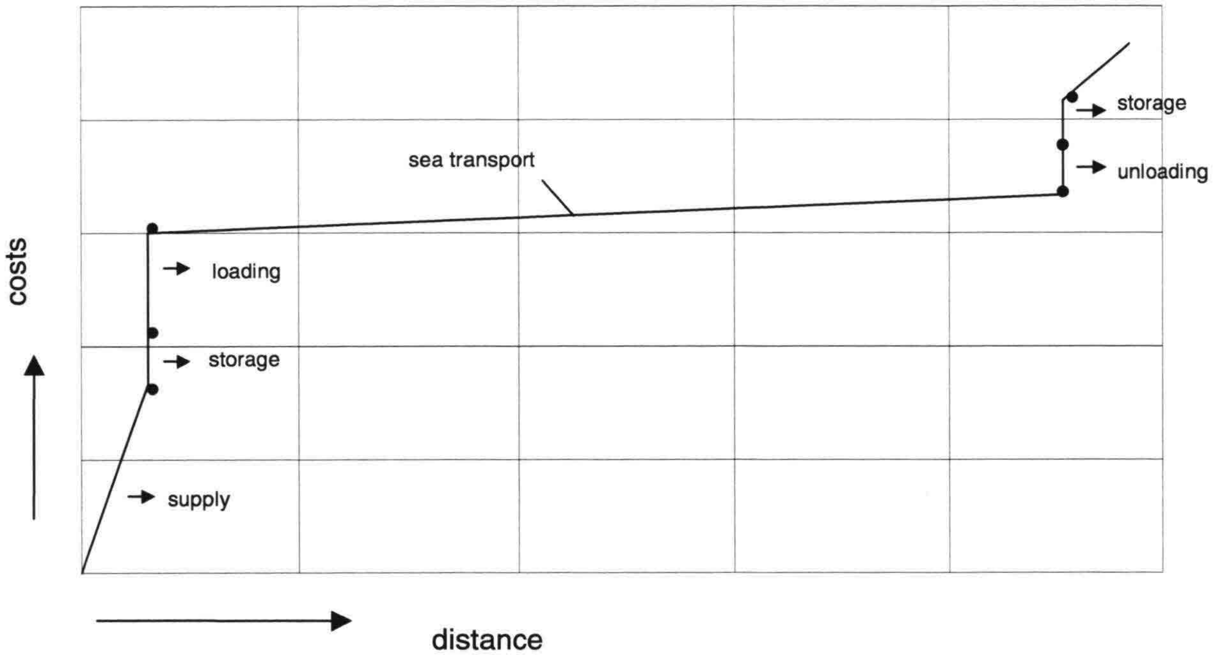


Figure 2- 1: Cost elements in a transport chain.

2.2. Specific data of merchant ships

2.2.1. Transport capacity

The tonnage of a ship is an indication of the carrying capacity in terms of the amount of cargo she can transport. Unfortunately, depending on the type of vessel, the country of origin, or the purpose for which the tonnage is used (for instance for harbour dues), there exist several ways to express tonnages. The most important ones are:

GRT - Gross Register Tonnage,
NRT - Net Register Tonnage, and
DWT - Dead Weight Tonnage

The relations between these three parameters are not fixed unconditionally: they depend mainly on the type of vessel concerned. However, within certain limits, the following relations can serve as a first approximation:

General cargo ships: DWT ≈ 1.5 * GRT ≈ 2.5 * NRT, and
Very large crude oil carriers: DWT ≈ 2.0 * GRT ≈ 2.6 * NRT

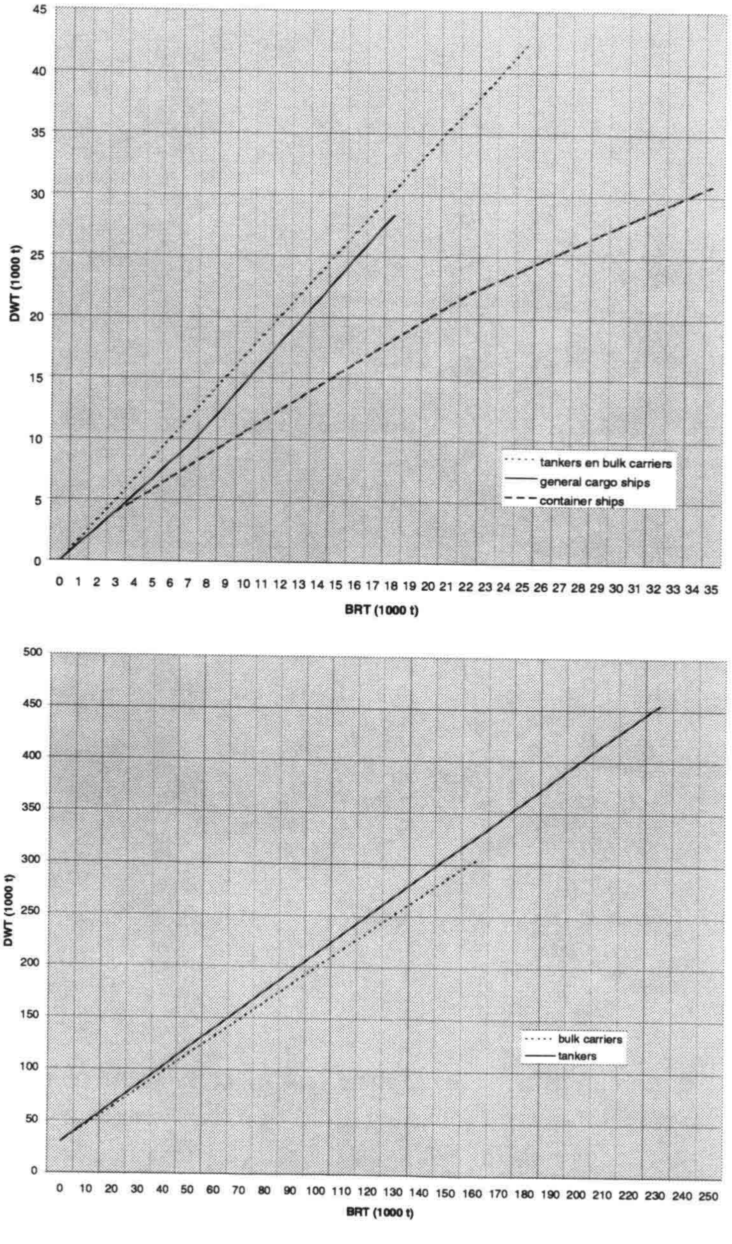


Figure 2- 2: BRT versus DWT

The definitions of the tonnages are as follows:

- GRT is the total volume of all permanently enclosed space above and below decks, with certain exceptions, such as the wheelhouse, chart room, radio room and other specific space above deck, expressed in tons, in which one ton is equal to 100 ft^3 = 2.83 m^3. GRT is normally used as the basis for calculating port dues.
- NRT is the total of all space destined for cargo, expressed in units of 2.83 m^3. The NRT is equal to the GRT minus the crew's accommodation, workshops, engine room etc.
- DWT is the difference between light and load displacement, in which:
  - Light displacement is the mass of the ship's hull, engines, spares, and all other items necessary for normal working performance.
  - Load displacement is the ship's mass when fully loaded, so including hull, engines, cargo, crew etc. Fully loaded means that the ship sinks into the water down to her summer draught line (see Plimsoll Mark).

  In other words, the DWT gives the mass of the cargo, fuel, crew, passengers, fresh water, victuals, etc. expressed in metric tons.

The following units are used:
- Metric ton (t = 1000 kg)
- English or longton (ts = 1016 kg)
- Short ton (sts = 907 kg) and
- Port tons or shipping tons

Port- or shipping tons are used to determine sea transport charges. A port or shipping ton is equal to 1 m^3 when the specific weight of cargo is smaller than 1 t/m^3 and equal to 1 t when the specific weight of cargo is bigger than 1 t/m^3.

For some specialised ships the carrying capacity is not only expressed in GRT, NRT or DWT, but also in other units, typical for the type of vessel concerned. Examples of this are:
- TEU This unit is normally used to express the capacity for container storage on board of a ship. TEU stands for Twenty Foot Equivalent Unit, which is the space taken by a standard container of the following dimensions:

Length =	20 feet	= 6.03 m,
Height =	8 feet	= 2.44 m, and
Width =	8 feet	= 2.44 m, thus
Volume =	6.03x2.44x2.44	= 35.9 m^3

- m^3 The carrying capacity of liquefied gas tankers is usually expressed in m^3.
- Street length or lane length

  This dimension is often used for so-called Ro/Ro vessels. It expresses the total loading length with standardised width of 2.50 m, available on board of the vessel. It is expressed in meters.

2.2.2. Vertical dimensions

Draught

The draught D of a vessel is the maximum distance in meters between the waterline and the keel of the ship (*Figure 2- 3*). Displacement tonnages are calculated in respect of the draught D and the stationary freeboard F, which is indicated on the ship's side.

The maximum draught line is indicated by the so-called Plimsoll Mark. This mark is composed of a circle and a horizontal bar with two letters on either side of the circle. The letters stand for the classification society of the Plimsoll Mark, which issues binding conditions for sizes and quality of materials to be used, tests to be carried out, etc. Without "classification" a ship is virtually non-insurable.

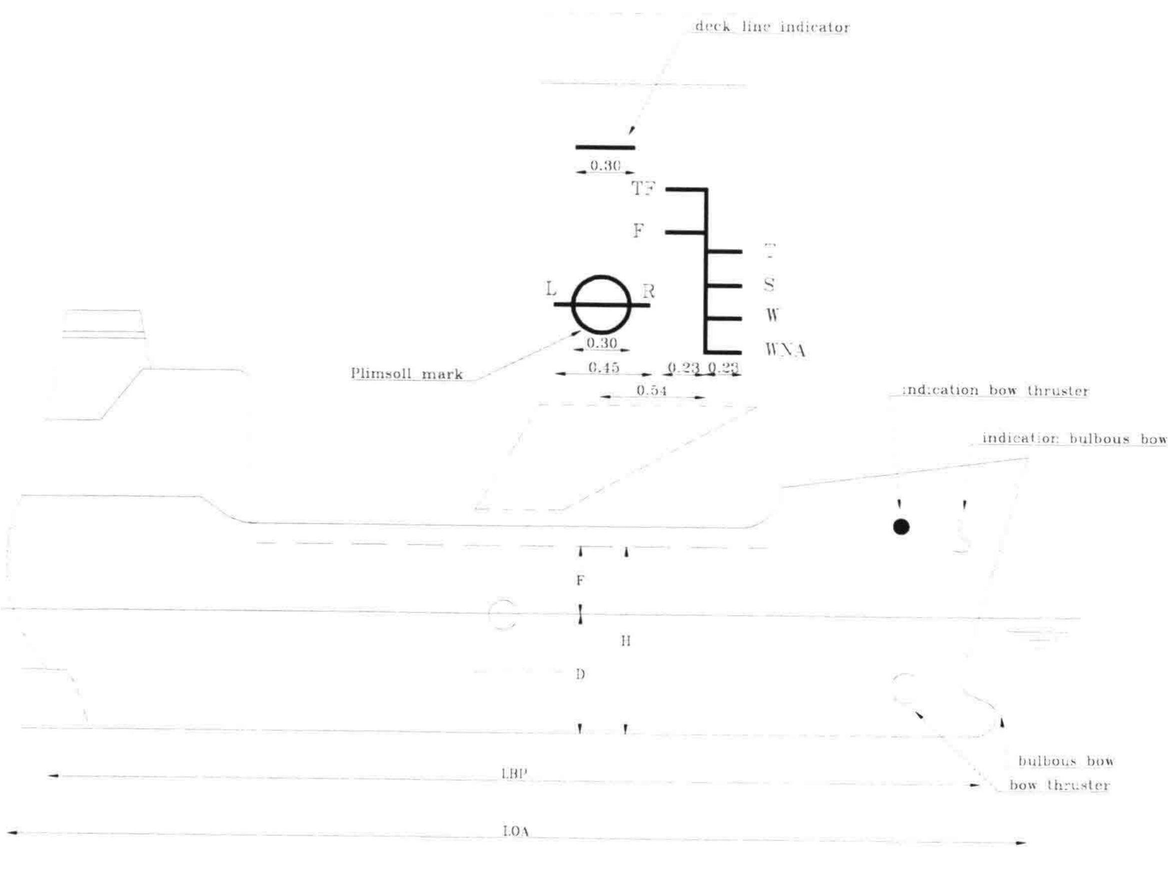


Figure 2- 3: Ship's dimensions

Most common letters are:

LR: Lloyd's Register (England)
BV: Bureau Veritas (France), and
AB: American Bureau of Shipping (USA).

The draught of a vessel is related to the density of the water in which she is sailing (uplifting force). Since the density does not have a constant value over the year, and also differs with longitude and latitude (a ship sinks deeper into the water in summer around the equator than in winter on the North Atlantic), another indicator is to be found at the right side of the Plimsoll Mark. This indicates the maximum permissible draught under various conditions, such as:

TF = Tropical Fresh Water
F = Fresh Water
T = Tropical Salt Water
S = Summer Salt Water
W = Winter Salt Water, and
WNA = Winter Salt Water on the North Atlantic

Incorporated in the markings of maximum permissible draught is also a certain safety margin. The draught of a vessel is indicated by numbers which are painted on both sides of the ship's hull, usually at the bow, amidships, and at the stern. Often, these Figures indicate the draught in feet (1 foot = 0.308 meter).

2.2.3. Horizontal dimensions

Length

The length of a vessel can be expressed in two different ways:
LBP: Length Between Perpendiculars, and
LOA: Length Over All
Both lengths are indicated in *Figure 2- 3*.

The definitions are as follows:

LBP: is the horizontal distance in meters between the points of intersection of the ship's bow and the summer salt water line when fully loaded and the vertical line through the axis of the rudder of the ship.

LOA: is the horizontal distance between two vertical lines; one tangent to the ship's bow and one to the ship's stern.

Beam

The beam or breadth B, is the maximum distance in meters between the two sides of the ship.

2.2.4. Other relevant data

Without going into the details of ship design some information is relevant for the manoeuvrability and hence for the design of approach channels and water areas inside a port.

Engine power and number/type of thrusters are determining in this respect. Extremes are large bulk carriers on one hand and (high speed) ferries on the other. Notwithstanding their size some of the large ore carriers and crude oil tankers are equipped with only one screw or propeller and have a relatively low engine power. They are designed for long distance, low speed transportation and will require assistance by 3 or 4 tugs during arrival and departure in the ports.

Ferries are generally overpowered and are provided with 2 or more propellers and often 1 bow thruster (*Figure 2- 4*). High-speed ferries have water jets instead of propellers.

Many ships built today are equipped with one or more thrusters, either at the bow or at the stern or both. For safety reasons the presence of a bow thruster is indicated on the bow above the waterline.

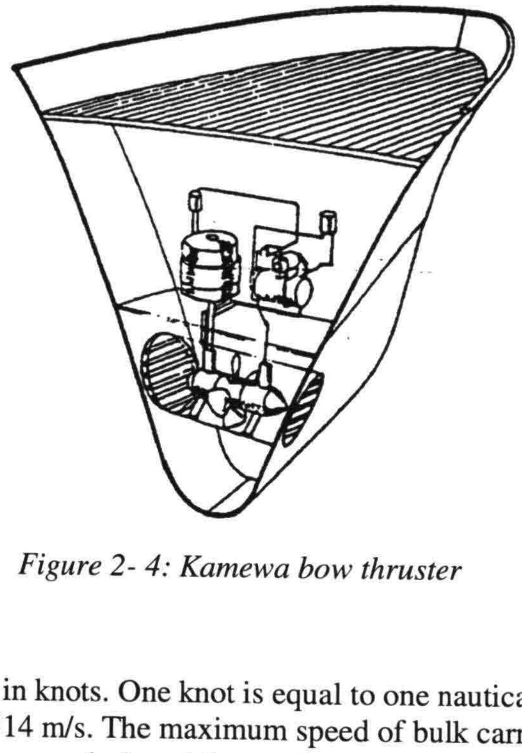


Figure 2- 4: Kamewa bow thruster

Vessel speed is expressed in knots. One knot is equal to one nautical mile (or 1852 meter) per hour, equivalent to 0.514 m/s. The maximum speed of bulk carriers and VLCC's amounts to 18 knots. Ferries are designed for maximum speeds of about 24 knots and empty high-speed ferries have maximum speeds of about 40 knots, while the service speed (full load) amounts to 35 knots.

2.3. Commodities and types of vessels

2.3.1. Introduction

Cargo flows can be subdivided into two main categories viz. liquid or dry bulk cargo (large quantities of unpacked cargo) and general cargo. The general cargo, in its turn, can be subdivided in breakbulk cargo (many pieces of various dimensions and weights), mass-breakbulk or neobulk cargo (many pieces of mostly uniform size and sometimes uniform weight), and containerised cargo.
In the next chapter these categories of cargo types will be discussed as well as the different types of vessels in which they are carried. Furthermore, special types of vessels will be treated, such as ferries and cruise vessels for passenger transport. For further reading on shipping business reference is made to the IHE lecture notes on Merchant Shipping (Kruk, 1990). Many of the examples of different types of ships shown in the subsequent pages have been taken from a book named 'Shipping' (Wijnolst e.a. 1996). And the graphs with typical ship dimensions have been updated on the basis of a recent study, 'Ship dimensions in 2020' (Lloyd's Register M.S., 1998)*.

2.3.2. Breakbulk or conventional general cargo

Breakbulk is defined as all kinds of boxes, crates, bags, sacks, drums, machine parts, refrigerated cargo as fruit, meat etc.
Generally the breakbulk cargo will be transported by one of the three types of breakbulk ships, i.e. conventional general cargo ships, multipurpose ships and refrigerated ships.

2.3.2.1. General cargo ship

A general cargo ship may carry all kinds of breakbulk cargo, viz.

Categories of breakbulk	Shape or packing	Cargo handling method
1. Bagged goods	Undefined shape	Ropes, on pallets
2. Normal breakbulk	Crates, boxes, drums	Ropes, hooks, pallets
3. Neobulk	Steel plates, bars and wire, lumber and timber, paper	Ropes and hooks, cassettes

The weight of each piece of cargo (a 'lift') is limited by the maximum lifting capacity of the shore based crane or the ship's derrick. Each piece of cargo is handled separately or sometimes as an assembly of some smaller items. The cassette system is relatively new, and designed for efficient handling of rolls of paper.

The general cargo ship is the arch type of cargo ship. All new, specialised vessels originate from the general cargo ship.

* In this version this has not been yet the case

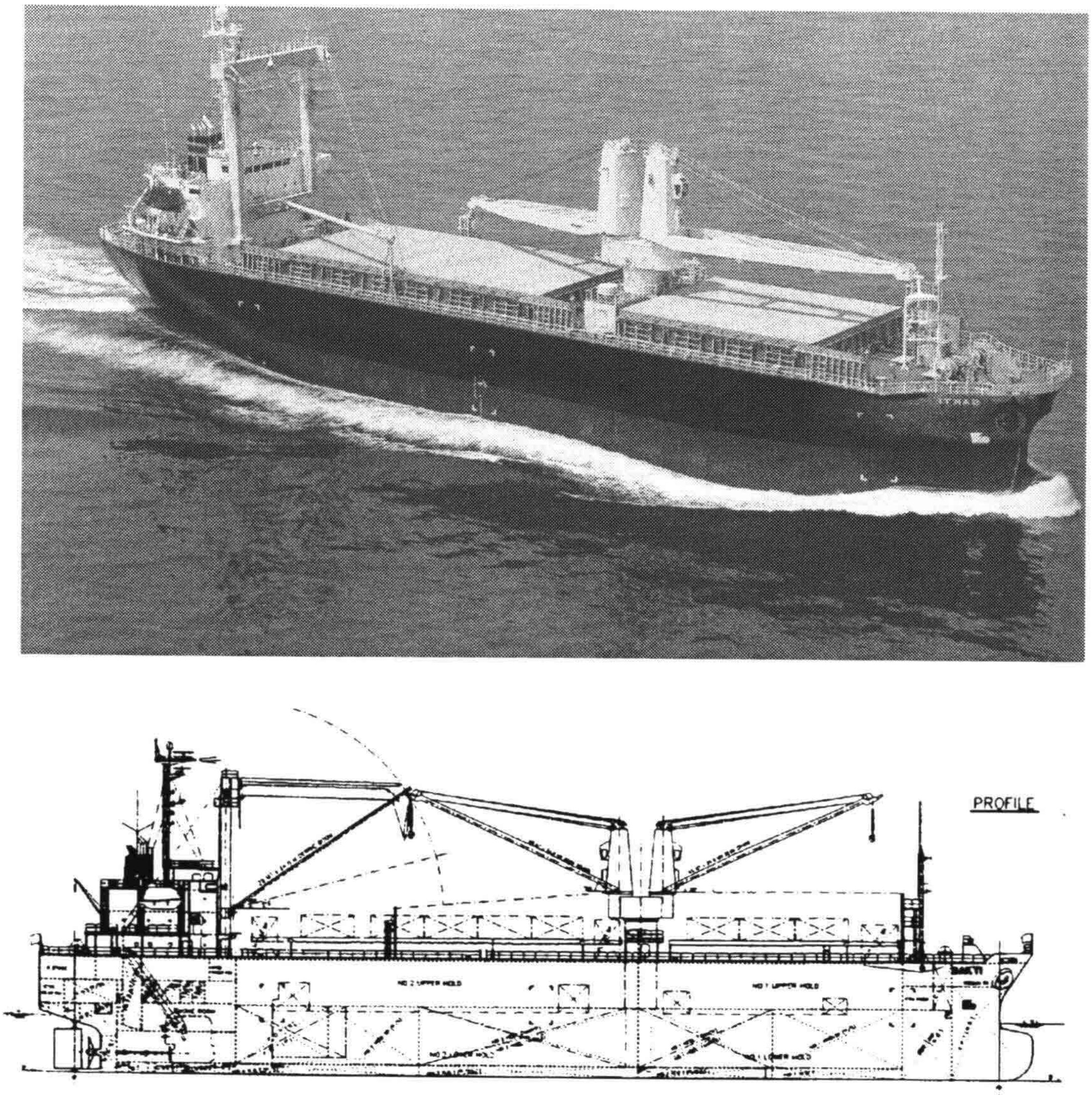


Figure 2- 5: General cargo ship 'Sakti'

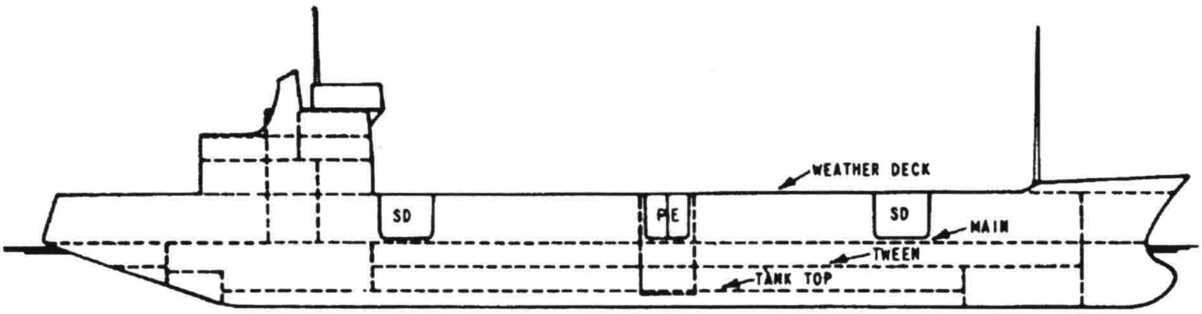
Length Over All:	113.22 m
Length Between Perpendiculars:	105.40 m
Breadth:	19.60 m
Draught:	7.29 m
Deadweight:	8,739 MT
Maximum speed:	13.30 knots

The capacity of the conventional general cargo ship ranges from 5000 to 25000 DWT. It has four to five holds (space for cargo storage below deck) and usually one or two tween decks, which run all along the ship. This makes it possible to stow cargo in such a way, that it can be distributed evenly over the ship's length and/or to unload a certain quantity of cargo in a certain port without moving other cargo as well.
The older general cargo ships can easily be identified by the many derricks (ship's cranes) placed on deck. These are arranged in such a way, that each hold can be served by at least two derricks. The older designs of general cargo ships show the wheelhouse amidships, but more recent designs show a tendency to place it three-quarters aft or aft.

The draught of the vessel is usually small, ranging from 7.5 to approximately 10 meters, which enables the ship to call at most ports of the world, even the smaller ones. An example of a general cargo ship is shown in *Figure 2- 5.*

Over the past years, when more and more emphasis was put on the reduction of the ship's turnaround time, some new developments took place in design, as well as in cargo handling methods, of the general cargo ship:

a. The openings of the holds (hatches) became wider and were placed in one vertical line to ease the vertical movement of cargo. It even became possible to lower small equipment for cargo handling, such as forklift trucks, into the holds. The aim to achieve unobstructed movements of cargo was also one of the reasons why nowadays most wheelhouses of general cargo ships are places aft instead of amidships.
b. Horizontal cargo handling through side loading ports *(see Figure 2-5a)*
c. The development of the Unit Load Concept (ULC), from pallets to other forms of unitization such as cassettes for paper.



pe	=	pallet elevator
sd	=	side door

Figure 2-5a: Horizontal cargo handling through side loading ports

2.3.2.2. Multipurpose ship

The multipurpose ship, in fact a general cargo ship, capable of transporting almost any piece of cargo, ranging from a small box to a container or even a truck. The designs made in recent years also show a limited capacity to carry bulk cargo, either liquid (oil, chemical products), or dry bulk (grain, ore, etc.) and refrigerated cargo. Especially directed toward less developed ports, the ship has heavy lifting equipment on deck.

The ship can easily be defined by:

a. The robust shape and heavy lift deck equipment
b. The hatch covers that have been constructed in such a way that they can withstand the load of heavy pieces of cargo or containers placed on it.
c. Bow thrusters and bulbous bow
d. Side loading ports for horizontal cargo handling.

An example of a multipurpose ship is shown in *Figure 2- 6.*

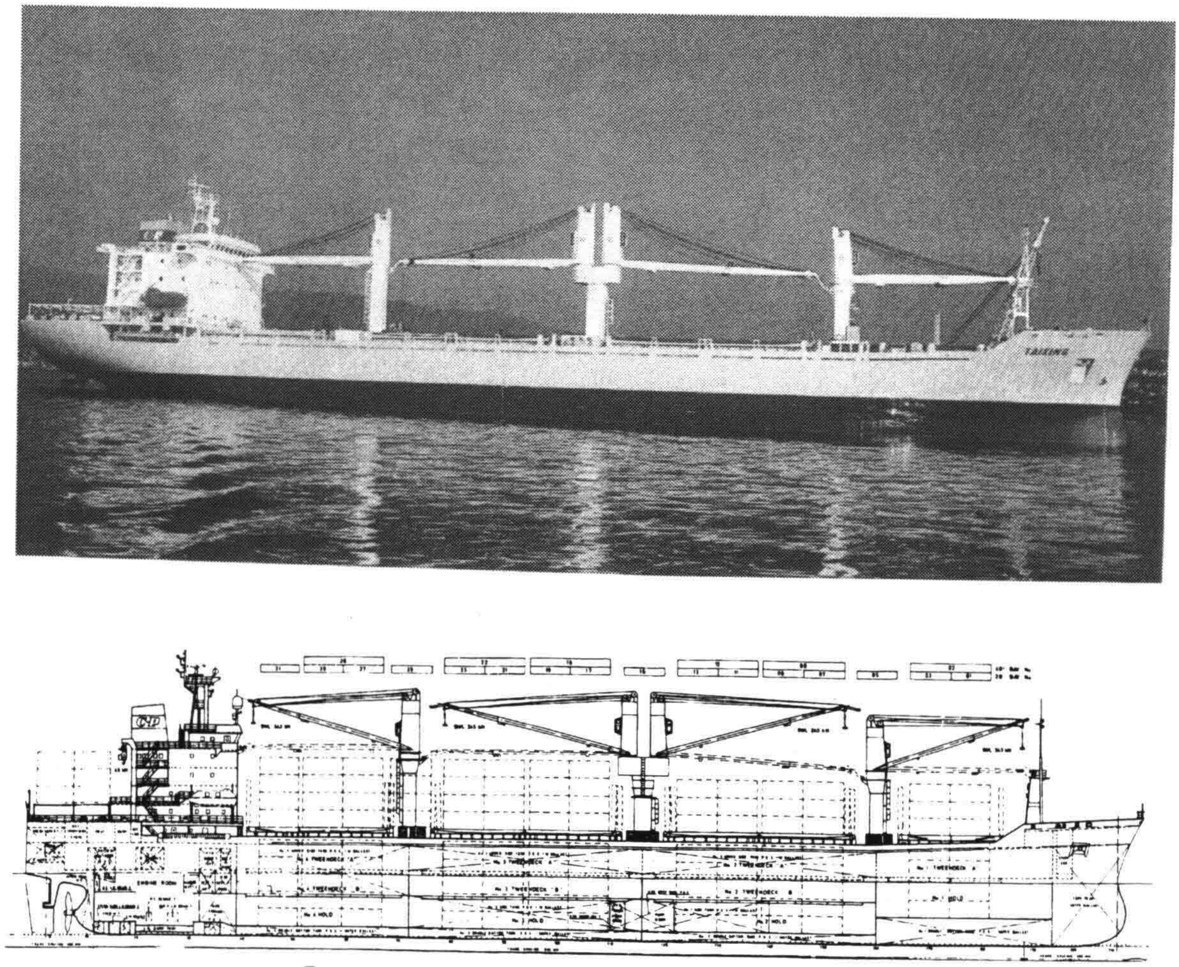


Figure 2- 6: Multipurpose ship 'Taixing'

Length Over All:	169.69 m
Length Between Perpendiculars:	162.50 m
Breadth:	27.50m
Draught:	9.32 m
Deadweight:	22,271 dwt
Maximum speed:	16.20 knots

2.3.2.3. Refrigerated general cargo ship (reefer)

This general cargo ship is solely used for the transportation of fruit, meat, or other perishable commodities, which are kept on board at temperatures between –30 °C and 12 °C.

The reefer distinguished herself from the conventional general cargo ship by the following features:

- the ship is usually painted white
- her speed is higher; usually from 18-25 knots
- she looks quite elegant and fast; the appearance is streamlined

In recent years, a trend exists to use refrigerated container ships instead of specialized ships such as a reefer. An example is given in *Figure 2- 7.*

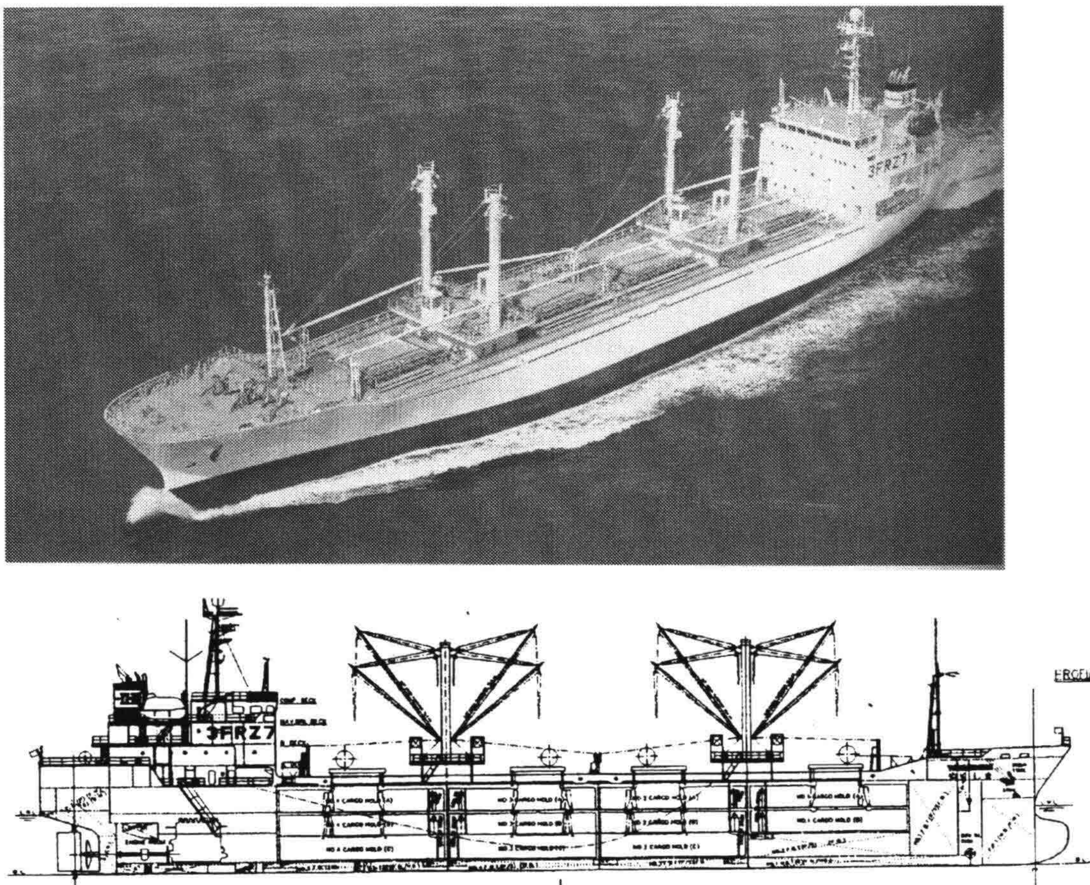


Figure 2- 7: Refrigerated cargo ship 'Yakushima'

Length Over All:	120.12 m
Length Between Perpendiculars:	111.60 m
Breadth:	16.80 m
Draught:	7.00 m
Deadweight:	5,563 MT
Maximum speed:	18.87 knots

2.3.3. *Container vessels*

Notwithstanding the introduction of ULC in the handling of breakbulk cargo the turnaround times of general cargo vessels remained high. After World War II world trade increased rapidly and with it the sea transportation, leading to serious congestion in the ports and long waiting times.
The container had been introduced in the fifties as standard size box for the transport of cargo by truck and rail across the USA. Its use in sea transport seemed a logic step in view of the abovementioned problems, but received initially severe resistance, in particular by the powerful unions of dockworkers. It did reduce the turnaround times and waiting times in ports substantially. Initially limited to coastal shipping along the US West and East Coast, the first SeaLand containers arrived in Rotterdam in 1966. Over the past 30 years container shipping has spread across the globe, taking over a major share of the general cargo trade.

The first containers had dimensions of 8 ft. x 8 ft. x 20 ft. (2.44 x 2.44 x 6.10 m). Because of this length the capacity of a ship or a container storage yard is still expressed in Twenty Feet Equivalent Units or TEU. Nowadays forty feet long containers are used besides the twenty feet, and other sizes have been introduced for length, width and height.

The increased productivity is partly due to the fact that many pieces of cargo are packed into one container, which can be handled in one lift, and partly due to the use of the twistlock during handling and transportation (*Figure 2-8*). In crane handling twistlocks are inserted into the four upper corner castings of the container and fastened in a matter of seconds. On a truck or railwagon the lower four corner castings are also fastened by twistlocks.

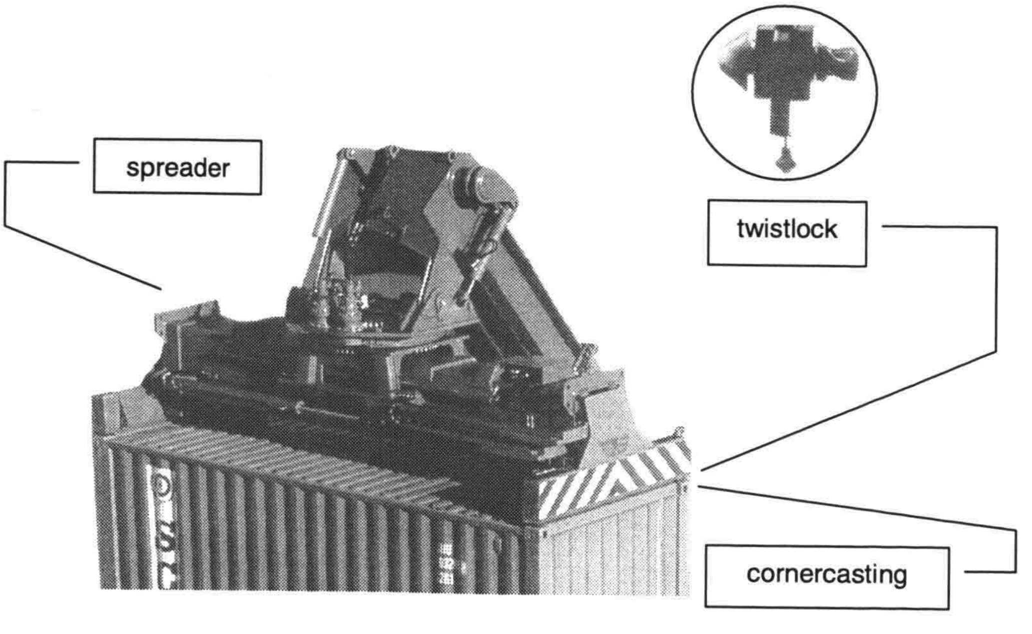


Figure 2- 8: Twistlock and cornercasting

The "first generation" container ships were general cargo vessels, converted to carry containers. Since then several classes of container ships have been built with increasing dimensions and capacities. (see Table 2-2)

Table 2- 2: Container vessel characteristics

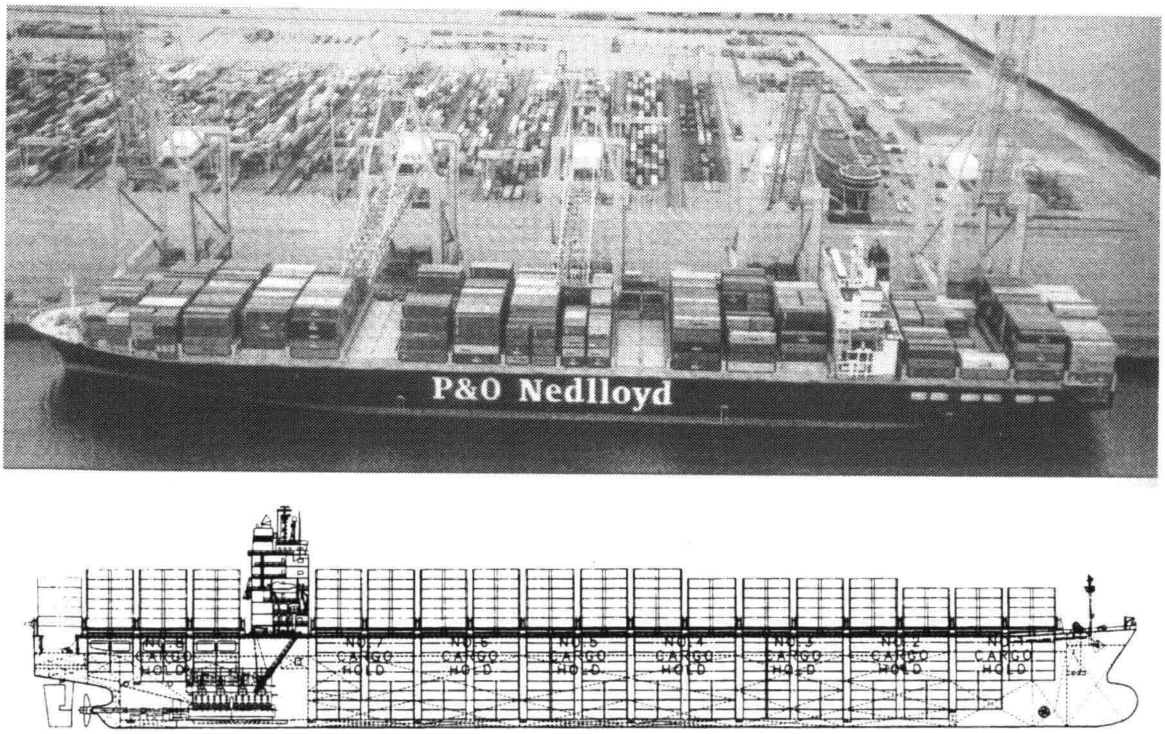
Class	TEU capacity	DWT (average)	L (m)	D (m)	B (m)
1st generation	750-1100	14,000	180-200	9	27
2nd generation	1500-1800	30,000	225-240	11.5	30
3rd generation	2400-3000	45,000	275-300	12.5	32
4th generation	4000-4500	57,000	290-310	12.5	32.3
Post Panamax	4300-4600	54,000	270-300	12	38-40
Jumbo	>6000	80,000	310-350	14	42.8

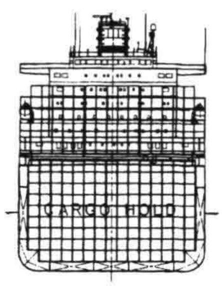
The following points should be noted:

(i) the second and subsequent generations ships were designed to carry only containers, the so-called full or cellular container ships. The boxes were placed below deck in the holds, divided into cells with vertical guiding rails along which the containers are lowered into and hoisted out of the hold. On deck the containers are arranged in rows parallel to the ship's axis and secured by lashing systems.

(ii) up to 4th generation the vessels have a beam limited to 32.3 m, allowing them to pass the locks in the Panama Canal. Traffic between East- and Westcoast of the USA was still of high economic (and military strategic) importance. In the eighties the Asia-Westbound and Pacific Trades became more dominant, and shipping lines made the step to Post Panamax, accepting that these vessels could not pass the Panama Canal.

(iii) in recent years the vessel size made a considerable jump to Jumbo class and further growth is foreseen in the near future to 8000 TEU and above (see *Figure 2-9*). It is pointed out that this growth does not only require greater depth, but also leads to higher cranes, with longer booms.





Length Over All:	299.00 m
Length Between Perpendiculars:	283.80 m
Breadth:	42.80 m
Draught:	13.50 m
Deadweight:	83,826 dwt
Maximum speed:	24.50 knots

Figure 2- 9: Jumbo container ship 'P&O Nedlloyd Southampton'

Another trend in container ship design was the introduction, by Nedlloyd, of hatchcoverless vessels with full height cell guides (including 4 tiers high above the board of the ship).

The time involved in lifting off the hatch covers, removing the lashings and placing both back (roughly two hours for the larger ships) would be eliminated. A number of ships of this design has been built (*Figure 2- 10*), but in practice the reduction of service time in port appears to be less than anticipated. Some negative effects of the design, e.g. overcoming seawater in the holds, made that the concept does not get broad follow-up.

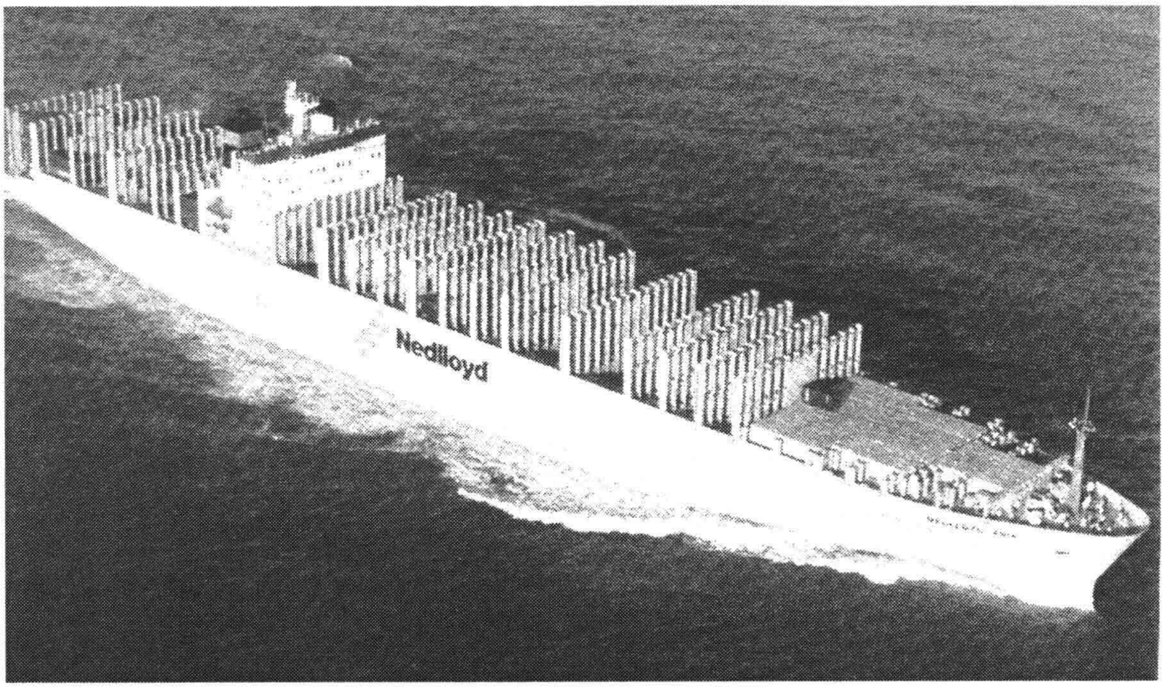


Figure 2- 10: Container ship with cell guides

In the early period of containerization some ships carried their own equipment to handle the boxes. This is the shiptainer, a gantrycrane on board of the vessel, able to run from forward to aft on rails on the deck. In ship new-building this is no longer practice, mainly because most ports have shore based cranes (portainers, see *Figure 2- 11*).

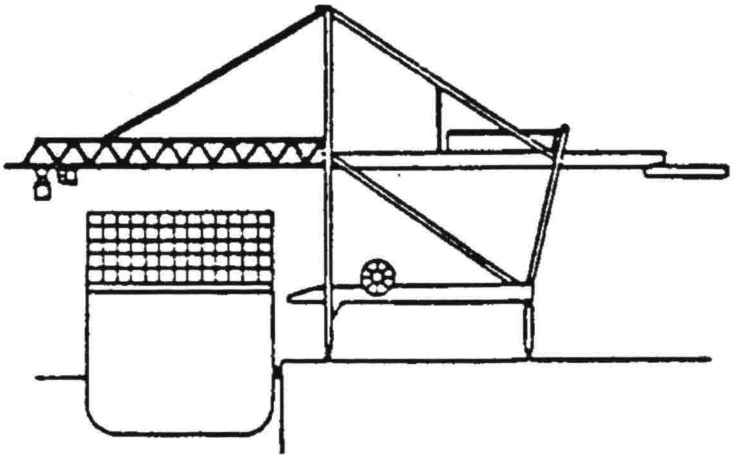


Figure 2- 11: A portainer

2.3.4. Ro/Ro vessels

Another mode of unitised cargo, which was developed in road transport, is the trailer. They are also known as continental containers, but have two important differences with the sea containers: they are not fit to carry the weight of other containers and they can not be lifted (no corner castings). While sea containers are sometimes referred to as Lo/Lo cargo (lift on / lift off), the transport of trailers and trucks is known as Ro/Ro (roll on / roll off). In most cases the chassis are carried overseas without the trucks. Movement onto and from the ship is done by special yard equipment. At some terminals the entire truck-trailer combination is taken aboard.

The Ro/Ro ships are therefore comparable with ferries: they must have a facility to drive the cargo on and off the ship. Contrary to the ferry, which normally sails on short routes only, this type of ship serves on the longer routes.

The first types of Ro/Ro ships usually had the ramp at the stern of the ship. When at sea it was pulled up into a vertical position and in port it was lowered onto the quay. The disadvantage of this type of ramp is, that a special place in the port or even a special berth construction is necessary *(see Figure 2-12)*. The manoeuvring with long trailers may be difficult, since much space is required which is not always available. The problems with high tide differences were solved by use of a pontoon between ship and quay.

To attain more flexibility in the allocation of a berth in a port, Ro/Ro ships were later on provided with a quarter ramp, which makes an angle with the axis of the ship and enables the ship to berth at any part of a straight quay (see *Figure 2-12a*).

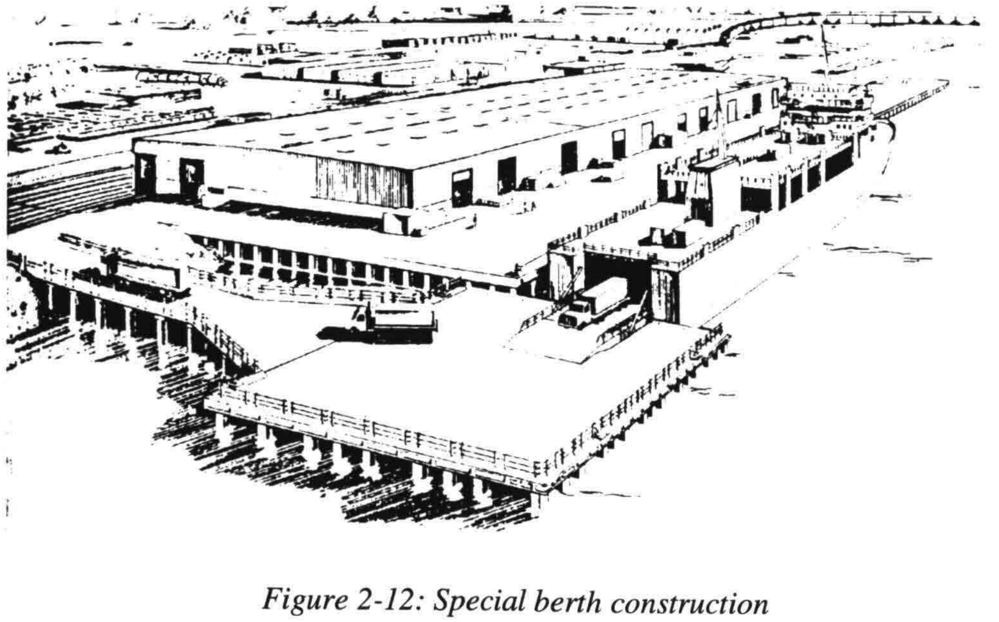


Figure 2-12: Special berth construction

The carrying capacity of Ro/Ro ships is usually expressed in lane length, being the total length of the lanes in which the Ro/Ro cargo is placed on the different decks of the ship (standard width of 2.50 m). The latest types of Ro/Ro ships have a total lane length of about 5300 m. An example of a Ro/Ro ship is given in

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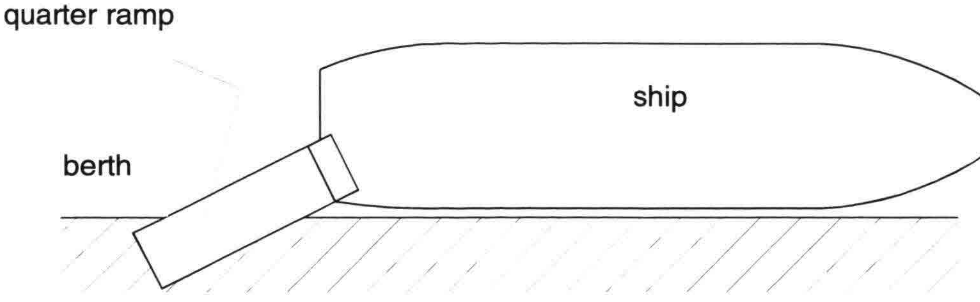


Figure 2- 12a: Quarter ramp

Various ship designs exist, combining Ro/Ro facilities with place for sea containers, the latter usually on the deck. An example of a Ro/Ro-container ship is given in *Figure 2- 14.*

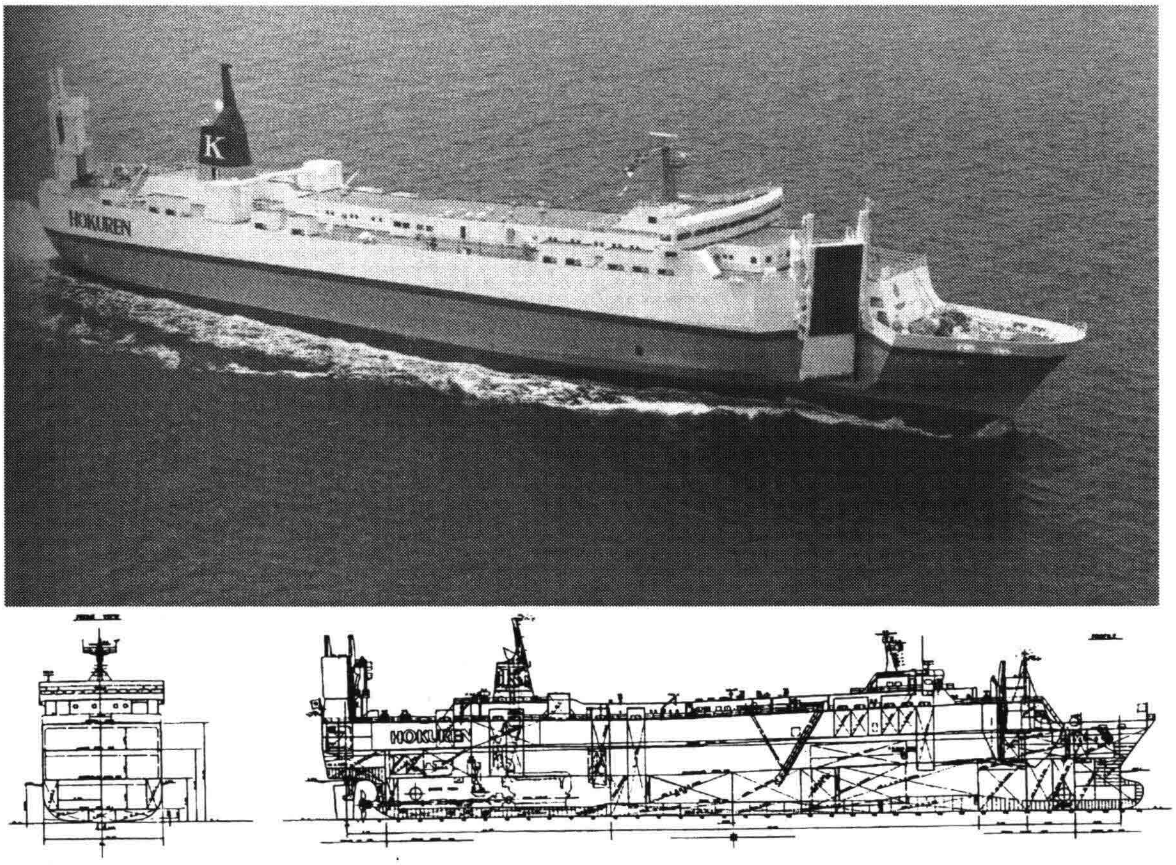


Figure 2- 13: Ro/Ro ship 'No. 2 Hokuren Maru'

Length Over All:	153.62 m
Length Between Perpendiculars:	142.80 m
Breadth:	21.40 m
Draught:	6.975 m
Deadweight:	5,445 MT
Maximum speed:	24.971 knots

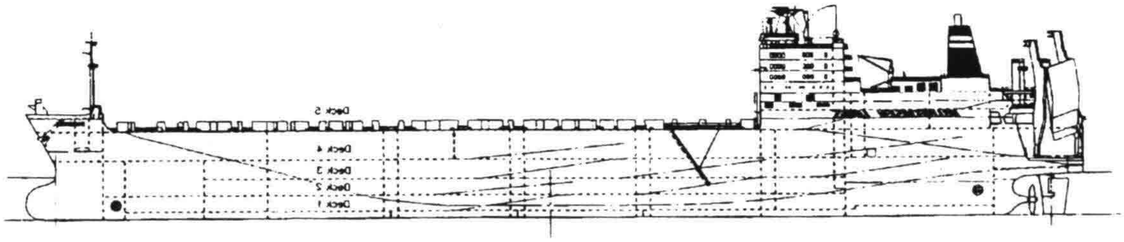


Figure 2- 14: Ro/Ro container ship 'Taronga'

Length Over All:	264.60 m
Length Between Perpendiculars:	249.00 m
Breadth:	32.26 m
Draught:	11.75 m
Deadweight:	47,144 T
Maximum speed:	22.16 knots

2.3.5. Car carriers and other special vessels

(i) *Car carrier*

These ships have been designed for the transportation of newly built motorcars from the producer to the consumer markets. Like Ro/Ro vessels they have ramps to the shore. In addition to the quarter ramp, these vessels often have one or more side ramps to speed up the loading and unloading process. Because the net load of motorcars is relatively low, these vessels have a small draught and a large freeboard, as shown in *Figure 2-15*. This implies that they are sensitive to wind and require substantial tug assistance while in port.

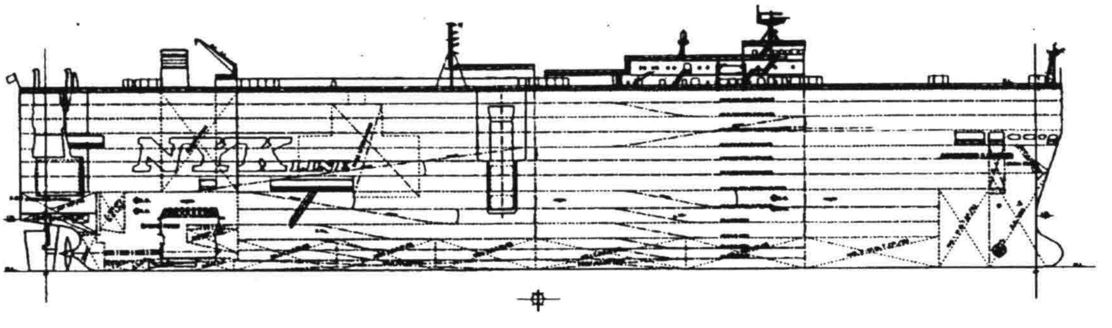


Figure 2- 15: Car carrier 'Aquarius Leader'

Length Over All:	199.93 m
Length Between Perpendiculars:	190.00 m
Breadth:	32.26 m
Draught:	10.00 m
Deadweight:	22,815 MT
Maximum speed:	20.61 knots

(ii) *Lash ship*

The lash (Lighter Aboard Ship) is an example of integration of sea and barge transport. The principle of the system is as follows:

1. The cargo is stowed into a floatable barge at the producer's premises.
2. The barges are pushed or towed to the place where the Lash ship is to arrive, where they are put in a barge parking area
3. After the Lash ship has arrived, the barges for the port concerned are unloaded and the already parked barges are put on board of the Lash ship.
4. The unloaded barges are put together in a formation and pushed or towed to the customer.

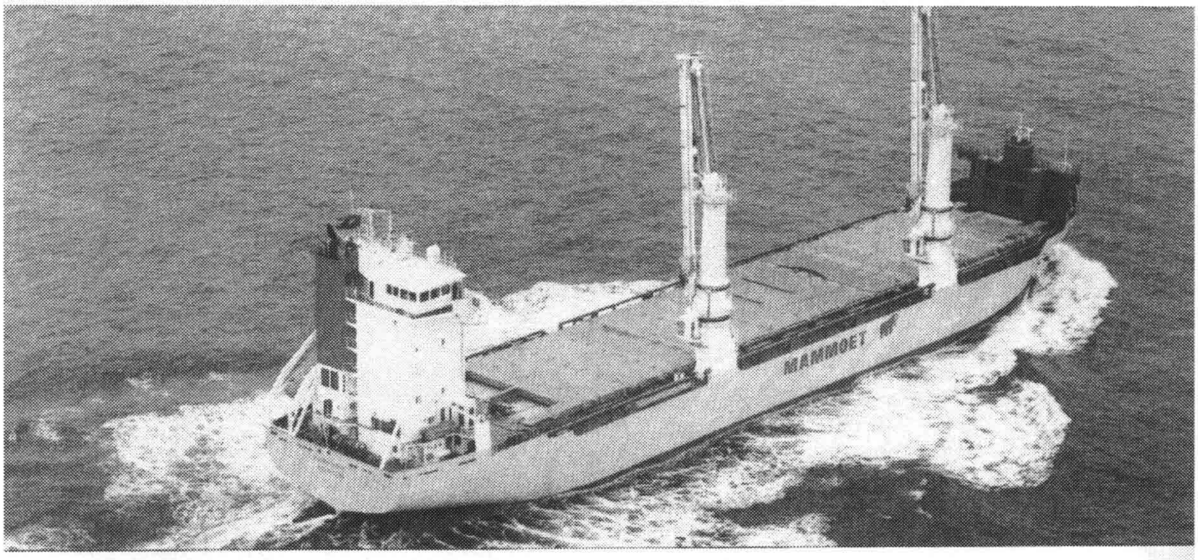
This set-up is the application of an advanced door-to-door transport system, provided consumer and producer can both be reached by water. Within the system the barges become the means of transportation itself.

Figure 2- 16: *Lash ship 'Arcadia Forest'*

The Lash ship is still in use, for instance in the Waalhaven, Port of Rotterdam, an area is reserved for the mooring of these vessels and the parking of barges. Yet there is no new building of Lash ships reported in recent years.

(iii) *Heavy lift carrier*

The Heavy Lift Carrier (HLC) is another specialized ship, designed to transport huge, heavy units of cargo, which cannot, or can hardly be transported by any other type of vessel. Cargo, carried by HLC's, may for instance be: dredgers, assembly parts of factories or refineries, drilling platforms, container cranes, etc. The ship is characterized by the vast deck-space, on which the superstructure with the wheelhouse has been placed at one of the extremes either at the bow or at the stern, to create as much deck place as possible. Another characteristic is the presence of the one or more heavy-duty cranes or derricks with capacities of up to 500 tons or more. The cargo can be placed on deck either by the ship's own gear or by auxiliary equipment, such as a floating or shore based crane or can be put on board in the roll-on/roll-off fashion, provided the HLC is equipped with a ramp. The method of operation of some HLC's is such, that the cargo can also be put on board by floatation, because the ship is submersible (in the same manner as a floating drydock). See *Figure 2-17* for an example of a heavy lift carrier.



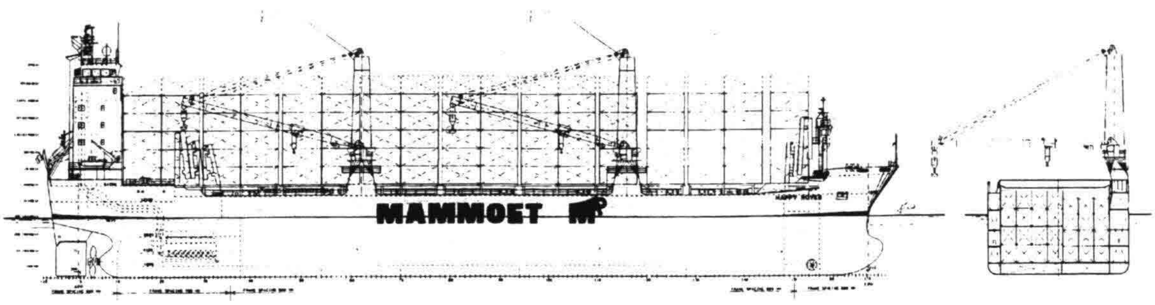


Figure 2- 17: Heavy lift carrier 'Happy river'

Length Over All:	138.00 m
Length Between Perpendiculars:	127.94 m
Breadth:	22.80 m
Draught:	9.50 m
Deadweight:	15,634 dwt
Maximum speed:	16.0 knots

(iv) *Cruise ships*

Modern cruise ships are getting bigger, to such extent that existing terminals become inadequate, in terms of water depth or passenger facilities or both. Hence a lot of new cruise terminals are built, especially in the popular regions such as the Caribbean, the Mediterranean, etc. See *Figure 2- 18.*

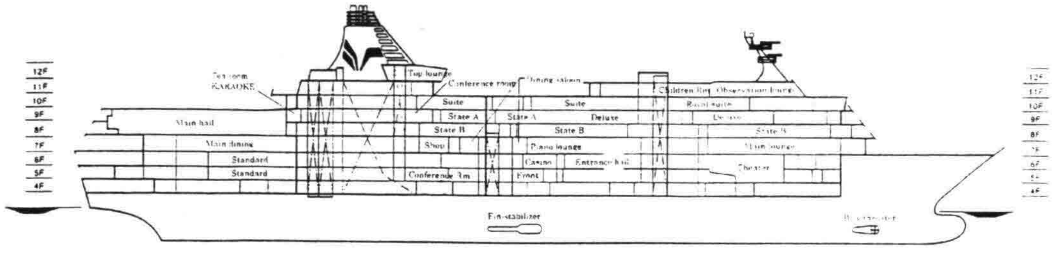


Figure 2- 18: Cruise ship 'Pacific Venus'

Length Over All:	183.40 m
Length Between Perpendiculars:	160.00 m
Breadth:	25.00 m
Draught:	6.50 m
Deadweight:	4,202 T
Maximum speed:	21.97 knots

(v) Ferry

Also the ferry vessel is showing much development, both in terms of size and speed. As mentioned before, the ferry is employed on fixed routes over limited distances. They carry passengers, motorcars and trucks in different percentages, depending on the demands for each. In the past ferries used to transport entire trainlengths, e.g. in connecting the raillines on the Danish islands with the German and Swedish systems. Although these rail ferries still exist, they are not common in other parts of the world.
The development of size is shown in *Figure 2- 19* which is one of the most recent designs.

The need to reduce transit time (in order to remain competitive with other modes of transport) led to the development of high speed ferries. Although smaller types have been in use for decades, several very large ships have recently come into service, such as the HSS1500 by Stena Line, between Hoek van Holland and Harwich. With its cruising speed of 40 knots, it reduces the total transit time by 50% and allows to make two return voyages per 24 hours, instead of the single voyage of the conventional ferry (see *Figure 2-20*).

Figure 2- 19: Ferry 'Clansman'

Length Over All:	99.00 m
Length Between Perpendiculars:	91.20 m
Breadth:	15.80 m
Draught:	3.22 m
Deadweight:	600 dwt
Maximum speed:	16.50 knots

Figure 2- 20: HSS 1500

(vi) *Fast ship*

In Section 2.1 it was mentioned that there is little competition between international shipping and air transport because of the clear market and freight rate differentiation. In recent years one exception has developed, i.e. the fast ocean going vessels, which are designed to transport certain high-value cargo which used to be carried by plane. In Japan the so-called Techno Superliner is actually built and in operation , having a capacity of 150 TEU, and a maximum speed of 54 knots.

For service between the US-Eastcoast and Europe the Fast ship concept has been developed in conjunction with a very special type of terminal, the Alicon system. This ship is designed to carry 1450 TEU at a cruising speed of about 40 knots, thus reducing the sailing time across the Atlantic Ocean from 8 to 3.5 days. The concept is not yet realised, but plans are advanced to start a regular service between Philadelphia and Cherbourg. An example of a fast ship is shown in *Figure 2-21*.

In terms of freight rate this type of vessel fits in between air transport and conventional shipping. Regarding environmental impact it also falls in between the two existing modes.

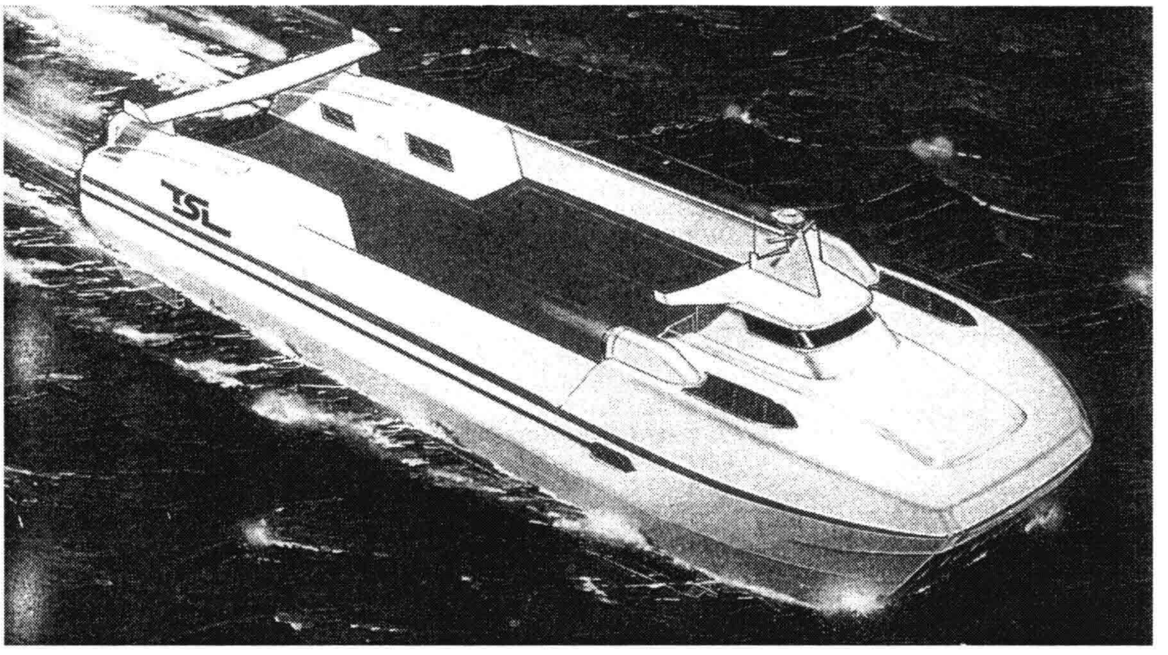


Figure 2- 21: Artist impression Techno-Superliner (1993)

2.3.6. Bulk cargo

2.3.6.1. Introduction

Bulk carriers usually carry large quantities of homogeneous, unpacked cargo, for instance liquids (oil, liquified gas), chemical products (phosphate, fertilizer), cement, iron ore, coal, agroproducts (grain, rice etc.). Because of the homogeneous nature, this cargo can be handled in a more or less continuous way. The handling of bulk cargoes can be executed in various ways, such as pumping (liquids), sucking (cereals), slurrying (mixture of dry bulk cargo and liquid, which can be transported by pipeline), or by a combination of grabs and a conveyor belt system (coal and ores).

Bulk carriers can also be subdivided in several types, which will be treated in the following sections. In principle there exist three types, viz.

1. liquid bulk carriers
2. dry bulk carriers
3. combined bulk carriers

The following Table gives an overview of the different bulk carrier types:

Table 2- 3: *Bulk carrier types*

Type	Cargo	Capacity range (1000 dwt)
1. Liquid bulk		
• Crude carrier	Crude oil	20-400
• Product tanker	Refined products	0.5-100
• Parcel tanker	Refined products, chemicals	0.5-40
• LNG tanker	Liquefied natural gas	60-90
• LPG tanker	Liquefied pressurized gas	0.5-70
2. Dry bulk	Ore, coal	100-365
	Chemical	5-70
	Agroproducts	0.5-10
3. Combined bulk		
• OBO	Ore or crude oil	70-150
• OCO	Ore cum oil	70-120

2.3.6.2. Liquid bulk carriers

(i) *Crude oil tanker* (see *Figure 2- 22*)
Before the last World War, the consumption of oil was limited, because in those days coal was the major source of energy, and crude oil was therefore transported by small tankers. When after World War II the consumption started to rise (and soon to boom), the modern crude oil tankers appeared and soon grew larger and larger in size, trying to keep pace with the demands and trying also to reduce the transportation costs as much as possible (cost per ton diminishes with increasing vessel size).

Figure 2- 22: Very Large Crude Carrier 'New Vanguard'

Length Over All:	332.94 m
Length Between Perpendiculars:	320.00 m
Breadth:	60.00 m
Draught:	21.10 m
Deadweight:	300,058 MT
Maximum speed:	16.80 knots

The most important producers (and exporters) of crude oil are the Middle East countries around the Persian Gulf, such as Saoudi-Arabia, Kuwait, the United Arab Emirates, Iraq and Iran, and countries as Nigeria, Venezuela and Indonesia. The most important consumers (and importers) of oil are the countries in Western Europe, Japan and the United States of America. There countries largely depend on the oil from oil-producing countries, especially those of the Middle East. The following figure illustrates the development of the size of tankers :

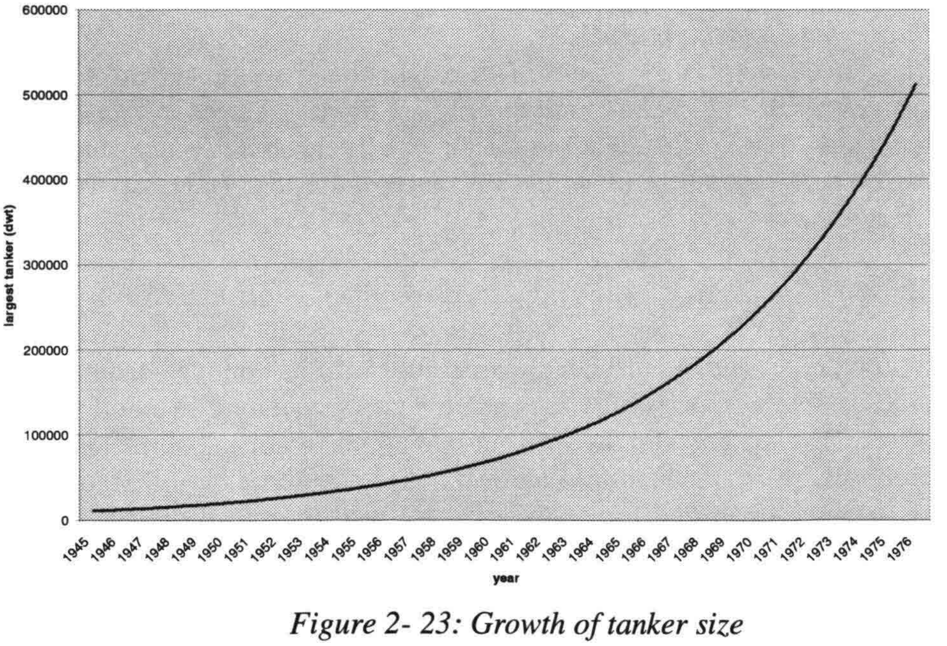


Figure 2- 23: Growth of tanker size

Nowadays the intermediate size tanker (50,000 – 200,000 dwt) is becoming more important again due to:

1. Levelling off or even some reduction in the world crude oil trade.
2. Increased use of the (improved) Suez Canal instead of around the Cape services.
3. The fact that, although VLCC's (Very Large Crude Carriers) and ULCC's (Ultra Large Crude Carriers) can transport very large quantities of crude oil on one voyage, they can only call at few ports in the world, because of their deep draught. In 1992 less than 10 ULCC's were still in operation world wide.

The crude oil tanker can easily be identified by her flat deck without derricks and hatch covers. Only some deck arrangements like stoplocks, pumps, pipelines and small hose derricks with the manifold amidships can be observed. A remarkable feature is the catwalk, a horizontal gangway, that runs along the deck from bow to stern, to enable the crew to move along the ship. Older types of tankers have, like the older general cargo vessels, the main superstructure amidships, but with the newer and bigger types all is aft; superstructure, wheelhouse, engine room, etc.

A remarkable feature of the very large types is the return of the crow's nest at the bow, which is necessary because of the limited view from the wheelhouse aft.

(ii) *Product tanker (see Figure 2-24)*

The definition of product tankers given by Lloyd's Register (Ref. Lloyd's Register Management Services, Ship Dimensions in 2020, Rotterdam, May 1998) is: a vessel with independent tanks for the transportation of petroleum products in bulk. Many tankers have a dead-weight capacity smaller than 7500 tons, but there is a large class of vessels with a capacity between 30,000 and 40,000 tons. The largest product tankers are about 110,000 dwt.

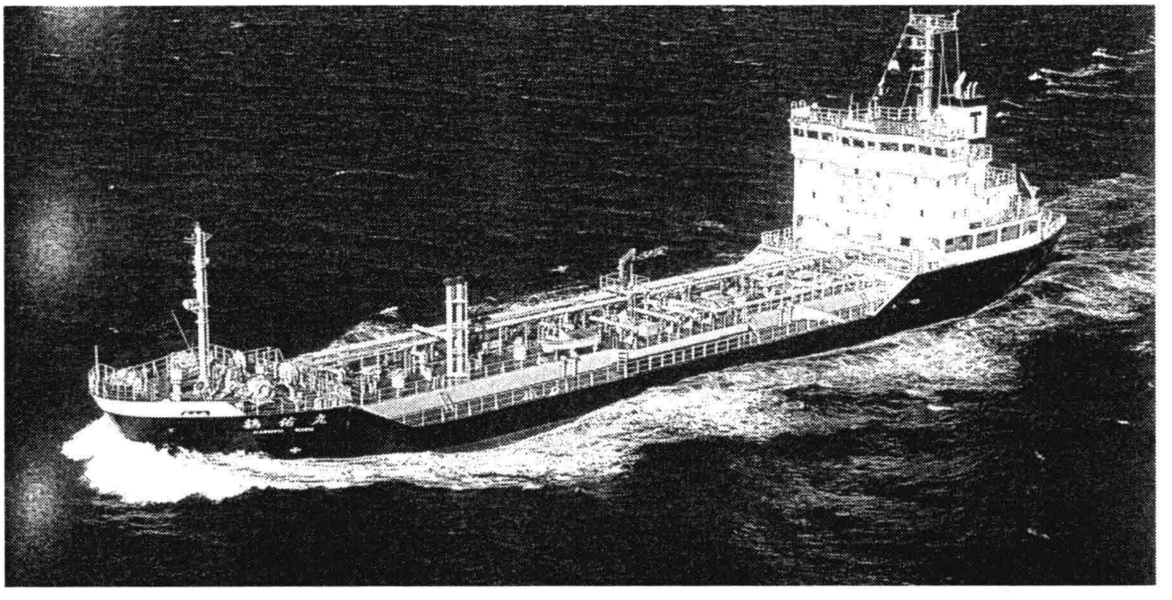
(iii) *Parcel tanker (see Figure 2-25)*

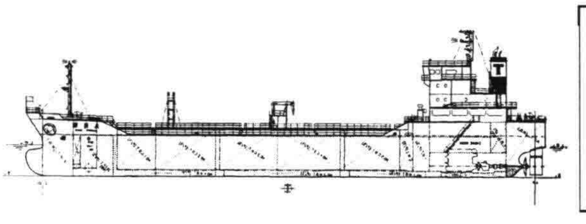
The parcel tanker is a specialised tanker for transportation of refined oil products, such as paraffin, diesel oil and/or chemical liquids. The parcel tanker has received her name from the fact, that the various relatively small compartments in the hold can be used separately, by which various products can be transported at the same time.

The parcel tanker can be distinguished from the crude oil tanker by various additional characteristics, such as numerous small tank hatches, many fore-and-aft running pipes and, amidships, the manifold with its complex arrangements of pipes and valves, connected to the ship's tanks system. The manifold is the focal point of the loading and discharging operations by means of the ship's own pumps. Close to the manifold are two light hose-derricks.

To reduce the hazards of fire, the holds fore and aft are equipped with double watertight bulkheads (cofferdams). One of the great problems of parcel tankers is the cleaning of tanks. When a certain type of cargo has been brought to her destination, and another type of cargo is to be loaded, the tanks have first to be cleaned. Well equipped ports facilities are available to execute this in a professional way. If this is not the case, illegal dumpings at sea may occur, which may seriously harm the marine environment.

A general lay-out of a parcel tanker is given in *Figure 2-25*.





Length Over All:	91.00 m
Length Between Perpendiculars:	86.00 m
Breadth:	15.80 m
Draught:	5.455 m
Deadweight:	3,898 dwt
Maximum speed:	13.13 knots

Figure 2- 24: Petroleum product tanker 'Kakuyu Maru'

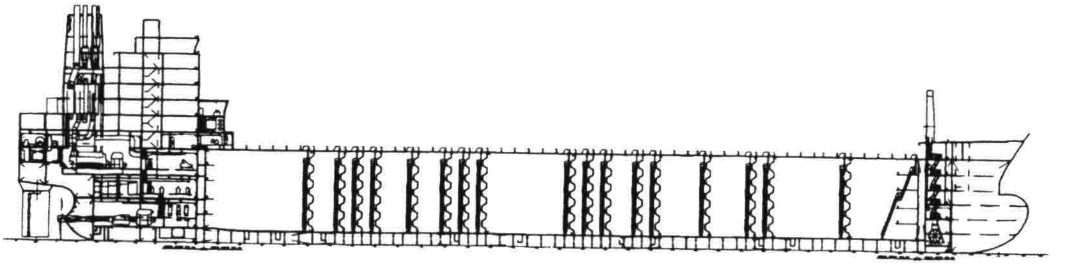


Figure 2- 25: Parcel tanker 'Stolt innovation'

Length Over All:	176.75 m
Length Between Perpendiculars:	168.50 m
Breadth:	31.00 m
Draught:	10.80 m
Deadweight:	37,015 dwt
Maximum speed:	16.50 knots

(iv) *Liquid gas tanker (see Figure 2-26)*

The gas is transported at a high pressure or at a low temperature or a combination of both. The products involved are:

- LPG (Liquefied Petroleum Gas), a mixture of propane and butane,
- LNG (Liquefied Natural Gas), which consists mainly of methane, and
- Other types of chemical gas, like ammonia, ethylene, etc.

The gas is mostly transported at asmopheric pressure and low temperature (LPG: -46°C and LNG: -162°C) in liquid form in separate tanks in the hold of the ship, i.e. the so called cryogenic transport. In liquid form natural gas retains only $1/634^{th}$ of its original volume. *Figure 2-27* gives the development of the liquefied gas carriers. For smaller quantities – e.g. coaster type and size ships – LPG is also transported in pressurised form at normal temperatures. LNG cannot even be liquefied by pressurisation at temperatures above -80°C. The capacity of gas tankers is normally expressed in m^3. In principle LNG-carriers are capable to transport LPG as well; but LPG tankers cannot carry LNG.

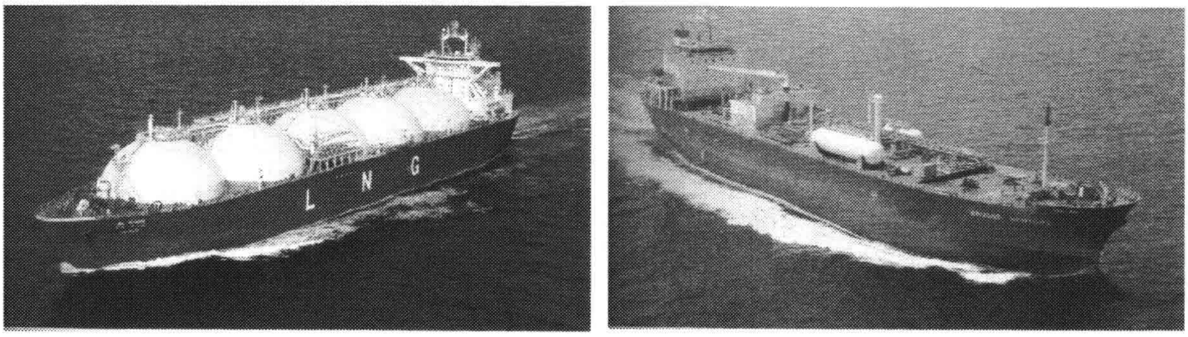
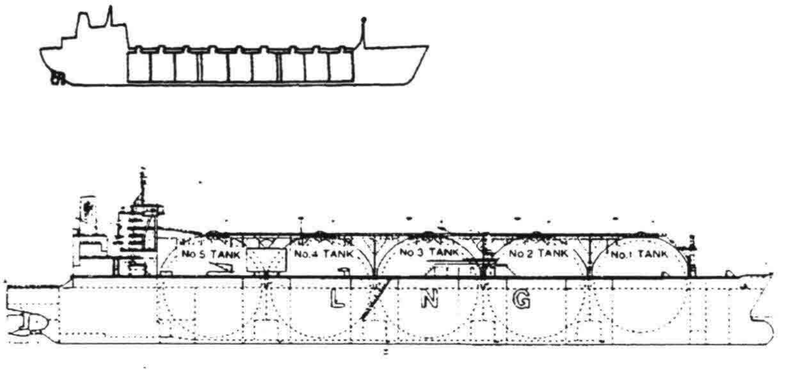


Figure 2- 26: The difference between LNG-tankers (left) and LPG-tankers (right)



Methane princess, 1964

Capacity:	27,400 m^3
LOA:	175.00 m
Breadth:	24.80 m
Draught:	7.90 m

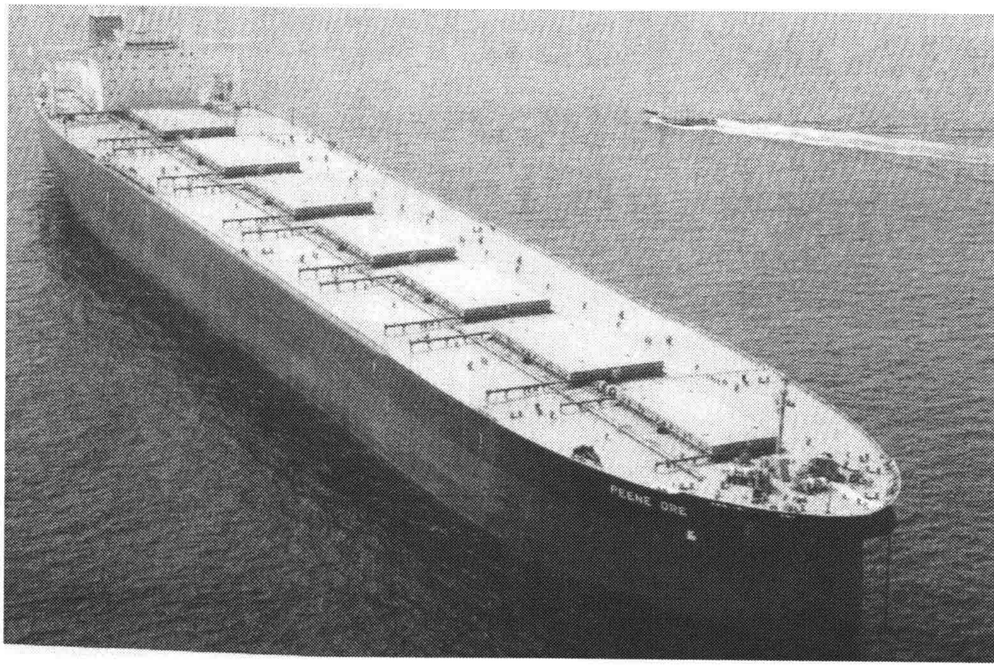
Al Khor, 1997

Capacity:	137,550 m^3
LOA:	297.50 m
Breadth:	45.75 m
Draught:	11.215 m

Figure 2- 27: Development of liquid gas carriers

2.3.6.3. Dry bulk carriers

Dry bulk ships are designed to carry big quantities of uniform, unpacked commodities such as grain, coal, ore etc. Loading is always carried out by shore equipment, unloading sometimes by shore equipment, sometimes by ship-based equipment. A large number of dry bulk vessels are 'ungeared bulk carriers' which have no self-loading capability. 'Geared bulk carriers' are equipped with derricks at all holds or with gantry cranes and do not require shore cranes. In contrast to the tanker, the dry bulk carrier has hatches. The hatches are usually very wide, in order to give access to the handling equipment in every place in the holds. The biggest bulk carriers presently in use (VLOC's = Very Large Ore Carrier) measure about 350,000 dwt, see *Figure 2- 28.*



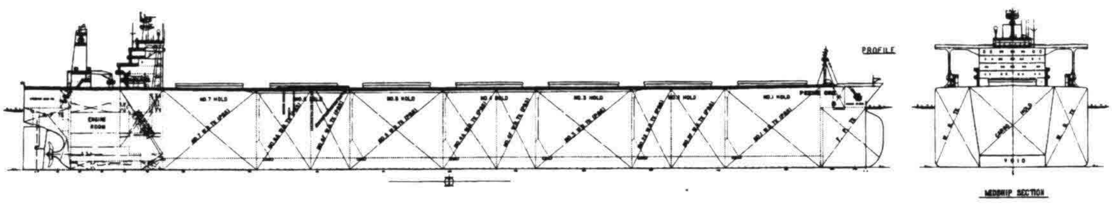


Figure 2- 28: Very Large Ore Carrier 'Peene ore'

Length Over All:	332.00 m
Length Between Perpendiculars:	320.00 m
Breadth:	58.00 m
Draught:	23.00 m
Deadweight:	322,398 dwt
Maximum speed:	14.70 knots

Some types of dry bulk ships, the CSU's (Continuous Self Unloader), are self-discharging via an ingenious conveyor system. Capacities of to 6,000 tons per hour can be reached (see also *Figure 2- 29*). The advantage of these self unloaders is that only some dolphins are necessary for a berth.

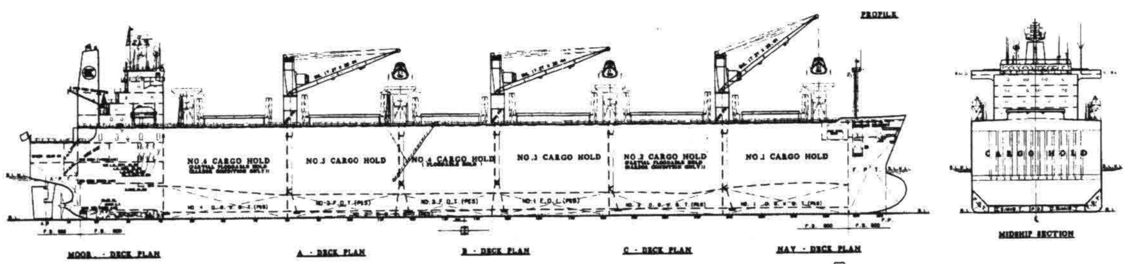


Figure 2- 29: Self-unloading wood chip carrier 'Keoyang majesty'

Length Over All:	221.00 m
Length Between Perpendiculars:	212.00 m
Breadth:	32.20 m
Draught:	10.70 m
Deadweight:	48,618 dwt
Maximum speed:	16.40 knots

2.3.6.4. Combined bulk carriers

Due to the specialized nature of the ship, bulk carriers often sail in ballast. The reason is that these ships usually transport raw materials or half finished products from the producer to the processing markets. There will obviously not exist a return cargo of the same or similar commodity from the consumer to the producer. For this reason the so called OBO and OCO carriers have been developed. This ship type may transport either dry bulk or crude oil or both.

The transport of ore played a very important role in the beginning of this development. First the ore oil carrier was developed (O/O). When increasingly lighter products (grain) were transported in bulk, the so-called OBO carrier was developed. Another development with regard to combination carriers was the OCO carrier.

The combination carriers can be distinguished from the ordinary bulk carrier by the presence of deck fittings (such as pipelines, hose derricks and manifolds), that can be observed on deck of a crude oil tanker in addition to the hatches of the dry bulk carrier.

(i) *OBO carrier (see Figure 2-30)*

The OBO carrier can transport either ore or crude oil. Usually the same holds are used. The OBO carrier has been developed mainly to transport oil. This means that when this ship transports oil, the holds are completely filled; in case of ore, the holds may only be partly filled, but the holds will be completely filled again when low density cereals or grains are transported. One of the problems consists of the need of cleaning of the holds each time before changes cargoes. Not always the waste water is discharged in an appropriate way. Some safety problems exist with respect to these carriers. Due to explosions two ships (owned by a Norwegian shipping company) have been wrecked.

(ii) *OCO carrier*

The OCO carrier can transport liquid and dry bulk cargo at the same time. This is possible by the special arrangement of the holds. The central section of the hold is reserved for dry bulk cargo. It is surrounded by tanks for the storage of lquid bulk cargoes usually crude oil (when ore is transprted mostly no carrying capacity is left for oil). By using separate holds for oil and dry bulk cargo no cleaning problems exist. One of the possibilities of making use of the OCO carrier is when two markets exchange bulk products, such as:

South America – USA : ore
USA – South America : crude oil

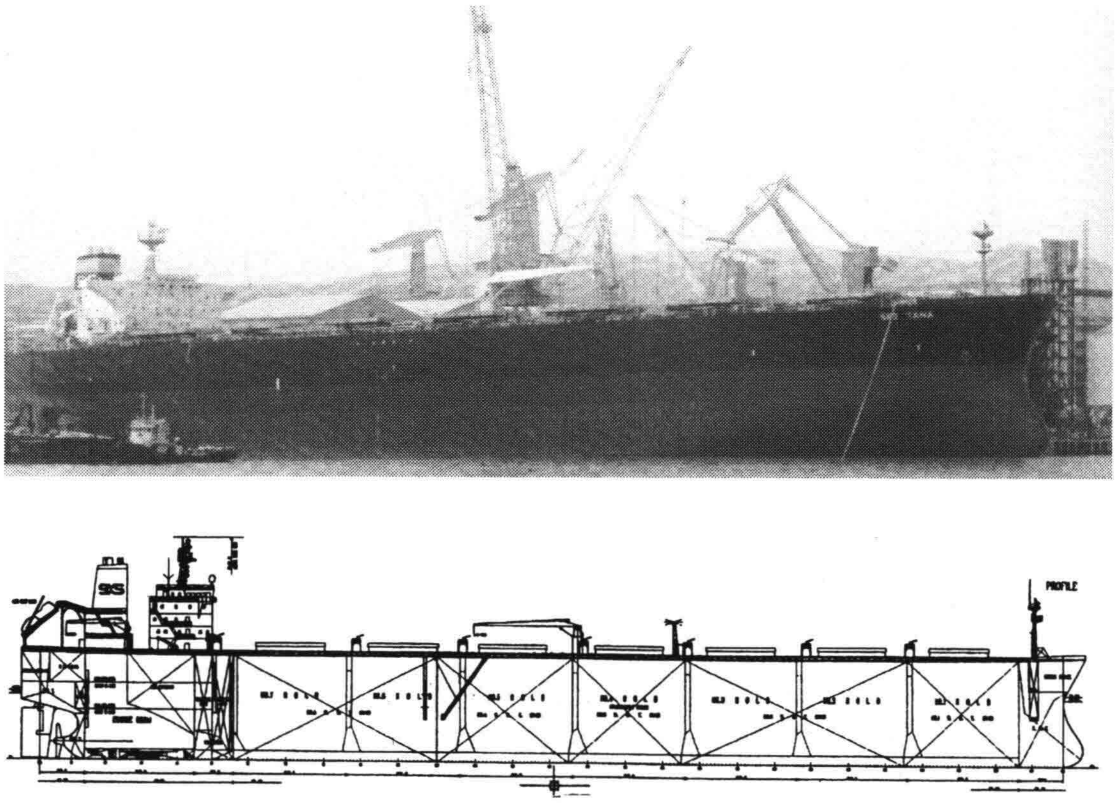


Figure 2- 30: OBO carrier 'SKS Tana'

Length Over All:	243.61 m
Length Between Perpendiculars:	234.00 m
Breadth:	23.20 m
Draught:	14.80 m
Deadweight:	109,891 dwt
Maximum speed:	15.90 knots

2.3.7. Short sea trader

The short sea trader is a sea going ship with a capacity of between 300 and 3000 dwt. In several countries short sea traders with capacities ranging from 300 to 1500 brt are referred to as 'coasters'. Usually, the short sea trader runs the shorter routes, connecting the ports around the North Sea, the Baltic Sea, the Mediterranean Sea and similar areas in the world. As discussed in the previous chapters, the size and therefore also the draught of ocean going vessels have increased sharply over the past decade. This has increased the importance of short sea traders, mainly due to the following two reasons:

- Large vessels tend to call at as few ports as possible, in order to reduce costs, and
- Large vessels are no longer able to call at every port due to restrictions caused by the dimensions of the ships

To maintain the connection between the ports of call of the large vessels and the other ports the short sea trader is a most useful tool. If a short sea trader is employed in this way, she is also referred to as 'feeder'. Due to her limited dimensions the ship can call at most ports. Furthermore it can be observed, that she is, because of the simplicity of the ship and the small crew, economic in use. The short sea trader can transport any kind of cargo, such as general, palletised, containerised or bulk cargo..

Depending on the type, the short sea trader is often fully equipped with cargo handling gear, which also enables her to load or unload cargo at small ports with limited facilities.

2.4. Tramp and liner trade

International shipping can be subdivided into two major categories:

- liner trade
- tramp trade

2.4.1. Liner trade

Liner trade is a seaborne trade of one company (or a consortium of companies), which maintains regular services between a certain number of ports. Within this trade one can further distinguish main routes: east-west and vice versa, north-south and vice versa and short-sea lines. The latter provide a regular service between a number of ports at the same continent, e.g. Rotterdam-Bilbao-Southampton-Rotterdam. The essence of all these lines is:

- times of arrival and departure in any port of the route are scheduled (and published) over a certain period in advance; high reliability
- tariffs are fixed over a certain period
- berth location in most ports is fixed

In container shipping a peculiar phenomenon developed, i.e. main lines, which call on only few ports in their route, with feeder ships collecting and distributing the containers within a region around such a 'main port'. Another name for this system is hub-and-spoke. The reasons for this development are clear: the main line vessels were becoming too large and too expensive to call on smaller ports. The transfer from main line vessel to feeder and vice-versa is called transhipment. The total container throughput of the main ports comprises hinterland cargo and transhipment cargo, the latter being counted double (on entering and on leaving the port). Singapore port has mainly transhipment cargo, whereas in Rotterdam the container throughput is about 15 % transhipment.

Over the past few years competition between the main line shipping companies, the 'mega carriers', has led to concentration and rationalization. Concentration implies merges and take-overs, leaving only about 20 companies to provide the intercontinental services. Rationalization was needed to maximize slot usage, in other words, to make sure that the vessels are loaded up to TEU capacity. This is achieved by forming consortia or alliances (see *Table 2-4*)

Table 2-4: Alliances (1998)

Name	Members	Number of ships	Fleet capacity (TEU)
Grand Alliance	**Hapag-Lloyd** **OOCL** **NYK** **P&O Nedlloyd** **MISC**	**91**	**355,250**
The New World Alliance	**APL** **Hyundai** **MOL**	**95**	**345,000**
United Alliance	**DSR-Senator** **Cho Yang** **Hanjin** **UASC**	**96**	**330,400**
Maersk/Sea-Land	**Maersk** **Sea-Land**	**69**	**264,500**
Cosco/K Line/ Yangming	**Cosco** **K Line** **Yangming**	**62**	**202,500**

Another way to achieve optimum usage of the capacity of scheduled ships is slot sharing. This implies the chartering of container space (slots) on a competitors vessel on an as-need basis. Notwithstanding all these measures to improve shipping economy, presently the relative overcapacity leads to low tariffs and poor performance of most shipping companies.

2.4.2. Tramp trade

Tramp trade is the opposite form of seaborne line trade. It is being applied whenever or wherever needed. Tramp trade is mostly found in the bulk shipping trade, where the markets are more varying than in merchant shipping. Sometimes tramp ships are contracted by liner companies on short or long term contracts, in case their own fleet is not adequate or available to provide the services required. Chartering occurs through open markets mainly in London and New York. The chartering through open markets is reason for strong varying tramp tariffs because of the limited flexibility of the transport capacity. Therefore raw materials processing industries are concluding long term contracts. This security of long term contracts offers the possibility to use larger and more specialized bulk carriers.

To illustrate the importance of tramp shipping, the distribution of the world crude oil transport in 1992 was presented:

Ca. 15%	was transported by vessels owned by the major oil companies
Ca. 84%	by independent tramp companies, which have leased their ships on short and long term contracts to oil companies and oil traders
Ca. 1%	was carried out by ships owned by governments

2.5. Graphs

Some graphs with respect to the main dimensions of ships are presented in the following Figures (based upon data from Lloyds Register of Ships and the sources).

Figure 2-31:	Main dimensions of general cargo ships
Figure 2-32:	Main dimensions container ships
Figure 2-33:	Main dimensions bulk carriers. Modern VLBC's (Very Large Bulk Carriers) do have an about 1 to 1.5 meter lower draught against somewhat greater length and beam. This is indicated by the second line for ships in the 170,000 to 210,000 dwt class. It represents the average over some 90 ships in that category built in the last ten years.
Figure 2-34:	Main dimensions crude carriers
Figure 2-35:	Main dimensions crude carriers > 40.000 dwt

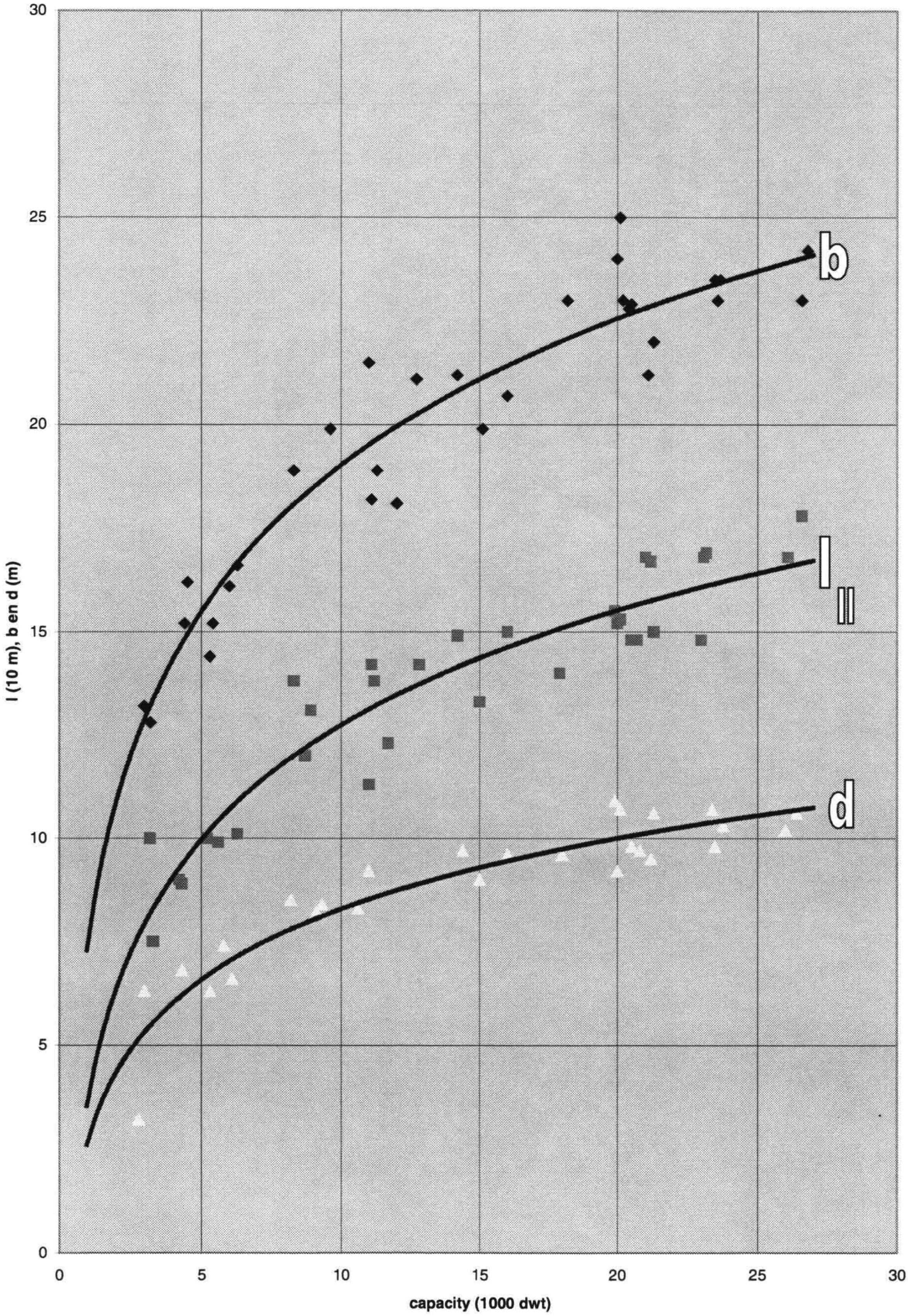


Figure 2-31: Principal dimensions of general cargo ships

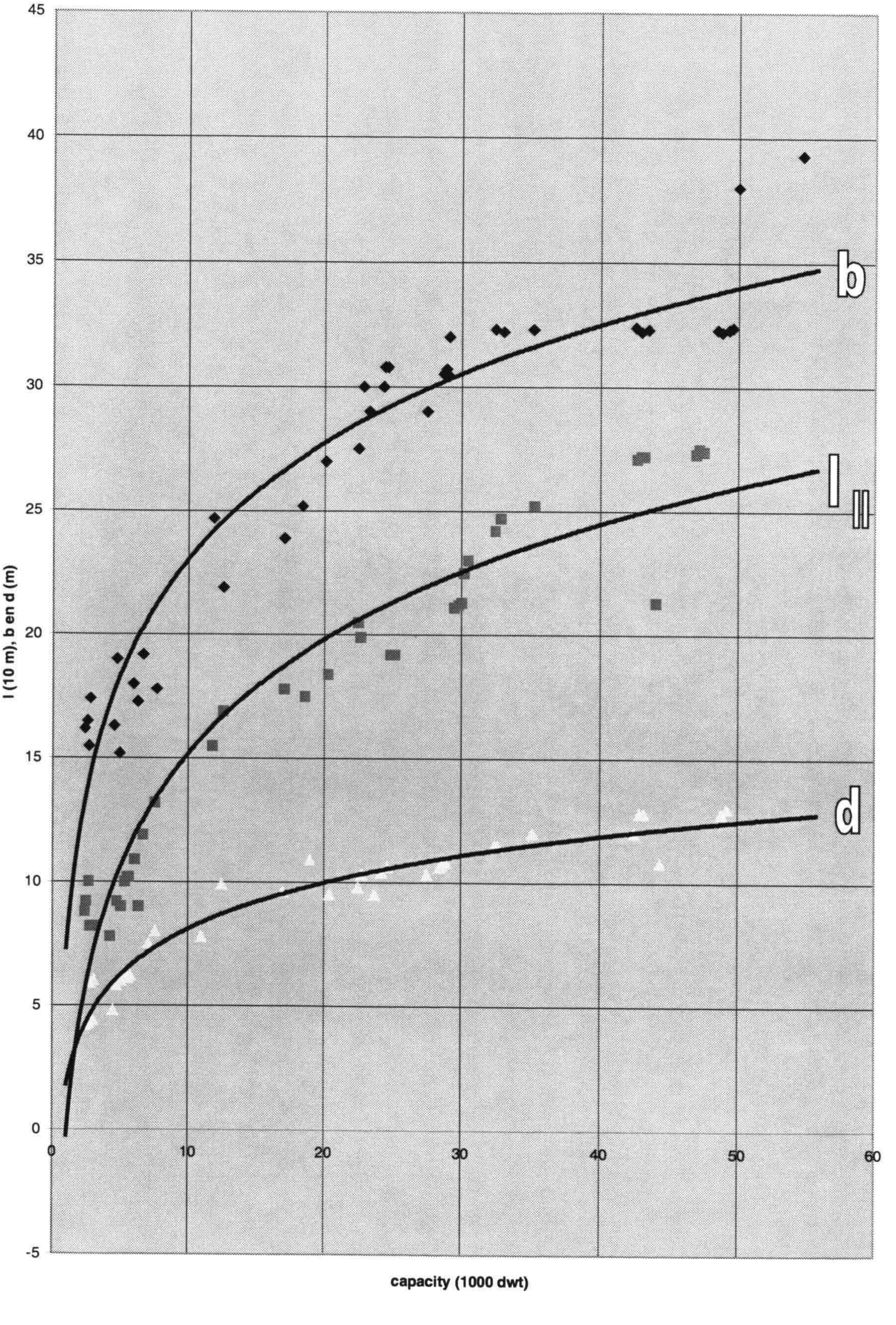


Figure 2-32: Principal dimensions of container vessels

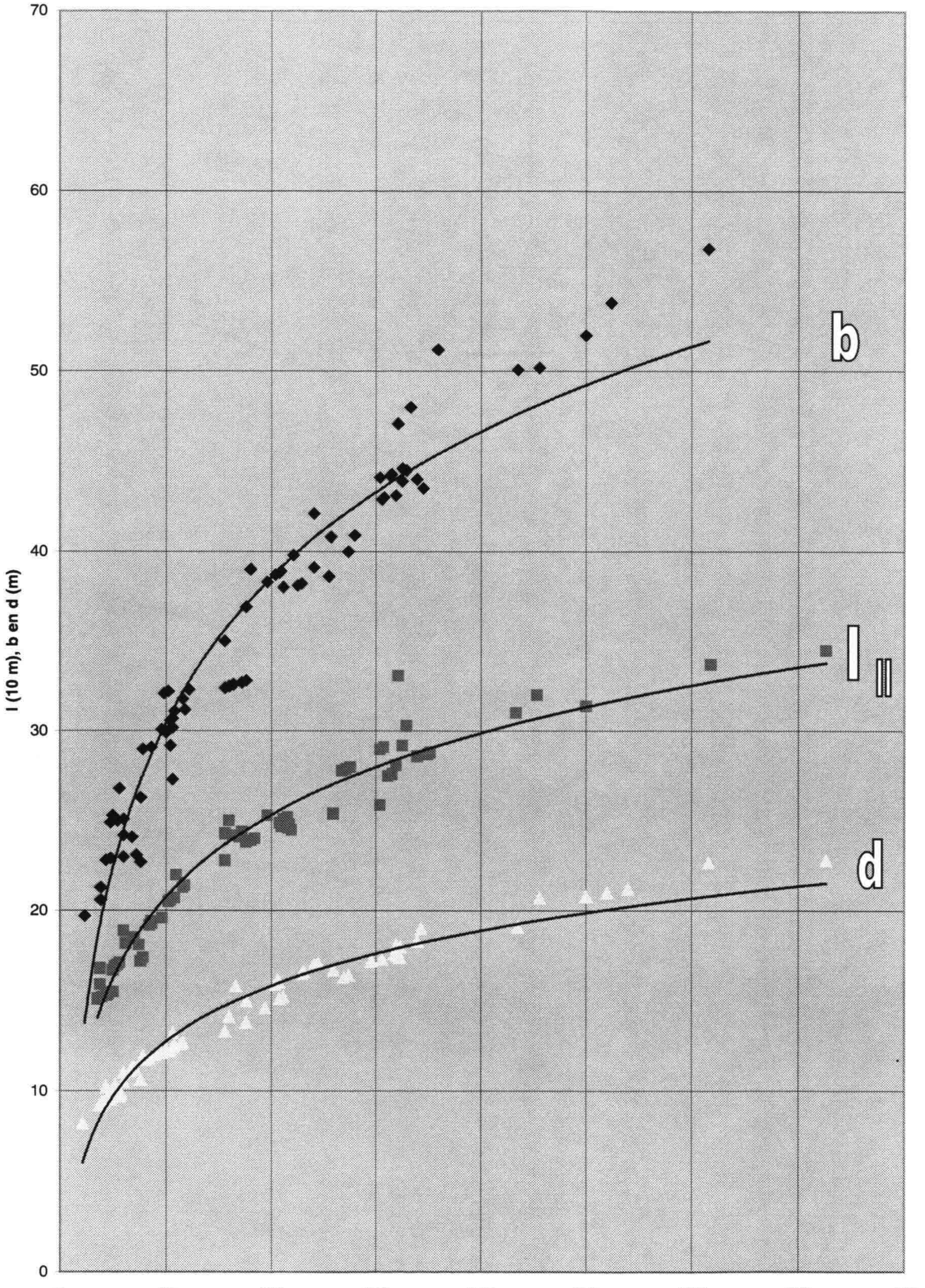


Figure 2-33: Principal dimensions of bulkcarriers

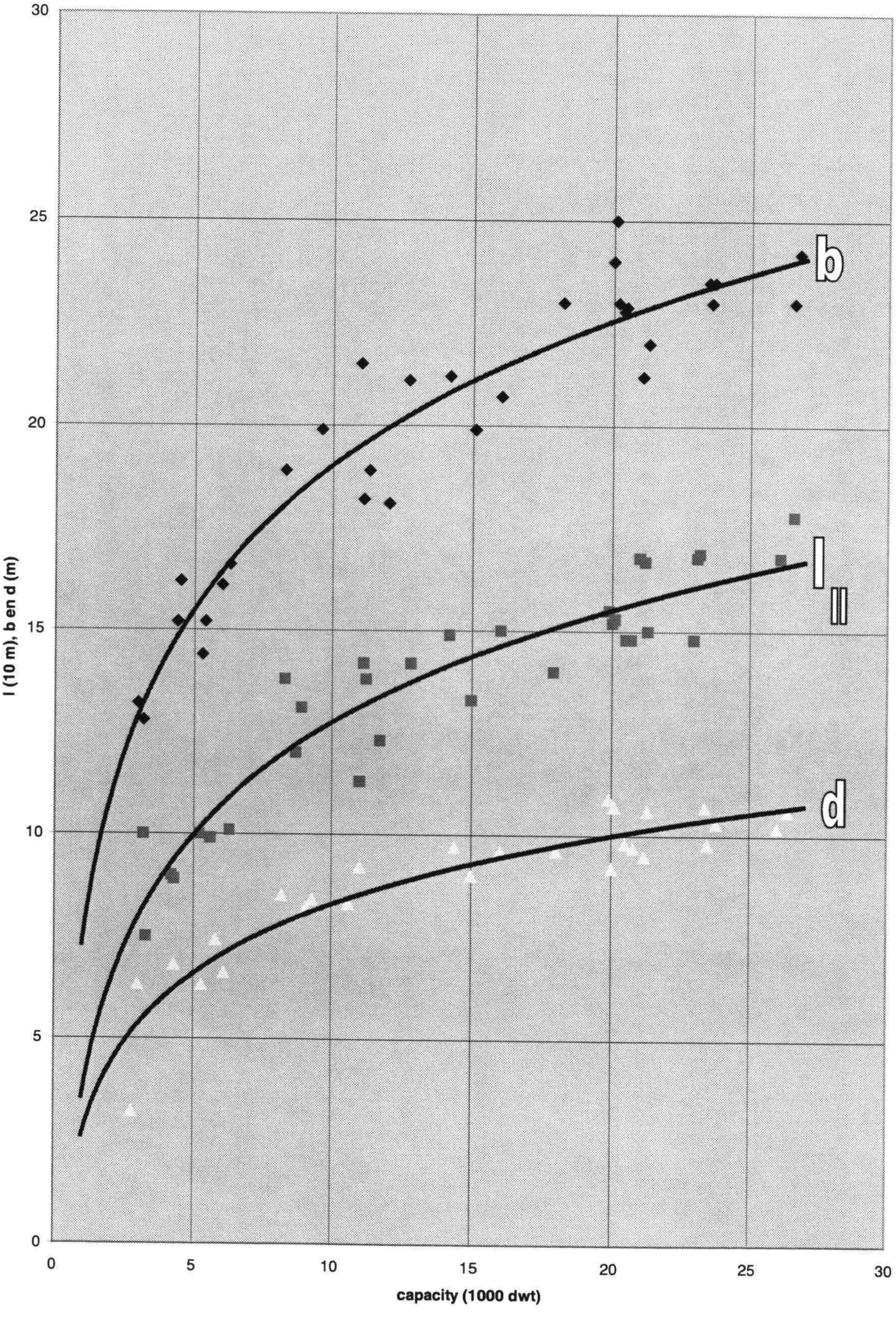


Figure 2-34: Principal dimensions of tankers

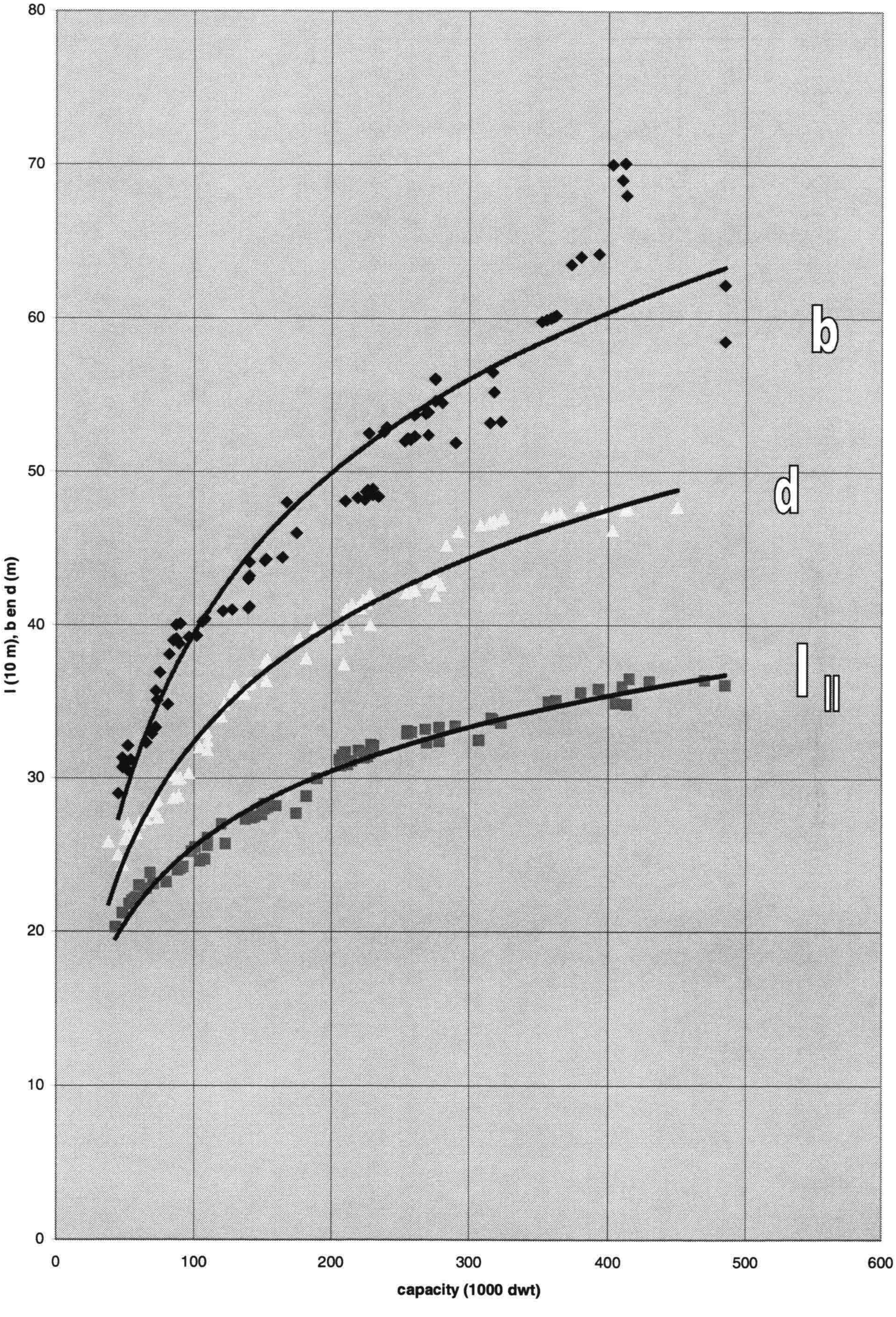


Figure 2-35: Principal dimensions of tankers > 40.000 dwt

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Chapter 3. Port Functions and Organisation

3.1. INTRODUCTION 3-2

3.2. FUNCTIONS 3-2

3.3. TRANSPORT CHAIN 3-5

3.4. ORGANISATION OF SEAPORTS 3-7

3.5. REFERENCES 3-8

Chapter 3. Port Functions and Organisation

3.1. Introduction

Before entering into planning and design of ports it is necessary to determine the functions of a port and to understand its organisation. Both factors are relevant for the economic and financial decisions to be taken as part of the planning process. Recently privatisation of (public) ports and private development of entirely new ports have become popular, but the success of these policies depends very much on the function and the legal and institutional conditions of the port concerned.

3.2. Functions

The primary functions of a port are:

- Traffic function: the port is a nodal point in the traffic, connecting water- and various land modes.
- Transport function: ports are turntables for various cargo flows.

Besides these, ports can have several secondary functions, such as:

- Industrial activities, often in relation to the cargo flows, to shiprepair and shipbuilding, or offshore-supply. But the vicinity of sea transport may in itself be the reason to locate an industry.
- Commercial and financial services, including banks.

The traffic function requires three conditions to be fulfilled, i.e. a good "front door", a good "backdoor" and sufficient capacity and services in the port itself:

- Entrance from sea, needs to be accessible and safe;
- Port basins and quays, adequate space for manoeuvring and berthing of the ships, capacity for handling and storage;
- Hinterland connections, road, rail, inland waterways, pipeline, depending on the transport function.

The safety of ships and crew is most important and receives much attention. This is understandable, when recognising that ships are designed for manoeuvring in open water and at cruising speed. Entering a port means speed reduction, entailing poor manoeuvrability, stopping in limited waters and often having other ships around. For this reason the nautical services are essential: starting with nautical aids (buoyage, lights), getting pilot assistance and tugs, and moving to high-tech aids to navigation: the Vessel Traffic Service (VTS), which implies monitoring of all vessel movements in a port by central radar.

However, a port with very good nautical entrance, but insufficient space and/or bad hinterland connections becomes quickly clogged and does not function. Hence the above three conditions must be in balance.
Regarding the transport functions the conditions are depending on the particular situation of the port:

(i) If a port has its 'natural' hinterland, which it serves for import and export without much competition, it is in the interest of society that this service is provided efficient, uninterrupted and at minimum costs. This led in the past to the 'public ports', which often failed to achieve these goals. They became either 'money earners', or had more ships at anchorage outside than berthed inside the port, or both.
(ii) Where several ports are competing for cargo from and to the same hinterland, or for the transhipment trade, the efficiency of cargo handling and costs for pilotage, harbour dues, etc. become important. Ports become business in itself and privatisation of port functions is a logical step to achieve the necessary efficiency.

In Section 3.4 this issue of public versus private will be further elaborated. Here the question is posed whether the transport functions deserve to be expanded in a competitive situation. The investment costs are high, which benefits justify them? This question has become more relevant, since the direct employment in the port has reduced drastically over the past decades as a result of improved handling methods and automation. There is no simple answer to the question, but some considerations are applicable:

- Some competition between ports is good to stimulate efficiency, and to keep the costs down. Too much competition leads to overcapacity and losses, which are in most cases paid by the public.
- Unfair competition (e.g. by subsidies) shall be avoided, because it leads to price distortion (European Commission, 1995) and overcapacity.
- In the cost/benefit analysis of port development projects, the long term, indirect, social benefits have to be included (Brucker, 1998).
- Ports should strive to include employment generating activities in their development strategies, in order to maintain the positive profile and public support in the local community.
- Environmental effects have to be taken into account on a rational basis, e.g. by quantitative evaluation methods and against a uniform set of regulations.

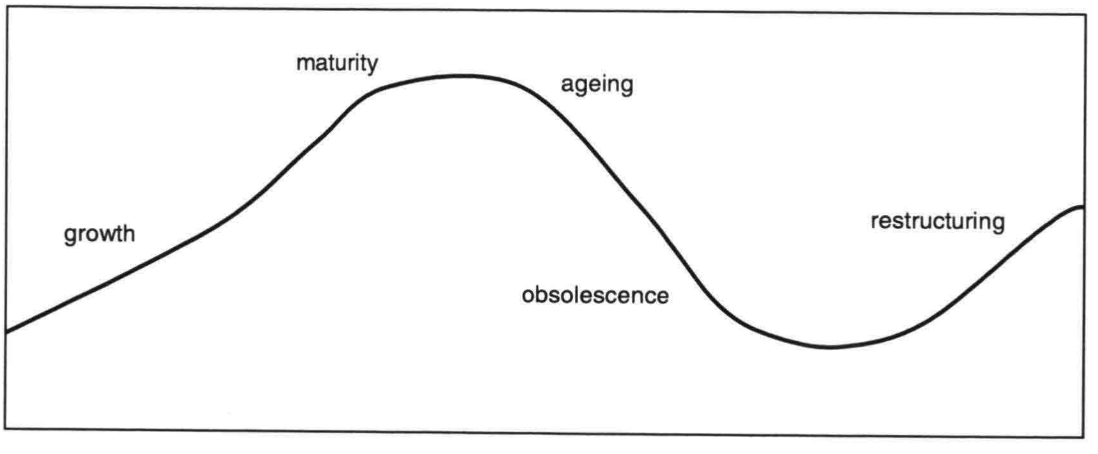
The above aspects are all related to the investment decision, in the planning stage of port expansion. In the direct competition between ports to attract certain trades and cargo volumes the following competitive factors are important:

- Availability of land for terminals and the related cost per m^2
- Port tariffs and dues
- Quality of the port and/or existing stevedores (efficiency, reliability, flexibility, handling costs)
- Quality of the hinterland connections

- Environmental requirements
- Customs regime
- Nautical safety

It is seen that in order to be able to attract new business, the port must have some excess space. It is important to realise that this may also be found inside the existing port boundaries, for instance where old and declined areas have become obsolete and can be converted to suit the requirements of new trades.

This process has been observed in many existing ports and is described in the so-called Port Life Cycle theory (Charlier, 1992). The cycle, shown in *Figure 3-1*, implies that a port area develops with the growth of cargo throughput, reaches maturity (or saturation), starts to age (due to changes in cargo pattern or in ship design) and then reaches a state of obsolescence, which will continue, unless a revitalisation process is initiated.



time / location	L1	L2	L3	L4	L5
T1	growth				
T2	maturity	growth			
T3	ageing	maturity	growth		
T4	obsolescence	ageing	maturity	growth	
T5	restructuring	obsolescence	ageing	maturity	Growth

Figure 3-1: The Port Life Cycle (Charlier, 1992)

The change-over from conventional general cargo to containerised cargo is a good example. In many ports this has made existing terminals obsolete, leaving deserted areas with empty warehouses.

The message is to start the revitalisation process before this happens, as soon as the signs of ageing become clear. This is a role of the port authority, but involves port planning in the same way as expansion outside the existing port boundaries.

3.3. Transport chain

In the previous section the transport function is stated to be carried out by the 'port'. Nowadays there are only few ports in the world where the port authority is also responsible for the ship unloading/loading and the storage of the goods. Often these activities are done by a stevedoring firm, which is specialised in it and therefore can provide better services at a competitive price. The place of the stevedore in the overall transport chain is shown in *Figure 3-2*. This scheme also explains the role of two other agencies: the forwarder, who is hired by the shipper of the cargo (not to be confused with the shipping company), to arrange the land transport, and a shipping agent, who in turn arranges for the shipping line and the stevedoring in the seaports on both ends.

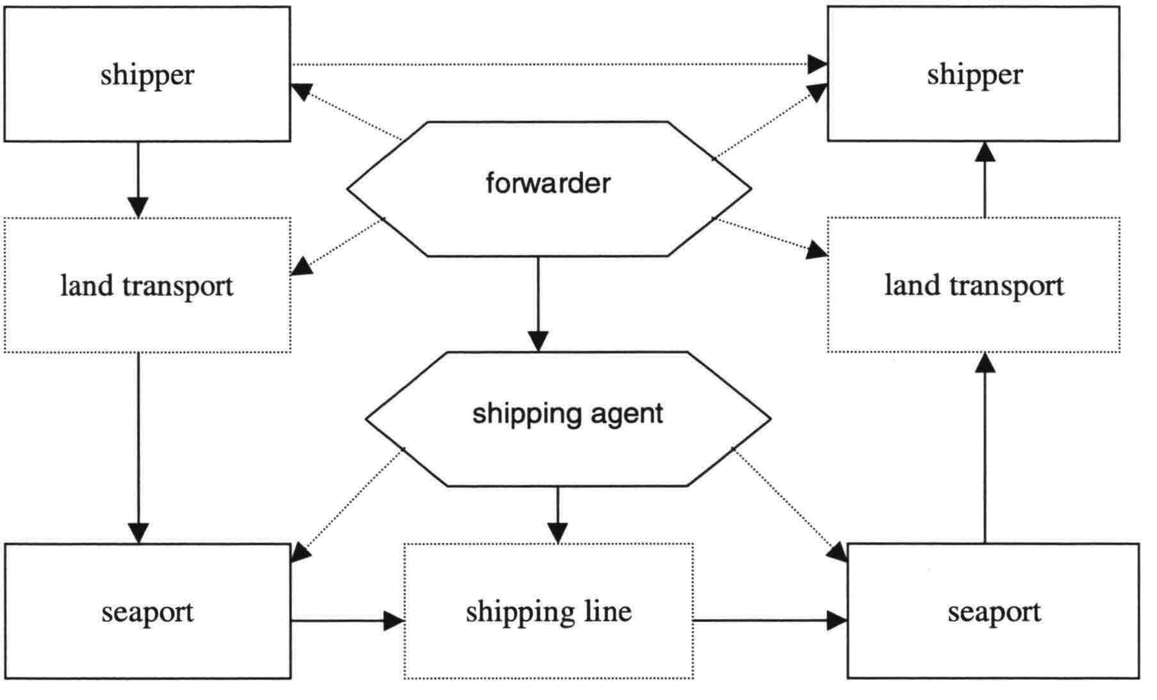


Figure 3-2: Elements in the transport chain

For large cargo volumes at regular intervals over a period of several years, forwarders tend to prefer one contract for the entire transport chain. In response to this, shipping companies have started to offer 'door-to-door' services, in particular for containerised cargo. And as a logical step shipping lines diversified their business to include land transportation and stevedoring. An example is Nedlloyd Cargo as a subsidiary of the shipping line. Other examples in the transport of liquid bulk are Van Ommeren and Pakhoed, which have integrated shipping, handling and storage within their respective companies.

At this point it is relevant to mention the growing market for intermodal transport. In Chapter 2 the competition between road, rail and IWT for the hinterland transport was mentioned. Intermodal transport concerns the combination of rail with road and IWT with road. The present policy of the Dutch Government is to stimulate this intermodal transport, in order to reduce the congestion of the road network and for environmental reasons. To illustrate the latter point *Figure 3-1* gives the number of units of the different transport modes needed for 1200 ton cargo. This is an indication of the corresponding energy consumption and air pollution.

Promotion of intermodal transport can be achieved by improvement of rail infrastructure for cargo (e.g. the Betuwe Line) and the infrastructures for IWT (widening of the Meuse and of various canals). Additionally there exists a subsidy for the private development of terminals along rivers and canals.

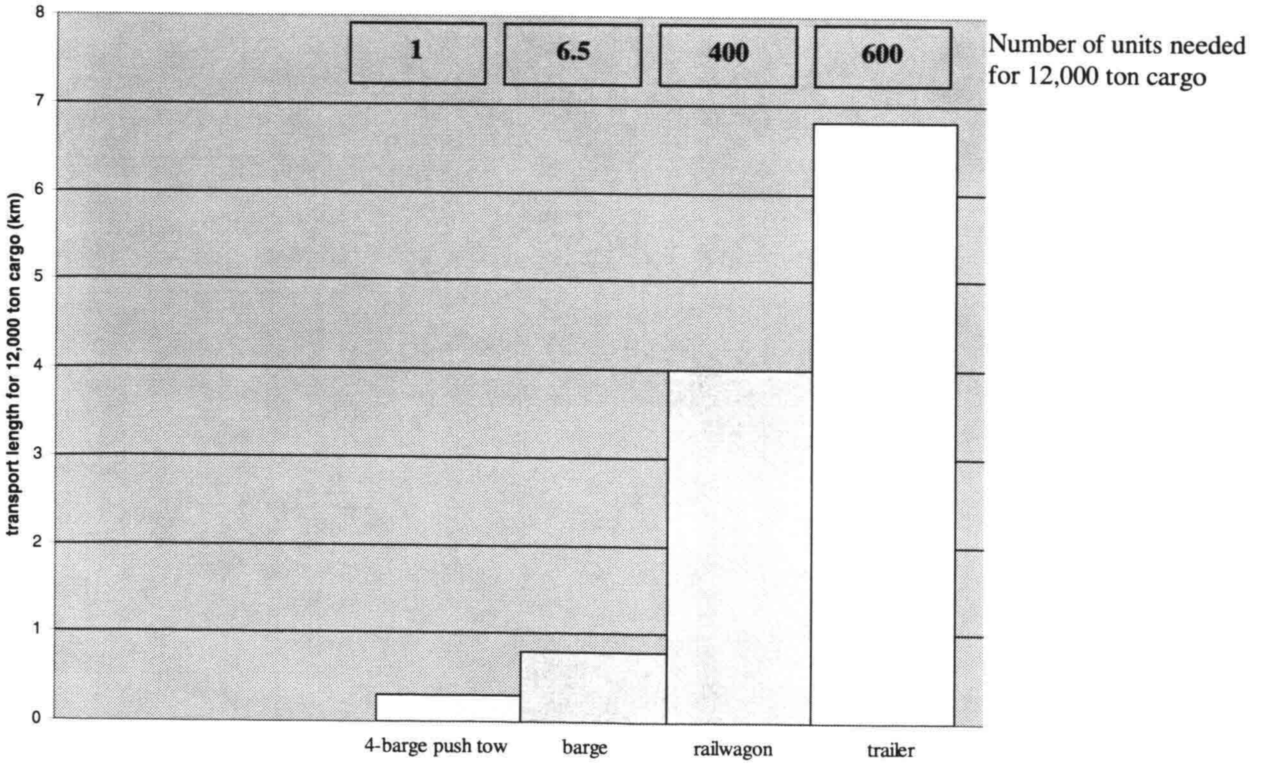


Figure 3-3: Transport length for different modes

3.4. Organisation of seaports

It has been mentioned that many ports started as a public organisation. Consequently they were government owned, be it the National Government, a municipality, or a separate status of Port Trust or Port Authority. Exceptions were so-called captive ports, built and operated by an industry for its own use, such as the tanker berths for a refinery or the bulk export terminal for a mining company.

World-wide one can distinguish three different forms of organisation of the public ports:

- The Service Port: all services including cargo handling and storage are provided by the port authority
- The Landlord Port: the port authority owns the land and gives concessions to private sector companies for provision of cargo handling and storage services. The port authority is responsible for the infrastructure, the nautical safety and access, including maintenance of approach channel and basins.
- The Tool Port: the port authority remains responsible for providing the main ship-to-shore handling equipment (usually light to medium multipurpose cranes), while cargo handling is carried out by private companies under licences given by the port authority.

A 1997 world review of the top 100 container ports shows that 88 out of 100 ports conform to the Landlord Port model. This is therefore becoming the standard, but for small ports, assuming 250,000-300,000 tons of general cargo per annum to be minimum for independent cargo handling company to be financially viable. Below this level the Tool Port model appears to be appropriate.

Besides these public ports fully private ports are becoming a trend. These are ports built and operated by private companies, including the responsibility for maintenance. Statutory functions like navigation safety, environmental protection and customs remain government responsibility (Juhel, 1999)

The latter so-called Built-Operate-Transfer (BOT) projects are seen by many politicians all around the world as an attractive way to create infrastructure and thus overcome congestion in the existing ports without public finance. The reality is that the return on investment of most projects is insufficient (based on a 30 year pay-back period). Consequently the only way to realise them is by a combined approach, i.e. public finance of certain basic infrastructures and private financing of the rest. This is either achieved by following the "Landlord" approach, or in a commercial investment by public and private partners jointly, the Public Private Partnership (PPP). This approach is applied by Amsterdam Port Authorities in the realisation of several new terminals.

The advantages of various degrees of private sector investment and participation are clear:

(i) It offers a good test on the financial feasibility of the port project (private sector is not interested in 'white elephants')

(ii) Once in operation the efficiency and profitability of the port is driven by the commercial interests of the private partner, and less by social and political considerations. A good example of this is the privatisation in 1989 of quite a number of ports in the United Kingdom, under the name Associated British Ports. In six years time ABP had turned them around and made profit. This was achieved by labour reductions of 85% of the original workforce. And notwithstanding this reduction the total throughput showed a 13% increase.

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Chapter 4. Port Planning Methodology

4.1. INTRODUCTION **4-2**

4.2. TYPES OF PLANNING **4-2**

4.3. PLANNING PROCESS **4-6**

4.4. PLANNING TASKS **4-9**

4.4.1 CARGO FORECASTS 4-9
4.4.2 FUNCTIONAL REQUIREMENTS AND PLANNING ELEMENTS 4-9
4.4.3 LAYOUT DEVELOPMENT 4-10
4.4.4 EVALUATION TECHNIQUES 4-14
4.4.5 PROJECT OPTIMISATION 4-16
4.4.6 ECONOMIC AND FINANCIAL ANALYSIS 4-18

4.5. GENERAL OBSERVATIONS **4-19**

4.6. REFERENCES **4-20**

Chapter 4. Port Planning Methodology

4.1. Introduction

In principle port planning is not different from other infrastructure planning: one determines the requirements at a future point in time, one develops a suitable lay-out with matching connections and a programme of (phased) development towards this target. What makes it special is the complexity of hydraulic, nautical and operational aspects involved, in addition to spatial planning, transport, environmental and legal aspects common to land infrastructure.

From the port authority or operator's viewpoint planning is needed to anticipate on future developments and ascertain that the infrastructure, once built, functions well. It is also an essential element in obtaining finance and all legal permits, which are necessary to implement the project.

The planning methodology as outlined in this chapter follows the general approach of the design methodology, as applied in other areas of civil engineering. The "elementary design cycle", applied at the "system's" level, can be recognised in the process, as outlined in Section 4.3.

4.2. Types of planning

Depending on the time horizon the following types of planning can be distinguished:

Type	Time horizon (years)	Example
long-term	20-30	masterplan
medium-term	5-10	first phase of a masterplan
short-term	1-2	minor lay-out changes

Furthermore the type of planning may vary depending on the scope and geographical extent:

- national or regional port planning
- planning of individual ports

The purpose of a masterplan is to have a blue print for future development, reserving space where it may be needed in the future, taking account of regulatory and environmental requirements, and creating an efficient and economic port operation. National and regional masterplans for port development were aimed at creating the optimum allocation of functions within a country or a region. This should take into account existing port capacity, hinterland connections, industrial development and cost of the infrastructure. Such plans were made during the past decades for countries like Indonesia and Malaysia, often with World Bank assistance. The accent lies here on economics: assessment of cargo flows for all commodities and cost/benefit analysis for the individual port projects leading to an optimum overall plan. The port planner plays a role in the evaluation of existing ports (can the efficiency and throughput capacity be improved, often even without new infrastructure), and in preparing lay-outs for new port facilities or extensions where appropriate. Preliminary design of infrastructure is needed to determine costs, but this is not done in great detail.

While it is evident that this type of planning is useful to make sure that the right investments are made at the best location, it must be realised that it is very difficult and often has limited applicability over longer periods of time. This has the following reasons:

(i) in sofar as the plan affects the future of existing ports in a negative way (limitation to certain type of cargo and hence in overall growth) the port authority and local community will resist it. Political lobbying starts to adapt the plan and otherwise one will ignore it.
(ii) several years after the plan has been formulated, the actual cargo flows may deviate considerably from the forecasts, conditions may have changed and the plan has become ineffective.

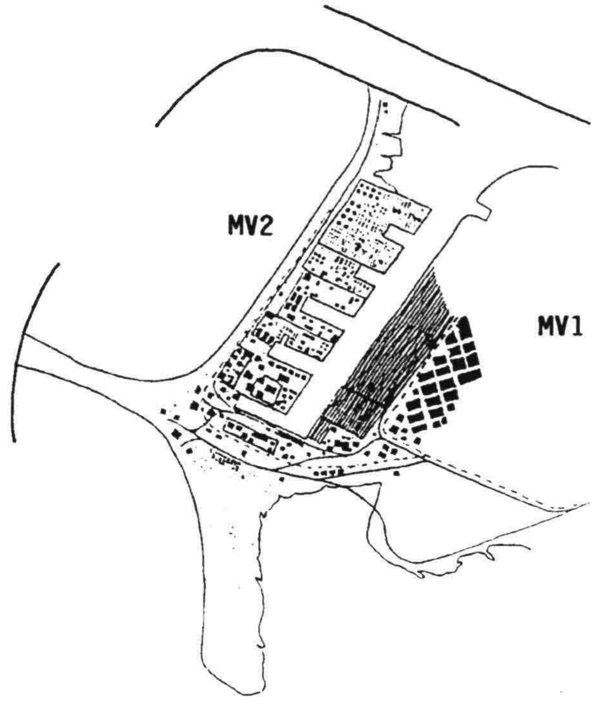
Western countries do not apply this type of national port planning anymore. What does happen is that in preparing the masterplan for an individual port (expansion), the possible overcapacity of neighbouring ports in the region is considered. An example of this is the ongoing planning process for Maasvlakte 2 (see *Box 4-1*)

Coming back to the types of planning according to time horizon: in the ideal situation the long-term, medium-term and short-term plans are interrelated. The masterplan provides the framework for medium-term plans, while these in turn form the basis for short-term projects. The masterplan needs an update at intervals of about 5-10 years, during which the actual throughputs are compared with the forecasted, the latter are adjusted, and accordingly the original phasing is reviewed and updated. In this way one could extend the horizon of the masterplan and achieve a rolling planning process, as visualised in *Figure 4-1*.

Project Mainport Rotterdam (PMR)

The port of Rotterdam is reaching saturation, as far as industrial areas with access to the (deep) port basins are concerned. In 1993 Rotterdam Municipality includes seaward expansion, Maasvlakte 2 (MV2), in an overall plan for infrastructure improvement, the ROM Rijnmond. It is interesting to note that the Plan 2000⁺, a masterplan for the ports' expansion dated 1969, presented the present Maasvlakte only as a first phase, and showed an MV2 and an MV3 and so on. Since that time the legal requirements for large infrastructure have changed (PKB and MER procedures) and the planning had to start from scratch.

In 1998 the process has reached a point where these procedures are started, carried out under responsibility of three ministries, forming the PMR organisation. The task is to look for solutions to the land-shortage in a broad way, also taking into consideration (i) possible solutions in South-West Netherlands and (ii) concentration within the Rotterdam port area. This is a typical example of regional port planning, be it that the solution has to satisfy the Rotterdam requirements.



Box 4-1: Maasvlakte 2 planning process

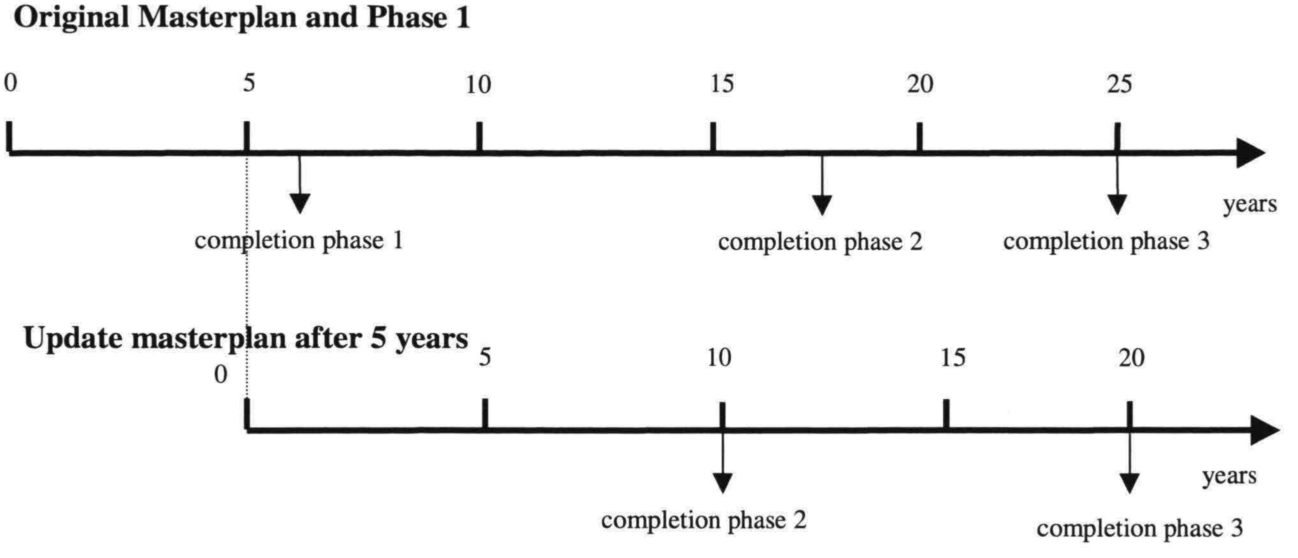


Figure 4-1: Rolling masterplan

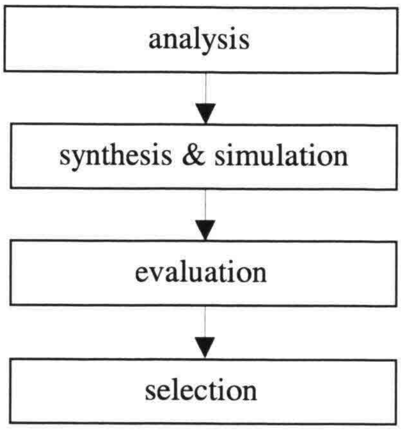
In practice there are not many ports in the world, which apply this process systematically. The updating of the masterplan (if one exists) is often more ad-hoc, when the need arises. And short-term plans are more often that not unrelated to the masterplan.

This does not mean that the masterplan should not be made. It simply shows that a masterplan should be flexible enough to follow fluctuations in economic development and changes in the transport patterns.

Usually the Phase 1 implementation follows directly upon approval of the masterplan. The lay-out for Phase 1 is refined by detailed studies of wave disturbance, morphological effects and manoeuvring conditions. Structural designs of quays and breakwaters are completed at a suitable level of detail for construction tenders.

4.3. Planning process

Each of the above described types of planning has its own particular character, but the main steps of the "elementary design cycle" can be recognised:



Sometimes this cycle is partly repeated, be it with increasing level of accuracy. This is the case in masterplanning, when one starts with a rough generation of lay-out concepts (often based on approximate site data) and selects 2-3 promising alternatives. These are subsequently worked out in more detail, using improved data, after which there follows again evaluation and selection (see *Figure 4- 2*).

It is important to maintain a balance between the accuracy of the input data and the level of detail of the design. As shown in Figure 4-2, the first generation of alternatives is done on the basis of available data on waves, currents, bathymetry, soil, etc. Often these are not applicable to the specific site, but of more general nature. Surveys may be started, but the results are not yet available. Hence the alternative lay-outs at this stage are not more than conceptual drawings, sketches, based on simple design rules. No need to work out any details, as long as the principal dimensions of approach channel, turning circle, quays and terminals are properly reflected in the different alternatives. The cost assessment (because cost is an important selection criterion in all stages) is still very rough, comparing the major cost elements (breakwater, dredging, quays). After the first selection better input data come available and the promising alternatives are elaborated. Preliminary design entails the use of applicable design standards, either national or international. The cost estimates have typically an accuracy of about +/- 30% .

When the selected alternative is optimised, on the basis of detailed site investigations and hydraulic, nautical and logistic analysis (model, simulation) the detailed cost estimates can be made leading to an overall accuracy of +/- 20%. At this level of accuracy the economic analysis can be made. Note: when the project moves into actual design and construction preparation the structural elements are designed and cost estimates will be brought to an accuracy of +/- 10%.

It will be clear that the planning process involves many different disciplines, and that teamwork is essential. The port planner must have sufficient knowledge of the various specialist areas to be able to direct the team, to integrate the results and to maintain the balance mentioned before. Some of the disciplines and specialisms are:

Technical
- Oceanography (wave climate etc.)
- Coastal engineering (morphology, breakwaters)
- Hydraulics (tides and currents)
- Hydro-nautics (approach channel, nautical design)
- Marine structures (quays, jetties)
- Dredging (excavation and land reclamation)
- Geology, geotechnology and seismic engineering (foundations, stability of structures)
- Transport technology (equipment)
- Terminal operations (logistics)
- Traffic engineering (road and rail connections)
- Safety engineering (consequences of hazardous cargo for the spatial plan)

Economics
- Macro-economics and transport economics (cargo forecasts)
- Econometry (economic and financial analysis)
- Commerce (financing, marketing)

Social / Environmental
- Spatial planning
- Environmentalists (air-, water-, noise-, soils pollution analysis)
- Legal advise (national and local planning requirements, permits)

In the following section some of the steps in the planning process will be further elaborated, in particular the non-technical, as these are not treated in the later chapters.

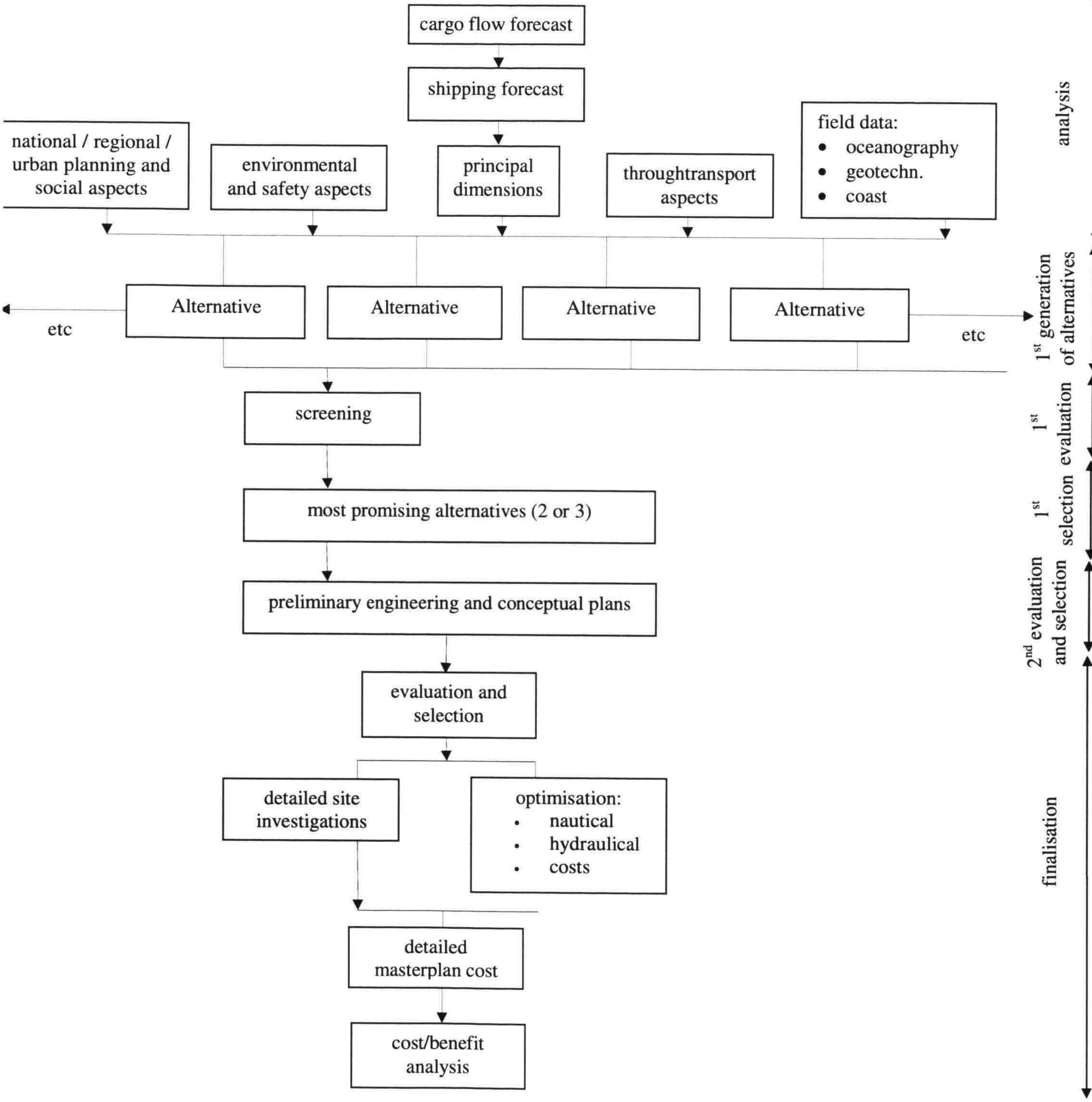


Figure 4- 2: The masterplan process

4.4. Planning tasks

4.4.1 Cargo forecasts

The forecasting process starts with the definition of a port's hinterland and a grouping of cargo flows according to economic and transportation characterisation into commodity groups. The more detailed this grouping, the more accurate the forecasts will be. Then the following steps will be taken:

(i) Assessment of economic and industrial development of the hinterland, often for different scenarios: positive, medium and marginal growth.

(ii) Translation of the results of (i) into trade flows, both incoming and outgoing cargoes. This is done for homogeneous types of cargo such as liquid and dry bulk, and for general cargo. The former category is derived from the difference of production and consumption within the hinterland, the latter is extrapolated on the basis of economic parameters, such as growth of Gross Domestic Product, GDP.

(iii) Potential shifts in cargo flows are investigated, caused by external – often geopolitical – influences. This may give an adjustment of the trade flows determined sub (ii).

(iv) Subsequently the volumes of cargo are estimated which will be transported over sea and an assessment is made of the type of shipping and the ship sizes.

(v) The next step is to analyse the different routing options that exist for all commodities and all combinations of origin and destination. Here the issue of several ports serving the same hinterland, thus of competition, plays an important role.

It will be clear that these analyses require specialist expertise and computer models. For expansion of an existing port an extrapolation of actual cargo flows is often made as a first assessment. It should be realised that this is very crude, especially when periods of 20-25 years are considered. In the container transport for instance port development is very rapid and shipping lines tend to shift large volumes from one port to another. In such a market a comprehensive analysis is indispensable.

4.4.2 Functional requirements and planning elements

A useful document, especially for ports in developing countries, is the 'Handbook for planners' (UNCTAD, 1985). Based on the cargo forecasts the number and size of ships can be determined, often taking into account the existing fleets. In some cases future developments of vessel size must be assumed (such as the present trend towards larger container vessels) and occasionally a port facility is built for a specific vessel, e.g. the dedicated LNG transport service between Brunei and Japan.

Once the expected fleet composition is known the functional requirements for the port can be formulated, in terms of vessel sizes per cargo type, design vessel, number per year, transport volumes to and from the hinterland, port services, etc. The principal dimensions of the port's wet and dry areas are determined by use of design formulae, which will be treated in subsequent chapters. In this way the functional requirements are translated into planning elements:

- Dimensions of approach channel, turning circle and other water areas in the port
- Dimensions of quays for different types of cargo
- Dimensions of terminal areas
- Hinterland connections
- Service areas, buildings
- Land required for industries
- Safety and environmental requirements, including safety distances for the handling of dangerous cargo

4.4.3 Layout development

This task had been mentioned before as the creative part of port planning. The planning elements have been prepared and must now be pieced together into a lay-out. Several lay-outs in fact, because there are many different solutions possible. While the planning elements have been determined on the basis of formal design rules or guidelines, making the lay-out does not follow formal rules. The specific local conditions play a dominant role and therefore no port lay-out is similar to another one. There are a few do's and don'ts, which should be kept in mind however, such as:

(i) Construction cost is an important factor in the feasibility of the port and can most strongly be influenced in this conceptual stage of lay-out development (once the lay-out is fixed, the possibilities for cost optimisation are very limited). When the port is located at the coast a balance of cut and fill is often the best solution, unless the soil is very hard (high dredging costs) or very soft (dredged material unsuitable for reclamation), see *Figure 4-3*. Also the length of breakwaters should be minimised as these form an important cost factor.

(ii) In case of strong offshore wave conditions the orientation of the approach channel should preferably be in line with the dominant wave direction (in order to have waves coming in "aft" of the vessel instead of "quartering" or "beam"). At the same time the configuration of the entrance proper should limit wave penetration. In practice these two requirements lead to a small angle between wave direction and the axis of the approach channel (see *Figure 4-4*).

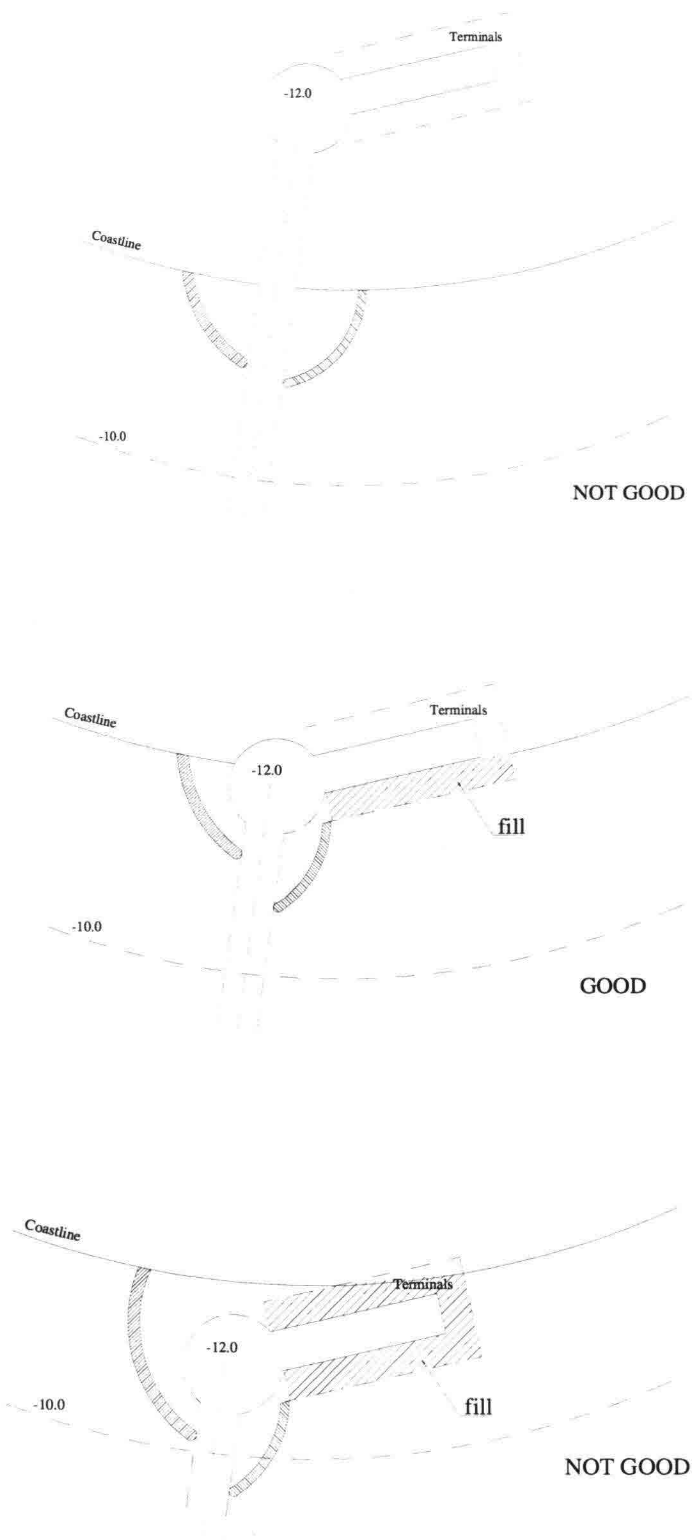


Figure 4-3: Balance of cut and fill

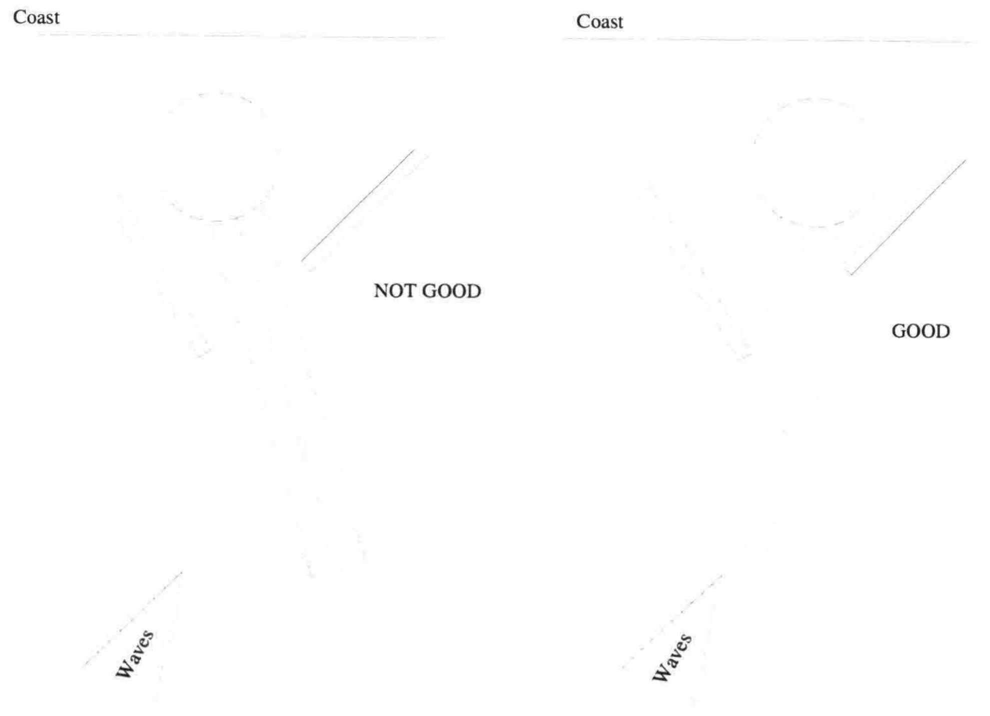


Figure 4-4: Orientation approach channel with respect to wave direction

(iii) When the port basins and entrance channel are protected by breakwaters these should not form a narrow "sleeve", but provide space immediately behind the heads (see *Figure 4-5*), for three reasons: 1). ships manoeuvring in a channel do not like a hard structure close to the channel boundaries, 2). when there is a cross-current along the entrance, vessels need lateral space in passing from the current into still waters, and 3). open space behind the breakwaterheads helps the diffraction effects and thus reduces wave penetration.
It is seen from *Figure 4-5* that the net breakwaterlength in b). is not increased compared with a), while the open lay-out also provides a lot more space inside the port for future development.

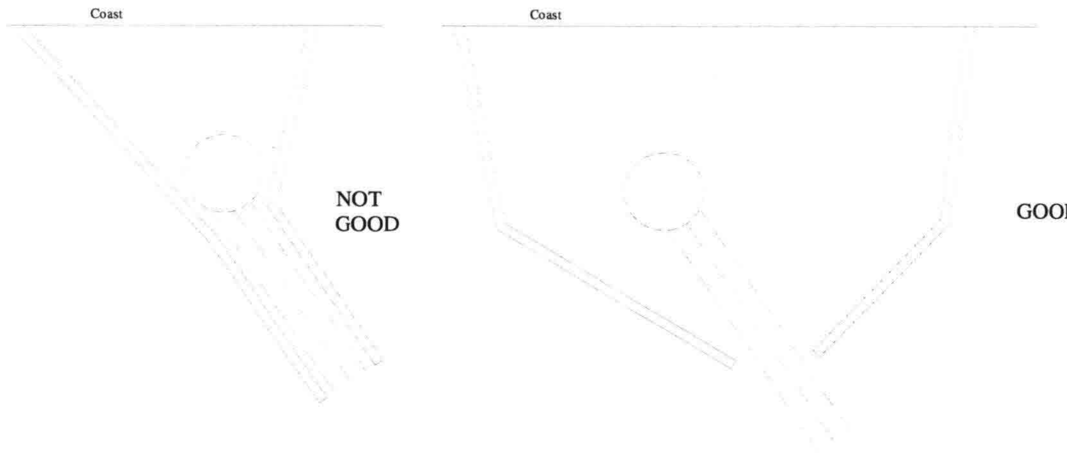


Figure 4-5: Breakwater alignment

(iv) Bends in the approach channel close to the port entrance or immediately behind it should be avoided: the vessel needs a straight course without the complications of steering through a bend.

(v) Then there are morphological effects to be taken into account. Without going into detail in this section, two basic principles are mentioned:

a. Along the alluvial coastline the littoral transport is present inside the breaker zone. Breakwaters should therefore reach to the corresponding waterdepth in order to avoid this sediment transport to deposit inside the approach channel. The breaker zone extends however with increasing deep water wave height ($d_b \sim 1.6 \bullet H_s$), and the question must be answered for what frequency of storms the breakwaters have to cater in this respect. A compromise is sought between very low frequency of occurrence leading to long breakwaters but minimum siltation, and a high frequency with short breakwaters and much maintenance dredging. As a first approximation the annual wave condition is often used, but in a design optimisation the minimum of capital construction cost + maintenance/dredging cost has to be determined.

b. When littoral transport occurs in both directions along the coast, breakwaters are also needed on both sides. Only when the wave climate is such that the littoral transport is unidirectional one breakwater may suffice.

(vi) Regarding the location of berths and terminals some general safety aspects can be formulated:

a. There should be no berths or hard structures in the stopping line of the vessels, also not beyond the turning circle. In case a stopping manoeuvre fails the vessel should be able to run aground in a soft bank.

b. Liquid bulk terminals preferable have to be located downwind from other port activities and certainly from urban centres. In case of an accident the negative effects (smoke, toxic gases or a vapour cloud) will thus have less impact.

4.4.4 Evaluation techniques

As mentioned before evaluation of lay-out alternatives takes place at different stages of the planning process: first screening of rough sketch lay-outs, followed by evaluation of the most promising alternatives, and finally an analysis of the economic and financial feasibility of the selected masterplan lay-out. The evaluation techniques become more elaborate in subsequent stages. A basic problem is that the criteria for evaluation are very different in nature and importance, varying from nautical safety to noise nuisance. There are quantitative and qualitative criteria which must be reduced to a common denominator for the purpose of evaluation.

The first screening remains often qualitative, but the selection of the masterplan lay-out requires a formal procedure which must be transparent and (as far as possible) objective. Two techniques are mentioned here:

- numerical evaluation
- monetary evaluation

(i) Numerical evaluation

The most common type of numerical evaluation is the multi-criteria analysis (MCA). The principle is that an object is evaluated with respect to a number of criteria, which may differ in importance. Such differences are expressed by giving "weights" to the criteria, by which the evaluation marks are multiplied.

A framework can be made of primary, secondary and tertiary criteria, each of which is given its own weight. The primary criteria can be set by a panel, representing all the disciplines involved, using an iterative process. The secondary and tertiary criteria which are sub-divisions of the primary ones, can be set by representatives of the various disciplines in question. In the MCA all alternative solutions are given values for all criteria. Multiplication of the valuation marks by the weight and addition eventually produce an ultimate quantitative appreciation.

On the one hand, the MCA method has the disadvantage of a still rather great subjectivity in setting weights. On the other hand, the entire calculation can easily be repeated with different weights, and the sensitivity of the outcome for this determined.

primary criteria	weight	secondary criteria	weight	tertiary criteria	weight
port technology	22	nautical & hydr.	10	approach route	1
				stopping length	3
				manoeuvring space	1
				nautical safety	2
				wave penetration	2
		flexibility	5	extension poss.	3
				re-allocation berths	2
		construction aspects	7	building time	3
				phasing poss.	4
spatial planning	5	flexibility	5		
				etc.	
env. aspects	8	aquatic env.	2		
		coastal morphology	2		
		noise	2		
		dust	2		
costs	16	capital costs	10		
		maintenance costs	6		

Box 4- 2: Example of an MCA score table

In the example above the weight of primary criterium is the sum of the weights of the corresponding secondary criteria, which in turn are summed up from the tertiary ones. This is not necessary however.

(ii) *Monetary evaluation*

In this type of evaluation all criteria of the various alternative projects are expressed in terms of money.
The advantage is that the marking is less subjective than with the numerical system. Giving a weight to the factor "costs" is no longer under discussion.
The disadvantage is that it is, generally, much more time-consuming and far more difficult, partly because of the necessity to express quantitative differences in money via risk analysis (for instance, the difference in safety of approach channels).
A reformulation of the evaluation criteria is necessary, for instance:

- Nautical safety: risk of collisions/running around/consequences for the ship and, possibly, for the local environment/resulting costs (it is necessary, for instance, to know or to estimate what percentage of collisions/strandings will result in the puncturing of one or more cargo holds).
- The safety of cargo handling & storage and industry with respect to the risk to the installation itself and to the local environment.
- Operational costs: a part of the costs will be about equal for all alternatives (for instance, port management). Differences arise from e.g. limitation of accessibility of

the port as a result of wind, waves, visibility, time lost at the berths because of wave movements and wind.

- Physical planning: extra costs that must be made in the region as a direct result of the development of the port in order to fit it into the physical planning, possible costs of hypothetical substitutes for specific facilities that will be lost ('shadow prices').
- Space and flexibility: the likelihood that it will not be possible to realise certain required developments of the port within a certain period. The resulting costs of having them realised elsewhere.
- Building and maintenance costs of the port.
- Etc, etc.

The costs of alternative projects should be compared on an annual basis:

- annual capital and maintenance costs
- annual operational costs
- the probability, on an annual basis, of certain calamities and their financial consequences
- etc.

The costs should be discounted, i.e. the present-day value be determined:

$$K_c = \sum_{t=1}^{t=n} \frac{K_t}{(1+i)^t} \qquad (4\text{-}1)$$

in which:

i	is the rate of discount (usually true interest, that is the actual interest minus the inflation component)
K_t	is the annual costs in the year t
K_c	is the present-day value

4.4.5 Project optimisation

Following evaluation of alternative locations and lay-outs and the selection of the most suitable one, the optimisation of the project can take place. This means, inter alia, the determination of and the final decision on the principal forms and dimensions of the port: access, entrance, primary manoeuvring space, number of service points (berths or quay length), terminal areas, etc. The tools and exercises used include computations, hydraulic model studies, navigation simulator studies, operation simulation models, with as an ultimate target the minimisation of costs. The tools are briefly described here, but are treated in detail in Chapter 5 and in the lecture notes on Service Systems.

(i) *hydraulic model studies, physical or mathematical*
Breakwater alignment and wave penetration, current patterns, sediment transport, siltation and erosion, breakwater stability and, possibly, navigational studies with the help of models.

(ii) *Navigation simulation studies*
Adapting the lay-out of the port and its approaches to optimise the nautical safety. Various systems exist, from complete fast-time computer models, including a programmed navigator (quick, cheap, but with limited possibilities) to full-scale real-time bridge simulators (with human navigators, ship's bridge, outside image, radar display, etc.)

Generally speaking, navigation simulator studies are more suited for a study of the nautical aspects than hydraulic model tests because they give a better reproduction of the steering effects. These usually play a greater role than the effects of the local physical surroundings, as sea bottom and channel changes (which in their turn can be more faithfully reproduced in a physical model). In most cases, both arrival and departure manoeuvres will have to be investigated. The departure manoeuvre mainly to verify if there is sufficient rudder control on leaving the shelter of the port under extreme current, wind and wave conditions.

In all cases, sufficient simulator runs will have to be made to obtain statistically reliable picture of deviations from the channel axis and of stopping distances actually used.

The ultimate object is the verification and optimisation of the form and dimensions of the port with respect to the approach channel, entrance and manoeuvring areas by means of risk analysis. Also to study e.g. the possibility of a reduction of the channel width as a result of the introduction of advanced aids to navigation and/or VTS systems.

(iii) *Computations*
E.g. with regard to the optimum depth of the port's approaches, taking into account 'tidal windows' for the maximum size vessels, the wave climate and vessel response, and a certain accepted probability of touching channel bottom.

(iv) *Logistic simulation models*
Study of the effect on ship waiting times of alterations to, inter alia:

- the number of berths or length of quay in the port
- the vertical tide windows
- the horizontal tide windows
- one/two-way traffic
- various services: tugboats, pilotage, etc.
- priority rules, safety procedures

The ultimate aim of this investigation is to produce the data needed to arrive at minimisation of the overall port costs per ton of cargo.

4.4.6 Economic and financial analysis

The economic and financial feasibility analysis of a (port) project is an essential element in the decision making process, either within the scope of a masterplan, or for an individual (medium-term) project. In the preparation of a project, for which external financing is sought (from International Financing Institutes such as World Bank, Asian Development Bank etc. and/or from commercial banks) these analyses are a prerequisite. But also for projects funded by a government or a port authority it should be a necessary check in order to avoid poor public investments.

The economic analysis is aimed at determining the Benefit/Cost ratio or the Economic Internal Rate of Return (EIRR) of the project, both being indicators of the return on investment in economic terms. Financial analysis is made to investigate the income and cashflow of the project throughout a predetermined period (often 25-30 years), taking into account the planned phasing of development. Sometimes the economic analysis is made for several alternatives in the evaluation phase, in addition or in lieu of MCA or monetary evaluation methods. In most cases however the economic and financial analyses are made for the selected alternative only and lead to optimisation thereof. It happens that the project, after having gone through the different stages of technical and nautical improvements, is found to have insufficient or even negative rate of return on investment, in which case drastic cost (and scope) reductions has to be found. This is often difficult and it is much better to make preliminary economic analyses in the early stages of the project to avoid such surprises.

The economic and financial analyses are specialist work to be done by econometrists. The basic principles however are outlined below.

(i) Economic analysis

All economic benefits and costs of the project are determined, which means that these are expressed in monetary value, converted to one reference year (often the year in which the analysis is made). An assumption is made of the inflation rate in the later years and benefit and costs made after the reference year are converted for this inflation.

Benefits of the port project may comprise ground rent, lease fees for terminals, income from pilot-, tug- and dockage charges. A very important benefit is the spin-off for the national economy, which is often difficult to ascertain however. The costs comprise capital investment costs and operation/maintenance costs. Risks and safety can be accounted for as explained in Section 4.4.4 (ii).

The economic return on investment is the difference of benefits and costs. When this difference is discounted (see again Section 4.4.4 (ii)) and summed up over the project period the Net Present Value is obtained (NPV). The EIRR now is the discounting rate, whereby the NPV becomes zero. As a guideline for projects in developing countries the Financing Institutions demand an EIRR which exceeds the commercial interest rate. Commercial projects in the developed countries often require an EIRR of 15-20 %. On the other hand there are (too) many public port projects for which the EIRR (if calculated at all) fails to satisfy the IFI criterium.

(ii) *Financial analysis*
Finally some words about the financial analysis. This is in fact a tabulation of expenditures (capital costs, operation and maintenance costs) and revenues per year, throughout the period over which the project is evaluated. The capital costs are shown in the years they are scheduled to be made, operation and maintenance costs, and revenues come into the picture as soon as terminals are ready to receive the cargo. The results can be expressed in terms of income or cashflow. In the latter case the capital costs are used (like in the economic analysis), in the former case these have been converted into depreciation costs on an annual basis.

4.5. General observations

a. The importance of flexibility and space in port planning is often underestimated. Forecasts regarding the quantity and types of the goods traffic and the related prognoses regarding the development of shipping are often only partially reflected in the real developments. This is caused by unforeseen events in the world economy, changes in the areas of production or consumption, a shift in the type of goods - for instance, from raw materials to semi-manufactured articles -, etc. Regular and, sometimes, radical adaptations of the port masterplan must, therefore, be possible. In consequence, the masterplan is not a static document, as mentioned before.
b. Frequent obstacles in port planning are:
   - Unsatisfactory basic data: outdated, insufficient or unreliable
   - Too much rigidity in the extrapolation of historical developments
   - Shortcomings in the systems approach and the planning methodology
   - Lack of insight and experience of local port authorities; insufficient understanding of the time and costs involved in in-depth studies
   - No adjustment to regional or national port developments
   - Too much attention to infrastructural provisions and an underestimation of the importance of operational and organisational aspects
   - Relatively too much accent on the port activities on the sea-side and too little on the land-side (more parts are 'ailing' on the land-side than on the sea-side, either in the port itself or in its hinterland connections)
   - Unfamiliarity with or underestimation of the demands that the reception of big, difficult-to-manoeuvre ships make on the infrastructure of the port, i.e. underestimation of the nautical requirements
   - Unfamiliarity with safety aspects associated with the handling of dangerous cargoes

Throughout the world, big mistakes have been and are still being made for many of the above reasons. In the past 10 to 15 years alone, hundreds of millions of dollars have been invested in new ports that, after completion, turned out to be either partly or completely non-functional.

c). Specific problems in many countries in the developing world are:

- Management
  The port management is often inefficient, too much of the decision-making process rests with the central government and too little with local administrators.
- Operations
  –Cargo handling and goods storage are frequently left in the hands of the port authority and this usually results in low productivity
  –Long transit times of goods in the ports
  –Inefficient organisation of storage facilities, leading to the necessity of overdimensioning of storage yards
- Customs
  Often an obstacle in the administrative goods handling. This contributes to the long periods that the goods remain in the port.
- Port congestion
  More often caused by organisational and operational shortcomings than by deficiencies in the infrastructure. It should also be borne in mind that organisational improvements are considerably cheaper than extensions of the infrastructure.
- Poor maintenance and lack of spares
  Necessitates port structures and equipment that require a minimum of maintenance and, occasionally, the purchase of an excess of cargo handling equipment.
- Specialisation in goods handling
  Often trying to catch up with developments in the West and according to imaginary needs. Specialisation should not be a forced process as drastic changes demand adaptations over a long period. Equipment should not be unnecessarily sophisticated and comply with local operational and maintenance skills.

  This implies that a lot of improvement can be achieved in existing ports, before starting to build new facilities. This should be taken into account in the early stages of masterplanning: how can the operations be improved, in terms of better management, simplified procedures, introduction of regular maintenance programmes etc.

4.6. References

UNCTAD, Handbook for planners in developing countries, April 1985.

Chapter 5. Planning and Design of the Water Areas

5.1. INTRODUCTION 5-2

5.2. SHIP MANOEUVRING AND HYDRODYNAMIC BEHAVIOUR 5-3

5.2.1 Basic manoeuvrability 5-3
5.2.2 Ship hydrodynamics 5-7

5.3. APPROACH CHANNELS 5-19

5.3.1 Alignment 5-19
5.3.2 Channel width 5-22
5.3.3 Channel depth 5-23

5.4. MANOEUVRING AREAS WITHIN THE PORT 5-29

5.5. PORT BASINS AND BERTH AREAS 5-32

5.5.1 Nautical aspects 5-32
5.5.2 Wave agitation 5-33
5.5.3 Harbour basin resonance 5-36

5.6. MORPHOLOGICAL ASPECTS 5-38

5.6.1 Littoral transport 5-38
5.6.2 Siltation of approach channels 5-40
5.6.3 Sedimentation inside the port 5-41

5.7. REFERENCES 5-42

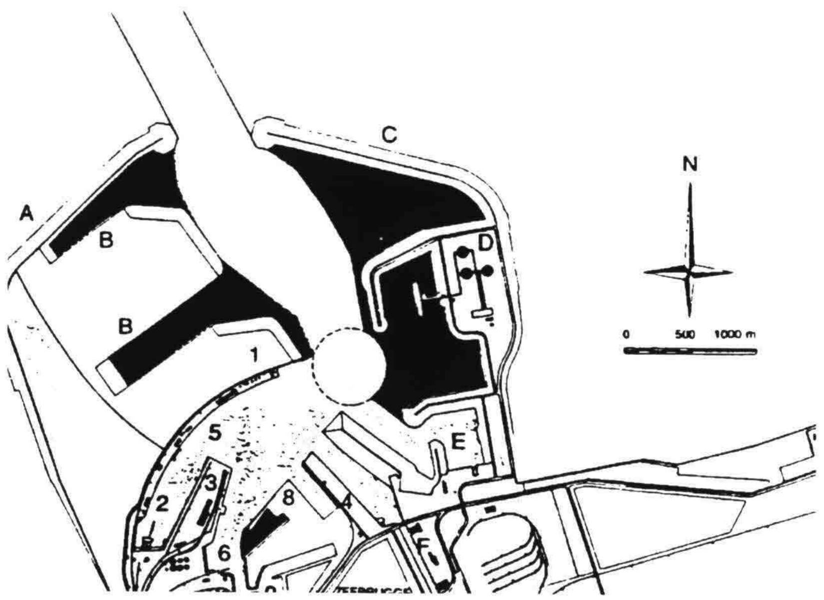
Chapter 5. Planning and Design of the Water Areas

5.1. Introduction

As explained in the previous chapter the lay-out of a port is to a large extent determined by its wet surface. This includes the orientation and alignment of the approach channel, the manoeuvring areas within breakwaters (if these are needed), turning circle, and port basins for the actual berths. These dimensions are of great importance, firstly because they constitute a major part of the overall investment, secondly because they are difficult to modify once the port has been built.

The design aspects are mostly centred on the ship: its manoeuvring behaviour under influence of wind, currents and waves, its vertical motions in waves, the horizontal and vertical motions at berth. We therefore have to understand somewhat more about the manoeuvring behaviour and hydrodynamic responses of the ship. Another aspect to be taken into account is sediment transport. What is the effect of the port lay-out on the natural process, and hence on the coast. And how can siltation inside the port and approach channel be minimised by the lay-out.

Finally environmental and safety aspects may play a role in the lay-out. In the design of new land for terminals within the Port of Los Angeles an area had to be allocated for an underwater habitat to replace an existing area. And in the planning for Maasvlakte 2 ample surface area needs to be created for nature development and recreation. Safety considerations lead in some cases to additional requirements, such as the LNG import jetty in Zeebrugge, which has its own basin, well isolated from other port areas.



A: Western Breakwater
B: Harbour basins planned
C: Eastern Breakwater
D: LNG-terminal

Figure 5- 1: The harbour of Zeebrugge

5.2. Ship manoeuvring and hydrodynamic behaviour

5.2.1 Basic manoeuvrability

Considering the factors which influence a ship's manoeuvring behaviour, the basic properties belonging to the vessel itself are called here vessel manoeuvring characteristics. They are determined by the ship's hull shape, its mass, the rudder system and dimensions, the propulsion system and the power. The manoeuvring characteristics are:

(i) the way the ship reacts to the rudder and to changes in propeller revolutions
(ii) turning ability
(iii) stopping ability

(i) Rudder efficiency

Turning the rudder creates a moment on the ship, when sailing. The effect of the propeller flow on the rudder increases this moment. Big tankers and bulk carriers commonly have a relatively small L/B (length/beam) ratio, in the range of 6 to 7, and a large block coefficient, in the range of 0.75 to 0.85. Together with the B/D (beam/draft) ratio, the ∇/p ratio (mass/propulsive power) and the rudder area, these factors mainly determine the manoeuvring characteristics. A small B/D ratio and a large block coefficient result in a relatively long time to react to an applied rudder angle; but, once the ship is rotating, it has a good turning ability.

It is clear that these characteristics are important for the manoeuvring ability of the vessel in a channel. However, equally essential is the way the human operator on the bridge uses these manoeuvring characteristics in steering the vessel.

In confined water, the time to reach ship's response to an applied rudder angle can be favourably influenced by a simultaneous rudder and propeller action, the latter only during a short time (a 'burst') to avoid a noticeable increase in ship speed. The effect of this manoeuvre increases at decreasing speed.

In general, course stability indicates the extent to which the ship reacts on external disturbances. A ship is called to be dynamically stable when the moment exerted by the rudder, counteracts the movement of the ship caused by the initial disturbance. After moment and forces become zero again, the ship follows its course. This does not occur with a dynamically unstable ship. The moment then strengthens the initial rotation. The ship continues turning, even after forces and moment reach a new state of equilibrium. In shallow water, the course stability tends to be better than in deep water.

It is noted that even without external disturbances the ship's real course shows a sinusoidal movement instead of the intended straight course. This is due to the speed of response of the helmsman and that of the ship in reacting to the rudder. The total width of the manoeuvring lane exceeds therefore the beam width of the vessel (see *Figure 5- 2*). The extent of this depends again on the ship's manoeuvrability, the ability of the helmsman, the visual information available and the overall visibility. This point comes back in Section 5.3.2.

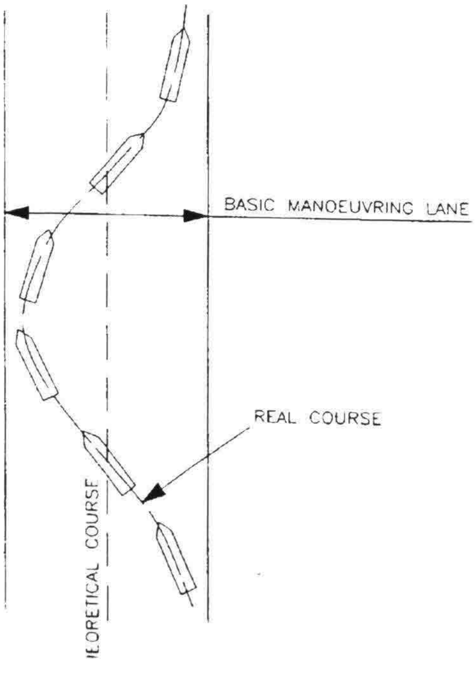


Figure 5- 2: Lane width of ship

(ii) Turning manoeuvre

The turning diameter in deep water at service speed and a rudder angle of 35°, varies considerably between types of ships and even between individual ships of the same category. Nevertheless, there are clear tendencies. Many container ships have a poor manoeuvring capability, particularly those container ships built, or originally built, to operate at high service speeds of 26 or 27 kn. For these ships, turning diameters are in the order of 6 to 8 L. Turning diameters for large oil and dry bulk carriers at service speeds in the 15 to 17 kn range, are in the order of 3 to 4 L, some even less than 3 L. LNG carriers are mostly in the 2 to 2.5 L range, which would also apply to a great number of conventional general cargo and multi-purpose vessels.

Turning capability at low speeds is often improved by the use of twin propeller arrangement or bow thrusters, or a combination of the two. These measures, however, do not constitute a universal remedy against inadequate manoeuvring capability. Many container ships, for instance, are equipped with twin propellers, but, due to the shape of the hull, the distance between the propellers is so small compared to the length of the vessel, that the additional turning moment that can be exerted, is virtually ineffective.

Bow thrusters are useful for berthing and unberthing operations, but at speeds of 4 to 5 kn or over, they loose much of their effect.

(iii) Stopping distance

The stopping distance is effected by:

- the size of the vessel and the relation propulsive power - displacement (= mass)
- the speed at which the vessel enters the port
- the stopping procedure

As concerns size, the ratio propulsive power - mass of the vessel is inversely proportional to ship size. In consequence, the power available for decelerating (or accelerating) decreases in a relative sense with increasing ship size (see *Figure 5- 3*). Also the astern power as a fraction of the installed power varies from one system to another, and may be as low as 50% for a vessel with steam turbine and fixed-blade propeller to close to 100% for a vessel with diesel engine and controllable pitch propeller.

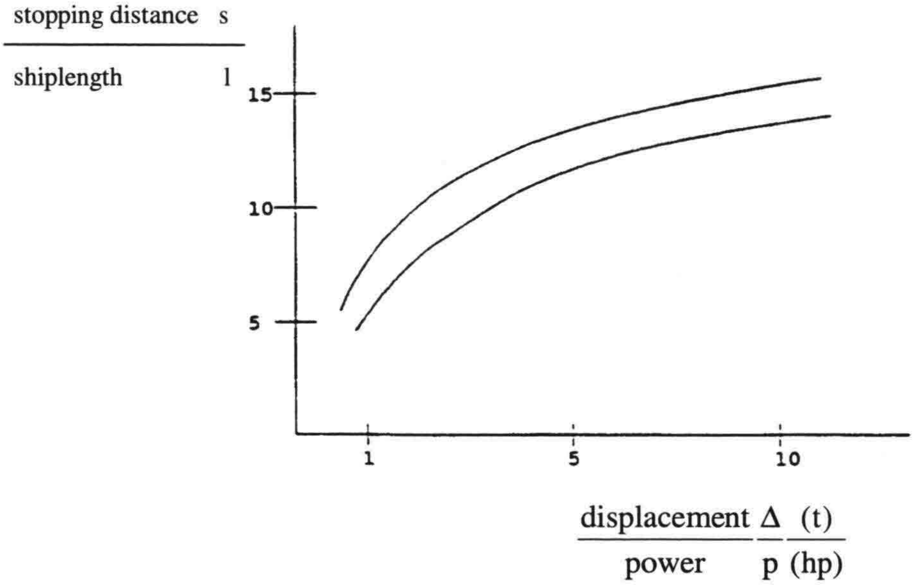


Figure 5- 3: Stopping distance of ships

This means that the distance 's', required for stopping from a given speed, expressed as a function of the ship's own length 'L', varies considerably and increases with increasing ship size. For example, a 10,000 dwt general cargo vessel is able to stop from a cruising speed of 16 knots in a minimum distance of about 5 to 7 L, say 900 m ('crash stop'), whilst a 200,000 dwt bulk carrier or tanker requires some 14 to 18 L, say 4800 m (starting from a low speed, say 5 kn, the stopping distances are obviously smaller; for a big tanker ≤ 3L, for a general cargo ship ≤L).

In the seventies a number of so-called 'fuel economic' bulk carriers and tankers have come into operation with very low propulsive power (for a 150,000 dwt bulk carrier, the

∇/p may be about 13 and cruising speed about 12 kn, against a normal ∇/p of about 8 and cruising speed of 15 kn for this size of vessel). Moreover, their engines cannot run at low rpm's; 'dead slow ahead' may be in the order of 6 kn. In consequence, to sail at low speeds they have to regularly stop or reverse their engine, which makes them quite difficult to manoeuvre in the confined space of a port.

With regard to the port entry speed, it will be obvious that the higher the speed, the bigger the stopping distance required. The minimum speed at which a vessel still has sufficient rudder control to make course corrections, is about 3 to 4 kn. However, waves and, particularly, crosscurrents in front of the port entrance may force a ship to maintain a much higher speed until it has arrived within the shelter of the breakwaters. This will be further discussed in Section 5.4.

A degree of course control can be maintained by giving periodically brief ahead propeller thrusts with the rudder set to give the desired course corrections. This, however, unavoidably leads to greater stopping distances.

Finally, as concerns the way of stopping, different procedures are possible. The two extremes are the crash stop on the one hand, and the fully controlled stop on the other. In the crash stop, the engines are set at full astern. It gives a minimum stopping distance, but, due to turbulent flow around the rudder, the vessel has no course control whatsoever. It turns either to starboard or to portside as shown in *Figure 5- 4*.

number		A2	A3	A4	A5	A6	A7	A8	A9	J1	J2	J3
rudder	deg.	0	0	0	0	0	0	0	0	30	30	30
speed	kt	9	4.9	14.8	4.2	15	2.4	13	5	16.2	11	14.4
revs		55.2	31.6	85.4	31	83	33.4	77.1	32	85.8	63.4	84
ast. revs		42	44.7	42.5	48.8	47.5	46.7	48.3	48.3	42.9	47.7	47.6
h/T		∞	∞	2.1	2.2	1.7	1.5	1.3	1.4	∞	∞	1.7

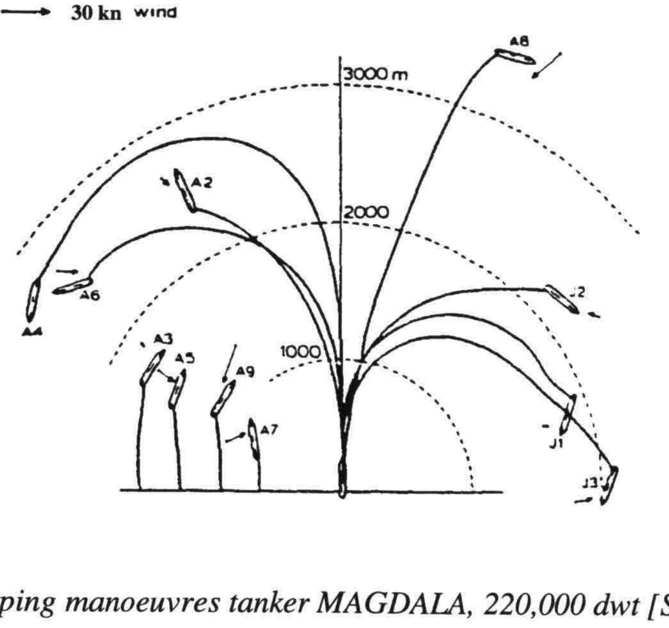


Figure 5- 4: Stopping manoeuvres tanker MAGDALA, 220,000 dwt [Source IAHP 1981]

5.2.2 Ship hydrodynamics

A basic understanding of the forces exerted by waves, currents and wind and the responses of the ship is necessary in port planning and design for the following reasons. Firstly the vertical motions of a ship in waves have to be taken into account in the design depth of approach channel, turning circle and other manoeuvring areas, and at the berth. Secondly the design of the mooring system at the berth of offshore jetty aims for restraining the vessel in its natural movements and therefore the ship motions and forces in mooring lines and fenders have to be determined.

(i) Sailing ships

A free floating vessel has six modes of freedom of motion: three lateral and three rotary. In consequence, a ship exposed to waves may respond in six different modes, or in any combination thereof (*Figure 5- 5*).

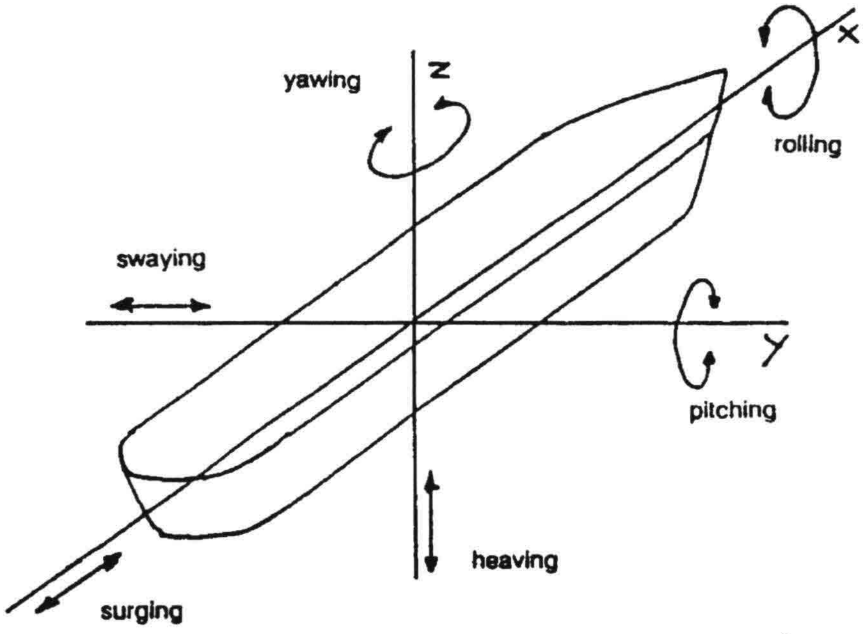


Figure 5- 5: Ship motions

In the vertical modes, a ship has its own natural frequency of oscillation. If excitation occurs in a particular mode in a frequency near the ship's natural frequency in that mode, resonance will result. Whether this resonance is important, depends on the degree of damping. Of the three modes - rolling, pitching and heaving -, the latter two are rather damped motions, but not so the roll motion which is quite resonance-sensitive. A ship sailing in a strong beam sea with a wave period near the ship's natural roll period, may develop very large roll angles in which it loses rudder control and may even capsize.

In deep water, the natural roll period is usually between 10 s and 17 s for merchant-type of ships. In wind-generated waves with (common) wave periods between 6 s and 10 s, roll motions need not be of great concern. However, the apparent incident wave period T_a will increase when the waves approach from astern (and decrease when the ship is sailing against the waves) and the ship has forward speed, and hence may become critical.

In order to determine the vertical oscillating motions of an arbitrary point at the ship's hull, the cumulative effects of heave, pitch and roll have to be considered. The system can be described mathematically as a mass-spring system with 6 degrees of freedom. On the free floating vessel the hydrostatic forces act as springs: if a ship dives with its nose into the water the excess buoyancy drives it back. In case of a moored vessel additional springs are found in the mooring lines and fenders.

The analysis of ship motions was for a long period of time done in model tests. Only in the seventies numerical models became sufficiently reliable to take over the role of physical models. The first computer models were linear. The response of the ship was calculated for a number of distinctive wave periods (or frequencies). The ratio of motion amplitude and wave amplitude for a particular frequency is the Response-Amplitude factor. Over the entire range of wave frequencies (the wave spectrum) the Response-Amplitude factors constitute a transfer function, the Response-Amplitude Operator (RAO). When we have the RAO function for a specific ship for different wave directions, we can calculate all motions individually for a give wave spectrum. *Figure 5- 6* is an example of the RAO function for the effect of roll, heave and pitch combined. By multiplying the values of the wave spectrum with $(RAO)^2$ the motion spectrum is obtained. Although the wave spectrum has a peak at about 0.14 Hz or T = 7 s, there is virtually no ship response because that frequency is far higher than the natural frequency of the ship motions. The low frequency peak of the wave spectrum, at 0.06 Hz or 16-17 s does give resonance, even though the RAO is not at its highest value. It is clear that the amplitude of the resulting ship motion would increase rapidly for wave periods above 17 s.

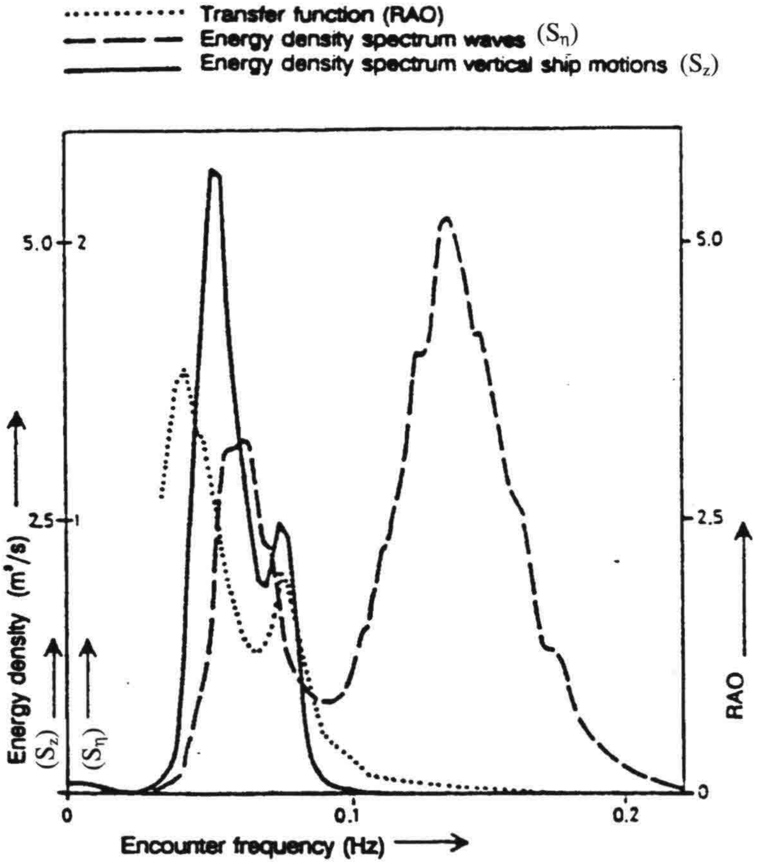


Figure 5- 6: Characteristic ship motions in waves

Finally, attention is drawn to the abscissa of *Figure 5- 6* giving the encounter frequency. This is the apparent wave frequency for the ship sailing at speed V_s. The relation with the actual wave frequency is obtained via the wave celerity as follows:

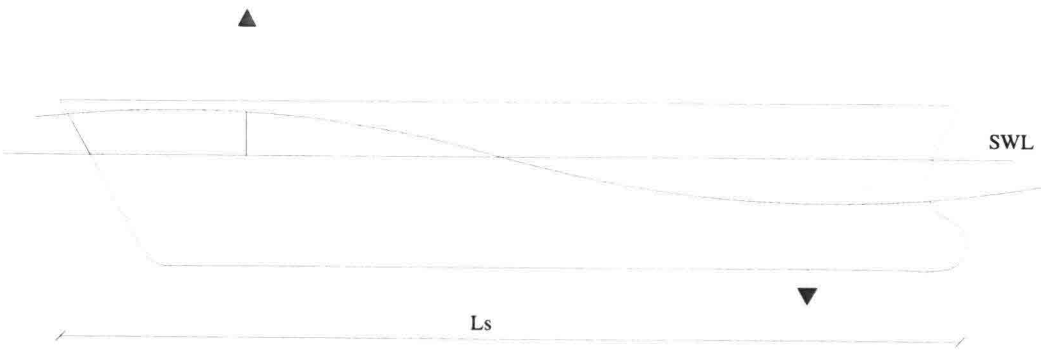
$$\frac{c_a}{f_a} = \frac{c}{f}$$

$$f_a = \frac{c_a}{c} \cdot f = \frac{c \pm V_s}{c} \cdot f \qquad \textit{(5- 1)}$$

For stern waves V_s is subtracted in above equation ($f_a < f$) and for head waves V_s is added. When waves come in under an angle with the ship's course the component of V_s has to be used in Equation 5-1.

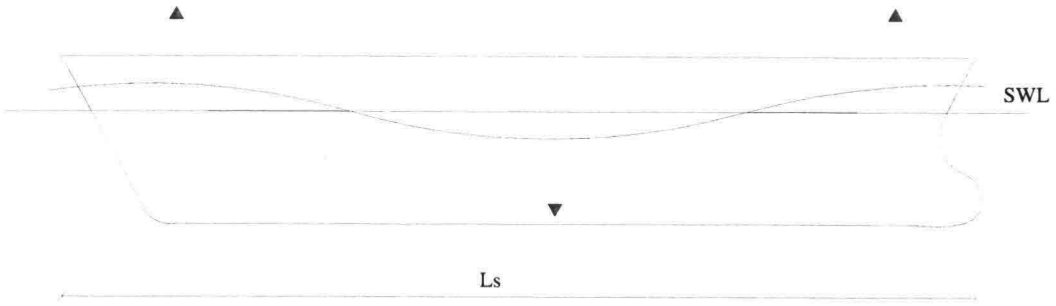
From the above introduction it may be concluded that the wave forces on and the response of a sailing ship in waves can not be easily determined by analytical formulae. Only a first assessment of possible resonance can be obtained from the following reasoning:

a. Pitching
When the ship sails in or against the direction of the waves, the moment exerted by the waves is maximum for $L = 2\ L_s$. The corresponding wave period gives the highest response factor. For a vessel length of 250 m, this means $L = 500$ m and (assuming relatively shallow water) a wave period $T - 30$ s. Such long waves are rare and if they occur have very small amplitude. For wave directions α close to 90° (beam waves) the critical wave length becomes $L = 2\ L_s \cos\alpha$, and hence much shorter wave periods lead to pitching resonance (always in combination with roll, leading to a cork-screw motion of the ship).



b. Rolling
The eigenperiod or natural period of a ship for roll depends on its size, metacentric height and mass distribution. Typical roll periods amount to 12-16 seconds for a 250,000 dwt tanker to 7-8 s for a 10,000 dwt cargo ship. For beam waves with periods close to the natural period resonance will occur. This is why ships try to avoid a course at right angle with the wave direction and why an approach channel perpendicular to the dominant wave direction should be avoided.

c. Heaving
For $L = L_s$ the resultant vertical force of the ship is zero, as shown in the sketch. For the corresponding wave period the heave response is zero. With increasing wave period, and thus wave length, the incident force and the heave response will increase. With decreasing wave period there may initially be a slight increase of response, but then it reduces to zero.



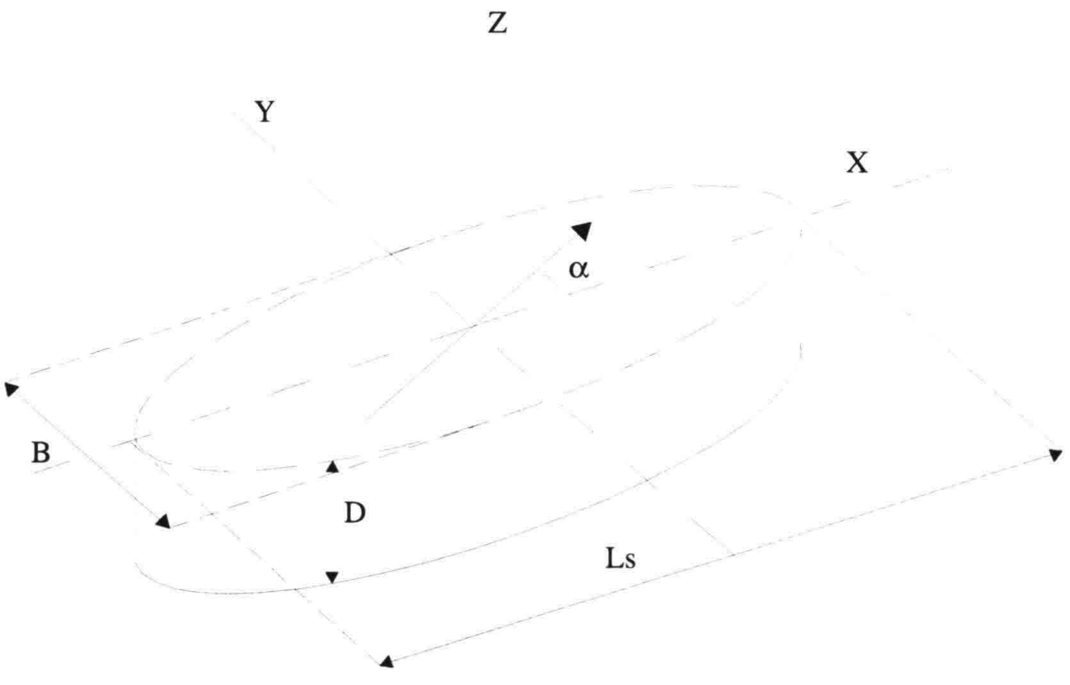
(ii) Moored ships

The assumption of linearity mentioned above holds reasonably well for sailing ships in first-order waves (i.e. the observed waves). In the case of a moored ship it becomes less accurate because the reaction forces of mooring lines and fenders are generally not linear. Moreover the moored ship, in particular a large one, becomes sensitive to so-called second-order or subharmonic wave forces, due to the high resonance periods for surge and yaw of the system. These wave forces include the wave drift force inherent to any random wave field, or additionally may be caused by very long low amplitude waves as occurring in swell propagating over large stretches of ocean or as edge waves along the continental shelf. The distinction between the "bound" and the "free" long waves is difficult to make. An indication is given by the analysis of long period wave recordings for the port of Sines (Vis, 1985). In these cases the ship motion analysis has to be made by means of the non-linear computer models, including all 6 degrees of freedom and the effects of second-order wave forces.

For a first estimate of wave, current and wind forces on a moored ship use is made of empirical formulae based on model tests and simplified computer computations.

a. Wave forces

The wave force in longitudinal (X) and lateral (Y) direction is derived from computer computations of the force on a vertical elliptical cylinder with dimensions L_s, B and D, held fast (i.e. not allowed to move in its mooring lines). It is stressed that this is a strong schematisation of reality, as even the most tight mooring system does allow some movement, especially with the aim to reduce the line forces.



The direction of the incident waves, with wave length L and height H, is α. The expressions for the wave forces read:

$$F_{x,max} = C_{mx} \cdot \frac{\sinh(2\pi\frac{h}{L}) - \sinh(2\pi\frac{h-D}{L})}{\cosh(2\pi\frac{h}{L})} \cdot \frac{\pi \cdot \cos\alpha}{8} \cdot b^2 wH \qquad (5\text{-}2)$$

$$F_{y,max} = C_{my} \cdot \frac{\sinh(2\pi\frac{h}{L}) - \sinh(2\pi\frac{h-D}{L})}{\cosh(2\pi\frac{h}{L})} \cdot \frac{\pi \cdot \sin\alpha}{8} \cdot b^2 wH \qquad (5\text{-}3)$$

with additionally:

C_{mx}, C_{my}	=	virtual mass coefficients	[-]
h	=	waterdepth at the berth location	[m]
D	=	sheltering width in the wave direction	[m]
	=	$B + (L_s\text{-}B) \sin \alpha$	
w	=	specific weight of seawater (= 10.25 kN/m^3)	

The coefficients C_{mx} and C_{my} have been determined for various wave conditions and ship sizes and are presented in dimensionless graphs, such as *Figure 5-7* (Goda, 1972, Proceedings 13[th] International Confeence on Coastal Engineering).

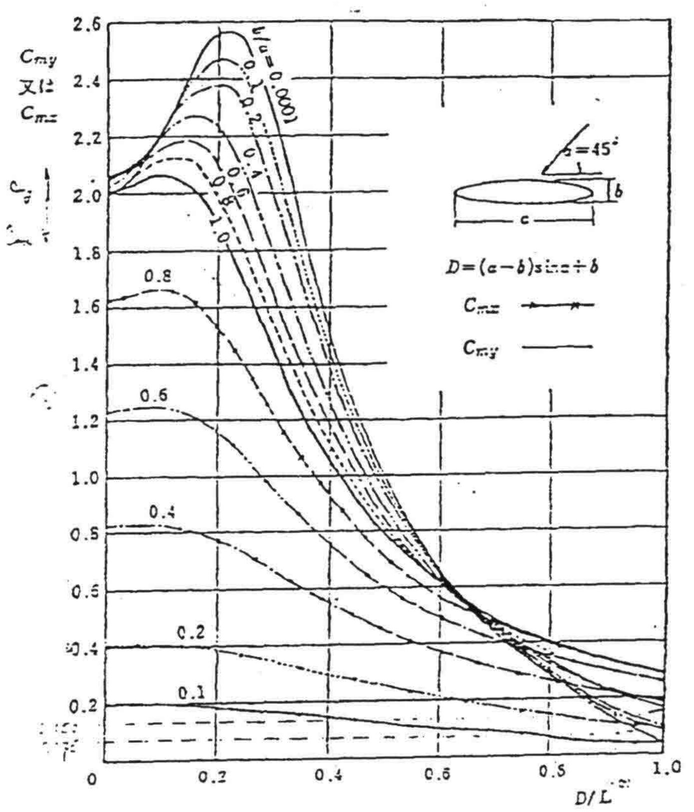


Figure 5- 7: Virtual mass coefficients for $\alpha = 45°$

b. Current forces
The current forces on a ship are proportional to the cross-sectional area underwater and the average current velocity squared. Like the force on a plate with area A in flowing water:

$$F = C \cdot A \cdot v^2$$

The value of C depends on the angle of current direction with the ship axis, on the underkeel clearance (the ratio of ship draught and water depth) and on the shape of the ship's bow: a conventional or a bulbous bow. Due to the asymmetry of the longitudinal section the working line of the lateral force may have a (small) offset from the point amidships, which is taken as the centre of the co-ordinate system:

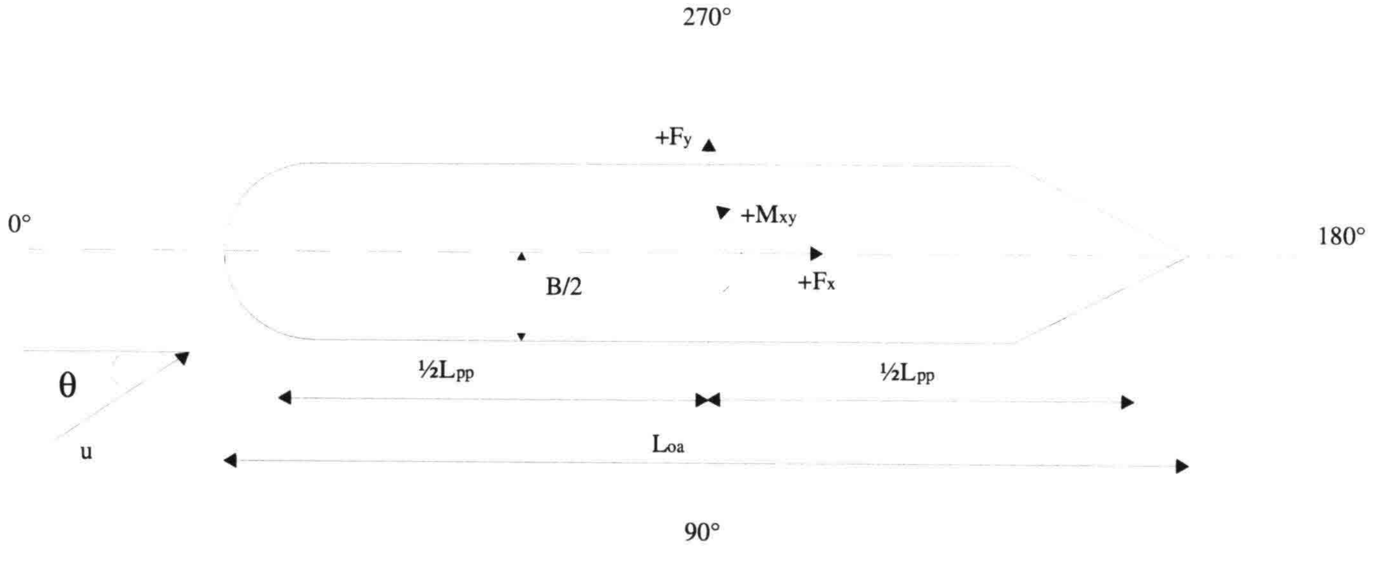


Figure 5- 8: Sign convention and coordinate system

This can be shown as a moment M_{xy} in addition to the lateral force F_y. But another way is to determine the two lateral forces at the fore perpendicular and at the aft perpendicular. This is generally more convenient for hand calculation, because the mooring lines fore and aft have their resultant at those points along the ship length. In the latter case the formulae for F_x, F_{yF} and F_{yA} become:

$$F_{xc} = C_{xc}(\frac{\rho_c}{7600}) \cdot V_c^2 \cdot D \cdot L_{pp} \qquad (5\text{- }4)$$

$$F_{yFc} = C_{yFc}(\frac{\rho_c}{7600}) \cdot V_c^2 \cdot D \cdot L_{pp} \qquad (5\text{- }5)$$

$$F_{yAc} = C_{yAc}(\frac{\rho_c}{7600}) \cdot V_c^2 \cdot D \cdot L_{pp} \qquad (5\text{-}6)$$

(It is noted that in all three equations $D \cdot L_{pp}$ is used, while one would expect $D \cdot B$ in the first one. This done for ease of calculation).

The forces are found in kN. The other parameters are:

C_{xc}	=	longitudinal current force coefficient	[-]
C_{yFc}	=	transverse current force coefficient fore	[-]
C_{yAc}	=	transverse current force coefficient aft	[-]
ρ_c	=	density of sea water (= 1025)	[kg/m^3]
V_c	=	average current velocity over the draught	[kn]
D	=	ship draught (for condition considered)	[m]

Values for the current force coefficient are obtained from graphs based on experimental (model) data. An example of such graphs for a waterdepth to draught ratio of 1.1 is given in *Figure 5- 9*. A complete set of graphs for different loading conditions and waterdepth to draught ratios is found in the OCIMF publication "Prediction of wind and current loads on VLCC's" (1977).

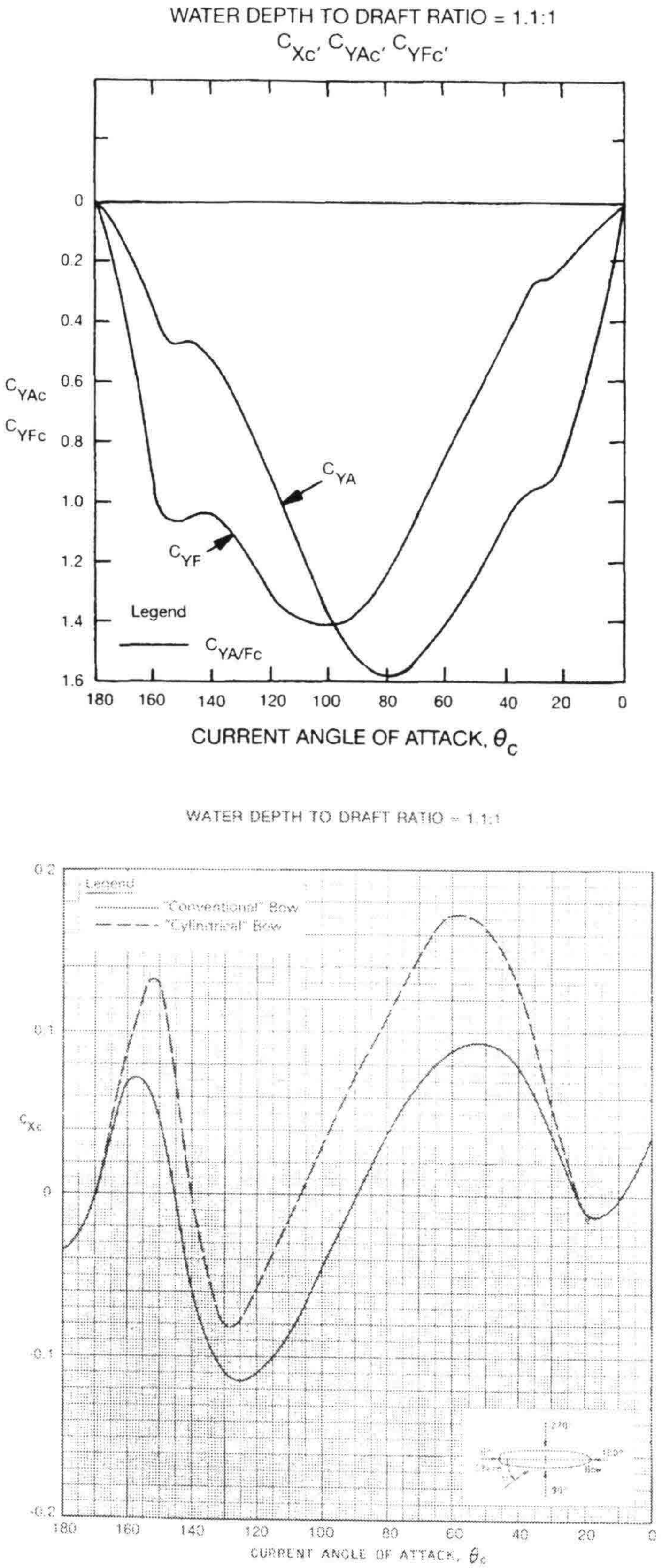


Figure 5- 9: Lateral current force coefficient at the forward and aft perpendiculars - loaded tanker

c. Wind forces

The wind forces are calculated in a similar way, applying the same sign convention as for current forces, using the following equations:

$$F_{xw} = C_{xw} (\frac{\rho_w}{7600}) \cdot V_w^{\ 2} \cdot A_T \qquad (5\text{-}7)$$

$$F_{yFw} = C_{yFw} (\frac{\rho_w}{7600}) \cdot V_w^{\ 2} \cdot A_L \qquad (5\text{-}8)$$

$$F_{yAw} = C_{yAw} (\frac{\rho_w}{7600}) \cdot V_w^{\ 2} \cdot A_L \qquad (5\text{-}9)$$

in which:

F_{xw}	=	longitudinal wind force	[kN]
F_{yFw}	=	lateral wind force fore	[kN]
F_{yAw}	=	lateral wind force aft	[kN]
C_{xw}	=	longitudinal wind force coefficient	[-]
C_{yFw}	=	lateral wind force coefficient fore	[-]
C_{yAw}	=	lateral wind force coefficient aft	[-]
ρ_w	=	density of air (1.223)	[kg/m^3]
V_w	=	wind velocity at 10 m elevation	[kn]
A_T	=	transverse above water area	[m^2]
A_L	=	longitudinal above water area	[m^2]

Again the coefficients are retrieved from graphs which are given in *Figure 5- 10* for C_{xw} and in *Figure 5- 11* for C_{yw}.

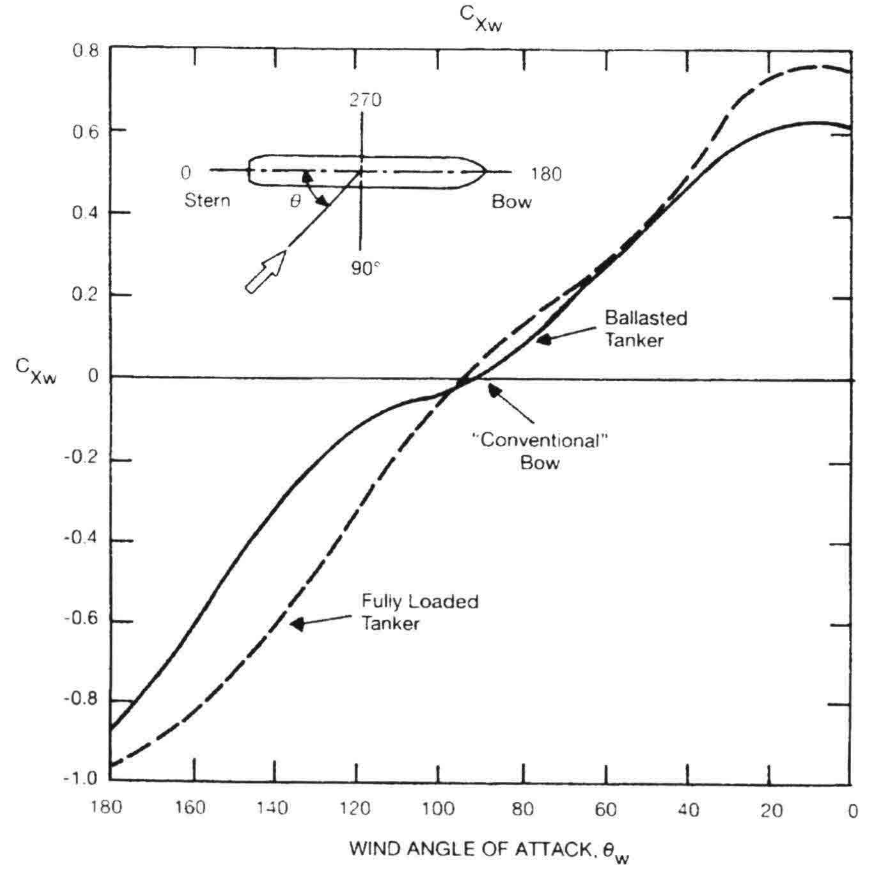


Figure 5- 10: Longitudinal wind force coefficient

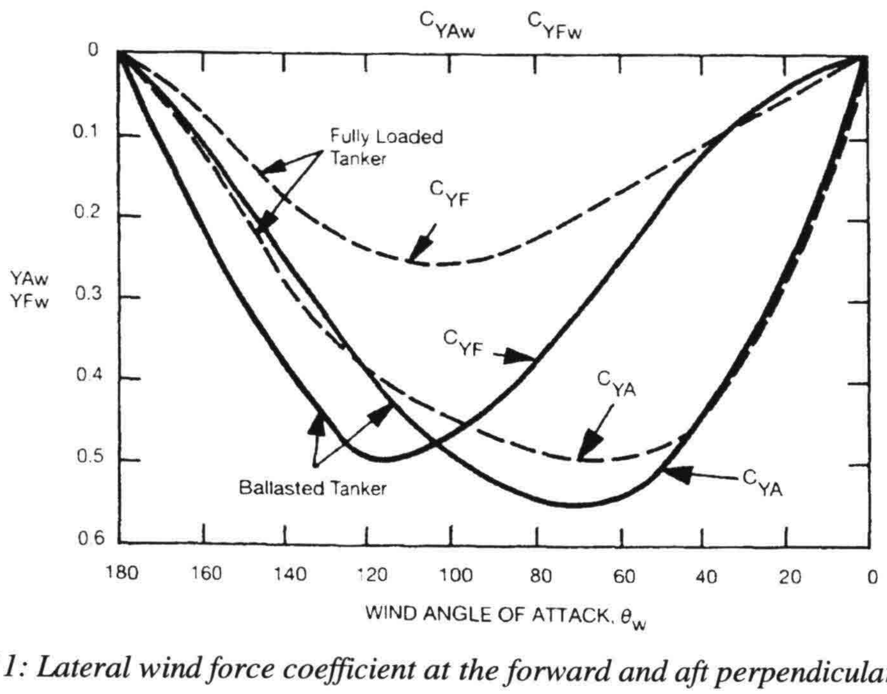


Figure 5- 11: Lateral wind force coefficient at the forward and aft perpendiculars

5.3. Approach channels

The approach channel is defined as the waterway linking the turning circle inside a port (or an open berth at an offshore jetty) with deep water. The three design parameters are alignment, width and depth. Although they are to some extent interdependent, they are treated separately below. The length of the portion between the port entrance and the turning circle is covered in Section 5.4 because it often determines the inner areas to a great extent.

Th International Navigation Association (PIANC) has published a Guide for Design of Approach Channels, which provides a valuable reference (PIANC, 1997). Some of the material here is taken from this report, without further reference.

The gradually increasing detail of the studies employed in the design, as mentioned in Section 4.3, is reflected in the methods proposed by this PIANC report. This distinguishes two stages, Concept Design and Detailed Design. In the process going from masterplanning and/or feasibility study to implementation, there may be even more stages and iterations. The main message of Section 4.3 is repeated: keep the level of detail proportional to the accuracy of input data and output.

5.3.1 Alignment

The following (sometimes conflicting) requirements apply to the alignment of an approach channel:

(i) the shortest possible length taking into account wave, wind and current conditions
(ii) minimum cross-currents and cross-wind
(iii) small angle with dominant wave direction
(iv) minimise 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.

In actual cases the local geometry and bottom conditions play an important role. Hard soil and rock introduce high dredging costs and can better be avoided.

As long as ships have no tug assistance (which is usually the case for the part of the approach channel outside the breakwaters) the radius of bends depends on the manoeuvrability of the design ship. In waterdepths normally encountered in a dredged approach channel (1.3 to 1.1 times the ship's draught) the required radius ranges from a minimum of 4 L_{pp} at a maximum rudder angle of 30° to a maximum of 16 L_{pp} at 10°

rudder angle (see *Figure 5- 12*). A rudder angle of about 20° is a good basis for initial design, leaving some margin of safety.

In the bend the channel width, as determined for the adjacent straight legs, may have to be increased because the swept path increases (see Section 5.3.2).

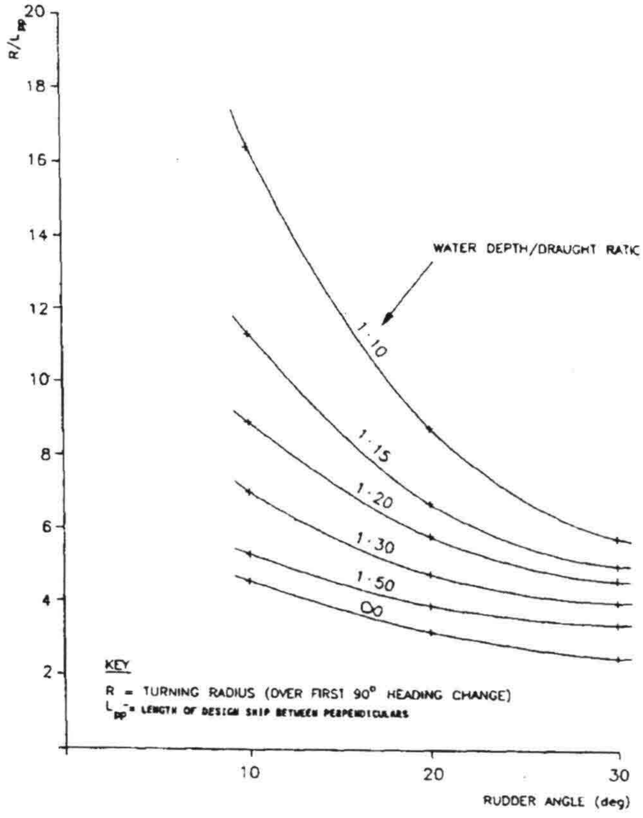


Figure 5- 12: Turning radius as a function of rudder angle and water depth

In very busy ports the approach channel develops into a system of dredged channels for the largest ships (channel bound traffic) and fairways marked by buoys. Both are available for inbound and outbound traffic, and in open sea all are separated by traffic separation zones. *Figure 5- 13* shows the existing system for the Port of Rotterdam.

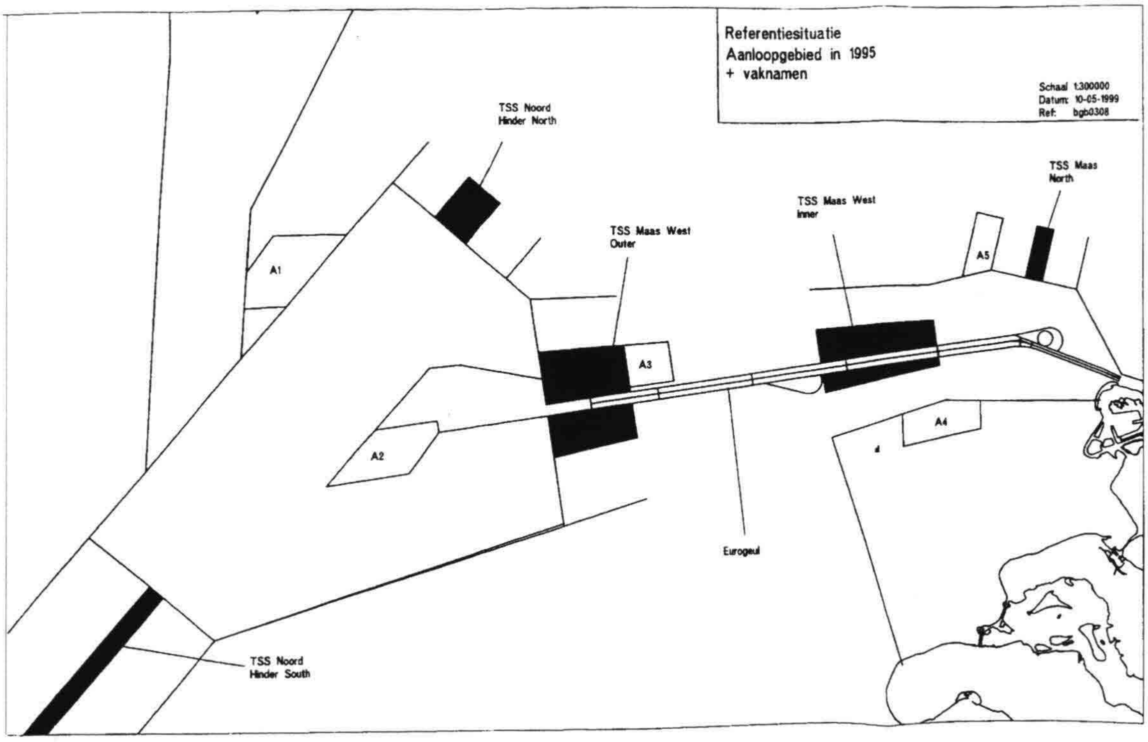


Figure 5- 13: Approach channel Port of Rotterdam

The capacity of channels and fairways needs to be determined by means of a simulation model. Such a model also allows to investigate the numbers of ship encounters within the system and the risk of collision. For a busy port marine traffic simulation models are applied to investigate the measures to reduce the risk, either by introducing more stringent traffic rules or by modifying the lay-out of the system.

While above guidelines are applied for the initial design, this is further checked and refined by Fast Time and Real Time Simulation techniques. FTS is a computermodel of the sailing ship under influence of currents, wind and waves. The ship follows a predefined course (the initial alignment) and offsets from it, by weather or in a bend, are corrected automatically. The result presents the behaviour of a ship controlled by an auto-pilot and this is at the same time the limitation of this method. When used and interpreted by an experienced nautical expert it is useful however, in particular in comparing different alternatives. The final check on alignment and width should be made in the Real Time Simulator (RTS). On the mock-up of a ship bridge, with a realistic outside view (changes as the ship progresses) and all controls and facilities available, a real helmsman steers the ship through the channel. This method approaches reality as good as it is possible and is also often applied in training pilots for their work in adverse conditions.

5.3.2 Channel width

As explained in Section 5.2.2 a sailing ship makes a sinusoidal track and thus covers a 'basic width', which is about 1.5 time the ship's beam. The effects of wind, current and waves require additional width, but so does the lack of visibility. Moreover certain margins are needed, which depend on the type of channel bank and the type of cargo. The PIANC Working Group, mentioned before, has developed a method for concept design, which accounts for all these aspects. For straight sections the channel width is described by the following equation:

$$W = W_{BM} + \sum W_i + 2W_B \qquad (5\text{-}10)$$

For a two-way channel the separation distance between the two lanes (W_D) is added.

The numerical values of each of the parameters are shown in *Table 5-1*, which is a condensation of the information in the PIANC report, but only for moderate manoeuvrability and slow vessel speed.

Only in case of a large tidal range (say in excess of 4 m) the above calculation method is superseded by another consideration, leading to a width of L_s. This because if a ship runs aground on one channel bank, it may turn on the tide and in a narrow channel it may run aground with its stern on the opposite bank. Since channel transit will normally take place around HW, the ship might break at falling tide and block the channel for an extended period.

Regarding the additional width in a bend, it has been mentioned that this depends on rudder angle and water depth / draught ratio. Taking a rudder angle of 20° the swept path of the ship in the bend amounts to 0.35 B for a water depth of 1.25 D. For smaller under keelclearance this additional width further decreases to 0.2 B at d = 1.1 D. It is common practice to apply the additional width only in case the adjoining straight leg has a minimum width W_{BM}. When width additions for wind current, etc. are included, these provide for the required space in the bend.

Table 5- 1: Channel width in straight sections

Width component	Condition	Width (m)
Basic width (W_{BM})	1.25 D < d < 1.5 D	1.6 B
	d < 1.25 D	1.7 B
Additional width (W_i)		
▪ prevailing cross-winds	15 - 33 kn	0.4 B
	33 - 48 kn	0.8 B
▪ prevailing cross-current	0.2 - 0.5 kn	0.2 B
	0.5 - 1.5 kn	0.7 B
	1.5 - 2.0 kn	1.0 B
▪ prevailing long current	1.5 - 3 kn	0.1 B
	> 3 kn	0.2 B
▪ prevailing wave height	1 - 3 m	1.0 B
	> 3 m	2.2 B
▪ aids to navigation	VTS	0
	good	0.1 B
▪ seabed characteristics	soft	0.1 B
	hard	0.2 B
▪ cargo hazard	medium	0.5 B
	high	1.0 B
▪ separation distance (W_P)	8 - 12 kn	1.6 B
	5 - 8 kn	1.2 B
▪ bank clearance (W_B)	sloping edge	0.5 B
	steep, hard embankment	1.0 B

5.3.3 Channel depth

The depth of approach channels depends on a number of factors (see *Figure 5- 14*):

- draught of the "design" ship, i.e. the ship with the largest draught, which may enter the port fully loaded (larger ships must be lightered before they can enter)
- other ship-related factors such as the squat (sinkage due to ship's speed) and trim (unevenness keel due to loading conditions) and the vertical response to waves (see Section 5.2.2)
- waterlevel, mostly related to tidal levels. But very long waves and tsunami waves must be taken into account when they occur frequently.
- channel bottom factors, including the variation in the dredges level and the effects of re-siltation after maintenance dredging.

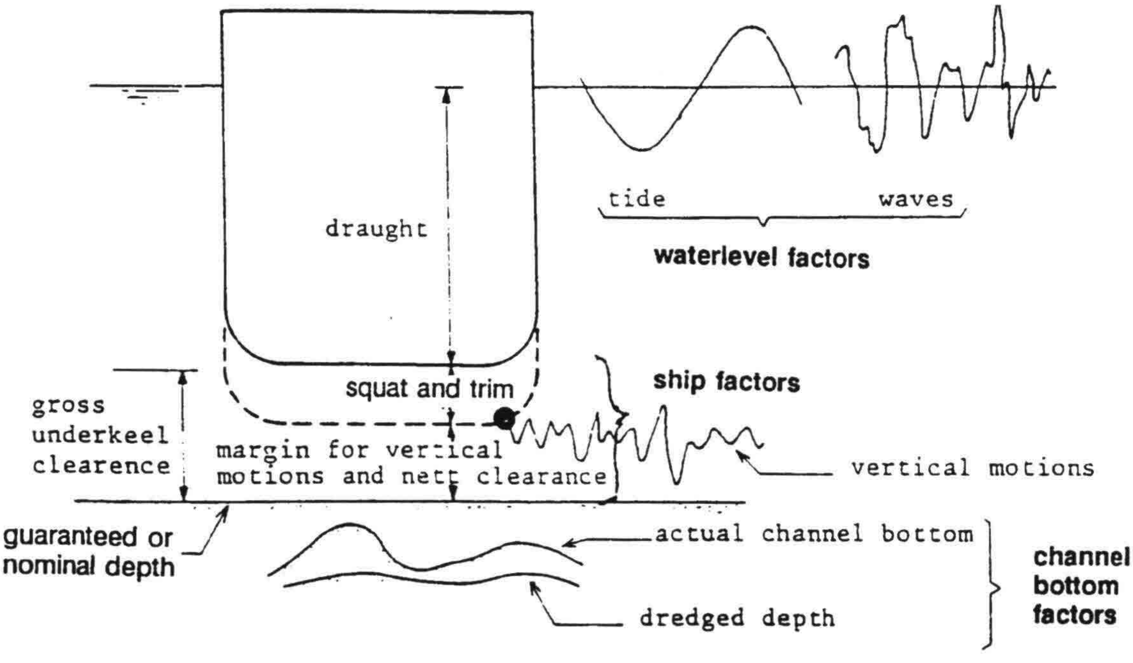


Figure 5- 14: Underkeel clearance factors

In a preliminary assessment of channel depth (in the absence of reliable information on waves and ship response) all these factors may be lumped together into one depth / draught ratio taken as 1.1 in sheltered water, 1.3 in waves up to one meter height and 1.5 in higher waves. While such high values may be justified for large ships in long waves (higher response), in North Sea conditions it will lead to considerable overdesign. A better method is to determine the various factors separately and to improve the calculation as more reliable data come available. In formula:

$$d = D - T + s_{max} + r + m \qquad (5\text{-}11)$$

in which:

d	=	guaranteed depth (with respect to a specified reference level)
D	=	draught design ship
T	=	tidal elevation above reference level, below which no entrance is allowed
s_{max}	=	maximum sinkage (fore or aft) due to squat and trim
r	=	vertical motion due to wave response
m	=	remaining safety margin or net underkeel clearance

In many countries the reference level for sea charts, including port areas, is Chart Datum (CD), often defined as the lowest low waterlevel during springtide (LLWS). This is easiest for mariners as in 99% of the time the actual waterlevel is above CD, giving extra safety for their ship. In The Netherlands waterdepths in coastal areas and the ports are given with respect to NAP and hence the tidal amplitude needs to be taken into account.

The channel depth below CD as shown on a nautical chart is guaranteed by the government or port authority responsible for maintenance. This means that the actual seabed may be decimetres below this guaranteed or nominal level, depending on the maintenance dredging program.

The value T is introduced when a port decides to introduce a tidal window: ships may only enter during a certain period around high water. Obviously such a measure reduces the nominal channel depth, but the entry limitation is not always acceptable to the shipping lines (e.g. the main line container vessels).

The values of s_{max}, r and m together also form the gross underkeel clearance or UKC. They may be estimated on the basis of experience: $s_{max} = 0.5$ m; $r = H_s/2$ (or the amplitude related to the significant wave height therefore assuming a RAO = 1) and m having a value depending on the type of soil along the channel, 0.3 m for soft mud, 0.5 m for a sandy bottom and 1.0 m for a hard soil or rock.

Alternatively s_{max} and r are calculated more precisely. For the ship response the actual RAO values are applied to the wave climate. For squat a number of different formulae exist, some of which are applicable in specific conditions only. A general formula for shallow water is given below (Barrass, 1979):

$$s = \frac{C_B}{30} \cdot S_2^{2/3} \cdot v_s^{2.08} \qquad (5\text{-}12)$$

In which:

s	=	squat	[m]
v_s	=	vessel speed	[kn]
C_B	=	block coefficient	[-]
S_2	=	S/(1-S)	[-]
S	=	blockage factor = A_s/A_{ch}	[-]

Equation 5-12 holds for canals, restricted channels and laterally unconfined water, as shown in *Figure 5- 15*. In the latter case the effective width of the waterway is introduced to calculate A_{ch}:

$$\frac{W_{eff}}{B} = 7.7 + 45(1 - C_w)^2 \qquad (5\text{-}13)$$

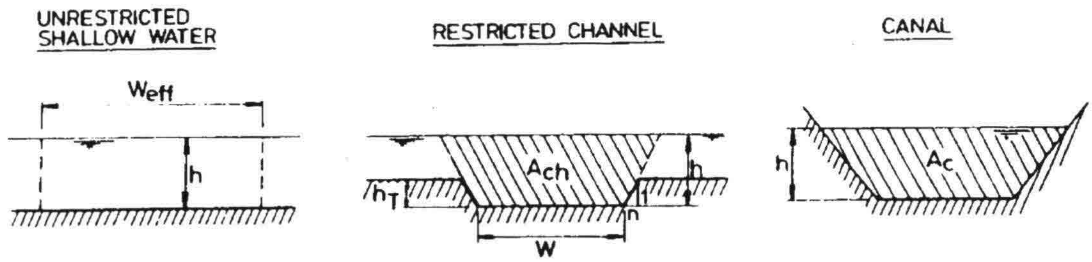


Figure 5- 15: Waterway configuration

Obviously, there is no sharp transition between laterally unconfined water and restricted channels. A channel with an underwater bankheight less than 40% of the waterdepth or a width larger than W_{eff} is considered laterally unconfined.

Equation 5-11 is basically a deterministic calculation with arbitrary values for the stochastic parameter r and for the safety margin m. Hence the real risk of a ship touching the channel bottom is unknown. In order to avoid possible overdimensioning the probabilistic method is introduced, whereby depth is calculated for an acceptable probability of bottom touch. In this approach the actual seabed profile can also be included as a stochastic parameter. The design formula reads then as follows:

$$Z = d + T - (D + s_{max} + r) \qquad (5\text{- }14)$$

in which d (= channel depth to reference level including dredging tolerance and the effect of resiltation), T and D are deterministic. For the parameters s_{max} and r the probability density function needs to be determined. Subsequently the probabilistic analysis is made on Level II or Level III for the probability of bottom touch:

$$\Pr(Z < 0) = a$$

This approach has been successfully applied for the depth optimisation in the Euro- and Maasgeul to the Port of Rotterdam. The design ship is the Berge Stahl (and a few bulk carriers with similar draught), the number of calls per year is not very high. Based on extensive studies on risk of damage to the ship the value of 'a' has been defined at 1/100 transits of the channel.

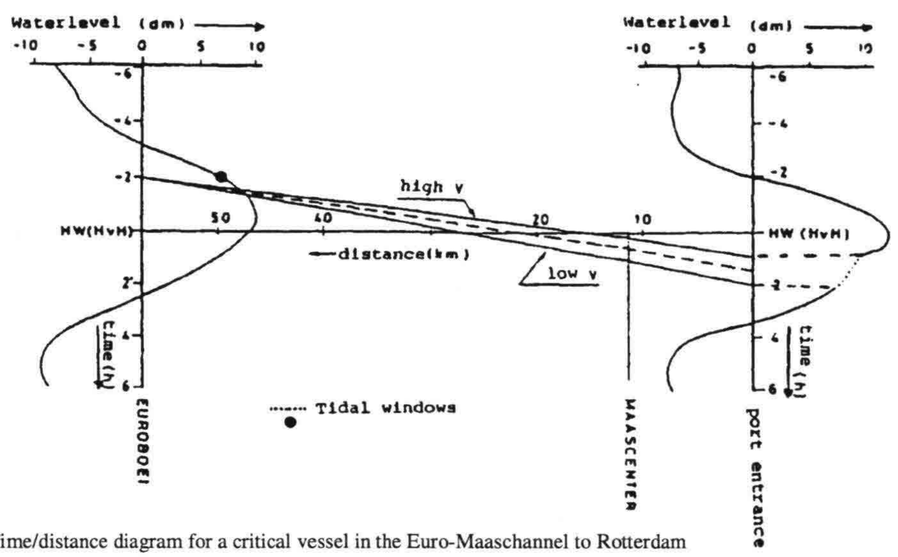
Finally two aspects are mentioned, related to the channel depth designs, namely the (vertical) tidal window and the concept of nautical depth.

(i) Tidal window

It is emphasised that for channels subject to tidal motion, not all ships need to be able to enter or leave port at all stages of the tide. On the contrary, it will often be more economic to restrict the navigability of the channel, at least for the biggest ships, to a limited period of the tide, the so-called tidal windows. This mostly refers to the vertical tide, but it may also apply to limiting tidal currents, i.e. to the horizontal tide (in addition, many ports have a wave window: wave conditions beyond which port entry is not permitted either for safety of the vessel itself, or due to the impossibility of pilots to board vessels).

The type and number of ships involved and the applicable degree of restrictions - i.e. the width of the tidal windows - has to be studied from case to case. It will normally be determined on basis of a minimisation of the sum of channel construction and maintenance costs and ship waiting costs. In actual practice there are often considerable hidden waiting costs, because ships tend to reduce speed well in advance of the harbour entry, rather than to have to wait at an anchorage.

When designing an approach channel with tidal windows the length of the channel and ship speed have to be taken into account as shown in *Figure 5- 16*. In fact, the window needs to be defined at the beginning of the channel in such way that ships entering within the window can traverse the length of the channel safely at a normal speed. In case of emergency (motor failure or a collision) there have to be anchorages along the channel, the last one close to the port entrance.



Time/distance diagram for a critical vessel in the Euro-Maaschannel to Rotterdam

Figure 5- 16: Vertical tidal window

(ii) Nautical depth

If the bottom of the waterway is covered with a non-consolidated, liquid layer of mud, a clear definition of the depth of the channel does not exist. Moreover the meaning of underkeel clearance changes, because there is no danger of damage to the ship when it sails through the upper part of the mud layer. The solution lies in defining the "nautical bottom" at a level, where its physical characteristics reach a limit beyond which contact with a ship's keel causes either damage or unacceptable effects on controllability and manoeuvrability. Accordingly nautical depth is defined as the vertical distance between the nautical bottom and the free water surface.

The above concept was subject of extensive studies both in laboratory and at sea in The Netherlands and Belgium, for the purpose of optimising the maintenance dredging volumes in the Europoort and Zeebrugge channels (PIANC, 1983). Without going into great detail the outcome was to define the nautical bottom at a certain density of the fluid mud layer, see *Figure 5- 17.* The density of 1200 kg/m^3 was determined for the Port of Rotterdam, but in other locations slightly different values may be specified. Quite extensive background information on survey techniques and the effects on manoeuvrability is given in PIANC 1997.

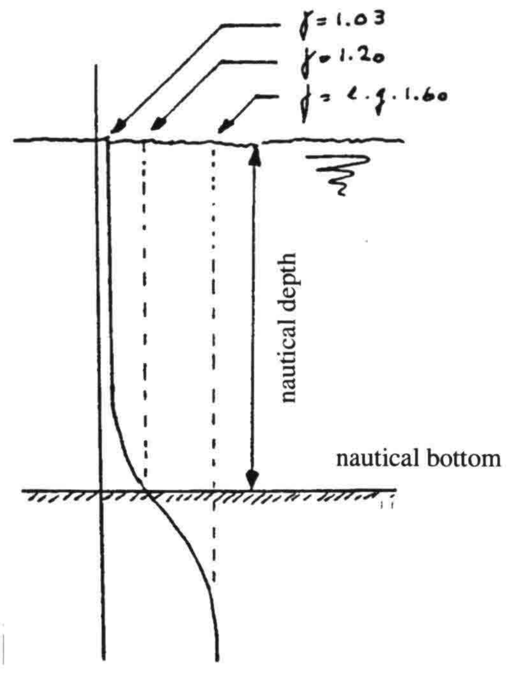


Figure 5- 17: Definition of nautical depth

5.4. Manoeuvring areas within the port

The manoeuvring of small to medium size vessels generally poses no special problem in the sense that specific measures have to be taken in the dimensioning of the port infrastructure. The required stopping lengths are limited (see Section 5.2.1) and can usually be accommodated in traditionally sized inner channels and manoeuvring spaces. Manoeuvring capability of these vessels is generally good, and upon entering port they will often manoeuvre and stop under their own power.

For large ships the situation is different. Because of their much longer stopping distance and because of the lack of course control during the stopping manoeuvre, they will mostly not be allowed to stop under their own power. This may already apply to vessels of approximately 50,000 dwt and over. This means that as long as no effective tugboat control is available, such ships have to maintain a certain minimum speed relative to the water, at which there is still sufficient rudder control available. This speed is about 3 to 4 kn, sometimes slightly less.

The above is of particular importance where large ships with dangerous cargo are concerned, i.e. crude and product tankers, liquid gas carriers, etc. The slowing down and stopping length then required within the port boundaries, i.e. in relatively sheltered water with little or no currents, is determined by the factors:

a) entrance speed of the ship
b) time required to tie up the tugboats and to manoeuvre them in position
c) actual stopping length

sub (a)
The entrance speed is basically determined by the requirements that, firstly, the vessel should have sufficient speed with respect to the surrounding water for proper rudder control, say 4 kn, and/or, secondly, that the drift angle should not exceed a tangent of about 1:4. The first requirement implies that if there is a following current near the entrance of e.g. 2 kn, the minimum entrance speed will be 6 kn. The second condition implies that if there is a cross current of 2 kn, the minimum entrance speed will be 8 kn. See also *Figure 5- 18.*

sub (b)
The time required for tying up tugboats depends very much on the expertise of the crews and the environmental conditions. In average circumstances this time will be in the range of about 10 minutes. If the ship moves too fast or if the waves are too high, the tugboats cannot tie up at all while maintaining acceptable safety standards. The maximum speed of the ship is 5 to 6 kn, the maximum wave height about H_s = 1.5 m. For favourably located harbours tugboats may make fast as a standard procedure already outside the port entrance. This, of course, very much reduces the manoeuvring space required within the port. Generally, the percentage of time that above conditions are exceeded is too high to accept as downtime.

sub (c)
The actual stopping distance is relatively short. The large ships give astern power the moment tugboats can control the course and, subsequently, stop in about 1.5 L from a speed of 4 kn.

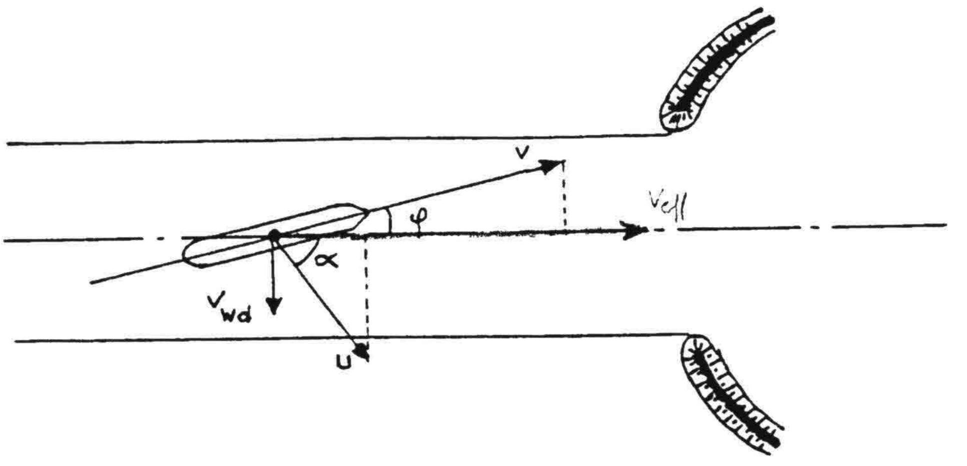


Figure 5- 18: Drift of the ship under influence of current and wind

v	=	ship speed with respect to water
v_{min}	=	minimum ship speed for rudder control (4 kn)
v_{eff}	=	ship speed with respect to channel bottom (design entrance speed)
u	=	current velocity
v_{wd}	=	transverse speed of ship as a result of winddrift
φ	=	drift angle
α	=	angle between current and channel axis

In *Figure 5- 18* the ship has to maintain an angle with the channel axis in order to counteract the forces due to current and wind. This drift angle is limited to about 14° because for greater angles the rudder control reduces too much.

The ship sails along the channel axis with a speed with respect to the channel bottom v_{eff}, which is calculated by either of the two equations:

i). minimum speed can be maintained, without too much drift angle,

$$v_{eff} = v_{min} \cos\varphi + u \cos\alpha \qquad (5\text{- }15a)$$

provided that $\tan\alpha \leq 1/4$

or $v_{min} \cos\varphi + u \cos\alpha \geq 4\,(u \sin\alpha + v_{wd})$

ii). the maximum permissible drift angle dictates the ship speed

$$v_{eff} = 4(u \sin \alpha + v_{wd}) \qquad (5\text{- }15b)$$

The consequence of the above requirements is that the length of the inner channel easily measures 2.5 km or more, if the port will be able to receive large ships under acceptable standard of nautical safety. However, there are no international rules to which the dimensions of port channels and manoeuvring spaces have to comply and the PIANC-guidelines do not address this aspect of stopping length.

In case of a captive port facility for dry or liquid bulk the solution is often to apply a horizontal tidal window, i.e. the ship may only enter when the tidal currents are below a certain value. For busy commercial ports this solution is unacceptable, because of the inherent limitations of access and resulting waiting time.
Note: in the Euro-/Maasgeul and Y-geul a horizontal tidal window has been introduced for the largest vessels, not for reasons of reducing the stopping length, but to achieve safety in more general.

The width of the inner channel is determined using the same guidelines given in Section 5.3.2. Obviously width additions for current and waves do not apply, because these are eliminated by breakwaters. Where ships enter under influence of cross-currents additional space is required immediately behind the breakwaters. Upon entering the drift angle has a tendency to increase because the bow of the ship is moving out of the current and the moment on the ship increases. An experienced captain or pilot will anticipate this movement by giving some rudder in opposite direction. In practice allowance is made for this aspect by extending the outside channel width for 2-3 L_s inside the breakwater before narrowing to the inside width (see *Figure 5- 19*).

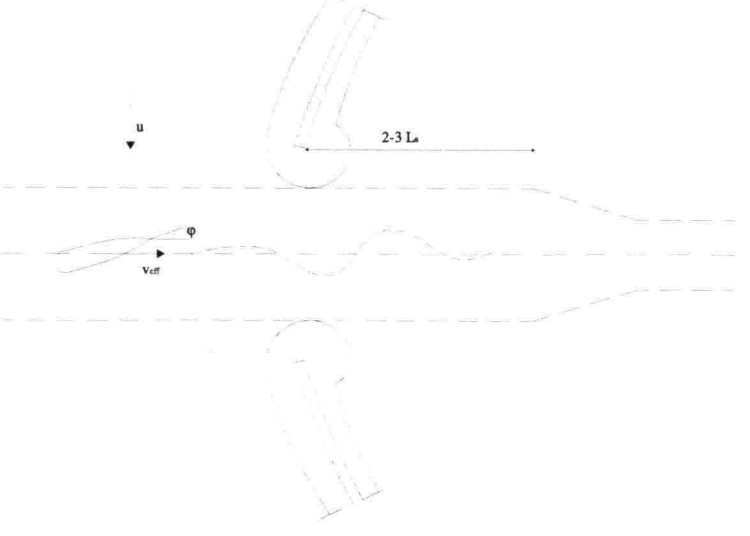


Figure 5- 19: Port entrance manoeuvre

The inner channel should end in a turning basin or circle, from where vessels, whether small or big, are towed by tugboats to their respective basins. The diameter of this turning basin should be ≥ 2L. In exceptional cases, for small ports where no tugboats are available, the diameter should be ≥ 3L. In case of currents, for instance in river ports, the turning basin should be lengthened to compensate for vessel drift during manoeuvring.

The length, width and lay-out of the inner channel can be optimised in a similar way as the width of an approach channel, viz. by fast-time manoeuvring simulators initially, and by a full-mission real-time simulator ultimately (see Section 5.3.1). Also here, the stochastic nature of human navigator performance plays an important role.

With the aid of statistical processing of the simulator results, the boundaries of the inner channel should be determined, that the probability of exceeding these boundaries is equal to or less than a given acceptable frequency. This acceptable frequency, in its turn, should in principle be determined on considerations of minimisation of overall costs, including the mean direct and indirect cost of damage when the boundaries are exceeded.

5.5. Port basins and berth areas

5.5.1 Nautical aspects

Port basins should be given a sufficient width for the safe towing in and towing out of the vessels, whilst other berths are occupied. For conventional cargo and container ships, this results in 4 to 5B + 100 (*Figure 5-20*). If B = 25 m (conventional general cargo ship), this means a basin width of some 200 to 225 m; if B = 32 m (container ships), the basin width should be about 230 to 260 m.

In case of very long basins, say 1,000 m or more, it is desirable that ships can be turned in the basin. The required width is about L + B + 50, or 8B + 50. For B = 25 m, this results in a width of 250 m.

For big tankers or bulk carriers, the desirable basin width - also for two-sided use of the basin- is 4 to 6B + 100 m. The lower value applies to favourable wind conditions, the higher to frequent and strong cross-winds. For B = 45 m, 5B + 100 m results in a basin width of 325 m.

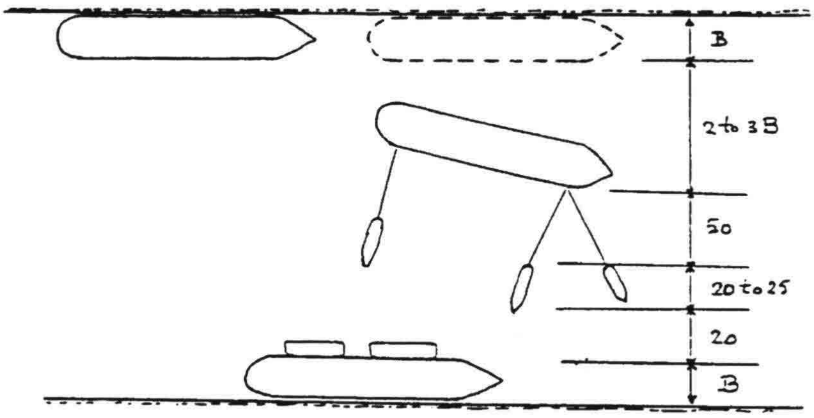


Figure 5- 20: Basin width

Regarding the berth orientation wave, wind and (in case of offshore or river berths) current conditions play a role. Ideally for safe berthing, the berth should be aligned within about 30° of the prevailing wind direction. Currents alongside the berth should be limited to 3 kn and perpendicular to the berth no more than 0.75 kn (OCIMF, 1978).

5.5.2 Wave agitation

Waves within the boundaries of a port may have been generated locally, or have penetrated from outside. Due to the limited fetch locally generated waves will generally be smaller and have short periods. But, some ports do have a fetch for specific wind directions which cannot be neglected, e.g. Rotterdam, New York, the Mersey ports in the UK, Bombay and the south-western part of the port of Singapore. If the fetch is, for example, in the 5 to 10 km range, wave heights (H_s) will be somewhat in excess of 1 m for a Beaufort 7 wind, and some 1.7 m for Beaufort 9, with periods T_p of 3 to 3.5 s. Since, moreover, these waves can be very steep, they will hamper harbour tugs and similar craft, but large sea-going vessels will not be affected at all.

Wave penetration into a harbour mostly takes place through the harbour entrance. However, also the overtopping of low-crested breakwaters of wave transmission through permeable breakwaters - the latter particularly for long period waves - may contribute to wave agitation within the port. For example, in the outer harbour of the port of Visakhapatnam on the Indian east coast, wave transmission through the quite permeable primary and secondary armour layers of the southern breakwater is an important cause for the local wave problems encountered.

It is very much necessary to access the magnitude of these phenomena at the design stage of the breakwater(s), as it is difficult to devise suitable means to reduce wave penetration once the breakwaters have been built.

In general terms, the problems encountered to limit wave penetration in a harbour increase with increasing wave period. In this respect, an old ocean swell with a period in the order of 12 to 16 s is already more difficult to protect against than wind waves of 6 to 8 s period. For still longer wave periods, as applies for seiches with a period of 2 to 3 min or more, the only solution often is to design the port's water areas in such a way as to minimise the effects.

The port lay-out has to satisfy two different requirements as far as wave penetration is concerned: (i) operational conditions must allow efficient loading and unloading of the ships at berth, and (ii) for limit state conditions the ship must be able to remain at berth safely.

(i) *Operational conditions*

In the preliminary design stage (masterplan or feasibility study) the wave penetration for operational conditions is often estimated on the basis of hand-calculations (Cornu or the wave penetration diagrams in the Shore Protection Manual) or simple computer models. The criteria at the various berth locations are in that case given as allowable wave heights for unloading/loading and for the relevant ship types (see *Table 5- 2*).

Table 5- 2: Limiting operational wave height

Type of ship	Wave direction wrt ship axis 0	45/90
	H_s (m)	H_s (m)
Bulk vessel (1.5-30 kdwt)	1.2	0.9
VLCC (200-250 kdwt)	2.0	1.6

It is clear that the above wave height criteria are quite crude, because the wave periods and the effects of the mooring system on ship movements are not taken into account. For detailed design of the port lay-out not only more accurate wave penetration models are applied, but also are wave heights translated into ship motions. Hence the design has to fulfil operational criteria in terms of ship movements in the relevant modes (OCIMF, 1978 and PIANC, 1995). *Table 5-3* gives a summary for different ship types.

Table 5- 3: Allowable ship motions

	Allowable motion amplitudes			
Type of ship	Surge (m)	Sway (m)	Yaw (°)	Heave (m)
Tankers	2-3	2-3	1	1.5
Bulkers	0.5-1.5	0.5-1.0	-	0.3-0.5
Container ship	0.5	0.3	1	0.3
Ro/Ro ship (at the ramp)	0.3	0.2	0	0.1

Some clarifications apply to the values of *Table 5-3*:

- The allowable surge and yaw motion of tankers is much higher because the ships are (un)loaded at a central manifold midships. In detailed design of the berth the type of loading arm determines the allowable motion in last instance.
- The motions of a containership are more critical because of the high precision needed for (un)loading containers and the delays when the container gets stuck in the cell guides.
- Ro/Ro ships are particular sensitive to ship motions due to the ramp connection with the quay.

The ship motion analysis is performed with advanced computer models, as outlined in Section 5.2.2. A typical example of the results of such a computation is given in *Figure 5-21*.

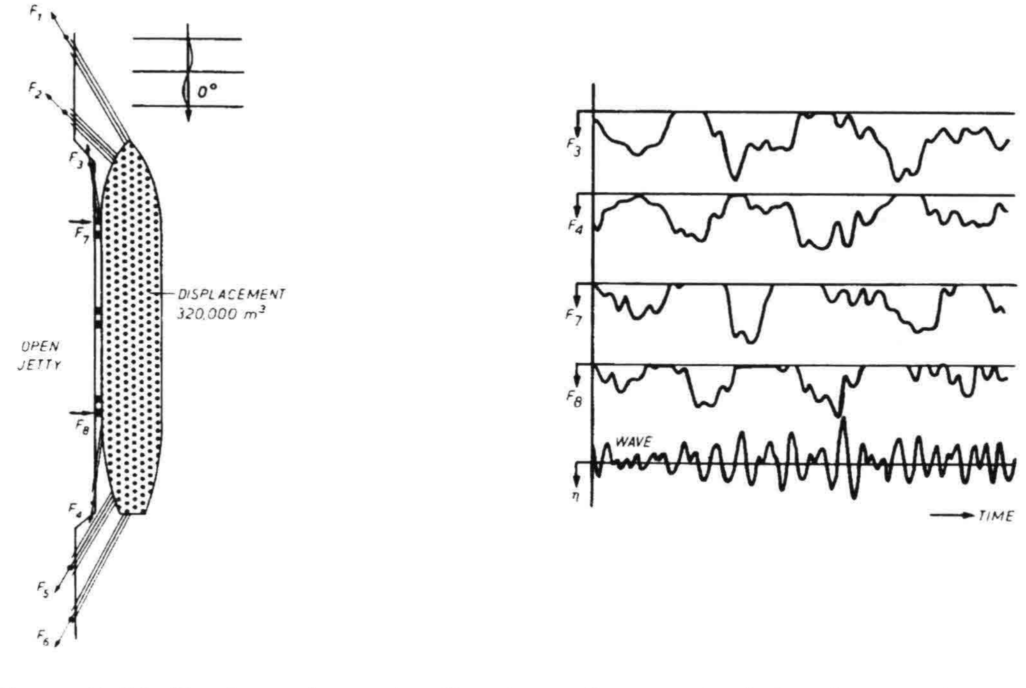


Figure 5- 21: Fender and mooring line forces for a tanker in head waves (source: WL/Delft Hydraulics)

(ii) *Limit state conditions*

For wave heights above the operational limit the (un)loading of the ship is interrupted, but the ship remains berthed till limit state conditions are reached. In ports, where wave disturbance does not play a role (e.g. ports behind locks or upriver) this condition does not occur and ships can stay inside even in extreme weather. Many of the older ports are examples of this "fugitive" type. Most newly developed ports can not afford to be fugitive and a limit state condition is determined as a trade-off between costs for breakwaters and shipping cost related to the loss of time. In case of an offshore berth the limit state may be chosen at a 1/yr wave condition, while in case of an enclosed harbour basin a 1/10 yr sea state may be more appropriate. In all cases the forces in the mooring lines and fenders have to be within the allowable limits. An interesting aspect here is that the fenders can be designed strong enough, but that the number and allowable strength of the mooring lines are often the deciding factor. To determine the line and fender forces requires again computer calculations (see Section 5.2.2). More details on types of mooring lines and fenders and their characteristics will be outlined in Chapter 10.

5.5.3 Harbour basin resonance

In case the period of the incident waves equals or approximates the natural period of oscillation of a harbour basin, resonance phenomena can be expected. This may lead to locally much greater wave heights and, consequently, to more severe problems for ships at berth. If a harbour basin has a more or less uniform depth and rectangular shape, the natural periods of oscillation T_n are as follows (see *Figure 5- 22*):

closed basins

$$T_n = \frac{2L_B}{n} \cdot \frac{1}{\sqrt{gD}}, \quad \text{with } n = 1, 2, \ldots \qquad (5\text{-}16)$$

open basins

$$T_n = \frac{4L_B}{(1+2n)} \cdot \frac{1}{\sqrt{gD}}, \quad \text{with } n = 1, 2, \ldots \qquad (5\text{-}17)$$

The closed basin condition would apply to basins with a very narrow entrance and to transverse oscillations.

In case of a more complex geometry of the basin boundaries and variable depths, mathematical models have to be used to determine the T_n in different basins.

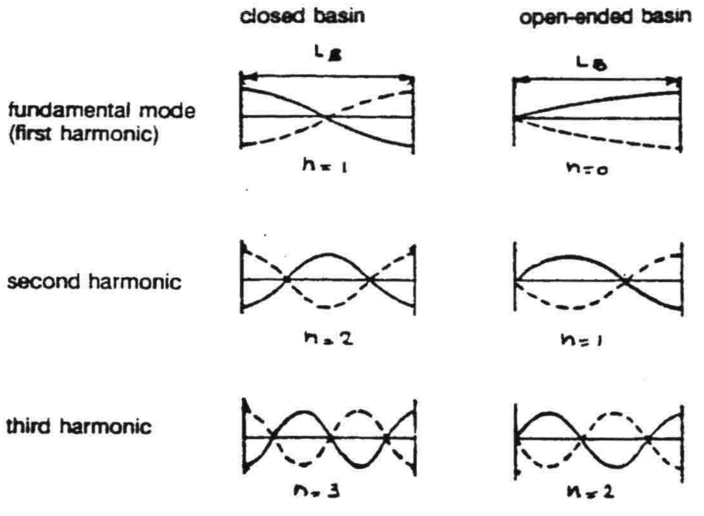


Figure 5- 22: Basin oscillation

This phenomenon should be avoided or minimised in the planning stage, i.e. by checking the selected lay-out and if necessary by modifying it. Changing the size of harbour basins often is not effective, because resonance then occurs for a slightly higher or lower wave period. The best approach is to avoid regular shapes ("organ pipes") and to introduce damping boundaries, where possible.

The problem of harbour resonance is particularly manifest along the borders of oceans, because of the long period swell (T_p = 10-16 s) and the occurrence of long waves with periods ranging from 30-300 s. Although the latter waves have small amplitudes, when creating resonance they can become a nuisance. An additional factor is that such long waves easily pass through rubble mound breakwaters, if their core is slightly porous. The third measure to avoid resonance is therefore to make the breakwaters as impermeable as possible.

In case harbour resonance occurs once the port is constructed it is more difficult to reduce the problem. Placing additional (impermeable) breakwaters close to the entrance to the basin is one method. Care should be taken that navigation is not impeded by the new structures. Another measure is to create additional damping at the closed end of the basin, but this is often conflicting with terminal functions. Moreover the dampening effect of a spending beach on long period waves is very limited. It is easier in such cases to provide additional, stiff mooring lines from the quay-side to reduce the effects of the resonance on the ship motions.

5.6. Morphological aspects

In three different ways morphological processes affect the port lay-out:

(i) The effect of a coastal port with breakwaters on the natural littoral transport, often resulting in accretion and erosion of the adjacent coastlines.
(ii) Siltation in the approach channel and in the area close to the port entrance, leading to maintenance dredging.
(iii) Sediment transport into the port area leading to deposition and maintenance dredging

5.6.1 Littoral transport

The first aspect is dealt with in the lecture notes on Coastal Engineering (ir. E.T.J.M. van der Velden, 1995). The process of accretion on one side may, in the case of relatively short breakwaters, fill up the triangle between the original coastline and the breakwater, after which littoral transport continues. This will cause accelerated siltation in the approach channel as shown in many existing ports (see *Figure 5- 23*).

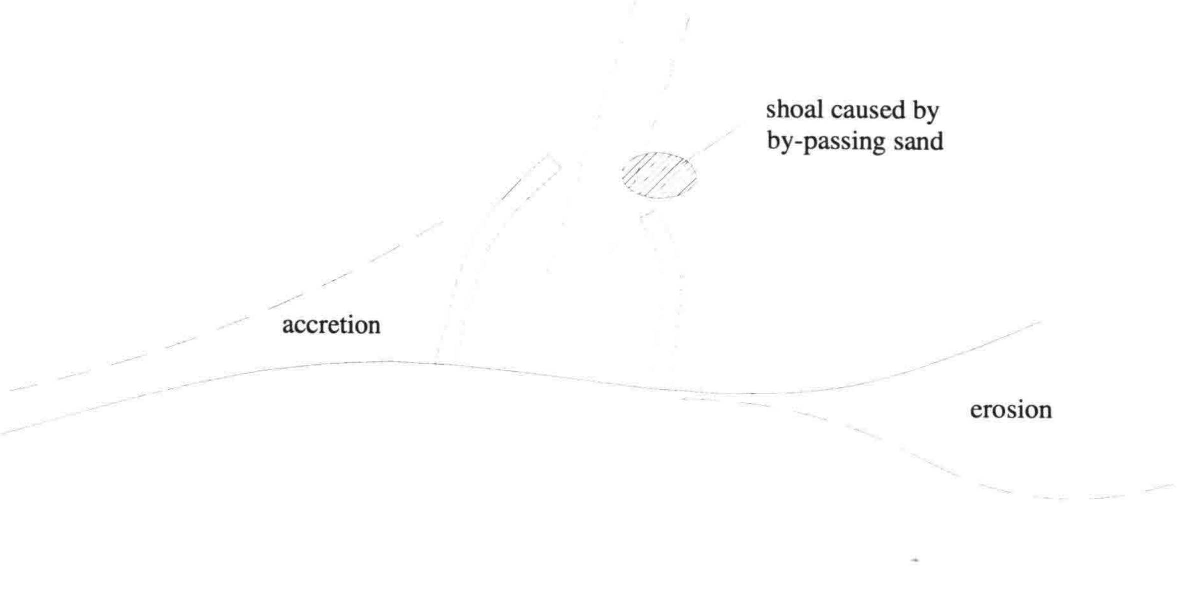


Figure 5- 23: Effects of the port on littoral transport

For the port planner this means the following:

- If there is substantial transport in both directions the port needs two breakwaters, reaching to sufficient depth to avoid that the instantaneous transport is deposited in the approach channel and harbour basins (as already mentioned in Section 4.4.2).
- If the littoral transport is predominant in one direction, one breakwater may be sufficient
- In both cases above the breakwater at the side whence the net annual transport comes from, has to be long enough to avoid by-passing sand to cause rapid siltation of the channel (instead of making the breakwater longer it is possible to design an artificial sand by-pass). The head of the second breakwater has to be positioned in such way that by-passing material is not drawn into the port, even if this is conflicting with nautical requirements (see *Figure 5- 24*).

The methods for calculating littoral transport, rates of erosion and accretion, and deposition rates in and around the approach channel are not treated in these lecture notes.

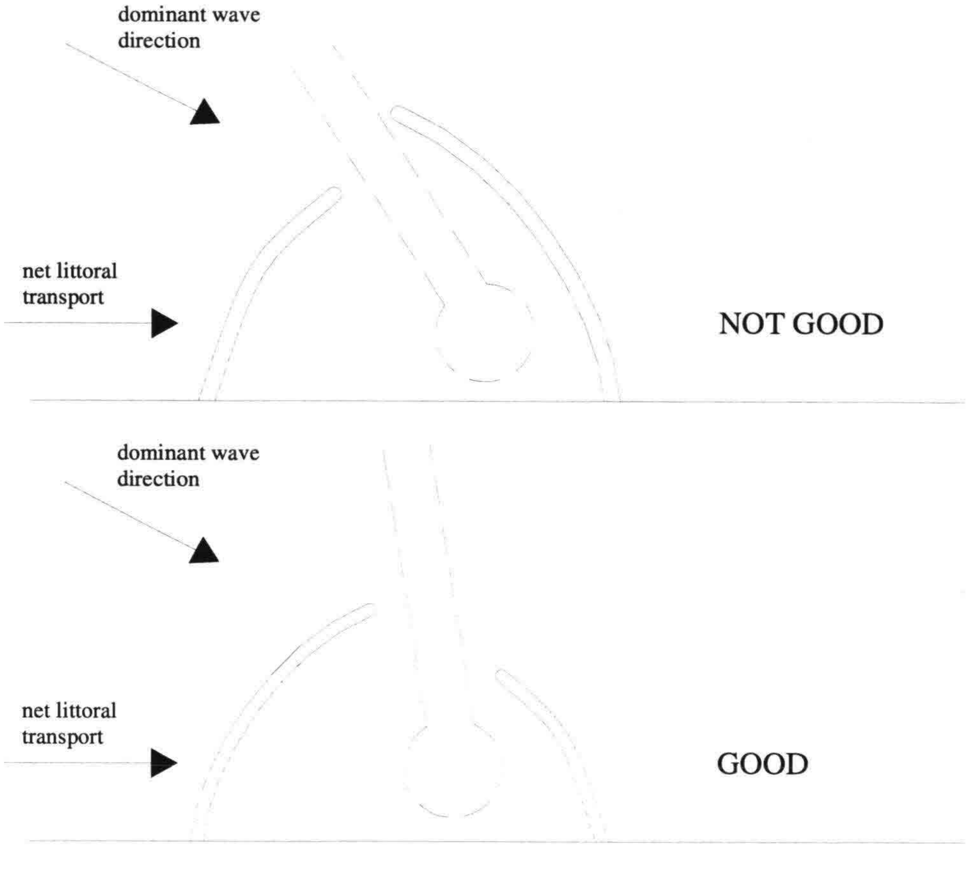


Figure 5- 24: Lay-out of breakwater heads in relation to littoral transport

5.6.2 Siltation of approach channels

Siltation in the outer channel can also be caused by settlement of sediments due to the increased depth / reduced current velocities. This mechanism becomes an important factor for channels located in coastal areas with fine material at the seabed, in estuaries or when a natural river has been deepened to allow larger ships to reach an upstream port. Examples are the Nieuwe Waterweg in Rotterdam, which was deepened from a natural depth of about NAP 6.0 m to 23.75 m at present, the channel to the port of Shanghai (from CD -7.0 m to -12.5 m) and the shipping channel in the muddy La Plata delta in Argentina, from CD -5.5 m to CD -9.0 m.

Computer programs are available to analyse the complex process of settlement and condensation of cohesive sediments. Again reference is made to Van der Velden (1995). Here an empirical method is mentioned, which is particularly useful for channels extending far into silty or muddy areas or in cases, where the natural riverbed is deepened to allow shipping. In such cases the annual siltation volumes may be estimated as a percentage of the overdepth (the difference between the new design depth and the natural depth).

$$V_d = C_r \cdot W_{ch} \cdot h_o \qquad (5\text{-}18)$$

in which

V_d	=	average annual volume of resiltation	[m^3/yr]
C_r	=	resiltation factor	[-]
W_{ch}	=	channel width	[m]
h_o	=	overdepth	[m]

The resiltation factor may be derived from an existing approach channel along the same coast or by comparing the morphological conditions with similar situations elsewhere in the world. Analysis of maintenance dredging volumes in major approach channels has shown that values of C_r between 0.5 and 0.7 are quite common and in the La Plata delta even $C_r = 1.0$ is found.

The method is so useful for preliminary assessment because it allows to take the consequences of (high) maintenance dredging costs into account in the early stage of concept development. The problem is that, contrary to the littoral transport effects, very little can be done in term of design to reduce this sedimentation effect. For new to build ports it may lead to reconsideration of the site for port development. And for the deepening of existing channels, it may be more economic to locate the necessary expansion nearer to the coast or even into the sea, where deeper water is available.

5.6.3 Sedimentation inside the port

Like the previous effect, the sedimentation inside the port area is also often caused by fine sediments entering through the entrance and/or from upriver and settling in the deepened basins and manoeuvring areas. Three mechanisms play a role in the sediment intrusion through the entrance:

(i) The tidal filling of the port.
(ii) Density currents at the entrance, where salt (and/or colder) water flows in at the bottom, while more fresh (and/or warmer) water flows out at the surface.
(iii) The exchange of sediment filled water in an eddy behind the breakwater forming the port entrance (see *Figure 5- 25*).

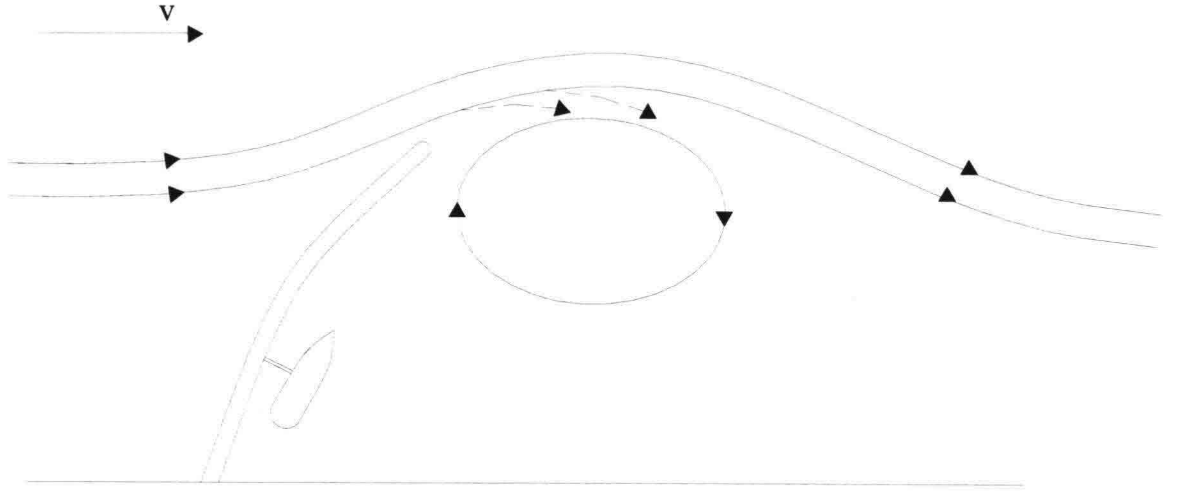


Figure 5- 25: Sediment exchange between main current and eddy

The annual rates of sediment deposition due to these processes are reasonably easy to estimate, based on preliminary data on sediment load and schematisation of the hydraulics. Very often various processes act at the same time, in concurrence with sediment flow from upriver. In such cases numerical models are applied for more accurate determination of the resulting maintenance dredging.

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Chapter 6. Planning and design of port terminals

6.1. GENERAL 6-2

6.2. SERVICES PROVIDED 6-2

6.3. TERMINAL COMPONENTS 6-3

6.4. TYPES OF TERMINALS 6-5

6.5. TERMINAL CAPACITY: MAXIMUM OR OPTIMUM 6-14

6.6. TERMINAL DIMENSIONS 6-16

Chapter 6. Planning and design of port terminals

6.1. General

Port terminals are those port facilities which constitute the factual interface between different modes of transport of the cargo. For example, from sea going vessel into inland barges, road or rail transport, pipeline or feeder vessel, and vice versa.

There are also IWT (inland water transport) terminals where the cargo is transferred from inland barge or self-propelled vessel to truck or railway wagon, or the other way around.

In commercial ports, the terminals are the 'raison d'être' of a port. All other facilities are provided only to enable the terminals to function, and that in a safe and efficient manner. For captive port facilities the terminal is only a necessary element to enable the key process, for instance a refinery or a power plant.

6.2. Services provided

The services provided by a port terminal normally comprise the unloading from ship to shore, or the reciprocal process, the temporary storage, sometimes a limited processing of the cargo, and the loading or unloading into or from the through-transport means.

Unloading is also quite frequently done by ship-borne gear. This applies to virtually all liquid bulk cargoes for which ship-borne pumps are used. It also applies to some dry bulk cargoes carried by geared bulk carriers or self unloaders, and to the use of ship's cranes on general cargo or multi-purpose vessels. The loading of bulk cargoes is almost always done by shore-based equipment.

Intermediate storage is not necessarily part of the services, but, in practice, almost always is. Many cargoes need customs checking and/or quality and quantity checks which precludes direct through-transport. However, a more important reason, particularly for bulk cargoes, is the difference in parcel sizes and loading and unloading rates of maritime transport on the one hand, and through-transport on the other. E.g. , a very large bulk carrier may unload ore at a rate of up to 5,000 t/h or 100,000 t or more per day. But it is very uneconomic to arrange the through transport at the same rates. In other words, an intermediate storage or buffer stock is necessary.

Apart from that, certain clients prefer to locate operational and strategic reserves in the port rather than at the site of production or consumption, which leads to increased storage demands.

The processing which a terminal can offer as a service, usually consist of packing or re-packing, bagging (e.g. grain or fertiliser) or blending (e.g. different grades of ore or coal). More complex forms of processing exist, but are not very common.

6.3. Terminal components

The components of a terminal are:
- the wet and the dry infrastructure
- the suprastructure
- the equipment
- the human resources

The **wet infrastructure** comprises part of all of a harbour basin in which one or more berths are located to accommodate the ships. The type of berth is largely dictated by the nature of the loading or unloading process (see *Figure 6- 1*).

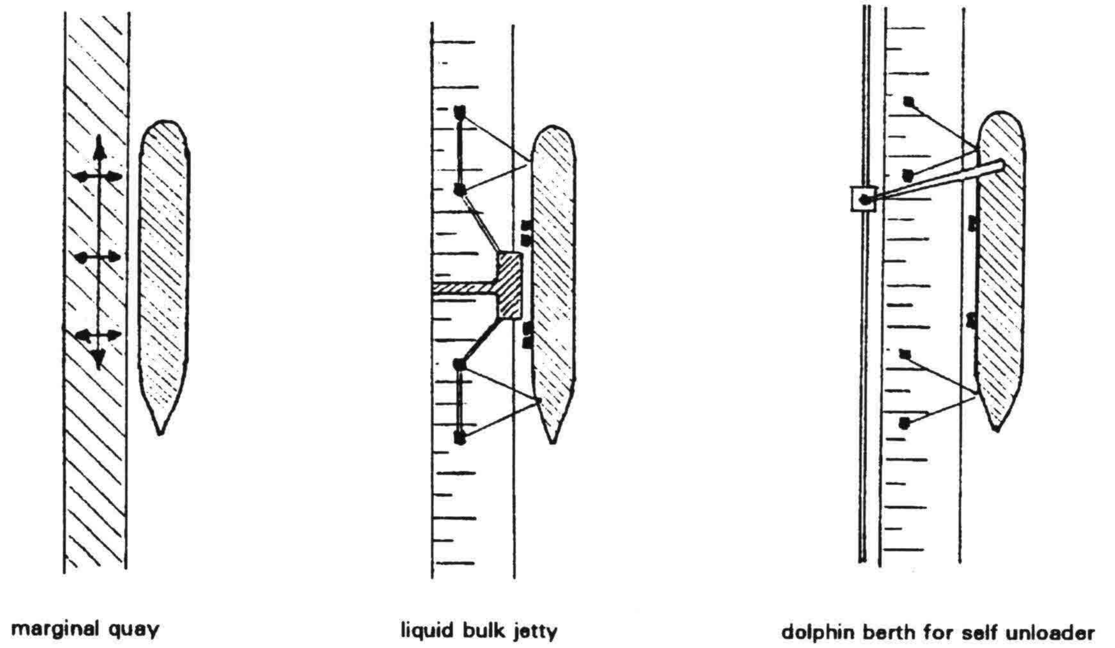


Figure 6- 1: Different types of berths

Relatively the most expensive is the marginal quay or wharf which is a quay connected over its entire length to the terminal area behind it. It thus permits longitudinal as well as transverse cargo movements to and from the storage areas over the full length of the ship. This is a prerequisite for the efficient handling of all non-bulk cargoes. Marginal quays are also often used for large dry bulk terminals when heavy gantry cranes have to be able to travel alongside a ship for unloading purposes. (Particularly for dry bulk cargoes, berths for loading and unloading respectively may be quite different because of the different equipment used).

Relatively, the cheapest form of berth -but not fully fitting in this overview- is the SPM (single point mooring) used for the loading or unloading of oil and/or oil products in open sea. A submarine pipeline connects the SPM (also mentioned SBM, single buoy mooring) to the shore.

Liquid bulk carriers load or unload through pipelines. They, generally, have a central midship manifold where pipelines from the different holds connect with hoses or (un)loading arms on shore. Such a process does not require shore-based equipment to travel alongside the ship. In consequence, a relatively simple and cheap platform suffices to carry the loading arms with -often-separate berthing or breasting dolphins and mooring dolphins to absorb the horizontal forces exerted by the ship.

But, also some dry bulk carriers are not very demanding with regard to berth and shore facilities. This applies to the so-called self unloader which carries its own unloading equipment. It consists of one or two longitudinal belt conveyors below the tapered holds, transferring to a vertical conveyor system which, in its turn, transfers the cargo to a horizontal conveyor carried by a swinging boom which can have a length of up to 70m.

The boom conveyor discharges in a hopper and conveyor system on shore. Because of the length of the boom, the only berthing facilities that are required, are breasting and mooring dolphins. (But, of course, the ship itself is more expensive per ton capacity than a conventional bulk carrier.)

The **dry infrastructure** comprises such items as storage area pavements -an expensive item for container terminals-, roads, foundations for crane tracks, drainage systems, etc. The dry infrastructure usually does not constitute the most spectacular part of the terminal, but it is, nevertheless, a very necessary one.

The **suprastructure** consists of the sheds and other covered storage spaces as silos, offices, workshops, etc.

Terminal equipment, either fixed or mobile, is found in a tremendous variety. Fixed equipment comprises mainly belt conveyors and stationary cranes. Mobile equipment moves either on rails (all sorts of gantry cranes, stacker-reclaimers, travelling hoppers) or on, mostly, pneumatic rubber tyres (RTG's, FLT's, straddle carriers, tractors/trailers, a.s.o.). Equipment will be discussed more in detail in the chapters dedicated to a particular type of terminal.

The fourth and final terminal component mentioned is the **human resources**. It is certainly not the least important one. As in most industries, productivity, efficiency and quality largely depend on the capability and motivation of management and labour force. An old but well run and well maintained terminal will generally provide a better service level to its clients than a modern well-equipped terminal that is poorly operated.

6.4. Types of terminals

There are as many types of terminals as there are ship types outlined in Chapter 2. Although the detailed aspects of planning and design are treated per type of terminal in the following chapters, a short overview is given here.

The main types of terminals that can be distinguished, are
- conventional general cargo terminals
- multi-purpose terminals
- ro-ro terminals
- container terminals
- liquid bulk terminals
  - liquid gas
  - crude oil
  - oil products
  - edible oil
  - chemical products
- dry bulk terminals
  - grain
  - ore and coal
  - special products (cement, sulphur, etc.)
- fruit terminals
- fish handling facilities
- IWT terminals
- ferry terminals

(i) General Cargo Terminal

The conventional general cargo terminal is one of the oldest and, traditionally, was designed for the handling of break-bulk and -later on- also unitised general cargo. Since break-bulk and unitisation have given way, to a large extent, to containerisation, the (conventional) general cargo terminals have lost much of their importance in modern ports. Nevertheless, they are still needed. In fact new ones are still being built because the traditional layouts and dimensions no longer suffice. A modern general cargo terminal has to be able to handle a much greater variety of cargo, including containers carried on deck of multi-purpose vessels, at a much greater speed.

Of course, not all ports can permit themselves to build specialised terminals for all sorts of commodities. The investments required are mostly considerable and can only be justified if there is a certain minimum cargo flow through such a special terminal. Also, the space is sometimes lacking for the development of a variety of special terminals. Finally, specialised terminals can only live up to expectations -greater handling speed, lower price and less pilferage- if they are managed and staffed by personnel trained for and experienced in this particular sort of operation.

Therefore, the answer to the question whether or not to specialise, is more than one of simple economics and arithmetic.

In developing countries, the rate of specialisation is lagging behind that of the industrialised world, not only for shortage of funds, but also because the training of management and labour is lagging behind. This is understandable and not at all disastrous. On the contrary, it is unwise to enforce specialisation too rapidly.

Talking in terms of cargo volumes handled, so apart from considerations of land availability and operational capability, a special container terminal cannot be expected to be economical at throughputs below approx. 50,000 TEU/year. A simple dry bulk terminal may become justified at a cargo flow of 0.5 to 2 million tons/year, depending also on the value of the cargo. For oil and liquid gas, specialisation is normally required from the very beginning, not so much for economic reasons as well as for safety reasons.

(ii) Multi-purpose Terminal

The difference between a modern general cargo terminal and a multi-purpose terminal is very small. Very often the latter is developed from the former by some changes in the terminal lay-out and in the equipment used. Most multi-purpose terminals combine conventional breakbulk with container and/or Ro/Ro cargo and the essence is that the containers are not any more occasional, but part of the regular cargo flow for which specialised equipment is available.
Converting an old general cargo terminal to a multi-purpose terminal is not so easy for a number of reasons:

a) more space is often required and it has to be open. Hence the existing sheds and rails, which often run along the quays, have to be removed.
b) the wheel loads of modern container cranes are greater and therefore the existing pavement is insufficient. If rail mounted cranes are used, the rails need foundations. Otherwise the stability of the quay front has to be checked and often to be strengthened.
c) the ramps of Ro/Ro ships can not be placed on the quay, when bollards are spaced too closely. Bollards should be lowered (see *Figure 6- 2*)

A typical example of a multi-purpose terminal is given in *Figure 6- 3*.

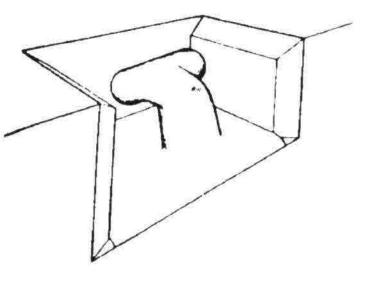


Figure 6- 2: A lowered bollard

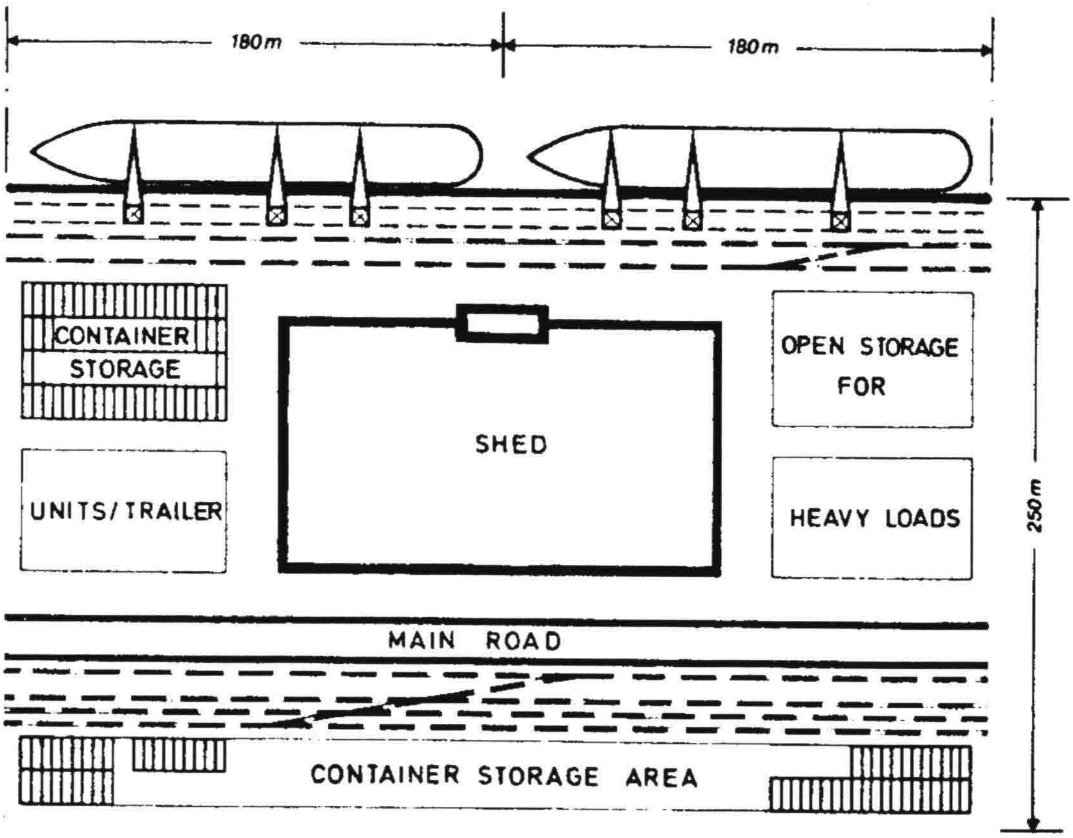
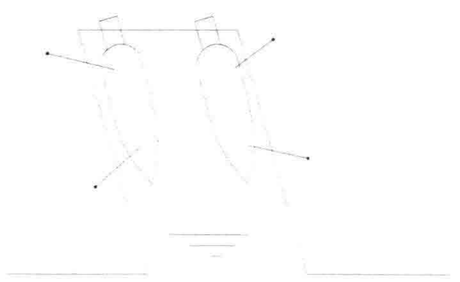


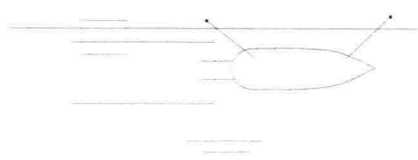
Figure 6- 3: A multi-purpose terminal

(iii) Ro/Ro Terminal

As mentioned in Section 2.3.4 the type of ramp on the Ro/Ro ship determines the quay lay-out: in case of a single stern ramp special arrangements are needed, such as shown in *Figure 2-12* and *Figure 6- 4*. The pontoon on the right is often used in case the tidal variation in the port is too large for the ship ramp.



a. conventional basin



b. floating linkspan

Figure 6- 4: Ro/Ro berths for stern ramp

For ships with quarter and/or side ramps a marginal quay is suitable, provided that there are no obstacles like bollards and rails. Ro/Ro terminals show a great variety of land side lay-outs, depending on how much parking space is needed for the trailers. Often this is very limited: trucks arrive between 1 and 3 hrs before departure of the ship and continue their journey immediately after disembarkation in the other port. When there is no long term parking of trailers the surface area requirement is low and the terminal can be located where-ever this space is available (possibly even at some distance from the berth location). The lay-out shown in *Figure 6- 5* is the terminal of StenaLine in Hoek van Holland.

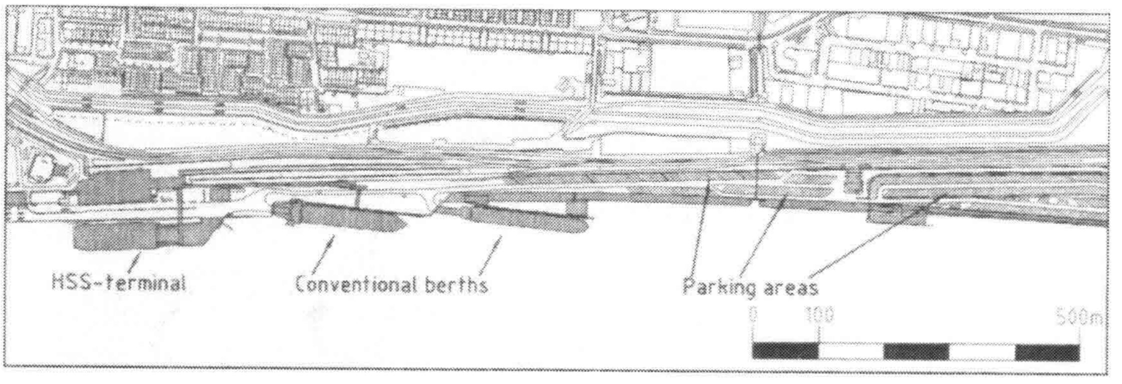


Figure 6- 5: StenaLine terminal

(iv) Container Terminals

Contrary to Ro/Ro terminals the storage of containers on the container terminal often takes several days (NW-European ports) to several weeks (some ports in developing countries). This leads to substantial surface area requirements, notwithstanding the fact that containers can be stacked 3 high or more. Furthermore the storage of containers has to be as close as possible to the berths in order to achieve efficient (un)loading. Container terminals can therefore be easily recognised as large areas with the stacks either parallel with or normal to the waterfront (depending on the transportation systems). Another characteristic point of modern container terminals is the giant portainer cranes with their boom in upright position, when idle. See *Figure 2-11*.

(v) Liquid Bulk Terminals

Whether for oil, chemicals or liquid gas these terminals all have one thing in common: the ships are (un)loaded via a central manifold midships and there is no need for heavy cranes moving alongside. This implies that the shore-side facilities can be concentrated on a limited surface area, often a kind of platform on piles. And depending on the local geometry and hydraulic conditions the platform may be located nearshore or at some distance from the coastline, connected by a trestle or isolated as a so-called island berth (see *Figure 6-6*).

A special case is the terminal with offshore (un)loading facilities located in deep water. To make a clear distinction from the Island Berth one could limit this type of facilities to floating buoys and/or jacket structures to which the ships are moored by bow hawsers and connected by floating pipelines. In practice one finds the Island Berth also being referred to as an offshore facility.

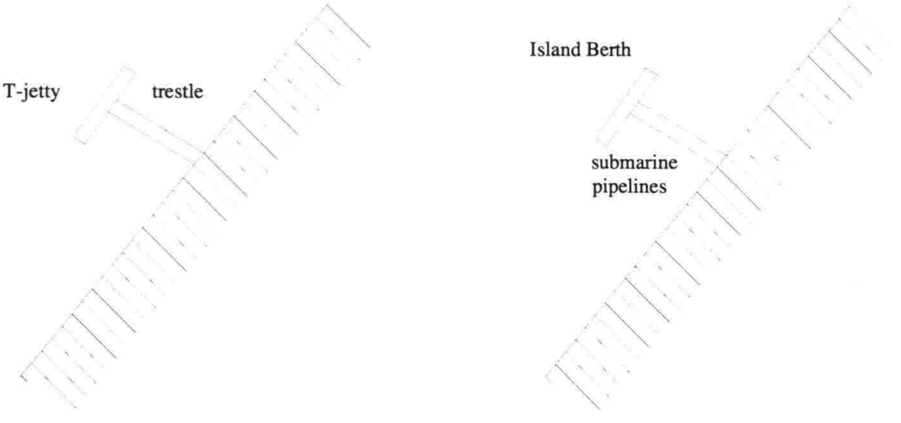


Figure 6- 6: Different configurations of liquid bulk terminals

In the latter case the liquids are pumped to/from the berth by means of submarine pipelines.

The actual landside facilities comprise storage tanks, which may be located at quite some distance (e.g. close to the refinery or chemical factory in view of safety procedures).

(vi) Dry Bulk Terminals

Like the previous category, the dry bulk terminals are often designed and built for one specific type of cargo, be it iron, ore, coal or grain. In view of the different transport processes needed for loading and unloading, there is a clear difference between the export terminal and the import terminal for the same commodity in most cases. The loading of bulk carriers in the export terminal is done by conveyor belts extending right above the ship, from which the material falls freely into the holds at constant and high capacity. At the import terminal the same cargo is unloaded by means of cranes, which must be able to move around in order to retrieve all the material within the hold and to go from one hold to another. As a consequence the export terminal may be more similar to the jetty / platform arrangement for tankers, while the import terminal needs a quay for heavy cranes (apart from the self-unloader shown in *Figure 6- 1*).

The storage part of the terminal is basically the same at both sides of water: the material is stacked in long piles in the open air or in closed silo's, depending on the type of cargo.

The piles are separated by the space for conveyor belts and the rails for the stacking / retrieving equipment (see *Figure 6- 7*).

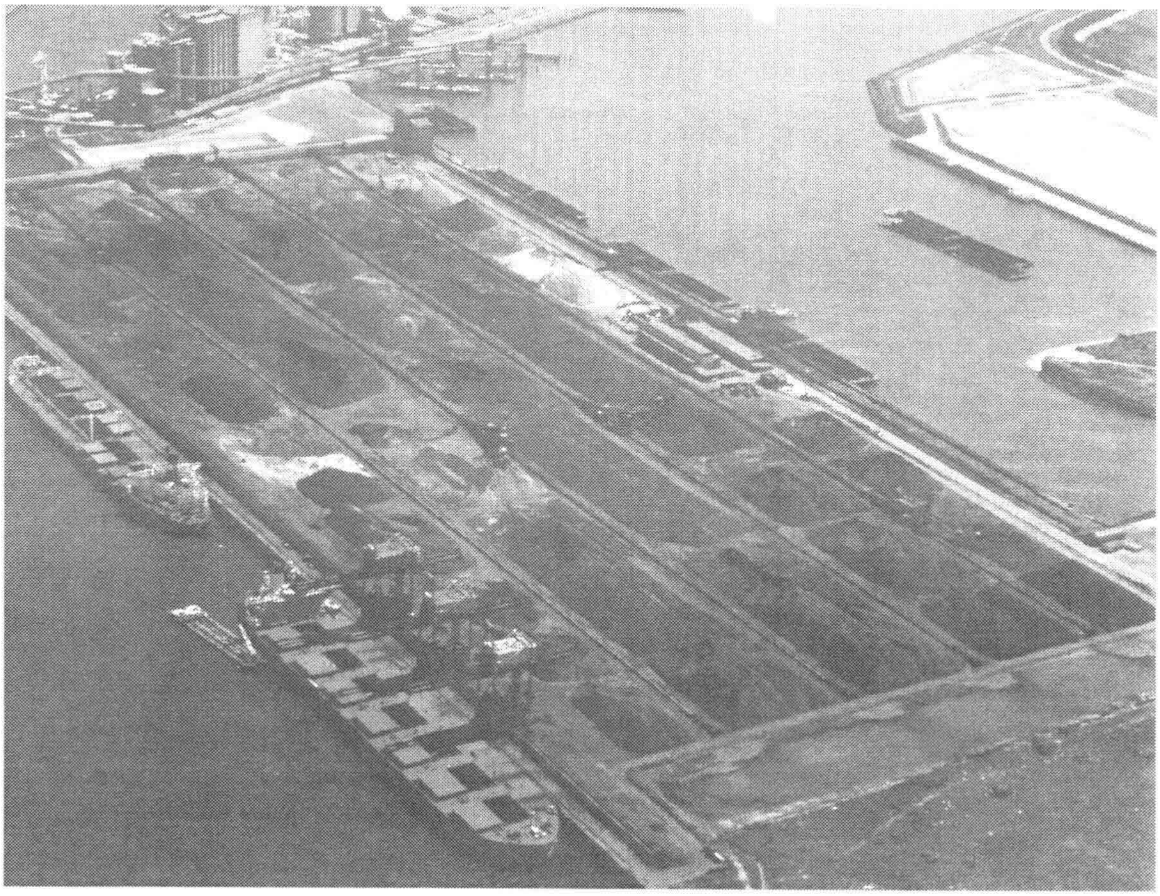


Figure 6- 7: A dry bulk terminal

(vii) Fruit Terminals

Modern fruit terminals are characterised by refrigerated warehouses, which are located near the waterfront. In some ports the cargo is transferred directly from the ship into the warehouse by means of conveyor belts. In most ports however there are luffing cranes at the quay, which can handle the different forms of packaging in which fruit is transported, palletised boxes or containerised. These cranes are much lighter that the ones on a container terminal or for dry-bulk handling, see *Figure 6- 8*.

Figure 6- 8: Fruit terminal

(viii) Fish Handling Facilities

As fishing ports may vary from a simple beach landing to a full fledged harbour, the facilities also show a large variation. The minimum requirement is a refrigerated shed for storage of the catch. When the fleet and size of fishing vessels grows the harbour is usually equipped with a whole range of facilities, comprising quays, fish processing and marketing buildings, and areas for supply of the vessels, berthing while in port and ship repair. A typical example of a modern fisheries port is given in *Figure 6- 9*.

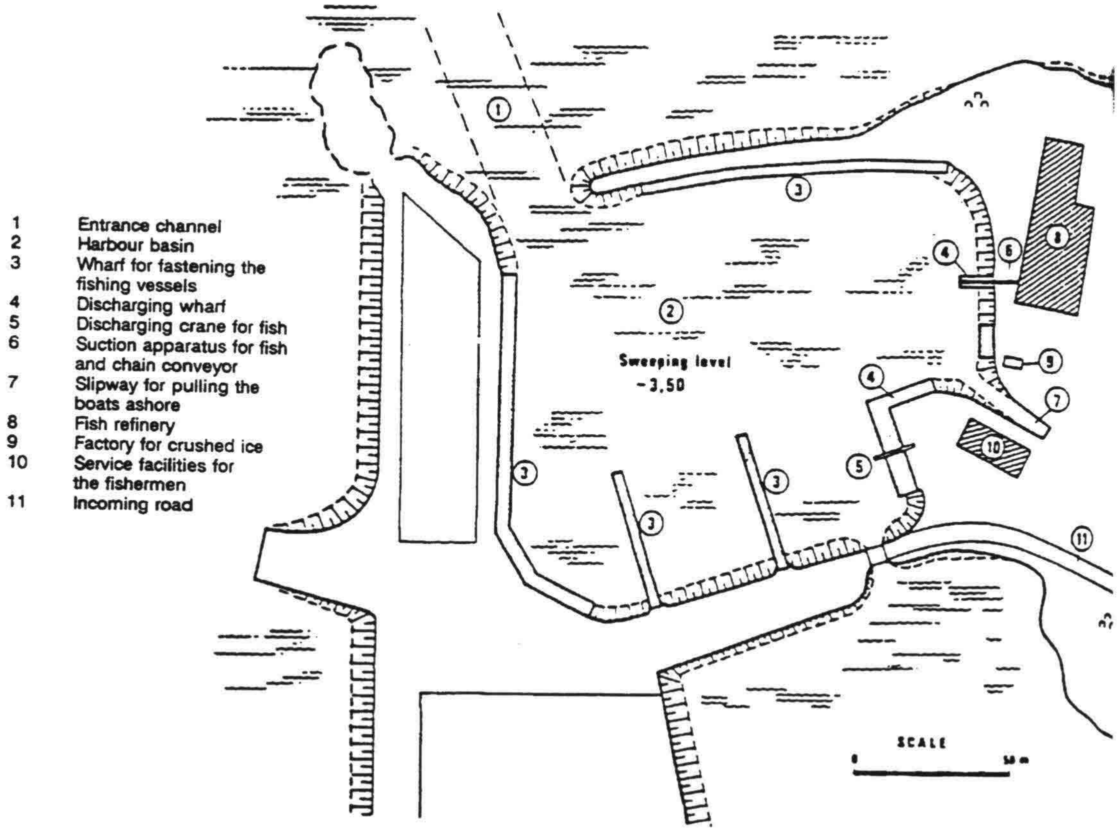


Figure 6- 9: Lay-out of the fishing port of Kalajoki, Finland

(ix) Inland Water Transport Terminals

Like the seaports the lay-out of barge terminals depends on the type of cargo handled. This may vary from multipurpose / containers to bulk cargo and the characteristics are similar to those of the seaport terminals. As mentioned in Chapter 3 the transport of containers by barge is rapidly increasing and with that the need for terminals. Very recently the Dutch stevedore ECT opened a barge terminal along the Rhine at Duisburg, with special container cranes and stacking areas for different types of containers. Similar terminals are found along the major rivers for the handling of relatively large numbers of boxes. Small scale terminals are gradually being established along the smaller rivers and canals, as demonstrated by the map of *Figure 6-10*.

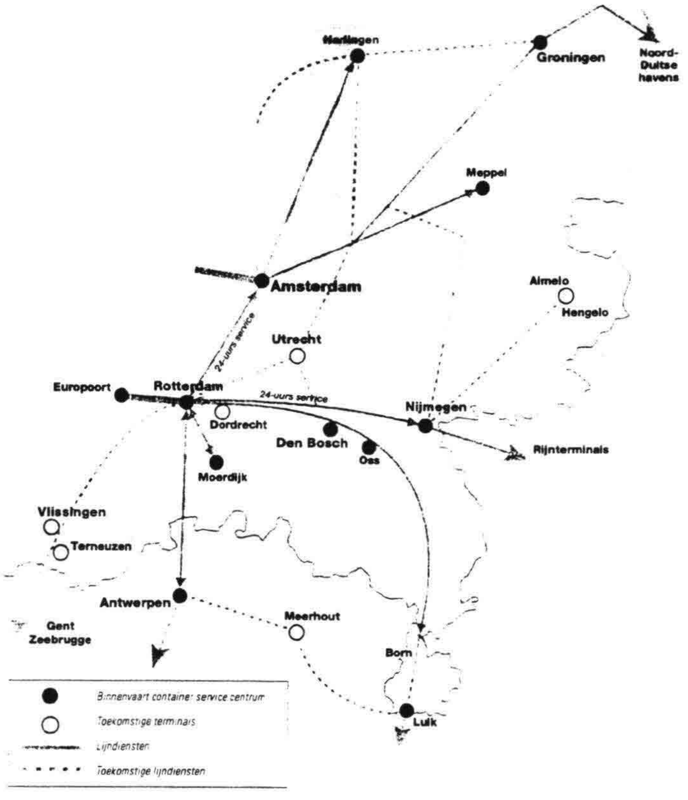


Figure 6- 10: Network of container terminals in The Netherlands

(x) (Passenger) Ferry and Cruise Terminals

While the Ro/Ro terminal is primarily built for cargo transport, the passenger ferry and cruise terminal is focussed on the quick and safe movement of passengers. It will be clear that there is an overlap between the two, where both cargo and passengers are transported by the same ship.

Passenger ferries and cruise terminals require a terminal building like a railway station, with ticket counters, waiting lounges, rest rooms, shops and restaurants. Between this building and the berthed vessel the passengers must be able to embark and disembark in a smooth and safe manner. For ferries this is normally achieved by bridges with sufficient capacity to minimise the time spent at the berth. In case of a cruise ship the time factor does not play an important role, but care is taken that passengers are transferred safely between the ship and the terminal building (see *Figure 6-11*).

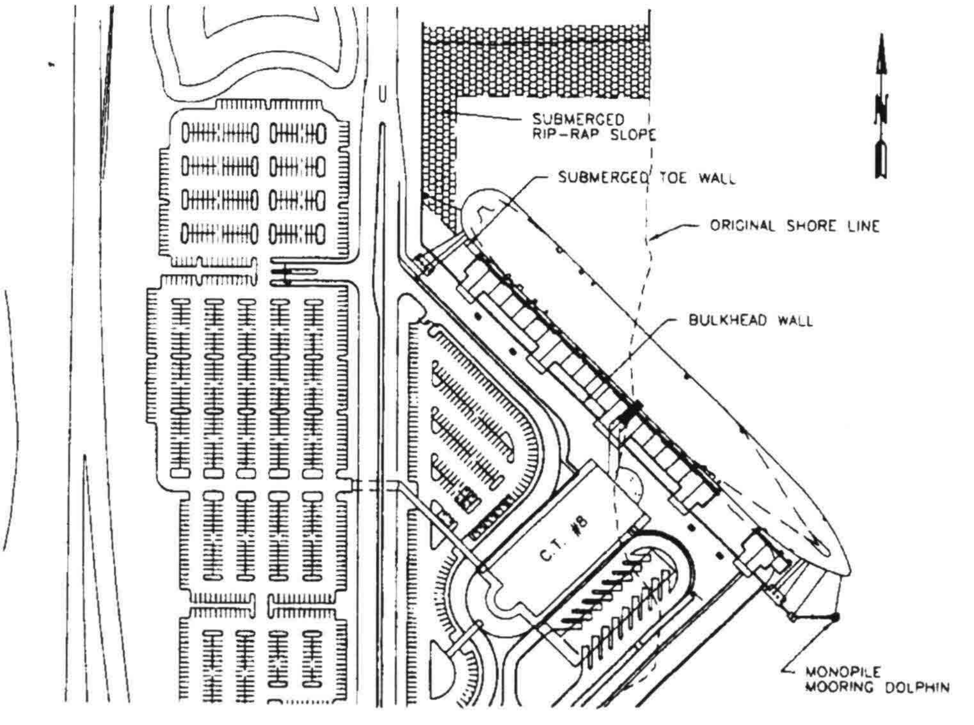


Figure 6- 11: Cruise terminal lay-out

6.5. Terminal capacity: maximum or optimum

Terminal capacity can be defined in different ways, and without specifying which definition is used and about which part of the terminal one is talking, a discussion makes no sense.

To start with, capacity can refer to (un)loading, it can refer to storage or to through-transport. Here it will be assumed that through-transport poses no bottleneck and that terminal storage capacity is tuned to the (un)loading capacity, but also constitutes no restraint. Needless to say that, in practice, this is not always the case.

In terms of (un)loading capacity we can distinguish, in a general sense, the following:
- maximum instantaneous capacity
- maximum annual capacity
- optimum annual capacity

The **maximum instantaneous capacity** can only be maintained for a short spell, e.g. when well rested crane drivers start unloading a still full dry bulk carrier. This sort of capacity is of no interest to the port planner, but it is of great interest to the equipment and system designer, because all equipment downstream must at least have the same peak capacity to avoid overload and clogging up.

The **maximum annual capacity** is the mean hourly capacity (averaged over a long period) x abt 21 (effective hours/day) x 360 (days/year). It is the capacity that can theoretically be attained if the berths have a 100% occupation, and provided that there are no constraints on the land-side of the terminal. But, since ship arrivals and ship loading and unloading are time-wise stochastical processes, a 100% occupation leads to tremendous congestion on the sea-side of the terminal and to excessive ship waiting times, it is of no real interest to anybody. However, it is the way that many port authorities opt to define the capacity of their port, because it shows impressive figures.

The **optimum annual capacity** is the sort of capacity with which the port planner has to deal. Unfortunately, 'optimum', again, can be defined in different ways. If 'optimum' is meant to be 'economic optimum', it generally is that capacity -or rather cargo throughput- for which the overall port costs per ton of cargo reach a minimum. The overall port costs comprise all fixed and variable terminal costs and all vessel-related costs during the service period as well as the waiting period, including all port dues. In a way, the restriction of costs to the port boundaries is a simplification, but for multiple and split transport chains one cannot do otherwise.

In case of integrated, centrally managed transport chains (which applies to many liquid and dry bulk trades), the true economic optimum can be sought, which is attained when the total transport cost per ton from source or supplier to consignee or consumer has reached a minimum. Port costs may then be well above an absolute minimum, e.g. because a deeper and more expensive channel and quay allow the use of bigger ships, which reduces maritime transport costs. In other words, when talking about optimum terminal capacity in those circumstances, it has to refer to a given size of ship, which size results from an earlier and more general optimisation exercise.

However, 'optimum' need not always refer to an economic optimum, i.e. there are other optimisation criteria imaginable and also used in practice. For instance, container terminals that have to operate in a heavily competitive regional market may wish to guarantee a certain minimum service level in order to attract shipping companies. Such a service level could be described, for example, by a guarantee that no more than x% of the vessels visiting the terminal, will have a waiting time in excess of y hours and/or that no more than m% of the vessels will have a total port time in excess of n hours.

The tools used in quantifying these optima, whether referring to cost minima or to service level, are, for relatively simple situations, the analytical queuing theory, or, for more complex conditions, discrete simulation models. They yield for specific boundary conditions the ship waiting times, which can be incorporated -if so desired- into the cost minimisation study.

6.6. Terminal dimensions

For different discrete numbers of berths or for different quay lengths the optimum cargo unloading capacity can be calculated in accordance with Section 6.5 above. Reciprocally, the optimum number of berths or the optimum length of quay for a projected cargo flow can be obtained by interpolation in between the so calculated optimum capacities.

What remains to be determined, is the optimum size storage area(s) F_{0c} required for this same projected cargo flow.

In general terms:

$$F_{oc} = \alpha \cdot A \cdot \bar{t}_d / 365 \cdot C \cdot f(P_s, P_l, P_{td})$$

in which:

F_{oc}	=	gross storage area required
A	=	specific area required to store a unit (ton, TEU, m^3) of cargo
α	=	(gross area x nominal storage height)/(net area x mean storage height)

(α is a constant for a given type of cargo and a given cargo handling method. The relation gross area/net area depends on the space required for equipment movements. The ratio nominal/mean storage height depends on the permissible mean height at full utilisation of the storage area. Sometimes this is equal to the nominal height, e.g. for palletised bags of cement, sometimes it is less, e.g. for containers.)

$\bar{t}_d$	=	mean dwell time of the cargo in the storage area in days
C	=	projected cargo flow (tons, TEU's, m^3) per year
P_s	=	probability density distribution in time of cargo arrivals or departures on the sea-side of the terminal

(P_s in itself is a function of the probability distributions of ship arrivals and of cargo volumes per ship.)

P_l	=	ditto of cargo arrivals or departures on the land-side of the terminal
P_{td}	=	ditto of the dwell time of the cargo on the terminal

Often, P_l and P_{td} may be assumed to be uniform. If this is not the case and/or if the type of distribution of P_s is inconvenient for an analytical approach, discrete simulation models may be used to determine the optimum size of storage area (as well as optima of number and capacity of terminal equipment).

A more detailed discussion will be given for individual types of terminals in the relevant chapters.

As a very rough order of magnitude indication, the following throughput capacity figures may serve:

- conventional general cargo 4 - 6 $t/m^2/year$
- containers 6 - 10 $t/m^2/year$
- coal 15 - 25 $t/m^2/year$
- iron ore 30 - 40 $t/m^2/year$
- crude oil 40 - 50 $t/m^2/year$

The m^2 refers to the total terminal area, including internal roads, offices, workshops and the like.

However, it is not difficult to present for each of these commodities examples which are either below or above the ranges indicated.

Chapter 7. Container terminals

7.1. INTRODUCTION 7-2

7.2. CONTAINER TRANSPORT AND TERMINAL OPERATIONS 7-3

7.2.1. CONTAINER TYPES AND SIZES. 7-3
7.2.2. THE TERMINAL PROCESSES. 7-4

7.3. LAY-OUT DEVELOPMENT 7-14

7.3.1. QUAY LENGTH AND NUMBER OF PORTAINER CRANES. 7-16
7.3.2. APRON AREA 7-19
7.3.3. STORAGE YARD 7-19
7.3.4. CONTAINER TRANSFER AREA AND BUILDINGS 7-24

7.4. REFERENCES 7-25

Chapter 7. Container terminals

7.1. Introduction

In Chapter 2 the (early) development of containerised transport has been treated. The most important recent developments are presented below, in as far as relevant for the planning and design of new terminals.

(i) The world container traffic reached a volume of 160 million TEU in 1997, representing 1500 million tons of cargo (Containerisation International, 1998). The top 20 container ports handled more than 50% of this traffic. Notwithstanding the Asia crisis the growth rate in 1998 remained around 5% and recent forecasts predict this growth to continue for the coming 5-10 years.

(ii) The size of container ships is still increasing as shown in *Table 7-1*. Whether a 15,000 TEU ship will ever be built is still subject of discussion. And the dimensions of such a vessel given in the table below are also subject of research. The cranes ordered for new terminals for these so-called Jumbo-vessels have already a boom reaching 60 m outside the quay front, indicating that 20 boxes across on deck is taken as a serious possibility.

Table 7-1: Development of container vessels
(source: Cargo systems, opportunities for container ports)

Container vessel	L (m)	B (m)	D (m)	Capacity (TEU)
1st generation	180-200	27.0	9	750-1100
2nd generation	225-240	30.0	10.5	1500-1800
3rd generation	275-300	32.0	11.5	2400-3000
4th generation	290-310	32.3	12.5	4000-4500
Post Panamax:				
APL C-class (1988)	275	39.4	12.5	4340
NYK Altair (1994)	300	37.1	13.0	4740
Reg. Maersk (1996)	318	42.8	14.0	6000
P&O Nedlloyd (1998)	340	42.8	13.0	6670
?	325	47.0	14.0	8000
?	400	69.0	14.0	15000

(iii) the growth of vessel size and TEU capacity poses new challenges on ports and terminal operators to keep the service time of these ships within 24 hours. Various directions are followed to solve this problem: increase of crane productivity, introduction of automation and the handling of the ship on both sides. Probably a combination of measures will be needed, but it will take years before the new technology will reach a stage of general acceptance.

The logistical process of container terminals is often determined by the future user, the stevedoring company or the shipping line, which operates its own terminals. They have their preferred terminal concept, based on past experience and in-house technical know0how. The port planner must integrate the requirements following from this logistical process with the spatial conditions of a specific location.
In the stage of masterplanning the future terminal operator is often not yet known. In this case the port planner will apply the general principles as outlined in this Chapter and will have to create sufficient flexibility in the lay-out to be able to accommodate future users.

7.2. Container transport and terminal operations

Before going into actual design aspect the logistical process on the terminal is described, starting with some further information on the central element, the container.

7.2.1. Container types and sizes

The International Standards Organisation (ISO) issued the official standard dimensions of containers:

- the most common standard is the TEU (Twenty feet Equivalent Unit), which is a container with L = 20 ft (6.10 m), B=8 ft (2.44 m) and H=8 ft or 8 ft 6 inches (2.60 m). Its own weight is about 24 kN. Its internal volume is approximately 32 m^3 and the maximum "payload" amounts to 220 kN. This implies that the container can not be filled to the limit with high density cargo. In practice the payload is much lower even, with an average value around 120 kN.
- The forty feet container (2 TEU or 1 FEU) measures twice as long and has the same width and height as the 20 ft container. Its own weight is about 45 kN and the internal volume measures 65 m^3. The maximum payload is only marginally higher than the TEU: 270 kN, but again the average payload in practice is only 175 kN.

Besides the ISO containers there are several other types in use, including:

- Oversize containers (longer than 40 ft).
- High Cube containers (higher than 8 ft 6 inches).
- Overwidth containers (wider than 8 ft).

The latter category originally measured 8 ft 2.5 inches (2.50 m), because that width allowed to place two pallets side-by-side and it was the maximum width permitted on the West European roads. Since this was relaxed to 2.60 m, the container width of 8 ft 6 inches has become more common.

The existence of non-ISO containers has several negative consequences, as can be expected:

- on the ship the cell guides in the holds are designed to receive ISO containers. Hence Oversize and Overwidth containers have to be placed on deck. This is limiting the flexibility of the loading schedules.
- On the terminal the Oversize containers need their own stacks, which again limits the flexibility.

- The "spreader", the frame used under the crane trolley or by the yard equipment to pick up a container by means of the four twistlocks at the corners, must be adjustable to accommodate the different sizes.
- For the onward transport of containers by road or rail different sizes require special provisions on the trailer or railwagon to fasten the containers at the corner castings.

Apart from the variation in size there is a range of special purpose containers (both ISO and non-ISO), including the following:

- refrigerated containers or reefers, requiring electrical supply points both on the ship and on the terminal.
- tank containers, open frames of (mostly) TEU size around a tank. Because of the hazardous contents these containers are separated from the rest in the storage yard.
- Flats, in fact just a bottom structure with corner castings used for large pieces of cargo, which can not be placed inside a box (but comply with the size and payload requirements).

All these require separate locations on the terminal and therefore have to be included in the planning.

7.2.2. The terminal processes.

The flow of containers through the terminal is shown schematically in *Figure 7-1*. Following the route of an import container, the different processes on the terminal can be described.

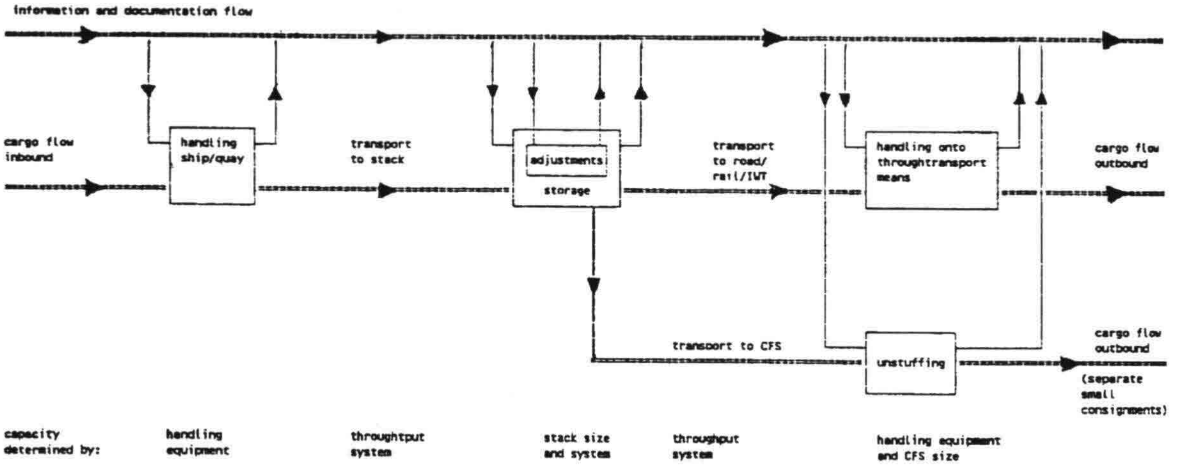


Figure 7-1: Flow of cargo through the terminal.

<u>At the quay</u>

Prior to arrival of a ship the containers to be unloaded have been identified (and those to be loaded have been arranged in the export stack in such a way that they can be transferred to the ship in the right order).

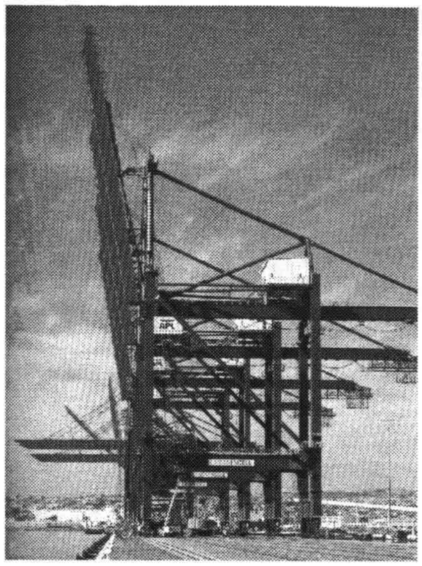
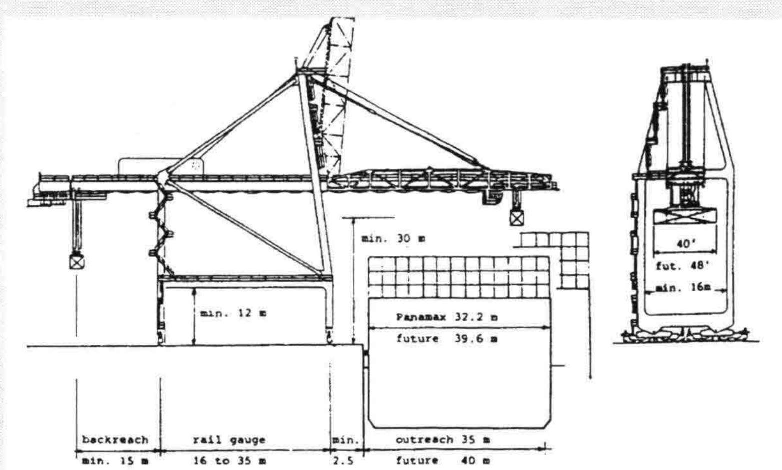


Figure 7-2: Post Panamax Portainer cranes in the port of Los Angeles.

Immediately after the ship has made fast the lashings are taken off the containers above deck and the ship-to-shore gantry cranes (or portainers) start unloading. A modern portainer crane is as high as a cathedral, especially with their booms up as shown in *Figure 7-2*.

These cranes are generally rail mounted, although recently mobile cranes have been introduced again. They are characterised by a boom arm, which can be lifted, as shown in Figure 7-2, or pulled inward, depending on the make. The cranes are provided with a trolley and a cabin, which moves with it, from which the crane driver (or operator) guides the trolley and the spreader to the right container on the ship. The container is picked up and transported to the space between the seaward and landward leg of the crane, where it is lowered and placed on the transport vehicle in use between quay and stack. Some typical properties of the crane are:

- *lifting capacity:* *around 400 kN*
- *boom length:* *going up to 55 m. for the hub terminals*
- *rail gauge:* *varying from 15 m. to 35 m.*
- *width between legs:* *min. 16 m. to allow Oversized containers to pass*
- *breadth outer bogeys:* *< 2 x 40', to allow cranes at every other bay*
- *crane productivity:* *peak 40-50 moves / hr.*
  average 20-30 moves / hr.



Box 7-1: Ship-to-shore gantry cranes

Between quay and storage yard

For the transport between the quay and the storage areas several options exist, depending on the size and the throughput of the terminal and on the preferences of its operator. In order of sophistication these are:

(i) Forklift truck (FLT, see *Figure 7-3*). Even the largest FLT's presently available can only handle 20 ft containers, with an average payload. For this reason the 20 ft containers have two rectangular channels in the bottom structure, for the forks of the FLT to pass under the box. A 40 ft container does not have this. In addition FLT's are provided with spreaders to pick up a container from above. Apart from this limitation the FLT needs sideway access to a stack, which can therefore be only two containers wide and requires much space between the stacks. In view of these limitations the FLT is used most often for the handling of empty containers only. On multipurpose terminals with limited container throughput and much space this type of equipment may offer an economic solution.

(ii) Reach stacker (see *Figure 7-4*). The difference with the FLT is that this machine handles the container by means of a spreader. Hence it can reach the second row of containers in a stack, which can therefore be four rows wide. However the space efficiency is still low.

(iii) Chassis (see *Figure 7-5*). Single trailers for use in the yard only, where they are moved by tractor units. The containers are stored on the chassis. This approach, quite customary in U.S. ports, has the disadvantage of low space utilisation, compared with the stack approach applied in Europe and Asia.

(iv) Straddle Carrier (SC, see *Figure 7-6*). For this equipment the stack consists of (not too lengthy) rows of containers, separated by lanes wide enough for the legs and tyres of the SC. Depending on the nominal stack height, 2- or 3-high, the SC can lift a container 1 over 2 or 1 over 3. Certainly in the latter case the SC becomes quite tall and difficult to manoeuvre since the driver cabin is on top. For reasons of space efficiency and flexibility in use the SC is quite popular among terminal operators however.

The above four types of equipment deal with the transport from quay to storage yard and within the yard. On high capacity terminals the two functions are often separated, with the following two types only used for quay-yard and vice versa, and dedicated cranes within the stack.

(v) Multi Trailer System (MTS, see Fig. 7-7). A series of up to 5 trailers interconnected and pulled by one yard tractor, offers a substantial reduction of the number of drivers needed. The system, developed and manufactured in The Netherlands, has a special device to keep all trailers in line when making a turn.

(vi) Automated Guide Vehicle (AGV, see Fig. 7-8). Developed and implemented by ECT on the Delta-SeaLand terminal on the Maasvlakte, these vehicles follow standard tracks in the pavement between quay and storage yard. They are remote-controlled from a central station and therefore mean a further drastic reduction of manpower. One of the "teething troubles" of this innovative design is that the pavement is showing rapid deterioration, due to the high wheelloads and the "rutting" (all AGV's follow exactly the same track which causes channels in the pavement).

Figure 7-3: A forklift truck

Figure 7-4: A reach stacker

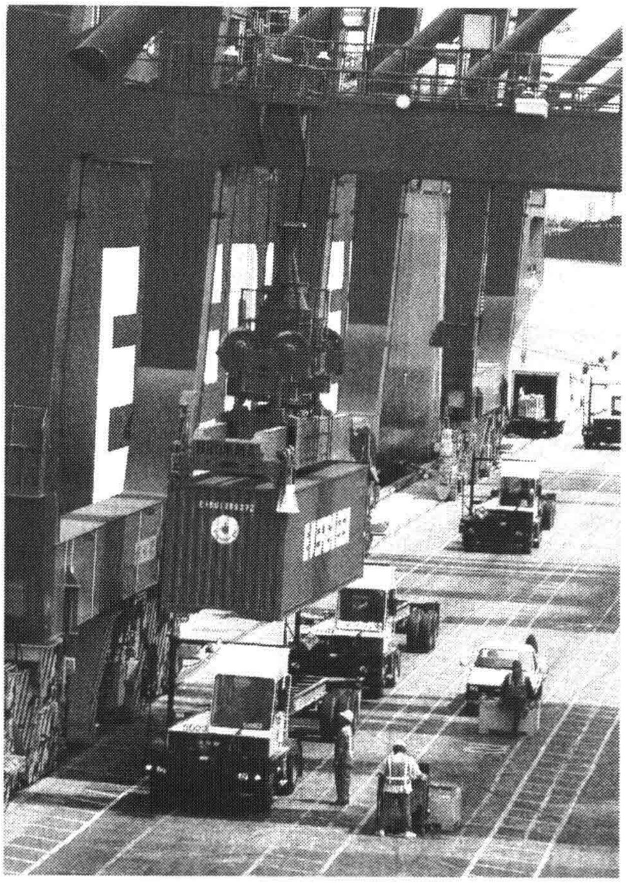


Figure 7-5: A chassis

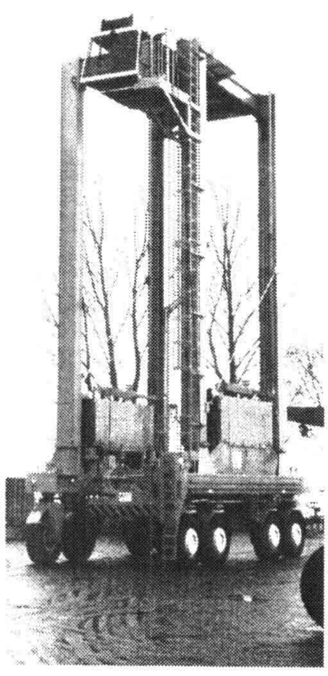


Figure 7-6: A straddle carrier

Figure 7-7: Multi Trailer System (MTS)

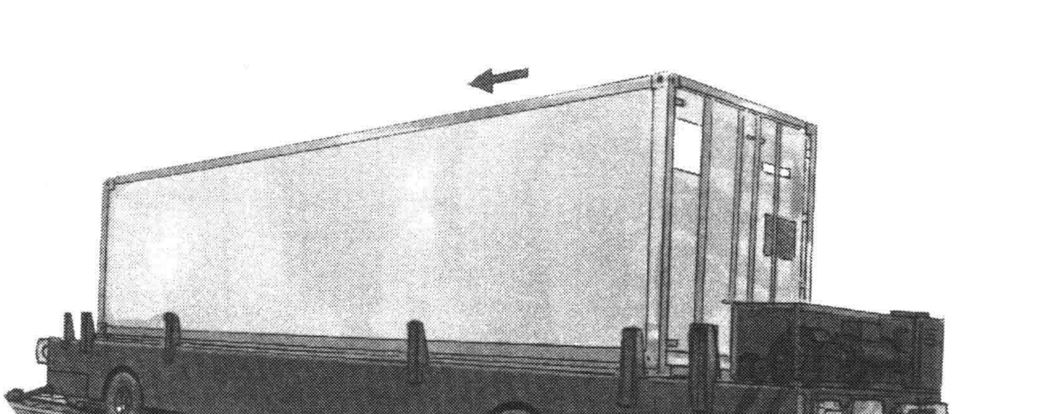


Figure 7-8: Automated Guided Vehicle (AGV)

ADVANTAGES	***DISADVANTAGES***
Fork lift truck / Reach stacker	
• *low investment equipment*	• *much storage space*
• *simple / flexible in operation*	• *labour intensive*
• *mostly used for empties*	• *only handles loaded 20 feet containers*
Terminal chassis	
• *low investment pavement*	• *much storage space*
• *low maintenance costs*	• *large number of chassis needed*
• *simple / flexible in operation*	• *low throughput capacity*
	• *labour intensive*
Straddle carrier	
• *high throughput capacity*	• *complicated equipment*
• *one type of equipment for entire terminal*	• *high investment and maintenance costs*
	• *highly qualified personnel needed*
	• *labour intensive*
Multi-trailer system (MTS)	
• *less labour needed*	• *less flexible in operation*
• *high throughput capacity*	
• *traffic peaks easily absorbed*	
Fork lift truck / Reach stacker	
• *minimum labour costs*	• *high investment and maintenance costs*
• *high throughput capacity*	
• *traffic peaks easily absorbed*	

Box 7-2: Quay to storage transport systems

Within the storage yard.

The MTS and AGV's deliver the containers outside the stacks and for fiurther handling within the stack separate equipment is needed. Various types of gantry cranes are used as described below.

(i) Rubber Tyred Gantry (RTG, see *Figure 7-9*). This gantry crane is commonly used in stacks up to 4 containers wide and nominal 2 high. They are flexible (can be moved from one stack to another), but require good subsoil conditions in view of the relatively high wheelloads on the pavement.

(ii) Rail Mounted Gantry (RMG, see *Figure 7-10*). Where the subsoil conditions are less favourable the RMG is preferable, because the rails spread the load better.. Notwithstanding the greater spanwidth of the crane (up to 10 containers wide) the crane bogeys provide for lesser wheelloads. Also the rail can be more easily supported, if needed.
While most RMG's have the rails at groundlevel, a new terminal in Singapore has an overhead crane running on rails on beams, supported by concrete columns at 18 m above groundlevel.

(iii) Automated Stacking Crane (ASC, *Figure 7-11*). The first cranes of this type were introduced by ECT in conjunction with the AGV's. They reach across 5 containers and operate 1 over 2 high. For the next terminal the cranes are designed for 1 over 3 high to improve the spatial efficiency.

ADVANTAGES	***DISADVANTAGES***
Rubber tyred gantry (RTG)	
• *good space utilisation*	• *high maintenance*
• *flexible, high occupancy rate*	• *needs good soil conditions*
• *high productivity*	• *highly qualified personnel needed*
Rail mounted gantry (RMG)	
• *good space utilisation*	• *high investment*
• *reliable, low maintenance*	• *inflexible*
• *automation possible*	
Automated stacking crane (ASC)	
• *minimum labour costs*	• *high investment and maintenance costs*
	• *labour intensive*

Box 7-3: Equipment within the stacks

Figure 7-9: Rubber Tyred Gantry (RTG)

Figure 7-10: Rubber Mounted Gantry (RMG)

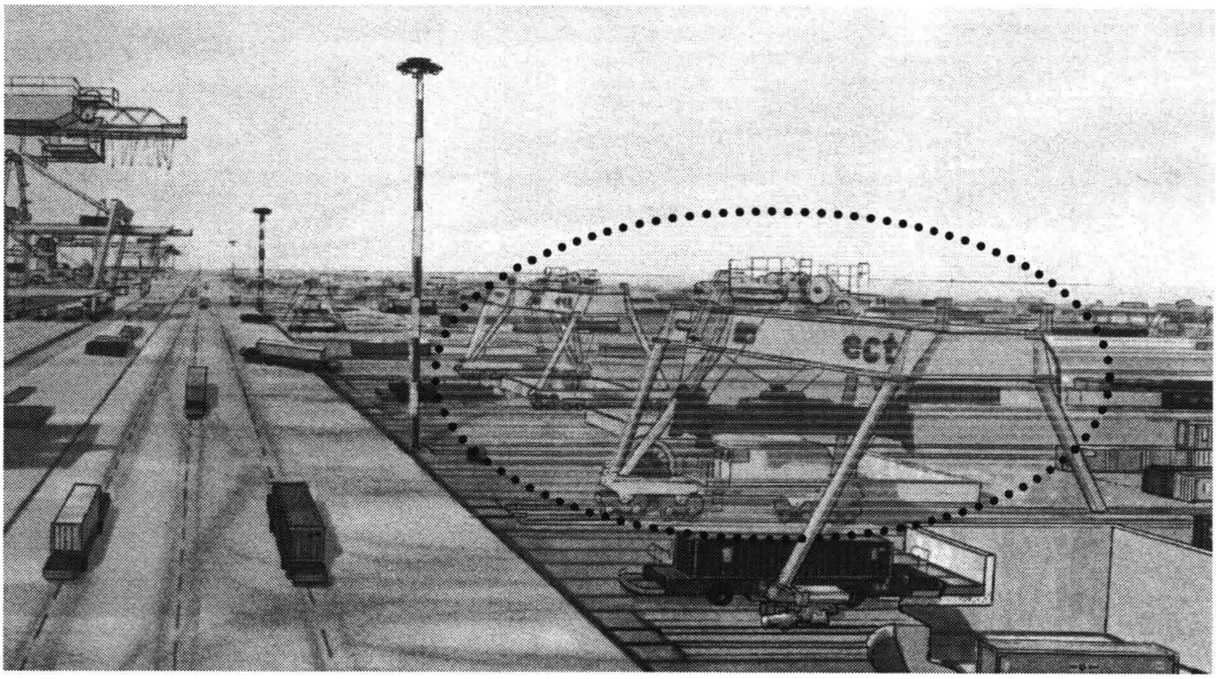


Figure 7-11: Automated Stacking Crane (ASC)

From storage yard to hinterland transport

The transport of containers between the stacks and the truck stations (and vice versa) is done mostly by SC, because these can move over the truck. From the yard to a rail- or inland barge terminal various types of equipment are used, depending on the distance. The same considerations apply as for the equipment between quay and storage yard.

The gate

For road transport this is the central element on the terminal. Here the import containers leave the terminal and the export containers arrive. All entrees and departures are recorded and customs formalities are dealt with. High capacity terminals require advanced information technology to avoid frequent queues and long waiting times for the trucks.

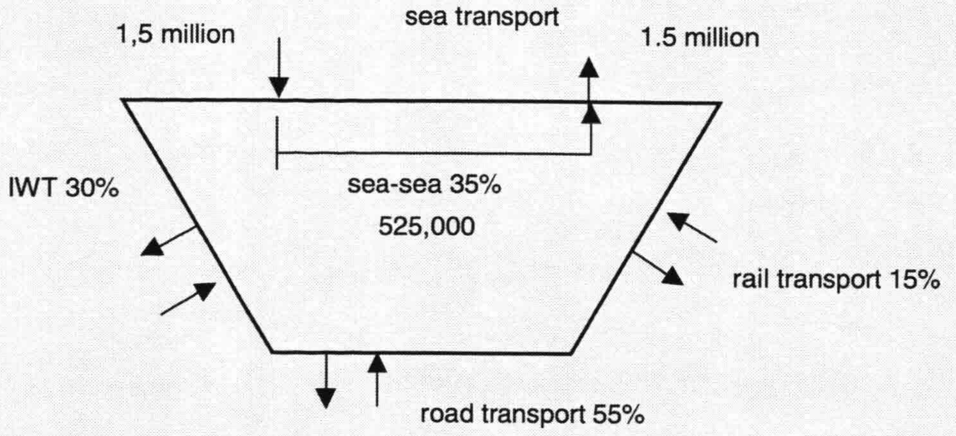
7.3. Lay-out development

The terminal lay-out depends to a certain extent on the handling systems chosen. An illustration of this fact is the orientation of the containers in the stack: on terminals with SC the length axis of the containers can be either perpendicular or parallel to the waterfront. In case of MTS or AGV the orientation is more likely to be perpendicular to the quay, containers being delivered or collected along the seaward face of the stacks.
This implies that the planning of a new terminal is a multidisciplinary exercise in which the preference of the operator for a specific handling system often forms the starting point.

For the lay-out the following planning elements have to be determined and quantified:

- quay length and number of portainercranes
- Apron area
- Storage area
- Container transfer area (to truck and rail)
- Buildings (container freight station, office, gate and workshops)

The dimensions of all planning elements are a function of the yearly averaged flows of containers, which are presented in the so-called modal split. The modal split gives the (forecasted) numbers of TEU's entering and leaving the terminal via the sea (main lines, feeder lines and short-sea lines), road, rail and IWT. An example of a modal split is shown in Box 7.4, with arbitrary numbers. The assumption that the flows are balanced per transport mode is clearly a simplification of reality. In most cases there is a distinct imbalance. The throughput figures shown include the empty containers, which normally are given explicitly, because they require separate stacking space.



	Number of containers
Total throughput	3,000,000
Sea import	1,500,000
Sea-sea 35%	525,000 -
Out via land	975,000
In via land	975,000 +
Total landside	1,950,000
Of which:	
Road 55%	1,072,500
IWT 30%	585,000
Rail 15%	292,500

Containers across the terminal:
Total landside + sea-sea = 2,475,000

Box 7-4: Example of a modal split

The modal split gives the transport flows in number of containers. This is relevant for the quay length design, because the container crane production is also in container(moves) per hour. For the capacity of the storage yard the division between 20 ft and 40 ft containers has to be known, because the surface area depends on this. The other capacity calculation are therefore also carried out in TEU. The above division is given by the TEU-factor, which is often characteristic for different types of port and can be derived from statistical data.

TEU-factor: $$f = \frac{N_{20'} + 2 \cdot N_{40'}}{N_{tot}} \qquad (7\text{-}1)$$

in which:

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

When the ratio of 20 ft to 40 ft containers is 4 to 6, the TEU-factor amounts to 1.6. In developing countries rather low TEU-factors are encountered, indicating that a large percentage of goods is transported in 20 ft containers. The main line traffic shows a shift towards 40 ft containers over the years, which is executed to continue for some time.

The initial planning is often based on relatively simple design formulae, as presented in the subsequent sections. The final lay-out is always optimised by means of simulations, which permit to analyse the complete terminal process, including the stochastic variation of ship arrivals, crane and other transport equipment availability, and container arrivals/departures via land.

7.3.1. Quay length and number of portainer cranes.

A first approximation of the number of berths and hence of the quay length is made on the basis of an estimated berth productivity. Such an estimate is made as follows:

$$c_b = p \cdot f \cdot N_b \cdot t_n \cdot m_b \qquad (7\text{-}2)$$

In which:

c_b	=	average annual number of TEU per berth	(TEU/yr)
p	=	gross production per crane	(moves/hr)
f	=	TEU factor	(-)
N_b	=	number of cranes per berth	(-)
t_u	=	number of operational hours per year	(hrs/yr)
m_b	=	berth occupancy factor	(-)

The gross crane productivity p is subject of much confusion, due to the lack of a commonly accepted definition. In Equation 7-2 p is the average number of containers moved from ship to shore and vice versa during the period between berthing completed and deberthing started. This period includes all sorts of "unproductive" intervals such as for crane repositioning from one hold to another, removal of hatches and replacing them, time loss between shifts and simple repairs of the cranes. A net crane production of 50-60 moves per hour is easily reduced to a gross productivity of 25 moves per hour by above losses.

For a modern terminal receiving 4000-5000 TEU ships on a regular basis and working 24 hours per day, 360 days per year the average ship size is assumed to be about 2000 TEU, with a length of 250 m. We would expect on average 3 cranes to be available per berth and a rather low berth occupancy of 35%. A gross crane productivity of 25 moves per hour and a TEU-factor f = 1.5 give a berth productivity of 340,000 TEU per year.

Subsequently the number of berths n is calculated as:

$$n = \frac{C_s}{c_b} \qquad (7\text{-}3)$$

where C_s is the total number of TEU entering and leaving the terminal by seagoing vessels (including empties). For a throughput of 2 million TEU/year one would need about 6 berths with the above productivity. And with an average ship length of 250 m the total quay length amounts to about 1650 m.

It is stressed that this estimation is very rough and should followed by a more precise calculation as outlined below. However, this approach gives good insight in the importance of various parameters. Some comments are relevant in this respect:

(i) a berth occupancy of 0.35 is rather low, but often encountered due to the stringent conditions posed by the shipping lines with respect to minimum waiting time.

(ii) a berth productivity of 340,000 TEU/yr is higher than most terminals can achieve at present. On many container terminals in developing countries the berth productivity is more in range of 100,000-150,000 TEU/yr. Although the berth occupancy is normally very high (80-90%, which creates in turn long waiting time for the ships) this can not compensate the rather low TEU-factor, the frequent breakdowns of equipment and the low crane productivity. On modern hub terminals the berth productivity can be as high as 500,000 TEU/yr, due to the high TEU-factor, larger average ship size and more cranes per ship, each with a high gross productivity.

(iii) The number of portainer cranes per berth depends on several factors:
-the range of vessel sizes and the (weighted) average size.
-the number of berths.
-the maximum number of cranes which can operate on one ship.

Along a conventional quay the cranes can work on every other hold. For practical reasons (including the movements of other transport equipment between the portainers and the storage yard) Post Panamax ships have not more than 5 cranes working simultaneously. Smaller vessels have less cranes. When a new terminal would start with one berth only, but should be able to handle a Post Panamax vessel efficiently, 5 cranes are needed for that single berth. For the latest generation of ships this is not enough (see Box 7-5). On the other hand when a marginal quay consists of several berths, the low berth occupancy permits to reduce the average number of cranes per berth. For the above example with 6 berths an average of 3 cranes is therefore justified, in a first approximation.

The second and more accurate method for determining quay length requires also a more precise input in terms of expected annual number of calls N and the average "parcel size" c_s, i.e. the number of containers unloaded and loaded per call. The relation with C_s becomes:

$$C_s = N \cdot c_s \qquad (7\text{-}4)$$

From the parcel size, the gross crane productivity and the number of cranes per berth the average service time is derived. By applying queuing theory the number of berths (service points in the system) and the related average waiting time are obtained, assuming random ship arrivals. It will be seen that relatively low berth occupancy rates are found, in order to keep the waiting time low.

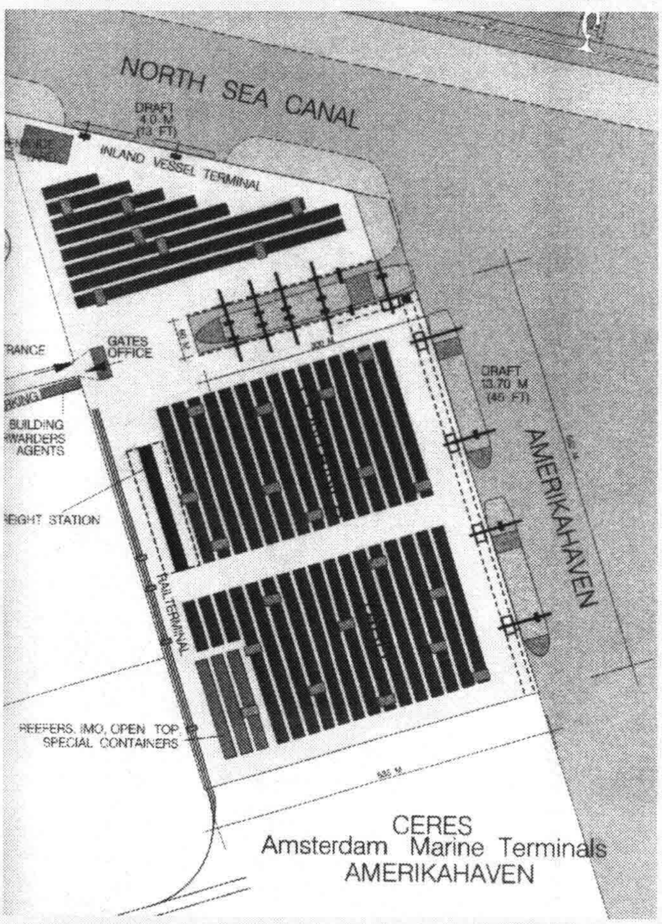
In practice most container ships sail on fixed routes and within tight schedules. Unless significant delays occur due to bad weather or vessel repairs, the ships arrive within about 1 hour of their scheduled time of arrival. This means that the assumption of random arrivals is conservative. Most likely the berth occupancy can be increased to 0.5-0.6 without significant waiting time resulting for the majority of the ships. In the competitive stevedoring market it is not easy to reduce the service level demanded by the shipping line. It will be interesting to check the berth occupancy of a terminal operate by the shipping line itself.

Another aspect of this service level is the maximum time spent in port, which is stipulated at 24 hours. The latest class of Post Panamax vessels with 6000 TEU and above can not be handled within this time period, when the parcel size exceeds 4400 TEU (assuming 1 hour for berthing and 1 hour for departure:

$p \cong f \cong N_b \cong 22 = 25 \cong 1.6 \cong 5 \cong 22 = 4400$ TEU

Solutions to this problem are sought in various directions, including improvement of the crane productivity by further automation and reduction of the cycle time. A very interesting solution is chosen for the new container terminal in Port of Amsterdam, as explained in Box 7-5.

The approach chosen for this new terminal to achieve a berth productivity of 300 moves per hour is to have a quay on both sides of the ship, each equipped with 5 portainer cranes with a gross productivity of 30 moves per hour. The width of the basin is designed at 55 m and all cranes have a boomlength of 60 m, thus capable to receive future "Jumbo"ships with 53 m beam, and to operate this at every hold at the same time. The lay-out of this berth within the overall terminal is shown below.



It will be clear that this innovative concept requires special procedures and facilities for safe, but fast berthing and deberthing.

Box 7-5: Ceres Paragon container terminal

7.3.2. Apron area

Once the quay length has been determined, the lay-out of the apron area can be completed. Along a line perpendicular to the waterfront one encounters the following lanes:

(i) a service lane of 3-5 m between the coping and the front crane rail, to provide access to the ships for the crew and for supplies and services.This space is also necessary to prevent damage to the crane by the flared bow of the ship during berthing under some angle.

(ii) The crane track spacing, which is primarily determined by considerations of crane stability (see Box 7-1). A second aspect is the space required for the transport equipment. On most terminals the containers are dropped off or picked up by the portainer within the space between the crane rails. When five portainers are working on one ship, each has transport equipment lining up, which preferably have their own lane for reasons of safety. And depending on the number of crossings of the landward rail along the length of the quay, there may be need for additional lanes.

(iii) The space immediately behind the landward rail is used to place the hatchcovers and/or to lift special containers (such as flats with bulky or hazardous cargo).

(iv) Finally there is a traffic lane for the SC, the MTS or AGV which commute between the storage yard and the quay. The width depends on the traffic system adopted. As a first approximation a width equal to that between the crane rails is reasonable.

It is noted that no hinterland connections are allowed on the apron area, contrary to the conventional general cargo terminals, where truck- and rail access onto the quay was customary. For reasons of efficiency and safety this is not possible on a modern container terminal.

7.3.3. Storage yard

The overall storage yard is usually divide into separate stacks for export, import, reefers, hazardous cargo and empties. In addition one finds a Container Freight Station (CFS) for the cargo, which is imported in one container, but has different destinations ("stripping"), or which comes from different origins and is loaded into one container for export ("stuffing"). After an import container is stripped and before an export container is stuffed, the cargo is stored in the CFS, which is covered.
The surface area requirements for the different stacks (import, export, reefers, empties, etc.) can be calculated as follows:

$$O = \frac{C_i \cdot \bar{t}_d \cdot F}{r \cdot 365 \cdot m_i} \qquad (7\text{-}5)$$

in which:

O	=	area required (m^2)
C_i	=	number of container movements per year per type of stack in TEU's
t_d	=	average dwell time (days)
F	=	required area per TEU inclusive op equipment travellig lanes (m^2)
r	=	average stacking height / nominal stacking height (0.6 to 0.9)
m_i	=	acceptable average occupancy rate (0.65 to 0.70)

The factor t_d (average dwell time) had to be considered separately for import, export and empty containers (for which dwell times are usually much longer). Also, fluctuations in dwell times may have to be considered although it has to be realised that the factor t_d is the average over a great number of containers, thus, generally, will not vary much.

t_d can be written as:

$$\bar{t}_d = \frac{1}{S(t)_{t=0}} \int_0^\infty S(t)dt \qquad (7\text{-}6)$$

in which:

S(t) = (quantity of containers still on area) / (total number unloaded containers)

ECT found that for their home-terminal the following dwell time function applies (see *Figure 7-12*):

S (t)	=	1	$0 < t < 1$
S (t)	=	$[(T-t)/(T-1)]^2$	$1 < t < T$
S(t)	=	0	$T < t$

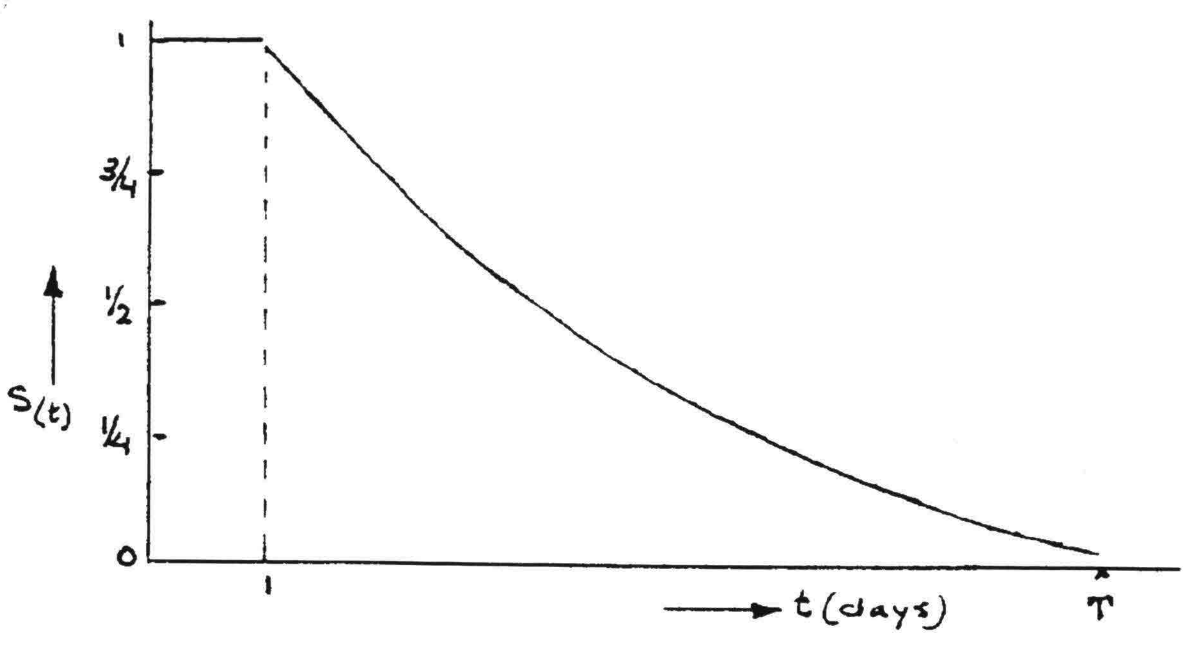


Figure 7-12: Typical dwell time function

From the above it follows that:

T	=	maximum dwell time (e.g. time within which 98% of containers have left the terminal)
t_d	=	(T+2)/3

T values:

- for Western Europe 10 days
- for developing countries 3 to 4 weeks

The factor F is empirical and depends on the handling systems and the nominal stacking height. Typical values are given below.

Table 7-2: Storage area per TEU for different equipment

System	*Nominal stacking height*	*m^2/TEU inclusive of travelling lanes (F)*
Chassis	1	50-65
Straddle carrier	2	15-20
	3	10-13
Gantry crane (RMG / RTG)	2	15-20
	3	10-13
	4	7.5-10
	5	6-8
Forklift Truck (FLT) or Reach Stacker	2	35-40
	3	25-30

The factor r reflects the fact that the sequence in which the containers will leave the stack, is partly unknown (mostly so for the import stack) and that extensive intermediate re-positioning of containers is expensive. Statistically, the need for re-positioning will increase with increasing stack height. Consequently, the value of r has to decrease. If the acceptable degree of re-positioning can be defined (e.g. 30% additional moves) as well as the degree of uncertainty in departure of containers from the stack, the optimum value of r can be found through computation or simulation. This degree of uncertainty depends, inter alia, on the mode of throughtransport. Rail and IWT can, generally, be programmed quite well, but the sequence of arrival of road vehicles not.

The factor m_i (optimum average occupancy rate) has to be introduced because the pattern of arrivals and departures of containers to and from the terminal is stochastic by nature. The optimum value of m_i depends on the frequency distribution of these arrivals and departures, and of the acceptable frequency of occurrence of a saturated stack. The number of container departures per unit of time may be more or less constant, at least for large terminals, but the number of arrivals is not. The container arrival distribution can have different forms and depends, on its turn, on the ship arrival distribution and on the variation of the number of containers per ship.

The surface area of the CFS does not follow equation 7-5, but is calculated as follows:

$$O_{CFS} = \frac{C_i \cdot V \cdot t_d \cdot f_1 \cdot f_2}{h_a \cdot m_i \cdot 365} \qquad (7\text{-}7)$$

in which:

C_i = number of TEU moved through CFS (TEU/yr)
(also called "Less than Full Container Loads" or LFCL)
V = contents of 1 TEU container (= 29 m^3)
f_1 = gross area / net area (-)
(accounting for internal travel lanes and containers)
f_2 = bulking factor
h_a = average height of cargo in the CFS (m)
m_i = acceptable occupancy rate (-)

The CFS resembles the transit sheets on the conventional General Cargo terminal. The containers are positioned around the CFS during actual transfer of cargo, which is also reflected in the volume of f_1 (≈ 1.4).

The volume of f_2 is introduced to account for additional space needed for cargo, which needs special treatment or repairs.

Finally the factor m_i again reflects the random arrivals and departures of this cargo, and the need to avoid a full CFS. Normal values are 0.6 - 0.7.

Calculation example

Assume a small terminal to be designed for a capacity of 70,000 TEU/year of which:
35,000 import (of which 15,000 via CFS[5])
25,000 export
10,000 empties

Normally, also a part of the export containers passes the CFS, but this is disregarded here. Container handling by straddle carrier, stacking three-high ($F = 13\ m^2$).

Expected t_d values for import, export and empty containers are 10, 7 and 20 days respectively.

Import
O_{import} = (35,000 x 10 x 13) / (0.6 x 365 x 0.7) = approx. 30,000 m^2

Export
O_{export} = (25,000 x 7 x 13) / (0.8 x 365 x 0.7) = approx. 11,000 m^2

Empties
$O_{empties}$ = (10,000 x 20 x 13) / (0.9 x 365 x 0.8) = approx. 10,000 m^2

CFS
O_{CFS} = (C_i x V / h_a x t_d x f_1 x f_2) / (m_i x 365) =
(15,000 x 29 / 2 x 5 x 1.4 x 1.1) / (0.65 x 365) = approx. 7,000 m^2

A possible layout for the above terminal is given in *Figure 7-13*.

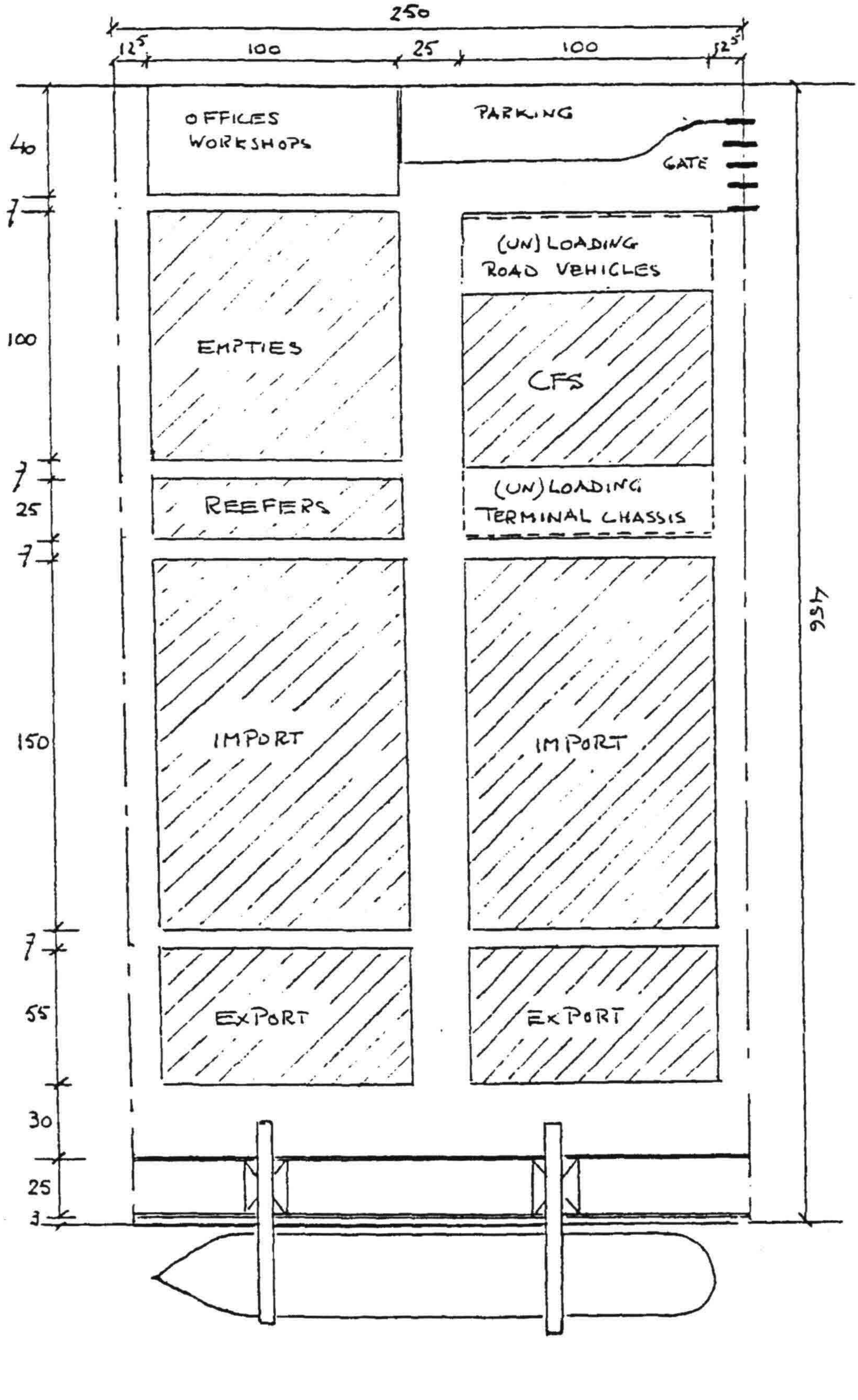


Figure 7-13: Example layout container terminal

Regarding this lay-out the following comments can be made:

(i) the export stacks are often located close to the quay in order to facilitate the loading process. The containers are positioned in these stacks prior to arrival of the ship, taking into account their order of loading.
(ii) in addition to the stack areas calculated above there are traffic lanes between the stacks. The 25 m width shown here is rather high.
(iii) on most terminals empties are stacked outside the gate (also because of the log dwell time) and higher than assumed in this example.
(iv) the gate is shown rather schematically and the transfer area between import stacks and truck/rail is not shown at all. These elements and the various buildings are dealt wth below.

The total gross surface area of this terminal amounts to 11.4 ha. The throughput- area ratio is about 6300 TEU/ha. Compared with this figure the major container terminals in Asia have 2-4 times higher ratio's:

	TEU/ha
Kaohsiung	15,400
Singapore	22,000
Hongkong	23,400

This difference is to a large extent caused by the efficient use of the storage yard, in particular by lowering the dwell time. To achieve this the stevedoring company must introduce incentives for shorter dwell time and penalties for longer dwell time than average, by applying a variable tariff.

7.3.4. Container transfer area and buildings

The trucks, which bring containers or come to collect them, enter the terminal through the gate. Here three functions are executed:

(i) administrative formalities related to the cargo, including customs inspection and clearance.
(ii) inspection of the boxes themselves (for possible damage).
(iii) instruction of the drivers to the location in the container transfer area.

The gate used to create long queues, due to the distinct peaks in the truck arrivals during the day. The introduction of electronic data processing and automated inspection of the boxes has shortened the delays at the gate considerably.

At the container transfer area the trucks take their assigned position. The area is usually located immediately behind the import stacks and the truck's position is chosen to minimise the distance to the import container to be picked up. The export containers are brought straight to the export stacks. The most common equipment for transfer is the Straddle Carrier.

Transfer to and from rail is sometimes done on the terminal itself. The rail track runs then parallel to the truck transfer area. More often a separate rail yard is made outside the terminal area with container storage area and gantry cranes. This facilitates the formation of so-called block trains, i.e. wagons which all have the same hinterland destination. They are also called

Rail Service Centres (RSC). The lay-out of these RSC's falls outside the scope of these lecture notes. Transfer from the container terminal to the RSC is done by trailer, which passes via the gate. On modern terminals an internal road may connect to the RSC, allowing use of terminal equipment such as MTS.

Transfer of containers to and from IWT barges is often done along the quays for sea-going vessels. This has two distinct disadvantages however:

(i). The portainer cranes are far too large for handling the small barges, which move more easily. Crane production is therefore low.
(ii). The barges often collect their cargo at several terminals, which is time consuming

The first disadvantage is overcome by creating a separate barge terminal, linked to the main terminal, but having proper equipment. An example of this is found at ECT's Delta Terminal on the Maasvlakte. To address both disadvantages it would be better to build a general barge terminal with connections to the different container terminals. This introduces an additional link in the transport process with two times extra handling. The associated extra cost makes this solution unattractive. It is expected that the rapid increase of the number of TEU transported by barge will allow to create multi-user Barge Service Centres (BSC) like the RSC, with internal connections to the surrounding container terminals.

Other building encountered on the terminal include the office building and the workshop for repair and maintenance of the equipment. The requirements vary per terminal.

7.4. References

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Ports and Terminals