The present lecture papers are an updated version - updated both in contents and format - of the earlier issues contained in the lecture books 'Havens' and 'Terminals'. They constitute the combined 'ports and terminals' part of the lectures f12 and f13. Chapters 1 to 6 form part of f12, whilst chapters 7 to 12 belong to f13. Chapter 1 was mainly compiled by ir. R. Groenveld.

The full curriculum of f12, furthermore, comprises:
* 'Servicesystemen in de verkeerswaterbouwkunde', ir R. Groenveld (Queuing theory part only.)
* 'Binnenscheepvaart en -scheepvaartwegen', ir J. Bouwmeester

Similarly, the additional sections of the f13 curriculum are:
* 'Servicesystemen in de verkeerswaterbouwkunde', ir R. Groenveld (Simulation part only.)
* 'Weerstand en capaciteit van scheepvaartwegen', ir J. Bouwmeester

It is self-evident that suggestions for corrections to or improvements of the present lecture papers will be welcome.

Delft, October 1993
prof ir H. Velsink
PORTS AND TERMINALS
PLANNING AND FUNCTIONAL DESIGN

prof ir H. Velsink

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MARITIME TRANSPORT: MEANS AND COMMODITIES

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1. INTRODUCTION

Transportation of goods may take place in different ways. In the beginning of the industrial period transportation by vessel was the only way. Now the international transportation of goods occurs by sea (ship), river (barge), road (truck), rail (train), or air (plane). Of these five so-called modes of transport, international navigation holds the biggest share viz about 90%.

After World War II, when the world economy began to boom at an average rate of growth of 6% per year, the developed countries started to search for means to decrease transportation costs, thereby especially looking for ways to reduce the time that ships were laying idle in ports while being loaded or unloaded. (see fig. 1 and 2).

The most attention has been paid to the improvement of cargo-handling techniques. The first step to decrease turn around time was achieved by the subdivision of cargo into major commodity or packaging groups. Due to this separation of cargo, based primarily on the method of cargo handling, specialized ships started to be developed as containerships, roro ships and barge carriers.

Fig. 1 Transport chain
International maritime trade can be discussed from a commodities viewpoint or from a transport means viewpoint. Here it will be mainly approached from the transport means viewpoint whilst also the transhipment methods will be discussed. But first a number of general aspects relative to international navigation will be mentioned.

2. SPECIFIC DATA OF MERCHANT SHIPS

2.1. Transport capacity

The tonnage of a ship generally expresses her 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
- NR - Nett 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:

Fig. 2 Cost elements in a transport chain
General cargo ships: \( \text{DWT} = 1.5 \times \text{GRT} = 2.5 \times \text{NRT} \), and

Very large crude oil carriers: \( \text{DWT} = 2.0 \times \text{GRT} = 2.6 \times \text{NRT} \)

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 \( \text{ft}^3 \) = 2.83 \( \text{m}^3 \). 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 \( \text{m}^3 \). 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 cargo, fuel, crew, passengers, fresh water, victuals, etc. expressed in metric tons.

The following unities are used:

- metric ton \( (\text{t} = 1000 \text{ kg}) \)
- English or longton \( (\text{lt} = 1016 \text{ kg}) \)
- short ton \( (\text{sts} = 907 \text{ kg}) \) and
- porttons or shipping tons

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

For some specialized ships the carrying capacity is not only expressed in BRT, 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, or a volume of

  \[ 6.03 \times 2.44 \times 2.44 = 35.9 \text{ m}^3 \]

  \( \text{m}^3 \): The carrying capacity of liquified gas tankers is usually expressed in \( \text{m}^3 \).
Street length - This dimension is often used for so-called ro-ro vessels. It expresses the total loading length with standardized width of 2.50 m available on board of the vessel. It is expresses in units of metres.

2.2. Vertical dimensions

Draught

The draught $D$ of a vessel is the maximum distance in metres between the waterline and the keel of the ship (fig. 4).

Displacement tonnages are calculated in respect of the draught $D$ and the stationary freeboard $F$, which is indicated on the ship’s side (fig. 4). The maximum draught line is indicated by the so-called Plimsoll Mark (fig. 3).

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.

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 (fig. 2.2):

- TF = Tropical Fresh Water
- F = Fresh Water
- T = Tropical Salt Water
- S = Summer Salt Water
- W = Winter Salt Water
- 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, midships, and at the stern. Often, these figures indicate the draught in feet ($1$ foot = $0.308$ m).

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.
Fig. 3  Pimsoll mark

Both lengths have been indicated in fig. 4.

The definitions are as follows:

**LBP:** is the horizontal distance in metres 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 low and one to the ship’s stern.

**Beam**

The beam or breadth **B**, is the maximum distance in metres between the two sides of the ship.
2.4. Propulsion

Propulsion engines are to be found in the engine room of the ship. They drive the ship’s propeller(s) to enable her to move forward and backward.

The most common propulsion engines are:

SR: Steam Reciprocating Engine,
ST: Steam Reaction Turbine,
TE: Electric Propulsion,
M: Diesel Engine,
GT: Gas Turbine, and
NR: Nuclear Reactor.

Of these various possibilities the Diesel engine is by far the most important one: approx. 90% of all the ships in the world are equipped with a diesel engine.

2.5. Engine

The maximum output of the ship’s engines is usually expressed in HP, which stands for Horse Power. The unit of Horse Power is: 1 HP = 736 Joule/sec = 0.736 kw.

The position of the engine room is only indicated (by the symbol (A)), when it is placed aft.

In combination with this, the number of propellers is often also indicated in case there is more than one, viz.:
(2) twin screw
(3) triple screw
(4) quadruple screw.

To illustrate the notations, the indication of the vessel "RHINE MARU" could be given, which is ST (A) (2). This notation means that the "RHINE MARU" is a vessel with a twin screw, driven by a steam reciprocating engine, which is placed aft.

Notwithstanding their size some VLCC’s are equipped with only one screw with a diameter as large as 32 feet (speed full ahead ca. 18 kn).

The speed S of seagoing vessels is expressed in knots. One knot is equal to one nautical mile or 1852 metres per hour (or 0.514 m/sec.).
2.6. Improvement of ship manoeuvrability

**Thrusters**

Many ships built recently are equipped with one or more thrusters, either at the bow or stern and/or at both places. Even twin thrusters have been applied.

![Kamewa bow thruster](image)
Thrusters consist of a horizontal tube through the ship’s bow or stern under the waterline in which a reversible screw is fitted. The screw is able, when rotating, to exert a beam force on the ship. The application of thrusters increases the manoeuvrability of ships considerably, especially when the ship is turning or approaching a berth.

Most ferries are equipped with bow as well as stern thrusters, which enables the ship to approach or depart from a berth in a right angle.

The only restriction of thrusters is that they have hardly any effect when the speed of the ship is more than 1 to 2 knots.

For safety reasons the presence of a bow thruster is indicated on the bow of the ship above the waterline (Fig. 4).

**Bulbous bow**

The bulbous bow (fig. 4) is also a more recent development in ship design.

It is aimed at the reduction of pitching (the up and down movement of a ship when sailing, due to wave action).
Furthermore, it increases the manoeuvrability and the speed of vessels when sailing in ballast.

Bulbous bows are also indicated on the bow of the ship (fig. 4).

**Stabilizers**

Stabilizers are fins below the waterline, fitted to passenger/cruise ships and ferries to reduce the effect of the rolling of the ship due to bad weather conditions.

### 3. COMMODITIES AND TYPES OF VESSELS

#### 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 break bulk cargo (many pieces of various dimensions and weights) and mass-break bulk or neo-bulk cargo (many pieces of mostly uniform size and sometimes uniform weight).

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 and if necessary the transhipment methods. Important trends in types of vessels and types of cargo will also be mentioned.

#### 3.2. Break bulk or conventional general cargo (5,000-13,000 dwt)

Break bulk is defined as all kinds of boxes, crates, bags, sacks, drums, machine parts, refrigerated cargo as fruit, meat etc.

Generally the break bulk cargo will be transported by one of the three type’s of break bulk ships, i.e. conventional general cargo ships, multipurpose ships and refrigerated ships.
3.2.1. General cargo ship

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

<table>
<thead>
<tr>
<th>categories of break bulk</th>
<th>shape or packing</th>
<th>transshipment method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. bagged goods</td>
<td>undefined shape</td>
<td>transshipment with ropes or on pallets</td>
</tr>
<tr>
<td>2. normal break bulk</td>
<td>crates, boxes, drums</td>
<td>transshipment with ropes, hooks, pallets</td>
</tr>
<tr>
<td>3. other types</td>
<td>unpacked goods as steel plates, bars and wire, lumber and timber</td>
<td>transshipment with ropes and hooks</td>
</tr>
</tbody>
</table>

The weight of each piece of cargo (a ‘lift’) is limited by the maximum lifting capacity of the shore based crane or of the ship’s derrick. Each piece of cargo is handled separately or sometimes as an assembly of some smaller items.

The cargo handling activities are illustrated in fig. 7.

![Fig. 7. Sequence of loading activities of a general cargo ship.](image)

In this figure and in figure 9 the following symbols are used to indicate an activity.

- temporary rest (awaiting the next activity)
- movement of cargo (either vertical or horizontal)
- final stowage (the end of the activities).

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

The capacity of the conventional general cargo ship ranges from 5000 to 13000 DWT. It has four to five holds (space for cargo stowage 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 ship 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 12 metres, 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 fig. 8.

![General cargo ship](image)

**Fig. 8.** General cargo ship TRIDENT ROTTERDAM - The Netherlands 1971 7226 BRT, 3715 NRT, 9022 DWT

- LOA = 168.91 m - Ship is equipped with side loading ports
- B = 23.30 m - for horizontal cargo handling.
- H = 12.50 m - Freezer capacity: 2700m³
- D = 8.24 m - Container capacity: 60 TEU
- S = 22.0 knots - Stülcken mast and heavy derrick
- E: M; 16000 hp - Bow thruster.

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 the 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 movement of cargo was also one of the reasons why nowadays most wheelhouses of general cargo ships are placed aft instead of amidships.

b. Horizontal cargo handling through side loading ports (see fig. 8 and 9).

c. The introduction of the pallet, which forms one of the basic elements of the Unit Load Concept (U.L.C.), and of the forklift truck (FLT).

The Unit Load Concept is a process, in which several separate items of cargo are bundled together to one unit, which can be handled with the 'conventional' cargo handling equipment, such as quay cranes, derricks, forklift trucks, etc. It is obvious that implication of the ULC gives remarkable savings in loading and discharging time, while no new, special (and mostly expensive) equipment is needed.

Examples of the ULC are:
Fig. 9  Comparison between conventional and horizontal cargo handling

**Palletized cargo**, for instance boxes (fig. 10, 11)

**Pre-slung cargo**, for instance pipes (fig. 12)
Usually, the sling stays with the cargo during the voyage to the port of discharge, so that the method can be applied there as well.

**Pre-strapped cargo**, for instance drums on a pallet (fig. 13)

**Shrink wrapping** of cargo

This method means the wrapping of a pallet with cargo by a plastic foil, which is shrunk tightly around the cargo by heating the foil. The advantages of this method, besides the fact that the cargo is palletized and unitized, are that it is better protected against bad weather conditions and pilferage.
A pallet is a wooden frame, as shown in fig. 10. It exists nowadays in many sizes, although the $0.8 \times 1.2 \text{ m}^2$ dimensions are most common (ISO standard). This size of pallet has a carrying capacity of 1000 kg. The average lifetime is approx. 6 months and its cost is about $20.\$.

### 3.2.2. Multipurpose Ship (12,000 - 25,000 DWT)

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 towards less developed ports, the ship has heavy lifting equipment on deck, sometimes the patented German Stülcken derricks with a lifting capacity of up to 250 tons.

The ship can easily be identified 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 thruster and bulbous bow.
d. Side loading ports for horizontal cargo handling.

An example of a multipurpose ship is shown in fig. 14.
Multipurpose ship FINNBUILDER - Finland 1977
16964 BRT, 14260 DWT
LOA = 174.30 m — Stern ramp for roro cargo handling
B  = 25.60 m — Three side ports
S  = 20.0 knots — Lifting capacity derricks: 40 tons
E : M(A) — Container capacity: 460 TEU
          — Bow thruster.

Fig. 14    Multipurpose ship

3.2.3.    Refrigerated General Cargo Ship (Reefer 5,000 - 20,000 DWT)

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 distinguishes 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 the reefer.
An example is given in fig. 15.
Reefer ALMERIA STAR - Great Britain 1976
9781 BRT, 11092 DWT
LOA = 155.81 m
B = 21.49 m
D = 9.15 m
S = 24.0 knots
E : M; 17400 hp - Reefer capacity 13.000 m³

Fig. 15. Reefer Almeria Star.

3.3 Mass Break Bulk (Neo Bulk)

3.3.1 Introduction

Transshipment of break bulk is characterized by many phases and actions.
In spite of the introduction of the U.L.C. this type of transshipment remains labour-intensive.
After the second world war the world-cargo transport has increased enormously by the growth of the industrial production.
In many ports this caused serious congestion (long waiting times of ships and because of that an unavoidable increase in transport costs).

One of the many solutions for this problem was the introduction of mass break bulk ships.
This system aims at a reduction of ship's turn around time.
It entails both differentiation and integration, differentiation in terms of specialized vessels for special types of cargo, integrating the different links of a transport chain. A classic example is the door to door transport of containers.

In figure 16 the percentage of time spend in port has been plotted as a function of the trip length in N.M. for break bulk and for container vessels.
It shows that the time spend in port decreases to about 10% of the total time using the mass break bulk system.
Fig. 16. Time spend in port of container ships and break bulk ships is a function of the trip length

In the following table an overview is given of the different types of mass break bulk carriers. In fact the heavy lift carrier is not a mass break bulk ship but because of its specialized character this type has been included as well.

a. Containership
   - first generation (converted general cargo ship)
     LOA = 180 to 200 m; B = 27 m; S = 20 to 22 knots; cargo: 750 - 1100 TEU
   - second generation (full cellular container ship)
     LOA = 240 m; B = 30 m; S = 24 knots; cargo: 1500 - 1800 TEU
   - third generation (full cellular container ship)
     LOA = 300 m; B = 32 m; S = 25 to 27 knots; cargo: 2400 - 3000 TEU
   - fourth generation (full cellular container ship)
     LOA = 300 m; B = 32 m; S = 18 knots; cargo: 4000 - 4500 TEU

Identification second, third and fourth generation: high freeboard, superstructure aft

Lately also so called "post Panamax" vessels have come into operation with a beam of abt. 40 m (instead of the 32.3 m max. for Panamax ships) and a TEU capacity in the same order as that of the 4th generation ships. They are more economical to operate but restricted in the routing.

Furthermore, initiated by Nedlloyd, hatchcover-less container ships have been developed with full height cell guides (including 4 tiers high above the board of the ship). As they do not require hatchcover handling or deck-container lashing, they may attain up to same 20% saving in port-time as compared to conventional
container ships. Nedlloyd’s UCC’s (Ultimate Contained Carriers) have a TEU capacity of 3568.

b. roro/container ship
cargo: containers, road building machines, motorcars, lorries and other cargo provided with wheels.
identification: same as a full container ship but provided with a ramp

c. roro/passenger ship
cargo: passengers, cars, lorries, trailers
identification: ramp, high super structure, ventilation shafts

d. roro/unit load ship
cargo: lorries and trailers
identification: ramp

e. lash ship (lighter aboard ship)
cargo: floatable barges
identification: great length, low super structure and huge gantry crane

f. seabee
cargo: floatable barges
identification: elevator to handle the barges simultaneously

g. bacat (barge catamaran)
cargo: floatable barges
identification: elevator to handle the barges between the hulls

h. car carrier
cargo: new cars
identification: side ramps, high and long superstructure ventilation shafts.

i. heavy light carrier
cargo: huge and heavy units
identification: vast deck-space, one or more heavy-duty cranes or derricks (500t)

3.3.2 Container Ships and handling equipment

Ships

The introduction of container ships has been a breakthrough in the reduction of the turnaround time of the merchant ships.

Actually the container is only a steel or aluminium strong box to carry cargo. The standardized dimensions are:

height 2.44 m (8 ft) or - the vast majority - 2.59 m (8½ ft)
width 2.44 m (8 ft)
length 6.10 m (20 ft container, 1 TEU, max. weight 20 t)
9.14 m (30 ft container, max. weight 25 t)
12.14 m (40 ft container, max. weight 30 t)
The American Container Shipping Company Sealand, however, uses solely her own containers of 35 feet (10.67 m) length.

Many types of containers besides the "conventional type" have been developed in order to conquer an even bigger share of products to be transported in containers. Examples are the reefer container, flat container, tank container etc.

Basic advantages of containerization are:
- reduction of the turn around time and thus reduction of port and transport costs
- damage and pilferage of cargo are reduced considerably and thus also insurance costs
- reduction in packing costs.

But also disadvantages exist.

Even today, almost all regular container services operate only between the developed countries of the world.

The most important reasons behind this are:

a. Containerization requires a vast capital outlay.
   Not only the ships are expensive, but also the handling equipment. The infrastructure of a port has to be adjusted to the requirements of containerization. All this asks for vast sums of money for investments. This money is often not available in developing countries. Moreover, such investments are only justified for high volume trades, which are rare in the developing world.

b. To make a container service profitable it is essential, that there are cargo flows from both sides, since the transportation of empty containers is relatively expensive. Many developing countries have no return cargo.

c. Until today, the majority of cargo carried by containers has mostly been the usual break bulk cargo consisting of finished or semifinished products. Only recently containers have been used for the transportation of bulk goods on a small scale. Unfortunately, the export cargo of many developing countries exists of bulk cargo.

Other disadvantages are stowage lost, high own weight of the containers and an unfavourable influence on employment in the port sector.

In the beginning of containerization, the containers were, carried by converted general cargo ships. Today, those ships are called the first generation of container ships which are mostly used for feeder services.

As soon as the container trade proved to be profitable, the first full containers whips were built (second generation).

The second generation container ship is mostly used on medium range voyages, such as USA-W.Europe.

For longer voyages, for instance from West Europe to the Far East, the third and fourth generation container ship is usually used.

The second, third and fourth generation container ships are easily to be identified.

The ships have a high freeboard and the superstructure is usually placed aft or at three-quarters. Sometimes a wheelhouse is placed forward. This is due to the fact, that the view from the wheelhouse placed aft is very much limited when many containers are stacked on deck.
The deck itself is flat and unobstructed by the hatch covers so that containers can be stacked on it in addition to those placed below deck in the slots of the cellular holds.

Depending on the size of the ship, containers are usually stowed up to six high in the holds and up to four on deck.

The speed of the ships is generally high, ranging from 20-27 knots.

There exists a certain relationship between the DWT and the TEU-capacity of container ships, viz.

\[
\frac{\text{TEU-capacity}}{\text{DWT}} = 0.05 - 0.06
\]

The size of most container ships is limited by the dimensions of the Panama Canal. The largest (fourth generation) container ships using this canal have the following dimensions:

\begin{align*}
\text{LOA} &= 289.50 \text{ m} \\
\text{B} &= 32.22 \text{ m} \\
\text{H} &= 21.50 \text{ m} \\
\text{D} &= 11.65 \text{ m} \\
\text{capacity} &= 57800 \text{ DWT} \\
\text{S} &= 18 \text{ knots} \\
\text{Propulsion} &= 28000 \text{ hp} \\
\text{container capacity} &= 4258 \text{ TEU}
\end{align*}

(including 146 TEU refrigerated containers).

Fourteen of these ships were built for the United States Line in 1984 and subsequent years. But the company went broke, and some of the ships have been purchased by the US President Lines for their Atlantic and Pacific trades.

**Lift on/Lift off equipment**

To handle containers on and off board a vessel a so called lift on/lift off procedure is used.

The sequence of activities of cargo handling for a container ship is illustrated in fig. 17.

![Fig. 17 Sequence of cargo handling activities of a container ship](image)

**Portainers**

Usually, the handling of containers at a more or less developed container berth is carried out by a heavy, shore based, gantry crane: the portainer. The procedure is as follows (and also applies to the other equipment to be discussed hereafter): the crane-driver lowers a steel frame, the spreader, which has the same length and width as that of the container to be handled, on the container.
The 'pins' (twist locks) at the four corners of the spreader fall into the corresponding oval corner fittings on the top of the container. Then the twist locks are turned over 90°, by which they are blocked, and the spreader is fixed to the container.

The portainer is an expensive piece of equipment. The newest portainer of ECT in Rotterdam costs about $ 7 million. This portainer is the latest development, it works with two trolleys and spreaders. The weight of the crane is about 850 tons.

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**Shiptainers**

Some container ships carry their own equipment to handle containers. This is the shiptainer (fig. 19), a gantry crane on board the ship, able to run from forward to aft along the deck. Some ships even have two or three shiptainers. The shiptainer was used especially in the beginning of containerization, because at that moment not many ports were equipped with portainers. At present it is often used for feeder services.
Although the container ship equipped with shiptainers is able to call at poorly equipped ports, the objection is, that the equipment, which requires a heavy investment, is only used when the ship is in port. Furthermore, the tracks of the gantry-crane consume space that could otherwise be used for the stacking of containers. Finally, the shiptainer requires much maintenance due to corrosion by sea water.

Other Cranes

When containers are occasionally handled at general cargo terminals, lift on/lift off procedure can be carried out by the ship’s own gear, by a big mobile crane, by a combined operation of two quay cranes, or by a multipurpose crane. Multipurpose crane’s exist with a lift capacity of 60 ton and more.

Terminal equipment

Various methods can be applied to move a container away from the quay after it has been landed by port- or shiptainer.

a) Straddle carriers.

When placed on the quay the container can be carried by a straddle carrier (fig. 20), to the stacking area on the terminal and left there to wait for further dispatch. Stacking by straddle carrier can be up to four layers high.

Straddle carriers have the advantage of flexibility and of operating at high speed, but the equipment is rather expensive and vulnerable to breakdown.

The driver of the straddle carrier has a limited view, so accidents may happen (and actually do happen), when strict safety rules are not applied.

In older designs the diesel engine and the hydraulically operated jacks gave cause to frequent oil spills on the terminal. Newer designs make use of an electric engine, and the results, appear to have mostly overcome.
b) Forklift truck

The second method is the movement of the container by a heavy forklift truck. The disadvantages mentioned for the straddle carrier, such as limited view of the driver and oil spills, are also applicable for most forklift trucks. Although the operating speed is slower, it has fewer breakdowns than the straddle carrier and it is cheaper.

A specific disadvantage when used for loaded containers are the high wheel loads on the pavement.
A special form of forklift is the reach stacker, which has a telescopic tilting forkbeam, enabling four high, double row stacking instead of single row.

![Fig. 21 Forklift truck](image)

c. Trailer

The container may also be placed on a trailer directly, in which case three different methods can be applied:

i) The container is placed on a road trailer, which is brought to the customer directly. This method is hardly ever used. The reasons are:
- Trailer drivers may have to wait for long periods.
- Commercial Traffic on the quay-side is mostly not permitted for safety reasons.
- Normally documentation and/or custom procedures have to be followed requiring intermediate storage of the containers.

ii) The container is placed on a terminal trailer which is moved by a tractor to the stacking area, where further handling is carried out by straddle carrier, forklift truck or transtainer.

iii) The third possibility is the method where every container (35 foot) is placed on a trailer and moved by tractor to the parking area, from where it is finally picked up by a road truck. Although this method reduces the complexity of quay-side activities, it requires a large open space for parking, since stacking is not possible.
d. Transtainer

A transtainer is a travelling gantry crane for the moving and stacking of containers. Nowadays, many types of transtainers exist, either on rails or on rubber wheel. Some types are so big, that they are able to stack containers five layers high. Transtrainers are also used to load and unload containers on or from railway wagons (fig. 22).

![Fig. 22 Transtainer](image)

Finally, an example of a third generation containership is given in Fig. 23.

![Fig. 23 Third generation containership](image)

Third generation containership TOKYO BAY - Great Britain 1972
59000 BRT, 35500 DWT
LOA = 289.55 m
LBP = 274.32 m
B = 32.26 m
H = 24.60 m
D = 10.97 m
S = 27.0 knots
E: ST(A) (2) - Container capacity: 2300 TEU

Fig. 23. Third generation container ship.

3.3.3. Roro - Container Ship

With the introduction of the full container ship the development had not come to an end yet.

This is due to the fact that:

- A number of commodities cannot be containerized like motorcars, road building machines, lorries etc.
- Some large container ships sailing in relatively low volume lines could not acquire enough cargo to reach their full capacity.
Therefore, the search continued for a vessel, that could take quite a large number of containers, but also a considerably load of non-containerized cargo. The sequence of loading activities is given in fig 24.

![Sequence of cargo handling activities of a ro-ro/containership](image)

**Fig. 24** Sequence of cargo handling activities of a ro-ro/containership

The first types of ro-ro/container ships usually had the ramp at the stern of the ship. When at sea it was pulled up into a vertical position and in the port it was lowered onto the quay (fig. 25).

![Ramp of a ro-ro/container ship](image)

**Fig. 25** Ramp of a ro-ro/container ship

The disadvantage of this type of ramp is, that a special place in the port or even a special berth construction is necessary (fig. 26). The manoeuvring with long trailers may be difficult, since much space is required which is not always available. The problems with high tidal differences were solved by the use of a pontoon.

![Berth construction for ships with a fixed ramp](image)

**Fig. 26** Berth construction for ships with a fixed ramp

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 of 45° with the axis of the ship and enables the ship to berth at any part of a straight quay (fig 27).
A more recent development is the so-called slewing stern ramp. This type of ramp, with lengths of up to 50 metres, can be slewed over 65°, which makes it even more flexible. The length of 50 metres enables ships equipped with this type of ramp to work continuously, even in ports with high tidal ranges. Disadvantages of the system are the relatively high costs of the ramp (up to 10% of the total costs of the ship) and the loss of storage space.

The carrying capacity of ro-ro/container ships is usually expressed in TEU as well as in street length; the latter being the total length of the lanes in which the ro-ro cargo is placed in the holds of the ship (standard width of 2.50 m). The latest types of ro-ro/container ships have a total street length of about 5300 m.

An example of a ro-ro/container ship is given in figure 29.
Roro-containership SAUDI DIRIYAH - Saudi Arabia 1983
40000 DWT - capacity 2050 TEU

- designed to transport containers,
- self-contained reefer containers
- vehicles, general cargo and heavy
- loads including explosives
- quarter ramp aft and combined side
- door and ramp to 3rd deck; fixed
- internal ramps between tank top, 2nd
  3rd and upper deck
- bow + stern thruster (each 1770 hp)

Fig. 29. Ro-ro/container ship

The space available in the holds for ro-ro cargo is never fully utilized, due to the
irregular shape of the items stowed on board. This actually leads to a considerable loss
of space, which may even go up to 60%, when compared to a conventional general
cargo vessel, where almost every m³ of space is used for the stowing of cargo.

3.3.4. Ro-ro Unit Load Ship

The ro-ro unit load ship differs from the ro-ro/passenger ship by the lack of accommod­
dation; she is purely meant to transport lorries and trailers.
Some vessels of this type have limited accommodation for drivers accompanying their
trucks (fig. 30).

Contrary to the ferry, which normally sails on short routes only, this type of ship,
usually referred to as ro-ro ship, also serves on the longer, intercontinental routes,
especially those to relatively poorly equipped or congested ports. This is due to the
fact, that the loading and discharge times of ro-ro vessels are rather short and also
because shore based cargo handling equipment is not required. The cargo handling
procedure is the same as that illustrated in fig. 24.
Roro Unit Load Ship ANGLIA EXPRESS - Italy 1976
6700 BRT, 4375 DWT
LOA = 147.61 m
B = 22.64 m
D = 6.60 m
S = 20.0 knots
E: M; 16000 hp

Fig. 30 Ro-ro Unit Load Ship

3.3.5. Lash - Ship (Lighter Aboard Ship, see fig. 31, 32 and 33)

The Lash is a further step in the development of integrated transport. The principle of this transport 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.

Fig. 30. Lash system
Fig. 31. Lash ship Arcadia Forest

Lash-ship BILDERDIJK - The Netherlands 1971
36974 BRT, 20553 NRT, 44094 DWT
LOA = 261.50 m
B = 32.20 m
H = 18.29 m
D = 11.28 m
S = 18.5 knots
E: M(A); 26100 hp - Carrying capacity: 83 Lash barges

Fig. 32. Lash ship Bilderdijk

3.3.6. **Seabee - Ship**

In principle, the system of the Seabee ship is equal to that of the Lash ship; it is also a type of barge carrier. There exist, however, some differences, viz:

1. Barges are lowered into and lifted out of the water by means of a huge elevator at the ship's stern (capacity about 2000 tons). Usually two barges are handled simultaneously.
2. The dimensions and the capacity of the Seabee barge are different from those of the Lash barge, viz.: 29.70 * 10.70 * 3.00 m. The carrying capacity is about 850 DWT.

3. The barges are placed parallel to the ship's longitudinal axis. Besides barges, the Seabee ship can also transport containers as single load, or in the barges. For this reason the capacity of the Seabee ship is also expressed in TEU.

   The common TEU - capacity is 824

The sequence of cargo - handling activities is presented in fig. 33.

Fig. 33. Sequence of the cargo handling activities of a Seabee ship.

Fig. 34. Seabee barges
3.3.7. Bacat-Ship

The Bacat ship is the third example of barge carriers. In the case of the Bacat (Barge Catamaran) the carrier consists of a twin hull ship (catamaran). The Bacat barge was originally designed for the British inland waterway system. The barges are pushed in between the two hulls and then lifted by an elevating platform. The Bacat barge is the smallest of the three types; the dimensions are:

16.80 * 4.65 m at a draught of 2.45 m. The carrying capacity is 140 tons. The ship, when fully loaded, accommodates ten of these barges and three Lash barges. The last one remain in the water between the two hulls and form some kind of temporary keel during the voyage of the ship. The time required to unload and load the Bacat ship (in total a movement of about 5200 tons) is about 6 hours.

Fig. 30. Bacat-ship BACAT 1 - Denmark 1973

Fig. 35. Bacat - Ship

3.3.8. Car Carrier

This type of vessel has been designed for the transportation of newly built motorcars from the producer to the consumer markets.
3.3.9. 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 space as possible. Another characteristic is the presence of 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). These various techniques are illustrated in fig. 38.

Fig. 38. Sequence of cargo handling activities of a Heavy Lift Carrier.

Semi-submersible heavy lift vessel SUPER SERVANT 1
The Netherlands 1977 (Wijsmuller) 14450 DWT
LOA = 139.00 m - Total deck space: 3500 m²
B = 32.00 m - Deck load: 15 t/m²
H = 8.50 m
D = 6.18 m (or 14.50 m submerged)
S = 13.0 knots cruising (15.0 knots maximum)
E: M(2); 8500 hp continuous (9350 hp maximum rating).

Fig. 39. Semi-submersible heavy lift vessel.
3.4. Bulk cargo

3.4.1. Introduction

Bulk carriers usually carry large quantities of homogenous unpacked cargo, for instance:

1. liquified gas
2. liquids (oil)
3. chemicals (fertilizer, cement)
4. ores
5. coal
6. grain, rice, cereals, 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 a liquid, which can be transported by pipeline), or by a combination of grabs and a conveyer belt system (coal and ores).

Bulk carriers can also be subdivided in several types, as will be illustrated in the following chapters.

In principle there exist four types, viz.

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

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

<table>
<thead>
<tr>
<th>Bulk Cargo</th>
<th>Cargo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Crude oil carrier</td>
<td>crude oil</td>
</tr>
<tr>
<td></td>
<td>VLCC &gt; 20,000 DWT (Very Large Crude Carrier)</td>
</tr>
<tr>
<td></td>
<td>ULCC &gt; 40,000 DWT (Ultra Large Crude Carrier)</td>
</tr>
<tr>
<td>2. Product tanker (up to 40,000 DWT)</td>
<td>refined oil products</td>
</tr>
<tr>
<td>3. parcel tanker (6,500 - 16,000 DWT)</td>
<td>refined oil products, chemical liquids</td>
</tr>
<tr>
<td>4. Liquified gas carrier (up to 130,000 m³)</td>
<td>LPG (mixture of propane and butane)</td>
</tr>
<tr>
<td></td>
<td>LNG (liquid natural gas, methane)</td>
</tr>
<tr>
<td>5. Dry bulk carriers (up to 330,000 DWT)</td>
<td>grains, coal, ore, fertilizers etc.</td>
</tr>
<tr>
<td>6. OBO-carrier</td>
<td>either ore or crude oil</td>
</tr>
<tr>
<td>7. OCO-carrier</td>
<td>liquid and dry bulk cargo at the same time</td>
</tr>
</tbody>
</table>

Fig. 41. Transshipment of cereals with pneumatic floating elevators.
3.4.2. Crude Oil Carrier

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 the Second World War the consumption started to rise (and soon to boom), the modern crude oil tanker 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.

The most important producers (and exporters) of crude oil are the Middle East countries around the Persian Gulf, such as Saudi-Arabia, Kuwait, the United Arab Emirates, Iraq and Iran, and countries such 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. These countries largely depend on the oil from the oil-producing countries, especially on those of the Middle East.

The following table illustrates the development of the size of tankers:
<table>
<thead>
<tr>
<th>Year</th>
<th>Largest tanker (DWT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1945</td>
<td>17.000</td>
</tr>
<tr>
<td>1955</td>
<td>50.000</td>
</tr>
<tr>
<td>1960</td>
<td>100.000</td>
</tr>
<tr>
<td>1966</td>
<td>200.000</td>
</tr>
<tr>
<td>1968</td>
<td>300.000</td>
</tr>
<tr>
<td>1976</td>
<td>550.000</td>
</tr>
</tbody>
</table>

Nowadays the intermediate size tanker (50 - 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.
3.4.3. Parcel Tanker

The parcel tanker is a specialized tanker for the 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 the 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. In 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 fig. 45.
3.4.4. Liquid Gas Carrier

The gas is transported at a high pressure or at a low temperature or a combination of both.

The products involved are:
- LPG (Liquified Petroleum Gas), a mixture of propane and butane,
- LNG (Liquified Natural Gas; consists mainly of methane), and
- other types of chemical gas, like ammonia, ethylene, etc.

The gas is mostly transported at atmospheric 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 1/634th of its original volume. Fig. 47 gives the development of the liquified gas carriers.

For smaller quantities - e.g. coaster type and size ships - LPG is also transported in pressurized form at normal temperatures. LNG cannot even be liquified by pressurization at temperatures above about -80°C.

The capacity of gas tankers is normally expressed in m³.

CAPIBALG - 1964
Capacity: 630 m³
LOA = 52.00 m
B = 8.50 m
D = 3.60 m
In principle LNG-carriers are capable to transport LPG as well; but LPG tankers cannot carry LNG.

3.4.5. Dry Bulk Carrier

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-unloading capability.

"Geared bulk carries" 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 abt. 350,000 DWT.

Some types of dry bulk ships, the CSU's (Continuous Self Unloader), are self-discharging via an ingenious conveyer system. Capacities of up to 6,000 tons per hour can be reached. (fig. 48).

The advantage of these self unloaders is that only some dolphins are necessary for a berth.

The dimensions are:

20000 - 70000 DWT

LOA = 200 - 250 m.

B = 20 - 30 m.

H = 10 - 17 m.

P = 7.5 - 12.5 m.

S = 12.5 - 15.5 knots

Fig. 48. Self-discharging dry bulk carrier

3.4.6. Combined Bulk Carrier (O/O, OBO, OC)

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 deck fittings (such as pipelines, hose derricks and manifolds), that can be observed on deck of a crude oil tanker in addition to the batches of the dry bulk carrier.

![Diagram of carrier types](image)

Fig. 49. Development of the combined carrier

### 3.4.6.1 OBO - carrier

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 cargos. Not always the waste water is discharged in an appropriate way.
OBO-carrier JOREK COMBINER - Norway 1976
66373 BRT, 117000 DWT
LOA = 245.02 m
B = 38.71 m
D = 16.00 m
S = 16.0 knots
E : M; 23200 hp

Fig. 50. OBO - carrier

Some safety problems exist with respect to these carriers. Due to explosions two ships (owned by a Norwegian shipping company) have been wrecked.

3.4.6.2 OCO - carrier (ore/cum/oil)

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 liquid bulk cargos usually crude oil (when ore is transported 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 used of the OCO - carrier is when two markets exchange bulk products, such as:
South America - USA : ore
USA - South America : crude oil
OCO-carrier GERTRUD FRITZEN - Free Republic of Germany 1968
22797 BRT
LOA = 190.75 m
LBP = 177.00 m
B = 23.70 m
H = 14.00 m - Dry bulk capacity : 12687 m$^3$
D = 9.73 m - Liquid bulk capacity : 24214 m$^3$

Fig. 51. OCO - carrier

3.5 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 of 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, palletized, containerized or bulk cargo. Therefore, a short sea trader is often regarded as a miniature of the larger ocean-going vessel.

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.

STANDARD DESIGN SHORT SEA TRADER (CONOSHIP)
the Netherlands 900 BRT, 1400 DWT
LOA = 65.70 m
LBP = 60.00 m
B = 10.70 m
H = 4.90 m
D 4.13 m  - Maximum hold capacity: approx. 1800 m³

Fig. 52. Short Sea Trader

After the second world war, passenger traffic by aeroplane started to boom, and many passenger ships started to disappear from the seas of the world. For some of them however, new employment was found in the tourist industry. They were (and are) used to make holiday trips for tourists to warm (usually tropical) and interesting places, especially in the Caribbean and Mediterranean Seas. For this reason, passenger ships are, today, often referred to as cruisers or cruise ships.
The cruise ship can easily be identified by the high superstructure, sometimes four to five continuous upper decks, many lifeboats and windows in the superstructure. The high freeboard is pierced by the portholes of the cabins below deck. Cargo handling equipment except a possible light derrick aft to serve the stores-holds, is not available. Today also the r-r/passenger ship is in use (ferry ship).

Cruise ship VISTAFJORD - Norway 1973

24292 BRT

LOA = 190.82 m
B = 25.00 m
S = 20.0 knots
E : M(2) - Maximum accommodation for passengers: 830 persons

Fig. 53. Cruise ship

4. TRAMP AND LINER TRADE

International shipping can be subdivided into two major categories:
- liner trade
- tramp trade

4.1 Liner Trade

Liner Trade is a seaborne Trade of one company or a consortium of companies, that maintain regular services between a certain number of ports. When a liner trade service is maintained by a number of vessels of different companies but it mutually agreed transport rates, this is called a conference.

Another possibility is, that a number of shipowners raise funds to emerge a new company to start a liner service. This is common practise when the costs of building, operating and maintenance of the company's ships are too high to be borne by one company only. Examples of this kind of liner service can be found in the container trade in particular. The ACL (Atlantic Container Line), for instance is a combination of the following shipping lines:

- Compagnie de Navigation Atlantique
- Cunard Steamship Company Ltd
- Holland America Line
- Swedish America Line
- Rederi A/B Transatlantic, and
- Wallenius Lines
The competition of non conference members is reduced by using so called fighting ships. These fighting ships transport cargo under the normal rates to fight the competition of the "outsider". The costs involved are absorbed by all members of the conference.

The main characteristics of the liner trade and conference are:
- Regular services: times of arrival and/or departure are scheduled beforehand
- Fixed tariffs: this may, sometimes, be a disadvantage
- Good services: including the services in port, such as local agents, facilities and priority in some ports
- Fixed berth in port: this is not the case in all ports of the world

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 the break bulk trade. 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 is presented:

c. 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.

5. GRAPHS

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

Fig. 54: BRT versus DWT of different ship types.
Fig. 55: Main dimensions of general cargo ships.
Fig. 56: The bend in curve b to a more or less horizontal line is caused by maximum allowable width of 32.3 m passing the Panama canal, the one of curve L" is a result of similar length limitation. The dots above these line refer to Post Panama vessels.
Fig. 57: Main dimensions bulk carriers. Modern VLBC's (Very Large Bulk Carriers) do have an abt. 1 to 1.5 m lower draught against a 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 build in the last ten years.
Fig. 58: Main dimensions crude carriers.
and 59
Fig. 54. BRT versus DWT
Fig. 55. Principal dimensions of General Cargo Ships
Fig. 56. Principal dimensional container vessels
Fig. 57. Principal dimensions of bulkcarriers
Fig. 58. Principal dimensions of tankers
Fig. 59. Principal dimension of tankers > 40,000 DWT
Literature references:


chapter 2.

PORTS AND INTEGRATED TRANSPORT CHAINS
- INTRODUCTION -
chapter 3.

PRINCIPLES OF INTEGRATED PORT PLANNING
PRINCIPLES OF INTEGRATED PORT PLANNING

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PRINCIPLES OF INTEGRATED PORT PLANNING

This introduction aims at giving a broad survey of the framework of port planning as a whole and the complex range of factors that play a part in it. Such a survey is necessary in order to clarify the mutual relationship of a number of subjects which have been discussed or will be discussed in the context of these lectures.

1. COMMERCIAL PORTS: FUNCTION AND DEVELOPMENT

Formerly

A port was primarily a commodities storage place and a distribution centre (for instance Amsterdam, Antwerp, London). Ships arrived at rather unpredictable moments. The cargo was stored in the port until market prices made it attractive to sell. Matters like nautical aspects and transhipment were of secondary importance.

A port grew with the increase of the short-term demand of the aforementioned function as a commodities storage place and distribution centre. There was hardly any systematic planning, at least not with regard to transport. Therefore, old ports are often badly situated and organized as far as transport technology is concerned.

Nowadays

The emphasis has shifted from commodities storage to a link or junction in intermodal transport chains and an interface between transport modes, where goods are transferred from one means of conveyance to another, where transport chains meet and part again. The port is attuned to a transport system that is as cheap and efficient as possible, particularly in terms of cargo handling.

Even now, storage inevitably still plays an important part, not as an end in itself but rather as a necessary evil. Necessary, because the discontinuities and irregularities in both the incoming and outgoing cargo flows require the maintenance of a certain buffer stock of commodities in the port.

In order to make the transport within the port as efficient as possible, it is necessary to streamline the movements of the transport means and the loading and unloading operations and to ensure the accessibility of the storage areas.

To meet these requirements, one must be able:

* to anticipate increasingly on developments in shipping and goods traffic, i.q. to anticipate on market demands
* to bring about an increasing degree of specialization in the goods handling according to their type and their packing

Apart from this, other circumstances have complicated the development of ports:

* the massive scale of present-day harbour activities
* the much increased density of population and the growing awareness of safety and environmental aspects
* the development in many ports of a port-orientated industry with all its consequences

The development of a port is, therefore, no longer an issue of local ad-hoc decisions but a matter of complex, multi-disciplinary long-term planning, both at regional and national levels.
2. TYPES OF PLANNING

On the one hand, a differentiation should be made according to time horizon:

- **long-term** period of about 20 years
  port strategic and infrastructural masterplan
- **medium-term** period of 3 to 5 years
  for instance, the planning, design and execution of new terminals or
  the first-phase implementation of a new port plan
- **short-term** period of 1 year
  procurement of equipment, small infrastructural improvements and
  adaptations

On the other hand, a differentiation should be made according to scope:

- national or regional port planning
- planning new individual ports
- extensions or adaptations to existing ports

In terms of time horizon, the discussion will be restricted to long-term planning because
medium-term planning is usually only a derivation from long-term planning. As in all planning,
work has to progress from large to small and what has to be realized in five years has to fit into
the canvas of infrastructural provisions that will be necessary in, say, ten or twenty years time.
it is, therefore, necessary to develop initially a long-term vision and strategy.

In terms of scope, in the first instance the planning of new individual ports will be discussed
because, in principle, all the relevant aspects of planning will then come under review.

The drafting of a national ports plan is primarily a matter of general and transport economics
and, as such, falls outside the scope of this discussion.

3. WHY AND WHEN ARE NEW PORTS NEEDED?

The construction of a new port may be considered because of one or more of the following reasons:

- The ‘choking’ of existing ports, such as the ‘urbanized’ ports (e.g. Marseilles, Algiers,
  Alexandria, Bangkok, Bombay, Madras, the original ports of Rotterdam and Antwerp, and
  many others).
- Insufficient water-depth in existing ports, and the impossibility or high cost of increasing it.
- The discovery of new mineral sources or the development of new agricultural areas.
  Generally speaking, increased economic activity in an area.
- Sometimes the possibility of stimulating development in certain -as yet- undeveloped areas.

In many cases, a carefully considered choice had to be made or must still be made between
the extension and improvement of existing ports and the construction of new ones.

The advantages of a new port are:

- it can be adapted to modern requirements
- it can be given a great degree of flexibility

The disadvantages are:

- in addition to the port itself, new through-transport routes (rail, road, inland waterways) will
  have to be developed at the same time
- a skilled workforce is not readily available
- port-orientated provisions and services are not immediately available and cannot be that
  easily mobilized (forwarding agents, shipping agents, workshops, banks, etc.)
- a new port, therefore, needs a long running-in time before it begins -to some extent- to
  operate efficiently
It is also important to prevent too large a decentralization of port activities - both regionally and nationally - as deep sea trade wants to call on as few ports as possible. ‘Ports must follow the trade, but the trade does not always follow the ports!’ It is wise to aim region-wise or country-wise at a minimum number of deep sea ports at strategic locations. This in conjunction with such small ports for feeder services as local trade and developments require them.

The above applies mainly to the normal multi-functional commercial ports. When bulk transhipment of only one or two products such as ore, coal or oil is concerned, the problem is usually simpler. These so-called dedicated ports are just a link in one or more well defined integrated transport chains and the processes of location selection, evaluation, decision and management are centralized by the owner(s) or operator(s) of those transport chains.

4. STAGES IN PORT PLANNING

In the port planning process, the following stages or steps can be distinguished in more or less chronological order. ‘More or less’, because there will be many overlaps and many feedbacks due to interrelation.

Long-term: masterplanning

(i) General definition of the objectives.
(ii) Delimitation of the coastal zone where the port has to be situated if it is to satisfy its requirements: centres of activity, connections with the hinterland.
(iii) Collecting existing data.
(iv) Rough forecast of the cargo flows: origin/destination, definition of the hinterland.
(v) Study of the likely shipping patterns: number/type/sizes of the ships for the various trades, i.e. translation of the cargo flows into a shipping forecast.
(vi) Provisional determination of the required areas of land and water and the required water-depth (primary programme of requirements, see section 8), nautical aspects.
(vii) A broad investigation into the local environmental conditions: geological and geotechnical, oceanographical and hydrographical, coastal-morphological, demographical and sociological, etc.
(viii) Generation of different outline plans for different locations, developing basically a complete overview of feasible solutions.
(ix) Screening of alternative locations and plans on the basis of criteria like:
   - the available areas of land and water (plus extension possibilities)
   - oceanographical considerations (waves and currents)
   - nautical considerations
   - coastal engineering considerations
   - geotechnical aspects
   - environmental aspects
   - connections with the hinterland
   - sociological considerations (urbanization, potential workforce)
   - industrial engineering aspects (situation of the area and elevation, cooling water, foundations, safety)
   - costs aspects (construction and maintenance)
   - accessibility (i.e. the frequency with which ports in alternative locations would have to be closed because of waves, currents and/or winds)
   Pre-selection of the most promising alternatives.
(x) The drawing up of provisional masterplans for these alternatives (see section 8).
(xi) Evaluation procedure plus final selection (see sections 9 through 11).
(xii) Location-oriented site investigation.
(xiii) Optimization (hydraulic model studies, navigation-simulator studies, land use, costs) (see section 12).
(xiv) Detailed masterplan and costs estimate, cost/benefit analysis.
The above is presented in a schematic way in figure 1.
Some of these steps within the masterplanning process will be further discussed in sections 7 through 12.

Medium-term

(xv) Cargo flow forecast for the period in question (in general, a more detailed plan and a more reliable forecast will be possible than for a long-term masterplan).
(xvi) Phase 1 development plan, including functional designs of the terminals, with due regard to safety and environmental aspects.
(xvii) Detailed geotechnical investigations.
(xviii) Provisional structural designs + costs estimates.
(xix) Capacity optimization.
(xx) Environmental impact assessment.
(xxi) Organization, operation, tariff setting.
(xxii) Financial/economic evaluation.
(xxiii) Decisions on investments and execution.
(xxiv) Detailed design, tendering procedure, execution.
(xxv) Manpower development and operational support.

5. THE DISCIPLINES INVOLVED

It will be clear that many divergent disciplines are usually involved in this type of planning operation. Some of these are:

Technical group
- oceanography and coastal engineering
- hydraulics
- hydro-nautics and nautical technology
- river engineering (sometimes)
- traffic engineering and road engineering (roads and railroads)
- transport engineering
- maritime engineering
- structural engineering
- dredging technology
- geology, geotechnology and seismology
- industrial engineering
- safety engineering

Applied economics group
- macro-economics
- business economics
- transport economics
- econometrics
- organization and management

Sociological/environmental group
- physical planning
- sociology
- ecology and biology
- environmental impact assessment

The port planner generally operates like an orchestral conductor. The conductor must have a reasonable knowledge of the possibilities and limitations of the various instruments, often he will be able to play one or more himself, but not well enough to give a solo performance. He certainly should resist any such ambition. On the contrary, he should give all his talent and energy to attain a fine-tuned and balanced performance of the orchestra.
6. INTERRELATIONS IN THE PLANNING PROCESS

The various planning steps were summed up in section 4 in an apparently logical and chronological order, but we have also mentioned that, in practice, many overlaps, interrelations and feedbacks naturally occur. By way of example, some of these interrelations and feedbacks are indicated in figure 2.

![Diagram of interrelations and feedbacks in the planning process]

Figure 2 - Interrelations and feedbacks in the planning process

One cannot carry out hydraulic model studies without keeping at the same time the nautical aspects in mind and -mutatis mutandis- one cannot optimize the hydro-nautical conditions of a port without considering aspects like wave penetration.

Similarly, it is not possible to define land requirements of port terminals without knowledge of the cargo handling and storage systems to be used. Reciprocally, the decision on these systems may well be influenced by considerations of land availability.

Also, original cargo flow forecasts may have to be adjusted on basis of feedback on port costs to be borne by the cargo.

It will, therefore, be obvious that a clear picture has to be formed of all factors involved in the total planning and their interrelation, before the actual investigation can begin. In other words, port planning demands a systems approach. This is further complicated by the iterative nature of the planning process, as schematically presented in figure 3, which as such is an elaboration of the seemingly simple sequence of activities shown in figure 1.
7. PRIMARY PROGRAMME OF REQUIREMENTS

The primary programme of requirements means the total range of generally defined demands that are needed to identify the alternative locations for building a port. They are:

- The horizontal dimensions of the port approaches, its entrance, manoeuvring space and basins.
- The required depths of these water areas.
- The land required for port installations and industry, and the length of the waterfront required for loading and unloading.
- The relative position of the land areas: distance and height in relation to the waterfront, the minimum distance to the residential areas and to other port activities in view of the type of cargo being handled, and the associated safety and environmental aspects.

The requirements are to be defined on the basis of the masterplan phase, i.e. on the requirements of the maximum planning horizon of approximately 20 years. Moreover, additional space must be available for possible extensions in a distant future.

8. PRELIMINARY MASTERPLANS

The abovementioned requirements, together with the environmental boundary conditions (currents, waves, bottom topography) have to be set down in a number of outline plans based on guidelines of a general nature. Some guidelines are already included in the total set of
requirements (e.g. nautical guidelines in the general dimensioning of the port entrance and manoeuvring space). Other general guidelines are, for instance:

- If possible, any curves in the axis of the port and the port entrance should be avoided, at least from a point some kilometres outside the entrance to a point within the turning circle.
- Situate the port entrance in such a way that incoming and outgoing shipping encounters minimum cross-currents and, particularly, strong cross-current gradients and cross-winds in front of the port entrance.
- If there is a dominant current pattern, the port should be situated in such a way that vessels approach and enter the port against that current.
- The port must offer adequate shelter from wave penetration, particularly at the location of the berths.
- Potential siltation problems must be accounted for.
- The handling of dangerous cargoes requires the introduction of a port zoning plan from the early beginning of planning activities.

There are often contradictions between guidelines. For instance, the orientation of the axis of the port in accordance with the minimization of the cross-current component might well lead to a greater wave penetration in the port.

Outline plans for alternative locations must continue to be made until it is reasonably certain that no possibility has been overlooked. After the first screening of the various alternative locations, only a limited number of serious possibilities remains. These are then developed further into conceptual masterplans and, at this stage, costs analyses can be made.

The comparison of these solutions for alternative locations -or alternative solutions for one particular location- is usually no easy task, because it is well-nigh impossible to satisfy all the demands and guidelines. Therefore, an evaluation procedure that is as objective as possible, must be developed.

9. EVALUATION PROCEDURES

The basic problem in the evaluation is that the criteria for evaluation are dissimilar, for instance sociological as opposed to nautical criteria, flexibility as opposed to costs. There are qualitative and quantitative criteria which must be reduced to the same common denominator for the purpose of evaluation, in other words, a quantification of qualitative norms. Some of the possibilities are:

- checklist approach
- numerical systems / multi-criteria analysis
- monetary systems

The checklist approach will not be considered further here as it is, generally speaking, too simplistic an approach for the purpose.

10. NUMERICAL EVALUATION

The numerical evaluation is usually produced as ‘multi-criteria analysis’. It comes in various forms, such as the measured success index technique, the expectation value technique and the concordance/discordance technique. In the following, the simplest one, the measured success index technique, will be briefly discussed.

A framework can be made of e.g. primary, secondary and tertiary criteria, each of which is given its own ‘weight’ or norm value.

The norm value of primary criteria can be set by a panel, representing all the disciplines involved, using an iterative process.
The norm values of the secondary and tertiary criteria which are sub-divisions of the primaries, can be set by representatives of the various disciplines in question.

After that, all the criteria are given a valuation. Multiplication and addition of norm values and valuation marks eventually produce an ultimate quantitative appreciation.

**Example**

<table>
<thead>
<tr>
<th>Primary criteria</th>
<th>primary norm value, for instance:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) port technology</td>
<td>10</td>
</tr>
<tr>
<td>(ii) physical planning</td>
<td>6</td>
</tr>
<tr>
<td>(iii) industrial development</td>
<td>6</td>
</tr>
<tr>
<td>(iv) coastal morphology</td>
<td>3</td>
</tr>
<tr>
<td>(v) costs</td>
<td>7</td>
</tr>
</tbody>
</table>

**Secondary & tertiary criteria**

The primary criterion (i) ‘port technology’ subdivided as follows into secondary and tertiary criteria:

(i) port technology

(a) **nautical and hydraulic criteria**

1. approach route (close to shore or obstacles?)
2. stopping length
3. manoeuvring space in port
4. nautical safety
5. traffic control
6. wave penetration in port
7. waves in front of the port
8. cross-current in front of the port

(b) **flexibility**

secondary norm value, for instance: 7

1. possibility of extension
2. possibility of changing function allocation (of port areas)

(c) **safety (passive)**

secondary norm value, for instance: 8

1. the position of danger zones in relation to the local environment
2. possibility of limiting disasters

(d) **building time**

secondary norm value, for instance: 3

In the above example, the tertiary criteria are assumed to have about the same ‘weight’. In that case, giving a valuation mark is sufficient and a norm value is not necessary. Other primary criteria can be subdivided in secondary and tertiary criteria in a similar way.

On the one hand, this numerical system has the disadvantage of a still rather great subjectivity in setting norm values, especially with regard to ‘costs’. On the other hand, the whole calculation can easily be repeated with different norm values, and the sensitivity of the outcome to shifts in the norm values determined.
11. MONETARY EVALUATION

In this type of evaluation all evaluation 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 alternative 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 of 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 local 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 realize certain required developments of the port within a certain period. The resulting costs of having them realized 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:

\[
K_e = \sum_{t=1}^{n} \frac{K_t}{(1+i)^t}
\]

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 \(t\)
- \(K_e\) is the present-day value

In view of the many uncertainties in the different cost and benefit elements, the traditional deterministic type of analysis and evaluation can best be replaced by a probabilistic approach, i.e. best gain values replaced by estimated probability density functions.
12. PROJECT OPTIMIZATION

Following evaluation of alternative locations and layouts and the selection of the most suitable one, the optimization 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, operational simulation models, with as an ultimate target the minimization of costs.

(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 scalemodels.

(ii) Navigation simulation studies
Adapting the layout of the port and its approaches to optimize the nautical safety. Various systems exist, from complete fasttime computer models, including a programmed navigator (quick, cheap, but with limited possibilities) to full-scale realtime 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 a statistically reliable picture of deviations from the channel axis and of stopping distances actually used.

The ultimate object is the verification and optimization of the form and dimensions of the port with respect to the approach channel, entrance and manoeuvring areas by means of a 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 minimization of the overall port costs per ton of cargo.
An example of a generally applicable advanced simulation model is ‘Harborsim’, developed by the Hydraulic Engineering Group of the Delft University of Technology. The model simulates the movements of the ships to and from the port, dealing with:

* a large number of ship types (and, necessarily, different categories per type) with different arrival patterns
* tidal conditions (water levels, current velocities) of each approach channel section
* weather conditions (storm and fog)
* day or night navigation

The general configuration of the model is given in figure 4, and consists of:

* an approach channel with a maximum of 4 sections (s1, s2, s3 and s4) (each channel section can be given a one- or two-way traffic designation, depending on the ship type)
* a maximum of 4 turning basins (s5, s7, s9 and s11), each of which gives access to a maximum of 10 basins (each basin may consist of a varying number of berths or varying length of quay wall [in the latter case providing a varying number of service points depending on the distribution of ship lengths])
Figure 4 - General configuration simulation model 'Harborsim'
In conclusion

- Port planning is no longer an essentially civil engineering effort, but very multi-disciplinary.
- A port can no longer be investigated independently, but only in the context of its function as an interface between different transport modes and as a link in a number of transport chains. In other words, it has to be studied in the light of the total transport systems and chains of which it forms part.
- In this respect it is noted that optimization of integrated transport chains -applicable to many bulk trades- can not be done by optimizing individual links separately, e.g. by minimizing the port costs to be born by the cargo. For example, port costs will often attain a minimum for relatively small ships as water depth usually is an expensive commodity. But the consequential high costs of sea transport -using small ships- may well outweigh the savings in port costs (see figure 5). Therefore, integrated transport chains always have to be studied in their entirety.

\[ \text{Figure 5} \quad \text{Cumulative cost in a transport chain} \]

13. 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, but as a 'career plan' for the port requires regular adjustment to the continually changing boundary conditions: readjustment of both strategic as well as infrastructural planning.

(b) Frequent shortcomings or 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 organizational 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-maneuvre ships make on the infrastructure of the port, i.e. underestimation of the hydronautical 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.

* Operation
  - 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 organization 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 port.

* Port congestion
  More often caused by organizational and operational shortcomings than by deficiencies in the infrastructure. It should also be borne in mind that organizational 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.

* Specialization in goods handling
  Often trying to catch up with developments in the West and according to imaginary needs. Specialization 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.
Safety and environmental demands

They still frequently meet with little understanding and interest, or even willingness, to spend money on them or to set up studies in these aspects. Safety and environmental provisions are often seen as a luxurious hobby of the prosperous developed world, which, in fact, they are not.

Practical design aspects which may affect planning, as available building materials, construction methods, etc. The choice of materials is often limited. On the one hand, local cement, aggregates, stone from local quarries, etc., have to be used. On the other hand, the aggressiveness of the sea in warm areas is much stronger than in temperate zones. In certain areas, this has led to large-scale and widespread problems.

Specific environmental conditions such as the occurrence of rock or coral formations in the port zone, or the seismicity of the area, can create a wide range of special problems.

(d) In section 12, concerning the optimization of the project, the element 'wave penetration' was also mentioned. This defines:

* the point where tugboats (inside the port) can start manoeuvring in position and tying up to assist the incoming ships (limiting significant wave height approximately $H_s = 1.5\,\text{m}$)
* the wave agitation at the berths and the possible resultant disturbance of the loading and unloading operations

As far as the latter is concerned, it is difficult to give specific limits of the admissible wave height, because this is closely connected with the wave period, the angle of incidence (with regard to the moored ship), the ship's natural period of oscillation, elastic properties of fenders and hawsers, etc. But it is also difficult to make model tests into this aspect for every berth, certainly not so for berths used by a great variety of ships.

In this connection, some indicative values are given: the given wave height limit (above which loading and unloading operations will have to be stopped) refers to the heights of residual deep water waves with periods in the range of about 7 to 12 seconds. Locally generated waves have a short period and have relatively little effect on the moored ships. On the contrary, waves with very long periods -seiches- can have a disastrous effect already at much lower wave height than is indicated in the table below.

### 0° (head on or stern on)

<table>
<thead>
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chapter 4.

PLANNING & DESIGN

OF A PORT'S WATER AREA
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1. HYDRO-NAUTICAL ASPECTS

1.1 General considerations

(i) Hydro-nautics is a borderline discipline between nautical engineering or naval architecture and hydraulic engineering. It investigates and predicts vessel behaviour in the confined waterways of ports and port approaches in order to be able to design these waterways at a desired level of safety.

It came into existence as a separate discipline in the sixties as a result of the very extensive research carried out for the planning and design of the deepwater ports of Antifer in France and Rotterdam-Europoort in The Netherlands. At this stage of time, it is a quite generally accepted specialist discipline in port development, certainly so in the development of deepwater ports.

What is involved is the determination of the lay-out and dimensions of a port's main waterarea, i.e.:

• the alignment and width of approach channels and port entrances
• the depth of approach channels
• the size and shape of manoeuvring spaces within the port, in particular the stopping space

These dimensions are of great importance, first of all because in many instances the water areas and the thereto related breakwaters constitute the biggest investment by far in the port infrastructure, secondly as e.g. entrance width, manoeuvring space and breakwater alignment are very difficult to change or adapt once the port has been built.

(ii) For deepwater ports that have to be suitable for the reception of large ships, say, in excess of 50,000 to 70,000dwt, the problem arises that the actual sailed track of these ships -as compared to the ideal track- may deviate considerably from those of conventional vessels. This is a consequence of the long reaction times of large ships to rudder motions or rpm changes. Such different manoeuvring characteristics can require the introduction of new limiting operational criteria for traffic in a port's approaches and other navigation areas. Mutatis mutandis, the provisions to be made for safe navigation to and from the ports may be extensive as compared to those for conventional vessels.

(iii) Important developments in sea transport are not necessarily restricted to past decades, but are continually stimulated by technological improvements and changes in transport demand. If a port and its facilities is not adapted to or keeps track of these developments, it will result in delays, congestion, accidents, collisions; in short: in inadequate functioning. The penalty for the regional and national economy is always heavy.

As already observed, adapting an existing port to new nautical requirements is often a difficult, time-consuming and expensive affair, if originally insufficient flexibility was incorporated in the design. Therefore, in the development of new ports, first of all, a thorough evaluation has to be made of the type, size and number of vessels that will make use of the port, initially and in the future, and whether these vessels will arrive and depart loaded or unloaded. Secondly, because of the inherent inadequacies and errors in these evaluations and forecasts, a maximum degree of future adaptability of the port's approaches and manoeuvring areas to new types of ships has to be built in.

(iv) The transition of a ship sailing in open sea to the mooring at a terminal generally can be divided in three phases. This division reflects the type of manoeuvres to be performed, dependent on the configuration of the specific local coastal area.
The first phase is the preparation for the transit movement, the second phase the negotiating of the port approaches itself and the final slowing down and stopping manoeuvre, and the third phase the approach and mooring to the berth. Similar phases apply for vessels leaving the port.

The nature of these transit phases is determined by representative maximum and minimum sailing speeds within which these transits can be performed within acceptable safety criteria. For example, there are maximum and minimum port entrance velocities within which a ship can still stop within the port boundaries without taking resort to crash stop procedures.

The above leads to requirements for the horizontal and vertical dimensions of the port's access and manoeuvring areas.

Manoeuvring characteristics of vessels with a big mass-inertia lead to big manoeuvring space requirements as compared to conventional vessels. Assistance of tugboats is required at slow sailing speeds and in confined waterways; usually, the efficacy of tugboat effort increases with decreasing vessel speed.

The possibility of failures in the steering machine or the propulsion unit of vessels during port transits cannot be neglected. The probability of such deficiencies increases with the increase of the intervals between maintenance and repair works, apart from the fact that these deficiencies already occur more frequently in port transits than in open sea because of the sudden changes in the regime of the engines. The potential effect of such deficiencies should be minimized as much as possible, particularly where dangerous cargo is concerned, by adequate port planning.

Deviation of the ideal track in port transits can be caused by many factors, one of them being the human element. Navigators are human beings, of whom no two react in the same way to a given situation. The dimensioning of the port transit areas should make allowance for the stochastical character of the variations in these human actions and reactions.

In a general sense, the actually sailed tracks depend on the manoeuvring characteristics of the ships concerned and on the condition of the waters in which it sails. These, in their turn, affect the actions taken on the bridge, necessary to guide the vessels through the subsequent manoeuvres of the port transit.

The control activities on the bridge are dominated by three different types of human actions:
* maintaining the required course
* countering at an early stage deviations from the intended track
* avoiding unstable vessels motions which might result in loss of control in steering the vessel (see figure 1)

Unstable vessel motions are associated with resonance conditions which are different for different types and sizes of vessels. Some forms of resonance can be mastered by human navigators, others not or not sufficiently. Therefore, in the planning of port approaches, the investigation into the response of design vessels on conditions representative for the coastal area concerned, is very important. The purpose always being to ensure safe navigation to and from the port.

Another essential element in this safe navigation is the availability to navigators of all necessary information: information on the ship's position with respect to the track to be sailed, information of a coordinative nature in the context of traffic surveillance and/or guidance in the port's navigation areas, and information on environmental conditions (wind, visibility, waves, currents, tides).
The desired and feasible degree of integration of the information systems, the required reach, accuracy and reliability, the peak density of the traffic as well as local atmospheric conditions, jointly determine the types and position of the aids to navigation\(^1\) to be procured and installed.

\[\text{y} = \text{deviations from the intended ship's path}\]
\[z_1 = \text{water level deviations sea surface}\]
\[z_2 = \text{sinkage deviations ship's bow}\]
\[z_3 = \text{bottom level deviations}\]

Figure 1  Ship's behaviour in confined water navigation - indications of instable motion pattern (schematically) in horizontal (a) and vertical (b) plane

Present-day research methods permit the systematic investigation of the dynamics of port transits and marine traffic flows (ref 11). Such investigations provide basic data, inter alia, for establishing procedures for navigators and VTS operators alike during port transits. Together with the introduction of advanced electronic navigation systems, it makes it possible to fulfil the basic conditions for the safe and efficient navigation to and from a port, also for big and vulnerable vessels.

\(^1\) Aids to navigation is equipment provided by the port or coastal authority: VTS or VTMS, buoys, leading lights, positioning systems, etc. Navigational aids is ship-born equipment.
1.2 Ship manoeuvrability and motions

1.2.1 Factors of influence
As from the late sixties, considerable research and development work has been carried out throughout the world to define the factors and the relationships which determine a ship's manoeuvrability and its response to its own control systems under real-life conditions in both open and restricted waters. The advent of the larger tankers and bulk carriers has provided the incentive for such development, the results of which are being applied in the design of ship hulls and ship control systems, in training, in setting navigational requirements and operational limitations and in the design of channels and other waterways.

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:

* the way the ship reacts on the rudder and on changes in propeller revolutions
* turning ability
* the extent of course stability
* stopping ability

1.2.2 Rudder efficiency
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 m/p ratio [mass/propulsive power] and the rudder area, they 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 (figure 2) 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 momentum exerted by resistance forces, counteracts the yawing of the ship caused by the initial disturbance. After momentum and forces become zero again, the ship follows a straight path, but with a changed course (figure 3a). This does not occur with a dynamically unstable ship. The momentum due to the resistance forces, strengthens the initial rotation. The ship continues turning, even after forces and momentum reach a new state of equilibrium (figure 3b). In shallow water, the course stability tends to be better than in deep water.
Figure 2  Effect of a sudden increase of propeller revolutions during rudder deflection
[source: Koelé and Don]

Manoeuvring of ships

disturbance

Figure 3  Dynamic course stability: a = stable, b = unstable
1.2.3 Turning manoeuvre

The turning diameter in deep water at service speed and a rudder angle of $35^\circ$, 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 27kn. For these ships, turning diameters are in the order of 6 to 8L. Turning diameters for large oil and dry bulk carriers at service speeds in the 15 to 17kn range, are in the order of 3 to 4L, some even less than 3L. LNG carriers are mostly in the 2 to 2.5L 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 turning momentum that can be exerted, is virtually ineffective.

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

1.2.4 Stopping distance

The stopping distance is affected by:

* the size of the vessel and the relation propulsive power - displacement (= mass)
* the speed with 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 (figure 4). 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 4 Stopping distances of ships](from IAPH)
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 10,000dwt general cargo vessel is able to stop from a cruising speed of 16 knots in a minimum distance of about 5 to 7L, say 900m, (‘crash stop’) whilst a 200,000dwt bulk carrier or tanker requires some 14 to 18L, say 4800m. (Starting from a low speed -say 5kn-, the stopping distances are obviously much smaller; for a big tanker ≤3L, for a general cargo ship ≤L.)

In recent years, a number of so-called ‘fuel economic’ bulk carriers and tankers hav come into operation with very low propulsive power. (For a 150,000dwt bulk carrier, the \( \rho \) may be about 13 and cruising speed about 12kn, against a normal \( \rho \) of about 8 and cruising speed of 15kn for this size of vessel.) Moreover, their engines cannot run at low rpm’s; ‘dead slow ahead’ may be in the order of 6kn. 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 4kn. However, waves and, particularly, cross-currents 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 1.3.4.

A degree of course control can be maintained by giving periodically brief ahead propeller thrusts with the rudder set to give the desired course correction (see section 1.2.2). 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 upon entering port. It gives a minimum stopping distance, but, due to turbulent flow around the rudder, the vessel has no course control whatsoever (figure 5). For traditional general cargo ships this is not so much of a problem, but for big ships it is within the constraints of a port.

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Figure 5  Stopping manoeuvres tanker MAGDALA, 220,000dwt [from IAHP]
In the fully controlled stop, the vessel -once in the port- maintains the minimum speed required for course control, whilst tugboats tie up for and aft, which takes 10 to 15 minutes at least. Subsequently, the vessel stops under its own power, but the tugboats keep the vessel on course. It leads to stopping distance of some thousands of meters which, of course, has a great impact on port planning and design (section 1.3.4). But, it is a safe procedure and widely accepted as compulsory for ports which have to receive big ships with dangerous cargo.

Non-recognition of these hydro-nautical aspects and considerations has led to costly errors in deepwater port development, as will be illustrated later.

1.2.5 Effect of local physical conditions

(i) The manoeuvring characteristics and manoeuvring behaviour are strongly influenced by environmental conditions. These are particularly:

- shallow water effects: increased resistance, squat, bank effects, changed response to rudder, improved course stability
- waves and swell: stable or unstable course deviations, increased resistance, sometimes reduced rudder response, vertical ship motions
- currents and winds: drift motions

Cross-currents or cross-wind components induce a sideways drift to vessels. In order to maintain course, a vessel will have to steer under an angle with its theoretical course. Since there are practical limitations to this drift angle, the phenomenon becomes of particular importance in port transit manoeuvres. The more so, because the effect of cross-currents increases with decreasing keel clearance.

Waves and swell have a considerable effect on course stability and on the required allowances for deviations from the ideal track when navigating in confined waterways. The effects, however, cannot be generalized, but have to be investigated for every situation.

The consequences of ship's response to waves and swell for the design depth of dredged channels are discussed in section 1.3.1.

(ii) The influence of water depth on a sailing ship becomes noticeable at a depth of about 4 times the ship's draught. The influence becomes significant at a depth of approximately 1.5 times the ship's draught. Shallow waters are, therefore, usually defined as fairways with a depth of 1.5 times a ship's draught, or less.

Effects of shallow water on the manoeuvring characteristics are an increased course stability against a decreased rudder efficiency. In other words, there will be a decreased tendency of a vessel to zig-zag around its ideal track on the one hand. On the other hand, turning radii will increase and the response to rudder angles will be slower. Due to increased resistance, stopping distances will relatively decrease in shallow water, although not in a spectacular way.

Another important shallow-water effect is the increase of the squat of a vessel, i.e. the sinkage resulting from the return currents along the sides and under the keel. Many investigations have been carried out in this phenomenon, and many formulae developed. The squat is essentially proportional to the square of the ship's speed. A general applicable formula is that of Dr C.B. Barrass (ref 10):

\[
\sigma = \frac{C_s}{30} \times S_t^2 \times V^{2.08}
\]

for shallow water: 
\( (1.1 < D/d < 1.5) \) (figure 6)
in which:  
$\delta$ = squat in metres  
$v$ = vessel's speed in knots  
$C_b$ = block coefficient  
$S$ = blockage factor (bd/BD)  
$S_2$ = $S/1-S$

Figure 6

for laterally-unconfined water (depth restrictions only):

$$\frac{B}{D} = 7.7 \times 45 \left(1-C_w\right)^2$$

in which  
$C_w$ = waterplane area coefficient ($A_w/bL$)  
$A_s$ = vessel's cross-sectional area in the plane of the water surface  
$L_s$ = vessel length

Figure 7

Obviously, there is no sharp transition between laterally confined and unconfined waters. For practical purposes, channels with $p/D \leq 0.4$ are considered as unconfined and those with $p/D > 0.4$ as confined (figure 7). It is also approximately the point that for deep drawing ships sailing close to the banks, bank-suction becomes noticeable. (Officially, in the English civil engineering terminology, channels with $p/D > 0.4$ are called 'canals'.)

In confined waters, with $B/b > 5$, often use is also made of the formula of Tuck {ref 13}.

(ii)

A special aspect of the shallow water effects is the sailing above or through low density mud (sling mud). For a number of ports, these aspects have direct consequences for their channel maintenance policy or accessibility criteria (Rotterdam, Shanghai, Bangkok, Paramaribo, Cayenne). The following conclusions are the result of prototype and laboratory tests:
Resistance
Navigation in the presence of mud gives a speed-dependent increase in resistance, which is observed particularly in the determination of the rpm-speed relationship. This resistance depends, apart from the keel clearance, etc., on the shape of the ship. Since the bulk of the resistance increase must be ascribed to wave-making resistance, the wet surface in ‘clean’ water is of importance. Here, a VLCC is probably the most unfavourable form of a vessel because of its high block coefficient.

Stopping distance
Because of the increased resistance, the stopping distance of a vessel will be appreciably reduced.

Squat and trim
When the ship’s bottom is still above the silt, increase in squat is noted because of the increase of current velocities between the keel and the silt. This is in agreement with the phenomenon in clean water in relation to a firm bottom. When just ‘above’ or ‘on’ the silt, a decrease in the squat through a change or disappearance in the flow of water under the keel is observed. With the keel actually in the silt, a reduced squat is observed because of the change in density.

Rudder efficiency
Because of the increase in resistance when silt is present and the higher rpm consequently necessary to maintain a given speed, the propeller slip-stream also becomes greater and, therefore, the flow round the rudder and, hence, the rudder efficiency increases.

Propeller efficiency
Because of the higher propeller speeds required, a smaller reserve will be present for short impulses of higher rpm’s or, more generally, in the use of the propeller.

Effect of the speed of travel
Considerably more rudder must be applied to round bends at low speeds. At these speeds, however, in general tugboat assistance will be available, so that this need not create problems. Mainly because of the higher rudder efficiency due to the higher propeller speed in navigation under silt conditions, dynamic movements, such as changes in course, will be initiated more directly, while -because of the damping action of the silt- less time and space will be necessary for their execution.

Prototype and laboratory tests have shown that navigation is still possible up to relative densities of about $\gamma = \gamma_{1.2}$. Generally, there will be a gradual transition from clean water to sling mud, dense mud and consolidated mud. The ‘nautical depth’, i.e. the depth determining the navigability of the fairway, is then defined at the level where $\gamma = \gamma_{1.2}$ is reached (figure 8).

1.3 Consequences for port planning
1.3.1 Depth of approach channels

(i) The required keel clearance factors and safety margins are schematically show in figure 9.

The vertical movement of a ship in response to wave and swell is a stochastical parameter, for which the probability of exceedance of a given value can be determined, if the local wave conditions as well as the ship’s response characteristics are known in sufficient detail (see also sub-section (iii) hereafter). These response characteristics, in their turn, may vary significantly between vessels of the same size and class. Also, the actual channel bottom level, as a result of dredging inaccuracies and sedimentation, is no flat plane nor are there fixed tolerances to determine a nominal level.
The actual channel bottom level could be defined by determining the probability distribution for the exceedance of given levels. If both distributions are known, the risk of a ship touching bottom during a port transit can be determined. On basis of this risk, the dredging level can be decided upon.
In other words, the spectrum of the distance of the critical point of a ship's keel to the sea bottom $Z(\omega)$ is the sum of the spectra -or probability density distribution- of:

- the response to wave motions (further discussed in sub-section (iii) hereafter)
- the tide
- the sea or channel bottom irregularities:

$$Z(\omega) = S(\omega) + T(\omega) + R(\omega)$$

in which $\omega$ is the wave frequency, assuming that these spectra can be expressed as a multiple harmonic function with a timescale for $R(\omega)$, the speed of the vessel with respect to the ground.

The probability of a ship touching bottom is the probability of the vertical displacement of the critical point of the ship's keel exceeding the average available keel clearance:

$$Z(\omega) > k$$

in which:

- $k$ = $\bar{T} + \bar{D} - d - sq$
- $\bar{T}$ = mean side level during channels transit (with respect to the reference level)
- $\bar{D}$ = mean channel depth
- $d$ = draught vessel
- $sq$ = squat and trim

For determining channel depth, it remains to be decided what is the acceptable probability of the ship touching bottom. In economic terms, this is the probability at which the lowest overall costs are attained, cost elements being:

- capital and maintenance dredging of the channel
- average damage expectation to ships
- average consequential damage expectation

The costs can best be expressed as the 'present-day value' of average annual costs over the economic lifetime of the channel.

It is noted that not all ship - channel bottom contacts lead to damage to the ships; it much depends on the intensity of the contact and on the nature of the channel bottom: mud, sand or rock.

Once a ship is damaged, different consequential damages may result. The channel may be blocked for some time imposing delays on other ships. If the vessel is severely damaged, loss of cargo may occur, which -depending on the nature and the volume of the cargo lost- may have very big consequences (e.g. Exxon Valdez!).

Determining channel depth according to the above principles constitutes the probabilistic method.

(ii)

It will be clear, though, that the application of the fully probabilistic method in practice encounters many difficulties, e.g.:

- Determining a probability density distribution of the seabottom exceeding certain values or translating irregularities into a multiple-harmonic function may entail difficulties if the bathymetry is subject to frequent and rapid changes.
- Probability and extent of damage to ships as a function of the force of bottom contact and nature of the channel bottom is only known in quite approximate terms.
- The probability and extent of consequential damages are even more difficult to assess, even in order of magnitude.

For that reason, mostly semi-probabilistic -if not deterministic- methods are used. For example, in determining the optimum depth of the Euro-Maaschannel to Rotterdam, the acceptable risk of a ship touching bottom during a channel transit was established in a deterministic way: 1 per
100 transits for the maximum size ship. (The probability of a ship sustaining damage as a result of touching bottom in the Euro-Maaschannel conditions is in the order of 1 per 500 to 1000 events.)

In the fully deterministic way, often use is still made -unjustly- of the old PIANC-ICORELS recommendations of 1980 [ref 2]. In these recommendations, the PIANC suggests, by way of approximation, that the gross underkeel clearance can be taken as follows:

* open sea areas exposed to strong and long stern or quarter swell, high vessel speed: 20% of the maximum draught
* channel and waiting areas exposed to strong and long swell: 15% of the draught
* channel less exposed: 10%

In fact, these percentages were based on Euro-Maaschannel conditions and the former, deterministic port access rules. But, obviously, this may vary appreciably from one location to another, depending on physical conditions and type and size of ships. For example at Richards Bay on South Africa’s east coast, up to 40% gross underkeel clearance can be required (150,000dwt bulk carrier, 17m draught). Moreover, it is emphasized that the above PIANC percentages apply strictly to large ships, which for this purpose are defined by PIANC as vessels of 200,000dwt or over. For conventional vessels, or even for LNG carriers, these percentages would in many instances be grossly insufficient. Therefore, the original PIANC guidelines should be used with the utmost care, or not at all. They have been partly replaced by the PIANC guidelines of 1985 [ref 3].

(iii)
It is emphasized 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 (figure 10), 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 the safety of the vessel itself, or due to the impossibility of pilots to board vessels.)

![Diagram of tidal windows](Image)

**Figure 10** Vertical tidal window

[Source: Maritime Approaches to the Netherlands Seaports, TU Delft, december 1984]

The type and number of ships involved and the applicable degree of restrictions -i.e. the width of the tidal window- has to be studied from case to case. It will normally be determined on
basis of a minimization of the sum of channel construction and maintenance cost and ship waiting cost. 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.

(iv) 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 11).

![Ship motions](image)

In each of these 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 most important modes of motion for port design purposes - 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.

It should be borne in mind that in decreasing waterdepth, the added mass and damping characteristics of a vessel change from those in deep water, depending on the period of oscillation. In deep water, the natural roll period is usually between 10s and 17s for merchant-type ships. In wind-generated waves with (usual) wave periods between 6s and 10s, 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, which will aggravate the situation.

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 magnitude of the response obviously depends on the relation wave period / natural period \( T/T_n \), or, if the ship is moving with respect to the wave propagation direction, on the relation apparent wave period / natural period \( T_a/T_n \). It also depends on the wave direction with respect to the position of the ship, and on the wave height, with which it is directly proportional, all other factors being constant.

Generally, a so-called ‘transfer function’ is used to define the relationship between wave and ship motion amplitudes or between the energy density of the wave spectrum \( S_{\omega} \) and that of the
ship response spectrum \( S_{zz} \) for a given wave direction. Figure 12 is an example of a transfer function for the effect of roll, heave and pitch combined. It gives the value of the energy densities and of the transfer factor or ‘response amplitude operator’, RAO, with \( S_{zz} = RAO^2 \cdot S_z \). Although the wave spectrum has a peak at about 0.14 Hz or \( T = 7s \), there is virtually no ship response because that frequency is far higher than the natural frequency of the ship motions. At about 0.06 Hz on the contrary, or \( T = 16 \) to \( 17s \), there is a strong response (RAO = about 3), no doubt due to resonance phenomena.

![Transfer function (RAO) - Energy density spectrum waves \( (S_{zz}) \) - Energy density spectrum vertical ship motions \( (S_z) \)](image)

**Figure 12** Characteristic ship motions in waves

Another example is given in figure 13 with separate response functions for pitch, heave and roll. Here, the ship response is not given as an energy density function but as an amplitude function.

In the roll motion, maximum response occurs at an apparent wave period \( T_a \) equal to the natural roll period of 16s of the VLCC involved. Since the ship sails with \( V = 4m/s \) with waves coming stern-in under 45°, the corresponding real (regular) wave period \( T \) can be calculated as follows (figure 14):

\[
C_s T_a = c T = L
\]

\[
T = \frac{C_s T_a}{C} = \frac{C - V}{C} T_a = \frac{C - 3}{C} \cdot 16
\]

Assuming, for simplicity’s sake, that shallow water conditions prevail, the long wave formula \( c = \sqrt{gD} \) applies.

With \( D = 23m, \ c = 15m/s, \ T = 12.8s \) and \( L = 192m \).

(Thus, \( D/L = 0.11 \), whilst the long wave formula is only fully valid for \( D/L \) values < about 0.04. In other words, the general wave formula

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The above value for $T$ will be found in the second horizontal scale of the roll response curve of figure 13.

Figure 13 Influence of period of swell on the vertical movements and the remaining underkeel clearance [source an unpublished report of Laboratoire National d’Hydraulique, France]

The shape of the pitch response curve can also be easily understood if it is appreciated that maximum response in the pitch motion is determined rather by the maximum incident momentum than by resonance conditions. Schematized and simplified, the maximum
momentum can be expected for \( L = 2L' \) (figure 16a), or by a period \( T = 2L'/c = 500/15 = 33 \)s. 

In the relevant graph of figure 13, it can be observed that the ship response does not have a peak at the natural pitch period of about 14s, but indeed continues to increase till beyond the end of the scale (at \( T = 20s \)). 

Similarly, heave response is not so much determined by resonance conditions, but rather by the magnitude of the net incident force. This force \( = 0 \) for \( L = L' \) (figure 16b), or at an approximate period of \( T = 250/15 = 16 \) to 17s. The lower graph of figure 13 shows indeed a near-0 response for that wave period. With increasing wave period, and thus wave length, the incident force and the heave response will increase. With decreasing wave period, the net incident force and the response will increase initially, but later on decrease again.

The summary graph 'remaining underkeel clearance', in which the effects of roll, pitch and heave are combined, clearly shows the importance of the long period waves -or long period components in a wave spectrum- with regard to the magnitude of the overall vertical ship motions.
The transfer functions of figures 12 and 13 clearly apply to one particular angle between wave direction and ship. If in a port approach channel the long period wave components are not restricted to a narrow sector (in the Euro-Maaschannel there is such restriction), several sets of transfer functions may have to be developed, each representative for a dominant wave direction. The great sensitivity of ship response to wave direction is illustrated by figure 15.

1.3.2 Width of approach channels

(i) A ship will generally not be able to navigate a channel in a position parallel to the channel axis or leading line. The forces acting on the ship by cross-currents and wind necessitate the ship to steer under an angle -the drift angle- in order to follow this leading line. In this way, a state of equilibrium is reached between external momentum and forces and those from resistance and rudder.

It is possible to determine this drift angle for varying circumstances by means of model tests. In confined water it turns out, that under the abovementioned external conditions the ship also needs a compensating rudder angle to keep the ship in average on a straight track. Especially for channel axis navigation in cross-currents, relatively big rudder angles are needed for course correction to preclude a further drifting away from the straight track. Therefore, limitations have to be set for the maximum allowable drift angle, to ensure that still sufficient reserve rudder angle is available for course correction. In accordance with PIANC recommendations, the tangent of this maximum drift angle is usually taken as 1:4, corresponding with an angle of about 14.5°. Sometimes, the angle is taken as low as 10°. The drift angle as such has consequences for the path width used by the vessel, which at 14.5° is approximately 2.6 to 2.7B. The limitation of the drift angle may have consequences for the minimum sailing speed in the channel.

The actually sailed track of a vessel is determined by:
- cross-current and cross-current gradient
- cross-wind
- speed of the vessel
- waves
- rudder response
- bottom topography
- position information
- human response

The channel width required for a one-way channel consists of the path width, the compensating width for the motions which a ship makes around the theoretical straight-line course, the compensating width for location information inaccuracy and a safety margin (figure 17).

![Figure 17 Approximate channel width requirements](image-url)
The translation of the above into actual dimensions is not a straightforward matter. One of the reasons is that the human response of the pilot or navigator is of particular importance here and of a stochastic nature. No two navigators will act or react in the same way in a given situation of vessel, physical conditions and other vessel traffic. Even a single person will often react differently in identical situations, but at different periods of time due to differences in momentary alertness and stress level.

Methods used for determining channel width are:
(a) The empiric method: making use of experience with other channels elsewhere, and converting qualitative opinions of navigators in quantitative terms.
(b) Physical model investigations.
(c) Fast-time mathematical navigation simulation models: incorporating computerized pilot reactions on computerized ship’s performance.
(d) Real-time navigation simulation: using a ‘full mission’ manoeuvring simulator (comparable to the flight simulators in aviation training) and live navigators.

Method (a) has all the inherent shortcomings to be expected. Since no two ports and port approaches are alike, it is difficult and dangerous to translate experience at one location into a design for another location. However, in the early stage of the design process, empiric values are often used to make a first assessment of channel dimensions [ref. 19].

Method (b) is hardly used any more. Its only advantage is the possibility of a good representation of fairway bank and bottom topography and changes therein. But, it does not allow to model the steering loop, i.e. the combination of the ship’s manoeuvring characteristics and its (human) navigator in a reliable way.

Method (c) is frequently used in early and intermediate design stages, as it allows a quick and inexpensive comparison of alternative designs and conditions. But, as the performance of the navigator is incorporated in a deterministic way, it is inadequate for final design and decision purposes.

Method (d) is the only one that enables the stochastic nature of the navigator performance to be taken into account, but only up to a certain extent. This is generally done by having different pilots or navigators make the same channel transit with the same vessel and in identical conditions of current, visibility, etc. From a total of approximately 15 such runs per set of identical conditions, a probability density distribution is made of deviations from the ideal track. From this distribution, the probability that the vessel will exceed the available channel width can be calculated. The weak point is the necessity to extrapolate the distribution curve into the low or very low frequency domain. It has already become evident that the often used normal distribution is much too unfavourable in this respect. The use of Pearson-type distribution appears more suitable, but whether they do give the desired degree of accuracy, is still unclear. See for a further discussion [ref 12].

Research and experience so far have shown that the required channel width depends particularly on environmental conditions as cross-currents and cross-current gradients (variation of these cross-currents per unit length of channel), waves and swell, wind, visibility, but also on the accuracy of information regarding the ship’s position and the easy ‘readability’ of this information to navigators. A minimum value for the width of a one-way channel (width at full depth) would be 5 times the beam B of the biggest vessel in the absence of cross-currents. An average value for average conditions would be rather 7 to 8B. Actual one-way channel width in existing ports varies between 4 and 10B.

For two-way traffic, distinction must be made between vessel types for which encounters are allowed. If two-way traffic is required for the biggest vessels, channel width should be increased relative to the one-way channel by 3 to 5B plus compensation for a drift angle.
Figure 18  Lay-out Euro-Maaschannel to Rotterdam
Channels subject to a big tidal range are often given a width \( >L_0 \), in which \( L_0 \) is the length of the biggest ships expected to call at the port. This because if a ship runs aground on one channel bank, it may turn on the tide and -in a narrow channel- also run aground with its stern on the opposite bank. Since channel transit will normally take place around HW, the ship might, subsequently, break in two at the falling tide. This could block the channel for an extended period.

In curves, ample and gradual widening should be provided for. The magnitude of this widening is, again, strongly influenced -apart from the radius of the curve- by currents and, particularly, by current changes. Reference is also made to the report by a joint working group of PIANC, IAPH and IMPA on conceptual design of approach channels [ref. 19].

1.3.3 Channel lay-out
The lay-out of an approach channel is often largely dictated by the local seabottom topography and other local conditions. In so far as alternative lay-outs are possible, the following aspects should be duly considered in their evaluation:

- A channel should show as little curvature as possible. Curves should, in particular, be avoided near the harbour entrance, as this is nautically already a difficult point.
- A single curve is better than a sequence of smaller curves. Distance between curves should be at least 10L.
- Curve radius should be \( >10L \), in exceptional cases \( >5L \), but with ample local channel widening.
- Cross-currents should be avoided as much as possible. This applies even more to high cross-current gradients, for instance near the harbour entrance and in curves.
- (Emergency) anchorages should be provided along the length of the channel, of which the last one should be located close to the port entrance.
- Channel orientation should preferably deviate, but not deviate too much from the main wave direction. Deviate, because if not, strong wave penetration in the port has to be expected. Not deviate too much, because ships experiencing heavy beam or up to quarter waves, may develop unstable vessel motions. In other words, channel transit will have to be prohibited in those circumstances. It would be a major drawback for a port if this occurs regularly.
- Channels should stay well away from obstacles like capes, under-water rock outcrops, and the like.

An example of a channel lay-out is given in figure 18.

1.3.4 Main manoeuvring areas within the port

(i)
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 1.2.4) 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 50,000dwt 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 4kn, 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 4kn, and/or, secondly, that the drift angle should not exceed a tangent of, say, 1:4. Firstly implies that if there is a following current near the entrance of, for example, 2kn, the minimum entrance speed will be 6kn. Secondly implies that if there is a cross drift as a result of currents and winds of, for example, 2kn, the minimum entrance speed will be 8kn. See also figure 19.

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 a minimum of 10 minutes and a maximum of 20 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 limiting speed of the ship is 5 to 6kn, the limiting wave height about $H_w = 1.5m$. This signifies that 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 harbours. Generally, this will not be the case. On the contrary, it may well occur that tugs have to wait till the ship is an appreciable distance past the entrance before conditions are acceptable.

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, say, 1.5L from an initial speed of 4kn.

---

Figure 19

$v$ = vessel speed with respect to water
$v_{\text{min}}$ = minimum vessel speed for rudder control (3 to 4kn)
$v_{\text{EFF}}$ = vessel speed with respect to channel bottom (design entrance speed)
$u$ = current velocity
$v_{wd}$ = transverse speed of vessel as result of winddrift
$\varphi$ = drift angle
$\alpha$ = angle between current and channel axis

$v_{\text{EFF}} = v_{\text{min}} \cos \varphi + u \cos \alpha$ (controlled by minimum speed for rudder control)

provided that $\tan \varphi \leq 1/4$, or:
\[ v_{\min} \cos \varphi + u \cos \alpha \geq 4 (u \sin \alpha + v_{\text{wd}}) \]

if not:

\[ v_{\text{eff}} = 4 (u \sin \alpha + v_{\text{wd}}) \] (controlled by maximum permissible drift angle)

The consequence of the above is that the length of the inner channel - in terms of aviation: the runway of the port - generally has to measure 2 to 3km or more, if the port will be able to receive large ships under acceptable standard of nautical safety. However, contrary to aviation, there are no international rules to which the dimensions of port channels and manoeuvring spaces have to comply. It is left to the insight of the designer and the safety-mindedness of the owner and investor.

By way of example, if a ship enters port at 6kn and slows down to 4kn over a period of 15 minutes, while tugboats manoeuvre in position, the distance travelled is approximately 2,300m. Add a distance of L immediately past the entrance before tugs can come near, and 2L for actual stopping, or, for instance 3L = 900m, the total length required from port entrance to the centre of the turning basin will be in the order of 3 to 3.5km.

An approximation of the form and principal dimensions of the inner channel and turning basin is given in figure 20. Figure 21 summarizes a number of relevant prototype observations at the entrance of Rotterdam.

![Diagram](image)

**Figure 20** Stopping procedure and inner channel dimensions

(ii)

As regards the shape of the inner channel, the navigable width should be increased in a transverse direction immediately past the port entrance. This because the drift angle of vessels upon entering has initially a tendency to increase; the bow of the vessel is in more or less current-free water, while the stern still experiences the cross-currents. Gradually, the width can be brought back to approximately \( \geq 7B \).

The boundaries of the channel should preferably consist of flat slopes and should be free of obstacles. Under no condition should oil or gas tankers be moored immediately adjacent to main manoeuvring areas.

The slowing down and stopping length mentioned in sub-section (i) above, can be reduced to the extent that the ship’s entrance speed can be reduced. The latter can be attained by limiting port entrance for large vessels to a certain maximum cross-current, i.e. by introducing a
horizontal tidal window. Although this has operational consequences, it may yet be economically attractive.

The concept of introducing 'planned port transit navigation' for large and very large ships - that is: making entry and departure subject to, inter alia, vertical and horizontal tide, as well as sea conditions - will in many instances be a sound one.

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.

Figure 21 Slowing down and stopping length

(iii) The length, width and lay-out of the inner channel can be optimized 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 1.3.2). 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 so 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 minimization of overall costs, including the mean direct and indirect cost of damage when the boundaries are exceeded.

(iv)
Disregard or ignorance of the aforementioned infrastructural requirements for the reception of large ships, can lead to grave and expensive errors in port design. There are several examples around the world. Figure 22 shows one such example.

Figure 22 Location: North African coast

It is a port, built in the early 70s and designed for VLCCs up to 2500dwt and LNG carriers up to 120,000m³ capacity. The available slowing down and stopping length from the entrance till the centre of the turning basin is only about 1,000m, whilst the main manoeuvring area is surrounded by berths for oil and gas tankers. This, obviously, invites disastrous collisions. Furthermore, wave agitation in the port was found to be often excessive. As a result, the port has severe operational restrictions; inter alia, by restricting entry in principle to circumstances in which tugboats can make fast to VLCCs and gas tankers well outside the port entrance. Even then, the port is still nautically unsafe.

1.3.5 Port basins
Port basins should be given a sufficient width for the safe towing in and towing out of vessels, whilst other berths are occupied. For conventional cargo and container ships, this results in 4 to 5B + 100 (Figure 23). If \( B = 25 \text{m} \) (conventional general cargo ship), this means a basin width of some 200 to 225m; if \( B = 32 \text{m} \) (container ships), the basin width should be about 230 to 260m.

In case of very long basins, say 1,000m or more, it is desirable that ships can be turned in the basin. The required width is about \( L + B + 50 \), or, say, \( 8B + 50 \). For \( B = 25 \text{m} \), this results in a width of 250m.
For big tankers or bulk carriers, the desirable basin width - also for two-sided use of the basin - is 4 to $6B + 100m$. The lower value applies to favourable wind conditions, the higher to frequent and strong cross-winds. For $B = 45m$, $5B + 100m$ results in a basin width of 325m.

![Diagram of basin width](image)

Figure 23 Basin width

2. HYDRAULIC ASPECTS

2.1 General considerations

In as much as a port per definition is at the interface of land and water, the hydraulic aspects of port planning and design are manyfold. They mainly comprise:

* Wave agitation inside a harbour at the location of berths hampering cargo handling operations or even endangering the safety of the ships.
* Wave attack on port structures like breakwaters and slope revetments, threatening their stability or integrity.
* Tidal and/or permanent currents and changes imposed by the port structures.
* Changes in the sediment transport and, in consequence, to the local coastal morphology caused by the changes in current and wave patterns. Siltation of a port’s water areas.

In certain cases, river engineering problems may come into the picture, as well as density currents, changes in the salt water penetration into the land, or other site-specific issues.

The different aspects are all dealt with in specialized lecture notes of Delft University of Technology or in numerous text books, to which reference is made if detailed information is required. In the present lecture notes, only a general overview will be given of those subjects that have a direct bearing on the planning and design of a port’s water areas.

2.2 Wave agitation

2.2.1 Causes

Waves within the boundaries of a harbour may have been generated locally, or have penetrated from outside. Due to the limited fetch, locally generated waves will generally be small and of short periodicity. 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 10km range, wave heights ($H_s$) will be somewhat in excess of 1m for a Beaufort 7 wind, and some 1.7m for...
Beaufort 9, with periods $T_o$ of 3 to 3.5s. Since, moreover, these waves can be very steep, they will hamper harbour tugs and similar craft, but large sea-going vessels will not be effected at all.

Wave penetration into a harbour mostly takes place through the harbour entrance. However, also the overtopping of low-crested breakwaters or 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 assess the magnitude of these phenomena at the design stage of the breakwater(s), as it is difficult to devise suitable means to reduce wave transmission once a breakwater has 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 $T_o$ of, say, 12 to 16s is already more difficult to protect against than wind waves of 6 to 8s period. For still longer wave periods, as applies for seiches with a $T_o$ of 2 to 3min or more, the only solution often is to design the port’s water areas in such a way as to minimize the effects.

Wave agitation as a result of wave penetration can be well investigated with the aid of mathematical models. For relatively simple cases and relatively short period waves, usable results can be obtained by defraction-only models. If these two conditions are not fulfilled, more complex models have to be used that incorporate also the refraction effects.

2.2.2 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:

- closed basins
  $$ T_n = \frac{2L_b}{n} \cdot \frac{1}{\sqrt{gD}} \quad \text{with } n = 1,2,\ldots $$

- open basins
  $$ T_n = \frac{4L_b}{(1+2n)} \cdot \frac{1}{\sqrt{gD}} \quad \text{with } n = 0,1,\ldots $$

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 can be used to determine the $T_n$ in different directions.

2.2.3 Response of moored ships

(i) Wave agitation in a port can lead to loss of efficiency or to total disruption of cargo transfer. In severe cases, it may cause the rupture of mooring lines resulting in major damage to ships and port structures.
For that reason, port planners and designers like to know the permissible wave height at berth for different types and sizes of vessels. There is, however, not much literature on the subject. A few authors have attempted to produce indicative figures, but emphasizing at the same time their limited value and validity.

The reason is that the definition of limiting wave conditions is quite complicated. In fact, the waves as such constitute no limiting factor but rather the vessel response. This response of a vessel at berth to a particular wave spectrum is not only determined by that wave spectrum and the hydrodynamic properties of the vessel, but also by berth orientation, elastic spring and damping characteristics of mooring lines and fenders, keel clearance and quay or jetty configuration. This explains why there is no simple answer.

Of the different modes of movement of a vessel -see figure 11- the only ones of real interest here are roll and yaw (rotary) and surge and sway (translatory). For a vessel at berth, big motions in either one of these modes of movement and/or high mooring forces are generally associated with resonance phenomena. Resonance occurs if the frequency of the excitation forces -wave forces- is close to the natural frequency of oscillation of the multiple mass-spring system formed by the ship, fenders and moorings.

This natural period of oscillation $T_n$ is different for different modes of movement.

For the roll motion, $T_n$ is not very much affected by the moorings. In other words, $T_n$ is more or less the same as for the vessel in free floating condition. For third generation container vessels or big ro-ro vessels -the loading and unloading of which is very sensitive to movement of the vessel-, a typical value would be in the 12 to 15s range, i.e. equal to that of a long to very long swell. If the period of the excitation force $T_e$ is much smaller that $T_n$, say less than half of it, the system will only respond very little. If $T_e$ is much bigger than $T_n$, the system will respond as if a constant force $F_e$ were applied to it.

That is why wind waves with a period of some 7s or less will not have much affect on these big ships, although they may be extremely troublesome for smaller craft. Of course, the wave direction with respect to vessel orientation is also of great importance for the magnitude and nature of the response.

Contrary to the roll motion, the surge and sway motions for a given mass of vessel are largely governed by the elastic properties of fenders and mooring lines. Stiff moorings give short natural periods of oscillation, whilst soft moorings lead to long periods. Extreme values for the abovementioned third generation container or ro-ro vessels would probably be, say, 15 to 20s
for hard fenders and all steel mooring lines to 120 to 150s for Yokohama type fenders and all nylon or polypropylene mooring lines.

The yaw motion is appreciably affected by both the properties of the mooring system and the hydrodynamic characteristics of the ship. $T_y$ will normally be in between that of the roll motion and the surge/sway motions.

(ii) The question is whether wave periods in the above range can be expected in specific new port developments and, if so, in association with what wave heights and direction. In many instances, conventional wave observations will have been made. They should provide the necessary input data for (mathematical) wave penetration studies.

Most conventional wave recorders cannot be used for the measurement of the very long-period, low-amplitude waves. These very long waves may either be 'free long waves', originating, for instance, from storms at remote locations or 'bound long waves'. The bound long waves are associated with the wave groupiness in a normal irregular short wave spectrum.

The period of these long components is some 20s up to a few minutes, and the wave height a few cm up to, say, 0.5m. Measurement can either be done by high accuracy pressure-type wave recorders or by a step gauge recorder. The occurrence of these long-period components and the frequency and magnitude is difficult to predict as it varies from coast to coast. Since they are the main source for the surge and sway -and sometimes yaw- motions of a vessel at berth, it is extremely important to start measurements at an early stage to obtain sufficient data. By way of illustration, F.C. Vis, et al., (ref 16) in conducting model tests for a particular port, found surge motions of 35,000 and 70,000dwt bulk carriers in the 2 to 3m range (between extremes) for long-period wave heights of 0.13 to 0.15m only.

The same authors developed a theory to predict the significant height $H_{sb}$ of the bound long waves from the wave spectrum of irregular short waves. This resulted in the following equations:

$$H_{sb} = \frac{0.22}{T_p^2} \cdot H_s^2 \quad \text{for} \quad \frac{D}{gT_p^2} > 0.09 \quad \text{(deep water)}$$

$$H_{sb} = \frac{0.08}{D^2} \cdot T_p^2 \cdot H_s^2 \quad \text{for} \quad \frac{D}{gT_p^2} < 0.04 \quad \text{(shallow water)}$$

in which:

$H_s =$ significant (short) wave height

$T_p =$ peak period of (short) wave spectrum

$D =$ waterdepth

Comparison of calculated and measured bound long-period wave heights at a port location at the Atlantic coast showed a good agreement. However, a later verification at a location on the coast of the Arabian Sea found measured long wave heights about twice as high as the calculated ones. Obviously, one has to be prudent in applying the theory.

(iii) It is noted that the surge/sway problems of vessels may be greatly aggravated if the natural period of oscillation of a harbour basin (in the first or in a higher harmonic mode) corresponds with the period of the incident long-period waves. The resulting resonance of the basin can lead to wave heights within the basin that are a multiple of the open water wave height, re section 2.2.2. Often, vessels will have to leave berth or risk breaking the mooring ropes. Many ports suffer from these 'seiches', for example Hualien in Taiwan, Cape Town in South Africa, the outer port of Amsterdam - to mention just a few.
As already observed, it is difficult to make defences against long-period waves by using breakwaters and similar structures. But, if the predominant wave periods are known from the beginning, harbour basin shapes and dimensions may be so determined as to minimize the effects of these waves.

2.2.4 Limiting ship motions

(i)
Rather than asking to define acceptable wave heights at berth, one could ask to define limit values of the vessel motions.

The least sensitive vessels are VLCCs, ULCCs and big dry bulk carriers, the latter during loading only. These ships can sustain surge and sway motions in the ±1 to ±1.5m range (2 to 3m between extremes), as far as the cargo transfer process is concerned. However, the safety of the mooring system and limitation of wear and tear of fenders may make it necessary to restrict these motions to a maximum of ±0.75 to ±1m.

Container and ro-ro ships, on the contrary, are very sensitive to movement with respect to the quay wall because of the nature of the cargo transfer process. In the roll motion, containers may already start jamming in the cell guides at an angle of a few degrees to the vertical. It is noted that the effective angle of deviation is a combination of roll and list. In the surge and sway mode, movements as low as ±0.1m have been reported to start affecting productivity in case of hard moorings, and thus relatively short-period motions. For soft moorings, the effect will probably become noticeable at motions of ±0.2 to ±0.3m.

Generally, the loss in efficiency is more severe when handling deck containers than when handling under-hatch ones.

In a draft version of the report of a PIANC working group on the 'movements of moored (container) ships at berth' [1991], the following limiting values are proposed:

<table>
<thead>
<tr>
<th>type of vessel</th>
<th>surge (m)</th>
<th>sway (m)</th>
<th>roll (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>container ship</td>
<td>±1</td>
<td>±0.6</td>
<td>±3</td>
</tr>
<tr>
<td>container/ro-ro ship</td>
<td>±0.2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The report refers to studies by, inter alia, Slinn [1979], Ueda [1987] {ref 17} and Per Bruun [1989] {ref 18}.

For the container ships, the lower value for the sway motion as compared to the surge motion probably is intended to reflect the somewhat shorter period of the sway motion. However, this does not seem to be logical because the sway motion is easier to follow for a gantry operator.

(ii)
Within limits, it is possible to influence the vessel motions at berth, particularly the surge and sway motions, by varying the fender and mooring line characteristics. As already observed, stiff moorings and fenders lead to small-amplitude short-period motions whilst soft fenders and moorings result in large-amplitude long-period motions. This does not necessarily mean that stiff moorings and fenders are to be preferred as they also result in bigger mooring forces and, thus, in an increased risk of mooring line failure and damage to ship and quay.

It also remains to be considered to what extent an operator of a multi-user terminal can dictate to the ship captains which number and type of mooring lines to use. But, at least, the selection of a fender system is the terminal owner/operator's prerogative.
Finally, when studying alternative mooring arrangements, it should also be avoided to design a system with a natural period of oscillation $T_n$ that approximates the natural period of oscillation of the harbour basin.

2.3 Currents

The effect of currents in a port’s approaches on port entry and departure procedures and, indirectly, on the dimensions of the manoeuvring areas, has already been discussed in sections 1.3.2 and 1.3.4. But, currents may also effect a ship at berth.

In principle, currents can induce movement of a ship at berth. E.g. strong yaw motions and resulting very high mooring rope forces -up to about 300 tons- are experienced at SMBs in the Singapore area. They appear to be caused by large eddies in the tidal currents, as has been demonstrated by a mathematical flow model at Delft University of Technology. Both the location and the current velocities of the eddies change rather rapidly with the stage of the tide.

In a semi-enclosed harbour basin, current velocities will probably be too low to create any problems. But, ports on tidal rivers as estuaries often have berths along the river itself. As current velocities may be high, berthing and de-berthing will often be restricted to a short period around the turn of the tide, although manoeuvring in a bow current may be acceptable as long as the current is strictly parallel to the berth.

Minor changes in the current direction may also cause yaw and sway motions of a ship at a fixed berth. In all instances, the mooring arrangement (mooring wires, dolphins, bollards) will have to be able to resist the static and/or dynamic current (and wind) forces, even in extreme conditions.

The static current forces can be calculated with:

\[ F_x = C_x \left( \frac{\rho}{7600} \right) v^2 \cdot d \cdot L_{bp} \]

\[ F_y = C_y \left( \frac{\rho}{7600} \right) v^2 \cdot d \cdot L_{bp} \]

in which:

- $F_{x,y}$ = force [tons]
- $\rho$ = relative density of water [kg.s$^2$/m$^4$]
- $v$ = current velocity [m/s]
- $d$ = draft of ship [m]
- $L_{bp}$ = length between perpendiculars [m]
- $C_{x,y}$ = coefficients

Values of $C_{x,y}$ for different angles of attack and different $d/D$ values may be found in (ref 15). E.g. for a full beam current (90° angle of attack), $C_x = 0$ and $C_y = 0.6$ for $d/D > 6$, but $C_y = 3.3$ for $d/D = 1.05$.

2.4 Sedimentation

For a discussion of sediment transport processes as such, reference is made to the lecture papers on coastal engineering.

Sedimentation in a port’s water areas leads to the need of maintenance dredging and, thus, is of immediate economic importance. The annual maintenance dredging in the port of Rotterdam and its approaches is in the order of $20 \times 10^6$ m$^3$ at a cost of about Dfl 40 million. As total cargo throughput is almost 300 million tons, the cost per ton of cargo is only some Dfl 0.15. But, an
average port with an annual cargo flow of, say, 10 million tons and a siltation of $5 \times 10^6 m^3$ at a dredging cost of probably some Dfl 15 million, would be faced with the problem to recover Dfl 1.50 per ton of cargo from port charges.

Adequate design of a port’s water areas can limit the sedimentation problem. Not much can be done about the settlement of suspended sediment in tidal basins, but this is generally also not the biggest problem. It is more important e.g. to try to make an approach channel partly or largely self-flushing with respect to any form of siltation by giving it adequate orientation and dimensions (as long as consistent with nautical requirements).

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chapter 5.

PORT TERMINALS
- INTRODUCTION -
## PORT TERMINALS - INTRODUCTION

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PORT TERMINALS - INTRODUCTION

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.

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.

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 5,000t/h or 100,000t or more per day. But, there are no means of through-transport, whether road, rail or inland navigation, that can even approximate such capacities. In other words, an intermediate storage or buffer stock is necessary. In a general sense, such buffer stock in a transport node is always necessary whenever continuous transport (e.g. pipeline) meets discontinuous transport, or two discontinuous transport flows with different discontinuities meet, or even two identical discontinuous transport flows with a phase difference.

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 fertilizer) or blending (e.g. different grades of ore or coal). More complex forms of processing exist, but are not very common.

3. TERMINAL COMPONENTS

The components of a terminal are:
* the wet and the dry infrastructure
* the suprastructure
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.

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 jetty 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.
4. TYPES OF TERMINALS; TO SPECIALIZE OR NOT, THAT IS THE QUESTION

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 terminals
* IWT terminals
* passenger terminals

The conventional general cargo terminal is one of the oldest and, traditionally, was designed for the handling of break-bulk and -later on- also unitized general cargo. Since break-bulk and unitization have given way, to a large extent, to containerization, 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 specialized 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, specialized 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 specialize, is more than one of simple economics and arithmetics.

In developing countries, the rate of specialization is lagging behind that of the industrialized 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 specialization 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, specialization is normally required from the very beginning, not so much for economic reasons as well as for safety reasons.

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 ship/shore and shore/ship transhipment, 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 transhipment capacity, but also constitutes no restraint. Needless to say that, in practice, this is not always the case.

In terms of transhipment 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 optimization exercise.

However, 'optimum' need not always refer to an economic optimum, i.e. there are other optimization 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 minimization study.

6. TERMINAL DIMENSIONS

For different discrete numbers of berths or for different quay lengths, the optimum cargo transhipment capacity can be calculated in accordance with section 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) \( F_{oc} \) required for this same projected cargo flow.

In general terms:

\[
F_{oc} = a \cdot A \cdot \bar{t}_d/365 \cdot C \cdot f(P_\nu, P_\nu, P_w)
\]

in which:

- \( F_{oc} \) = gross storage area required
- \( A \) = specific area required to store a unit (ton, TEU, m\(^3\)) of cargo
- \( a \) = \((\text{gross area} \times \text{nominal storage height})/(\text{nett area} \times \text{mean storage height})\)

\( a \) is a constant for a given type of cargo and a given cargo handling method. The relation gross area/nett area depends on the space required for equipment movements. The ratio nominal/mean storage height depends on the permissible mean height at full utilization of the storage area. Sometimes this is equal to the nominal height, e.g. for palletized 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, m³) per year
Ps = probability density distribution in time of cargo arrivals or departures on the sea-side of the terminal

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

Pₜ = ditto of cargo arrivals or departures on the land-side of the terminal
Pₜₙ = ditto of the dwell time of the cargo on the terminal

Often, Pₜ and Pₜₙ may be assumed to be uniform. If this is not the case and/or if the type of distribution of Pₜ 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/m²/year
- containers: 6 - 10 t/m²/year
- coal: 15 - 25 t/m²/year
- iron ore: 30 - 40 t/m²/year
- crude oil: 40 - 50 t/m²/year

The m² refers to the total terminal area, including internal roads, offices, workshops and the like.

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

7. TERMINAL ORGANIZATION

Terminal organization varies over different countries and ports.

In quite a number of ports, particularly in developing countries, a large share or all of the terminal operations is still in the hands of the port management which consists of civil servants in the service of local or national governments. Sometimes the pure stevedoring -loading and unloading cargo in or from the ship’s holds- is privatized, sometimes even not that. The terminal managers and labour force are then also civil servants, remunerated according to government wage scales and without any real incentive with regard to efficiency and productivity.

In most of Europe and North America, terminal operations have traditionally been in private hands, but in rather dispersed ways. After the second world war, the large single terminal operating company has emerged which controls all cargo handling, storage and possible processing operations from ship’s hold till the terminal gate.

In The Netherlands and most of continental Europe, with their so-called ‘landlord ports’, these terminal operators rent the waterfront (quay) and the required land area from the port authority (which is a municipal or governmental institution) on a long-term lease. The operating company itself is responsible (financially, technically and maintenance-wise) for paving, for erecting all buildings and for equipment procurement and, of course, for terminal organization and
operation. This works quite satisfactorily and efficiently and may be considered the best form of organization for terminal operation.

The above applies to the multi-user terminals. Some dry bulk terminals, many liquid bulk terminals and some ro-ro and container terminals are single-user terminals. It is then often that single user who also operates the terminal, although there are exceptions, e.g. sections of the ECT terminals in the port of Rotterdam are reserved for Sealand as single user, but still operated by ECT.
chapter 6.

CONVENTIONAL GENERAL CARGO TERMINALS
CONVENTIONAL GENERAL CARGO TERMINALS

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1. INTRODUCTION

The conventional general cargo terminal is the oldest type of port terminal. Due to specialization in port operations, the demand for general cargo terminals is, generally, decreasing, but certainly will not disappear. The requirements with which a general cargo terminal has to comply, have changed over the years.

As a consequence of unitization and mechanization during the past decades, the ship/quay handling capacity increased by some 100%. However, the throughput capacity per m² of the terminal as such has hardly changed, because no spectacular differences occurred in the transit time, density and stacking height of the goods. As a result, much more harbour area is required for the same quay length. In addition, the terminals have to handle containers which arrive as deckload of conventional general-cargo or multi-purpose vessels and, incidentally, other heavy and/or voluminous cargo.

Containers and other big objects cause obstructions and delays in the normal quay traffic during the loading, unloading and transport, certainly where it concerns old terminals with narrow aprons of 12 to 15m. Therefore, new terminals are made with wide aprons of 25 to 50m (distance between frontside quay wall and frontside of shed).

Transport of goods to and from the terminal is dealt with for a major part by heavy road transport nowadays, which requires spacious parking areas in the terminal and sufficient traffic lanes and manoeuvring space around the sheds and storage areas. This adds again to the growing need for harbour area. Many existing general-cargo terminals are restricted in their capacity due to limited area available. It is, therefore, important to design new terminals, right from the beginning, with ample 'breathing space'.

2. THE GENERAL-CARGO TERMINAL

(a) THE CARGO
* Break bulk represents a diminishing percentage.
* Much cargo is palletized, pre-slung or otherwise unitized.
* The percentage of containers varies.
* Occasionally, there are non-standard heavy loads.

(b) EQUIPMENT
* Tractor+trailers
* Forklifts
* Light mobile cranes (specifically for open storage)
* 1 heavy multi-purpose crane (per 1 or 2 berths for dealing with containers and heavy loads)
* 1 or more heavy forklifts (again for containers and heavy loads)

Approximate numbers required for a single berth assuming loading/unloading of 3 holds at the same time, with 1 gang per hold. Consequently, 3 gangs working simultaneously.

For a complete forklift operation (economical for distances between quay and storage area of up to 75 to 100m), 3 forklifts per hold, thus 9 in total.

For longer travelling distances, a mixed operation forklift/tractor+trailer is used. Required per hold:
* 1 forklift for the loading of trailers
* 1 forklift for the off-loading of same
* 2 tractors plus 8 trailers

Which gives in total for three holds:
* 6 forklifts
* 6 tractors
* 24 trailers

Moreover, the open storage and the shed require 1 or 2 mobile cranes plus 2 forklifts.
The numbers are indicative and nett. For all self-propelled equipment one should count with a percentage of spares of 20 to 25% for maintenance and repair.

(c) VESSELS
* Conventional general-cargo vessels
* Multi-purpose vessels

Occasionally:
* full container ships
* coasters (short-sea trade)

For some terminals:
* IWT barges and vessels

(d) LOADING & UNLOADING CAPACITIES
Indicative figures for the deep-sea trade based on 3 to 4 gangs per ship.

<table>
<thead>
<tr>
<th>Cargo Type</th>
<th>Indicative Loading Capacity (Ton/Shift/Ship)</th>
</tr>
</thead>
<tbody>
<tr>
<td>conventional general-cargo (break bulk)</td>
<td>200 - 300</td>
</tr>
<tr>
<td>timber and timber products (bundles)</td>
<td>300 - 600</td>
</tr>
<tr>
<td>steel products (bundles)</td>
<td>500 - 1,000</td>
</tr>
<tr>
<td>palletized and pre-slung cargo</td>
<td>300 - 500</td>
</tr>
<tr>
<td>containers</td>
<td>800 - 1,300</td>
</tr>
</tbody>
</table>

3. THE LAYOUT OF THE TERMINAL

A cargo flow scheme is given in figure 1. A schematic cross-section is shown in figure 2. The high and low values of the dimensions indicated are, of course, approximate. They have their origin in the practical experience with regard to the need for driving and manoeuvring space for road vehicles and cargo handling equipment.

The required dimensions of sheds and other storage facilities have to be further determined, as will be discussed in section 4.

(a) RAILWAY CONNECTION
In modern terminals, no railway tracks are installed any more on the quay apron. In earlier times, much direct delivery transhipment took place from ship to railway wagon. This, however, was a rather slow process due to delays caused by the shifting of wagons. It also hampered the working of other holds and the cross-transport on the quay in general.

At present, there is a greatly diminished amount of cargo in general-cargo vessels, that is suitable for direct delivery (packed bulk cargo). Since, moreover, the installation of a railway track on a quay wall is rather expensive, there is a general tendency to shift the railway connection away from the quay, preferably to the rearside of the terminal, or alternatively between shed and open storage.

(b) ROAD CONNECTION
As already observed at many terminals, the transport to and from the terminal is largely effectuated by road transport. In old 'city ports', this may constitute a problem as the road vehicles have to

---

1 Tons are given as weight tons of a 1,000kg. Many port statistics are, however, still recorded in 'shipping' or 'revenue tons'. These shipping tons are the basis upon which the ship owner calculates his freight charges.
* for a load with a relative density < 1: 1 shipping (or revenue) ton = 1m³
* for a load with a relative density > 1: 1 shipping ton = 1 weight ton = 1,000kg

Generally, the average weight of a revenue ton is approximately 0.5 to 0.6 weight ton.
cross extensive urban areas. Problems may also arise in expanding ports in developing countries with a poor road infrastructure. No terminal, no port can have a greater import/export capacity than the combined capacity of its through-transport arteries. Therefore, a port study can normally not be restricted to the port (or terminal) boundaries.

At the terminal itself, the smooth and safe circulation of road vehicles and the provision of ample parking space for waiting vehicles requires due attention.

(c) IWT PROVISIONS

Ports and terminals located near a navigable river or canal system will need special provisions to accommodate the IWT craft. At first sight, it would appear economical to provide special shallow-depth quay walls for IWT purposes, as these are much cheaper per unit of length than those required for the deep-sea trade. However, in practice only few terminals have special IWT berthage as often the IWT vessels can be served at (temporary) unoccupied sections of the deep-water quay or, in case of direct delivery, when moored to the deep-sea vessel on the basin side.

But as often many IWT craft will be waiting, either because the cargo is not yet there or cannot yet be received, or because all quay space is occupied by deep-sea vessels which have priority berthing rights, special waiting accommodation will generally have to be provided. This can normally consist of simple mooring piles with a catwalk connection to the shore. Also the location of storage spaces on the terminal will have to be selected with the easy transfer of cargo to and from IWT craft in mind.
Figure 2 - CROSS-SECTION TERMINAL
(d) QUAY CRANES
Travelling quay cranes were used specifically in connection with direct delivery of cargo from ship to railway wagon in order to prevent too much shifting of the wagons. This consideration does no longer apply, as the direct delivery has virtually disappeared. Moreover, the lifting capacity and operating speed of ship's gear has very much increased over the years.

Therefore, in general, quay cranes are no longer used in modern general-cargo terminals, except for heavy multi-purpose cranes.

(e) BERTH LENGTH
Traditionally, this length was related to the length of the largest vessel frequently calling at the port, increased with 10 to 15m extra length for and aft. This method is correct for a single berth, but not for multiple berths in a straight continuous quay front.

UNCTAD investigated, for a number of actually observed ship length frequency distributions and for the relation average berth length/average ship length as a variable, the probability of additional waiting times as a result of insufficient available quay length (UNCTAD, 'Port Development', 1984). From this, the following graph has resulted:

This graph shows that with an average berth length equal to 110% of the average ship length, no additional waiting times occur.

With a large number of berths in a row, the average length theoretically could be reduced even more. In practice, this is not the case because only a very limited shifting of ships along the quay front is acceptable.
4. DETERMINATION OF REQUIRED STORAGE AREA

The area required for the separate storage facilities (transit shed, open storage, warehouse) has to be determined from the annual tonnage and the average transit time (or dwell time) of the goods as main parameters. For instance for a transit shed, the required floor area $O_{cs}$ can be calculated as follows:

$$O_{cs} = \frac{f_1 \cdot f_2 \cdot T_{ts} \cdot t_{av}}{m_{ts} \cdot h \cdot \rho \cdot 365}$$

in which:
- $T_{ts}$ fraction of total annual tonnage $T$ which passes the transit shed (see section 5)
- $t_{av}$ average dwell time of the cargo in days
- $\rho$ average relative density of the cargo as stowed in the ship (e.g. 0.6)
- $h$ average stacking height in the storage (e.g. 2m)
- $f_1$ proportion gross/nett surface in connection with traffic lanes for forklifts, etcetera (e.g. 1.5)
- $f_2$ bulking factor due to stripping and separately stacking of special consignments, damaged goods, etcetera
- $m_{ts}$ average rate of occupation of the transit shed storage

Example:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{ts}$</td>
<td>120,000/year</td>
</tr>
<tr>
<td>$f_1$</td>
<td>1.5</td>
</tr>
<tr>
<td>$f_2$</td>
<td>1.2</td>
</tr>
<tr>
<td>$t_{av}$</td>
<td>10 days</td>
</tr>
<tr>
<td>$m_{ts}$</td>
<td>0.7</td>
</tr>
<tr>
<td>$h$</td>
<td>2m</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.6t/m³</td>
</tr>
</tbody>
</table>

the required surface $O_{ts}$ will be 7200m², e.g. a shed of 60*125m.

$m_{ts}$ has to be determined in such a way, that most of the fluctuations in $t_{av}$ and in the cargo flows per unit of time can be absorbed.

The factor $m_{ts}$, consequently, clearly depends upon the number of berths (the same is valid for $T_{ts}$). The optimum value depends also strongly on the possibility of occasionally storing excess cargo outside the terminal and the extra costs thereof.

If statistical material is available, an optimization can be made by means of the probability distributions of the relevant parameters. This is, however, mostly not the case. For that reason, $m_{ts}$ is usually arbitrary chosen in the 0.65 to 0.75 range.

In case clear seasonal fluctuations occur in the cargo flows, the required storage area has to be calculated on basis of the peak season figures instead of annual throughput.

For determining area requirements for open storage and warehouses, an identical procedure can be followed, though the value of the parameters may differ.
5. DETERMINATION OF BERTH CAPACITY

The annual berth capacity $T$, based on ship-shore and shore-ship transfer, is:

$$T = p \cdot n \cdot t_{\text{eff}} \cdot m_b$$

In which:
- $p$ average production per gang/hour
- $n$ average number of gangs per vessel (berth)
- $t_{\text{eff}}$ effective number of working hours per year
  (with a 2-shift system, 6 days/week, 50 week/year and 1 hour loss of time per shift, it equals $\{16 - 2\} \times 50 \times 6 = 4200$ hours/year)
- $m_b$ average berth occupancy

Example:

For $p = 30t/hour$, $n = 2.5$, $t_{\text{eff}} = 4200$ hours, $m_b = 0.60$

the annual berth capacity becomes $T = 189,000t$

The above berth capacity calculation refers to the transhipment capacity ship-shore and vice-versa. It will equal the actual terminal capacity provided that the storage capacity and through-transport capacity match this transhipment capacity. At many older terminals, this condition is not fulfilled.

The value of $m_b$ needs to be determined from case to case. If ship arrivals would be perfectly regular, if all ships would carry the same amount of cargo and, moreover, if the values of 'p' and 'n' would be constant, $m_b$ could equal 1. But it will be evident that in practice there is a considerable fluctuation in all of these parameters.

Thus, for each individual case an optimum value of $m_b$ will have to be determined on the basis of, inter alia, the locally applicable distribution of ship arrivals (e.g. random) and of ship service times (e.g. Erlang-2). In an existing port these distributions can generally be obtained from available statistics, in new ports one can only draw on the experience elsewhere.

Different optimization criteria are possible, e.g.:

* Ensuring a certain service level (ship waiting time should not exceed $x$ hours for more than $y\%$ of the ships served).
* Average ship waiting time should not exceed more than $2\%$ of average ship service time (an often used but disputable criteria, because it rewards poorly functioning terminals).
* The minimization of the sum total of idle berth costs and ship waiting costs.
* The minimization of total port costs per ton of cargo, in which 'total port costs' is the sum total of all terminal costs (fixed and variable, berths idle and operational) and all ship costs (fixed and variable, waiting and loading/unloading).

The latter criterion is the most logical one, but also the most difficult.
6. CAPACITY OPTIMIZATION

Capacity optimization on basis of minimum total transport is schematically represented in figure 4.

The question is, how to determine the minimum $P_2$ of the total transport costs per ton in the port.

6.1 Analytical approach

Based on a given number of berths, varying arrival and service time distributions and varying values of the volume of cargo handled, a calculation can be made of the corresponding service times and waiting times. Together with the different cost elements of berths and ships, this will result in the corresponding total costs and costs per ton. By iteration, a minimum can be determined and, hence, the optimum occupancy rate of the berths and the optimum berth capacity (see figure 5).

It is noted that when all boundary conditions, parameters and the optimization criteria remain equal, $m_b$ will increase with an increasing number of berths, provided that the berths are 'interchangeable' (because of the decreasing probability that all berths will be confronted with peak traffic at the same time). For general cargo terminals, the optimum value of $m_b$ mostly varies between 0.45 and 0.75.

By repeating the above for varying numbers of berths, the $s_{T_{opt}}$ can be plotted against $s$. Reciprocally, this method can be used to find the optimum number of berths for the annual tonnage actually expected to be handled (see figure 6).

In this way, the traffic forecast for a port can be translated into a phased extension planning of the port infrastructure. In applying the queuing theory in relation with general cargo terminals, generally, use is made (on the ground of observations in practice) of the Poisson distribution for ship arrivals (corresponding with an Erlang-1 distribution for the inter-arrival times) and an Erlang-2 distribution for the service times (see also figure 7).

If in existing ports sufficient statistical material is available, it is, of course, recommendable to verify the abovementioned assumptions.

For further mathematical elaboration, reference is made to the relevant lecture notes and to, e.g., E. Page, 'Queuing Theory in Operations Research'. The assumed distribution of arrivals and service times has, in itself, a rather large influence on the calculated waiting times. UNCTAD's 'Port Development' illustrates this with the graph of figure 8.

6.2 Logistic simulation

The development and use of logistic simulation models make sense if factors have to be taken into account, which, due to their number or nature, make an analytical treatment of the problem difficult or impossible. (E.g. disturbing influences on arrival patterns as tidal windows, or working with a variable instead of a discrete number of berths.)

For the planning of general cargo terminals, there are, generally, so many uncertainties (traffic forecasts, productivity and availability of labourers, etc.) that a very advanced optimization is of little use. See in this context also G. Tarr and G. Crook [UNCTAD] 'Numerical Aids to the Planning of Berth Capacity', Dock & Harbour Authority, february 1979.

For specialized terminals, for problems like complex port entry rules and for integrated transport chains, etc., simulation models are, however, a useful and sometimes even indispensable tool. For further details, reference is made again to the relevant lecture notes.
The ship costs per ton during the service period diminish only if the production per day is raised with increasing $m_b$, e.g. by using more gangs and/or shifts.

The variable berth costs go up by increasing $m_b$ due to saturation symptoms and declining productivity of people and plant.

The minimum of the total transport costs $P_2$ corresponds with a lower $m_b$ value than the cost minimum $P_1$ for the port costs only.

**Fixed costs**: capital cost of quay, cranes, sheds (independent of tonnage of throughput)

**Variable costs**: wages, maintenance, fuel

---

1) The ship costs per ton during the service period diminish only if the production per day is raised with increasing $m_b$, e.g. by using more gangs and/or shifts.

2) The variable berth costs go up by increasing $m_b$ due to saturation symptoms and declining productivity of people and plant.

3) The minimum of the total transport costs $P_2$ corresponds with a lower $m_b$ value than the cost minimum $P_1$ for the port costs only.
* number of berths $s$
* arrival and service time distributions
* average load/ship
* varying number of ships
* varying total goods cargo volume

\[ \Rightarrow \]

corresponding
waiting times,
service times,
occupancy rates

\[ \rightarrow \]

corresponding total transport
costs in the port

determine minimum by iteration

\[ \rightarrow \]

optimum occupancy rate $m_b$ for given $s$

\[ \rightarrow \]

optimum annual tonnage $sT_{opt}$ for given $s$

Figure 5

\[ \begin{align*}
\text{optimum annual tonnage } sT_{opt} \\
\text{number of berths } s
\end{align*} \]

Figure 6
POISSON

\[ P_n = e^{-a} \frac{a^n}{n!} \]

in which:

- \( P_n \) probability of \( n \) arrivals per time unit (e.g. per day)
- \( a \) average number of arrivals per time unit

ERLANG

\[ P(t) = \frac{(k\mu)^k \cdot t^{k-1}}{(k-1)!} e^{-k\mu t} \]

and:

\[ P_0(t) = \int_0^\infty P(t) \]

for \( k = 1 \):

\[ P_0(t) = e^{-\mu t} \]

for \( k = 2 \):

\[ P_0(t) = e^{-2\mu t} (1 + 2\mu t) \]

in which:

- \( \mu \) average service time
- \( t \) Erlang value
- \( P_0 \) probability density of service time \( t \)
- \( P_0(t) \) probability of service time > \( t \)

---

Figure 7 - EXAMPLE: Erlang divisions for \( \mu = 1/5 \)
M/E2/4 means:
arrival time distribution: M = Markovian (random) = Poisson distribution
service time distribution: E2 = Erlang 2
4 = number of service points (berths)

Figure 8
chapter 7.

CONTAINER TERMINALS
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</tr>
</thead>
<tbody>
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<tr>
<td>7. Terminal layout and dimensions</td>
<td>14</td>
</tr>
<tr>
<td>References</td>
<td>19</td>
</tr>
<tr>
<td>Annexure I</td>
<td>21</td>
</tr>
<tr>
<td>Annexure II</td>
<td>22</td>
</tr>
</tbody>
</table>
CONTAINER TERMINALS

1. DEVELOPMENT OF CONTAINER TRAFFIC

It was in the early 1950's that MacLean Trucking (later 'Sea-Land') and Matson Navigation Company started with the first containerized transports along the east and west coasts of the USA as a purely domestic operation. The early period was characterized by teething troubles with operational systems, stacking and loading equipment, as well as with information exchange and management in this new, capital intensive branch of port activity.

Since there was a simultaneous development by transport companies (sea, railway and road) on the one hand, and by terminal operators and equipment suppliers on the other hand, different approaches with respect to the set-up of container terminals gained support.

Soon, the containerized transport started spreading from the domestic US transport scene to the international maritime transport market, first in some Atlantic trades, with the Pacific following suit. Some countries or regions have long resisted the arrival of containers in their ports -South Africa, South America and, particularly, Brazil- but ultimately had to give in. In 30 to 40 years' time, world container trade has increased dramatically as well as the size of ships and terminals (see figure 1). By now, container transport has spread to all corners of the world and still shows an impressive growth rate.

At present, some distinct trends can be discerned, which does not mean that the container world has stabilized.

Shipowners and ships

- The main general cargo trades are for the majority containerized (sometimes more than 90%), using mostly 3rd generation container vessels with a capacity of approximately 3,000 TEU, by preference with diesel engine propulsion and speeds of around 22 knots per hour.
- Many trades are unbalanced, requiring the return of an economically unattractive percentage of empty containers.
- Many shipping companies have merged to form new consortia or are at least operating in conferences. A 3rd generation container ship has an annual ton/mile capacity which is 5 or 6 times as high as that of a 15,000dwt multi-purpose ship. This made the formation of bigger combines necessary in order to maintain an acceptable short interval between sailings from the different ports. There is a tendency among these big ship operators to extend their services beyond the carriage of containers by sea and to offer door-to-door transport through the procurement of road, rail and IWT companies.
- The size of containers has been standardized according to ISO regulations to mostly 8ft wide, 8 or 8.6ft high and 20 or 40ft long boxes.
- However, in the past few years, 4th generation and 'post-panamax' container vessels have been introduced as well as containers with deviating larger width, height and length as will be discussed later on. This creates quite significant problems for many parties in many places.

Throughtransport

- Road transport is still the dominating form of throughtransport due to its traditional strong points of flexibility and speed. However, transport by rail -particularly in the USA- and by inland navigation are gradually increasing. This can be contributed to rising energy and labour costs which affect the road transport unfavourably.
- Particularly in Europe, the existing road network cannot absorb the continuous and rapid growth of container traffic.

1 Twenty-feet Equivalent Units
IWT and, to a lesser extent, rail are offering more frequent and better services (but, of course, retain the disadvantage that, in general, tertiary transport by road to final destination is necessary).

Particularly in the USA, where the railway system is not electrified and permits the carriage of wider and higher loads, block trains have emerged that carry containers two-high at very competitive prices. They operate partly between container ports and main industrial centres, partly on an east/west coast ‘land bridge’ service.

Terminals

These, generally, provide a reasonable service to all connecting transport modes, thereby using a variety of equipment types and storage systems. Big differences occur in the utilization of the available areas and in occupancy rates of quays and equipment.

Use is made of middle-size computers to control the information stream. Recently, a start was made with the application of small computers for data communications systems and processing.

The bulk of the capital outlay in terminals -some 75% of the total- is absorbed by the civil engineering works, such as drainage, foundations, quay walls, pavement of storage areas and roads, buildings, etc.

Specialized container terminals are seldom economically justified for annual throughputs of less than 50,000 TEU.

Terminals are increasingly confronted with the consequences of the introduction of oversize containers and post-panamax ships which make much of the existing container handling equipment obsolete.
The expected continuing growth of the container traffic between the large industrialized areas and the developing countries (Caribbean, South America, Indonesia, India, Pakistan, Africa, etc.) asks for an increased storage and handling capacity in the future. In these developing countries, the desired capacity increase can be realized, either by the construction of new, specifically prepared container terminals, or by optimization of existing multi-purpose facilities. In both cases it will be necessary to carefully select the system to be used in order to obtain the best possible utilization of considerable investments in infrastructural and mechanical facilities.

In many ports of the world, this utilization is not very efficient, also due to inconsistencies in the design of the terminals. Especially, the set-up of new container terminals in areas where there is only limited experience with the container trade, should be based on simplicity, reliability and low maintenance.

2. CONTAINER SHIPS AND CONTAINERS

Container ships are usually classified according to ‘generation’:

<table>
<thead>
<tr>
<th>Container vessel</th>
<th>TEU capacity</th>
<th>DWT (ave)</th>
<th>L (ft)</th>
<th>B (ft)</th>
<th>D (ft)</th>
<th>B (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st generation</td>
<td>750 - 1100</td>
<td>14,000</td>
<td>180 - 200</td>
<td>9</td>
<td>27.0</td>
<td></td>
</tr>
<tr>
<td>2nd generation</td>
<td>1500 - 1800</td>
<td>30,000</td>
<td>225 - 240</td>
<td>11.5</td>
<td>30.0</td>
<td></td>
</tr>
<tr>
<td>3rd generation</td>
<td>2400 - 3000</td>
<td>45,000</td>
<td>275 - 300</td>
<td>12.5</td>
<td>32.0</td>
<td></td>
</tr>
<tr>
<td>4th generation</td>
<td>4000 - 4500</td>
<td>57,000</td>
<td>290 - 310</td>
<td>11.5 - 12.5</td>
<td>32.3</td>
<td></td>
</tr>
<tr>
<td>Panamax-plus</td>
<td>4300 - 4600</td>
<td>54,000</td>
<td>270 - 300</td>
<td>11 - 12</td>
<td>38 - 40</td>
<td></td>
</tr>
<tr>
<td>Conbulk</td>
<td>mostly Panamax-size bulk carriers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Quite a significant number of Panamax-plus vessels will be launched in the near future. It is, moreover, not unreasonable to expect that around the year 2000, container vessels with a TEU capacity of 6000 or over will enter into service. Due to the limitation in stacking strength (9 high according to ISO standard), there are reasons to assume that the ultimate limit will be a vessel with a TEU capacity of about 6800, with L = 345, B = 45, D = 13.4 and having a deadweight capacity of 78,000t [ref 5].

Containers are made in varying sizes. The most important are:

<table>
<thead>
<tr>
<th>Type</th>
<th>External dimensions (feet)</th>
<th>Maximum payload (tons)</th>
<th>Actual average payload in Rotterdam (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 1A</td>
<td>40 8 8 or 8'6&quot;</td>
<td>abt 27</td>
<td>16</td>
</tr>
<tr>
<td>1B</td>
<td>30 8</td>
<td>abt 22</td>
<td>14</td>
</tr>
<tr>
<td>1C</td>
<td>20 8 8 or 8'6&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1D</td>
<td>10 8 8 or 8'6&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>non-ISO</td>
<td>20 8'6&quot; 9'6&quot;</td>
<td>abt 33</td>
<td></td>
</tr>
<tr>
<td>40 8'6&quot; 9'6&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45 8'6&quot; 9'6&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48 8'6&quot; 9'6&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53 8'6&quot; 9'6&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bell</td>
<td>20 8'2&quot; 8'6&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 8'2&quot; 8'6&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Apart from the above, there are tank containers, flats, platforms, etc., with generally different heights.
* Total numbers of containers are usually expressed in TEU.
* 'High cube' containers are containers with a height of 8'6" or over.  
* 'Oversize' containers are containers with a length exceeding 40ft.  
* In the meantime, ISO has also accepted the 9'6" height and is considering to standardize lengths in excess of 40ft.  
* The 8'6" width has the great advantage that it can accommodate broadwise 2 standard European (and US) stevedoring pallets, whereas the 8' wide containers cannot. The 8'2½" has been developed by Bell Lines of Ireland because it can also take the 2 pallets and still complies with European road regulations with regard to maximum width.  
* The great majority of containers worldwide have a height of 8′6″.  
* The oversize containers originate from the US internal market (85 to 90% of US trade is internal trade and only 10 to 15% international trade). Road regulations in the US allow larger trailers than in Europe. The 40ft (or 2x20ft) is, therefore, uneconomic for US conditions. Unavoidably, these oversize containers are also appearing on the world container scene.

The world's most important container ports are listed below, together with the throughputs of 1986 and 1989 in TEU.

<table>
<thead>
<tr>
<th>Port</th>
<th>Throughput in million TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1986</td>
</tr>
<tr>
<td>Hongkong</td>
<td>2.77</td>
</tr>
<tr>
<td>Singapore</td>
<td>2.21</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>2.87</td>
</tr>
<tr>
<td>Kaohsiung (Taiwan)</td>
<td>2.48</td>
</tr>
<tr>
<td>Kobe (Japan)</td>
<td>1.88</td>
</tr>
<tr>
<td>Busan (Korea)</td>
<td>1.53</td>
</tr>
<tr>
<td>New York</td>
<td>2.34</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>1.32</td>
</tr>
<tr>
<td>Keelung (Taiwan)</td>
<td>1.76</td>
</tr>
<tr>
<td>Hamburg</td>
<td>1.62</td>
</tr>
</tbody>
</table>

Source: Ocean Shipping Consultants

Of the top ten, only the throughput of New York has decreased. The biggest growth by far can be found in the East Asian ports.

In 1990, the throughput of Singapore has increased to 5.22 million TEU, which made it oust Hongkong from the first place.

3. THE CONTAINER TERMINAL - SYSTEMS APPROACH

The provision of services to shipping lines and inland transport firms is the main product of a container terminal and, in each situation, one has to weigh the requirements of the connecting transport modes in order to determine the type and scope of the local service product that will have to be supplied.

A package of services required by a mainline ship operator could include, e.g., the following elements:

* To complete with a 99% reliability, all loading and unloading operations of individual ships within 24 hours, calculated from the moment of mooring until departure time.
* To have such an organization of storage and loading systems, that simultaneous treatment of sea vessels and through transport means can be achieved without harmful effects on speed and reliability.
* The availability of facilities for treatment of all types of containers, thus also for 'off-standard containers' (for dangerous cargoes, too high, too wide loads, reefers, etc.).
• The safe treatment of containers in relation to the ships and terminals’ personnel as well as to the containers and their contents (damages).
• The availability of a 100% reliable monitoring system for the physical storage and loading of containers as well as for the information flows.
• The ready availability of ‘on-line’ information for internal and external use (agents, shippers and customs).
• A great deal of flexibility and the possibility to improvise in case of exceptional traffic demands.

The stochastic arrival pattern of transport means, each with a variable number of containers, requires terminal systems with a highly variable handling and storage capacity. It will be clear that terminal capacity and response to varying conditions can only be studied by considering the terminal system in its entirety embracing the infrastructure, the available or planned cargo handling facilities and the information and communication system.

If one should wish to minimize the costs over the whole transport chain, it will be necessary that users and operators of container terminal facilities agree on the required service level, that may well be less than the one described above.

In order to decrease the terminal costs per TEU, the container terminal operator will try to attain a high occupancy ratio of the quays, the storage areas and the loading systems, and will preferably maintain a permanent and fixed labour pool.

Only a few shipowners have recognized the favourable cost consequences of a situation by which an incidental waiting period of ships of some hours can result in a, say, 40% quay occupancy and a 60% crane occupancy.

4. CONTAINER HANDLING AND TRANSPORT

In figure 2, a simplified schedule is given for the flow of import containers through the terminal. In a reverse sense, it is equally applicable to export cargo.

Container loading or unloading into or from a ship is done by heavy container gantry cranes, often called ‘portainers’. Except for a number of small feeder container vessels, container ships do not carry their own gear. The portainer places the containers either temporarily on the quay platform between the crane rails or directly on trailers, depending on the transport system to and from the stacks.

The most common transport systems from quay to stack are tractor/trailer and straddle carrier, the latter only being economic for short distances. ECT in Rotterdam has developed the multi-trailer system in which a single tractor pulls up to six terminal chassis which have a special steering mechanism that makes them follow the same track, thus avoiding the need for wide curves.

Container handling in the stack -placing, reshuffling and lifting out- may be done by RTG\(^2\), RMG\(^3\), straddle carrier, FLT\(^4\), telescopic stacker (which is a FLT with an extendable arm) or side-loader (a side-loading FLT). The RTG’s and RMG’s are often called ‘transtainers’. The FLT types are not very common for loaded containers, for reasons that will be discussed later on.

\(^2\)Rubber-Tyred Gantry
\(^3\)Rail-Mounted Gantry
\(^4\)Fork Lift Truck
A certain degree of intermediate reshuffling of the stack is unavoidable (unless a stack is only one-high), because the sequence of removal of containers from the stack is unknown beforehand, particularly for import containers. Loading onto road trucks may be done directly from the stack by the stack handling equipment. However, some terminals do not wish road vehicles on the terminal premises for safety and security reasons. In that case, another transport phase by tractor/trailer and/or straddle carrier has to be introduced.

The same separate transport is required if the containers are to be loaded on IWT craft or railway wagons. Actual loading on IWT vessels has to be done by portainer (which can be much smaller and cheaper than the ones used for seagoing container vessels). Loading of railway wagons is usually effectuated by RMG.

Approximate purchase price ranges for terminal equipment are:

- portainer (for serving sea going vessels)  US$ 3.5 - 7 million
- straddle carrier  0.5 - 1 million
- FLT 8-15 tons lifting capacity  0.2 - 0.4 million
- FLT 20-40 tons lifting capacity  0.3 - 0.6 million
- telescopic stacker 45-55 tons  0.4 - 0.6 million
- side-loder  0.6 - 0.8 million
- RMG  1.5 - 2.5 million
- RTG  0.8 - 1.6 million
- terminal chassis  10,000 - 20,000
- terminal tractor  50,000 - 100,000
- container, 20ft, steel  2,500 - 3,000

The different types of equipment are discussed in more detail in section 6.
The above summary description of container handling and stacking systems is by no means exhaustive. E.g., certain terminals still operate partly or entirely with the chassis system in which all containers remain stored on the terminal on a terminal chassis. Other terminals transfer containers directly from portainer to RMG and stack in a semi-automated process (see figure 3). But, the discussion here will be restricted to the most common systems.

Figure 3 - Double trolley cranes in service at La Spezia, Italy, with direct transfer to stacking crane
(Source: La Spezia Container Terminal)

5. THE QUAYS AND CRANES

Although the costs of a terminal's services are determined by a large number of factors (type of storage and loading systems, wages, labour productivity, occupancy rates, etc.), three cost elements play a very important role:
* the quay
* the portainer cranes
* the storage area

The above elements together represent approx. 75% of the total investment for a container terminal.

Originally, quay length and number of cranes were determined by using averaged values for ship arrivals and number of containers to be handled in conjunction with peaking factors to account for coinciding ship arrivals and other irregularities. The next step was the application of the queuing theory, which method, however, has severe limitations. At present, logistic computer simulation models are mostly used.
The present-day complete container terminal simulation package contains, among others, the following input variables:

- The ship arrival pattern, realized by a number of ship generators which arrange ship arrivals according to a random or other distribution. Interaction between different generators is possible.
- The ‘attributes’ of the ships, i.e. length, quantity of containers, unbalance in loading/discharging, 20’/40’ length containers.
- The quay length, with a special berth allocation algorithm included in the programme.
- The quay occupancy before and after the factual operational handling procedures.
- The desired number of cranes to service a ship and a crane allocation algorithm, if the demand is bigger than the available number of cranes.
- Crane productions, either as an average with a noise function or stochastic within boundaries.
- Dwell time distribution of containers in their respective stacks.
- Simulation length (often more than 1,000 ship arrivals).

The programme provides, among others, the following information:

- distribution of the waiting time of ships
- distribution of the norm time exceedings
- the required number of slots with probabilistic occupancy distribution
- quay and crane occupancy rates
- the consequences of increasing or decreasing the number of cranes

This type of simulation gives a good insight into the sensitivity of the choice of the various parameters. It also clarifies and quantifies the risk of certain choices.

Observation in practice, supported by simulation studies, has led to a number of general conclusions:

- The level of investments in quays, storage areas and cranes is sensitive to the definition of the desired service level (permissible waiting time of ships). High service requirements unavoidably result in low occupancy of quays and cranes.
- The total port time of vessels should be mainly determined by the required service time.
- The total terminal quay length does not have to be a multitude of a single berth length.
- Especially small terminals can increase their efficiency (with equal service level) by making arrival arrangements with shippers.
- Reduction of the dwell time saves stacking area and, hence, internal transport.
- The land transport can improve its own performance by arranging for an arrival pattern which is evenly distributed over the day.

The actual annual crane production and berth handling capacity varies very much from one terminal to another. An estimate of a mean value can be made as follows:

- Assume no capacity constraints due to lack of storage space or transport and stacking equipment.
- Gross production per container crane: 20 boxes/hour.
- Loss of time due to opening and closing of holds: 10%.
- Average number of cranes per ship: 2.
- Net operation period: 0.8 x berthing period.

Thus, production per 24 hour working day: $2 \times 20 \times 0.9 \times 0.8 \times 24 = 690$, say 700 containers per 24 hours per berth (during full occupancy!).

Capacity per year:

- Assume a berth occupancy factor of 40%.
- 360 available working days per year.

Total: $0.4 \times 360 \times 700 = \text{abt 100,000 container/year/berth}$. If the division between 20ft and 40ft containers is, e.g., 40%:60%, then the 100,000 containers are equivalent to 160,000...
TEU/year/berth. If the average payload would be 12 tons, this corresponds to almost $2 \times 10^6$ ton/year/berth.

Many terminals do not attain this capacity, particularly in developing countries. The UNCTAD conducted a survey in 20 of those ports, and found berth productivity figures from 225 to 750 containers per 24 hours, with an average of 450. Causes are frequent equipment breakdowns, waiting for transport to and from stacks, longer crane cycle times, etc. If, in addition, there is only a 6 day work week (say, 300 available days per year) and if there are only, say, 20% 40ft containers (the percentage 40ft containers in developing ports is mostly low), the capacity becomes: $0.4 \times 300 \times 450 \times 1.2 = \text{abt } 65,000 \, \text{TEU/year/berth}$.

But, deviations do also occur to the positive side. In 1990, Singapore’s Tanjon Pagar terminal, so far handling almost all of the Singapore container traffic, handled $5.09 \times 10^6$ TEU over 9 mainline and 2 feeder berths, using 32 portainers. Assuming the 2 feeder berths to be equivalent to 1 mainline berth, the production equalled some 500,000 TEU/year/berth, whilst crane production was about 160,000 TEU, probably corresponding with some 100,000 containers/crane/year. This is a positive extreme, resulting from relatively high occupancy figures, high labour productivity, modern container cranes and low cycle times, and high equipment maintenance standards. (The total tonnage handled was $75.9 \times 10^6$, resulting in an average payload of 14.9t/TEU.)

In view of this wildly varying productivity, it will not surprise that the actual costs of handling a container through a terminal also varies from a low of US$70 to 80 (Hongkong, Singapore) to a high of about US$350 (Bombay, Calcutta).

6. STORAGE AND HANDLING SYSTEMS

Since it is not feasible to have containers handled directly from one mode of transport to the next, it will always be necessary to have an intermediate storage on a terminal. The dwell or transit time can vary from some hours to many weeks. Some terminals in Rotterdam attain an average of about 2.5 days, while in some developing countries averages of 10 days or more are quite common. This is due to an inadequate organization, time-consuming customs formalities, etc.

For handling and stacking of containers, special equipment is used (terminal tractors with chassis, gantry cranes, straddle carriers, heavy forklift trucks, side-loaders, etc.).

The civil engineering provisions required for a container storage area vary strongly with the equipment used, and they have to be duly considered when selecting the container handling system and equipment. It may happen that a storage system is rejected because of the civil engineering consequences.

Furthermore, for civil engineering structures, one has also to consider the large number of load fluctuations caused by the continual coming and going of equipment. Typical wheel loads are shown in figure 4.

Special provisions have to be made for containers with special loads, such as:
* electrical connections for containers with cooled or frozen products (reefers)
* mechanical installations by which cooled air can be pumped through so-called port hole containers
* provisions for storage of containers with dangerous cargo
* provisions for the internal cleaning of containers
* possibilities for a climate-controlled storage of containers (bulbs, potatoes, etc.)
* provisions for the weighing and inspection of containers
The container storage capacity per hectare is, generally, not the main controlling factor for the choice of a handling system. The throughput capacity (and, especially, the short-time throughput capacity) is of greater importance. Also here, the simulation model can play an important role.

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>WHEELLOAD</th>
<th>WHEEL - TYPE</th>
<th>TIRE/ WHEEL SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAX.</td>
<td>GEM.</td>
<td>TYPE</td>
</tr>
<tr>
<td>Container Cranes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st gen. Pacco</td>
<td>300</td>
<td>250</td>
<td>steel</td>
</tr>
<tr>
<td>2nd gen. Conrad Stork</td>
<td>600</td>
<td>350</td>
<td>steel</td>
</tr>
<tr>
<td>Railway Gantry Cranes:</td>
<td>200</td>
<td>150</td>
<td>steel</td>
</tr>
<tr>
<td>Rail M. Stacking Cranes:</td>
<td>350</td>
<td>250</td>
<td>steel</td>
</tr>
<tr>
<td>Rubber M. Stacking Cranes:</td>
<td>400</td>
<td>250</td>
<td>pneumatic rubber tire</td>
</tr>
<tr>
<td>Straddle Carriers:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-high stacking Nahlen</td>
<td>170</td>
<td>110</td>
<td>=</td>
</tr>
<tr>
<td>4-high stacking Nahlen</td>
<td>160</td>
<td>90</td>
<td>=</td>
</tr>
<tr>
<td>Terminal Trucks:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-trailer system:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trucks Floor</td>
<td>40</td>
<td>40</td>
<td>=</td>
</tr>
<tr>
<td>Chassis 2x20' of 40'</td>
<td>65</td>
<td>45</td>
<td>=</td>
</tr>
<tr>
<td>Forklift Trucks:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20KN electric Linde</td>
<td>26</td>
<td>20</td>
<td>solid rubber tire</td>
</tr>
<tr>
<td>40KN diesel Linde</td>
<td>44</td>
<td>35</td>
<td>pneumatic rubber tire</td>
</tr>
<tr>
<td>120KN Kaimer</td>
<td>71</td>
<td>60</td>
<td>=</td>
</tr>
<tr>
<td>420KN Taylor</td>
<td>200</td>
<td>150</td>
<td>=</td>
</tr>
<tr>
<td>Terminal Chassis:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20' 1-axle</td>
<td>35</td>
<td>25</td>
<td>=</td>
</tr>
<tr>
<td>2x20' 3-axles</td>
<td>30</td>
<td>20</td>
<td>=</td>
</tr>
<tr>
<td>40' 2-axles</td>
<td>30</td>
<td>25</td>
<td>=</td>
</tr>
</tbody>
</table>

Figure 4 - Wheel loads of terminal equipment

Some principal advantages and disadvantages of specific container handling systems are indicated below.
<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chassis system</strong></td>
<td><strong>Requires a large site (can be expensive)</strong></td>
</tr>
<tr>
<td>• low civil engineering investment</td>
<td>• high investment in chassis</td>
</tr>
<tr>
<td>• simple equipment</td>
<td>• storage peaks difficult to absorb</td>
</tr>
<tr>
<td>• low maintenance costs</td>
<td>• not suitable for automation</td>
</tr>
<tr>
<td>• very flexible in operation</td>
<td></td>
</tr>
<tr>
<td>• operation requires little training</td>
<td></td>
</tr>
<tr>
<td><strong>Straddle carrier system</strong></td>
<td></td>
</tr>
<tr>
<td>• moderate civil engineering investment</td>
<td>• complicated equipment</td>
</tr>
<tr>
<td>• traffic peaks can be well absorbed</td>
<td>• rather high maintenance and energy costs</td>
</tr>
<tr>
<td>• high occupancy rate of equipment</td>
<td>• requires highly qualified personnel</td>
</tr>
<tr>
<td>• high throughput capacities possible</td>
<td>(operation and maintenance)</td>
</tr>
<tr>
<td><strong>Forklift system &amp; telescopc stackers</strong></td>
<td>• requires special safety precautions</td>
</tr>
<tr>
<td>• very suitable for stacking of empty containers</td>
<td>• additional internal transport required</td>
</tr>
<tr>
<td>• simple to organize</td>
<td>• high site maintenance costs</td>
</tr>
<tr>
<td><strong>Small gantry crane system on pneumatic tyres (RTG system)</strong></td>
<td>• not suitable for automation</td>
</tr>
<tr>
<td>• good use of site</td>
<td></td>
</tr>
<tr>
<td>• high occupancy rate of equipment</td>
<td></td>
</tr>
<tr>
<td>• simple to organize</td>
<td></td>
</tr>
<tr>
<td>• automation possible but difficult</td>
<td></td>
</tr>
<tr>
<td><strong>Large gantry crane system on rails (RMG system)</strong></td>
<td></td>
</tr>
<tr>
<td>• maximum use of site</td>
<td>• rather high civil engineering investment</td>
</tr>
<tr>
<td>• low breakdown percentage</td>
<td>• high maintenance and energy costs</td>
</tr>
<tr>
<td>• low maintenance costs</td>
<td>• requires special safety precautions</td>
</tr>
<tr>
<td>• automation possible</td>
<td>• requires highly qualified personnel</td>
</tr>
<tr>
<td>• requires medium-qualified personnel</td>
<td></td>
</tr>
<tr>
<td><strong>For the selection of handling systems, local conditions are important, e.g.:</strong></td>
<td></td>
</tr>
<tr>
<td>• soil conditions</td>
<td></td>
</tr>
<tr>
<td>• accessibility of the site (customs requirements, etc.)</td>
<td></td>
</tr>
<tr>
<td>• financing possibilities</td>
<td></td>
</tr>
<tr>
<td>• availability of qualified personnel</td>
<td></td>
</tr>
<tr>
<td>• expected growth rate</td>
<td></td>
</tr>
<tr>
<td>• anticipated need for future full- or semi-automation of container handling</td>
<td></td>
</tr>
</tbody>
</table>
Much attention has also to be paid to:

- functional requirements
- high number of load fluctuations (fatigue)
- safety
- comfort of personnel
- provisions for a rapid and easy maintenance

The procurement policy of container terminals has to be aimed at the continuous character of terminal operations and at the standardization of the equipment. It has to be kept in mind that the total cost of equipment is a combination of capital costs, maintenance costs and operating costs.

It is advisable to evaluate the total costs per container move, averaged over the total lifetime. Investments should be aimed at the avoidance of breakdowns. The breakdown of equipment causes breakdown of an entire transport process. The loss of production capacity cannot be regained. Penny-wise can be pound-foolish, see annexure I.

7. TERMINAL LAYOUT AND DIMENSIONS

As explained before, the terminal layout depends, to a certain extent, on the handling systems chosen. A schematic cross-section is given in figure 5.

![Figure 5 - Cross-section container terminal](image)

The set-back of the front crane rail of at least 2½m from the coping is necessary to prevent damage to the crane by the overhang of ships. The fast and strongly flared container ships have a pronounced overhang in the bow section and, when berthing under some angle, this overhang can well extend over the quay front. A sizeable number of portainers already has not survived this embrace.

The crane track spacing is determined by considerations of stability and of cost (of the crane itself and of the crane rail foundation: limitation of bogey loads) and also by operational considerations. Particularly if FLT's are used in this part of the terminal (which is not customary but does happen at some terminals), they have to be able to manoeuvre perpendicular to the crane track and, thus, require a wide spacing.
Often, the area immediately behind the rear crane rail is reserved for storing vessel hatchcovers during loading and unloading operations. This avoids the necessity of repeated re-handling of these covers and, therefore, saves time.

Railway tracks and road vehicle lanes are as much as possible located in the rear zone of the terminal. An exception could be made for specialized ship-rail transhipment terminals as found in the USA, where inland container transport by rail plays a much bigger role than in Europe.

Apart from the areas indicated in the cross-section, space will have to be reserved for:
- container freight station (CFS)
- workshops for equipment maintenance
- office buildings for terminal operating company, customs, first aid, etc.
- road vehicle parking
- entry lanes with weighing and inspection facilities
- damaged containers and hazardous cargoes

In determining the terminal layout, due attention must also be paid to the modes of through transport, and possible changes therein, in a not too distant future. For the time being, for most European terminals, most through transport is by road—say 75 to 80%—, the remainder being handled by rail and sometimes inland water transport (IWT). The anticipated growth in container traffic is such, that the already congested road network cannot absorb it without major and unlikely extensions. A gradual shift to rail and, particularly, IWT appears unavoidable. Terminal layouts should anticipate on these developments in terms of being able to accept those shifts without major reconstruction and without introducing severe complications for the internal traffic flow.

Stack area

The area requirements for the different stacks (import, export, reefers, empties, etc.) can be calculated as follows:

\[
O = \frac{C_i \times \bar{t}_d \times F}{r \times 365 \times m_i}
\]

in which:
- \(O\) = area required \([m^2]\)
- \(C_i\) = number of container movements per year per type of stack in TEU’s
- \(\bar{t}_d\) = average dwell time \([\text{days}]\)
- \(F\) = required area per TEU inclusive of equipment travelling 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) has 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 realized 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:

\[
\bar{t}_d = \frac{1}{S(t)_{t=0}^{\infty}} \int_{0}^{\infty} S(t) \, dt
\]

in which:
- \(S(t) = \) (quantity of containers still on terminal) / (total number unloaded containers)
ECT found that for their home-terminal, the following dwell time distribution applied (see figure 6):

\[
S(t) = \begin{cases} 
1 & 0 < t < 1 \\
[(T-t)/(T-1)]^2 & 1 < t < T \\
0 & T < t 
\end{cases}
\]

From the above it follows that:

- **T** = maximum dwell time (e.g. time within which 98% of containers have left the terminal)
- \( \bar{t}_d = (T + 2)/3 \)

**T** values:
- for Western Europe 10 days
- for developing countries 3 to 4 weeks

![Figure 6 - Typical dwell time distribution](image)

The factor \( F \) is empiric and depends on the handling systems and the nominal stacking height. Typical values are given below.

<table>
<thead>
<tr>
<th>System</th>
<th>Nominal stacking height</th>
<th>( m^2/TEU ) inclusive of travelling lanes (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chassis</td>
<td>1</td>
<td>50 - 65</td>
</tr>
<tr>
<td>Straddle carrier</td>
<td>2</td>
<td>15 - 20</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10 - 13</td>
</tr>
<tr>
<td>Gantry crane (RMG/RTG)</td>
<td>2</td>
<td>15 - 20</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10 - 13</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>7.5 - 10</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6 - 8</td>
</tr>
<tr>
<td>Forklift (FLT)</td>
<td>2</td>
<td>35 - 40</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>25 - 30</td>
</tr>
</tbody>
</table>
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.

In annexure II an example is given for the determination of the optimum value of \( m_i \), assuming a normal distribution of container arrivals.

**Calculation example - stack areas**

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 (\( F = 13 \text{m}^2 \)).

Expected \( \bar{t} \) values for import, export and empty containers are 10, 7 and 20 days respectively.

**Import**

\[
O_{\text{import}} = \frac{(35,000 \times 10 \times 13)}{(0.6 \times 365 \times 0.70)} = \text{approx. 30,000m}^2
\]

**Export**

\[
O_{\text{export}} = \frac{(25,000 \times 7 \times 13)}{(0.8 \times 365 \times 0.70)} = \text{approx. 11,000m}^2
\]

**Empties**

\[
O_{\text{empt}} = \frac{(10,000 \times 20 \times 13)}{(0.9 \times 365 \times 0.80)} = \text{approx. 10,000m}^2
\]

**Calculation example - CFS**

\[
O_{\text{CFS}} = \frac{(C_i \times V \times h_\nu \times t_{s\nu} \times f_1 \times f_2)}{(m_i \times 365)} = \frac{(15,000 \times 29/2 \times 5 \times 1.4 \times 1.1)}{(0.65 \times 365)} = \text{approx. 7,000m}^2
\]

in which:

\( V \) = represents the contents in \( \text{m}^3 \) of 1 TEU container (29m\(^3\))
\( f_1 \) = gross/net area ratio

\(^5\)Container Freight Station
\[ f_z = \text{bulking factor} \]
\[ m_i = \text{acceptable occupancy rate} \]
\[ h_s = \text{average height of cargo in shed [m]} \]

A possible layout for the above terminal is given in figure 7.

Figure 7 - Example layout container terminal
The detailed layout of stacks and traffic lanes depends on the type of equipment used. As already observed, road vehicles are avoided as much as possible on the terminal itself. However, if for stack handling RTG's and RMG's are used, intermediate transport - e.g. by straddle carrier - would be required to and from the central loading bays at the terminal boundary. To avoid these extra costs, some of these terminals do allow road trucks on clearly marked one-way traffic lanes in the stack zone.

Quay length

For a small one-berth terminal as used for the above calculation example and figure 7, the quay length is dictated by the length of the biggest vessel to be received. It will, generally, be between 250m and 300m for 3rd generation container vessels.

For a multi-berth terminal it is, in principle, uneconomic to determine the quay length on basis of a discrete number of single berths because of the variation in ship lengths. This variation will be different from port to port and from region to region. But, for example, it might well be that a 450m quay length in average can accommodate 2 vessels; on the one hand it can only receive one maximum size vessel at a time, on the other hand it could handle three feeder vessels.

The quay length will have to be optimized based on the local vessel length distribution, the loading/unloading capacity (crane capacity and number of cranes, which may also be varied), number of containers per vessel, and other relevant parameters with due regard to the optimization criterion used. This may be minimization of overall port cost per container, but more often the provision of a specified minimum service level, as discussed in section 3. The moment that the concept of a discrete number of service points (fixed number of berths) is abandoned, the queuing theory can no longer be applied in this optimization process, and a logistic simulation model has to be used - as discussed briefly in section 5, and in detail in the relevant lecture papers.

Terminal width

The terminal width (measured perpendicular to the quay front for an ideal rectangular terminal) is simply the quotient of the total area (stack areas, traffic lanes, CFS, etc.) and the optimized quay length.

Because of the vastly increased container crane capacity and use of a larger number of cranes per ship, the transhipment capacity per unit length of quay has very much increased over the past 10 or 15 year. In consequence, the terminal width requirements have increased. Around 1980, a width of 400m was a fair average providing 10ha for a single berth. The ECT Delta terminal now has a width of 600m, and the new terminal in Antwerp has as much as 800m.

REFERENCES

[3] Containerization International (magazine)

ANNEXURE I

Comparison of cost per handling move for 2 types of straddle carriers\(^6\)
(1980 price level)

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<tr>
<th></th>
<th>Manufacture A</th>
<th>Manufacture B</th>
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<td>* initial investment</td>
<td>$425,000</td>
<td>$575,000</td>
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<td>(completely erected on the site)</td>
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<tr>
<td>* estimated lifetime in operating hours</td>
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<td>* realizable number of operating hours per year</td>
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<tr>
<td>* depreciation period in years</td>
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<tr>
<td>* realizable number of handling moves per hour on average distances</td>
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<td>* capital cost per year</td>
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<tr>
<td>* total maintenance cost per year</td>
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<td>* cost of tyres per year</td>
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<td>Total cost per operating hour</td>
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<td>Total cost per handling move</td>
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Conclusion

From a cost point of view, the application of the more expensive straddle carrier can save 42.5% in direct handling cost. Besides, it can positively effect the service to be offered.

Note

The higher initial investment for 'manufacture B' is forthcoming from:
* higher operating speeds and acceleration resulting in a handling capacity increase
* highly improved operators’ comfort and safety (visibility, strongly reduced noise level, easy manoeuvrability, etc.)
* better accessibility ad special provisions for maintenance
* service period only after 1,000 operating hours
* longer lifetime through the application of quality components and the use of fatigue calculation methods

\(^6\)Source: ir J.C. Rijsendrij, ECT, 1981
The factor $m_i$ (optimum average occupancy rate) should be derived from a frequency distribution of container arrivals/departures (or separate distributions of ship arrivals/departures and number of containers per ship). A frequency distribution of container arrivals/departures could, for example, closely resemble a normal distribution.

**Normal distribution:**

![Normal distribution diagram]

**Density function:**

$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

**Probability of exceedance:**

$$K_x = \int_{x_{10}}^{x_{\infty}} f(x) \, dx$$

**With transformation:**

$$\frac{x-\mu}{\sigma} = u$$
Density function:

\[ f(u) = \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}} \]

Probability of exceedance:

\[ K_u = \frac{1}{\sqrt{2\pi}} \int_{u}^{\infty} e^{-\frac{v^2}{2}} dv \]

This is the standard normal distribution, i.e. a normal distribution for \( \mu = 0 \) and \( \sigma = 1 \).

A table giving the values of \( K \) as a function of \( u \), is attached and can be found in most statistical handbooks.

Example
Assume a large terminal with normally distributed container arrivals (combined effect of irregular ship arrivals and variable number of containers per ship).
Assume also as a design requirement a maximum 1/100 chance of reaching full occupation of the import stack, that means maximum 1 on each 1,000 time units.
Take as time unit \( t_a = \) average dwell time containers, say 4 days.
Assume, moreover, \( \mu = 5,000 \) (number of containers per 4 days) with a mean deviation of \( d = 600 \).
Since the standard deviation \( \sigma = (\sqrt{\pi/2})d \), or \( \sigma = \text{abt.} 1.25d \) (only in case of normal distribution).
Thus, \( \sigma = 1.25 \times 600 = 750 \).
The \( K/u \) table shows for \( K = 0.001 \) a corresponding value of \( u = 3.10 \).
In other words, the number of container arrivals corresponding with a probability of exceedance of 1/100 is:

\[ (x-5,000) / 750 = 3.10 \quad \text{or} \quad x = 7325 \]

And the factor \( m \), (optimum average occupancy rate) becomes:

\[ m = \mu/x = 5000/7325 = 0.68 \]
STANDARD-NORMAL DISTRIBUTION

Probability of exceedance of values of $K \times 10^4$

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chapter 8.

OIL & LIQUID GAS TERMINALS
# OIL & LIQUID GAS TERMINALS

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1. INTRODUCTION

Oil and gas terminals are separately classified in ports, since:
* The quantities involved in transhipment per vessel are generally very large in comparison with the transport of other commodities.
* The goods transhipped are mostly classified as 'dangerous', leading to special safety requirements.
* Loading and unloading occur through one central manifold on the ship, placed more or less at midships. As a result, (un)loading equipment does not have to be able to move alongside the ship to service the different holds, and, thus, no full-length marginal quay is required. For carrying the (un)loading arms and auxiliary equipment, a relatively small platform is generally sufficient.

Consequently, there are striking differences with regard to dimensions and nature of the port facilities required as compared to other trades.

2. OIL TANKERS AND GAS CARRIERS

2.1 Oil tankers

The transport of crude oil generally happens in large tankers (VLCC's) of 200,000dwt or more. Refined products are transported by product tankers of up to 100,000dwt.

Due to the market developments, the ULCC's, of around 500,000dwt, have become rare. Only Exxon still has a number of these ships in its fleet.

Dimensions are given in the following table:

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<th>water displacement [tons]</th>
<th>length ( L_{on} ) [m]</th>
<th>width [m]</th>
<th>fully loaded draught [m]</th>
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<tr>
<td>150,000</td>
<td>185,000</td>
<td>297</td>
<td>44.2</td>
<td>17.1</td>
<td>5.5</td>
</tr>
<tr>
<td>200,000</td>
<td>240,000</td>
<td>315</td>
<td>48.8</td>
<td>18.9</td>
<td>6.4</td>
</tr>
<tr>
<td>250,000</td>
<td>295,000</td>
<td>338</td>
<td>51.8</td>
<td>20.1</td>
<td>7.3</td>
</tr>
<tr>
<td>325,000</td>
<td>375,000</td>
<td>346</td>
<td>53.4</td>
<td>24.7</td>
<td>7.3</td>
</tr>
<tr>
<td>400,000</td>
<td>455,000</td>
<td>381</td>
<td>59.4</td>
<td>25.9</td>
<td>9.1</td>
</tr>
<tr>
<td>500,000</td>
<td>560,000</td>
<td>412</td>
<td>65.6</td>
<td>27.5</td>
<td>10.7</td>
</tr>
</tbody>
</table>

2.2 Liquid gas carriers

Marine transport of LNG (mainly methane, relative density about 0.45) and LPG (a mixture of mostly propane and butane, relative density about 0.6) takes place in refrigerated form, LNG at a temperature of about -165°C and LPG at about -50°C. The only exceptions are some small coastal tankers that carry

---

For the preparation of these lecture notes, extensive use has been made of (ref 1).

1very large crude carriers
2ultra large crude carriers
3liquefied natural gas
4liquefied petroleum gas

olg.trm/1992*10
pressurized LPG (at about 7 bar). LNG cannot be liquified by pressure at normal temperatures, whilst the carriage of pressurized LPG in big ships would require too great wall thicknesses for the cargo tanks.

The load capacity of liquified gas carriers is always given in cubic metres instead of dwt. Dimensions are given in the following table:

<table>
<thead>
<tr>
<th>cargo [m³]</th>
<th>water displacement [tons]</th>
<th>length Loa [m]</th>
<th>width [m]</th>
<th>fully loaded draught [m]</th>
<th>fully loaded freeboard [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>15,000</td>
<td>138</td>
<td>19.2</td>
<td>7.0</td>
<td>4.3</td>
</tr>
<tr>
<td>20,000</td>
<td>33,000</td>
<td>177</td>
<td>24.5</td>
<td>9.5</td>
<td>5.0</td>
</tr>
<tr>
<td>35,000</td>
<td>43,000</td>
<td>187</td>
<td>27.0</td>
<td>10.5</td>
<td>7.8</td>
</tr>
<tr>
<td>50,000</td>
<td>57,000</td>
<td>202</td>
<td>30.0</td>
<td>11.8</td>
<td>8.0</td>
</tr>
<tr>
<td>75,000</td>
<td>69,000</td>
<td>220</td>
<td>34.8</td>
<td>11.5</td>
<td>9.2</td>
</tr>
<tr>
<td>100,000</td>
<td>90,000</td>
<td>245</td>
<td>39.9</td>
<td>12.7</td>
<td>12.3</td>
</tr>
<tr>
<td>125,000</td>
<td>110,000</td>
<td>278</td>
<td>42.0</td>
<td>13.6</td>
<td>14.5</td>
</tr>
</tbody>
</table>

*values are given for the heaviest product: LPG
*by the middle of 1992, two 250,000m³ LNG tankers were under construction in Korea

There is a considerable difference in draught between LNG/LPG carriers and oil tankers:

<table>
<thead>
<tr>
<th>LNG 133,000m³</th>
<th>VLCC 150,000dwt</th>
</tr>
</thead>
<tbody>
<tr>
<td>length [lpp]</td>
<td>280</td>
</tr>
<tr>
<td>width [m]</td>
<td>42</td>
</tr>
<tr>
<td>draught (loaded) [m]</td>
<td>11.5</td>
</tr>
<tr>
<td>load capacity [tons]</td>
<td>60,000</td>
</tr>
<tr>
<td>loaded freeboard [m]</td>
<td>14.5 - 16.5</td>
</tr>
</tbody>
</table>

The draught of the LNG tanker in ballast is only slightly less than the loaded draught, as the tanker has to take in a relatively large quantity of ballast water for stability reasons.

The above table also shows the high freeboard figure for the LNG vessel, which results in a high resistance to wind. Especially, in case of spherical tanks (Ross-Mosenberg system) where the tanks extend approximately 17m above the deck, the influence of the wind is considerable. The low density of the load and the high position of these ships lead to significant differences with oil tankers as regards their behaviour in waves.

3. THE NATURE OF THE PRODUCTS

The liquid form in which oil and gas are transported, enables rather high loading capacities of up to approximately 25,000m³ per hour. Vessels smaller than 200,000 to 250,000dwt can load or unload with net hourly capacities equal to 10% of their deadweight tonnage. Consequently, these ships occupy the port facilities for a short period only, about 1 to 1.5 days. Loading is performed by shore-based pumps, unloading by ship-based pumps.

The liquid form permits off-shore loading and unloading by means of pipelines, hoses and mooring buoys. In case of crude oil and oil products, this may be done through sub-marine pipelines and floating single-point moorings (SPMs). For refrigerated gases, the technology for sub-marine cryogenic pipelines and SPMs has not yet been developed.

Another important characteristic of oil and gas is the inflammability. In consequence, there are strict safety requirements for the transport, handling and storage of these products, especially for liquified
gases. The relative density of a typical middle-east crude is about 0.85. For LNG, this is between 0.43 and 0.50, and for LPG between 0.58 and 0.60. Propane, as a component of LPG, liquifies at atmospheric pressure at a temperature of -50°C, LNG at -162°C to -165°C. The volume of the LNG is thereby reduced to 1/600th of the original volume.

Figure 1 shows the relation between temperature and minimum pressure required to liquify different gases.

![Diagram showing temperature-vapour pressure relationships of some liquefied gases.]

**Figure 1** Relation between vapour pressure and temperature of different gases

### 4. TERMINALS

#### 4.1 General

The shape, dimensions, locations and arrangement of terminals are dictated by their function. This can be:
* transhipment and storage (e.g. Maasvlakte Oil Terminal, Bullen Baai Curaçao)
* supply to refinery and distribution from refinery
* combination of both foregoing possibilities (e.g. Shell Europoort)
The diversity of products has to be taken into account. Terminals belonging to refineries have a more or less fixed pattern of requirements regarding facilities, dictated by the volume and origin of the crude imported and the range of products produced.

Typically, a medium-sized refinery, with an annual throughput of 5 to 6 million tons, would need facilities to receive, say, 20 to 30 VLCC's of 200,000dwt. The products may be exported in some 100 to 240 product tankers in the 25,000 to 50,000dwt range. Two to three berths would be required to accommodate these ships.

If no sheltered deep-water port already exists, it may well be economically attractive to unload the crude at an off-shore SPM/SBM and, thus, avoid having to dredge the channel and basins and to build a jetty for big tankers. In that case, two berths, able to receive 50,000dwt product tankers, would be sufficient.

For bigger throughputs, the SPM solution becomes less attractive because of lower unloading rates (as compared to a fixed jetty), greater delays and greater threat of pollution.

Simulation models will have to establish the actual requirements for berths, transhipment capacities and storage capacities.

4.2 Types of terminals

The most important parameters for the choice of types are:

- cost
- safety
- reliability

The cost calculations need to include:

- inaccessibility due to current, waves, wind, visibility, etc.
- maintenance (e.g. dredging)
- influence of future extensions, if expected

The following types of oil terminals can be distinguished:

(i) **Conventional sheltered ports with storage areas**

The berth mainly consists of a jetty (figure 2) and dolphins, or of a multiple buoy mooring (MBM).

(ii) **Off-shore single buoy moorings (SBM)**, the most common form of single-point moorings, SPM), in case of large ships and insufficient water depth near the shore (figure 3).

The traditional off-shore terminal consists of one or more SBM's with sub-marine pipelines to the shore where storage takes place. The pipelines can be dug in, but this is not always necessary. Trenching (digging in) may be required for:

- the stability of the pipeline (currents and waves)
- protection against damage (anchors, fishing gear)
- the avoidance of unacceptable stresses in the pipeline due to small curve-radii or long free spans

The sand or gravel cover of the pipelines ranges from 0 to 5m, depending upon the location and the circumstances.

(iii) **Off-shore terminals with floating storage**

This new application can be economical in cases of small or remote oilfields. The terminal is an SBM with a permanently moored storage vessel. Tankers come alongside this vessel for loading (figure 4).

For the loading and unloading of liquid gas, mostly ports are used. Exceptions are a floating LPG liquefaction and storage plant in Indonesia and an unsheltered off-shore LNG loading terminal in Brunei, which will be discussed later.
4.3 Location of the terminal - safety considerations

The location selection is based on the following considerations:

Export or import
For the export terminal, the location of the oilfield or gasfield is the main determining factor. For the import terminal, the suitability of the site and the presence of sheltered natural or artificial deep-water harbours will often dictate the choice of a site for the terminal and/or refinery.

Storage area
Availability of an adequate area for tankfarm and, possibly, refinery. Geotechnical factors can be important.

Waterdepth
The available waterdepth in relation to the draught of the envisaged vessels and the required initial and maintenance dredging are also important factors.

Safety and reliability
This concerns the technical as well as the operational safety and reliability. The technical safety and reliability refer to matters as, e.g.:
sheltered berthing
* no seiches in the harbour basin
* no sudden siltation in the entrance channel
* storm frequency
* persistent low water conditions
* regular visibility problems
* night-sailing restrictions
* tidal restrictions
* presence of good functioning port services
* presence of tug assistance
* etc.

*Figure 3 Single buoy mooring (SBM)*

With regard to safety, it must be mentioned that the surroundings of the terminal, and the refinery, need to be protected against the hazards associated with the terminal, and vice versa (figures 5 and 6). Due to the nature of LPG and LNG, the consequences of spills can be more severe than with oil terminals, because the liquid gas evaporates faster (consequently, gas clouds may form) and because fires produce, in general, a greater heat radiation.
Thus, for terminal planning purposes, different safety distances have to be taken into account:

* The distance to possible leakage or spill sources on the terminal within which vapour clouds may develop with an inflammable or explosive density (density above LFL$^8$ or LEL$^7$). Within these boundaries, no uncontrolled ignition sources may occur.
* The distance to possible fire sources in the terminal within which heat radiation may cause physical harm to people.
* In case toxic products are used or processed, the distance to possible leakage or spill sources within which vapour clouds may develop with a density that, again, may cause physical harm to people.

For the calculation of these safety distances, reference is made to, inter alia {ref 15}, {ref 16} and {ref 18}.

![Figure 4 Floating storage](image)

**Figure 4 Floating storage**

It will be clear that the possibility of spills must be reduced to the utmost minimum. In consequence, all oil and gas terminals should be located in special port basins which are not accessible to other traffic and which can be easily closed off by floating booms in case of accidents. Furthermore, the (un)loading speeds can be restricted, so that in case of e.g. a rupture in the loading arms, the size of the spill can be limited, depending also on the closing speed of the emergency valves. Various other safety measures are taken by the terminal operators to reduce the possibility of calamities.

However, relatively small events like the rupture of pipes or flexible hoses, the failure of valves, flanges, seals or gaskets, will occur occasionally, even on the best run terminals. It is particularly for these 'routine events' that the strict abidance to safety distances is important to minimize the effects.

---

$^8$lower flammable limit
$^7$lower explosive limit
At the other extremity, there are the major accidents like main tank failure which can result in catastrophes that are almost impossible to defend against by safety distances. E.g., TNO calculated that if a 28,000m$^3$ load tank of an LPG carrier is ruptured and ignites, a column of fire will develop with a diameter of 600m and a height of 550m for a duration of 6min; first degree burns will be sustained up to a distance of 2200m. With delayed ignition, an explosion may occur (with LPG, but not with LNG) which, under unfavourable weather conditions, leads to a loss of 10% of the living quarters at a distance as far away as 7 to 11km.
For these major accidents, the best and only defence is to take such precautions, both in planning, design and in operational procedures, as to bring the probability of occurrence at an extremely low level. For example, all other ship traffic may be stopped in the neighbourhood of an LNG/LPG tanker sailing within a port's boundaries, and low-visibility navigation may be prohibited. Also, LNG/LPG storage tanks may be provided with a double wall, so that in case of an -in itself very improbable- failure of the inner cryogenic tank, the product will be contained within the, e.g., concrete outer wall (figure 7).

Figure 7 LNG storage tank, Zeebrugge

5. THE BERTH

The location of the oil terminal berth can be in open sea or bay, as well as inside a harbour. Local conditions dictate the best choice. While in Europe harbours and river mouths offer the required protection, it is a widespread practice in the Middle East to make the terminals off-shore (Ras Tanura, Kuwait, Kharg Island).

For the feasibility of off-shore fixed berths, waves and currents are the decisive parameters. In case of swell (periods more than 12s), a good orientation towards the wave direction is a necessity {ref 6} and {ref 7}. But, an orientation parallel to the local currents is equally necessary.
Very roughly, the following limiting wave heights apply for the use of jetties and SBM's {ref 10} {ref 11}:

<table>
<thead>
<tr>
<th></th>
<th>during berthing without swell [m]</th>
<th>during berthing with swell [m]</th>
<th>during loading or discharging [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>jetty</td>
<td>1.5 - 2.0</td>
<td>1.0 - 1.5</td>
<td>2.0 - 3.0</td>
</tr>
<tr>
<td>SBM</td>
<td>2.0 - 3.0</td>
<td>2.0 - 3.0</td>
<td>4.0 - 6.0</td>
</tr>
</tbody>
</table>

The above figures for the jetties very much depend upon the arrangement of the mooring system, orientation towards wave direction and shape of the wave spectrum. Of course, there is also a strong influence of currents and wind. Berthing with wind speeds higher than 12.5 to 15m/s is considered to be unsafe, and is, therefore, not allowed.

Considerations of excessive wear and tear of the fender system may reduce the limiting wave height at a jetty during loading and unloading well below the above given figures. The offshore solutions are further discussed in section 8 hereof.

For a conventional berth inside a harbour basin, the following principles have to be observed:
* For safety reasons, oil and gas berths should be separate from other port facilities. No other shipping should be allowed inside the oil and gas basins.
* The mooring system has to be of such sturdiness that the ship can, at all times, stay safely berthed, also when a storm is forecasted. Thus, a sudden departure with its inherent risks, can be avoided. This very much applies to liquid gas tankers, as these can only sail with either full or empty cargo tanks. ('Empty' means with 1 or 2% residual cargo to keep the tanks refrigerated on the return voyage.) Contrary to oil tankers, gas tankers have no partitions in their cargo tanks, which, when in open sea, would lead to lurching of the liquid in the tanks if only partially filled. This, in its turn, would cause rupture of the tank wall as well as loss of stability of the ship.

As concerns the length of waterfront required per berth, for safety reasons the space between two ships, berthed in line, should be approximately equal to the width of the biggest ship. It should also be taken into account that the manifold of many ships is not located exactly in the middle of the ship, but sometimes up to 15m fore or up to 10m aft of the centre. It is, therefore, advisable to take as a minimum centre-to-centre distance of 2 adjacent berths: the length of the longest ship + 1x the width of the largest ship + 2x 15m.

6. Jetties and dolphins

6.1 L and T jetties

Oil and gas jetties (figure 8) generally consist of the following components:
* An **approach bridge** with a roadway of 2.5 to 3.5m width and a pipe track (preferably in one layer for easy inspection), plus service ducts, lighting and guard rails. The pipe track can be either next to the roadway and on the same level, or underneath the road. The length of approach bridges varies, depending upon the local conditions, from tens of meters to many kilometers.

* The **jetty head** consisting of a platform with:
  - loading arms
  - service area
  - service building
  - jetty crane
  - fire fighting tower
  - gangway
  - etc.

A typical size of a jetty head is 20x35m².
* The berthing or breasting dolphins which serve to:
  - absorb the kinetic energy of the berthing ship
  - hold the vessel during on-shore wind
  - fasten the ‘spring’ lines of the vessel (although, sometimes, also special mooring dolphins are used)

* The mooring dolphins to fasten the transverse mooring lines (breast and stern lines).

6.2 Fingerpiers

Fingerpiers have the advantage of having berths at either side of the pier, with the possibility of joint use of the approach bridge, platform (partly) and mooring dolphins. But, care should be taken that the distance between ships does not become too short, causing mooring lines to become too steep. A minimum distance from ship to dolphin of 30m should be adhered to.

6.3 Approach bridges and jetty heads

Approach bridges and jetty heads are, in essence, simple structures for which local building regulations apply.

For the roadway loading, the design load is the biggest vehicle that passes during normal use, unless the building of the jetty as such entails special requirements. Normally, a 15t truck constitutes a reasonable design criterion.

In many cases, the design of the approach bridge is determined by the number and dimensions of the pipelines. Spans for the pipelines may not be too big (4 to 12m) due to the stiffness requirements. Special attention has to be paid to pipeline anchors and expansion bends (loops). In case of LNG lines, often bellows are used, instead of loops.
When designing approach bridges, it should be tried to have the pipeline anchors coincide with the fixed points of the approach bridge. Expansion bends should coincide with the expansion joints of the bridge. The bridge has to be sufficiently rigid in all directions. The vertical deflection should be no more than 1/1000 of the span to prevent that, when draining the lines, a residue of the product remains at the lower part of the pipeline.

The dimensions of the jetty head are mainly determined by the space requirements of the manifold and the loading arms. The required minimum distance between successive loading arms is 3 to 4.5m, depending on their size.

6.4 Breasting dolphins

In section 6.1, the functions of breasting and mooring dolphins have been mentioned. Since breasting dolphins (also called berthing dolphins), contrary to mooring dolphins, have to be able to absorb the kinetic energy of the berthing ship, they have to be flexible. This flexibility can be attained either by elastic deformation of the dolphin itself (e.g. by using a number of relatively small-diameter, thick-walled steel piles) or by elastic deformation of the fenders, or by a combination of the two. Mooring dolphins have to withstand only quasi-static loads and, as such, are most economically designed as stiff structures (e.g. a single large-diameter steel pile).

The impact energy to be absorbed by a dolphin from a berthing ship (figure 9) is:

$$E = \frac{M C_m C_s}{2 (k^2 + r^2)} \cdot [v^2 (k^2 + r^2 \cos^2 \gamma) + 2 v \omega r k^2 \sin \gamma + \omega^2 k^2 r^2]$$

in which:
- $v$ = approach velocity of the ship's centre of gravity at the time of impact
- $M$ = mass of the ship (displacement)
- $C_m$ = virtual mass factor
- $C_s$ = stiffness factor
- $k$ = radius of gyration of the vessel (for big ships about 0.2L)
- $r$ = distance between centre of gravity and point of impact
- $\omega$ = angular velocity of the ship upon impact
- $v_r$ = approach velocity of the ship at the point and time of impact

![Figure 9 Berthing ship](image)

The factor $C_m$ has to be introduced to incorporate the effect of a volume of water that moves with the vessel; the moment the vessel starts to decelerate, long waves develop on both sides of the ship, with an increase of the water level on the upstream side and a decrease on the downstream side. This level difference results in a lateral force on the ship.

$C_m M$ is the hydrodynamic mass of the vessel. The value of $C_m$ depends, inter alia, on the keel clearance, the type and geometry of the berthing, the approach velocity and the deceleration gradient after
contact with the dolphin. Values between 1.3 and 2.5 are used, the lower values applying for relatively big keel clearance and solid berths (continuous quay with closed front).

Vasco Costa introduced the approximation \( C_m = 1 + 2 \frac{D}{B} \), in which \( D \) and \( B \) are the draught and the beam of the ship \{ref 9\}. It is a simplification because it disregards e.g. the important effect of the keel clearance.

The factor \( C_s \) depends on the relative elasticities of the dolphin and the ship's hull, as some of the energy will be absorbed by elastic deformation of the latter. \( C_s \) is, generally, about 0.90 to 0.95 and, thus, only of secondary importance.

It is usually assumed that \( \gamma \) is about 90° and the \( \omega \cdot r \) is small compared to \( v \), so that \( v_\gamma = v \). In that case, the expression for impact energy can be written as:

\[
E = \frac{1}{2} M C_m C_s C_v v^2
\]

in which:

\[
C_v = \frac{k^2}{k^2 + r^2}
\]

\( C_s \) is normally 0.60 to 0.85.

Another procedure to determine dolphin and fender loading is that of the 'Impulse Response Function Method', for which reference is made to \{ref 20\}.

It will be clear that the magnitude of the impact energy is largely determined by the approach velocity of the ship. As a simple guideline may serve:

* favourable conditions of current and wind, \( v = 0.10 \text{m/s} \)
* average conditions of current and wind, \( v = 0.15 \text{m/s} \)
* unfavourable conditions of current and wind, or berthing with smaller vessels, \( v = 0.25 \text{m/s} \)

More detailed recommendations are given in \{ref 14\}. Prototype measurements carried out by Shell at 4 refinery terminals resulted in the graph of figure 10, which demonstrates that the probability of exceedence of the above indicative values is still rather high.

The availability of statistics for different classes of vessels allows the setting of design values based on an accepted probability of exceedance. British Petroleum measured dolphin and fender deflections, and thus impact energy, for an extended period \{ref 19\}. For an accepted probability of exceedance of 1/3000 (or once per 20 years), this resulted in the design values tabled below. The design values given for Shell are partly based on approach velocity measurements, and partly on certain design philosophies, e.g. the fear that a long habit of berthing big ships at specific locations may result in a decrease of caution.

<table>
<thead>
<tr>
<th>dwt</th>
<th>British Petroleum</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[ton.m]</td>
<td>[ton.m]</td>
</tr>
<tr>
<td>50,000</td>
<td>103</td>
<td>120</td>
</tr>
<tr>
<td>100,000</td>
<td>152</td>
<td>183</td>
</tr>
<tr>
<td>150,000</td>
<td>185</td>
<td>250</td>
</tr>
<tr>
<td>200,000</td>
<td>215</td>
<td>345</td>
</tr>
<tr>
<td>300,000</td>
<td>260</td>
<td>515</td>
</tr>
</tbody>
</table>

Because of the normally oblique approach of a vessel, the breasting dolphins have to be calculated for an eccentric lateral impact force \( [F] \) in conjunction with a friction force of about 0.5F. This unfavourable combination of forces requires special precautions to prevent rotation (figure 11a).

The magnitude of \( F \) depends on the energy \( E \) to be absorbed, the ultimate deflection of the dolphin and fender \( \delta \) and the elastic properties of dolphin and fender. For the piles of a steel-piled dolphin, there will essentially be a linear relation between \( F \) and \( \delta \), but most fenders show a non-linear response (figure 12 and \{ref 4\}). As a result, \( F \) will generally be in between \( E/0.3\delta \) and \( E/0.5\delta \).
It is not only the breasting dolphin that has to be able to withstand the impact force $F$, but also the ship's hull may not sustain damage. The permissible hull pressure is $200\text{kN/m}^2$ for LNG/LPG tankers (and for dry bulk carriers), $250\text{kN/m}^2$ for oil tankers up to about 100,000dwt, and $300\text{kN/m}^2$ for oil tankers above that limit. However, in view of the US regulation that new oil tankers have to be provided with a double hull (i.e. separate cargo tank), which will lead to a lighter outer hull structure, it would appear safe to assume a generally applicable limit of $200\text{kN/m}^2$. The fenders or fender skirts will have to be designed and dimensioned accordingly, and fender skirts must be mounted on the dolphin in a flexible way, so as to be able to adapt themselves to the position of the ship's hull (figure 11b).

In the above, only the design requirements resulting from the energy absorption function have been discussed. Design requirements resulting from quasi-static forces transmitted by a ship exposed to wind and/or current, are essentially identical to those of mooring dolphins and will be discussed in section 6.5 hereafter.
As concerns the minimum number of breasting dolphins required: in case of only a slight difference in ship dimensions, berths with 2 breasting dolphins belong to the possibilities. The ctc distance between the breasting dolphins has to be maximum 0.4 times the length of the smallest vessel, and at least 0.3 times the length of the largest vessel. This is necessary to stay within the limits of the straight sides of the tankers, but also to provide a stable support for the bigger ships.

It is clear that very soon, two pairs of breasting dolphins are required. This can also be seen as a matter of security; the inside dolphins serve as a sort of insurance premium in case of damage of the outer dolphins.

6.5 Mooring dolphins

For each size-class of ship, a multiple mooring line plan has to be made. In most cases, this will lead to 4 - 6 breast and stern line dolphins and, possibly, to 2 - 4 spring dolphins. Mooring dolphins are equipped with quick-release hooks and electrical capstans. The mooring dolphins have 3 hooks each. The safe workload of the hooks should preferably be equal to the breaking strength of the heaviest mooring lines. Contrary to traditional practices, the breast and stern mooring lines should run as much as possible at a right angle to the ship (ref 12).
Jointly, the mooring dolphins (and mooring lines) should be able to resist any wind and current force exerted on the ship, that would move the ship away from the berth. The general formula for wind and current forces is:

\[ F_{x,y} = C_{x,y} \cdot \rho \cdot A \cdot v_{\varphi}^2 \]

in which:
- \( C_{x,y} \) = coefficients for wind and current forces in the direction \( x \) (lateral) or \( y \) (longitudinal)
- \( \rho \) = density of air or water respectively
- \( A \) = exposed area of the ship above water (for wind) or under water (current)
- \( v_{\varphi} \) = current or wind velocity from a direction with angle \( \varphi \) with the ship (\( \varphi = 0 \), head wind or current)

For currents, the value of \( C \) varies strongly with the keel clearance. Figure 13 gives values for \( C_{y \text{-current}} \) for different values of \( \varphi \) and \( d/D \). Figure 14 gives values for \( C_{y \text{-wind}} \) and \( C_{x \text{-wind}} \) (and \( C_m \) for the moment exerted on the ship). Further data may be found in [ref 13].

Figure 13

```
LATERAL CURRENT FORCE COEFFICIENT

\( C_y \)

Legend
Water Depth To Draft Ratio
- - - - - - - 1.05
- - - - - - 1.10
- - - - - 1.20
- - - - 1.50
- - - - 3.00
- - - - 6.00
- - - 26.00
```

\( \varphi \)
In case of exposed jetty terminals, the dolphins (both breasting and mooring dolphins) must also be able to resist the forces directly or indirectly induced by the waves. Normally, all-steel mooring lines, or hawser, are used for tankers, but in case of appreciable exposure to waves, softer moorings (e.g. steel with nylon 'header') may be required to limit mooring line forces. This leads to greater ship motions which may make it necessary to disconnect the loading arms if the motion amplitude starts to exceed certain critical values. Normally, for long-period horizontal motions -surge, sway and yaw-, amplitudes of ±2.5 to 3m are allowed. LNG loading arms often have an auto-disconnect set at ±2.5m. Some load/elongation curves for different types of mooring lines are given in figure 15.

Figure 14  Wind load coefficients [source Delft Hydraulics]
As in practice there is much uncertainty with respect to the actual distribution of the overall current, wind and wave forces over the different mooring lines, mooring dolphins are often conservatively calculated for the combined breaking strength of the different mooring lines that may be attached.

To verify and optimize mooring arrangements for berths in difficult situations, physical model tests are still used. Although mathematical models exist, the complexity of the multiple mass-spring system and of the different excitation forces often sheds doubt on the reliability of their results.

6.6 Special aspects of LPG/LNG jetties

The following aspects require special attention:
* The stringent safety requirements have an influence on the design in the form of more conservative values for safety coefficients, acceptable stresses, etc.
* In the case of leakages or spills anywhere in the pipeline system, the very low temperatures of LNG can expose steel structures to so-called ‘cold showers’ which cause an irreversible brittleness. Therefore, exposed steel structures have to be protected, e.g. by applying a cover of concrete or by incorporating the structure in a concrete floor.
* For the design of various parts of the jetty, especially the loading platform, spatial forms have to be avoided which facilitate the development of so-called ‘gas pockets’.
* By applying isolation material around the pipelines, the surface exposed to the wind doubles or trebles with subsequent higher wind forces.

Figure 15  Load extension curves for mooring lines
Acceptable deformations and rotations of the structure are small and are also determined by the nature of the applied isolation materials. An elaborate system of fire-fighting equipment is required.

7. STORAGE AREAS

The size of storage areas for oil and liquid gas depends on the number and dimensions of the tanks and the distances between these tanks. Space has to be added for pipetracks, roads, pumping stations, buildings, etc. The dimensions of the tanks depend upon the size of the vessels, the intervals between ship arrivals and the diversity of the products.

In case of oil tanks, the distance between the tanks is mainly determined by the criterion that each tank has to be surrounded by a concrete or earth wall (bund) at such a distance and of such height, that in the event of the collapse of a full tank, the oil can be contained within the bund. For example, a tank of 100,000m³ surrounded by a 5m high bund (4m useful) requires a surface of 25,000m² or 160mx160m.

Operational storage capacity is, generally, in the order of 1 month consumption. In addition to this, there may be a strategic storage.

Liquid gas storage is more dangerous than oil storage, and requires special safety provisions as discussed already earlier. E.g., any escaping liquid from pipeline or tank rupture should be contained in as small as possible an area to minimize the evaporation surface.

As a guideline for space requirements, an LNG terminal with a throughput of 6 million tons per year requires, roughly, 15 to 20ha for storage, in 4 tanks of 60,000 to 80,000m³ each. This direct need for space is exclusive of the safety zone which must be kept free of uncontrolled sources of ignition.

8. OFFSHORE TERMINALS

8.1 SBM's

The advantage of an SBM is that the ship always takes the most favourable position in relation to the combination of wind, current and waves. Tankers of up to 50,000dwt can be handled within 24 hours. The SBM is attractive due to the simplicity of the system and the low investment costs. Figure 16 shows an SBM with multiple-chain anchors. The system with 6- or 8-chain anchor is the most common.

As a comparison of the investment cost, a VLCC jetty, fully equipped and including local dredging, requires an investment of approximately 2.5 times the investment needed for an SBM with a 36" submarine pipeline of 5km length. In addition to the differences in investment costs, there are the expenses for tug assistance which is required for vessels berthing alongside a jetty, but not required for those mooring at SBM's. Mostly, 3 or 4 tugs are used. Their capacity depends on the size of the ship and is often calculated with: required bollard pull = (ship displacement/100,000 x 60 + 40) tons. E.g., a 200,000dwt tanker, with a displacement of 240,000 tons, would require a joint static pulling power of the tugs of 180 to 200 tons.

For the SBM a simple mooring launch is sufficient.

But, on the contrary, maintenance costs for SBM's are considerably higher than for jetties. In particular, the hoses (underwater between pipeline and buoy, and the floating hoses between buoy and ship) require strict inspection and frequent replacement, although the technology has very much improved over the years.

In general, for small to moderate yearly throughputs SBM's are more economical than jetties. Only with big ships and for large throughputs, jetties become more economical.
Figure 16  SBM with multiple-chain anchoring

The following overview given in [ref 11] compares aspects of the main systems:

<table>
<thead>
<tr>
<th></th>
<th>jetty</th>
<th>multiple buoy moorings</th>
<th>SBM's</th>
</tr>
</thead>
<tbody>
<tr>
<td>access from shore</td>
<td>direct</td>
<td>by sea</td>
<td>by sea</td>
</tr>
<tr>
<td>number of hoses</td>
<td>1 - 8</td>
<td>1 - 4</td>
<td>1 - 3</td>
</tr>
<tr>
<td>time between arrival and start of pumping</td>
<td>2 hours</td>
<td>5 hours</td>
<td>2 hours</td>
</tr>
<tr>
<td>mooring possible with wind up to 30 knots and head waves of</td>
<td>1.0 - 2.0m</td>
<td>1.5 - 2.0m</td>
<td>2.0 - 2.5m</td>
</tr>
<tr>
<td>oil transhipment with wind up to 40 knots and head waves of up to</td>
<td>1.5 - 2.0m</td>
<td>2.0 - 2.5m</td>
<td>3.0 - 4.5m</td>
</tr>
<tr>
<td>ship has to leave berth with wind of 60 knots and waves higher than</td>
<td>-</td>
<td>2.0 - 3.0m</td>
<td>3.5 - 5.0m</td>
</tr>
<tr>
<td>preference regarding ease of berthing and de-berthing</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>possible tide effects</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>damage sensitive parts</td>
<td>fenders</td>
<td>buoy chains</td>
<td>hoses</td>
</tr>
<tr>
<td>assistance during berthing and mooring</td>
<td>tugs and flats</td>
<td>flats and tugs desirable</td>
<td>flats</td>
</tr>
<tr>
<td>assistance for the departure</td>
<td>tugs and flats</td>
<td>flats</td>
<td>none</td>
</tr>
</tbody>
</table>

The attractiveness of SBM's is also based on the fact that they can be used in very deep water (figure 17).
Figure 17 Deepwater SBM

An SBM buoy mainly consists of the following components:

* buoy body
* turning table
* swivel

The buoy body is divided into watertight compartments. There should be ample freeboard to avoid submerging of the buoy during maximum load. The maximum gradient may not exceed 10 to 15 degrees. The design load of the buoy should be equal to the breakload of the hawsers.

As regards selection of a buoy's location, it will be obvious that the sub-marine pipelines, i.e. the distance to the shore, should be as short as possible. But, it is equally obvious that there must be a zone of sufficient deep water around the buoy to ensure safe arrival and departure manoeuvres of the ships for different directions of wind, waves and currents. For that reason, the distance from the buoy to the critical waterdepth should be at least 3 times the length of the biggest ship.

8.2 Fixed offshore terminals

In areas where sea conditions are generally calm, the construction of fixed offshore terminals may be considered, in the form of loading/unloading platforms and dolphins. The platform may be connected to the shore by pipe trestles or by sub-marine pipelines. Figure 18 shows an example of the latter: the Kharg Sea Island loading terminal (Iran), designed for 500,000dwt tankers on one side and 300,000dwt tankers on the other.

Another example and a quite innovative design is given in figures 19 and 20. It is the Brunei LNG loading terminal, designed and operated by Shell. It is located some 4.2km offshore. The jetty head with special loading crane has been connected to the onshore storage by means of a simple trestle which carries the LNG pipelines. The ships are moored, assisted only by mooring launches, with the bow towards the sea and the stern close to, but free from the jetty head. This concept was chosen to avoid the need for tug assistance and channel dredging. The ships and the loading crane are
specifically adapted to each other, and, hence, only the 7 LNG carriers of 75,000m³ each, especially designed and built for the Brunei-Japan trade, can be handled here.

Construction was started in February, 1971 and was completed in October, 1972 at a cost of some £15 million, bringing the total capital investment in the Crude Oil Terminal on Kharg Island to £167 million.

Figure 18  Sea Island, Kharg

The mooring system allows the ship to change its position during loading over an angle of 2×40° to keep waves head-on all the time. The mooring system is a 'soft' system with the steel mooring lines provided with a 60m nylon header. This allows a displacement in the horizontal plane of up to 12m. The loading system is provided with a quick-release device (and no-return valves) which can be operated from the ship. The terminal was inaugurated in 1972 and has given virtually trouble-free service since. A more detailed description is given in {ref 1} and {ref 8}.
Figure 19  Layout of LNG berth
Figure 20  LNG berth loading crane
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chapter 9.

DRY BULK CARGO TERMINALS
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DRY BULK CARGO TERMINALS

1. INTRODUCTION

Before going into the different aspects of bulk terminals, it may be useful to elucidate the meaning of the word bulk. Traditionally, the expression was used for a commodity that was loaded or discharged in a loose form, e.g. coal or unbagged grain. More recently, however, there has been a tendency to talk about bulk shipments in the sense of shipments by the full shipload or substantial part-load, whether or not the commodity is handled by bulk cargo methods in the traditional sense. So, one can speak of a bulk shipment of steel plates, bundled timber or bagged cargo. For this latter form of bulk shipment, also the terms of mass breakbulk or neobulk are used. However, the terminals to be discussed hereafter are dealing with the actual bulk transport and, specifically with the dry bulk commodities.

One has to differentiate from the start between loading and unloading terminals. Contrary to virtually all other terminals -liquid bulk, containers, general cargo-, the dry bulk terminals are mostly designed for one-way traffic only and, as a result, loading and unloading terminals are basically different in character.

The best location of a dry bulk loading terminal is not necessarily close to the main centre of commercial and industrial activities in the area, but rather in the vicinity of the origin of the commodity, e.g. near the mining centre. Important site solution criteria are the natural conditions, the land communications and the available depth of water, since big bulk carriers have a considerable draught. Due to the large quantities often handled in these ports, extensive storage facilities are required and the necessary land area has to be available. As a result, worldwide many of the big loading terminals are so called 'dedicated' terminals or ports, designed and developed to handle only one particular commodity, but in very large quantities.

Unloading terminals are much more diverse, both in location, size and cargo handling system. In consequence, a relatively large part of this paper will deal with unloading terminals.

2. DRY BULK COMMODITIES

Dry bulk commodities can be divided into:

* major bulk
  (i) iron ore
  (ii) coal
  (iii) grain
  (iv) phosphate
  (v) bauxite/alumina

* minor bulk
  e.g. sugar, rice, bentonite, gypsum, wood shavings & chips, salt, fish, copra

The total world maritime transport of minor bulk constitutes about one third of that of major bulk. A short description of the major bulk commodities is given below.

(i) Iron ore
This is the most important dry bulk commodity, representing some 20% of the total dry cargo shipment by weight. The ore shipped has a stowage factor which varies between 0.30m$^3$ and 0.52m$^3$ per metric ton, with an average of 0.4m$^3$.

Iron ore, generally, is dusty and so it is normally necessary to provide dust extraction equipment. The density of iron ore limits the stacking height in terminals because of the limits of the load-bearing capacity of the ground. The angle of repose is usually less than 40°.

Sometimes, the iron ore undergoes a concentration process before being shipped. The concentrate is then baked into small spheres or pellets.

(ii) Coal
Coal has a stowage factor which varies between 1.2m$^3$ and 1.4m$^3$ per metric ton.

All types of coal, also anthracite, are subject to spontaneous combustion, caused by heating of the coal, as it absorbs oxygen from the air. But, the sensitivity to this phenomenon differs from one type to
another, which is important for the planning of the coal stockpile, as it may restrict the permissible height. Generally, the dust nuisance can be controlled by the use of water sprays at transfer points and discharge positions and on stockpiles. The angle of repose varies from 30° to 45°.

(iii) Grain
Under this heading belong wheat, barley, oats, rye, tapioca, etc. These grains have different densities and properties, so, consequently, they also have different storage and handling requirements. Since grain is a perishable commodity, it is necessary to have proper ventilation and protection against weather conditions and pests during shipment and storage. In the grain trade, variation in seasonal conditions results in large fluctuations in transportation requirements. Various types of vessels of different sizes are used, including combined carriers.

(iv) Phosphate
Phosphate rock is the main raw material for the fertilizer industry. It is very dusty and absorbs moisture very rapidly, which can create problems for unloading. The average stowage factor is 0.92 m$^3$ to 1.0 m$^3$ per metric ton. Practically all shipments are in the form of a powdery concentrate. The material is very fine, and special provisions have to be made to prevent dust problems.

(v) Bauxite/alumina
Bauxite ore, when processed into alumina, is the basic raw material for the production of primary aluminium. The two raw materials differ greatly in bulk density. Bauxite stows at 0.80 m$^3$ to 0.88 m$^3$ per metric ton, and alumina at 0.6 m$^3$. Handling characteristics are also different. The trend is towards conversion of bauxite to alumina at the source, which halves the transportation requirements. Particularly alumina is dusty and requires precautions against soil and air pollution.

3. DRY BULK SHIPS
Dry bulk carriers are designed for the transport of commodities such as grain, coal, iron ore derivatives, bauxite, phosphate, cement, etc. Carriers have also been designed and built for the transport of both dry and liquid bulk cargo. These are the so-called OBO carriers (ore/bulk/oil). Since the holds are alternatively used for the dry and liquid bulk cargo, they need to be cleaned at every change, which is a disadvantage. The OCO carriers (ore cum oil) have separate holds for liquid and dry cargo, in this way avoiding the many cleaning operations. Another type is the OSO carrier (ore/slurry/oil). Neither the OBO nor the OCO carriers have been used on a big scale, due to their limited application potentials.

The loading of bulk carriers virtually always occurs by shore-based equipment. Unloading may be done by shore-based equipment-the most common method- as well as by ship-borne equipment. In the latter case, one can distinguish between geared bulk carriers and self-unloaders. Geared bulk carriers are vessels equipped with deck-mounted grab cranes, generally one for every hold. Self-unloaders are equipped with a continuous unloading system. It usually consists of one or more longitudinal horizontal belt conveyors in the lowest part of the ship, which are fed from funnel-shaped holds through hydraulically operated valves or doors. The horizontal conveyor unloads onto an inclined or vertical conveyor which, in its turn, transfers the cargo on a third conveyor mounted on a revolving boom (up to 80 m long). From there, the cargo drops into a shore-based hopper (see figure 22).

These self-unloaders originate from the coal trade on the big lakes in the USA, but are more widely used now in different parts of the world for the shorter transport distances (coal from Sumatra to Java) or for through-transport from a main port to a secondary port or industry terminal (coal from Rotterdam to Sines, Portugal). The advantage is that no shore cranes are required, but particularly that a simple dolphin berth (instead of a continuous marginal quay) is sufficient to berth the ship, even in case of very wide slopes (see figure 1). The disadvantage is that the ships are more expensive per ton capacity and more vulnerable to mechanical breakdowns, e.g. a broken conveyor belt is difficult to repair in the confined space at the bottom of the ship.
For smaller required capacities, the short sea traders are used, also called coasters. They have the advantage of being able to visit virtually all ports due to their restricted draught. They are equipped for transport of bulk and general cargo and, usually, have their own unloading gear.

For general information, curves are given showing the relationship between the length overall, beam and full-load draught as a function of the DWT for the main range of conventional dry bulk carriers (see figure 2). The biggest bulk carriers in existence to date measures 350,000dwt and has a $L_{oa}$ of about 380m, $B=63m$ and $d=23m$.

For non-conventional bulk carriers, typical dimensions are:

<table>
<thead>
<tr>
<th></th>
<th>self-unloaders</th>
<th>short sea traders</th>
</tr>
</thead>
<tbody>
<tr>
<td>dwt</td>
<td>20,000 - 70,000</td>
<td>300 - 3,000</td>
</tr>
<tr>
<td>$L_{oa}$</td>
<td>200 - 250m</td>
<td>40 - 95m</td>
</tr>
<tr>
<td>$W$</td>
<td>20 - 30m</td>
<td>5.5 - 13m</td>
</tr>
<tr>
<td>$H$</td>
<td>10 - 17m</td>
<td>3 - 8.5m</td>
</tr>
<tr>
<td>$Dr$</td>
<td>7.5 - 12.5m</td>
<td>2.5 - 6m</td>
</tr>
</tbody>
</table>

It is emphasized that the type of cargo (low or high relative density) is governing the actual draught of the carrier. Detailed information is given in {ref 1}.

The actual draught, in its turn, controls the possibility to enter a port with restricted depth. Therefore, it is important to judge the most efficient -and economic- relation between:

* types of commodities to be transported, and their bulk densities
* type of carrier most suitable for that purpose
* cargo combination possibilities
* technical restriction of ports on call
4. UNLOADING SYSTEMS

4.1 General

There is a variety of unloading systems and equipment, some continuous, some discontinuous, and with a wide range of capacities. The main systems are (see figure 3):

* grabs
* pneumatic systems
* vertical conveyors
* bucket elevators
* slurry systems
* self-discharging vessels

Figure 2 Principal dimensions of dry bulk carriers
The capacity of the unloading equipment is usually decisive for the throughput capacity of the terminal, as the capacities of other terminal equipment should be geared to that of the unloading facilities. However, there is confusion in defining capacity. The following three definitions are currently used:

(a) **Peak capacity**, also known as *cream digging rate*, is defined as the maximum (hourly) unloading rate under absolutely optimum circumstances: a full hold, an experienced crane operator and at the start of his shift.
This unloading rate has to be the design capacity of all down-stream plant and equipment: belt conveyors, weighing equipment and stackers. If not, it would give rise to frequent blockages and stoppages in the cargoflow. It is, therefore, of prime importance for the systems designers and equipment suppliers.

(b) Rated capacity, also known as free digging rate, is defined as the unloading rate, based upon the cycle time of a full bucket or grab from the digging point inside the vessel to the receiving hopper on the quay and back, under average conditions and established during a certain length of time.

(c) Effective capacity is defined as the average hourly tonnage attained during the unloading of the entire cargo of a ship. The necessary interruptions for trimming, cleaning up, moving between holds, etc., are taken into account, but not the scheduled non-working periods, such as night time, weekends, etc.

The effective capacity multiplied by the annual operational availability of the berth times the permissible rate of occupation gives the annual berth capacity which is the main parameter for the port planner. In other words, whereas the equipment designer is primarily interested in the peak capacity, the port planner’s interest is in effective capacity.

For the grab unloading system, the different capacities relate about as follows:

* peak capacity 2.5
* rated capacity 2.0
* effective capacity 1.0
* effective capacity 0.8

(unfavourable conditions, i.e. narrow hatches)

For the continuous unloading systems, the differences are smaller, but vary considerably from one system to another. For example, a mechanical chain unloader for raw tapioca still requires trimming and cleaning up in the hold, which results in a large discrepancy between rated and effective capacity, but self-unloading vessels can maintain the rated capacity over almost all of the unloading time.

To add to the confusion, port authorities, in their marketing efforts, at times use a ‘maximum berth capacity’ or sometimes simply called ‘berth capacity’, which is the effective capacity, but calculated for a 100% rate of occupation. Such figures have no real significance because in those conditions, a tremendous congestion would develop and the port or terminal would be out of business in a very short time.

In the following, the main unloading systems will be discussed.

4.2 Grabs

The grab, normally, is used for picking up material from the vessel hold and discharging it into a hopper located at the quay edge, feeding onto a belt conveyor (see figure 4).

The attainable handling rate for a grab is determined by a number of factors, such as hoisting speed, acceleration of the grab bucket, travelling speed, horizontal and vertical distances, closing time of the grab, skill of the operator, the properties of the material being handled, shape and size of cargo holds, and cleaning requirements. Mechanical restrictions and operator fatigue restrict the number of crane cycles per hour that can be attained to about 60, though 40 is closer to a normal average. The payload deadweight ratio of the grab bucket effects the net production; the normal ratio is 1:1, but new designs are approaching 2:1.

A bulk cargo terminal for a range of commodities will require a set of 2 or 3 grab buckets per crane (one in use, one on standby and/or one in repair). Commodities with significantly different physical characteristics need an additional set of grabs. The types of grabs vary considerably, depending on the product which has to be handled. The principal materials handled often by grab are iron ore, coal, bauxite, alumina and phosphate rock. Smaller, mobile, grabbing cranes deal with raw sugar, bulk fertilizers, petroleum coke and varieties of beans and nutkernels.
Figure 4  Heavy grab ship unloader by PWH with 85t lifting capacity. The unloading capacity is 4,200 metric tons per hour on coal. [source Bulk Solids Handling]

Another type of grabbing crane, different from the already mentioned overhead trolley crane, is the revolving grabbing crane (see figure 5).

Here, the grab lifts the material and discharges it into a hopper at the front to eliminate slewing during operation. The hopper feeds a conveyor or it can discharge directly into trucks or railwagons. Lifting capacity of a grab goes up to 85t (EMO, Maasvlakte).

Typical ranges of rated capacities are:
* travelling overhead trolley grabbing crane unloader  500 - 2500 tons/hour
* revolving grabbing crane, lifting only  500 - 700 tons/hour
* revolving grabbing crane, with 90° slewing  200 - 250 tons/hour

Occasional lower and higher capacities occur.

Based on measurements, Hoogovens Ijmuiden distinguishes the unloading process in three stages with decreasing productivity as indicated in figure 6.
4.3 Pneumatic systems

Pneumatic equipment is classified into:
* vacuum or suction types (from several places to one spot)
* pressure or blowing types (from one spot to several places)
Bulk cargo with low specific gravity and viscosity, e.g. grains, cement, powdered coal, fish, fish-meal, alumina, etc., may be handled by pneumatic systems. A disadvantage of the pressure type is the dust problem.

The construction of vacuum pneumatic conveyors is simple, and there is no spillage of materials during transport. However, the power consumption is high, compared with other transporting systems.

The pneumatic elevator can be:
* quay-based (see figure 7)
* floating (mounted on a pontoon)

![Diagram of pneumatic handling equipment](source UNCTAD Port Planning Handbook)

1. Combination vacuum/pressure system: conveying grain from ship into bagging hopper
2. Combination vacuum/pressure system: conveying from ship to barge
3. Vacuum-only system: transferring grain from ship into truck or railwagon loading hopper
4. Vacuuming grain from ship: loading grain by gravity into barge

Typical unloading rates (rated capacity) are in the 200 to 500t/h range, but capacities as high as 1,000t/h occur.

In case of relatively small throughputs and/or non-dedicated terminals, portable pneumatic equipment may be used with a capacity of about 50t/h. More than one unit may be used at a time, serving different holds (see figure 8).
4.4 Vertical conveyors

Different types of vertical conveyors for unloading purposes are:

* chain conveyor
  typical rated capacity: 200 tons/hour
* vertical screw conveyor
  900 tons/hour
* spiral conveyor
  75 tons/hour

The chain conveyor is usually built inside a rectangular casing, whilst the vertical screw conveyor (see figure 9) is a full-blade screw contained in a tubular casing. Transport by chain conveyors is restricted to dry, friable materials, whilst the screw conveyor can deal efficiently with fine-powdered and granular materials, suitably sized lumpy materials, semi-liquid materials and fibrous material. The throughput is restricted to the rate at which material can freely flow into the feed aperture.

For unloading or loading of bulk (in bags or boxes), a vertical spiral conveyor may be used (see figure 10).

4.5 Bucket elevators

A bucket elevator consists of a continuously rotating bucket wheel, suspended from the luffing boom of the travelling unloader. This bucket wheel digs up the material and feeds a continuous bucket elevator. The quay has to be constructed to withstand the dynamic digging forces and the weight of the structure of the equipment. Alternatively, a bucket chain elevator can be used, with the buckets acting as digging scoops. As in the case of the wheel elevator, the bucket elevator is suspended from the luffing boom. Often, still the full hold of a ship cannot be covered whilst the different travelling, luffing and slewing motions to be performed during unloading make the equipment mechanically vulnerable (see figure 11).
Feeder for coal with collecting vanes and digging blades

Figure 9

Spiral conveyor
- unloading 1500 bags of 50kg per hour
- loading 2100 bags of 50kg per hour
- bulk loading 800t/h maximum

Figure 10
Figure 11  Movements of a continuous unloader  
[source prof G. Prins, 'Stortgoed Terminals', TU Delft]

Maintenance costs of bucket elevators may be considerable. In terms of cost per ton unloaded, they appear to be less efficient than grabs, taking into account the total capital expenditure and the operating costs. However, the free digging rates of the biggest unloaders built to date are around 5,000t/h, against about 4,000t/h for a grab system.

A bucket elevator has the following functional features:
* The bucket elevator assembly is always held vertical for easy operation due to the application of the parallel link (pantograph) motion.
* The bucket elevator can rotate freely to enable high unloading efficiency and easy operation.
* The swing-out and catenary mechanism of the bottom half of the elevator are provided for easy access of material under the hatch overhang and for efficient clean-up operation.
* An L shaped configuration can be attained by swinging the elevator 90° at the second sprocket wheel for digging the bottom layer (see figure 12).
* The elevator, the boom conveyor and the transfer points are totally enclosed to eliminate dust.
An automated unloading system can be provided.
Variable speed control of the bucket elevator can be provided for handling materials with different densities.

IHl's Continuous Ship Unloader for Reynolds Metals Co., Corpus Christi, Texas, is designed to unload 70,000 DWT ships at the rate of 2,000 t/h bauxite. Year of delivery: 1991. (Photo taken during erection of machine) (see also "bulk solids handling" 2/91, p. 539)

Figure 12 General arrangement and main operating functions of IHl's continuous unloader [source Bulk Solids Handling]

In some designs for free-flowing material, the buckets are attached to a steel wire which is pulled over and through the cargo (see figure 13). In other installations, the digging function is performed by a bucket wheel that unloads onto a vertical conveyor (see figure 14).

4.6 Slurry systems

Ore and coal, after mixing with water, can be transported as slurry. But, so far this form of bulk transport did not yet find a very wide application. Coal slurry pipelines occur in the USA for the land transport of coal to powerplants and, e.g., in India for iron ore to a pellet plant. To limit pumping velocities, and thus transportation cost, the coal or ore has to be ground very fine, which gives problems for the later de-watering. The lower limits of transport distance and transport quantities for economic viability appear to be in the order of 50km and 5 million t/y respectively.

In the maritime transport, it is the Marcona Corporation which has pioneered the slurry system, using vessels from 50,000dwt to 140,000dwt, a.o. for the transport of iron ore from Australia to Japan. But, worldwide the maritime transport of slurries is only a small fraction of the total bulk transport.

One of the difficulties is the environmental problem posed by the slurry water. In case of land transport, the slurry water, after the de-watering process, can be returned by separate pipeline for re-use. But, when loading a ship -for economic reasons, the slurry is transported in the form of about 85% solids and 15% water-, the excess water generally will have to be collected and treated to avoid serious water pollution. This is expensive and, in case of SBM loading terminals, also technically difficult.
At the unloading terminal, waterjets have to be used in the ship’s holds to bring the solid matter again in suspension, which is necessary for pumping. Before use in power plant or blast furnace, the slurry must, once again, be de-watered to an acceptable low water content of 10% or less. This can be done for not too fine materials in settling ponds, and otherwise by filters, cyclones or thermal drying. Whatever process is selected, there is, once again, the problem to get rid of the polluted excess slurry water, which explains the limited application of the slurry system till the present.

4.7 Self-unloading vessels

A discussion of these vessels and some of their advantages and disadvantages has already been given in section 3. A more complete listing of these advantages and disadvantages is given hereafter.

Advantages
* Reduction in voyage times due to high unloading rates (up to 10,000 t/h and over for iron ore and big vessels).
* Multi-port discharge because no -or only very simple- shore-based unloading equipment is required.
* Cargo blending; cargo of different qualities, requiring blending, can be loaded in separate holds and blended into the conveyor belt system.
* Ship discharging flexibility: direct to stockpiles into hoppers located on platforms off-shore into other vessels into warehouses or silos with a rooftop access
* Environmental and pollution control; stringent requirements can be met.
* Simple and cheap berth structure; a few dolphins will do.
* No stevedoring assistance required.
Figure 14  Design of the continuous bulk unloader
[source Bulk Solids Handling]

Disadvantages
(as compared to conventional bulk carriers)
* Higher capital cost of vessel (about 15%).
* Higher crew costs; specialized unloading experts required.
* Lower carrying capacity; the self-unloading equipment takes space.
* Greater mechanical vulnerability and, thus, higher downtime.

5.  LOADING SYSTEMS

The loading of bulk cargo is virtually always a continuous process in which one or more movable ship
loaders are fed by a belt conveyor system from the stockpile and drop the cargo in the different holds of
the ship. In case of dry and dusty products, the ship loader will have to be provided with a telescopic or
spiral chute to reduce drop height and fall velocities.

Load capacities vary from a few thousands t/h to 20,000 t/h (Tubarao, Brazil). Particularly for the very
large loading terminals, receiving big bulk carriers and requiring great water depths, the selection of
location, terminal layout and loading system should be a joined effort of mechanical and civil engineers as the respective problems are very much inter-related.

The most common ship loader is a travelling crane on a quaywall or jetty, to which the ship is berthed (see figure 15). But, as for big bulk carriers quaywalls of some 300m length are required, with a great retaining height, the civil sub-structure becomes relatively expensive.

For that reason, the so-called radial and linear ship loaders have been developed, which are less expensive in terms of sub-structure (see figure 16).

Figure 15  Loading terminal  
[source prof G. Prins]

Figure 16  Shiploaders  
[source P. Soros]
Linear loaders
The bridge of the loader rotates around a pivot, and is supported by this pivot and by a straight railtrack parallel to the ship. Apart from rotating, the bridge also travels longitudinally across the pivot. Due to this combined movement, the frontside of the bridge moves parallel to the ship's side. In order to reach the holds of the vessel, a loading boom with horizontal and vertical motion is connected to the bridge.

Radial loaders
The bridge of this loader also moves around a pivot, but is supported at the other end by a circular track. A telescopic loading boom is attached to the bridge. This boom can reach all the holds of the ship which is berthed at a number of dolphins placed in one line. An alternative to this system, allowing the ship to head in different directions, has the dolphins placed in a circle segment, or provides a buoy mooring for the ship. The latter solutions are used for unsheltered terminals to minimize wave effects.

6. ON-TERMINAL HANDLING AND STORAGE

6.1 Transport systems

Transport systems are required to bring the cargo from the quayside to the storage area(s), and vice-versa. These storage areas can be in the open air or under cover in sheds or silos. This transport is mostly effectuated by conveyors, but occasionally by cable ways -a looped steel wire with buckets-, special rail cars or off-highway trucks. Here, the discussion will be restricted to conveyors.

Most conveyors are belt conveyors which are widely used for handling of dry bulk. In theory, unlimited distances can be covered, but the use of conveyors is generally restricted, for transport-economic reasons, to a few kilometres. For longer distances, rail or road transport often becomes more appropriate, although belt conveyors of more than 100km occur, e.g. for the transport of phosphate from mine to port in Morocco.

Advantages of the belt conveyor system are:
* simple construction
* economy of maintenance
* efficiency, with low driving power requirements
* adaptability
* complete discharge of handled materials

A disadvantage is the limited vertical angle at which normal belt conveyors can operate. A substantial difference in height requires a considerable amount of space.

Conveyor belts for bulk materials are troughed; flat belts are used for packaged materials. For special applications, so-called pipe conveyors and hose belt conveyors have been developed (see figure 17a-b-c). It are essentially normal troughed conveyors which beyond the loading and off-loading points are folded into a U-shape or circle which, first of all, results in an enclosed, dust-free system, and, in the second place, allows rather narrow curves and steep gradients to be introduced. For the conventional straight conveyors, transfer of cargo from one belt to another occurs at transfer points, which for dusty commodities have to be enclosed (see figure 18).

Other types of conveyors are:
* Chain conveyors
  This conveyor has a flighted chain which moves inside a totally enclosed casing with a partition at half width. In can be used up to an angle limited by the material characteristics. The process is dust-free and is particularly suitable for the handling of grain.
* Screw conveyors
  This very compact form of handling takes place inside a totally enclosed casing, either U-shaped or tubular.
* Fluidizing gravity conveyors
  The conveyor consists of a sloping trough covered with a porous medium. This type of conveyor is particularly made for the transport of powders. When air is passed upward through the porous cover, the powder mass expands and behaves as a fluid.
6.2 Stacking, storage and reclaiming

Stockpiles must be planned in such a way, that a maximum amount of material can be stored on a minimum area. The possibility thereto depends on the bearing capacity of the subsoil, the characteristics of the materials and on the outreach and height of stackers and reclaimers.
If weather conditions may affect the quality of the material, a covered storage will be required. The feed-in generally takes place from a high belt conveyor, situated along the apex of the building, and reclaiming occurs by means of a scraper/reclaimer or underground conveyor (see figure 19).

![Figure 19 Storage shed](image)

The area required for stockpile depends on the following factors:

* height and shape of stockpiles
* size of shipload distribution
* ship arrival distribution
* through-transport distribution
* ship loading and unloading rates
* strategic reserves to be maintained
* relation gross - net area

Both the ship arrival distribution and the through-transport distribution, in addition to normal stochastic fluctuations, may well show seasonal fluctuations. Therefore, no general rules apply, and area requirements have to be calculated according to the specific local conditions that apply.

Bulk commodities must often be segregated according to their properties. For unloading terminals, each stockpile must be able to accommodate at least a full shipload from each source.

When using motortrucks or railcars for transport from ship to storage, it may be convenient to use a storage bunker or truck silo in conjunction with the open storage. Special care must be taken to avoid segregation of free-falling material, entering an empty bunker. Specially designed spiral chutes arrest the free fall of the material.

The equipment used for bringing the bulk cargo into storage are the so-called stackers, whilst for retrieving material from the stockpile reclaimers are used. Stackers are travelling machines with a stacking boom with belt conveyor. Transfer of the bulk material from the main transport conveyor onto the stacker conveyor occurs by means of a tripper (see figure 20) which is attached to the stacker and, thus, can move back and forth along the stockpile.

Reclaimers are similar travelling machines, but equipped with a reclaiming device, e.g. a bucket wheel, and an intermediate belt conveyor. Sometimes, bulldozers are required to push parts of the stockpile within reach of the reclaimer.

Often, the capabilities of stacking and of reclaiming is built into one and the same machine, which results in the well-known stacker-reclaimers (see figure 21).
Figure 20  Principle of belt loop or tripper

Figure 21  Stacker-reclaimer

The above equipment is virtually all bulky and heavy, and requires sturdy and heavy cranetrack foundations.

6.3 Blending, processing, weighing

Particularly for iron ore and coal, blending of different grades is required before delivery to the powerplant or steel industry, with rather strict requirements of the homogeneity of the mix. The desired result can be achieved by specific stacking and reclaiming methods. For example, the stockpile may be built up in longitudinal layers of different grades, whilst reclaiming is effectuated by transverse scraping drum reclaimers. A great variety of tailor-made solutions may be found in different terminals around the world.

Processing of dry bulk is limited in port terminals. It is mostly restricted to bagging of grains, sugar, cement and similar products.

Bulk commodities must often be weighed immediately prior to loading or after unloading, for payment purposes or for checking against shipping documents. Batch weighing methods are employed as well.
as continuous weighing of the material on a moving belt conveyor. Sampling is sometimes required to satisfy the customer. For obtaining a correct composition of a particular batch, it is essential to take a series of samples automatically at timed intervals.

Figure 23 gives a bird’s eye view of a modern multi-product bulk terminal.

7. CLIMATIC AND ENVIRONMENTAL CONSIDERATIONS

The climatic conditions prevailing at the terminal location may influence the planning of the stockyard operation to a great extent. In very cold areas, special low temperature steel has to be used for the construction of the reclaimers, gears have to be heated, and one has to cope with high cutting forces in frozen material. In rainy seasons, some materials require covered storage.

The same is true where the environment must be protected against dust. Environmental considerations begin to play an ever increasing role. As a result, provisions like a waterscreen at hopper openings, fully enclosed conveyor belts, no-spill grabs and partly or fully enclosed storage are common practice at new installations.

Figure 22 Self-unloading gear of the M/V Western/Eastern Bridge
[source Bulk Solids Handling]
Figure 23  Swartouw terminal, Rotterdam
REFERENCES

{1} The Principal Dimensions and Operating Draughts of Bulk Carriers, University of Liverpool, Marine Transport Centre.

{2} Bulk Solids Handling, the International Journal of Storing and Handling Bulk Materials, TransTech Publications, Germany.


Ref {4} gives an extensive reference list.
chapter 10.

FISHERY PORTS
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1. INTRODUCTION

Over the years, fish has gained importance as a source of food (protein). While fishing in many waters is restricted by quotas, most developing countries bordering the sea are -and will be- looking for ways to create or improve their fisheries and are, therefore, involved in fishery port development.

A fishery port can involve, in addition to the unloading, handling and marketing of fish through a specialized terminal, industrial areas where fish is processed, and also service and maintenance facilities for vessels, nets and gear.

Fishing activity is dependent on the availability and nearness of fish, and is mostly seasonally influenced. Therefore, the fishing activity shows peaks and lows with either the majority of the fishing fleet at sea or almost all of the fleet resting at the port.

It is advisable to separate fishery activities from commercial port activities. First of all, for reasons of nautical safety, small-craft traffic, including the movement of fishing vessels, should be kept away from deepsea ports as much as possible. Secondly, waterdepth requirements and, thus, basic design criteria are totally different for the two types of ports. Thirdly, the smell of a fishing port will often not be acceptable in commercial ports, whilst, reciprocally, the fishery products may become contaminated by e.g. ore dust. Fourthly, the type of operations, the equipment used and the mentality of the people running the ships and the terminals are so different that they do not fit very well under one and the same umbrella.

2. TYPES OF FISHERY PORTS

Fishery ports can be distinguished according to the purpose they serve, e.g. as follows:

2.1 Simple landing places
They serve fishermen, bound to a certain location, generally operating on fishing grounds at a short distance away. It may be that such landing places can hardly provide any natural shelter for beaching and launching of vessels. Sometimes, protection is available when the landing place is located in bays, rivermouths, estuaries and the like.

In order to improve the effectiveness, the landing place should provide a ramp or small berthing quay, together with simple facilities for handling of the catch. The provision of some services and facilities for maintenance and repair will increase its value.

2.2 Coastal fishery ports (see table i)
These are the home-base for small coastal fishing vessels up to some 20m in length. Fishing grounds may be a bit further away, requiring trips of a few days' duration.

The vessels are equipped with somewhat more sophisticated gear and equipment, compared with those of the first mentioned group. Hence, more protection is required, and the provision of services, with the related infrastructure, should be more elaborate.

2.3 Near-distance fishery ports (see table ii)
These will frequently include a number of provisions, required by the smaller coastal vessels, but they are mainly meant for vessels with lengths from 25m to 40m. Fishery grounds may be several hundred miles way, requiring trips of several days to some weeks.

Vessels may be equipped with limited processing facilities on board, e.g. heading, gutting and icing in containers and, occasionally, with a chilling unit. Navigational aids and other mechanical and electronic equipment belong to their outfit. The ports must, therefore, provide the means to supply, repair and service these types of equipment in addition to the normal port services.
2.4 Ocean fishery ports (see table iii)
Such ports are used as home-base by the large, modern factory-type fishing vessels. These vessels are equipped to make long trips on the ocean, and they have a great flexibility as to the location of its home-base. When fishing at faraway locations, they may stop at ports of call for discharging purposes and for taking provisions. Sometimes, servicing takes place at advanced bases and even transhipment can be established to enable the vessel to remain a longer time on the fishing grounds. Processing of the fish takes place on board, such as deepfreezing, canning, etc.

The port has to be fully equipped to handle and maintain these types of ocean going vessels, and to deal with the large, but already processed catches. In consequence, normal commercial port facilities are often used by these vessels.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>CHARACTERISTICS</th>
<th>REQUIRED FACILITIES</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities for catches</td>
<td>Different types of fish are lined up one by one, then auctioned off. Fish is kept fresh, packed in ice and shipped off immediately. Seabream and other high-price fish are often shipped live.</td>
<td>Handling sheds Ice-storehouses (Freezer warehouses) Live fish-tanks</td>
<td>Special live-fish transport vehicles are necessary to convey live fish to consuming district.</td>
</tr>
<tr>
<td>Facilities for fishing boats and gear</td>
<td>Storage warehouses and repair areas will be necessary when nets and similar fishing gear items are used. When located away from neighbour ports, the need will exist for fuel oil supplies at home port. For small boats, it will be easier to use the slipway than the wharf. It will also be possible to perform maintenance and repair work, such as barnacle removing and painting.</td>
<td>Fishing gear warehouse Fishing gear drying area Oil storage tank (Oil supply equipment) Slipway</td>
<td></td>
</tr>
<tr>
<td>Facilities for people</td>
<td>Areas for gathering, discussions, training and other activities by local people are a must. Fishermen’s unions are organized to ensure smooth fisheries operations.</td>
<td>Fishing village centre Fishermen’s cooperative office</td>
<td></td>
</tr>
</tbody>
</table>

Table i - Coastal fishery characteristics and required functional facilities
<table>
<thead>
<tr>
<th>ITEM</th>
<th>CHARACTERISTICS</th>
<th>REQUIRED FACILITIES</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities for catches</td>
<td>Fish landed is sorted by type, boxed, auctioned, shipped.</td>
<td>Handling sheds</td>
<td>Catches are sometimes transported directly from the wharf by truck.</td>
</tr>
<tr>
<td></td>
<td>Large fish volumes mean large amounts of fish boxes required.</td>
<td>Fish boxes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fish is handled fresh, with the great majority refrigerated or frozen after landing</td>
<td>Refrigerators</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Parts of catches will be salted and dried, boiled and dried, canned or processed in similar fashion</td>
<td>Freezers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Processed products are temporarily stored in warehouses</td>
<td>Cold storage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large amounts of polluted water will be created by processing and handling areas</td>
<td>Reefer vehicles</td>
<td></td>
</tr>
<tr>
<td>Facilities for fishing boats and gear</td>
<td>Catches are packed in ice in transport ship storage bins for hauling to port. Large amounts of ice are, thus, needed to preserve freshness</td>
<td>Ice-making plants</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voyages vary from 1-2 days, with extended trips 3 weeks in length. Steady supplies of fuel oil at stable prices are demanded.</td>
<td>Ice-storehouses</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Net fishing gear may need to be repaired and stowed away.</td>
<td>Ice supply equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Offshore fishing boats are comparatively large, with special facilities required for repairs.</td>
<td>Oil supply equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Need to treat waste oil produced by fishing boats</td>
<td>Oil storage tanks</td>
<td></td>
</tr>
<tr>
<td>Facilities for people</td>
<td>Large volume and value of catches attract many fishmongers and middlemen.</td>
<td>Fishing gear storage and repair stations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comparatively large size of offshore fishing ports creates need for comprehensive port administration.</td>
<td>Fishing boat repair station</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Desirable to separate fishing port from the cities.</td>
<td>Waste oil treatment plant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Public transportation to and from the port.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table ii - Offshore fishery characteristics and required functional facilities
<table>
<thead>
<tr>
<th>ITEM</th>
<th>CHARACTERISTICS</th>
<th>REQUIRED FACILITIES</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities for catches</td>
<td>Large catches: mechanical unloading. Landed catches are auctioned, shipped. Direct transfer to cold storage facilities in many cases. Processing done on board or in port where landed.</td>
<td>Cargo handling equipment and storage space (mobile cranes, forklifts, conveyor belts) Handling sheds Refrigerating/freezing plant Processing plants</td>
<td>Sometimes done by ship's derrick crane Catches are placed one by one -40°C to -50°C Need for treatment facilities for resulting polluted process water</td>
</tr>
<tr>
<td>Facilities for fishing boats and gear</td>
<td>Fuel oil costs account for large percentage of fisheries costs, need for stable prices through storage. Long voyages create need for procurement of clothing, food, etc. Need for electric power supply from shore when boats docked in port. Long voyages create need for large volumes of drinking water. Scrupulous repairs and checks are vital; boat or equipment breakdown at sea could mean disaster. Need for information on shifting market prices to boats at sea. Weather reports are also vital.</td>
<td>Oil supply equipment Oil storage tanks Clothing and food stores Electric power outlets Drinking water outlet, etc. Fishing boat repair stations Radio stations</td>
<td>Ample oil storage capacity if space allows Procurement from local shops in most cases Normal power and water supplies used if adequate Need for facilities including docks</td>
</tr>
<tr>
<td>Facilities for people</td>
<td>Boats carry 20-30 crewmembers, and travel long distances; family members often send off or greet fishermen when boats set sail or return. Health care for fishermen is vital. High volume and value of products handled attract many traders and middlemen. Ports are large which requires a comprehensive administration. Surrounding areas are usually developed cities; desirable to separate fishing port from lifestyle activities. Public transportation to and from the port.</td>
<td>Lodging Clinics Offices, banks, auction building Fishing port administrative offices Parks Greenbelt Bus service</td>
<td></td>
</tr>
</tbody>
</table>

Table iii - Distant fishery characteristics and required functional facilities
3. SITE SELECTION

Generally, fishermen establish settlements near to existing fishing grounds, even if little or no natural shelter can be found for beaching and launching of vessels. If possible, a fishery port should be developed at a site where, in addition to favourable natural conditions, fishing activity already takes place. Fishermen are usually reluctant to change. Fortunately, fishermen usually settle in locations where some protection against nature is already available (bays, rivermouths, estuaries).

At potential sites for port development, surveys, including hydrographic, hydraulic, meteorological and sub-soil investigations, should take place. Table (iv) gives an idea of the required information at each site. Some of this required information is common to all ports. Other items are specifically related to fishing ports. Preliminary lay-outs and cost estimates should be prepared for comparison. In an economic analysis, the expected catch volumes, the composition of the fishing fleet, distance to fishing grounds and to fish markets should be considered. Also, the presence of a labour force should be taken into account.

Fishing techniques change. Since in future developments bigger vessels may be introduced, it is advisable to select locations where later on a deepening of the port and its access from the sea appears technically and economically feasible.

<table>
<thead>
<tr>
<th>SEA</th>
<th>PORT</th>
<th>LAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tides * amplitude</td>
<td>Vessels * type, size and number</td>
<td>Access * road</td>
</tr>
<tr>
<td>* type</td>
<td>* peak landing volumes</td>
<td>* rail</td>
</tr>
<tr>
<td>Winds * directions</td>
<td>Distance to fishing grounds</td>
<td>Settlement * size</td>
</tr>
<tr>
<td>* durations</td>
<td></td>
<td>* fishermen</td>
</tr>
<tr>
<td>* storms</td>
<td>Nearness to commercial ports</td>
<td>* labour</td>
</tr>
<tr>
<td>Waves * types</td>
<td>Expansion possibility</td>
<td>Available services * water</td>
</tr>
<tr>
<td>* height and period distributions</td>
<td>Natural shelter</td>
<td>* electricity</td>
</tr>
<tr>
<td>* dominant directions</td>
<td></td>
<td>* fuel</td>
</tr>
<tr>
<td>Bathymetry</td>
<td></td>
<td>* workshops</td>
</tr>
<tr>
<td>Areal photographs</td>
<td></td>
<td>Topography</td>
</tr>
<tr>
<td>Currents * at different tide stages</td>
<td></td>
<td>Sub-soil profiles</td>
</tr>
<tr>
<td>Sub-soil profiles</td>
<td></td>
<td>Availability or nearness to construction materials</td>
</tr>
<tr>
<td>Coastal conditions * littoral drift</td>
<td></td>
<td>* timber</td>
</tr>
<tr>
<td>* expected siltation, erosion</td>
<td></td>
<td>* gravel</td>
</tr>
<tr>
<td>* dredging</td>
<td></td>
<td>* rock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* sand</td>
</tr>
</tbody>
</table>

Table iv - Site information to be considered

4. FISHING VESSELS

The fishing vessels, method and gear used, depend on the kind of fish caught, whether pelagic (close to surface, moves fast) or demersal (close to bottom, moves slowly) and, in general, on the state of development of the fishing industry in a country. The number and characteristics of the vessels as related to the catch determine the required facilities to be provided by the fishery port.
Small coastal vessels, with a length of 3m to 15m, operating with inboard or outboard motors, sails or rows, are mainly made of wood (nowadays also of re-enforced plastic), whilst vessels from 15m to 25m length are, more often, made of steel. Hold capacity in this category is usually between 0.5 and 20 ton, whereas the bigger vessels can go up to 60 ton in special cases. Catches are substantially lower when fish is caught for direct human consumption in comparison with catches for processing into fishmeal. Draught of the former vessels is in the order of 1m to 2m, whilst the larger ones have draughts up to 3.5m. Typical draughts are shown in figure 1.

The fishing cycle of the smaller coastal vessels is 1 or 2 days, and up to a week for the larger vessels using ice of salt to preserve fish. Smaller vessels generally use gillnets, lines and traps for fishing, while the larger vessels make use of purse seining or trawling¹. The use of ice onboard and boxing at sea is a measure for the state of development of the fishery.

Big coastal vessels, ranging from 30m to 40m length, have a draught up to 4.5m, and can carry up to 500 ton of fish, with 1 to 2 weeks autonomy. Usually, fish is refrigerated or iced on board. Some limited processing can take place onboard, like heading and gutting.

¹purse seining using a large fishing net that hangs vertically with floats and the top and weights at the bottom, the ends being drawn together to enclose fish as it is hauled aboard

trawling using a large wide-mouthed fishing net dragged along the bottom of the sea
High-sea vessels, ranging in length from 25m to 80m, have up to about 3,000 ton fish hold capacity and an approximately 1 month autonomy. Fish is iced, refrigerated, frozen or processed on board. Tuna vessels fall in this group.

Factory ships have tonnages and draughts similar to smaller commercial vessels, and are often supplied with fish by smaller vessels. Generally, these ships utilize commercial port facilities, since the investment necessary for accommodating them in a fishery port is economically unattractive.

The dimensions of fishing vessels and, particularly, the relations between the dimensions vary according to vessel types, climatic and sea conditions, construction materials and local traditions. Figure 2, therefore, gives only the approximate relations between beam \([B]\), depth \([D]\) and length overall \([LOA]\) of the vessels.

The graph has been drawn as an average for trawlers and purse seiners. For these types of vessels, the depth is generally 0.5 times the beam. For longliners -and other angling boats- the beam should be decreased by 10% and the depth should be decreased by 20%.

The gross tonnage \([GT]\) is commonly used to classify fishing vessels for administrative purposes. However, the method of the tonnage measurement differs considerably from country to country. \(2.83m^3\) (100 cubic feet) of enclosed space is considered as 1 gross ton. One method of calculating the gross tonnage is based on the cubic number of a vessel, which is the product of length, beam and depth. This method necessitates the introduction of a block coefficient \([C]\) to take the streamline of the vessel into account. This block coefficient ranges from 0.5 to 0.65 for the smaller fishing vessels when the cubic number of the vessel is based on length overall. The gross tonnage then ranges from 0.18 to 0.23 times the cubic number.

As a first approximation, the following formula can be used:

\[
GT = 0.2 \times LOA \times B \times D
\]

Figure 3 gives the average cubic number for trawlers and purse seiners.

The fish hold capacity of the various types of fishing vessels varies so greatly, that not even average figures can be given, but only average maximum and average minimum values. Figure 3 gives these averages for purse seiners and trawlers.
Figure 3  Cubic number and fish hold capacity of fishing vessels

5. PORT PLANNING

5.1 Access channels

Width
Access channels should have a width in accordance with the required number of lanes. Figure 4 gives an idea of the required width. Approach conditions to the port should be taken into account, regarding wave action, currents and wind and extra margins near hard obstacles like breakwaters. The channel width is also influenced by the ease and the accuracy with which a navigator can determine his vessel's position with respect to the centre line. As such, the width is effected by factors like the horizontal movement of channel marker buoys due to tidal and other currents.

Figure 4  Channel width
An overall minimum value for the channel width would be about 30m to 40m, applicable to small indigenous vessels and favourable nautical conditions. However, usually widths vary from 90m to 200m. For an outer channel for two-way traffic, as a rule of thumb, the minimum width is about 10 times the beam of the maximum size vessel. For an inner channel, 8 times the beam of the maximum size vessel will do.

**Depth**
The minimum depth of an entrance channel is determined by the following factors:
* maximum draught of the maximum size vessel
* ship motions due to waves
* variations in waterlevels due to tides and wind
* sinkage of the vessel due to squat
* minimum keel clearance
* channel bottom topography
* character of the bottom material (also of importance for side slope)

No rules of thumb can be given, as particularly the wave response may vary greatly from one case to another. Reference is made to the relevant lecture paper.

### 5.2 Basins and berths

#### 5.2.1 Basin width
The basin width should be sufficient for easy manoeuvring and turning around of the biggest vessels, while others are moored to the quays. This signifies that for a maximum ship size of 30m, the basin width should measure approximately 160m to 170m, i.e. 5L to 6L.

The basin should provide unloading, resting, mooring, manoeuvring and servicing areas for the vessels.

#### 5.2.2 Acceptable wave action at the berths
Acceptable wave action at the berths depends on height and period of waves, and whether vessels are berthed parallel or perpendicular to penetrating waves. For periods under about 6s, small coastal vessels can be unloaded with a significant wave height $H_s$ up to 0.3m when berthed perpendicular to approaching wave crests, or about 0.15m when berthed parallel.

Bigger vessels can be unloaded and serviced up to about $H_s = 0.5m$ and $H_s = 0.25m$ respectively, for abovementioned wave approach directions. For the latter vessels and wave periods over about 6s, an $H_s$ up to 0.3m and 0.15m for perpendicular and parallel berthing respectively, is acceptable.

Acceptable wave heights are given for normal unloading procedures with a small crane or derrick, and are not valid for special unloading devices.

#### 5.2.3 Berthing arrangements
Berthing can take place:
* **Parallel** to the quay (figure 5)
  This is advantageous for unloading, since fish can move directly from the vessel into the terminal. Consequently, high unloading speeds can be attained, but the required quaylength is large. Along such a 'marginal' pier, services like fuel, water and ice, are usually only provided over part of its length. However, for bigger fishing vessels which generally make only a brief stop for unloading, refuelling and crew change, services should be available over the full length of quay.
Oblique berthing (figure 6)
This reduces required quaylength and can be advantageous, provided that there is only little variation in the size of the vessels, in case of a 'saw tooth' quay shape. In case of a straight quay, vessel size variation is not so important a factor.

Perpendicular to the quay (figure 7)
Berthing can take place either head-on or stern-on. Required quaylength is considerably reduced. This type of berthing, however, virtually limits the unloading possibilities to manual operations.
5.2.4 Required quaylength

Factors, influencing the required quaylength for unloading, are:
- the number of vessels, based at the port
- the quaylength required per vessel while berthing, which depends on the berthing arrangement
- the time that vessels spent unloading in relation to the time spent resting and at sea (fishing cycle periods)
- the influence of fishing seasons and peak periods (fishing vessels normally operate between 150 and 240 days per year)
- non home-based vessels, using the port
- the accumulation of boats inside the port, e.g. before national holidays

It is hardly possible to set up a calculation system which is valid for all types of situations, keeping in mind the many factors involved. If the behaviour pattern is reasonably predictable, average values can be used, and an irregularity factor can be introduced to compensate for the essentially stochastic character of the different parameters. If sufficient statistical data are available, or if an intelligent guess can be made of the different probability density distributions, quaylength can be optimized with the aid of a logistic simulation model.
A first estimate of the required unloading quaylength can be made with the following formula:

\[ L = Q (l + s) f_1 / r.h \]

where:
- \( L \) = quaylength
- \( Q \) = total peak daily discharge in the ports
- \( r \) = main unloading rate per vessel per hour
- \( h \) = number of unloading hours in a day
- \( l \) = main vessel length
- \( s \) = space between vessels
- \( f_1 \) = irregularity factor for the vessels (between 1 and 2)

Resting quay or jetty length, as an alternative to mooring for unloading, can be estimated with the following formulae:

\[ L_b = N_b (l + s) / R \]

where:
- \( L_b \) = required berthing quaylength for resting of vessels
- \( R \) = number of vessels abreast (2-3)
- \( N_b \) = number of vessels at rest = \( N_h (d_r + d_u) / c \) \( f_2 \)
- \( N_h \) = total number of vessels
- \( d_r \) = resting days in a cycle
- \( d_u \) = unloading days in a cycle
- \( c \) = number of days comprising a fishing cycle
- \( f_2 \) = irregularity factor

In case of the resting quay, flexibility can be found in berthing vessels more than 2 or 3 abreast. In special situations, it is possible to berth up to 6 abreast, which gives a considerable increase in capacity (figure 9).

Figure 9 Beam-on at fingerpiers
5.2.5 Quay apron width
Considerations for determining the width of the unloading quay, are the following:
* Exposure of the fish to rain or sunshine should be as short as possible.
* If operations are mechanized, the passage of, e.g., service trucks should not be hampered too much.
* When mobile transport equipment such as forklift trucks or lorries are used, adequate space should be available for turning and passing.
* When transport is mainly perpendicular to the quay, the required width can be less than when there is also parallel transport.

A number of these considerations are, however, contradictory among themselves. For each case, an appropriate compromise should be sought.

As a first approximation, the following values can be given for the width of a marginal quay apron:
* for manual operations, with or without help of ships gear : 1.5m - 4m
* for operations with shore-based cranes and conveyors or roller tracks: 4m - 8m
* for operations with forklift trucks and/or lorries : 8m - 20m

The width of fingerpiers can vary up to 15m. Sometimes, the reception shed is located on the fingerpier if the available land area is very restricted.

5.2.6 Quay level
Quay platform level is determined by adding tide, waveheight and construction height above waterlevel. For big tidal differences -say, 5m to 6m or more-, dock harbours may be made to facilitate unloading and to avoid high and expensive quays. However, the construction and operation of the necessary ship lock will generally only be economically justified for relatively large fishing centres (see figure 10).

5.2.7 Ship maintenance and repair
For vessel repair and maintenance, a conventional slipway or simple lifting device is usually sufficient (figure 11). Where larger vessels are involved, synchrolifts may be required. Vessels up to 250 ton can be handled by mobile straddle carrier-type ship lifts. The capacity of repair and maintenance facilities can be determined on the basis of 5 to 15 days per ship per year, depending on the efficiency of the facility and the skill of its labour force.

In tidal ports with sufficient tidal range, repair and maintenance work is sometimes carried out during low tide, whilst the vessels rest on keelblocks in front of the quay.

In addition to the hauling/lifting facilities, workshops will be required (mechanical, woodworking, electrical, electronics, etc.) as well as storage sheds to hold repair materials, e.g. timber and steel elements. A problem, especially in developing countries, is the difficulty of obtaining spareparts due to the lack of standardization in the fishing fleet, absence of a local service agency, restrictive foreign exchange policies and import limitations.
Figure 10  Boulogne-sur-Mer: Fishing port and areas reserved for the fishing industry

Figure 11  Drydocking arrangements
5.2.8 Fishflow
Fishflow through the port, as from the ship's hold, can comprise all or some of the following activities (figures 12 and 13): unloading, washing, sorting, boxing, weighing, icing, marketing, distribution, storage. It requires a good organization and a terminal lay-out enabling a smooth commodity flow.

Figure 12  Vessel cycle and fishflow

Figure 13  Fish handling procedure
5.2.9 Buildings and other facilities

Market hall or shed (figure 14)

After unloading the catch from the vessels, fish for direct human consumption is usually brought into a market hall or shed, where it is sold to merchants who take care of the onward transport and distribution of the fish. The various activities which may all or partly take place in the market hall or shed, are the following: cleaning, sorting, grading, weighing, re-icing, boxing, display, auction, packing, discharge. Facilities may further have to be provided for boxes and equipment storage, internal transport, temporary cold storage, auction room, offices, amenities, merchant stalls.

The lay-out arrangement and the total space requirements for market halls depend very much on the types and quantities of the catch, the extent of preparation before sales, the system of display, the auction system and the number of auctions, the destination of the catch and the distribution system. Depending on the above factors, the total space requirements may range from $6m^2/t$ to as high as $25m^2/t$ per auction. As first approximations, the following figures can be given:

- preparation of the catch before sales: $4m^2/t$ per auction
- display and auction, varying types and qualities: $12m^2/t$ per auction
- display and auction, uniform products: $6m^2/t$ per auction
- storage of boxes and equipment and temporary storage of products: $4m^2/t$ per auction
- offices and merchant stalls: $4m^2/t$ per auction

Figure 14 Possible lay-out of market hall
For access to the hall, lifting doors extending along both sides of the hall between structural columns, are the most flexible solution. The floor of the shed should not consist of ordinary concrete, but must, in one way or another, be provided with an anti-skid surface. In the shed, electric power and lighting and running water must be available. The water supply is often separated in a fresh- and a sea-water supply. The latter should be a high-pressure system (4 to 5 bar) for cleaning purposes. The installation of the electric wiring, receptacles and switches requires special care, because of the very wet and corrosive environment. The electric lighting should not change the natural colour of the fish.

Ice factory
In the initial port planning stages, it may not be required straight-away to plan an ice factory in detail, but it is strongly recommended to allocate a certain area of land for the establishment of such an ice factory in future. Ice is not only required for the preparation of fish on board the vessels, but it is also required for preparation of the fish for public auction and for onward transport.

There are two main types of ice factories:
* block-ice factories (blocks from 10kg to 150kg)
* small-ice factories

A characteristic difference in the lay-out of these types of factories is that block-ice factories have a horizontal transportation system, while small-ice factories usually work vertically, with the ice falling from the ice producing machine into the storage silo underneath.

Space requirements for block-ice production range from 10m$^2$ to 20m$^2$ per ton of ice per day capacity. Block-ice stowage factor is 1.4m$^3$/t. Block-ice storage requires some 1.5m$^2$/t.

Space requirements for small-ice production range from 1m$^2$ to 6m$^2$ per ton of ice per day capacity. For some types, a building height of up to 10m may be required. Small-ice stowage factor is 1.6m$^3$/t to 2.1m$^3$/t. Small-ice storage requires some 0.5m$^2$/t to 1m$^2$/t.

Cold storage
Fresh fish is mostly stored, while being iced, in a so-called 'chill room' which is cooled to a few degrees centigrade below zero. Frozen fish is stored in a frozen storage room with a temperature of -20°C. Space requirements can be estimated to range from some 0.5m$^2$/t to 1.5m$^2$/t, including access space and the relation gross building area over nett cold storage areas.

Offices, canteens, rest rooms
Space requirements depend entirely on the type of fishing port, the number of people involved in fishing operations, port management and administration.

Other facilities
These include:
* net drying and repair
* fire-fighting
* supply stores
* fuel storage
* gear sheds (maintenance and repair)
* waste and waste water treatment
* drainage
* roads and parking lots

Example lay-out
Figure 15, in addition to figure 10, gives an example of the lay-out of a fishing port, namely the port of Kalajoki in Finland.

6. UNLOADING EQUIPMENT

Sometimes, vessels use on-board equipment, but more often quay-side cranes, derricks, etc., are used for unloading. The unloading technique further depends on whether the fish arrives un-boxed or boxed. A number of unloading devices are available, such as pneumatic systems, vertical and horizontal conveyor belts, bucket elevators, pumps, etc. (see figures 16 and 17). In each case, it should be very carefully considered what is the most cost-effective equipment.
7. FISHERY PORT ORGANIZATION AND MANAGEMENT

Various organizational systems exist:
* privately owned
* autonomous port or port trust
* municipally owned
* state owned

In all instances, a port manager or port director is in charge of the proper functioning of the port. The port captain or harbour master will control all vessel movements inside the port to ensure a proper utilization of the quays as well as to ensure the nautical safety. The port engineer will deal with maintenance and repair of the structures and facilities, and will propose extensions and improvements and supervise development works. An administrator will keep a record of statistical data on landing operations and catch rates. He will also be in charge of the usual administrative functions.
Other services such as unloading, sales, ice supply, cold storage, water and power supply, waste treatment, security, fire-fighting and the provision of repair facilities may form part of the port organization's activities and, as such, require separate offices. But, it may also be that a number of these activities are dealt with by fishery organizations or private owners under the general regulations of the port authority.

In case of small ports, the organization can be reduced to a one-man administration force with some clerical and technical assistants.

8. REFERENCES

Figure 17  Unloading equipment
chapter 11.

MARINAS
## MARINAS

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1. Yachting and yachts

Yachting covers so many different aspects, that a very thorough analysis of the requirements to be met must take place before port development can be initiated. It stands to reason that the facilities to be built and the services to be put into operation are closely dependent on the specifications of the ships to accommodate and on the way they are operated. This varies according to:

* The origin of yachtsmen (local people living more or less near the harbour and using their boat during weekends or holidays, tourists staying in a resort in the port vicinity, charters, etc.).
* Their tastes (sailing, ocean cruising, yacht races, fishing, water-skiing).

Thus, the facilities to develop can fit into the pattern of the development plan of a whole maritime waterfront oriented at yachting or, conversely, they can simply complete the hotel or para-hotel trade. It cannot be overemphasized that such options should be duly considered, since the blind transfer of ‘patterns’ that were successful elsewhere, may give rise to great disappointment.

The structure of the fleet that enables to determine the lay-out and the size of berthing facilities is a factor of major importance for the preliminary survey. The diagram of figure 1 shows that, from port to port, the assumptions that have to be taken into account for the drawing up of plans vary quite a lot. The disparities would certainly be bigger if one was considering the actual frequency of ships’ visits at these very ports.

![Figure 1](image-url)

**Figure 1** Percentage of ships exceeding the given lengths
The port structure is directly connected with the characteristics and operating conditions of boats, viz.:

* The general design of the entrance fairway and its dimensions depend to a large extent, on yachts that call at the port, which hug the wind by less than 45° (at least, small-sized boats having no auxiliary engine).
* Small craft can - and often have to - be put ashore, their launching taking place on ramps or by means of forklift trucks. Weather conditions can even entail a quasi-permanent lay-up of big craft under shelter.
* Craft making cruises require, during their stops, accommodation facilities related to life afloat.
* Incorporation of maintenance and repair operations on more or less large craft, requires the development of special facilities (yards, dry-docking facilities).

Sizes of yachts are given in figures 2 and 3.

---

**Figure 2**

MOTOR BOATS

(1) width of berthing front

(2) mean width

Width of berthing front =
= breadth of the ship +
+ side clearance for fenders
2. General lay-out of the port

What a yachtsman expects from a marina, is a series of services given in a pleasant environment:
* adequate shelter from high seas
* docking services: periodical maintenance of his boat at reasonable prices and without undue waiting
* mooring and watching of ships
* seasonal storage ashore of small ships in open yards or in sheds
* parking for yachtsmen's cars
* quick execution of incidental repairs
* marketing of new and used boats
* administrative or private services (harbour master's office, weather forecasts, customs, clubs, medical needs, etc.)

The choice of a site for a marina, if not dictated by existing facilities which have to be integrated in the new project, should result from maritime and nautical considerations, with a view to simplifying the nature of the works to be carried out, and to lowering the cost. It should also depend on environmental considerations in accordance with rules, standards and regulations that locally apply. Lastly, the integration of the port into all other developments in progress or being planned ashore, has to be ensured.
For masterplanning purposes, the most important factor usually concerns wave conditions. Along open coasts, marinas must generally be protected by gravity-type breakwaters. In more protected areas, other systems can be considered, e.g. floating breakwaters, though the greatest care has still to be taken in this field.

Ports often comprise an outer harbour in which waves are still somewhat rough, and an inner harbour -better sheltered- in which the actual berths are located. When the tidal range is small, the inner harbour can be designed to provide a sufficient depth of water to keep boats afloat at all times. When the tidal range is big, it is often accepted that the berths fall dry at LW. If not, a relatively expensive shipping lock has to be provided.

Access conditions to the harbour have to be carefully considered. The lay-out, of course, will have to ensure an adequate protection of the entrance channel against wave action and against siltation.

Furthermore, the lay-out should be such that sailing ships can enter or leave the port without systematically putting the engine on, which implies that channels shall be wide enough to tack, whenever needed. Moreover, ships' movements must be able to continue without undue problems, even during rush hours.

The above implies that the entrance channel must be properly oriented, and should have a width of 40m or more.

3. Basins and berths

In port zoning or basin designation, distinction is usually made between:
* basins in ports of call that do not require large back-up areas (no car park), and around which the harbour master’s office, administrative offices (customs, border police, weather forecasts, etc.) and different service facilities (lavatories, showers, information, post office) are set up.
* basins assigned to yachts registered at the port, surrounded with big car parks.
* basins for maintenance which, in addition to floating repair berths, comprise lifting equipment and a general technical area, including yards for boats to be dry-docked, workshops and laying-up sheds.

The size of the basins, or zones, will have to be determined according to the particular requirements of the port. As a first estimate, their total area can be taken as equal to 80\(\times\) the total capacity of the port, in terms of number of yachts that can be accommodated:

\[
S(\text{m}^2) = 80C
\]

Mooring facilities are oriented in such a way, that ships will be moored in the eye of the prevailing wind.

The scheme adopted for the position of the different berths, and, especially, the clearance between the piers and berths, depends on several factors that have to be carefully weighed in every case. Any port characterized by high tidal range and, consequently, by strong tidal currents, or by frequent and strong winds, will require larger manoeuvring areas in-between piers (and shorter piers) than a sheltered port at which the tidal range is small.

Figure 4 shows the spacing E [in m] between piers and the gross water surface W [in m\(^2\)] used per boat with respect to its length L, when the most favourable conditions of current and wind prevail. Figure 5 shows an example of the lay-out of a large marina.

The size of car parks to be developed, depends mainly on the kind of utilization of the boats accommodated in the harbour. The number of vehicles to park can range from a few units to twice (or even 2.5 times) the number of boats laying in the harbour. Taking into account the high cost and all environmental inconveniences of car parks at the seaside, the trend is towards minimizing facilities in the port and transfer of the parking lots to inland locations. Boats carried on road trailers have to be provided with ordinary launching equipment (usually a ramp, at least when the tidal range is not too big) and close to a vast parking lot for boats and, if need be, for cars. This applies, in any case, to ships laid-up ashore.
pier without catwalks
boats moored forward

\[ W = \frac{E + p}{2} (b + 1) \] or \[ E = 4L \]

thus \[ W = \frac{1}{2} (4L + p)(b + 1) \]

---

pier without catwalks
boats moored at piles

\[ E = 3.5L + 2 \]

\[ W = \frac{1}{2} (3.5L + p + 2)(b + 1) \]

---

piers with catwalks
2 boats per catwalk

\[ E = 3.5L \]

\[ W = \frac{1}{4} (3.5L + p)(2b + f + 0.5) \]

---

piers with catwalks
4 berths per catwalk

\[ E = 5.5L + 5 \]

\[ W = \frac{1}{8} (5.5L + p + 5)(3b + f + 1) \]

Figure 4a-b-c-d

---

Lay-out marina Lake Michigan [source ref 1]
4. Port structures

Jetties and breakwaters generally represent a big share of the total cost of the marina. Thus, they deserve a thorough design effort.

The breakwaters should be designed to prevent wave overtopping—at least, when there is no outer harbour, since pleasure craft riding at anchor can only bear very small waves (amplitudes of 30cm, at the utmost, with respect to the comfort of people living afloat, or 60cm with respect to safe mooring). Such requirements entail high crest levels for breakwaters, but which cannot be acceptable in some cases. Environmental considerations can, indeed, require that, e.g., the breakwaters do not screen the landscape and horizon for people walking around the port area. One is, therefore, led to lower the crest of the breakwater through such means as a seaside berm, a spilling basin or a very flat slope. The most commonly used types are rubble-mound breakwaters. However, vertical or composite breakwaters are sometimes used in deeper waters.

Quays and stationary jetties are only found in marinas in which the tidal range is low (less than 1.50m), for the level of the boat deck must stay close to that of the berthing facility to facilitate embarkation and disembarkation. The design should take into account vertical loads of 400kg/m² and horizontal loads due to wind forces on the berth and on the boats, and due to berthing impacts.

The wind force may be assessed from the formula:

\[ F = \frac{V^2}{1.63} \]

in which \( F \) (wind dynamic pressure) is expressed in N/m², and \( V \) (wind speed) in m/s. This pressure applies to the above water part of the berth and to ships. We often find pressures of 1,000N per linear metre of mooring front.

Floating berths are often used, even in tideless waters, because of their low cost. They need well-sheltered marinas and can hardly receive boats more than 15m long.
REFERENCES


chapter 12.

PORTS AND TERMINALS
FOR INLAND WATER TRANSPORT

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# PORTS AND TERMINALS
## for
### INLAND WATER TRANSPORT

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PORTS AND Terminals
for
INLAND WATER TRANSPORT

1. Location and lay-out of IWT ports

An inland water transport port can vary in scope from a sophisticated multiple basin complex with up-to-date handling equipment, to a one-berth terminal on the bank of a river where, now and then, some goods and/or passengers are transhipped. But, a commercial IWT port always is an inter-modal node of land-based and water-borne transport.

In addition to the commercial ports, one can distinguish along rivers and canals:
* harbours of refuge, providing shelter to ships during floods or ice drift
* night stop ports, where ships without night navigation aids may lay overnight
* service harbours for contractors' equipment, survey launches, etc.

But, this paper will be restricted to a discussion of commercial ports. Among these commercial ports can be distinguished:
* The general-purpose port which is a multi-user interface between IWT and other modes of transport (road, rail) and which, generally, offers storage facilities.
* The dedicated container or other port terminal, sometimes multi-user, sometimes single-user.
* The industrial port which is, in general, the end of the line of IWT, and directly unloads raw materials and loads (half-)finished products.

2. The vessels

2.1 General

The type and size of vessels used for inland navigation varies widely from one region or river basin to another, and is often the result of historic developments and of specific local conditions as available waterdepth, current velocities, type and volume of the commodities to be carried and degree of technoeconomic development. On rivers, coastal canals and 'backwaters' in India, one can still observe a multitude of small wooden ships with sail-assisted human propulsion [the so-called 'country craft'], next to motorized barges. Wooden canoes cut from a single tree and either punted or provided with an outboard engine, depending on the affluence of the owner, may be found from Surinam to Kalimantan and from Thailand to Ecuador. They all play an essential role in the local transport of goods and passengers.

At the other end of the line are the huge push-barge convoys, carrying up to 50,000 tons, travelling up and down the Mississippi river in the USA, and the sea-going vessels plying up the Amazon as far as Iquitos in Peru.

2.2 The european scene

In Europe, self-propelled vessels and barges for push-tows have been standardized and divided in classes which correspond with waterways with a given minimum waterdepth and width. The classification has been recently modified; the new version is given in figure 1.

Nowadays, the self-propelled vessels form the majority of the craft plying the european waterways. Occasionally, they can be seen pushing or side-towing a dumbbarge to increase their carrying capacity.

At present, a number of cargo vessels are being converted, and new ships are being built, to carry containers which, at long last, have found their way in numbers to waterborne transport. This is not surprising as, except for the short distances, IWT is quite competitive. From Rotterdam to the middle Rhine area, the current tariff is about DfL 280/TEU for loaded containers, and DfL 170 for empties, exclusive of handling charges at the terminals (about DfL 70 at the IWT terminal, and DfL 120 at the sea
<table>
<thead>
<tr>
<th>Type des voies navigables</th>
<th>Classe de voies navigables</th>
<th>Autonomie et circulation</th>
<th>Conteneurs poussés</th>
<th>Hauteur minimum sous les ponts</th>
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<th>Type de bateau : caractéristiques générales</th>
<th>Type de conveyeur - Caractéristiques générales</th>
<th>Minimum height under bridges</th>
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<tbody>
<tr>
<td>Dénomination Designation</td>
<td>Longueur Length</td>
<td>Largeur Beam</td>
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<tr>
<td>----------------------------</td>
<td>-----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>I</td>
<td>Pé实质 Beige</td>
<td>38.50</td>
</tr>
<tr>
<td>II</td>
<td>Kam-Campana Campion-Beige</td>
<td>50.55</td>
</tr>
<tr>
<td>III</td>
<td>Gustave Koenigs</td>
<td>67.80</td>
</tr>
<tr>
<td>I</td>
<td>Grosse Flasne</td>
<td>41</td>
</tr>
<tr>
<td>II</td>
<td>Bassa Motorowa 500</td>
<td>57</td>
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<tr>
<td>III</td>
<td>67.70</td>
<td>8.20-9.00</td>
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<td>IV</td>
<td>Johann Walker</td>
<td>80.85</td>
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<tr>
<td>V a</td>
<td>Grande Rhône  Large Rhone Vessels</td>
<td>93-110</td>
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<tr>
<td>V b</td>
<td>172-183</td>
<td>11.40</td>
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<tr>
<td>VI a</td>
<td>95-110</td>
<td>22.80</td>
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<tr>
<td>VI b</td>
<td>140</td>
<td>15.00</td>
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<tr>
<td>VI c</td>
<td>270-280</td>
<td>22.80</td>
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<tr>
<td>VII</td>
<td>285</td>
<td>31.00</td>
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</table>
Eventually, roll-on/roll-off carriers for trailers, as used on the Danube, may find their way on the Rhine to relieve road congestions on the long hauls. Quite common are already the heavy-load ro/ro barges, specially designed to transport odd-sized equipment for powerplants, chemical industries and offshore platforms.

There is a big fleet of tankers ranging in size from 300 tons till over 3,000 tons, plying all the navigable waterways. Since the first inland tanker was constructed in 1903, their technical outfit has been gradually improved and adapted to the various POL\(^1\) products, of which the safety requirements form an important aspect.

The majority of the tanker fleet consists of self-propelled vessels, occasionally pushing a tank dumbbarge. Other more specialized tankers carry chemical products and liquid gases, and are provided with extensive and expensive safety devices. But, skill and knowledge of crew and operators form the basic ingredients for a safe transportation and handling of dangerous products.

Traditionally, the coasters used to penetrate deep inland with their overseas cargo. However, their manoeuvring characteristics are not exactly what is required for navigation in confined and shallow waters. Often, a dangerous situation or accident occurred when coasters merged into the inland traffic. Nowadays, the ‘Rhine coaster’, a new type of sea-river vessel, is growing popular for this purpose of linking inland ports with overseas destinations without transhipment. Based on the lines of modern inland vessels and adapted to sea-going requirements, they operate successfully and safely.

Push-barges have grown in size from 1,200 tons at 3.00m draught till 2,700 tons at 4.00m draught by increasing length as well as beam. Consequently, the tow sizes grew from 5,000 tons in a four-barge convoy till over 10,000 tons. Nowadays, the maximum size convoy on the Rhine consists of 6 barges, carrying 15,000 tons and needing all of the 6,000hp installed in fourth-generation pushers. These 6-barge push-tows were formally accepted after a long period of tests and trials in the seventies and early eighties.

In 25 years, the installed push-boat power has dramatically risen from the initial 1,200hp on 2 screws till the said 6,000hp on 3 propellers. However, the rising fuel prices have somewhat dampened the ideas of this unrestricted expansion. Often, it can be noticed that big pushers sail at lower than normal cruising speed with throttled power.

In the present conditions, the 4,500hp pusher may turn out to be the optimum size, considering also the economic speed in restricted water. A draught of 2.4m (pusher) is more or less the maximum for year-round commercial navigation in the Rhine catchment area.

Self-propelled cargo vessels have grown substantially as well, carrying up to 4,000 tons. Whereas the principally private owners of these vessels did not dare to think of ships bigger than 1,300 tons some time ago, they now have also fallen for the economy of scale. Still, a great number of the 300 tons ‘Penishe’ class vessels are in operation, and all sizes in between.

Passenger vessels have shown a remarkable development as well, but on the Rhine these vessels are commercially operated in the summer season only.

All of the IWT fleet makes use of the available waterway infrastructure of which, in average, the cost per tanker is quite low compared to other modes of transport; see the table below:

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\(^1\)Petroleum Oil Lubricants; in general: oil products.
### 3. TYPES OF PORTS

#### 3.1 Open river ports

Open ports on rivers with a confined flood plain may be located either in that flood plain, i.e. in between the river and the HW dike, or beyond the flood plain outside the dike.

If inside the HW dike (figure 2):
- To keep quays dry, the area must be reclaimed above HW. This may obstruct the river discharge during floods.
- The entrance channel will also disturb HW current patterns, and ships will be hindered by cross-currents when entering or leaving the port basin.

![Figure 2 Riverport and reclamation inside dike; flooded during HW; possibly flow obstruction](image)

If outside the HW dike (figure 3): The entrance channel cuts through the dike, so the port must be enclosed by new dikes and/or quays with a deck level equal to the crest level of the dikes.
Main advantages and disadvantages of open ports are:

**Advantages**
* always accessible
* full-width entrance channel available

**Disadvantages**
* variable water level
* wave disturbance from the river
* expensive berths due to water level difference
* low cargo handling efficiency due to relatively much vertical transport
* siltation
* expansion often difficult

Some open ports have a second river connection upstream (figure 4). This second connection must be closed by means of a retaining lock to avoid short-circuit currents. Advantage and disadvantages of such a system are:

**Advantages**
* flushing of basin possible
* time saving and easier manoeuving for part of the traffic

**Disadvantages**
* expensive
3.2 Closed river ports

Closed river ports are provided either with a retaining lock or a ship lock.

**River port with retaining lock** (figure 5): The retaining lock serves as an HW defence, and can be closed when the river exceeds a certain level. This closure blocks all traffic.

![Figure 5 Riverport outside dike with ship retaining lock](image)

Main advantages and disadvantages are:

**Advantages**
* less expensive berths than for open port
* easy expansion

**Disadvantages**
* periodically, vessels are locked in (including those with dangerous goods!)
* lock width limits ship size
* upgrading means new lock
* pumping required when lock is in use (seepage and leaks)
* when open, same as for open port
* construction, operation and maintenance costs of lock

An example is the port of Cuyk on the river Meuse (figure 6). The retaining lock is closed during a few days per year only. It limits ship widths to 14m.

**River port with ship lock** (figure 7): Main advantages and disadvantages are:

**Advantages**
* constant water level
* sheltered mooring (against waves from other vessels)
* minimum vertical transport of cargo
* relatively cheap berths

**Disadvantages**
* loss of time due to locking
* lock width limits ship size
* pumping needed
* in case of calamities, difficult evacuation
* construction, operation and maintenance costs of lock
* waiting berths needed for lock

An example is the port of Oss on the river Meuse (figure 8).
Retaining lock
HW dike

Figure 6 Port of Cuyk

Figure 7 Riverport outside dike with ship lock
3.3 Canal and river ports: lay-out and dimensions

Figures 9 to 20 show some examples of shapes and dimensions of IWT ports, which are self-explanatory.
Figure 9 Riverport entrance to be in line with fairway axis

Figure 10 Commercial harbour basin along canal (smallest size)

Figure 11 Commercial harbour basin along canal

Figure 12 Multiple harbour basins along canal
Figure 13 Multiple harbour basins along canal, adapted to pushtows

Figure 14 Multiple harbour basins along river

Figure 15 Training wall partition between harbour basin and canal, minimum size

Figure 16 Training wall partition between harbour basin and canal, maximum size
Figure 17 Training wall partition between harbour basin and river

Figure 18 Quaywall along widened section of canal

Figure 19 Quaywall along river

Figure 20 Triangular basin along canal
* The port entrance for river ports should preferably be oriented in an upstream direction, i.e. in such a way, that the majority of the loaded vessels can enter against the current. Occasionally, vessels may come loaded from an upstream origin; they may have to turn in the river before entering the port.

Whenever possible, river ports will be located on an outer curve of the river to benefit from available natural water depth, and to minimize siltation problems.

The angle between the river channel and the port entrance should be as small as possible, i.e. the entrance alignment should be as much as possible tangent to the channel to facilitate navigation and to ensure good visibility (see figure 9). This visibility of the port entrance from the river, as well as visibility of river traffic by vessels intending to leave the port, is of great importance for safety reasons.

If, due to local constraints, a port entrance has to be designed at a significant angle with the river channel, a vessel entering port will start veering when the fore-part of the ship is in more or less current-free water, whilst the aft ship still experiences the river (cross-)current. To avoid ship groundings, a local widening of the entrance will have to be made.

Port entrances should be sufficiently wide for ships to pass each other. A minimum value for European conditions is 60m. If push-tows frequently visit the port, the minimum value is 80m.

* Special provisions for barge traffic may have to be made. Of course, it is operationally the most convenient if an entire push-tow can enter the port basin, but, particularly for smaller ports, this would result in too large and expensive lay-outs. In that case, a special mooring berth has to be provided near the port entrance, where the pusher and the different barges can be disconnected. Subsequently, the barges are towed to their loading/unloading stations by a small harbour-tug. For a 4-barge push-tow, the mooring berth has to measure 225x25m.

* Depending on seasonal and stochastic fluctuations in ship arrivals in a port, the situation will arise with a certain frequency that not enough cargo handling berths are available for all ships requesting to be serviced. In this connection, waiting berths will have to be provided to moor ships safely until loading/unloading berthage has become available. A waiting berth may consist of simple dolphins and a catwalk to the shore.

* Within the port, a turning basin or turning space should be available with a diameter of, at least, 100m at full depth.

* Ships with dangerous cargo require special treatment. Since the inland water transport of mineral oil products and liquified gases increases rapidly, this issue constitutes a point of special concern for many IWT ports. Whenever possible, these vessels should be in fully current-free water in basins, exclusively reserved for these cargos and which can be easily sealed off by floating booms in case of spills or other accidents.

4. TERMINALS

4.1 IWT cargo terminals

When cargo is moved over the waterway from an inland terminal to a seaport terminal, and vice versa, or between IWT terminals, suitable provisions should be present for cargo handling, for storage and for interchange with other modes of transport. The main component at an inland terminal's infrastructure will be a quay or jetty, where vessels can safely moor at any water level, and where loading and unloading can be performed efficiently. Quays will often be used for terminals in closed river ports.

Jetties for terminals in open river ports can be either fixed or floating. A choice between the two is dependent on the method of cargo transfer that will be applied (manual or mechanized), but also on the water level variations to be expected as well as the configuration of bank or embankment at the selected site for a terminal (see also section 4.4). A fixed jetty has the advantage that it can be constructed rigidly and stable, even allowing heavy equipment and trucks to drive on it. A serious handicap is that, even with limited water level variations, the jetty platform rises high above the vessel's deck during the
low water stage. This can be met by the construction of a number of jetties for various levels, but the costs involved could easily turn the balance in favour of floating jetties.

Another disadvantage of fixed jetties is that they can seldom be moved to other and more suitable locations, when a changing configuration of the river bank or a changing transport pattern would require so. A floating jetty has the flexibility to be moved at any time, but the weak point is often the construction of a land-connecting footbridge or ramp. This is particularly so when this bridge has to span a considerable length of shallow water or mud along the bank. A floating jetty must also be secured against lateral movements, either by anchors, moorings or guide poles. Especially during high floods, the force of the current against the pontoon and a pack of vessels moored alongside, may be considerable.

4.2 Cargo handling

In developing countries, the most common way of cargo handling is, and will remain for a long time, the traditional manual handling. Apart from the fact that this is often the cheapest and most reliable method, it also serves an important social objective: employment which, in the circumstances locally prevailing, is of greater interest than handling speed or efficiency. Nevertheless, some form of mechanization, or partial mechanization, can also be observed on different terminals in the developing world.

From an engineering point of view, mechanization of cargo handling has a considerable impact on the design of an inland terminal and, especially, on the design of a jetty. The jetty is the crucial part of the process of cargo transfer from vessel to land, and vice versa. There, a substantial amount of vertical transport takes place, combined with horizontal transport over the jetty to or from truck, wagon or storage shed (figure 21).

When the cargo is handled manually, the jetty platform should preferably be level with the vessel deck, but there remains a notable vertical lift from the vessel's hold onto the deck. Some sort of lifting gear, preferably on the jetty itself, will facilitate this part of handling, and will also eliminate the problem of a jetty towering above the vessel during low water stages. This lifting gear can range from a simple (hand-operated) derrick to an electric hoist, or even a more sophisticated piece of equipment as a mobile crane. With this equipment, further mechanization is within reach when additional trucks, flatcars or forklift trucks are used for horizontal transport. But, it will require stable and not too sloping jetty platforms as well as metalled roads or railtracks for through-transport.

In case of a floating jetty, connected to the bank by a footbridge or ramp, a part of the vertical and horizontal transport can be achieved with conveyor belts, provided that, in general, the slope does not exceed 25° to 30°. The conveyor belt, being a very versatile piece of equipment for cargo handling, can also be used on a fixed jetty with large water level variations. This installation is not only perfectly suited for the transfer of bulk cargo as sand, gravel, rock and coal, but also for bags, small bundles, cartons and small crates. Bulk cargo should preferably be carried on flat-top barges, from where it can be easily shovelled onto the conveyor belt.

Other methods of mechanized cargo handling include the use of overhead ropeway systems, cable-suspended drag buckets, various types of grab or continuous barge unloaders, and the like, which are usually designed for applications in industrial ports or terminals.

IWT container terminals require one or more container cranes with a lifting capacity of about 40 tons. Since the beam of IWT vessels or barges is less than that of sea-going container ships, the crane’s outreach from the quay edge can be appreciable less than that of cranes of deep-sea terminals. Also, the trolley and hoisting speeds are mostly lower, resulting in lower investment cost. Nevertheless, a capital outlay of some Dfl 3 million, or over, is still a big investment in IWT terms.
Figure 21

(a) Jetties in tidal reaches for manual cargo handling

(b) Fixed jetties with a cargo handling derrick or crane

(c) Conveyor belt, used on a floating jetty

(d) Conveyor belt, used on a fixed jetty

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4.3 Storage

At the landside of a terminal, ample room for storage sheds should be provided as close as possible to the terminal jetty. For calculation of area requirements, reference is made to the lecture paper on 'General Cargo Terminals'. Whereas the shed floor, if possible, is level with the jetty platform, this shed floor should be about 1m above the roadway at the bankside to facilitate loading of trucks and wagons in case of manual cargo handling.

Many commodities can be stored in the open, when the risk of pilferage is limited and when the commodities are not sensitive to rain. Also in the dry period, when in tropical countries the majority of the cargo will be transported, sheltered storage need not be necessary for many commodities. For this reason, ample open-air storage space for bulk commodities, but also for stacks of bags or crates, should also be provided.

4.4 IWT jetties on rivers with a large seasonal hydrograph

The considerable investments in the construction of a terminal capable of coping with large water level differences must be justified by the throughput. As long as that throughput is not guaranteed, the investments should be kept to a minimum. Often, a shore connection with planks on floats, e.g. empty drums, will allow loading and unloading with a local workforce. But, when the cargo flow is growing, a more permanent facility will be needed. Once a feasibility study shows that the investment in a jetty is justified, the design of a jetty adapted to the local conditions can start.

Figure 22 shows a schematic shore cross-section and a hydrograph.

![Hydrograph](hydrograph.png)

**Figure 22** Translation of HHW and LLW in adapted jetties

It seems logical to design one jetty for HHW and one for LLW, and, if desired, one -or more- in between. But, in practice it is often not done so for the following reasons:

* For an appreciable period of time, the water level is in a zone where the lowest jetty is too low and the middle one too high.
* HHW is exceptional and lasts for a short period only (e.g. 1 week every 10 years) and, therefore, does not justify the investment in a jetty. Furthermore, during such exceptional high levels, the current will reduce shipping to a minimum, and road and/or rail connections are probably flooded.
* During the period that a jetty is flooded, but not yet enough to float a barge over it, the terminal is hard -if not impossible- to use (figure 23). The water levels, projected on the hydrograph, demonstrate that this situation can last for several months per year.
* Even when the three, or more, jetties are constructed staggered along the shore, the solution is not attractive because the lowest jetty is used more than twice as long as the others combined, and, therefore, should attract more than half of the investment.
In general, a floating jetty is the cheapest solution (figures 24 and 25). It allows trucks to come near the barge and, thus, reduce carrying distance for the dock labour. The road should not be constructed too steep (maximum 1:15) to allow a loaded truck to negotiate it without undue effort. Along the road, rails or channel irons should facilitate movement of the connecting bridge or ramp when it has to be raised or lowered. The ramp must be connected to the pontoon with solid hinges. This allows the use of the anchor and mooring winches of the pontoon to move the ramp. If required, a winch near the top of the slope may be needed to help pull the ramp upward.

Bollards or mooring rings should be installed along the slope for fixing strong mooring wires. The anchors should be provided with enough shackles of heavy chain to resist current and mooring forces. An additional advantage of this kind of jetty is the possibility to move the floating part to another site once the terminal becomes obsolete.

Some examples are given in figures 26 to 28. Figures 26 and 27 show terminal facilities in Bangladesh for relatively low water level fluctuations in the lower reaches of the Brahmaputra/Ganga river system. Figure 28 shows port facilities at Iquitos on the Amazon in Peru, designed for a water level difference of 10.60m. Certain navigable river stretches in China sustain level fluctuations of as much 30m for which it becomes quite difficult to design good terminal facilities.
Figure 25  River terminal cross-section AA

Figure 26  Barisal, design of floating launch station with anchors  [source ref 13]
Figure 27  Floating landing stage moored to dolphins  [source ref 13]
Figure 28 Port of Iquitos on the Amazon river, Peru: general lay-out and typical cross-sections [source ref 14]

1 — location of an old dock
2 — part of an old dock incorporated into the new pier
3 — new pier
4 — access bridge
5 — bridge support pontoon
6 — ramp between bridge and pier
7 — ramp between two parts of a new pier
8 — inshore mooring cables
9 — bridge keeping prestressed cables
10 — depressed inshore mooring cables
11 — offshore mooring cables
12 — anchors
13 — land-based piled deadmen
14 — winch
15 — upstream floating log
16 — downstream navigational aids
17 — concrete block
18 — slope protection
4.5 Design criteria for a simple IWT canal berth

For a simple fixed berth along a canal, some design rules have been developed in the Netherlands. First of all, it is stated that such berths should not be situated along canals with busy traffic, because it hampers the throughput capacity of the canal itself: at the terminal, all passing ships must temporarily slow down to prevent breaking mooring ropes, etc. (traffic rule). The minimum dimensions are presented in figure 29, from which it is clear that the berthed ship remains entirely out of the canal cross-profile.

![Figure 29 Main dimensions of terminal along canal](image)

A berth may be a quaywall, a fixed jetty or a floating jetty. Whatever it is, the structure must be capable to carry the vertical loads of cargo, trucks, people, cranes, etc. (see figure 30). In addition, it must withstand the horizontal loads.

![Figure 30 Design loads for quaywalls](image)

The indicated forces may fluctuate considerably, so a thorough analysis is needed. Particular attention should be given to sudden change of the water pressure caused by passing ships.

Ship impacts may be considerable, e.g. in case of a failing manoeuvre (kinetic energy to be absorbed). In this respect, a very subjective criterion plays a role, namely how rough a berthing manoeuvre is still
considered 'normal' or 'acceptable'. For quaywall designs, the concentrated design load (acting on 0.5m$^2$) is taken as shown in figure 31.

![Figure 31 Design load on quaywalls and bollards](image)

The given values of design loads on quaywalls and bollards apply to stiff structures (sheetpile walls). If a good flexible fendering is provided, the impact loads will decrease. One should check if a design load for the quaywall can really be exerted, considering the design ship's own strength.

Bollards should be situated near the quay or jetty edge, so that a deckhand can put a mooring line directly over the bollard when the ship approaches the berth. The design load depends on the mooring lines on board of the ships. The rule of thumb for the mooring forces is the same as for the aforementioned collision loads; so, for inland vessels about 10 to 30 tons. These forces may act both in a longitudinal and a lateral direction. Spacing between bollards should be about 10 to 30% of the design ship length (figure 32). This will also fit for many smaller vessels. The shape and size of the bollards on the jetty are very important to prevent unnecessary wear and to avoid lines slipping over the bollard's top.

![Figure 32 Spacing of bollards](image)

Near a berth, ships will often be manoeuvring. Consequently, the risk of concentrated screw-race erosion is relatively high, and should be given due attention (figure 30). To prevent stability problems, possible sheetpiling should be given some overdepth.

The external forces acting on a jetty (figure 33) are much alike the forces on a quaywall. Special stiffening will be needed to withstand the longitudinal forces exerted by a moored ship which is affected by passing ships and/or regular flow in the canal. Attention should also be given to the risk of screw-race erosion, because it is very likely to attack the bank slope. Damages of that slope may not be noticed in time, and a serious bank slide might be the result. Repair of the slope revetment under the jetty will be very troublesome.

For a further discussion of design aspects and relevant guidelines, reference is made to ref 4.
4.6 Inland passenger terminals

Even at a pure passenger terminal, a certain amount of cargo has always to be handled, ranging from personal luggage and unaccompanied baggage to crates and barrels for local stores, depots and shops. This sort of cargo is usually light and limited in volume, and is not to be compared with regular freight movements to and from factories or with transport of agriculture products, bulk commodities and the like. Hence, the design of a passenger terminal must not be mixed with the completely different criteria applying to a cargo terminal.

Both types of terminal have in common that the jetty, or landing stage, is the most important component. For a passengers jetty, the prevailing requirement is to have a landing platform which is, more or less, level with the vessel's embarkation deck. In most cases, this will result in the choice for a floating jetty. This is certainly the case for stations where substantial seasonal level variations do occur. In most tidal areas, a fixed jetty with stepped levels may be used.

4.7 Seaport terminals for IWT vessels and lighters

Of all types of terminals, suitable for handling of inland vessels, seaport terminals will, normally, be the most expensive ones. This type often stands model for future terminals that will be built on a smaller scale, also at locations far in the hinterland. A typical lay-out is given in figure 34.

Lighterage cannot be successfully performed without a special terminal where lighters, or barges, can be loaded or unloaded in an efficient way. Such a terminal can be part of the original port complex, for instance, where shallow berths or space restrictions make the location less suitable to receive any more sea-going vessels. But, more often, a lighter terminal will be located away from the original port site, where new links with the hinterland can be created that bypass congested areas around an old port.

Similar to the seaport's IWT complex, but on a smaller scale, the lighter terminal is an intricate set-up where rail, road and water transport modes meet, and where transfer of cargo has to be performed, often complicated by intermediate storage. The throughput capacity of a lighter terminal may range from 1,000 to 2,500 tons of cargo per year per meter of quay length, depending on the type of commodities and the efficiency with which they will be handled. The above figure is based on an effective working time of 75% out of the maximum available hours per year, or $0.75 \times 24 \times 365 = 6600$ active hours.
Mechanization is the key to achieve high output per meter quay. Maintenance of equipment is important to maintain a high level of output. A well-equipped workshop, skilled mechanics and a sufficient amount of spareparts and spare moving stock (usually 25% of the total) should be available.

Figure 34 Example of the lay-out of a seaport terminal for the handling of inland barges [source ref 15]
REFERENCES


[16] PIANC, Bulletins and Congress Papers of the 4-yearly congresses, Section I, Inland Navigation.
