1

PORT PLANNING

Constantine D. Memos
National Technical University of Athens
Zografos, Greece

1.1 INTRODUCTION

Port development can refer either to the creation of a new port or to the expansion of an existing one, usually aimed at increasing its capacity or upgrading port operations. The issue of port development is examined at three different levels: national, local, and port terminal. Complete study of the above can be a complicated procedure since it presupposes a contribution by many specialists of various disciplines. The analysis laid out in the following pages derives from the discipline of a civil engineer specialized in port planning who has undertaken the task of conceiving and designing the pertinent elements, in most cases as part of an interdisciplinary team charged with the overall port development planning. In designing at the port or terminal level, aspects pertaining to the maritime aspects of ports are also dealt with. Such issues include the general layout of breakwaters and quays and the design of entrances and maneuvering areas.

1.2 PORT PLANNING AT THE NATIONAL LEVEL

1.2.1 National Port Policy

Until recently, ports in many countries have usually been developed as part of local port development programs. Such programs normally do not take into consideration the corresponding plans of other ports within the country, a factor that would have resulted in better coordination for increased national benefit. Indeed, in many cases, instead of attempting to achieve mutual complementing of aims, undue competition tends to develop between ports within the same country. In government-owned ports this situation can result in uneconomical investment of national capital in competing projects, and moreover, in loss of opportunities to attract a portion of international maritime traffic.

The competitive tendencies relate to the foreign trade of the country, foreign goods in transit, and goods being transshipped: the international flows that evidence potential for development as opposed to internal transports, which have more-or-less preset movement patterns. These trade flows can be defined as follows:

- *Foreign trade flows* relate to the exports and imports of a country, and consequently, have their origin or destination in that country.
- *Goods in transit* are those goods in international flow whose land transport leg uses the territory of the country and one of its ports.
- *Goods being transshipped,* where both origin and destination are located outside the country but both of whose transport modes are marine. Consequently, in this flow only the specific ports of the country are used, not overland transport.

The latter two flows in general make up the target of the competition between ports in a country.

Given that major ports constitute integral elements of the transport network of a country, it is evident that some sort of framework for centralized coordination of port development efforts is required at a national level. A significant service that such coordination would produce refers to determination of the most suitable ports for attracting transit or transshipment movement on a national level. This acquires particular significance nowadays, where such cargo movement is conducted mainly in containers, and the corresponding port installations are very costly.

In more general terms, the existence of a national port policy could broadly define the role of each port in a country, so that in the context of the national economy, the available funding can be employed as productively as possible. Depending on a country's development and its tendency for privatization, the allocation of roles to each port may be conducted in such a manner as to permit a large percentage of these ports to be released from national coordination and to undertake their own development.

1.2.2 Definitions of Port Functions

Today, the port has acquired its standing within the intermodal transport system by constituting a nodal point between two transport modes. In seaports, one mode concerns maritime transport; in river ports, this mode concerns river transport. The nodal linkage between two different modes of transport should be functional, permitting efficient and secure movement of passengers, cargo, and vehicles. A civil port is a passenger, cargo, or combined port depending on the traffic that it serves. In a combined part, both passengers and cargo provide a significant percentage of the traffic. Of course, specialized ports exist, such as marinas (for harboring pleasure craft), fishing ports, and naval military bases.

There are two basic methods of loading and unloading cargo to vessels. They are *lift on–lift off* (Lo-Lo), which refers to the loading and unloading method, employing either the vessel's gear or quay-side cranes, and *roll on–roll off* (Ro-Ro), which refers to the loading and unloading method conducted by horizontally moving equipment. Vessels allowing this type of loading and unloading are equipped with a loading ramp that permits the movement of cargo handling equipment and other vehicles (trucks, forklifts, straddle carriers, tractors, etc.) between quay and vessel.

At cargo ports, the type and packaging of cargo products determine the manner of loading and unloading as well as of other operations. Thus, the following basic categories of port terminals can be identified, each having varying equipment and operational features:

- *General cargo terminals.* These are terminals equipped with conventional cranes, which handle cargo in all types of packaging compatible with cranes. The packaging could be parcels, sacks, pallets, or containers. The latter should not, however, constitute a major percentage of the traffic, because otherwise a specialized container terminal would be required to improve throughput performance.
- *Container terminals.* In this case, containers are handled using special loading/unloading, transfer, and stacking equipment. They are typified by extensive yard areas for container stowage.
- *Multipurpose terminals.* These terminals combine a variety of functions in a single terminal, where containers, but also conventional general cargo or other packaged products, can be handled.
- *Ro-Ro terminals.* Here cargo is transferred within a roll on–roll off system, with loading and unloading of cargo by horizontally moving lorries, forklifts, tractors, and so on.
- *Bulk cargo terminals.* At these terminals, liquid or dry bulk cargo without packaging is handled. Usually, pumping machinery with suitable piping or grab cranes is used at these terminals.

The main quantity that may be affected by a suitably implemented national port policy lies in international cargo flow. Consequently, the initial and basic step in formulating a country's port system includes the determination of those ports that will undertake to serve the flows of foreign trade, transshipment, or transit. These flows operate more-or-less independently of one another, and thus for simplification of the analysis, may be studied individually.

The basic criteria to be considered in developing a proposition as to the roles of a country's ports may be classified into the following four groups:

1. The national and regional development policies of the country
2. The transportation infrastructure of the hinterland and its prospects
3. Existing port capacity and potential for development
4. Cargo forecasts for each port

After each of the three independent international flows has been examined, the findings should be pooled, to define the core of the country's port system. Thus, the role of each port that participates in international cargo flow will be specified and the basic cargo throughputs can be determined. Considering these throughput values, and factoring in the national flows, master plans can be drawn up for individual ports.

Apart from international cargo flow, other aspects of the overall port development study are usually examined. Although these are not of primary significance in the formulation of the core of a national port system, they do have a role in evaluation of the main subsystems and in developing the final proposal. Such aspects include:

- Special bulk cargoes, such as coal, cement, petroleum products, grains
- Industrial ports
- Shipbuilding and ship repair
- Free zones
- Coastal shipping
- Passenger movement

1.3 PORT PLANNING AT THE INDIVIDUAL PORT LEVEL

1.3.1 Port Development Planning

1.3.1.1 Port Development and Master Planning. The master plan of a port allocates the land within the port to the various uses required, describes the projects needed to implement the plan, and gives an indicative implementation scheme by development phase. These phases are related directly to the projected port traffic which has to be monitored closely. When in due course a decision is reached to proceed with implementation of a development scheme, this should be integrated smoothly with, or derive from, the master plan for the port. Therefore, it is important that a master plan exist, and drafting one should be among the primary concerns of port management. Of course, a variety of continuously varying factors have a bearing on such a plan, ranging from statistical data on port traffic to international treaties. For this reason, the plan should be revised regularly, at least every five years. Moreover, if during the design of a particular development phase the need arises for a review of the plan, this should be conducted concurrently, if possible, to ensure compatibility with the other functions and operations of the port. However, the lack of a master plan at a particular port should not delay the making of decisions for small-scale immediate improvement, although it is recommended that at the first opportunity an effort should be made to draft a master plan for the port.

1.3.1.2 Long-Term Planning. In the event that a national ports plan does not exist, the consultant should proceed with drafting a master plan, after studying the following components of long-term planning:

1. The role of the port—in particular:
   a. The servicing of its inland area as regards foreign trade
   b. The support that the port may offer to the region's commercial and industrial development
   c. The attraction of transiting and transshipment traffic
2. The responsibility of the port for the construction of both port and land works. Frequently, more than one agency becomes involved: for example, when a port area is serviced by a railroad.
3. The land use in the area and the potential for expansion of the port. It is important that there be general agreement between interested parties over the proposed expansions and land use so that the resulting master plan meets with wide acceptance.
4. The policy for financing the port development, which may be formulated on the basis of its own resources and/or through a state grant.

In general, in modern port development the basic requirement is for large expanses of land to ensure productive operation of the individual terminals. Therefore, a careful examination of point 3 assumes particular importance.

1.3.1.3 Medium-Term Planning. As stated, each port development scheme should be incorporated in the master plan and should proceed to implementation following the results of an appropriate feasibility study. The latter study should refer individually to each independent section of the overall development proposal, such as a container terminal or a bulk cargo terminal. Thus, under a positive but reduced yield from the overall proposal, the risk of concealment of a nonproductive section is avoided. The drafting of a port development plan calls for the conduct of the following special studies:

1. Analysis of the functionality of the port as regards the services offered in conjunction with capacity
2. Designs, with budgets
3. Operational design, with budget
4. Financial and financing study

In large port development projects it is customary to reexamine the organization and management of the port operating agency and to recommend organizational improvements on a small or larger scale. It is possible that many of the ports in a country do not warrant a development effort beyond maintenance of existing structures or appropriate modification, such as to serve fishing vessels or pleasure craft. Such modifications are nowadays met quite frequently, since old ports, traditionally being part of the core of their town, cannot easily incorporate large land expanses needed in modern port layouts. Also, environmental and social issues do not allow in many cases major expanses of an old port site. The requirement that the citizenship should be granted free access to the waterfront of their city is gradually being respected by more and more authorities. Nevertheless, the problem of what to do with the old port installations is a complex one, where both the needs of the local community and the benefits of the relevant port authority should be accommodated. As noted above a common trend is to change the character of a past commercial port into a marina or fishing vessels refuge. There are also examples (London, Marseille, etc.) where old ports were completely refurbished into commercial or recreational zones, some of them arousing controversial discussions among town-palnners.

Moreover, since ports interact in many ways with the surrounding township, port master planning should take into account, apart from strictly engineering issues, such aspects as social, economic, and environmental constraints and should easily fit within the relevant town and regional plans. This frequently calls for a compromise between the requirements of the port and the local authorities.

1.3.2 Principles of Port Design

1.3.2.1 Guiding Principles. If the undertaking involves the development of an existing port, before proceeding with development plans it would be prudent to make efforts to (1) increase productivity and (2) improve existing installations. Factors that contribute to increasing productivity in an existing port are improvements in loading and unloading practices, to the overall operation of the port terminals, and to modernization of cargo handling and hauling equipment. As pointed out, the expansions that may be required additionally to the improvements above should be incorporated in the master plan of the port and should be implemented within a time horizon in order to constitute productive projects according to the pertinent feasibility studies.

Particularly as regards the individual terminals within a port, the respective capacity calculations are based on different factors, depending on the nature of each terminal as follows:

1. In conventional cargo terminals, the required number of berths is determined first, to keep vessels' waiting time below a specified limit, determined by economic and other criteria.
2. In container terminals, the land area required for the unobstructed movement of cargo flow is calculated.
3. For specialized bulk cargo terminals, the cargo flow during loading and unloading

has to be calculated first, to ensure that vessels will be serviced within acceptable periods of time.

As arrival times of commercial vessels at ports cannot adhere to an exact schedule, enabling ready scheduling of requisite berthing and eliminating waiting time, to determine the number of berths a compromise is usually made between two extreme situations: on the one hand, the minimization of vessel waiting time, and on the other, the maximization of berth occupancy.

1.3.2.2 Port Costs. Two factors constitute port costs: investment cost, which does not depend on traffic, and operating cost, which does. If the cost were to be expressed per unit of cargo throughput, the relation between cost and traffic volume is depicted as in Figure 1.1. A ship's cost in port is also made up of two constituents: the cost of the vessel's waiting time and the cost of the ship while berthed. The ship's total port cost curve expressed as above is shown in Figure 1.2. The sum of the port cost and the cost of the ship in port provides a total cost, as shown in Figure 1.3.

Traffic corresponding to point *B* in Figure 1.3 is less than that at point *A*. This means that the optimum traffic volume for a port is lower when the total cost is taken into account than when either the total port cost or the total vessel cost is considered. Of course, the difference between *A* and *B* depends on vessel types, which determines the corresponding vessel cost curves.

A measure often used to describe the level of service offered to vessels is the ratio of waiting time to service time. It is generally recommended that this ratio be lower than, say, 20%, but there is a danger here of showing an improvement of service provided through a unilateral increase in service time. This is why for the purposes of evaluation, absolute values of total vessel waiting time at the port are also required.

1.3.2.3 Traffic Fluctuations. Even a proportionally small but persistent increase in the traffic of a port may very quickly cause congestion in a port lacking in reserve spaces; the congestion will cause a reduction in the productivity of serviced vessels, which aggravates the problem further. The increase in traffic may be

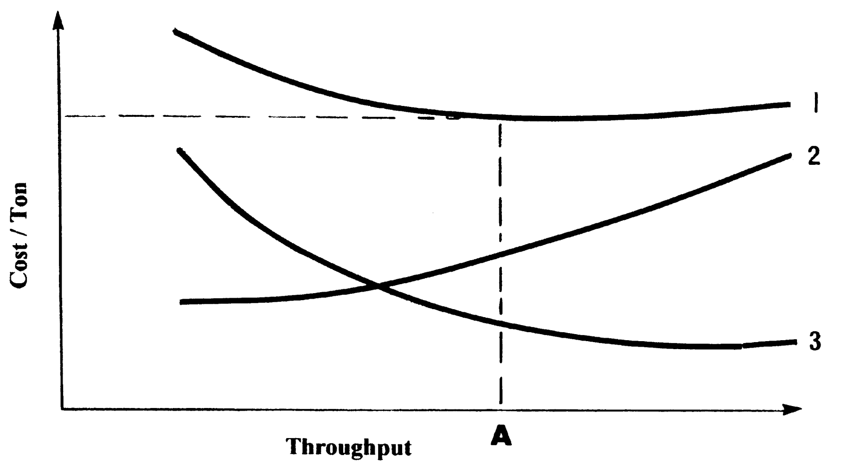


Figure 1.1 Port cost as a function of cargo throughput. 1, Port's cost; 2, cost of operation; 3, capital cost.

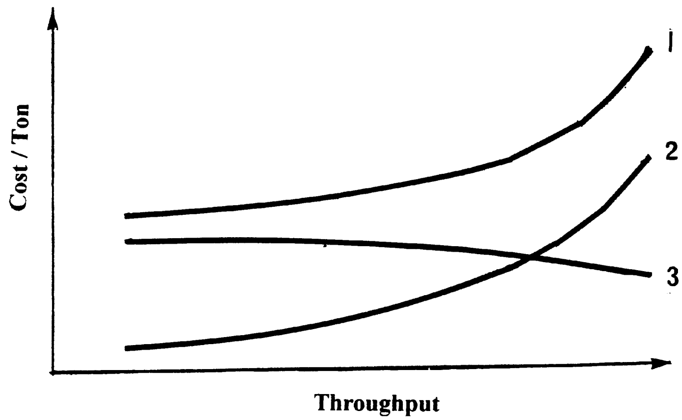


Figure 1.2 Cost of ship in port. 1, Ship cost in port; 2, cost of waiting; 3, cost of berth.

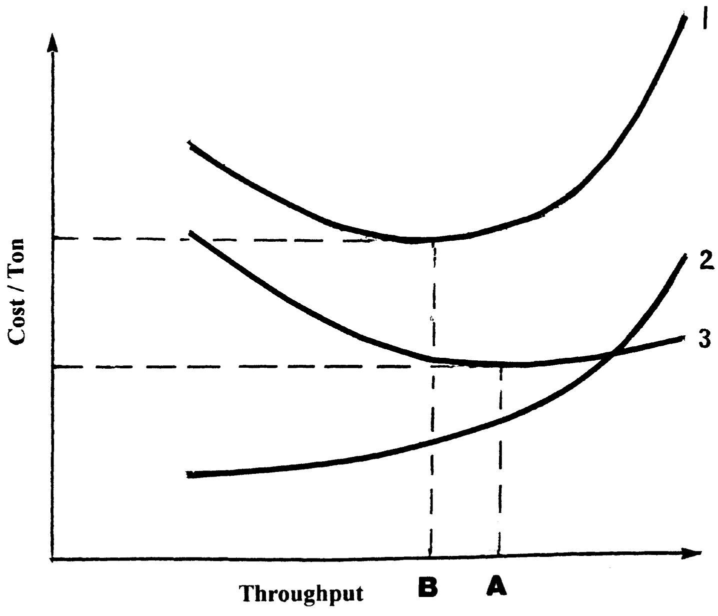


Figure 1.3 Total vessel–port cost curve. 1, Total cost; 2, cost of vessel; 3, cost of port.

caused by a new shipping line, larger cargo volumes, more frequent or occasional vessel calls, and so on. Even a change in the packing method of a product of large throughput may affect the efficiency and productivity of a port adversely. It is assumed that the problems created by a steady increase in traffic will be met in good time through the implementation of suitable development projects based on the master plan of the port.

The fluctuations around more-or-less regular average traffic may be faced by a carefully designed emergency plan according to which old quays, anchorages, and so on, on reserve, which are not used as vessel servicing positions, may be brought into operation. Usually, the reserve capacity of a port consists of inexpensive installations, which, however, give rise to a high cost of operation. These reserves should be allocated equally among all the port's sections. Other means of a temporary increase to port capacity could be an improvement in cargo handling: for example, an increase in work gangs per vessel serviced, the hiring of additional mobile cranes or other equipment, or the use of lighters for loading and discharging on two sides.

The size of the cargo to be taken for planning purposes should be selected carefully so that potential fluctuations may be absorbed with some acceptable increase in vessel waiting time. As regards high-cost installations and vessels, a method of smoothing the peaks in waiting time is that of *serving by priority,* according to which, when the vessel arrives at a predetermined time, it will have guaranteed access. The more such agreements between ports and liner operators are signed, the greater the smoothing of the traffic curve.

1.3.2.4 The Optimum State. The chief benefit from investments in port projects is the possibility if reducing total vessel time at a port. Despite the fact that ships are the first party to benefit, in the medium term both the port and the country benefit overall from the development of ports. From a practical point of view, optimization of the waiting time–quay use issue may result in a 75% occupancy factor for a group of, say, five general cargo berths, which produces a wait of half a day, for an average service time of 3.5 days. This means that over a long period of time: 55% of vessels will berth immediately, 10% of vessels will wait for 2 days, and 5% of vessels will wait for 5 days. It can be deduced from the above that the fact that some vessels experience excessive waiting times does not necessarily mean that the port is congested.

1.3.2.5 Grouping of Installations. Depending on the type of cargo traffic and on the equipment required, berthing positions and other installations are grouped in more-or-less independently operating areas of a port. This grouping implies specialization in the type of cargo traffic being served in each port section. Thus, better utilization is achieved: for example, in wharf depths and quicker servicing of vessels and cargoes. However, there are also disadvantages to grouping port installations. Basically, the flexibility obtainable by the greater number of berths is reduced. This offers a more productive exploitation of both water and land spaces.

Implementing a sort of grouping therefore should proceed when conditions are ripe: for example, when there is high traffic or when a good number of berths are required. An intermediate stage of providing a multipurpose terminal serving two (or even three) types of movement may be interposed prior to the final stage of specialized port terminal. This terminal will require cargo handling equipment capable of handling more than one type of cargo. Such equipment may be more expensive, so the servicing of vessels and of cargoes may not attain the efficiency of specialized terminals, but there is more than acceptable utilization of equipment and in general of the entire installation of a multipurpose terminal. A multipurpose terminal should retain some flexibility so that in the future it may be converted into a specialized terminal when conditions permit.

1.3.3 Cargo Volume Forecasts

1.3.3.1 Scope. Cargo volume forecasts for a port provide estimates of:

- The types and quantities of the various goods to be moved through the port

- Packing by type of cargo
- The number of vessel calls corresponding to the quantities above

If a national ports policy has been drawn up, the magnitudes above will already be known; otherwise, forecasts are made individually for the specific port under consideration. There is potentially great uncertainty in forecasts, and therefore the planning should accommodate flexibility to enable adaptation to meet future traffic. The parameters considered in cargo volume forecasts include:

- Population and national product
- Regional development programs
- The transport network and its projected future
- Coastal shipping
- Diversion of a portion of the traffic to other harbors

It is customary to hold interviews with government and local authorities, the shipping community, and interested parties to gain an understanding of the present and future traffic patterns. An independent review of global commercial and trade prospects that play a major role in traffic forecasts should also be conducted. Usually, the dependence of the results on the parameters is estimated on the basis of sensitivity control of the various calculations. Thus, in addition to the central forecast, we frequently include both an optimistic and a downside forecast, based on the corresponding growth scenario. An important port function involves monitoring the accuracy of the forecasts by comparing them with actual traffic.

1.3.3.2 Cargo Flow Combination. Usually, forecasts of significant cargo flows are conducted by type of cargo and by route. Bulk cargoes should be distinguished by type of cargo; container and Ro-Ro cargoes are distinguished by type of vessel performing the carriage. Ro-Ro cargoes may consist of (1) containers, (2) vehicles, (3) general cargo, and (4) products of intermediate unitization.

Container cargoes are calculated in 20-foot equivalent units (TEU), inclusive of empty containers. Forecasts should provide for some increase in the number of products accepting containerization. The net weight of the TEU ranges from 5 to 18 tons, depending on the stowage factor of the cargo within the container. For instance, if this factor were 2.8 m^3/ton, the net weight per TEU would amount to 10.4 tons. The results of cargo projections by cargo type and route should be reformulated by cargo category (e.g., dry bulk cargo). The total probability of a complex flow depends on the partial probabilities of the constituent flow forecasts and on the degree of their interdependence. It is advisable to analyze the flows of products with intense seasonal fluctuation separately and then to add them to the other flow forecasts.

1.3.3.3 National Transshipment. To estimate the transshipment flows either originated from or directed to a national port, and of the corresponding quays required, the alternative cargo flows between ports A and B should be examined. The latter implies that the required volume of cargo could be delivered to each port either directly, or the total volume of cargo directed to both locations will be delivered to one port only, from which it will be transshipped to the other location either by land, or by sea using smaller ships (coasters). For details, consult the proceedings of a United Nations conference (1978).

1.3.4 Port Productivity

The productivity of a port is the measure of its ability to move cargo through it within a unit of time under actual conditions. It is known that cargoes undergo various stages of handling while in port. For example, imported goods undergo the following handling procedures:

- Discharging while a vessel is berthed
- Transport to storage area and stowage
- Removal from storage and transport to area of transshipment or to means of overland transport
- Loading onto means of overland transport
- Departure from the port

Obviously, the total productivity of a port is determined by the lowest partial productivity of each link in the cargo handling chain. The conditions prevailing at the port at any given moment, such as weather conditions, human resources, and condition of machinery, affect the productivity of the partial procedures considerably. Consequently, a substantial time range representative of prevailing conditions has to be assumed for the evaluation.

The cargo handling practices pursued in each port have a decisive bearing on productivity, and any attempt at their improvement should also factor-in a period of adjustment of these practices to the new machinery and handling methods. Generally, a reference to any measure of productivity should be correlated with its corresponding time period. If this involves an extensive time period, on the order of several months, productivity may be reduced to half its value achieved in a short period of time (e.g., 1 hour). This may apply to all the particular procedures and handling of cargo flows within the port. For instance, over a short period of time, say a few hours, the container discharge efficiency at the dockside phase may amount to 750 TEU per day per berthing position, whereas over a period of several months the corresponding output for the same berth may drop to 400 TEU per day. Obviously, the long-term efficiency rate is important in the design of port installations.

Since the total efficiency of a commercial port or terminal is determined by the lowest productivity of the partial handling leg, every intervention for increased productivity should be directed initially at the least efficient procedure, with the purpose of balancing it out with handling legs of higher efficiency. The following are the most typical pairs of consecutive cargo handling legs in port cargo handling procedures:

- *Dock loading and unloading:* transport from quay to storage area, or vice versa
- *Transport from storage area to means of overland transport:* flow of means of transport to and from inland areas

An efficiency equalization between each of the constituent parts of a cargo handling pair should be achieved, measured on an hourly (or even daily) basis. Equalization should also be effected between the pairs themselves, although over a greater time period, that of a week, during which the cargoes remain in the storage areas, where the various checks and other procedures are conducted. This requirement for efficiency equalization ensures smooth functioning of the storage areas, thus averting the risk of congestion.

Efficiency increase may be achieved by intervention in three areas: (1) human resources, (2) technical matters, and (3) management and procedures. Intervention in the first area involves mainly an improvement in working conditions; in the second area, equipment renewal, better maintenance, and backup provisions; and for the third area, procedure simplification, imposition of a maximum time limit for cargo to remain at the storage areas, and so on.

It should be noted that an increase in productivity of a terminal by L % does not reduce vessel servicing time by the same percentage, but rather by $L/(1 + L)$, as is easily deduced by the definition of loading/unloading productivity at the quay (= cargo loaded or unloaded/vessel servicing time). The efficiency of a port terminal is affected by the quantity of cargo to be loaded to and unloaded from a vessel. It has been found that a large quantity of homogeneous products increases productivity, but usually this is not considered in the relevant calculations.

1.3.5 The Master Plan

1.3.5.1 Port Categories. From a construction point of view, ports may be classified into the following categories.

Artificial Ports. Artificial ports are those constructed along a shoreline by means of earth fill or excavation (Figure 1.4). In both cases these ports have to be protected from the adverse effects of waves and currents. In the former case (Figure 1.4*a*) the land part of a port is created by means of earth fill, and in the latter case (Figure 1.4*b*) the port basin is created artificially by means of excavation of land adjacent to the shoreline. The geometry of the excavated basin depends on port size and mode of operation. The excavated harbor is joined with the sea via an approach channel. The entrance to this channel is usually protected from waves and current by means of breakwaters and dikes. For more information on excavated harbors, readers are referred to Memos (1999).

Ports Constructed in a Natural Harbor. Examples are shown in Figure 1.5. Significant factors to be considered in opting for one of the foregoing types of port is availability of land, land fill material, soil quality, depth of water, environmental conditions, and others.

1.3.5.2 Port Location. Traditionally, ports are situated in a location central to the urban area they serve. The port is thus surrounded by urbanized area, and both further development of the port and access to it are rendered difficult. This situation restricts expansion of the port required to meet modern demands. In most cases, a feasibility survey for relocation of the port outside the city will have to be conducted. The prerequisites for such relocation are (1) secure maritime approaches, (2) ample availability of land area, and (3) satisfactory access by land.

For an initial new site evaluation, an extensive list of data to be collected is usually drawn up. Some of the items included are:

- Uses and ownership of the land
- Topography and access
- Existing utilities and structures at the site
- Wind and rainfall data
- Hydrographic information
- Geotechnical data, including potential sources of construction materials
- Environmental assessment of the area

During the initial site evaluation, some aspects of the project that may affect its development should be investigated. These may include necessary permissions and ownership implications, dredging and spoil disposal requirements, environmental constraints, and so on. In cases of inability to relocate, an alternative to be examined is that of establishing additional land facilities inland such as an inland depot.

1.3.5.3 Design Criteria. During the master planning stage of a project preliminary design criteria should be proposed covering aspects such as types of operations to be undertaken (e.g., containers, transit and transshipment flows, import/export; design vessel, operating equipment).

1.3.6 General Layout of Port Works

1.3.6.1 Guiding Principles. The arrangement of port works should be such as to ensure easy berthing of vessels, secure efficient cargo loading and unloading, and safe passenger embarkation and disembarkation operations. Specifically, easy access of vessels to a port should

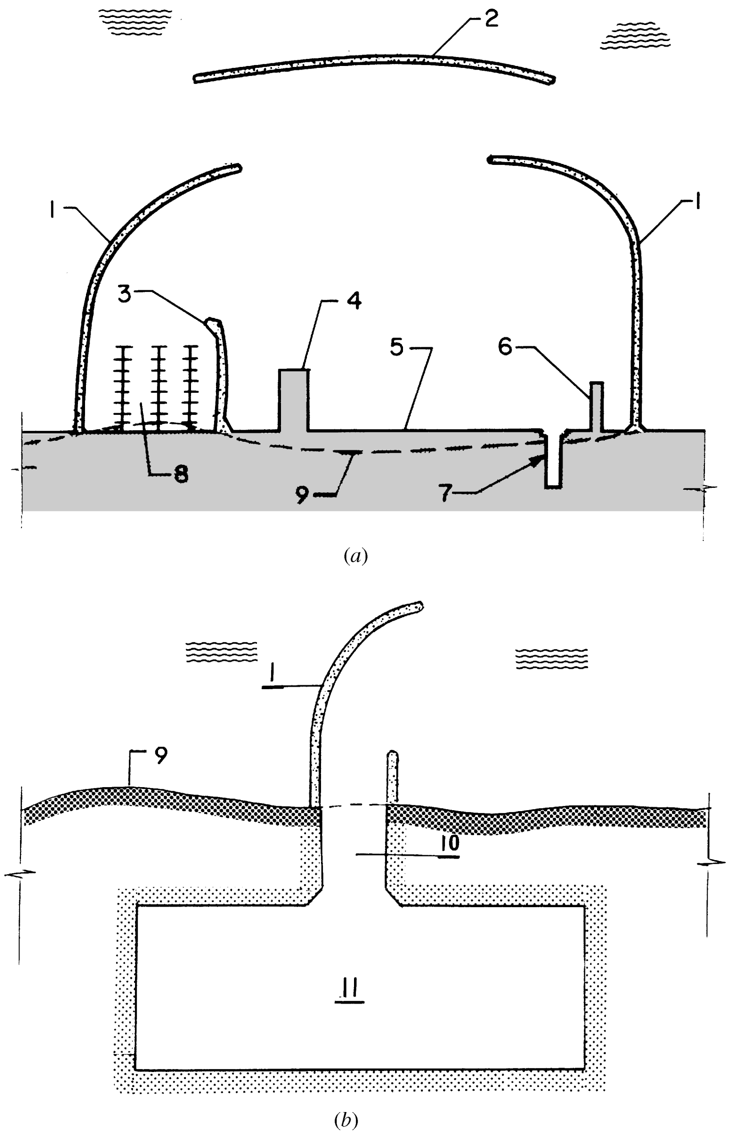
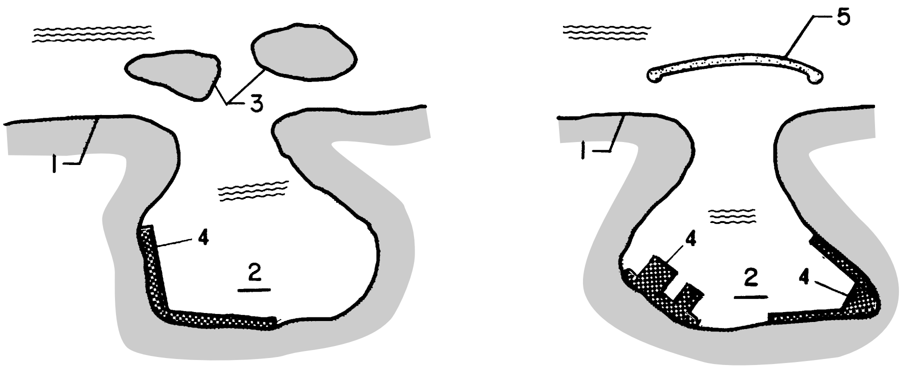


Figure 1.4 Conceptual arrangements of artificial ports: (*a*) created by earthfill; (*b*) created by excavation. 1–3, Breakwaters, 4, pier; 5, marginal wharf; 6, outfitting pier; 7, dry dock; 8, marina; 9, existing shoreline; 10, approach channel; 11, excavated basin.



(*a*) (*b*)

Figure 1.5 Ports constructed in natural harbors. (*a*) Entrance to the harbor is naturally protected by existing islands. (*b*) Entrance to the harbor is protected by the breakwater. 1, Coastal line; 2, harbor; 3, existing island; 4, port facilities; 5, breakwater.

be ensured through an appropriate navigation channel, a suitably designed port entrance, an adequate maneuvering area, and avoidance of undesirable erosion or deposition of material in and around the harbor area.

Factors to be considered in drafting a well-designed layout of port works include winds, waves, and currents and also the transportation of deposits in the study area. The existence of river or torrent mouths in the vicinity of the works has to be considered seriously in choosing the location and arrangement of the harbor.

The disturbance of harbor basins is a significant parameter, and low agitation should be achieved through a suitable arrangement of harbor structures. Specifically, the appearance of reflection and resonance phenomena within the harbor should be avoided through the use of absorbing beaches and suitable geometry of the structures that delineate it. The problem of excess wave agitation should be explored in either a physical or a mathematical model in order to arrive at an optimum layout of port works. Such models may also be used to optimize the constituent elements of the port, such as the port entrance.

Several of the subjects above may be tackled successfully by providing for an outer harbor that functions as a relief zone for the incoming waves, thus producing easier port-entry conditions. Next comes a closer examination of the most important elements that have a direct impact on the general layout of the principal port structures. For issues related to the navigation channels that serve ports, readers are referred to Chapter 10.

1.3.6.2 Port Entrance. The port entrance demands careful consideration to ensure quick and safe entry of vessels in the harbor. The orientation and width of the entrance should reconcile two opposing criteria. For reasons of comfortable navigation, the harbor entrance should communicate directly with the open sea and should be as wide as possible. On the other hand, the narrower and more protected the entrance, the smaller the degree of wave energy and deposits that penetrate the harbor basin, resulting in more favorable conditions for attaining tranquility of the in-harbor sea surface.

It is recommended that orientation of the entrance be such that vessels entering the harbor have the prevailing wind to the fore. Transverse winds and waves create difficult conditions for steering a vessel through the critical phase of entering the harbor basin, and a layout of port works that would permit frequent occurrences of such situations should be avoided.

Naturally, in most cases, the designer is obliged to compromise, as mentioned above. Obviously, the designer should avoid placing the entrance in the zone of wave breaking because of the difficulties to vessel maneuvering that may arise. Frequently, the entrance is formed by a suitable alignment of the protection works, whose structure heads are suitably marked with navigation lights. In the event that it is not possible to avoid transversal winds and waves, it is recommended that calm conditions at the harbor entrance be created by means of extending the windward breakwater to a satisfactory length beyond the entrance, at least to the length of one design vessel. In such cases it is advisable that the superstructure of the outward port structure be raised so that the wind pressures on the sides of the incoming vessel are reduced.

To attain the calmest possible conditions at the harbor entrance area, it is recommended that the external works in its vicinity be formed with sloping mounds so that wave energy in the entrance area can be absorbed. Breakwaters with a vertical front near the entrance may cause difficult navigation conditions there, because of the reflected and semistationary wavetrains created in that region. Moreover, in designing the layout of the harbor arms that bound the entrance, care should be taken that any sedimentation of deposits in the area be reduced. For significant projects, study of the entrance usually culminates in a physical model in which optimization of the arrangement is effected by conjoining all the relative requirements.

The width of the harbor entrance is defined in terms of the smallest length vertical to the entrance axis for which the minimum required draft applies. The depth at the entrance is generally determined by the maximum draft of the design vessel to be served. This figure should be taken beneath the lowest low water so that the harbor will always be accessible. In areas with a large tidal range in which the sea level can fluctuate by several meters, the question arises as to whether it is necessary to ensure accessibility to the port at all times. To meet such a requirement would signify an increase in the dredge depth equal to the range in tidal level. Alternatively, it could be accepted that the entrance be equipped with gates and that the port not be accessible during certain low-tide periods. Because such periods are foreseeable, as relying mainly on precise astronomical predictions, and because they are of relatively small duration, this solution is not to be rejected offhand, particularly if the harbor is accessible by means of long access channels. Vessels wait in the open sea up to the time when the channel is navigable for a specific vessel. Obviously, the internal harbor works of a tidal harbor will be compatible as regards drafts, with the planned navigation channel drafts suitably increased by a factor to compensate for the tidal increase during the open phase of the harbor. Thus, the vessels may always be safely afloat as long as they are in the harbor. Such a solution for periodic operation of the port entrance and channel has shortcomings, of course, because of vessel delays and other harbor malfunctions. Consequently, a careful cost–benefit analysis should be conducted prior to deciding the extent to which the port will be of free or of limited navigability. Such problems do not arise in ports with relatively small tidal fluctuations.

A safety factor of about 15% of the design vessel draft is sufficient for purposes of defining the minimum entrance depth. Alternatively, a margin of about 1.5 to 2.0 m over the draft of a loaded vessel gives a safe water depth at the port entrance. The width of a free entrance usually ranges between 100 and 250 m, depending on the size of the port. It is recommended that width be at least equal to the length of the design vessel the port is to serve. Thus, for small harbors it is possible to specify

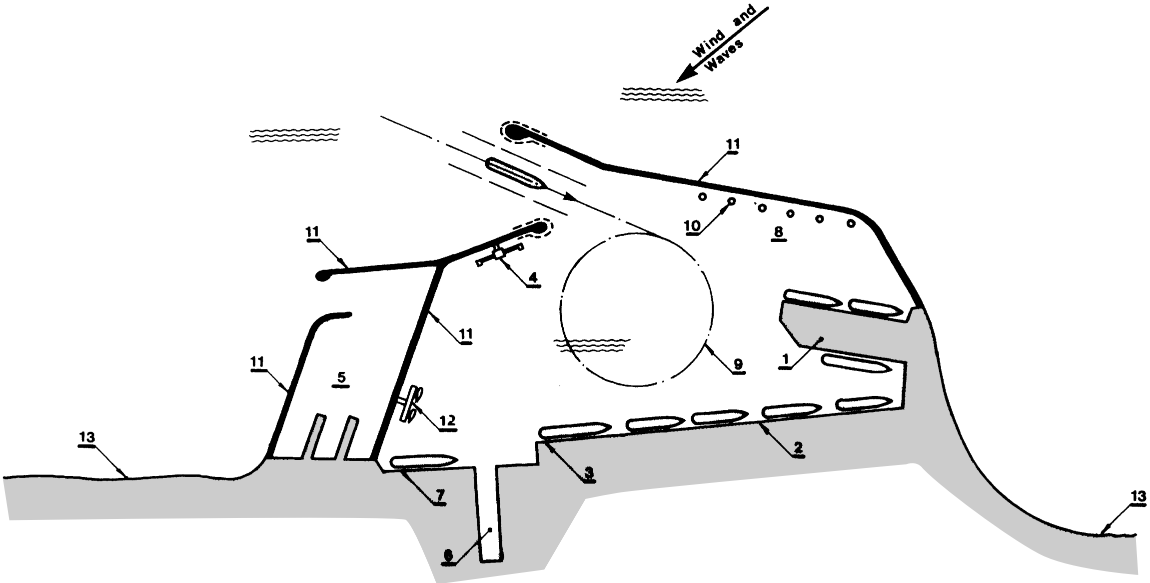


Figure 1.6 Layout of a large multipurpose artificial port. 1, General cargo terminal; 2, container terminal; 3, passenger terminal; 4, oil berth; 5, fishing port; 6, dry dock; 7, ship repair area; 8, anchorage area; 9, maneuvering circle; 10, mooring dolphins; 11, breakwater; 12, tugboat berth; 13, coastal line.

entrance width to be as low as, say, 50 m. The corresponding width of a closed port is significantly smaller than the sizes above. For more information, readers are referred to Tsinker (1997) and Chapter 9.

1.3.6.3 Maneuvering Area. When a vessel enters the harbor basin, its speed needs to be reduced to proceed with anchoring and berthing maneuvers. In practical terms, these maneuvers may be conducted at a normal speed of 8 to 11 knots over a length of 2 to $3L$, L being the vessel length, although larger distances may be required for larger vessels with modern hydrodynamic shapes. A significant consideration in determining the required length for minimizing speed is the vessel's fittings in maneuvering equipment, as well as the type of propeller; if the latter is of variable pitch, the distance can be reduced to $1.5L$. The maneuvering area is located either in the outer harbor, situated between the port entrance and the main port, or in the main harbor basin closest to the entrance.

Apart from reducing speed during an initial stage of straight movement, the vessel conducts maneuvers for positioning itself appropriately for the berthing position, which has been determined beforehand. This expanse of sea, called the *maneuvering area* or *circle,* should have dimensions calculated on the basis of the harbor's design vessel. If the port is sufficiently large, more than one maneuvering area may be designed and located at intervals of about 1 km. Figure 1.6 depicts the layout of a large artificial port with a maneuvering circle.

The diameter of the maneuvering circle required is affected directly by the type of rudders and propellers with which a vessel is equipped, whether or not tugboats will be employed, or whether anchors or wrapping dolphins will be used. For unfavorable maneuvering conditions, no tugs, and vessels with only one rudder, a $4L$ diameter is required, whereas in favorable conditions with modern navigation systems, a $3L$ diameter may suffice. Instead of a circle, maneuvering requirements may be satisfied by an ellipse with $3L$ and $2L$ axes, the main axis being lengthwise of the vessel's course. If maneuvers are conducted with the aid of tugboats, the minimum diameter of the maneuvering circle may be reduced to $2L$. A corresponding decrease is also achieved if the vessel is fitted with a second rudder or a lateral propeller, usually a bow thrust.

During towage, a vessel's engines usually are stopped or are in excellent synchronization with the tugboats. Furthermore, if a vessel has the ability to use bow and stern anchors or wrapping doplhins, the diameter of the maneuvering circle may reach the minimum dimension of $1.2L$.

In the maneuvering area, the sea surface is generally calmer than that at the entrance, and it is advisable that the lateral currents in this area be weaker than approximately 0.15 m/s. Furthermore, the reduction in available draft due to squat is insignificant in the maneuvering circle. Consequently, the required draft in the maneuvering area may be somewhat smaller than that at the entrance. In most cases, a safety margin of about 1.5 m below the maximum draft of the design vessel is sufficient.

To avoid accidents, the maneuvering area should be surrounded by a safety zone from fixed structures or vessel moorings. It is accepted that the width of this zone is a minimum of $1.5B$, where B is the design vessel's beam, and in any case it should be above 30 m. More information is given in Chapter 9.

1.3.6.4 Vessel Anchorage and Mooring. Perhaps the most significant role of a harbor is to provide shelter to vessels and to protect them from waves, currents, and strong winds. Once ships enter port, they generally use one or more anchors for their maneuvers, and while they are preparing for their berthing, mooring lines are also used, tied to the dock bollards. It may be necessary to immobilize vessels before entry into port, either while waiting for a free berth or for the tidal water to rise above the critical level at the entrance channel. This is achieved either by using the ship's anchors or by using suitable mooring buoys or dolphins located in the waiting area. Detailed information on anchors and anchorage area is provided in Chapters 7 and 8.

1.3.6.5 Wave Agitation in the Port Basin. It was mentioned previously that the basic function of a port is provision of a protected anchorage for vessels and the facilitation of quick and safe loading and unloading operations and embarkation and disembarkation of passengers. Therefore, the absence of disturbing waves in the basin that would impede the smooth functioning of the port is mandatory. The study of disturbances in a harbor basin should take as input the prevailing wave pattern and provide as output the percentage of time during which the port, or individual sections of it, cannot be operational. As stated earlier, the main factor causing an interruption in the operation of a port, and indeed one that demands careful examination, is that of wind-generated waves. Apart from penetration through the entrance, wave transmission and overtopping at breakwaters should be considered in determining surface agitation in a basin.

It follows that planning the layout of port structures is of crucial importance in attaining the necessary tranquility of the sea surface in a harbor basin. That is why particular attention must be paid to this problem in the course of studying the layout of port works. A satisfactory answer may be obtained by laboratory testing of various designs in a physical model. In these tests, wave disturbance is recorded at suitably selected locations in the harbor basin, as well as resulting movements of berthed vessels. The acceptable limits of these movements are determined depending on the loading and unloading method and the type of cargo handling equipment being used.

Apart from physical models, a good deal of information can be obtained from mathematical models, which can be developed to various degrees of accuracy. In this case, the wave heights in sections of the harbor basin are determined under various environmental conditions and degrees of absorption of the solid boundaries, although it is exceedingly difficult to simulate vessel movements. Wavelengths of the incident wave field have a particularly significant effect on vessel behavior; certain wavelengths produce dangerous conditions, as noted below when we discuss disturbance due to long oscillations. Any examination of port basin tranquility does, of course, include an assessment of the cost of the port works required to obtain each degree of basin calmness.

Long Oscillations. Apart from wind-generated waves, a range of other natural factors can disturb a harbor basin, although to a lesser extent. Many of these have to do with extreme events, such as storms and seismically created waves. In such cases, many harbors do not offer satisfactory shelter to vessels, which prefer to sail out to the open sea to avoid sustaining or causing damage in port.

Among these factors, those most significant as to continuous effects on harbor basins and therefore on ships' operations can generically be termed *long oscillations* (*seiches*). In effect, these refer to trapped oscillations with periods in excess of 30 s caused by changes in atmospheric pressure, long waves caused in the open sea by barometric lows, surf beats, edge waves, and so on. A serious problem arises when the harbor basin's geometry favors the development of resonance at the frequencies of the free oscillations prevailing in the region. In such cases, the flow velocity at the nodes of the oscillation of the free surface may reach 0.5 m/s even though the vertical surface excursions may generally be small. Long waves with periods usually in the region of 1 to 3 min place stresses on docked vessels, particularly when this involves larger ships with taut mooring lines. The phase velocity of these long waves in relatively shallow harbor waters is given approximately by $(gd)^{1/2}$, d being the uniform depth of water. Consequently, for a harbor basin with a rectangular plan of dimensions $L \times W$ with an entrance on the W (width) side, the resonance period of standing waves, T_L, along the two directions will be

$$T_L = \frac{4L}{n(gd)^{1/2}} \qquad n = 1, 3, 5, \ldots \qquad (1.1)$$

with a node of the standing wave at the entrance and an antinode at the opposite end of the harbor basin, and

$$T_w = \frac{2W}{n(gd)^{1/2}} \qquad n = 1, 2, 3, \ldots \qquad (1.2)$$

with antinodes at both opposing docks.

A basic means of avoiding resonance in a new harbor is the design of harbor basins with such geometry that the frequencies above are far from the usual frequencies of long waves in the region. The latter may be traced through the use of recording devices of surface elevation not sensitive to high-frequency waves. In cases where the harbor evidences complex geometry, the typical resonance modes are determined through mathematical models, or even through physical models in some cases, in a way similar to examination of the disturbance due to wind waves. As known, low-frequency waves may penetrate harbor basins without undergoing significant reduction of their amplitude. That is why any attempt toward a better layout of the protection works and of the entrances will be fruitless with regards to the elimination of long waves.

Recommendations for Improving a Port Basin's Tranquility. It is obvious that a basic element in designing a port is to achieve the lowest possible disturbance in the harbor basin, particularly close to berths. For this reason, it is recommended that the following factors be examined:

1. Provision for an adequate extent of the outer harbor area and of all the harbor basins, for dispersion of wave energy penetrating the harbor
2. Provision for spending beaches in suitable locations of the harbor, especially those attacked directly by waves entering the basin.
3. Provision for absorbent wharves with suitable design for dissipating disturbing wave agitation. It is recommended that this type of work be checked through physical modeling because the phenomena of conversion of wave energy, expelling of air, upward loading of the crown slab of the quay, and so on, are sufficiently complex and do not easily lend themselves to analysis through mathematical modeling.

In any case, the usefulness of absorbing quay walls is debatable, chiefly because of the wave reflection caused by berthed vessels at their sea side, a fact that reduces the efficiency of these structures considerably.

1.3.6.6 General Layout of Protection Works

Layout of Main Structures. Works whose function is to ensure the calmest possible conditions within harbor basins and along quays, particularly from wind-generated waves, are termed *harbor protection works.* These may include the following:

1. Breakwaters, usually constructed either connected to the shore or detached. Shore-connected breakwaters are classified as *windward* or *primary* and *leeward* or *secondary*. The former protect the harbor from the main wave direction, and the latter protect from waves of secondary directions. Frequently, leeward breakwaters are partially protected by windward breakwaters.
2. Jetties, usually arranged in pairs to form entrances to harbors located inward from the shoreline or in rivers. Paired jetties may also increase the flow speed and thus prevent sedimentation.

Figures 1.4 through 1.6 depict certain common arrangements of outer port works, depending on the type of harbor. The free end of protection works is called the *structure head,* and the remainder is the *structure trunk*. The effect of harbor works to be constructed on the transport regime of sediments in the region is particularly important. Quite often, port works are located in the surf zone, where the largest percentage of sediment transport takes place. Consequently, the effect of these works on coastal erosion or deposition may be quite significant. The phenomena usually caused by harbor protection works as regards sedimentation is a concentration of deposits upstream of the windward breakwater, erosion of the shore downstream of the leeward breakwater, sedimentation in the vicinity of the harbor entrance and the approach channel, and others (Figure 1.7).

The solution to such types of problems is not an easy matter, and in many cases recourse to the method of sand bypassing is considered to minimize the dredging required for mainte-

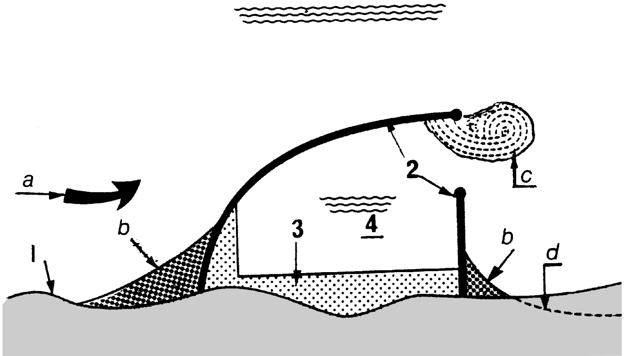


Figure 1.7 Effects of harbor works on coastal sedimentation. a, Longshore littoral transport; b, accretion; c, deposition; d, erosion; 1, natural shoreline; 2, breakwater; 3, landfill for port construction; 4, artificial harbor.

nance of drafts. The general idea in designing the layout of protection works should be to favor the transfer of sediment to deeper waters, where they are less harmful. Application of this general rule is not always easy, of course; that is why port designers usually resort to laboratory tests of the general arrangement of a harbor's defense works.

The protection structures are in principle laid out such as to provide the space required for a calm harbor basin, maneuvering areas, and necessary safety margins. Following that, an examination is conducted to ascertain the degree to which a large portion of the outer works is located in the wave-breaking zone. Selected values of wave heights are examined and the required modifications to the layout of the works are made so that the works are placed outside the breaking zone of the crucial design waves. This is done to reduce wave loads on the relevant structures and consequently, their cost. An important step follows: that of forming the harbor entrance in accordance with the guidelines of Section 1.3.6.2. Another point that relates to the shape of the breakwaters refers to the avoidance of angles to the open sea smaller than 180°, to evade a concentration of wave energy, with adverse effects on the structure's integrity.

Finally, the possibility of water renewal should be investigated, to reduce pollution of harbor basins to the minimum possible. It is not easy to suggest arrangements that can attain this target. As regards intervention in the harbor's protection works, the matter is usually handled by providing openings across the body of the structure, to facilitate water circulation. However, for these openings to be effective, they should be of sufficient width, which of course results in allowing significant disturbance into the harbor basin. Also, undesirable sediments may enter the harbor and be deposited if the openings extend down to the seabed. Therefore, in most cases the openings are not extended at depths beyond the surface layer in which the wind-generated water circulation generally takes place, to prevent the transfer of heavy sediments that occurrs at the lower part of the water column.

1.3.6.7 General Layout of Inner Port Works

Geometric Elements. The arrangement of berths and docking installations follows the principles noted in Section 1.3.6.5. Layouts that favor enhancement of long oscillations should be avoided, and it is also recommended that spending beaches be placed in suitable locations in the harbor basin. The geotechnical properties of the seabed in the project area play a significant role in deciding the general layout of the inner works. If a rocky seafloor is present, it is usually advisable to place the line of wharfs close to their final depth, to avoid expensive excavations of the rocky bed. If the latter is soft, the location of the wharfs is determined by, among other factors, a detailed technical and economic comparison of reclaiming versus dredging.

It has been pointed out that maneuvering surfaces should have a security distance of between 30 and 50 m from any vessels docked at the planned berths. Figures 1.4*a* and 1.6 give the main elements of a harbor's inner works. As a general rule, the plan must ensure that the shape of the docks provides for better use of the harbor basin and easier navigational conditions for vessel maneuvers, and that the functioning of dock equipment and machinery is not hampered. Furthermore, to keep pollution of harbor basins to a minimum, placing docks and basins in recessed positions of a harbor should be avoided, because the renewal of water there is weak. If narrow piers are planned (e.g., only for the mooring of small vessels), it is advisable to examine the possibility of designing them on piles with openings for facilitation of water circulation. The development of a port over time is generally associated with a required strip of land parallel to the berths. Previously, this strip was planned to be about 50 m wide; later, adapting to technological development in cargo handling, this was increased to 100 and 200 m. A result of this change was a tendency to shift from narrow piers that created a zigzag layout of docks to straight quay lines parallel to the shore, which ensures large land areas.

The linear dock arrangement, however, takes up a far greater length of coast, which frequently is very expensive, or not feasible to acquire for other reasons. In such cases, wide piers are used to increase quay length. Their width can be 300 m or more, and they may be placed at a small angle to the shoreline if this would have the benefit of protecting them from waves and provide better operational conditions.

Quay length is determined by the particular method of docking and by the number of berths. Alongside berthing for a vessel of length L requires a quay length of $b = L + 30$ to 40 m or $b = 1.2L$. For Ro-Ro stern (or bow)-to-shore berthing, the required quay length b is determined by the vessel's beam B and is roughly $b \approx 1.2$ to $1.5B$. The minimum depth h of the sea at the quay is determined by the design vessel's maximum draft d_{max}. A safety factor for this value (i.e., pilot's foot) in the region of 1 m should be added to cover for any heaving motion due to wave disturbance. Thus $h \approx d_{max} + 1$ m. The dimensions usually recommended for seaport docks are illustrated in Figure 1.8. Other inner installations apart from berthing quays, such as dry docks, slipways, and maintenance quays, should be situated independent of the customary loading and unloading quays and as much as possible in protected areas of the harbor.

Connections with Inland Areas. It has already been mentioned that the nature of a modern cargo port resembles more a cargo handling hub within a combined transport system than a sea transport terminal point. Consequently, a basic element in the smooth operation and development of a terminal are the port's inland connections. These connections, through which nonsea transport of goods to and from the port is effected, may be road or rail accesses, artificial or natural inland navigable routes, airlines, or oil product pipelines. Road, rail, and river connections (to which we refer later) can also connect a port with specialized cargo concentration terminals located in suitable inland depots. These stations serve to smooth out the peaks in demand and supply of goods to a port

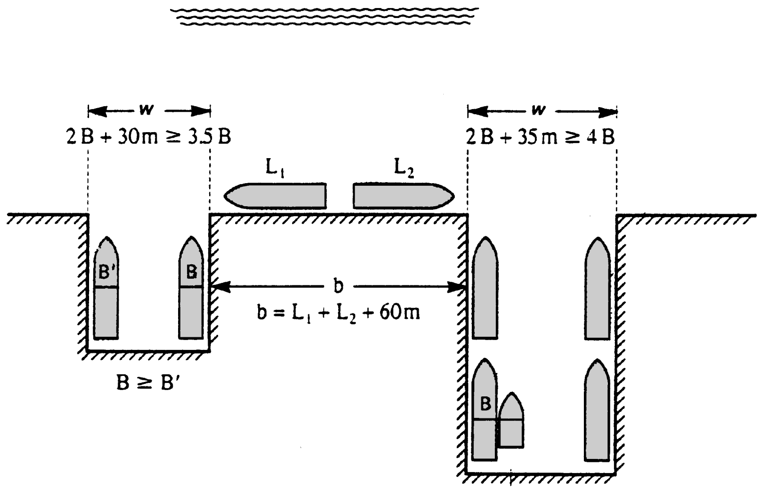


Figure 1.8 Main dimensions of sea docks.

that has limited storage areas. Figure 1.9 depicts some general arrangements of such connections.

The provision of inland storage areas forming part of a port is a modern tendency pronounced in container transport, which creates the need for larger backup areas and also a need for boxes to stay in port for a shorter time. The transport of goods between port and inland depots is thus carried out quickly and efficiently, in contrast with the traditional servicing of all destination points directly from a port without intermediate transshipment. In addition to being effected by road, the connection between port and inland depot may be by rail, particularly when the distance is great. In the latter case, the loading of trains, when this involves imports, may be effected at a small distance from the port, where the goods are forwarded through a system of wheeled trailers fed from the port, as shown in Figure 1.10. In each case, the traditional arrangement in general cargo terminals in which rail (or road) vehicles approach the docks for immediate loading and unloading of cargo through the use of dock cranes is being abandoned. The main reason for this development is that loading/unloading vehicles obstruct dock operations, in addition to the frequent inability to coordinate ship–train operations, resulting in vessel delay. Two alternative handling options are available in this respect: (1) the full cargo can be forwarded inland via port sheds, or (2) "direct" loading/unloading to and from rail or road vehicles can be retained but conducted at some distance from the docks. The second alternative demands an additional fleet of tractors and platforms to link docks with transshipment areas to means of overland transportation. This alternative solution is depicted in Figure 1.11 together with the traditional arrangement, which, as mentioned, is gradually being abandoned by many ports.

The tendency to shift land transportation away from docks is even more prevalent in container or Ro-Ro port terminals. Inland connections are allowed only to reach a delivery and receiving area, which in container terminals is generally located near the container freight station (for details, see Section 1.4.3). In most cases, road access to ports is appealing, particularly for small and moderate distances.

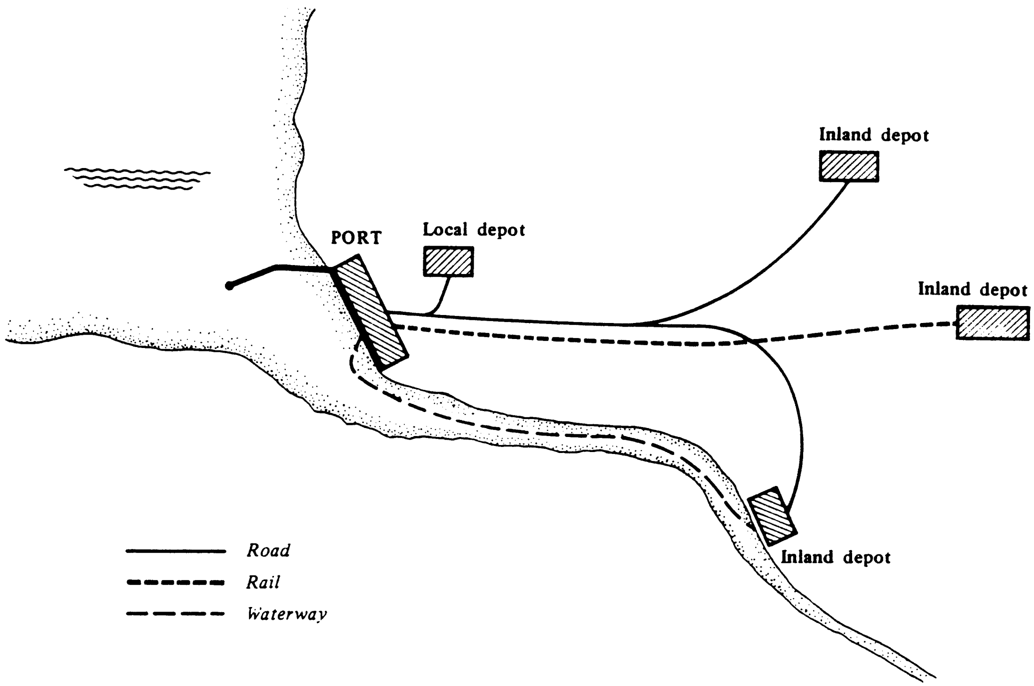


Figure 1.9 Connection of a port with an inland cargo collection terminal. (From United Nations, 1978.)

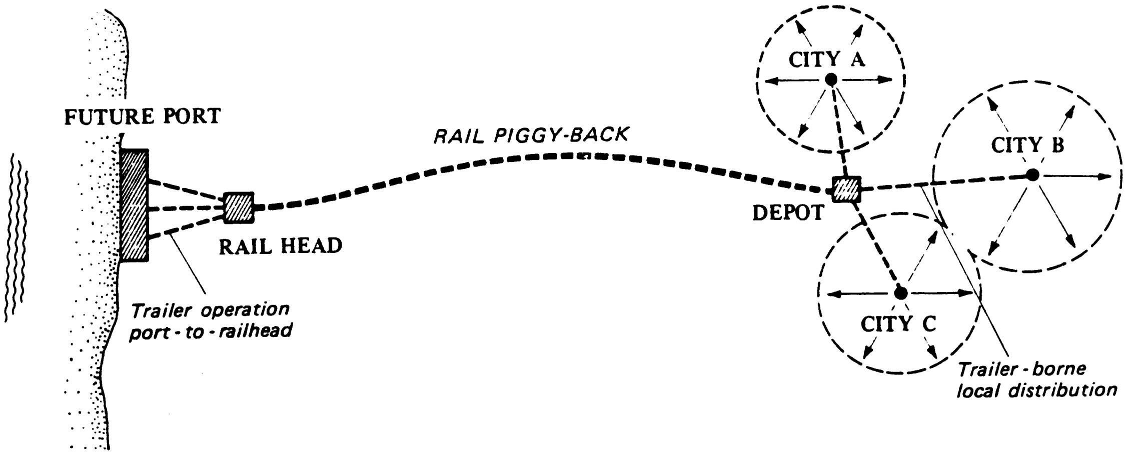


Figure 1.10 Combination of road–rail connections of the port with the inland depot. (From United Nations, 1978.)

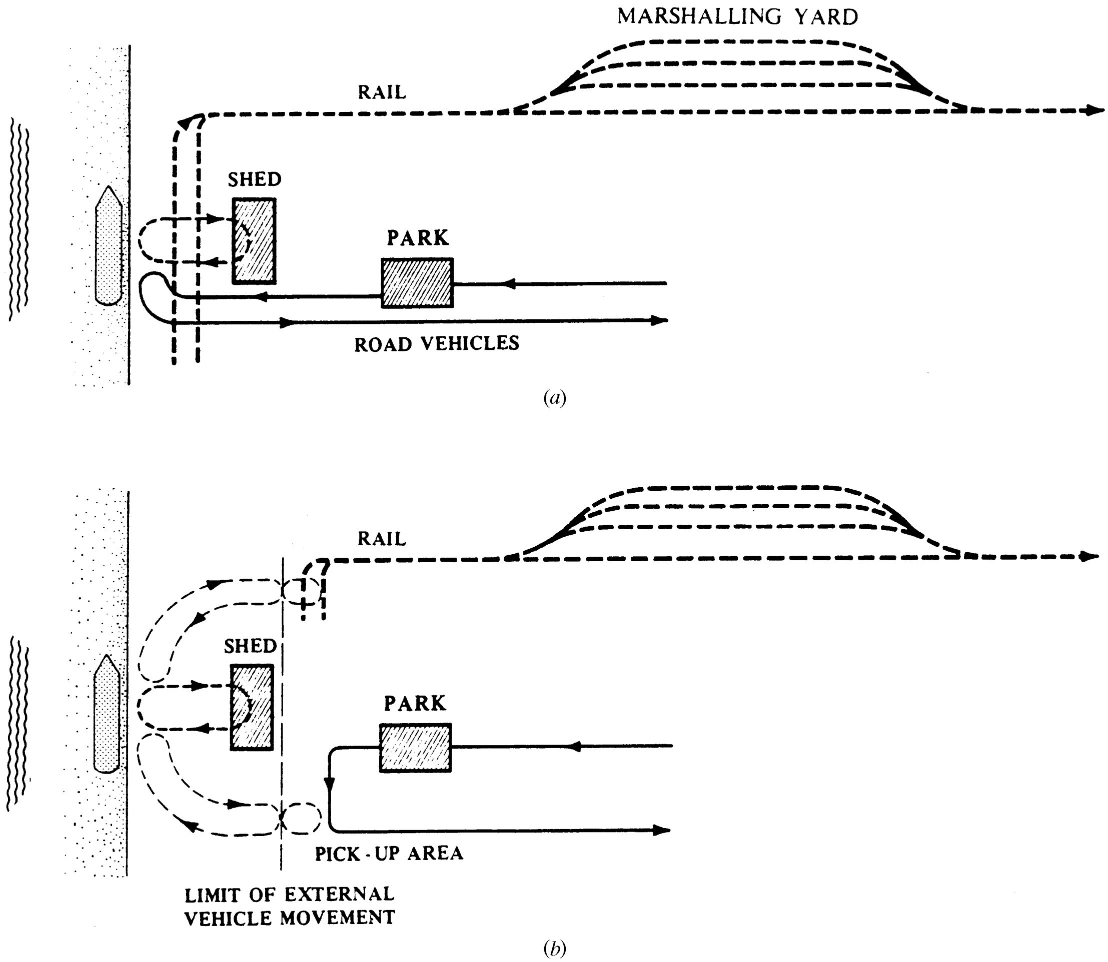


Figure 1.11 Restricting the approach of vehicles to the docks: (*a*) traditional approach; (*b*) alternative approach. (From United Nations, 1978.)

The variety and types of road vehicles render them versatile, and in conjunction with a dense road network in many regions, make them suitable for "door-to-door" service. Rail connection at ports offers security, speed, and economical transport of bulky goods over large distances.

Many ports throughout the world are constructed at the mouths of navigable rivers or canals, to connect them with other areas by means of inland navigable routes. Connections by inland navigation offer economy and are particularly suitable for the transport of bulk cargoes and for supporting combined transports between river ports and seaports that serve barge-carrying vessels.

Additional Points to Be Considered. Several issues of general application to the layout of land installations of a port are listed below.

1. The conventional berthing positions for general cargo require a smaller draft at the quay (usually 7.70 to 10 m) than those required for containers or bulk cargo.
2. Much larger land areas are required in terminals where containers are to be handled.
3. Care should be taken in drawing up the land use so that smells from bulk cargoes carried by prevailing winds do not damage the environment.
4. Security issues should be examined, particularly as regards flammable materials or explosives.
5. Product compatibility should be examined for cargoes adjacent to their respective handling areas. For instance, pairing coal with grains is incompatible, as is pairing grains with fertilizers.
6. The overall traffic pattern in the land area at a port should be examined, to avoid potential congestion or a need for bridging.

1.4 PORT PLANNING AT THE TERMINAL LEVEL

1.4.1 Port Development

1.4.1.1 Phases of Port Development. The course of development of a port or port terminal usually undergoes phases, which also indicate its age. Evolution from a traditional break-bulk cargo port to a specialized unitized cargo port may be gradual. However, it is distinguishable into qualitative changes that take place in specific periods throughout the overall life of the port. These phases are as follows:

Phase 1: Traditional General Cargo Flow. A port with break-bulk or packaged bulk cargo terminals, such as for bagged grains or petroleum in barrels.

Phase 2: Break-Bulk Cargoes. When break-bulk cargo flow exceeds an economically acceptable limit, these cargoes are transported in bulk form and the port develops a special bulk-cargo terminal. At the same time, the break-bulk berths are increased, to accommodate the higher demand.

Phase 3: Unit Loads. Unit loads start being carried on conventional vessels in small quantities in units such as palettes, containers, or packaged lumber. At the same time, break-bulk cargo flows, particularly those of bulked break-bulk cargoes, start diminishing to levels that require separation of cargo terminals for various cargo categories.

Phase 4: Multipurpose Terminal. Unitized cargoes on specialized vessels start appearing in quantities that do not yet require development of a specialized terminal. Thus, a multipurpose terminal is created in which break-bulk cargo traffic is diminished, although unitized cargo is also handled. At the same time, the specialization of dry bulk cargo terminals continues.

Phase 5: Specialized Terminal. With an increase in unit loads beyond certain levels, specialized cargo terminals are created for handling containers, packaged lumber, and Ro-Ro. The multipurpose terminal of phase 4 is converted into a specialized terminal, with the addition of specialized cargo handling equipment. Break-bulk general cargo is reduced further.

It should be noted that in normal situations, the transition from phase 3 to phase 5 should progress through phase 4, so as to provide an opportunity to the port to increase unitized cargo traffic to volumes that will enable economically feasible development of a specialized terminal in phase 5. Moreover, in the event that a port has entered phase 3 of its development, care should be taken to avoid creating additional general cargo berths.

1.4.1.2 Review of Existing Port Installations. The examination of existing installations should precede any decision to expand old, or to construct new, port terminals. The purpose of such a study is to identify any functional difficulties that would detract significantly from the theoretical productivity of the marine and land sector of the port terminal. In many cases, improved organization of the component operations of the port terminal produces a significant increase in its productivity. In addition to an improvement in the terminal's organizational structure, there is the possibility of introducing structural changes and upgrades of port installations, which will usually necessitate a considerable expenditure. It should be noted that in many cases, technological developments and changes in packaging and cargo handling methods frequently render the upgrading of existing installations a difficult and complicated task. At the same time, the existence of spare capacity is always a desirable feature in a modern port able to accommodate peaks in cargo flows, albeit with reduced productivity. Thus in cases where the recommended installation upgrade marginally covers the expected demand, it is recommended that old installations be placed on standby to cover unforeseen requirements and that expansion of an existing, or construction of a new, port terminal be opted for.

1.4.1.3 General Cargo Terminal. The first phase in a design for expansion of an existing break-bulk cargo terminal or for the creation of a new one involves diligent collection and analysis of statistical data regarding the existing terminal's output. This analysis will also determine the "age" of the existing terminal—in other words, the degree to which the owners of this break-bulk cargo terminal are prepared to see it evolve into a multipurpose terminal or even into a specialized container or bulk-cargo terminal. This decision will be based on the percentages of the flows and the unit loading that conventionally packaged cargoes assume over time.

Analysis of these data will also reveal whether berth productivity falls short of theoretical values. In this case, and particularly if significant vessel waiting times are observed, the cause of the reduced output should be looked into carefully. Usually, a standard efficiency rating per berth with a high degree of break-bulk cargo traffic is 100,000 tons per year, whereas if unitized cargoes constitute 30 to 40% of the traffic, this productivity figure may rise to more than 150,000 tons per year.

1.4.1.4 Bulk Cargo Terminal. To decide on the expansion of a bulk cargo terminal, the data from the existing terminal have to be considered. Just as in the case of break-bulk terminals, the purpose of this examination is to determine whether the lower productivity of the terminal is due to malfunctioning or to increases in traffic volume. In ore-exporting terminals, the latter case may be due to improvements in mining technology or to discoveries of new deposits. The study should focus on such issues as coordination between the various phases of product movement, on lags, if such exist, during which no product is available for loading on the vessel, and on the method of cargo movement over land. The findings of this examination will lead to a decision either to improve the operational procedures and the equipment of the existing terminal, or to create an additional bulk cargo terminal.

1.4.2 General Cargo Terminal

Despite the fact that the general cargo terminal is becoming increasingly scarce, the main factors pertinent to its organization and operation are presented below, so they may also be used in the study of a multipurpose terminal.

1.4.2.1 Vessel Waiting Time. It is generally accepted that arrivals of general cargo vessels follow a Poisson distribution. According to this, the probability $P(n)$ for n vessels to arrive in port within a specified period—usually 1 day—is

$$P(n) = \frac{(N)^e e^{-N}}{n!} \tag{1.3}$$

where N is the average number of arrivals per day over a long time period. The observation above is equivalent to saying that the distribution of the time intervals t between successive arrivals is negative-exponential:

$$P(t) = e^{-t/T} \tag{1.4}$$

where T is the average of these intervals over a large time period. On the basis of existing data it is estimated that the time periods t for servicing of berthed vessels follow an Erlang distribution with $K = 2$. The Erlang distribution is expressed by the formula

$$P(t) = e^{-Kt/T} \sum_{n=0}^{K-1} \frac{(Kt/T)n}{n!} \tag{1.5}$$

where T is the average servicing time. Within reasonable accuracy, queue theory can provide values of vessel waiting time for various degrees of utilization of the system. In the case of the general cargo terminal, assumptions are made of random arrivals and distribution of servicing times according to an Erlang2 distribution. This in fact corresponds to an $M/E_2/a$ queue, where M denotes the Poisson distribution of arrivals and a is the number of berths.

1.4.2.2 Berth Occupancy. The occupancy rate of a group of berths expresses the percentage of time that berth positions are occupied by ships being serviced. The effect of berth occupancy on waiting time depends on the probability distributions of arrivals and of servicing times as well as on the number of berths available to the sector of the port being examined. With regard to a general cargo terminal, an $M/E_2/n$ queue is usually assumed, as stated above. The effect that the grouping of berthing places on vessel waiting times can be seen through the congestion factor, defined below, values of which are contained in Table 1.1. In general, a larger number of berths enables greater occupancy rates for the same waiting periods.

For the sake of demonstration, let us assume 10 general cargo berths and an average of two vessel calls per day headed for these berths. If the average servicing time is 3.5 days, the occupancy factor k_0 is

$$k_0 = \frac{2 \times 3.5}{10} = 0.70$$

in which case the congestion factor k_0', which in average terms expresses waiting time as a percentage of servicing time, amounts to 6% or 0.2 day. Now, if the total of these berths is divided into two independently operating groups, with one vessel call per day per group, the occupancy rate remains the same, while the congestion factor is tripled, to 19%. Table 1.1 provides an approximation of the waiting time for the queue above expressed as a percentage of the average servicing time as a function of the number of berths and of their occupancy.

The optimum berth use depends on the cost ratio between berths and vessels. The values given in Table 1.2 give occupancy factors generally recommended for a 1:4 cost ratio, depending on the number of berths of the general cargo terminal. It should be noted that the

Table 1.1 Congestion factor in queue $M/E_2/n$

Occupancy Factor	Number of Berths 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.10	0.08	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
0.15	0.13	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
0.20	0.19	0.03	0.01	0	0	0	0	0	0	0	0	0	0	0	0
0.25	0.25	0.05	0.02	0	0	0	0	0	0	0	0	0	0	0	0
0.30	0.32	0.08	0.03	0.01	0	0	0	0	0	0	0	0	0	0	0
0.35	0.40	0.11	0.04	0.02	0.01	0	0	0	0	0	0	0	0	0	0
0.40	0.50	0.15	0.06	0.03	0.02	0.01	0.01	0	0	0	0	0	0	0	0
0.45	0.60	0.20	0.08	0.05	0.03	0.02	0.01	0	0	0	0	0	0	0	0
0.50	0.75	0.26	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0	0	0	0	0
0.55	0.91	0.33	0.16	0.10	0.06	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0	0	0
0.60	1.13	0.43	0.23	0.14	0.09	0.06	0.05	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01
0.65	1.38	0.55	0.30	0.19	0.12	0.09	0.07	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02
0.70	1.75	0.73	0.42	0.27	0.19	0.14	0.11	0.09	0.07	0.06	0.05	0.04	0.03	0.03	0.03
0.75	2.22	0.96	0.59	0.39	0.28	0.21	0.17	0.14	0.12	0.10	0.08	0.07	0.06	0.05	0.05
0.80	3.00	1.34	0.82	0.57	0.42	0.33	0.27	0.22	0.18	0.16	0.13	0.11	0.10	0.09	0.08
0.85	4.50	2.00	1.34	0.90	0.70	0.54	0.46	0.39	0.34	0.30	0.26	0.23	0.20	0.10	0.16
0.90	6.75	3.14	2.01	1.45	1.12	0.91	0.76	0.65	0.56	0.50	0.45	0.40	0.36	0.33	0.30

Source: United Nations Conference on Trade and Development (UNCTAD), 1978.

Table 1.2 Recommended occupancy factors

Number of Berths	Occupancy Factor k_0 (%)	Congestion Factor k_0' (%)
1	40–50	50–75
2	50–60	26–43
3	53–65	14–30
4	56–65	11–19
5	60–70	9–19
6–10	62–75	2–21
>10	70–85	0–26

higher factor values are more fitted for $E_2/E_2/n$ queues, which are more applicable to container terminals.

1.4.2.3 Number of Berths. The key parameter in the design of a general cargo port terminal is that of the number of berths. This parameter depends mainly on the annual cargo throughput of the terminal and on the predetermined level of vessel servicing to be offered by the terminal. The latter depends on the corresponding waiting periods discussed previously. The number of berths n can be expressed as

$$n = \frac{Q}{24k_0 qprN} \tag{1.6}$$

where Q is the annual cargo flow estimate (tonnes), k_0 the berth occupancy factor, q the average tonnage handled by one gang per hour (calculated from statistical data of this or a similar port), p the fraction of time during which the berths are operational (e.g., if the total daily working hours per berth is 16 over 6 days per week, this factor would be $16 \times 6/24 \times 7 = 0.572$), r the average number of gangs concurrently loading or unloading an average-sized vessel (depends on cargo type and vessel size), and N the days of berth operation in a year (days when berths are in a position to receive vessels, e.g., not closed for maintenance).

The number of berths, n, may also be expressed approximately as a function of cargo throughput, Q, expressed in units of 100,000 tons per year as follows:

$$n \simeq \frac{Q}{k_0} \tag{1.7}$$

where k_0 is the occupancy factor. Having determined the number of berths in the terminal, berth length is then calculated on the basis of the length of the design vessel to be calling at the terminal. Berth length is generally taken to be 20% above the design vessel length. Wharf width should typically include free sea space of at least two design vessel widths. The productivity per running meter of a general cargo berth usually ranges from 600 to 1200 tons of cargo per year for average occupancy. Where container units are handled by conventional quay cranes or by vessel gear, this output may reach 1600 tons per year.

1.4.2.4 Storage Area. A small portion of the total throughput of a general cargo terminal is either loaded directly to or discharged directly from land transportation means without requiring storage at the terminal. The other cargo is stored for a period of time in sheds, open areas, or warehouses. The required cargo storage area A (thousands of m^2) can be expressed as a function of known parameters, by adopting the following simple relation:

$$A = \frac{1.7}{365}\left(\frac{QD}{dH}\right)\left(1 + \frac{p}{100}\right) \tag{1.8}$$

where Q is the annual tonnage to be stored (thousands of tons; this refers to the portion of total cargo flow that requires storage); D the average storage duration (days; it is assumed on the basis of existing statistical data); d the cargo density [tons/m^3; this may be calculated using the stowage factor (in m^3/ton), typical values of which are shown in Table 1.3]; H the average stowage height (m; depends on type of cargo, its packing, and stowage means; an average value is 2 to 3 m; the smaller the stowage height, the larger the storage areas, but simpler mechanical means are required for cargo handling; for this reason, comparisons should be made between various alternatives); and p the peak factor, multiplies the average area required to accommodate cargo flow peaks (usually, this increase is between 25 and 40%).

The factor 1.7 in eq. (1.8) covers the extra space required because of the splitting of consignments into smaller units and accommodates areas not used for stacking, such as corridors and offices. Assuming a rectangular shape of the storage area, the dimensions of the shed may be calculated to have a width of roughly half the length. In any case the width should be above 40 to 50 m.

In ports, cargo is stored in sheds, warehouses, or in the open. Sheds usually are steel frame constructions at ground level, situated

Table 1.3 Typical cargo densities

Cargo	Stowage Factor (m^3/ton)	Cargo Density (tons/m^3)
Bagged cement	1.0	1.00
Plaster, bagged	1.2	0.83
Sand, bagged	0.5	2.00
Animal feed, bagged	1.5	0.67
Bagged coffee	1.8	0.56
Citrus fruits	2.5	0.40
Cotton bales	2.7	0.37
Bagged flour	1.3	0.77
Grapes	3.9	0.26
Frozen fish (boxed)	2.1	0.48
Paper rolls	2.5	0.40

lengthwise and relatively near the wharves and used for cargo storage over a short period of time. Conversely, since they are not part of the fast-track cargo handling chain, warehouses are usually situated behind the sheds so as not to take up valuable space near the berths. Cargo that is to remain in port for a substantial period of time is stored there. Such situations arise when the port owners wish to engage in the warehousing of goods: for instance, goods requiring ripening or separation and repackaging for direct ex-warehouse sale. Contrary to sheds, warehouses may be multistoried buildings, although single-storied warehouses are more practical. A typical layout of a general cargo terminal for three berths is shown in Figure 1.12.

1.4.2.5 Sheds. The basic requirements for a port shed are as follows:

1. To be of sufficient width, which should extend at least to 40 to 50 m
2. To have as few columns as possible within the storage area
3. To have sufficient ventilation and lighting
4. To have a smooth and durable floor surface
5. To have an adequate number of large sliding doors, with easy handling
6. To save floor space by placing offices at a higher level
7. To be constructed so as to enable expansion or other envisaged modifications

The shed floor should be adequately sloped to enable drainage. Usually, such a slope is specified up to 1:40 for purposes of good functioning of handling equipment and stacking stability. The shaping of this slope may be combined with the construction of a loading platform lengthwise to the land side of the shed, to an approximate height of 1 m. A loading platform is needed to connect the shed with inland areas by road and by rail, if such a connection exists. Rail tracks are laid embedded so as not to protrude from the floor surface. If it is not possible to create a permanent platform as indicated above, mobile loading ramps may be employed. In this case, the shed floor may be shaped with a double slope, with a watershed along the lengthwise axis of the shed.

The width of the area between the shed and the berth (apron) is about 20 to 30 m. Traditionally, conventional portal cranes placed on rail tracks alongside the quay have been used in this zone, and railcars approached this zone to load and unload directly from the dock cranes. Experience has shown that it is difficult to load and unload railcars satisfactorily, with the result that cargo handling efficiency is reduced. Currently, the practice of approaching general cargo berths by rail has been abandoned, and cargo flow is effected through sheds and warehouses.

A further development in the dockside zone is the increasingly reduced presence of dock cranes on rails. Many such cranes, which in the past were characteristic of general cargo terminals, are now being replaced by versatile heavy mobile cranes supplemented, if possible, by a vessel's gear. Apart from loading and unloading heavy unitized cargo at the dockside, these cranes, with an approximate 20-ton lifting capacity, may assist operations in other areas of a terminal. In general, the number of cranes and their lifting capacity depend on the type and volume of cargo and its method of handling at the port. The overall width of the land zone required to sustain all cargo handling operations in a modern general cargo port terminal should extend 200 m from the quay line.

1.4.2.6 Cargo Handling. Following unloading by cranes of general cargo onto a dock, transporting and stacking it in sheds follows. A reverse course applies in the case of cargo export. Transfer to and from a shed may be effected in the following ways: (1) use of a

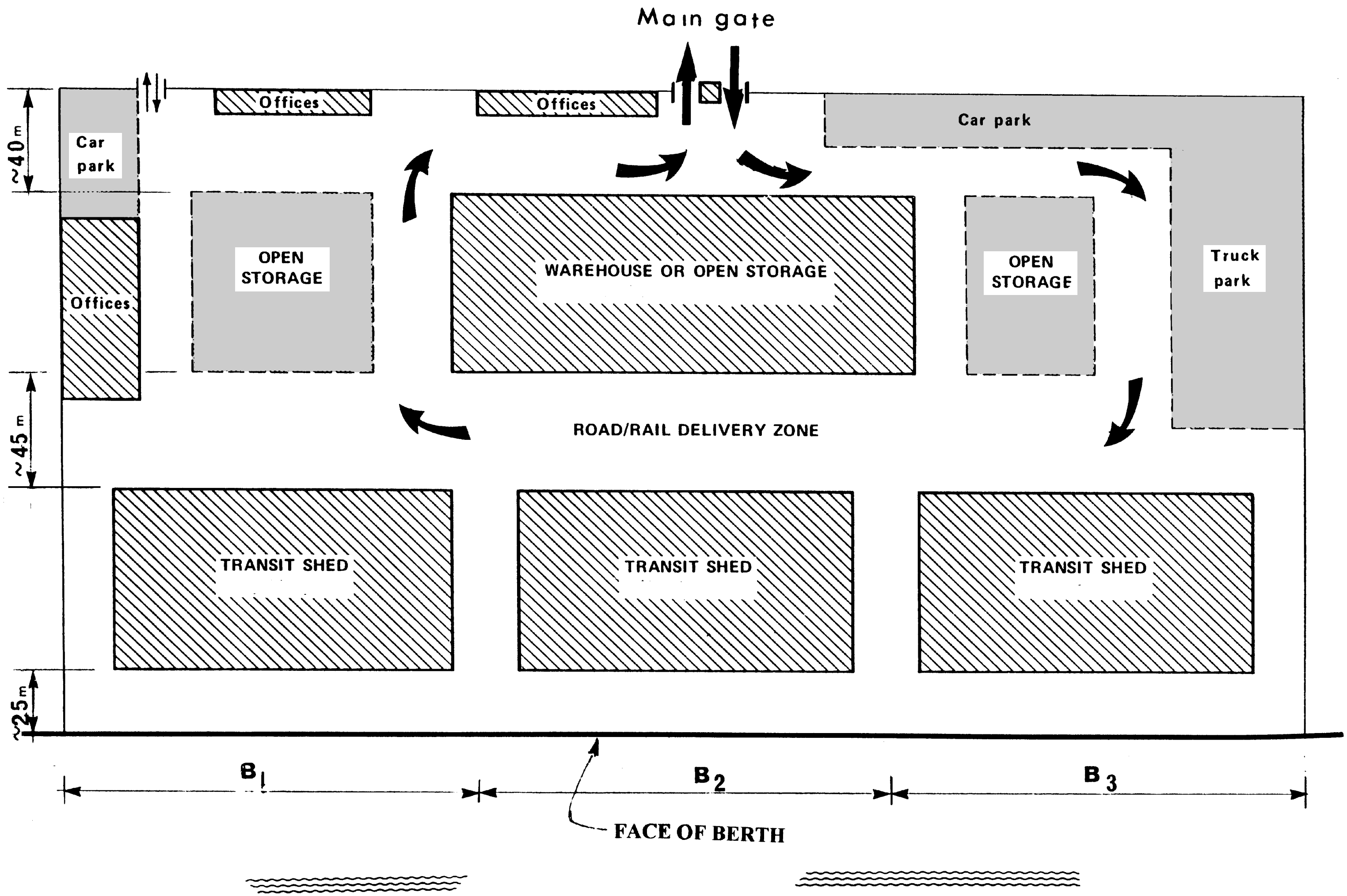


Figure 1.12 Typical layout of a general cargo terminal.

tractor–trailer combination and (2) use of heavy forklift trucks. Cargo unloaded by dockside cranes can be placed directly on trailers that are transported back and forth by tractors. Under normal working conditions, a tractor may service three or four trailers. If forklifts are used instead of tractors and trailers, the cranes discharge the cargo directly onto the dock floor for forklifts to pick up. Cargo stacking at a shed is effected by means of forklifts, while in open storage areas it is performed either by forklifts or by 10-ton mobile cranes. In the absence of statistical data, the cargo handling equipment required at break-bulk cargo terminals may be calculated by means of the following approximate norms:

- Number of loading and unloading gangs per vessel: $3\frac{1}{2}$ for oceangoing vessels; $1\frac{1}{2}$ for feeder vessels
- 3 forklifts per gang, or 2 tractors and 8 trailers per gang
- 0.8 forklift and 0.4 stacking crane per gang

Furthermore, for equipment an extra 20 to 25%, and for trailers an extra 5%, is required for repair and maintenance purposes.

1.4.3 Container Terminal

1.4.3.1 Cargo Unitization. One of the most significant developments in maritime transport was the establishment some 40 years ago of the container as a cargo packaging unit. Over the past 30 years the amount of goods shipped in containers increased at a rate of about 7% per year (i.e., more than double the growth in the world economy and 50% over the expansion in world trade). In the container terminal, increased throughput productivity is attained in addition to other advantages, such as canceling the need for extensive sheltered storage areas, security, and standardization in equipment dimensions and required spaces.

Containers are transported mainly in specialized vessels, classified into ‘‘generations’’ depending on their size. Typical dimensions of modern container ships are given in Chapters 2 and 10. Most container ships are capable of crossing the Panama Canal (Panamax-type vesssels), allowing 13-box-wide storage across the deck. During the 1990s post-Panamax vessels appeared, having capacities exceeding 8000 TEU with drafts of 14.5 m. These vessels have beams of 43 m, allowing 17-box-wide deck storage. It has been announced that in 2004 two containerships of 9800 TEU will enter trans-Pacific service. Engineers consider that there is no technical constraint to building a ship of 15,000 or even 18,000 TEU, the latter size being imposed by the shallowest point in the Malacca Strait in Southeast Asia, allowing a draft of 21 m. Such megaships might have a length of 400 m and a beam of 60 m, giving 24-box-wide deck storage. Table 1.4 shows the principal dimensions of some of the new generation vessels together with the projected 12,500 TEU capacity vessel. This latter Ultra Large Container Ship (ULCS) was found to be of an optimal size by a study carried out by Lloyds Register of Shipping and Ocean Shipping Consultants. These gradually increasing dimensions of new vessels have a significant impact on the geometric requirements of ports' layout. Thus berths of up to 400-m long with water depths down to 16 m become increasingly the norm for modern container terminals. Also, gantry cranes should be able to cope with increased beams and the capacity of handling equipment should be compatible with larger consignments. Containers can be stacked in the hold or four high on the ship's deck. Difficulties arise with large stacking heights as regards container fastening and other aspects.

The container ships mentioned above are oceangoing vessels and in many cases avoid making frequent calls at nearby ports. Thus, smaller, intensively utilized feeder vessels are employed in short distances for the collection

Table 1.4 New generation container ships

Vessel Name	Launch Date	Dead-Weight Tonnage	TEU	LOA (m)	Beam (m)	Draft (m)
Hyundai Admiral	1992	59,000	4,411	275	37.1	13.6
NYK Altair	1994	63,163	4,473	300	37.1	13.0
APL China	1995	66,520	4,832	276	40.0	14.0
Ever Ultra	1996	63,388	5,364	285	40.0	12.7
Hajin London	1996	67,298	5,302	279	40.4	14.0
Regina Maersk	1996	82,135	6,418	318	42.8	12.2
NYK Antares	1997	81,819	5,798	300	40.0	14.0
Sovereign Maersk	1997	104,696	8,736	347	42.9	14.5
ULCS		120,000	12,500	400	60	14.8

or distribution of cargoes from a region (e.g., the eastern Mediterranean). These feeder vessels are of 30 to 350 TEU capacity and usually have no lifting gear. Loading and unloading are conducted by means of a single dockside gantry crane, with a corresponding reduction in output. These feeder vessels are usually Ro-Ro or combined type. Table 1.5 lists the main dimensions of typical feeder vessels.

Because of the container terminal's specialization and the large investment involved, a minimum level of cargo volume is required to render the investment profitable. This throughout depends on individual conditions and ranges typically around 70,000 TEU annually. It is characteristic that the investment cost per TEU for an annual traffic rate of 20,000 TEU is triple that of the corresponding cost for 80,000 TEU. Containers are of simple rectangular shape, as shown in Figure 1.13. Table 1.6 lists the typical dimensions of various container sizes. It is estimated that in the future the trend toward greater container length, in the region of 45 ft, and a weight of over 35 tons will gain momentum.

1.4.3.2 Cargo Handling. Practice has shown that the actual productivity of container terminals is significantly lower than the theoretical productivity. An average daily productivity per berth used to be in the region of 450 TEU for many small container terminals, whereas large modern terminals can achieve up to 2000 movements, as in the port of Singapore. A concept of narrow docks has been proposed, where a vessel could be served by cranes at both sides, thus achieving high productivity, on the order of 300 movements per hour per berth.

Table 1.5 Typical dimensions of feeder vessels

Feeder Vessel Type	Dead-Weight Tonnage	TEU	Length (m)	Beam (m)	Draft (m)
Ro/Ro	4580	176	130	17	6.25
Lo/Lo	1260	106	77	13	3.70
Combined	2080	111	87	14	4.70
Combined	6500	330	115	19	7.40

Figure 1.13 Steel container.

Loading and unloading operations are carried out by means of powerful dock gantry cranes that can attain an output of 25 to 30 TEU per hour, although usually their average productivity is lower. The operational life of a typical gantry crane extends to 15 years and 2,000,000 operating cycles. Some typical gantry crane dimensions are:

• Lifting capacity	30–50 tons
• Rail gauge	15–40 m
• Maximum lifting height above dock	25 m
• Maximum depth beneath dock	15 m
• Maximum seaward overhang	25–40 m
• Landward overhang	5–25 m

Large quayside gantry cranes may serve vessels up to 18 container rows, while several terminals around the world are already operating gantries capable of serving vessels 22-boxes wide with outreaches more than 60 m, serving super post Panamax vessels. Among the advances in gantry technology the twin-lift spreaders are worth mentioning, capable of handling two 20-ft boxes simultaneously. The critical operating parameter of a dock gantry crane is its output, which should be as high as possible to reduce vessel berthing time. For this reason, methods of making the loading/unloading cycle at the dock independent of the transport cycle of the boxes to open-air storage are employed, to attain a continuous supply to and removal of containers from the dock gantry crane. Extensive land areas, required for storage of containers forwarded through a terminal, constitute the distinguishing characteristic of specialized container terminals. In the case of

Table 1.6 Selected container sizes

ISO Type	TEU	External Dimensions (m)	Maximum Lifting Capacity (tons)	Cubic Capacity (m^3)
1C (20 ft)	1	6.05 × 2.435 × 2.435	20	29.0
1A (40 ft)	2	12.190 × 2.435 × 2.435	30	60.5
1B (30 ft)	$1\frac{1}{2}$	9.125 × 2.435 × 2.435	25	45.0
1D (10 ft)	$\frac{1}{2}$	2.990 × 2.435 × 2.435	10	14.1

imports, containers are transferred from docks to the stacking yard, for pickup a few days later for overland transport. The reverse procedure applies for exports. The simplest handling procedure involves the use of container chassis such as the one depicted in Figure 1.13.

The procedure followed in the case of imported containers involves the following stages:

- Loading of the container by dock gantry crane onto a container chassis
- Transport of container chassis by tractor to the storage area
- Chassis and container retained in storage area until delivery

Unloaded container chassis are parked in a dedicated lot. In a storage area, containers may be handled by straddle carriers, miscellaneous rubber-tired high-lift (front loader) high-reach stackers, and so on. For details, consult Chapter 2. Loaded containers may be stacked to a maximum height of three or four, depending on the type of equipment used. Empty containers may be stacked six or seven high. Representative examples are shown in Figures 1.14 through 1.16.

The minimum width of corridors between container rows in a linear layout is approximately 1.20 m, to enable access by a straddle carrier's legs. Circulation lanes are provided at regular intervals, forming a road network for the use of straddle carriers and other vehicles. These lanes have a minimum width of 12 m when they have to allow for turning of the rubber-tired straddle carrier, and 5.5 m in other cases. Usually, free gaps about 0.80 m wide are also allowed between the smaller surfaces of adjacent containers to facilitate handling, inspection, and so on.

This handling system may be simplified as regards the variety of equipment. Thus, tractors and chassis may be replaced by rubber-tired straddle carriers so that the latter also carry out the transport of containers from docks to the storage area. However, using straddle carriers for long distances does not put them to optimum use. Other disadvantages of these vehicles include the problem of requiring frequent maintenance and repairs and providing limited visibility to the operator; on the other hand, they are exceedingly versatile machines. Recent technical developments in straddle carriers include the incorporation of twin spreader systems, similar to those used in quayside gantry cranes.

Another method of cargo handling in the stowage area is through use of special gantry cranes with a 45-ton lifting capacity that can stack containers four, or even five, high (Figure 1.14). These gantry cranes, usually called *portainers,* may move on rails, spanning about 20 container rows. They can also be fitted with tires, in which case they have a smaller span, in the region of six or seven container rows and smaller stacking capacity; usually three to four container height. Portainers on tires are, however, more versatile and capable of being applied to various operations.

Stowage gantry cranes are preferred in container terminals with large throughput, particularly export traffic, and are amenable to adaptation for automated applications in container placing and identification. It is noted that information technologies are applied increasingly in most operations that take place in modern container terminals, not only in box stacking. A recent attempt toward full automation between dockside and yard was manifested in the design of dockside and stacking gantries with overlapping reaches.

Yard gantry cranes may also be used to move containers between open-air storage and rail or road vehicles. The handling systems above may be combined to suit the requirements of any particular port terminal. It is evident that with exports, a higher stacking height

Figure 1.14 Containers stacked in storage area by gantry crane.

can be accepted than in the imports section because of the reduced probability for additional maneuvers to reach an underlying container in the stack.

Overhead cranes were recently introduced in Singapore port. These are capable of stacking nine boxes high spanning ten rows across. They are operated remotely, having a high degree of automation built in.

New ideas on container storage are also being considered to replace the method of placing the boxes on the ground with automated racking systems.

1.4.3.3 Storage Yard. Containers remain in open-air storage areas for a few days until they are forwarded to either sea or land transport. Indicative average values of waiting time for imported containers is roughly 6 days, and 4 days for containers destined for export, while empty containers usually remain in port about

Figure 1.15 Containers stacked by high-reach stacker with telescopic boom.

10 to 20 days. The required container storage area depends on the stowage method and available equipment. Table 1.7 lists the area required per container, including space for access to the corresponding handling equipment.

The vehicle access lanes at the container terminal should have a width of 3.5 m for trucks or trailers, 5.5 to 7.0 m for straddle carriers, and 5 m for side loaders. In 90° bends, the widths above become 6, 12 to 15, and 7.5 m, respectively. Front-loading forklifts require an access lane of width equal to the length of the containers handled, increased by a safety margin of approximately 1.0 m on each side.

The performance of various transport and stacking equipment may be calculated by the time it takes to stack (or to remove) a container

Figure 1.16 Container storage area; typical linear container stacking configuration.

Table 1.7 Gross storage area requirements

Stacking Method	Container Height (no. containers)	Storage Area (m^2/TEU)
Trailer	1	65.0
Straddle carrier	3	10.0
	4	7.5
Gantry crane	3	10.0
	4	7.5
	5	6.0
Forklifts, side loaders	2	19.0
	3	13.0

and by the average speed of the vehicle. Stacking time ranges from 0.5 to 1 min for straddle carries, 1 to 2 min for forklifts, and 2 to 4 min for side loaders. Average speed ranges from 450 to 500 m/min for trucks, tractors, and side loaders, to 400 to 430 m/min for straddle carriers, and 300 to 350 m/min for forklifts.

The storage area, E, in hectares required in a container terminal may be calculated using the relation

$$E = \frac{QD}{3560} \frac{e}{f} \left(1 + \frac{p}{100}\right) \qquad (1.9)$$

where Q is the number of containers handled annually (thousands of TEU), D the average container waiting time (days), e the area required per TEU (m^2; taken from Table 1.6 on the basis of the maximum possible height), f the ratio of average to maximum stacking height, and p the peak factor (%).

The working surface of an open-air storage yard is designed according to the type of container equipment used. It could be either paved or simply gravel covered. Usually, heavy forklifts impose stricter requirements on road surfaces than do tractors or straddle carriers. The rolling zones of portainers on tires are usually reinforced. The U.K. guidelines indicate the need for a minimum thickness of bituminous surfacing of 18 cm to avoid reflective cracking due to the cement-bound base. Bituminous surfacing is relatively inexpensive, but it can be damaged by corner castings in the container storage area. Cast-in-situ concrete is more expensive, inflexible, but generally hard-wearing. The other options include gravel, reinforced concrete plinths with gravel or other infill, and block paving. Gravel is the cheapest option, but it tends to spread onto adjacent readways, to get stuck in corner castings of boxes, and to render slot marking difficult. Block paving is relatively expensive but is being accepted as the most flexible surfacing for storage yards, since it allows lifting and relaying of damaged sections.

The yard surface should display a 1:40 to 1:50 gradient for efficient runoff of rainwater. However, a yard surface should ideally be horizontal for box stacking, so a compromise of about 1:100 gradient is generally used. Continuous slot drains or individual catch pits provided along roadways collect runoff and discharge it to outfall pipes. The terminal-included yard and gates should be amply illuminated to ensure efficient round-the-clock operations. Lighting is generally provided by high-mast columns, typically 30 to 50 m high. Layout of columns should be considered carefully to avoid risk of collision or taking up vital space in the storage area, achieving at the same time a more-or-less uniform illuminance. Fire-fighting facilities in the form of fire hydrants should also be provided throughout the terminal, including the storage yard. Hydrants can be in pillars or in pits, the latter case requiring a standpipe to be attached before hoses can be connected. A typical paved surface storage yard is shown in Figure 1.16.

1.4.3.4 Container Freight Station and Other Areas. A percentage of the containers handled at a container stripping terminal pass through a special shed, where chartering, container repacking, stuffing, and cargo reallocation operations are conducted. This shed, called a *container freight station* (CFS), should have a capacity calculated on the basis of 29 m^3 per TEU. The CFS's design area, S (in thousands of m^2), can be estimated by the formula

$$S = \frac{QD}{365}\frac{29}{h}(1 + r)\left(1 + \frac{p}{100}\right) \quad (1.10)$$

where Q is the annual CFS container throughput (thousands of TEU), D the average duration of stay (days), h the average stacking height (m), r the access factor (accommodating space for lanes, maneuver areas, etc.), and p the peak factor (%).

Along the two long sides of the shed, containers and trailers are served, respectively, to facilitate repacking operations. Trucks can park outside or even within the station. The CFS is usually located at the rear of open-air storage areas of the terminal. It is possible, however, in case the land required is not available within the terminal, to plan for this installation at a distance from the port, and to maintain an exclusive connection with it. This arrangement is preferred, for example, when an expansion of an existing port within an urban area would otherwise be required in an area where obtaining additional space normally presents a problem. Figure 1.17 indicates the two arrangements in question.

In addition to open-air storage areas and container freight stations, other spaces are needed to cover requirements, such as maneuvering for land vehicles (road or rail), personnel parking, customs, administration building, refrigerated containers, storage of hazardous or flammable materials, and maintenance workshops. These additional installations amount to about 2 to 3 ha per berth.

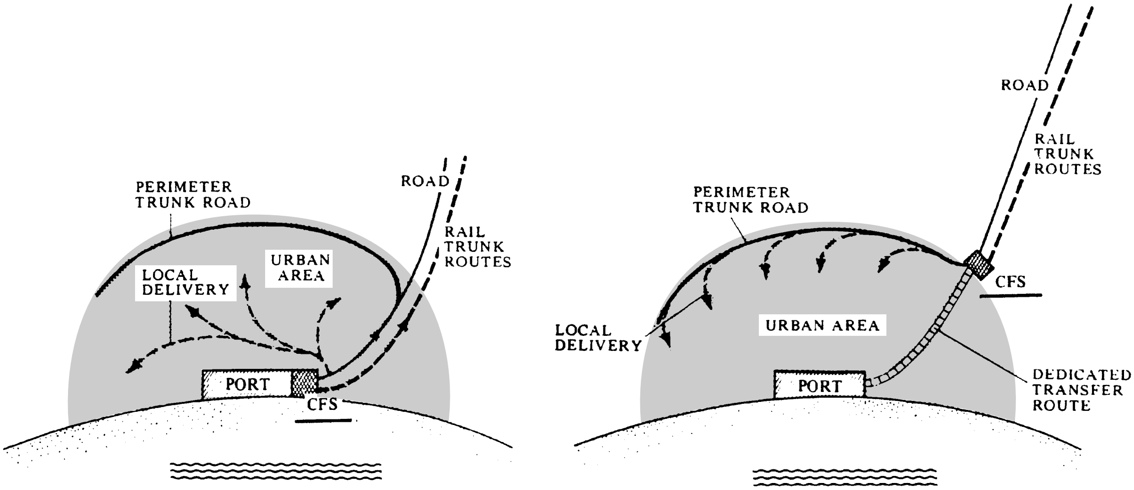
1.4.3.5 Berths. Another parameter required for the design of container terminals is the number of berths required. To estimate this number, the number of berth-days needed annually, D, is calculated initially using the relation

$$D = \left(\frac{T}{HPm} + \frac{1}{12}\right)C \quad (1.11)$$

where T is the ship's cargo to be loaded or unloaded (TEU), H the vessel working time per day, P the average quantity of TEU handled hourly per crane (including work stoppages or breakdowns), m the cranes per berth (allowing for an efficiency factor as follows: 1 crane/berth: $m = 1.0$; 2 cranes/berth: $m = 1.9$; 3 cranes/berth: $m = 2.4$; 4 cranes/berth or more: 80% efficiency per crane), and C the annual number of vessels calling at the container terminal.

It should be pointed out that the real-life data of crane productivity vary significantly between ports. However, a design figure of 120,000 TEU per crane per year can be used for initial planning purposes. To convert the annual number of berth-days into the number of berths required for the terminal, an optimum level of vessel servicing has to be determined, after having analyzed the corresponding waiting queue.

For specialized container terminals, the assumption is usually made that the time intervals between successive vessel arrivals do not follow the negative exponential distribution applicable to general cargo terminals (see Section 1.4.2.2), but rather, follow an Erlang distribution, with $K = 2$, because here there is some regularity of container ship arrival compared to that of general cargo vessels. It is further assumed that vessel servicing time follows an E_2 distribution as well. Table 1.8 gives the average waiting time (congestion factor) for an $E_2/E_2/n$ queue as a percentage of servicing time for various degrees of berth use (occupancy). Using the data of Table 1.8, the choice of the suitable number of berths for a container terminal is calculated by eq. (1.11) through trial and er-



(*a*) (*b*)

Figure 1.17 Location of a CFS within (*a*) and outside (*b*) a port.

Table 1.8 Congestion factor in queue $E_2/E_2/n$

	Number of Berths							
Occupancy	1	2	3	4	5	6	7	8
0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.15	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.20	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.25	0.09	0.02	0.01	0.00	0.00	0.00	0.00	0.00
0.30	0.13	0.02	0.01	0.00	0.00	0.00	0.00	0.00
0.35	0.17	0.03	0.02	0.01	0.00	0.00	0.00	0.00
0.40	0.24	0.06	0.02	0.01	0.00	0.00	0.00	0.00
0.45	0.30	0.09	0.04	0.02	0.01	0.01	0.00	0.00
0.50	0.39	0.12	0.05	0.03	0.01	0.01	0.01	0.00
0.55	0.49	0.16	0.07	0.04	0.02	0.02	0.01	0.01
0.60	0.63	0.22	0.11	0.06	0.04	0.03	0.02	0.01
0.65	0.80	0.30	0.16	0.09	0.06	0.05	0.03	0.02
0.70	1.04	0.41	0.23	0.14	0.10	0.07	0.05	0.04
0.75	1.38	0.58	0.32	0.21	0.14	0.11	0.08	0.07
0.80	1.87	0.83	0.46	0.33	0.23	0.19	0.14	0.12
0.85	2.80	1.30	0.75	0.55	0.39	0.34	0.26	0.22
0.90	4.36	2.00	1.20	0.92	0.65	0.57	0.44	0.40

Figure 1.18 Small craft harbor at Monaco.

ror after estimating the days at berth required annually. Typically, a key performance indicator for a container terminal is the number of TEUs handled per annum per linear meter of quay. Based on data from major international container terminals, a design figure of 1000 TEU per annum per linear meter of quay may be used for the initial planning of well-equipped facilities.

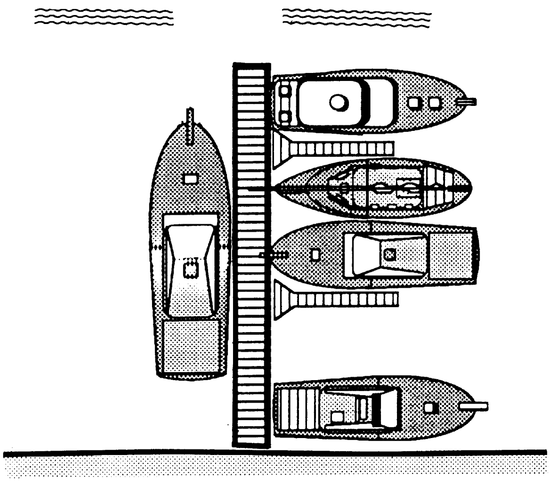
1.4.4 Marinas

1.4.4.1 Basic Design Criteria. Marinas provide harboring and supply and repair services for pleasure boats. Recently, marine tourism and other recreational activities, such as amateur fishing and sailing, have increased rapidly worldwide, with a corresponding increase in pleasure craft and in a requirement for mooring spaces. To be classified as a fully developed marina, a harbor should satisfy certain criteria that extend beyond the provision of mooring slots. These services include water and bunker supply, availability of a repair unit, vessel lifting and launching arrangements, a supplies and provisions outlet, and vessel dry berthing. An example of a fully developed small craft harbor is shown in Figure 1.18.

Pleasure boats fall mainly into two categories: motor-powered and sailboats. Boats of these categories differ with regard to the geometric characteristics necessary for designing the moorings and in general, all the elements of a marina. The percentage of participation of

Table 1.9 Typical design parameters of pleasure boats

Length (m)	Number of Vessels (%)	Powerboats (%)	Sailboats (%)	Draft (m)		Beam (m)	
				Powerboats	Sailboats	Powerboats	Sailboats
0–5	50	40	10	0.80	1.40	2.20	1.80
5–9	30	21	9	1.00	2.00	3.60	3.00
9–12	10	5	5	1.20	2.40	4.10	3.40
12–15	7	4	3	1.040	2.080	4.80	3.90
15–20	3	2	1	1.660	3.40	5.30	4.40
Total	100	72	28				



(*a*) (*b*)

Figure 1.19 Typical moorings.

each category in the total number of vessels to be serviced in the marina depends primarily on the country and the marine region involved. Over time, these percentages vary in accordance with the development of this type of recreation as well as other parameters. A typical allocation of pleasure boats into the two categories above and five length classes is given in Table 1.9, where the figures refer to typical dimensions of the largest vessel in each class.

1.4.4.2 Dock Layout. Marinas possess docks, often floating docks, for vessel berthing, which may be either parallel (Figure 1.19*b*) or perpendicular (Figure 1.19*a*) to the quay line. Perpendicular berthing is effected either with light buoys, fixed or dropped anchors, or through the use of fingers. Fingers placed perpendicular to the main dock form single or double boat slips. Usually, single boat slips are for the use of relatively large boats; smaller boats are accommodated in double boat slips. Figure 1.20 indicates a mooring method in a double boat slip. For purposes of economy, the length of a finger may be designed to be smaller than that of the largest boat by a percentage depending on the size of the boat to be served. The ratio of finger length to the largest boat length may be a minimum (according to British Standards) of $\frac{3}{4}$ for boats up to 10 m, $\frac{7}{8}$ for lengths up to 15 m, and 1.0 for larger boats. Obviously, it is advisable that this reduction in length be applied in comfortable navigating conditions and low environmental loads, such as wind and waves.

Navigation channels within a harbor basin should be sufficiently wide to permit the necessary maneuvers. For comfortable conditions, this width should be $2L$ for motorboats and $2.5L$ for sailboats, where L is the length of the design boat. In sheltered areas and favorable conditions, the channel width can be reduced to $1.75L$ or even $1.5L$, measured between fixed or movable obstacles, such as between fingers or moored boats. The width of boat slips B de-

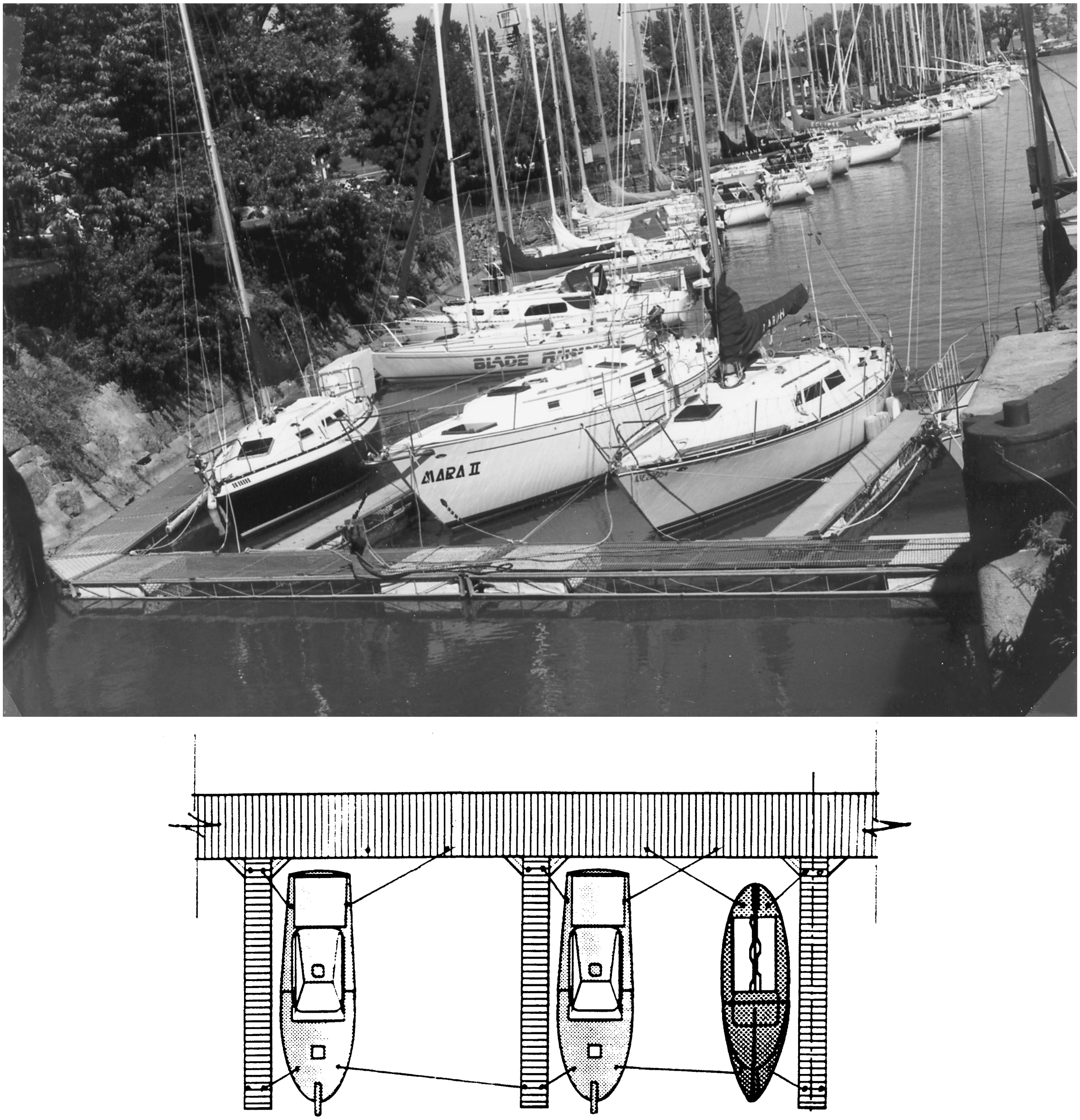


Figure 1.20 Vessel mooring in a double boat slip.

pends directly on the beam of the maximum boat W to be served. For a single boat slip it is $B = W + 2C_1$; for a double boat slip it is $B = 2W + 3C_2$ where C_1 and C_2 are the respective safety clearances. These depend on boat size, and according to the American Society of Civil Engineers (ASCE, 1994), they are as given in Table 1.10.

Usable water depth at slips and channels should be maintained at 0.50 to 1.00 m greater than the maximum draft of vessels using the marina. In moorings without fingers, a common type of mooring arrangement in the Mediterranean, safety clearances between moored boats are maintained at 0.5 m for boats up to 7.5 m long, 0.75 m for boats up 12 m, and 1.0 m for larger boats. Finger width lies around 0.9 m for finger lengths between 9 and 11 m and 1.2 m for lengths between 12 and 15 m.

The width of floating docks at which the fingers are connected at right angles depends on the total length of each dock, which is related directly to the number of people using them. The figures in Table 1.11 are typical dock widths for marinas of rather high-level specifications. Access between floating docks and fixed marginal quays is achieved by means of articulated ramps, as shown in Figure 1.21. These ramps are usually hinged on the fixed quay while the other end, resting on the floating dock, is fitted with a connecting plate rolling on the floor of the floating dock. The maximum longitudinal ramp slope is 1:4 ($m = 4$), the usable ramp width $W = 1.20$ m, and the rail height $H_r = 1.10$ m above the walking surface.

Table 1.10 Safety clearances in boat slips

Boat Length (m)	C_1 (m)	C_2 (m)
7.3	0.46	0.41
9.7	0.60	0.51
12.2	0.76	0.61
15.2	0.91	0.71
24.3	1.06	0.81

Table 1.11 Floating dock width

Dock Length (m)	Dock Width (m)
Up to 100	1.5
100–200	1.8
Above 200	2.4

1.4.4.3 Floating Docks. Floating docks are commonly adopted to ensure the availability of mooring slots in marinas, because of the relatively small loads they receive from berthed vessels and operation loads. They are made up of floats on which passageway decking, usually wooden, is fitted. The floats may be either full or hollow, and they are basically constructed of expanded polystyrene, fiberglass, or plain concrete. Floating docks are anchored through gravity anchors and chains or by vertical piles that prevent horizontal movement. An example of a gravity anchor is depicted in Figure 1.22. Gravity anchor design calculations are made using the customary methods for floating bodies. In these methods, boat impacts and wind forces on berthed boats have to be considered. Dock fingers are lighter constructions designed similar to floating docks. For more recent information on mooring systems for recreational craft, readers are referred to data from the Permanent International Association of Navigation Congresses (PIANC, 2002).

1.4.4.4 Marina Services. A well-organized marina possesses a range of facilities and equipment for its users.

Freshwater Supply. Water pipes—generally, those of the local water supply network—run the length of the docks and supply water to vessels through appropriate outlets. Usually, fire hydrants are provided in a water supply network. They are positioned at approximately

Figure 1.21 Articulated access ramp to a floating dock.

50-m intervals and are equipped with a 1.5-in. flexible hose kept at special firefighting points. Fire hydrants are attached to water mains of relatively large diameter, typically 2 in. or more. As water is not the most suitable firefighting means for a fire caused by fuel or an electrical short-circuit, there is a tendency to replace conventional fire hydrants with chemical fire-extinguishing equipment located appropriately in the marina.

Roughly 1-in.-diameter pipes are needed for water supply of adequate pressure, excluding firefighting service, to serve up to 50 mooring slots. Flexible pipe sections are placed at crossings between floating elements and at shore connections to absorb the corresponding movements. Pipelines exposed to the sea are made of plastic or steel to avoid corrosion. Measurement of water consumption can be made centrally for the marina as a whole or individually at outlet points. The points of water supply are frequently combined with the power supply within special pillars.

Power Supply. Power supply sockets should be provided along the length of docks to provide an electric current of 20, 30, or 50 A at 120 or even 230 V. Typically, every vessel exceeding 6 m in length should have access to the relative power outlet. Cabling is arranged in special ducts or suspended lengthwise along docks, to satisfy safety regulations. Grounding is provided by means of returns to shore. The marina lighting network is arranged in parallel with that of the power supply. The lighting fixtures are either incorporated in the supply

Figure 1.22 Raw iron gravity anchor used for anchoring of floating docks.

points or are mounted on independent poles preferably 3 m in average height.

Telephone Connection. The telephone system offered by each marina depends on the needs of the particular situation and in conjunction with cost, on the level of services offered. There have been systems of full coverage, with suitable supply points at each mooring position, and others with a telephone switchboard and paging or with the more accessible method of card-operated phones. In any event, the development of cellular telephony has nearly eliminated the need for providing telephone service to marinas.

Waste Disposal and Sewerage. An increasing number of pleasure boats possess systems for disposal of their accumulated waste by means of pumping. It would be useful to provide, preferably on a fixed dock, appropriate intakes and conduits connected to the local sewerage network. For solid waste, garbage dumpers are placed at suitable locations, accessible to garbage trucks.

Storage Lockers. Many marinas provide lockers for the storage and safekeeping of provisions, equipment, and so on, close to the moorings. These lockers may be combined with the water or power supply stands described above.

Bunker Supply. A bunkering point can be situated on an appropriate berth of the marina, connected to shore storage tanks. Pumps with measuring devices are located on this dock. Care must be taken to avoid accidents, such as fuel leakage into the marina basin. Bunker supply points are usually combined with installations for receiving slops and removal of chemical substances from boats' tanks. Frequently, design of the fuel supply is assigned to companies engaged in marina bunkering.

Cleats and Fenders. Along the length of docks, cleats or light bollards are to be provided at suitable intervals. In the case of alongside berthing, these will be located at either end of the berthing place, with one more in the middle for vessels exceeding 10 m. Cleats are manufactured of rustproof alloys or of hardwood. Boats can also be tied fast on piles, placed for this purpose along lines parallel to the docks, thus delimiting the boundaries of the navigation channels within the marina. In addition, floating dock guide piles may also be used for mooring purposes. Fenders of fixed or floating docks constitute serious equipment for the safety of both vessels and marina installations. Various types of fenders are used, such as continuous rubberform alongside a dock, single tires hanging vertically on the sides of the dock, or vertical wooden or plastic fenders for soft contact.

Vessel Lifting and Launching Installations. Boat lifting and launching procedures are a significant part of an organized marina. A large variety of lifting arrangements could be used as required. The commonest arrangements for vertical lifting in marinas are the travel lift, the fixed jib crane with horizontal boom, the special forklift, and the monorail. The travel lift (Figure 1.23) is equipped with a crane mechanism mounted on a steel frame usually fitted with rubber tires. It travels along and above the water surface of a boat slip so that it can be placed above the boat to be lifted. Travel-lift frames can be open at one end for servicing sailboats. Lifting a vessel is done using appropriate nylon slings.

A fixed jib crane (Figure 1.24) with a horizontal boom is placed in an appropriate location in a marina and at such a distance from the dock as to avoid damage from a potential collision with the dock wall of boats being lifted. The transfer of significant point loads from a crane on the quay wall should be taken into consideration in the design of the latter.

A special forklift possesses a vertical stem that enables the forks to reach below the bottom of the boat to be lifted. The forklift approaches the dock, alongside which a suitable retaining bar has been fixed to avert accidents. A safety margin between the movable parts of the forklift and the vertical dock wall should also be factored into the design. These forklifts may be used for boat storage during the winter layup period. An example of multilayered winter storage of pleasure boats is depicted in Figure 1.25.

Finally, monorails are easy-to-use installations since the conveyor holding the vessel moves by remote control. The conveyor is suspended over rails running centrally along the length of the monorail. The monorail is placed transversally to the dock and extends over the sea by means of a protruding beam to enable vertical lifting and relaunching of vessels. Figure 1.26 indicates the approximate relation between the length and weight of motor-driven craft and sailboats, from which the required lifting capacity of the marina's equipment can be estimated.

The commonest method of launching relatively small boats, which normally constitute the majority of vessels, is by use of launching ramps. These are slopes extending above and below sea level with nonskid surfaces formed by means of deep, gently sloped grooves of sufficient width. The vehicles that are to pull out or launch boats approach these ramps laterally with special trailers and make use of the wire rope that holds the vessel. A submarine

Figure 1.23 Travel lift frame for launching and retrieving pleasure boats.

horizontal gravel mound is provided to stop a vehicle from falling into the sea in the event of an inability to brake. The ramp width is a minimum of 5 m. A sufficient expanse for parking vehicles pulling boat-bearing trailers should be provided for in a suitable location close to the ramp. Moreover, this area should also contain a space for rinsing seawater off the vessel, the trailer, and the boat. Runoffs should be collected for treatment because it usually contains oil, mud, and so on, that should not be allowed to flow back freely into the harbor basin. Embarkation and disembarkation docks and berths for boats waiting their turn to be lifted should be situated near the launching slip. In areas with weak tides, small floating ramps may be used for relatively small vessels. Table 1.12 summarizes the basic characteristics of the primary vessel lifting and launching systems.

Auxiliary Buildings and Installations. A well-organized marina should contain a number of auxiliary buildings and networks that should be arranged and designed according to the needs they are to serve. The following are the most important such buildings and installations:

- *Marina administration building*. This structure houses the administration, accounts, inquiries, telephone switchboard, and so on.
- *Harbor master's building*. This structure is used to house the navigation and security

Figure 1.24 Fixed jib crane.

services. It may be combined with the administration building.

- *Boat repair shop*. This building or area constitutes a point of attraction for many pleasure boats. It may be designated only for small or for larger vessels, in which case the arrangement for vessel lifting and transfer to the boat repair shop is designed accordingly. A range of equipment from simple wheeled carriers to powerful lifts and rails are used for the transport of vessels to and from the repair shop.
- *Repair and maintenance building*. This structure is used for land equipment and machinery. Usually, this building is combined with the vessel repair shop if a shop is provided.
- *Provisions kiosk*. All types of consumables and durable goods related to operation of the marina may be supplied through a shop in the marina, as part of the administration building or otherwise.
- *Sanitation areas*. Approximately one toilet for each 15 mooring places should be provided at intervals of less than 300 m.
- *Road network, utilities networks, and lighting*. These are designed as for urban areas.
- *Entrance gate and fencing*. Security is always a sensitive issue in marinas, and special care should be given to protection from theft and vandalism. Fencing of the marina land area and safeguarding of its perimeter contribute a great deal.

Figure 1.25 Winter storage for pleasure boats.

- *Parking lots*. Attention should be paid to ensure adequate parking space for marina users, with clear signposting and unobstructed traffic flow. A typical parking place with a trailer occupies an area of 3 m by 12 m.

Boat Dry Stacking. A good number of marinas provide shore areas for laying-up vessels ashore. Dry stacking of boats is preferred by many users because of the improved maintenance achieved (washing with sweet water, etc.), but it adds extra capacity to the marina. Under normal circumstances, dry storage is provided for vessels smaller than 2 tons, but if the marina possesses the appropriate mechanical equipment, much larger vessels can be laid-up ashore. Table 1.13 lists typical dimensions and weights of pleasure boats for dry berthing.

The majority of small sailing boats, under 4.5 m, are placed by hand, keel upward, on special shelves, after their mast has been removed. Motor vessels under 7 m are placed on shelves by forklift, keel downward (Figure 1.25). The stacking areas may be open-air or sheltered. Larger vessels, both sailboats and motor vessels, are usually placed on special trailers which are drawn by their owner's vehicle from and to the storage area. When the storage is done on scaffolding, marina personnel undertake handling of the vessels. The lifting and launching equipment methods referred to previously are employed. Moreover, special arrangements can be used that combine lifting

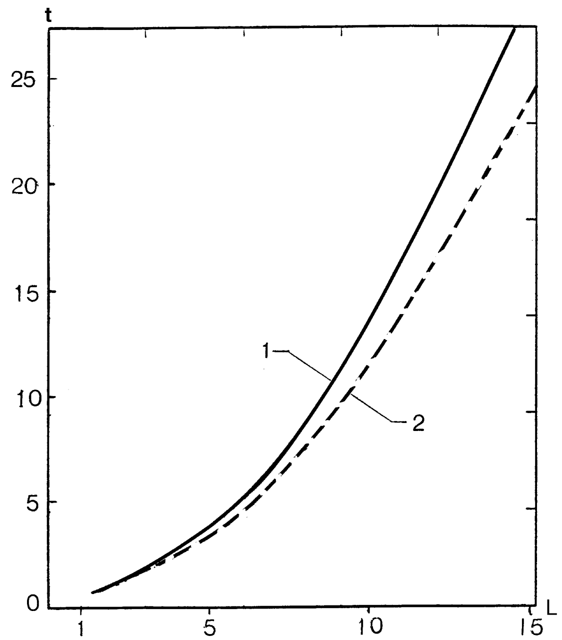


Figure 1.26 Approximate relation between length and weight of pleasure boats. 1, Motorboats; 2, sailboats. *Note: L* in meters, *t* in tons. (Adapted from U.S. Army Corps of Engineers, 1974.)

and launching with transport and stowage at the dry berthing positions. Such an arrangement may include a forklift suspended from a gantry crane operating in a covered vessel slip. The layup slots are arranged appropriately on scaffolds along the wet slip perimeter.

One of the advantages of laying-up ashore is that a marina requires a far shorter quay length than that of conventional mooring arrangements, amounting to approximately 15% of the latter. The total required marina area is smaller than the corresponding surface for wet berthing. For instance, a 200-vessel marina of an average 6.5-m-long vessel with 22-m-wide navigation channels requires roughly the surfaces denoted in Table 1.14 when it uses exclusively wet or dry berthing.

Marina Water Renewal. Marina basins frequently suffer from seawater pollution deriving from the marina area and also directly from craft using the marina. Pollution of the surrounding region may result from wastewater or stormwater effluents discharging in the marina basin and from surface water that carries a sig-

Table 1.12 Principal vessel lifting and launching system characteristics

No.	System	Lifting Capacity (tons)	Number of Vessels Transferred Daily	Turnover Cycle[a] (min)	Appropriate for Large Tide Fluctuation
1	Dry dock	Adequate	1–2	20–60	Yes
2	Slipway	Adequate	1–6	20–60	Yes
3	Lifting platform	Adequate	1–10	20–50	Yes
4	Ramp and tractor/trailer	5	100–250	3–8	No
5	Crane and trailer	15	20–50	20–40	Yes
6	Monorail	20	30–80	10–30	Yes
7	Forklift	2	100–250	3–8	No (special accessory required)
8	Travel-lift with straps	250	~50	10–20	Yes

Source: Adapted from PIANC (1980).

[a]Lifting, landing of vessel, and return of equipment to its original position.

Table 1.13 Typical dimensions of vessels for dry stacking

Boat Class	Beam (m)	Length (m)	Height (m)	Weight (tons)
I	<2.40	<5.40	0.90–1.50	<1.25
IIa	2.40^{-}	4.80–6.30	1.20–1.80	0.75–1.75
IIb	2.40^{+}	5.40–7.20	1.50–2.10	1.75–2.75
IIIa	>2.40	6.30–7.80	1.65–2.40	2.25–3.25
IIIb	>2.40	7.50–8.70	2.10–2.70	3.00–4.25

Source: Dry Stack Marinas, Florida.

Table 1.14 Typical space requirements in a small marina (thousands of square meters)

	Berthing	
Marina Surfaces	Dry	Wet
Land	9.5	5.1
Sea	2.5	13.2
Total	12.0	18.3

nificant polluting load. Boats may give rise to pollution through effluents from washing, garbage, oils, and so on. In each case the possibility exists to avoid seawater pollution through appropriate design of networks in the surrounding region by not allowing discharges within the port and by providing for the collection of garbage and other refuse from the boats, as mentioned above. At the same time, pertinent regulations governing protection of the marine environment have to be enforced.

In any case, frequent renewal of marina water is desirable to avoid potential eutrophication due to the lingering pollution. For this reason, marinas with two sea entrances have an advantage as regards their ability to enhance some streaming motion, which boosts the exchange of marina waters with offshore seawater. Usually, an effort is made to invigorate these streams by leaving openings at key locations across the protection structures. It is obvious that the problem becomes even more acute in regions with a weak tide, such as the Mediterranean. It has been estimated that the water quality begins to be unacceptable when the period of water renewal exceeds roughly 10 days. In severe cases, when no other method of coping with a problem is available, recourse can be taken to mechanical mixers, which are positioned in the marina basin to create artificial water circulation, thus renewing the polluted water. For detailed information associated with small craft marina design, construction, and operation, readers are referred to a work by Tobiasson and Kolmeyer (1991).

1.4.5 Fishing Ports

1.4.5.1 Main Features. Annual world sea fishing products amount to approximately 100,000,000 tons, with China providing one-fifth of the catch. Of this quantity, 28% is converted into fishmeal, the balance being consumed by people (29% fresh fish, 12% canned, 8% cured, and 23% frozen). Fishing ports serve professional fishing vessels and demonstrate a series of particularities which differentiate them from other commercial ports. These particular characteristics are summarized below.

The services that a fishing port is required to provide to fishing vessels are not limited to safe mooring to discharge the catch. The port should also be able to provide a suitable number of places for safe anchorage to fishing vessels during long periods of inactivity. Due to the nature and duration of the stay of such fishing vessels at port, the mooring types and rules of safe clearances determining the berthing positions of vessels are less strict than those for a commercial port.

In addition to being a refuge, a fishing port should possess small to medium-sized shipbuilding and repair facilities. This is because in addition to conducting purely repair work, fishing vessels conduct their regular maintenance work while in port. Thus, fishing ports should provide all the necessary means to ensure a minimum level of maintenance of the fleet they serve. Similarly, there are significant differences between the land zone of a fishing port and that of a conventional commercial port. For a fishing port, there is the systematic conduct of commercial activity regarding the catch, with the frequent presence of industrial units for processing and packaging. Consequently, the nature of a fishing port expands and it no longer acts as a hub in a combined transport system as is the case with conventional ports. Rather, it evidences the features of a commercial and industrial zone, and its land area is set out accordingly.

Moreover, it should be noted that in most fishing ports no exporting sector exists, and consequently, only unloading of vessels is carried out at the docks. In line with the specific requirements and characteristics above, a fishing port may include, in addition to loading wharves and mooring positions, the following elements:

- Repair docks
- Launching ramps
- Repair workshops
- Open-air spaces for drying nets and repairing nets and vessels
- Provisioning and equipment stores
- Sheds for storage of ships' gear
- A sheltered area for cleaning and sorting the catch
- A sheltered area for exhibiting the catch and for conducting the relevant commercial transactions
- Offices and ancillary areas
- Fish processing and packaging units
- Refrigerators for maintenance of the catch
- An ice-making unit
- Fuel, power, fire safety, and water supply networks
- Open-air areas for fish drying

There are a large variety of fishing vessels, and therefore the periods when vessels are away at sea for fishing vary accordingly. Vessels fall under the following categories:

I. Small vessels up to 30 gross registered tons (GRT), capable of putting out to sea for 1 day. These vessels are usually not equipped with refrigerating equipment.

II. Medium-sized vessels between 30 and 150 GRT, with a fishing autonomy of about 1 week. These vessels are equipped with a refrigerated hold.

III. Deep-sea vessels over 150 GRT, equipped with refrigeration and deep-freeze installations. Times out at sea for this category usually extend to 1 month. Such vessels may reach the 2000-GRT size.

IV. Large specialized industrial vessels.

Figure 1.27 shows the type of packing and respective processing stages of the catch toward consumption corresponding to the categories of fishing vessels above.

1.4.5.2 Design Criteria for Marina Installations. In each case, the design vessel determines the scale of a port and its constituent

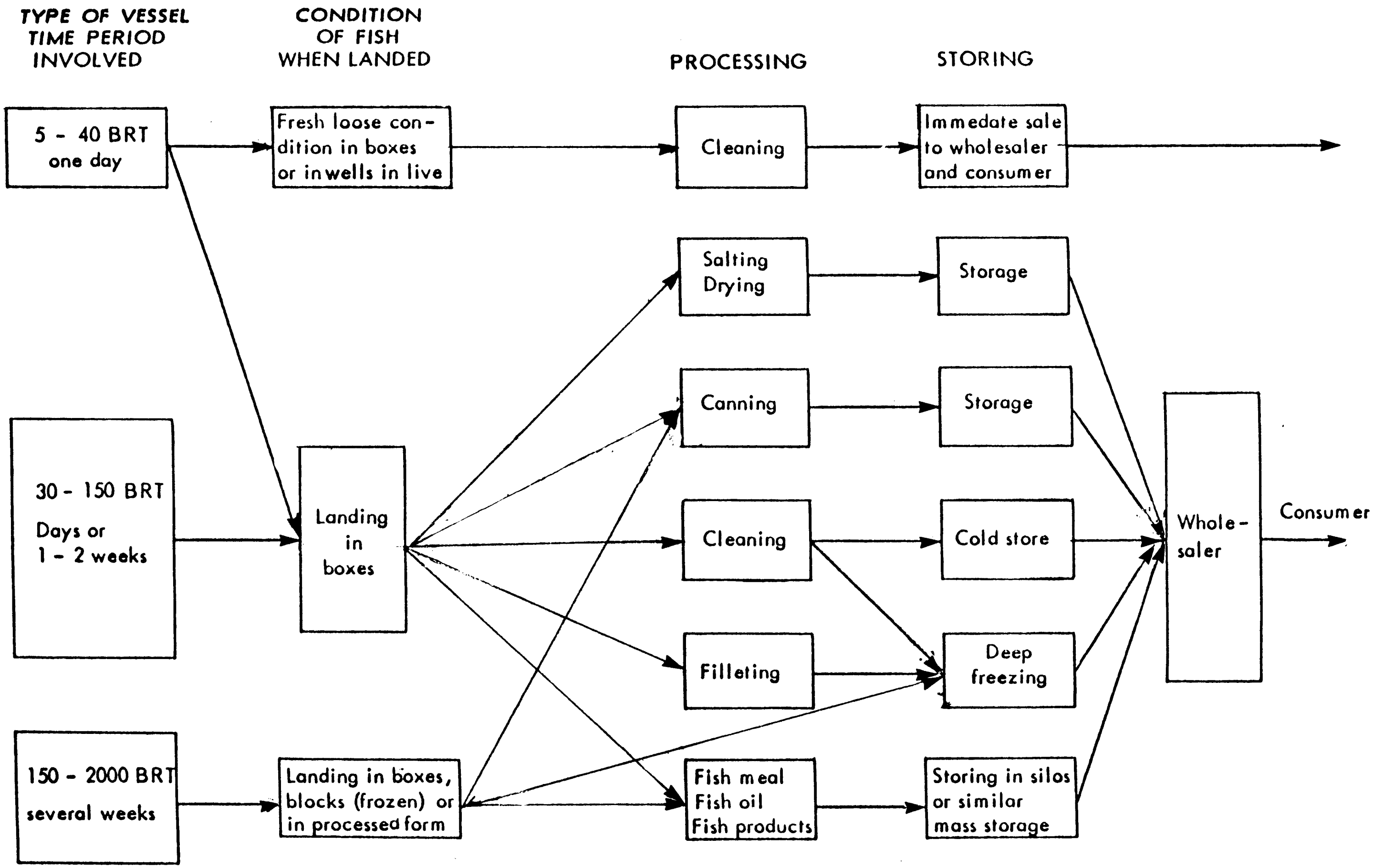


Figure 1.27 Processing methods of catch and distribution stages. (After Bruun, 1981.)

elements. Thus, depending on vessel size, the entrance width of a port usually ranges between 20 and 120 m. Table 1.15 lists typical dimensions of fishing vessels falling under the categories listed in Section 1.4.5.1. Based on the earlier discussion, an indicative fishing cycle for each vessel category is given in Table 1.16. The total duration of the cycle consists of days at sea and days in port for unloading and provisioning, from which an estimate of the required moorings can be made.

Repetition of the fishing cycle within the year depends on climatic conditions, the pertinent regulations determining the fishing period, local conditions, and repair and maintenance requirements. Category III or IV vessels usually need two months annually for such work, while smaller vessels take up a significant portion of their overall time for repairs and maintenance. These percentages may vary according to region; thus the allocation of overall time by vessel category listed in Table 1.17 is purely indicative and should always be adapted to local conditions. In a fully developed fishing port, the functions in the second to fifth columns in Table 1.16 are conducted in different sections of the port. Of course, there are situations where the functions, such as the second and third columns, may be combined in the same location without the need to move the vessel around.

Table 1.15 Typical dimensions of fishing vessels

Vessel Category	Length (m)	Draft (m)	Beam (m)
Ia	<7	<1.0	<3.5
Ib	7–10	1.0–1.5	3.5–4.0
II	10–20	1.5–2.5	4.0–6.0
IIIa	20–30	2.5–3.5	6.0–7.0
IIIb	30–60	3.5–5.0	7–10
IV	60–170	5.0–8.5	10–24

Table 1.16 Indicative duration of fishing cycle

Vessel Category	Days at Sea	Unloading and Provisioning (days)	Duration of Cycle (days)
I	1	1	2
II	6	4	10
III	35	5	40
IV	45–100	~8	50–110

Fishing vessel arrivals at port adhere to a more-or-less given pattern with peaks at certain periods of the year. Indicative occupancy factors of the landing quays may be in the range $n = 0.4$ to 0.7, depending on vessel size. A rough way of calculating the number of unloading berths is to consider that about 15% of the number of vessels using the port should be able to find a free unloading berth at any time. The functions in the third to fifth columns in Table 1.17 require additional berthing facilities since such functions are normally conducted in locations other than those housing the unloading operations. Consequently, to calculate the number of these positions, it is necessary to determine occupancy factors n just as in the unloading sector. Table 1.18 lists several values of factor n for the various vessel categories and port functions. The factor $n = 1.0$ in the fourth column reflects the fact that the said "function" actually is the idle time of an obligatory stay in port.

Fishing vessels usually are secured alongside or in a tight arrangement stern to shore along straight docks. There are ports with a sawlike arrangement of unloading docks (e.g., Esbjerg in Denmark), to increase the number of vessels being served. In the case of a simple straight dock, the requirements for the water area relevant to the mooring type shown in Figure 1.28 can be accepted. Depending on the vessel category and its function, two (or more) rows of vessels moored side by side could be considered. For reasons of safety, this increase

Table 1.17 Allocation of fishing vessel time (days per year)

Vessel Category	Days at Sea	Unloading of Catch and Loading of Provisions	Bunkering/ Provisioning and Associated Idle Time	Idle Time and Small-Scale Repairs and Maintenance	Major Repairs and Maintenance	Number of Fishing Cycles per Year
I	140	70	75	75	5	140
II	170	85	30	70	10	28
IIIa	250	20	15	65	15	7
IIIb	250	20	15	60	20	7

Table 1.18 Indicative occupancy factors

Vessel Category	Unloading of Catch and Loading of Provisions	Bunkering/Provisioning and Associated Idle Time	Idle Time and Small-Scale Repairs and Maintenance	Major Repairs and Maintenance
I	0.7	0.7	1.0	0.8
II	0.6	0.6	1.0	0.7
IIIa	0.5	0.5	1.0	0.6
IIIb	0.4	0.4	1.0	0.5
IV	0.4	0.4	1.0	0.5

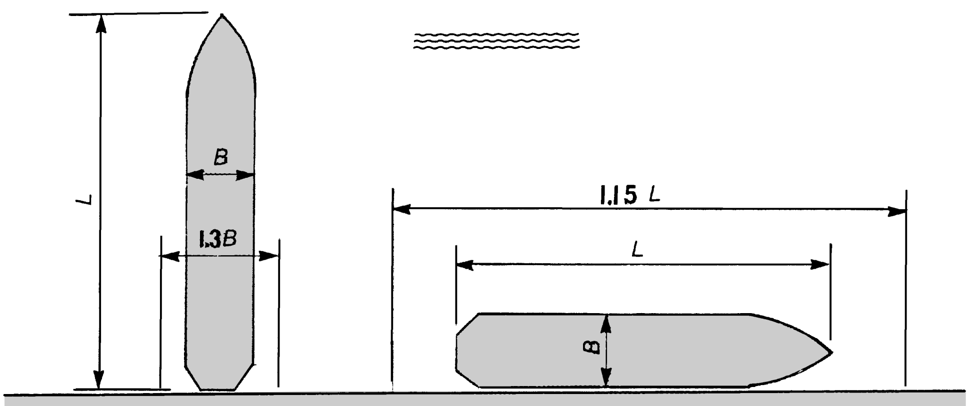


Figure 1.28 Mooring types of fishing vessels.

in number of vessel mooring places should not exceed a factor of about 50%. Table 1.19 gives indicative values of the hold capacity of fishing vessels.

Fishing vessel provisioning involves primarily fuel, water, and ice. The quantities of fuel and water required are estimated on the basis of the capacity of the respective tanks of the vessel. Some indicative values of the latter are given in Table 1.20.

Table 1.19 Net capacity of fishing vessels

Vessel Category	Length (m)	Hold Capacity (m^3)	Dead-Weight Tonnage
Ia	<7	1.5	0.8
Ib	7–10	4.5	2.5
II	10–20	25	15
IIIa	20–30	85	55
IIIb	30–60	400	250
IV	60–170	500–3500	300–2200

Table 1.20 Vessel tank capacities

Vessel Category	Length (m)	Fuel (tons)	Water (tons)
Ia	<7	0.3	0.2
Ib	7–10	0.8	0.5
II	10–20	10	5
IIIa	20–30	50	12[a]
IIIb	30–60	300	20[a]

[a] Additional seawater supply.

Category III and IV vessels usually have their own refrigeration installations and do not require stocking of ice. Vessels of the other categories need about 3 tons of ice on average per day during the fishing season. Unloading of the catch is effected in a manner related to packing type, hence by size of vessel. Usually, the vessel's own lifting gear, 3- and 6-ton mobile cranes, and corresponding forklifts suffice for the unloading and forwarding of catch to the cleaning sheds. Unloading by conveyor belts applies to catch packaged in boxes or crates. Given the tendency for improved packing of the merchandise during the voyage, particularly in the larger fishing vessels, the use of conveyor belts is becoming increasingly popular.

1.4.5.3 Land Installations. As stated in Section 1.1, the land installations of a fishing port are diverse and differ from those of ports for other commercial purposes. When a fishing port is fully developed, its land installations include the auction shed, the central building with cleaning and sorting areas, an exhibition area and auction room, a packing room with ice, refrigerators for overnight or longer storage of the catch, deep-freeze stores, salted or dried fish stores, weighing rooms, packaging material stores, and auxiliary installations (offices for administration, sellers, buyers, etc.). Depending on the particular situation, the cold display for auctioning may be replaced by a display of the catch in ambient conditions (PIANC, 1998).

The dimensions of an auction shed depend mainly on whether the display of the fish relies on a sample or on the totality of the catch. In the latter case, the building is located adjacent to the unloading zone of the dock, whereas in the former, it could be located farther inward of the port, at the same time being smaller than in the preceding case. Some basic criteria of the individual functions taking place under roof are listed below, to assist in the preliminary design of a shed with full view of the catch:

- Washing and sorting — 15–30 tons/m^2 annually
- Exhibit and sale — 1–15 tons/m^2 annually
- Weighing and arrangement — 7–15 tons/m^2 annually
- Storage in freezer — Capacity for 2–3 days' production
- Packaging plant — 6–12 tons/m^2 annually
- Access corridor — 8–16 tons/m^2 annually
- Auxiliary installations — May be installed in a mezzanine or on the ground floor, requiring 15 to 20% of the overall building

The typical overall building width ranges from 40 to 80 m. Frequently, a separate shed is provided for cleaning and storage of containers of the catch. The washing area for the containers requires about 1 m^2/ton per year, while the storage area varies depending on the specific packing type—a representative value being 0.2 m^2/ton of annual product handling. The wastewater from the washing of both the catch and the packaging containers should be conducted through floor grilles to a suitable treatment installation prior to final disposal. The floor should slope around 1:75 to facilitate surface drainage.

Repair and maintenance work may be provided by a series of installations, ranging from the simplest ramps to the most complex shiplift or dry dock facilities. A lifting arrangement providing ease of application on relatively small vessels is the Syncrolift, equipped with a vertical lifting platform supported by four legs at both sides (Tsinker, 1995). Repair/maintenance installations may use the longitudinal or transverse transport system for moving vessels to/from their respective dry berth for repair or maintenance.

REFERENCES AND RECOMMENDED READING

Agerschow, H., H. Lundgren, T. Sorensen, T. Ernst, J. Korsgaard, L. R. Schmidt, and W. K. Chi, 1983. *Planning and Design of Ports and Marine Terminals*, John Wiley and Sons, New York.

ASCE, 1969. *Report on Small Craft Harbors,* No. 50, American Society of Civil Engineers, Reston, VA.

———, 1994. *Planning and Design Guidelines for Small Craft Harbors,* American Society of Civil Engineers, Reston, VA.

———, 2001. *ASCE Proc. Specialty Conference Ports '01,* Norfolk, VA.

Bruun, P., 1981. *Port Engineering,* 3rd ed., Gulf Publishing, Houston, TX.

Brunn, P. 1989–1990. *Port Engineering,* 4th ed. (Vols. 1&2), Gulf Publishing Company, Houston, TX.

Chapon, J., 1966. *Travaux Maritimes,* Eyrolles, Paris.

Dally, H. K. (ed.), 1983. *Container Handling and Transport,* CS Publications, Worchester Park, Surrey, U.K.

E.C. COST 330, 1998. *Telinformatic Links between Ports and Partners,* Final Report of the Actions, European Comission, Brussels, Belgium.

European Commission, DG Environment, 2001. *Assessment of Plans and Projects Significantly Affecting Natura 2000 Sites. Methodological Guidance on the Provisions of Article 6(3) and Article 6(4) of the Habitats Directive 92/43/66,* Brussels.

European Sea Ports Organisation, 1995. *Environmental Code of Practice,* Brussels, Belgium.

Frankel, E. G., O. G. Houmb, and G. Moe, 1981. *Port Engineering,* Gulf Publishing Company, Houston, TX.

Herbich J. B. (ed.), 1992. *Handbook of Coastal and Ocean Engineering,* Vol. 3, Gulf Publishing Company, Houston, TX.

Hershman, W. (ed.), 1988. *Urban Ports and Harbor Management: Responding to Change along U.S. Waterfronts,* Taylor and Francis, New York.

IMO, 1991. *Port Logistics,* Compendium for Model Course 5.02, International Maritime Organization, London.

Knapton J., and A. Meletiou, 1996. *The Structural Design of Heavy Duty Pavements for Ports and Other Industries,* The British Precast Concrete Federation, 3rd edtion, London.

Memos, C., 1999. Lecturers on Harbor Works, "Symmetry" Publ., Athens, Greece.

PIANC, 1980. *Dry Berthing of Pleasure Boats,* Suppl. Bull. 37, Permanent International Association of Navigation Congresses, Brussels, Belgium.

———, 1997. *Review of Selected Standards for Floating Dock Designs,* Suppl. Bull. 93, Permanent International Association of Navigation Congresses, Brussels, Belgium.

———, 1998. *Planning of Fishing Ports,* Suppl. Bull. 97, proceedings of Specialized ASCE Conferences on Ports, PIANC Congresses, Harbor Congresses, and the other specialized conventions. Permanent International Association of Navigation Congresses, Brussels, Belgium.

———, 1999. *Environmental Management Framework for Ports and Related Industries,* PECO, Brussels.

———, 2002. *Mooring Systems for Recreational Craft,* Rep. WG10, Permanent International Association of Navigation Congresses, Brussels, Belgium.

Takamatsu, T., M. Yosui, and H. Sanada, 2002. *A Port and Harbor Vision to Connect People's Lives with the Sea and World,* PIANC Proceedings, 30th Congress, Sydney, Australia.

Tobiasson, B. O., and R. C. Kolmeyer, 1991. *Marinas and Small Craft Harbors,* Van Nostrand Reinhold, New York.

Tsinker, G., 1995. *Marine Structures Engineering: Specialized Applications,* Chapman & Hall, New York.

———, 1997. *Handbook of Port and Harbor Engineering: Geotechnical and Structural Aspects,* Chapman & Hall, New York.

UNCTAD, 1984. *Port Development: A Handbook for Planners in Developing Countries,* United Nations, Geneva.

UNCTAD, 1992. *Développment et amélioration des ports, Les principes et l'organisation modernes des ports* (*Development and Amelioration of Ports, Principles of Modern Port Management and Organization*), UN-Unctad, Conseil du commerce et du développment, Commission des transport maritimes, groupe intergouvernemental spécial d'experts des ports, GE.92-50027/1038C, Geneva.

UNCTAD, 1996. *Sustainable Development Strategies for Cities and Ports,* UN-Unctad, IAPH & IACP, Geneva.

UNCTAD, 2001. *Review of Maritime Transport,* United Nations, Geneva.

United Nations, (Food and Agriculture Organization), 1970. *Fishing Ports and Markets,* Fishing News Books, Oxford.

———, 1978. Conference on Trade and Development, U.N., New York.

U.S. Army Corps of Engineers, 1974. *Small-Craft Harbors: Design, Construction, and Operation,* SR 2, USACE, Washington, DC.