



TECHNICAL COMMUNICATION

Port Engineering and Its Relation to Coastal Engineering

Per Bruun

34 Baynard Cove Road
Hilton Head Island, SC 29928, U.S.A.

ABSTRACT

BRUUN, P., 1998. Port engineering and its relation to coastal engineering. *Journal of Coastal Research*, 14(3), 1152-1157. Royal Palm Beach (Florida), ISSN 0749-0208.

This paper compares the two fields port and coastal engineering outlining their similarities in basic physical aspects including hydrodynamics and aerodynamics and their forces on fixed and moving elements. It describes the highly diversified field of port transportation engineering and makes suggestions for education in port engineering involving all the common basic aspects followed by education in a number of port transport engineering subjects, including economic analysis and some port related civil structural engineering topics.

ADDITIONAL INDEX WORDS: *Port and coastal engineering, port transportation, port transportation equipment, port structures, engineering education.*



INTRODUCTION

Port Engineering agglomerates many fields ranging from vessels transporting merchandise from one port to another to the transport of materials being loaded or unloaded at the port from or to storage areas by other means of transportation. This "port cocktail" includes fields such as naval architecture, ship hydrodynamics, design of basins and navigation channels, design of inlet and entrances, maintenance of channels and basins, ship-handling and maneuvering, design and construction of breakwaters, quays, piers and terminals for bulks, liquid or solid, loading and unloading facilities and equipment, computerized controls and the planning and design of land areas for the reception and storage of goods. Furthermore, it includes the transportation and handling equipment and numerous fields of services to navigation, like electronic controls, aids to navigation and navigational aids, pilot services, tug-assistance, and, finally, administrative facilities needed to serve all aspects of port activities.

Port engineering is an old field. The first ports were located in fjords and rivers. Four to five thousand years ago the Phoenicians established ports on the open sea coast in present day Lebanon. The port of Tyre was built of heavy blocks locked together with copper dowels. The Romans built the famous naval port on the Tiber River at Ostia. Medieval ports such as London, Rotterdam, and Hamburg were all located on rivers, or in estuaries, bays and sounds. The same was true of

the first American ports like New York, Boston, Baltimore, Washington (Georgetown), and New Orleans.

Ships

Ships come in many varieties and serve various transportation needs as bulk-carriers for oil, gas, coal, minerals, ores, grains, fertilizers and fruits, and container bulk, including refrigerated (Lift on/Lift off) and RO/RO (Roll-on, Roll-off) facilities. Old ports usually included long sections of wharfage, rather narrow piers mainly single or grouped terminals for particular commodities, like oil, minerals, containers *etc.*

Old Ports

Old ports rely on the length of quays with certain limited depths. Arrivals of vessels are often proven to follow a Poisson-distribution, while servicing of the vessel follows an Erlangian distribution. Matters related to arrival and servicing are of particular interest to developing countries where port congestion often is a severe problem causing vessels to wait for days or but weeks before berths are available. This situation in turn is reflected in the cost of shipping contributing adversely to the economy of the port operation and its customers and to the national economy.

New Ports

Recent developments of ports are characterized by the need to accommodate vessels with greater drafts. Tankers for crude oil have reached 0.6 million DWT (dead weight tons).

Ore carriers of up to 0.4 million DWT have been built. The largest container vessels are now 60,000–80,000 DWT with room for about 6,000 20 ft containers and with speeds up to 32 knots. Unitized transports by containers and pallets including roll-on/roll-off carriers, have also expanded rapidly. This has required the development of special ports and transportation systems. It has also contributed to the development of a new port engineering field called "Terminal Technology", which concerns the use of marine terminals for a variety of purposes. Port development for bulk carriers includes facilities for mooring tankers in the open sea at buoys or at platforms with no connection to land other than the pipeline for loading or unloading of oil. Open sea loading terminals for ore carriers are usually connected to land by a bridge structure carrying conveyers and other necessary installations. New ports may be established in areas of no former ports including the offshore, or they may be direct expansions of old ports.

Attempts are always made to locate new ports where adequate natural depths are available. By the introduction of ships of deeper drafts many old ports became land-locked. This was true for some of the world's largest river-ports like the ports of Shanghai, London, Rotterdam, and Hamburg. To cope with that situation, they had to develop satellite ports closer to the open sea. The above-mentioned four ports did so. The solution at times is a compromise between the need for full protection of vessels versus the width of channels with minimum maintenance dredging which also is an important economic consideration. The Port of Rotterdam is a river port built on the banks of the river Maas. Its outer harbor is Europort for giant oil-carriers, bulkers and large terminals for container vessels. Combined with Rotterdam they are the world's largest port complexes handling 250 million tons per year. The largest port in the U.S. is the Port of New Orleans, handling 150 million tons/year. While old ports may have kilometers of wharfage and highly congested port areas, often too small to offer adequate services, new ports are characteristically composed of a number of single terminals each serving a particular purpose like bulk for oils, gas, minerals, coal, grains or containers. Each category of cargo poses restrictions on the use of the respective land-areas considering safety and pollution aspects. Large basins able to contain oil spills of major order surround oil storage tanks. Gas tanks, particularly for liquefied natural gas, must be placed a safe distance apart, for berth / berth or berth / tank *e.g.* 300 m. Loading or unloading of coal or minerals must not release to the surrounding atmosphere excessive quantities of dust, necessitating the use of special technologies limiting the quantities of dust causing pollution. In comparison to that, container-operations are "clean", but generate noise. Bulkhandling by continuous conveyor belt operation develops noise too. Container cranes and the associated gear running on the quay-apron may produce excessive noise. Ill-smelling, dust-developing and noisy terminals are now built in or relocated to areas remote from residential areas, thereby avoiding adverse effects for human beings. The result is the development of a number of terminals separated by land-areas used for storage for industries. Each single terminal must then provide the necessary area for operation, including loading and

unloading, quay aprons, roads and storage areas. It is self evident that such terminals will cover large areas and therefore must be located where areas and possibilities for expansion readily exist. Existing old ports are often situated in a town that owes its existence to a river or a bay with relatively limited depth conditions. Many U.S. ports like New Orleans, Savannah, Charleston, New York and Portland (Oregon) owe their existence to such natural conditions. The old harbors gradually became "framed-in" by the lack of adequate depths and had to "burst" their restrictions in order to obtain space for their future operations. The introduction of larger and deeper draft vessels developed the need for deeper navigation channels and basins to be dredged and maintained, often at high costs justified by increased revenues and earnings. Such major port developments and expansions were usually financed by public funding, *e.g.* in the U.S. by the federal government for dredging with state and local governments often participating in such projects. During recent years, in some cases, maintenance projects for entrances have also become sediment (sand) transfer projects to serve down-drift beaches on a cost sharing basis between the federal state and local governments. The latest experiences have demonstrated a trend towards the elimination of federal contributions to smaller projects encouraging a take-over by state and local governments, while the dredging of deeper channels to major ports served by a federal navigation channel is mostly financed by federal funds. This circumstance has led to a comprehensive dredging research program under the U.S. Army Corps of Engineers at the Waterways Experiment Station, Vicksburg, Mississippi. This program comprises new developments and improvements of existing dredging technology and better monitoring of dredging operations including new or improved survey methods, *e.g.* using laser-technology and, pollution controls including the introductory checking of materials and spoil waters as well as the disposal of the dredged materials in deep waters or in confined nearshore or on shore with proper de-watering systems. Ocean spoil may have to be protected by special protective covers to make certain that polluted material is not eroded and carried away causing undesirable effects for the environment. It is true, however, that the cost of dredging operations thereby has increased considerably, thus necessitating efforts in reducing the cost of the entire operation by special dredging equipment like side-casters at tidal entrances and various improved and more effective methods of agitation dredging, in the U.S. particularly at the Gulf Coasts river ports, like New Orleans. Furthermore more economic transports of dredged materials, better dumping procedures, reduction of costs associated with the protection of disposed materials, and more rapid monitoring of all operations during and after actual operation. Obviously this depends on the availability of effective and reliable sampling procedures and survey methods. Pollution controls in this context are urgently required and anti-pollution laws or regulations need to be observed. This always increases the overall cost of dredging.

CIVIL ENGINEERING ASPECTS OF PORT ENGINEERING

Ports on the open coast usually need breakwaters for protection. Very few breakwaters are built nowadays. There

have been many problems with breakwaters. Fortunately better moorings can often substitute them. Jetties protect entrances at tidal inlets. In the U.S. there many jetty-protected inlets. Berths, quays and piers are usually built of steel or reinforced or pre-stressed concrete. Terminal structures may rely on piles or sheets or perhaps on concrete caissons. From the sea-side they are designed based on loads exerted by vessels in berthing or de-berthing mode and at the berth, caused by winds, currents or waves combined with loads produced by ship propellers and winches during operations. From the landside soil pressures and loads on the terminal structure cause loads by the equipment operating there. All loads may include a certain degree of impacts such as during the berthing operation and by irregular movements of cranes or other mechanical causing shock loads. A great number of different port structures exist. Steel structures have now often been replaced by concrete structures or by concrete-filled steel pipe structures, particularly in the offshore. For quay-walls special steel, anticorrosion structures and prestressed concrete structures are common, the latter for relatively light designs. Floating ramps for RO/RO installations and even floating pontoon-ports have been built, sometimes for military applications in landing operations

MECHANICAL EQUIPMENT IN PORT OPERATIONS

Loading and unloading requires equipment for speedy and safe handling. Equipment for bulk-operations include cranes carrying clam-shelves for continuous loading/unloading the equipment is bucket wheels, screw-types, or pneumatic, which are more economic and efficient than shells with capacities up to 6,000 tons/hour compared to up to 1,500 tons/hour for shells. For handling of containers large quayside portal cranes on rail or on crawlers are common. In operation they must be served by quayside equipment like gantry-cranes, trans-tainers, reach-tainers, forklifts, side-lifts, tractor-trailers etc. The latest development is large-scale forklifts enabling stacking of 40 ft containers up to 6 or 8 in a vertical row. With respect to storage large buildings arranged like beehives, computer controlled "computainers" are now becoming available for fully automatic operations applicable also for outdoor storage. All of this requires rather sophisticated engineering operational techniques. For developing countries one should, however, avoid over-sophistication. Evidently, mechanical equipment for handling and computerized control is an expanding field. It has its merits for large operations that call for efficiency and speedy handling of large elements and quantities. The development of such equipment and procedures related to port operations is a major field.

The most important equipment for the maintenance of ports still is a tool used for the upkeep of depths. Such equipment includes dredgers of various types and design. Almost all dredging of ports is undertaken by hydraulic dredgers pumping directly from the dredging site to the disposal location or by hopper dredgers which leave the material dredged in their hull for disposal elsewhere following steaming to disposal area. For such operation dump barges may

also be applied. Sidecasters may be used for the opening up of channels for dredging by larger equipment and for maintenance of smaller tidal entrances. Agitation dredging is used extensively at the Mississippi River entrances. Submerged pumps like the "punaise" and the bottom operated Crawl Cats and Dogs are entering the market and may find application in tidal entrances and for beach nourishment.

PORT ENGINEERING AND ITS RELATION TO COASTAL ENGINEERING

From the preceding sections it may be realized that port and coastal engineering are partially overlapping fields in theoretical as well as in several practical aspects. Both are ocean and shore-related with port engineering extending up-river or bayward and into the adjoining land-areas. Port engineering is concerned with the transport of commodities by ships and by land-based equipment. Ships are accommodated in ports located on the open shore, in bays, fiords and rivers, or along navigation channels. Ship and port installations are subject to natural forces by winds, waves and currents. So are coastal engineering structures.

The most important parameter in port design still is the depth that determines ship size. Waves and currents including tidal, wind and density carry material along the shore and in channels and rivers. Bottom-material may be scoured or deposited. Scour produces "greater depths" and space in port channels, but "erosion" in the coastal engineering context.

If deposition of materials takes place it is a nuisance in port engineering, while it may be a blessing in coastal engineering as a stabilizing agent. To maintain depths in port and navigation basins or channels removal of material by proper dredging equipment is necessary. To maintain the stability of shores subject to erosion, large-scale dredging and-filling operations replacing the material eroded by new material are needed often using the same equipment as in port engineering. The materials to be dredged in port and coastal engineering may differ considerably. Maintenance in port engineering usually produces fine material of silt and clay-size which is then disposed where it is expected to have little or no adverse effects on the environment. Material for beach nourishment must fulfill certain specific requirements to grain size, specific weight and minerals content. No clay or silt or chemical waste products or organic matter are permitted. While materials dredged in ports and navigation channels are often polluted and must be disposed of without damaging the environment; this is never the case with material to be used for beach nourishment. Such material is required to be tested beforehand thoroughly for possible undesirable ingredients which could be of chemical or organic origin. Only clean sand material is acceptable for beach nourishment.

FIELDS OF SIMILARITY BETWEEN PORT AND COASTAL ENGINEERING

Fields of similarity include the need for data on currents, tides, winds and waves. They are equally important in port and coastal engineering, in layout and design. Combined with

bathymetric information they determine amounts of sediment transport with known sediment characteristics. When material is scoured from the bottom in a port project it usually is an advantage for navigation, but it could be a disadvantage to structures. When scour takes place in coastal engineering, it means erosion that is not desirable.

Winds, waves and currents are the determining factors for vessel behavior under all oceanic conditions and they are also the determining factors for vessel behavior in a navigation channel or entrance. So they are for the stability of beaches. They cause forces on objects, whether such objects are moving, like ships, or fixed in port and coastal structures. Among other things the physical parameters for design are the same, but they are used for different applied purposes. The same is true for soil characteristics, whether they are used to determine forces in port engineering, for beach material characteristics, or for channel stability evaluations.

Basic parameters are partly used for the same purpose in port and coastal engineering including the computation of forces on sediments on the bottom of the ocean or in the channel and partly also for the computation of forces on fixed structures like breakwater in port and coastal engineering and forces on movable elements like ships. This includes maneuvering forces during berthing, de-berthing and for "vessel at berth." When forces by current winds and waves are transferred through the vessel to structures like drag quays and piers, they cause forces, inertia and drag depending upon vessel size and geometries acting on berth structures and mooring forces to be absorbed or met by cables and fenders. The port engineer must know how to compute these forces as well as forces acting as loads on the quay and its structures exerted by loading, unloading and transportation including forces by wind. Hydrodynamic and aerodynamic forces are basically the same in port and coastal engineering, but their respective actions may be different. Obviously, the needs for data in port and coastal engineering are identical. So is the usage of these data to determine forces on fixed or movable objects. The objects themselves may differ greatly in dimensions, character and behavior. In port and ocean engineering forces act on elements which are almost always moving and highly time-dependent just as the forces themselves.

HOW AN EDUCATIONAL PROGRAM IN PORT AND COASTAL ENGINEERING CAN BE ESTABLISHED

From the above sections it seems obvious that the two fields share a common background in basic elements on forces by currents, waves and winds acting on elements which are fixed or moving. Basic education, therefore, will be the same and is the backbone in a diversified field involving sediment transport mechanics, common to both fields, and ship hydrodynamics which is naval architecture in the open sea and ship handling technique in berthing, de-berthing and at berth in port engineering.

A basic physical elements course in port and coastal engineering covers both fields. After that the two fields develop along different lines in applied aspects. Disregarding naval architecture and handling of ships in the open ocean, the ship

is brought to its berth through a navigation or entrance. This involves the design, construction and maintenance of channels and finally basins. In the final phases the ship moves to its berth, after which the main task of loading or unloading occurs. Coastal engineering has no relation to this aspect, but it does include dredging for maintenance of navigation channels and bypassing of material at tidal inlets as well as the entire field of construction and maintenance of beaches by nourishment. In addition, dune design and maintenance and finally structural engineering like breakwaters, jetties and sea walls are included.

With the ships arrival port engineering opens up a wide and highly diversified engineering field involving the following:

- (1) statistical analyses of arrivals, waiting and quay time.
- (2) statistical analyses of berth occupancy and utilization. For container vessels distinguishing between LO/LO and RO/RO.
- (3) statistical optimization of handling procedures by equipment of varying capacity and procedures covering loading/unloading and transport to storage areas for later pick up. This is a puzzle of coordinated inputs by various capacity equipment resulting in optimum efficiency which usually, but not always, also provides for optimum economy. It may include the transport to and from storage areas.
- (4) statistical analyses of storage facilities for containers, open short and long-term transit sheds, non-refrigerated and refrigerated storage containers and other highly mechanized and computerized systems resulting in speedy handling.

All these handling fields are still developing new and better equipment. For bulk loads like coal and ore continuous loaders and unloaders of up to 6,000 to 8,000 tons/hour are replacing the use of clamshells. For container-handling, crawler-type cranes, with very long booms are competing with the normal portal container cranes on rail which are more rigid in their performance than the crawler crane. The large UNCTAD (United Nations Conference on Trade and Development) report "Port Development" (1978) advises on basic principles of modern port planning in particular for development countries. The main problem is expressed in two concluding UNCTAD paragraphs as follows:

(iii) The paramount importance of a far-sighted port development policy does not appear to have been fully appreciated in the past by many governments. As a result, ports have often been unable to keep up with rate of expansion of a country's overseas and coastal trade.

(iv) The consequences of a failure to provide proper port capacity BEFORE the increased traffic arrives are clearly illustrated by recent congestion in many ports of the world, in particular in developing countries. The enormous sums of money lost through congestion would often have been sufficient to build a lavish system of modern ports. The development of still more efficient equipment, however, is continuing.

PRACTICAL SUGGESTION FOR THE EDUCATION OF PORT ENGINEERS WITH SPECIAL REFERENCE TO THE U.S.

As basic physical elements in port engineering are the same as in coastal engineering, one may conclude that if basic courses in coastal engineering are taught the ground work in port engineering education, special statistical relations and procedures may be added to this basic education. The next step is to include port engineering's special use of basic principles in subjects like navigation, layout of channels and basins. The PIANC (Permanent International Association of Navigation Congresses) has numerous reports on these subjects. The latest "Approach Channels: A Guide for Design" report by the joint Working Group of PIANC and IAPHIC (International Association of Ports and Harbours) supplement to Bulletin No. 95 (January 1997) advises on channel geometries versus ship geometries and physical conditions of currents, winds and waves.

The width and depth of the navigation channel are determining factors for the Safety of the vessel moving in the channel. Model studies of various kinds, including mathematical/hydrodynamics, may be run combining vessel characteristics with acting forces. The so-called "man in the loop" simulators permit the ability to incorporate human elements directly in the tests using visual displays. In the berthing procedure the vessel may have to turn around, often under tug-assistance. Such maneuvers are also simulated in the model and so are mooring and fendering forces.

In all major ship navigation channels in the world ship passage from the ocean to the berth is now monitored from radar control towers advising the ship's captain and pilot. Maneuvering of large vessels requires special skills that must be secured by education and experience. Theoretical but calibrated, risk analyses, which consider the possibility of collision and grounding, are available for the determination of risks in all phases of the ship's movements. Students may be taught basic principles of layout and design of channels and basins and how to test them in models.

When the vessel is safe at berth the large unloading/loading theatre starts. The numbers of factors influencing unloading/loading operations are immense ranging from capacities of various types of cranes and other equipment to transport equipment on land. This covers pipelines for oil and gas, conveyor belts, bucket ladders or spirals, pneumatic systems for grains and cement and container transport equipment.

Continuous unloaders of various types are invading the bulk market. The designer of transport facilities must know the capacities of each type and other operational characteristics including safety, risk and maintenance factors. Transport of oil and gas in pipelines is subject to many safety requirements. Possibilities of breakdowns or damage to single elements in the transport chain must be met by prepared counter-measures. The single element in the chain of course must be coordinated properly, so that the possibility of bottlenecks is eliminated. The quayside has to be designed and prepared for the traffic and all storage facilities must offer adequate space and easy handling for in and outbound operations and be served by practical connections by road and/

or rail to the hinterland. Economics, of course, is a major parameter in the puzzle. Controls of weights, volumes and numbers must be established and operated safely with necessary warning systems for malfunction. The success of the operation finally depends on skillful personnel who are able to impose a certain degree of uniformity without failing. And a human reserve capacity is absolutely necessary.

In a university course one cannot possibly teach such topics in detail, but instructors can inform students about mechanical equipment which enables them "to play" with the subject. The final education may be best achieved by practical experiences following operations in the battlefield. During the design process a number of alternatives must be considered with a variety of boundary conditions and inputs. Comparisons with other projects will be helpful. So will the number of conferences held on port subjects and papers written and published in national and international journals and proceedings.

A parameter of major importance in the analyses is the selection of the location of a new port facility, including depth conditions and areas available for the installation and its future expansion. Also its links to the general transportation systems and its ecological and pollutionary effects are conditions to be considered seriously. In a port course this could be explained briefly with reference to examples.

Selection of the type of structure that shall be used is an important technical and economical decision. Old ports have sheet pile walls, block walls or piled wharves. Sheet pile walls are mainly used for medium depths up to 12 m. For deeper waters, piled walls become more economical. This in particular is true for terminals for oil and gas. For heavy bulk terminals caissons are often used in massive dolphin structures. Piles may also be large concrete-filled cylinders of special steel. For container terminals sheet pile or piled walls are both in use. The design of such structures is a civil engineering job. Many port engineers were educated as structural civil engineers and picked up transportation engineering in their work. Some ports also employ economists. A port engineering course should probably include the characteristics of various structures without going deeply in design calculations which belong to structural and soil mechanical engineering.

CONCLUSIONS

- (1) In the introductory phases of port engineering coastal engineering are very important.
- (2) Navigational aspects and ship handling are important subjects in port engineering. The design of navigation channels and entrances and their maintenance is based on knowledge and principles of sediment transport and stability generally taught in coastal engineering. Dredging is a combined port and coastal engineering subject. Its basic aspects may be taught in the basic course.
- (3) Maneuvering of vessels in narrow channels and in basins is associated with certain risks. The principles of risk analyses and of traffic control should be included in a port course.
- (4) Berthing/de-berthing and safety at berth is a port engineering field that should be emphasized in a course.

- (5) Transportation analyses in port engineering all-important, its principles should be taught, possibly by the assistance of an economist. This refers to all kinds of ports and terminals. This field includes:
- a. Traffic analysis, ship arrival and departure, time at berth, waiting time, de-moorage *etc.*
 - b. Loading and unloading principles and equipment and optimization.
 - c. Quay-transportation features and equipment optimization.
 - d. The establishment of transportation links, storage areas and facilities of any kind needed and the corresponding analyses for operation and risks.
 - e. Operational controls including computerized systems.
 - f. Ecological effects including pollution in a port operation.
 - g. Principles of maintenance of facilities. This includes mechanical as well as electrical engineering aspects.
 - h. Principles of economic analyses related to port engineering and to the operation of a port.
 - i. Socio-economic aspects related to port engineering, including insurance, taxes *etc.*
 - j. The activities by international organizations specialized in port engineering with side interest in ocean as well as coastal engineering. Attention in particular is called to the activities by PIANC and the IBRD (International Bank for Research and Development located in Washington, D.C. USA).
 - k. Human aspects including how to acquire skilled personnel for operation of the port, and how to maintain their skills.

It should be realized that every port has its own "face" depending upon the commodities the port shall handle, and it may be subject to changes in the long run. Face-lifts may be needed. One thing is sure: port engineering is an expanding field with a lot of opportunities in future trades and expanding economies. It is definitely a field for the younger generation.