Part 3
SITE CRITERIA

Chapter 17

ENVIRONMENTAL CHARACTERISTICS OF SOME MAJOR TYPES OF HARBORS

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The operational requirements for an ideal harbor are (Chao Hwa et al. 1945, Stewart 1945):

a. Provision for shelter from the waves of the open sea and a limited fetch.
b. Provision for shelter from strong winds from all directions.
c. Depth enough for a large vessel to maneuver over an extensive area.
d. Good holding ground for anchoring.
e. A deep draft entrance from the sea.
f. A minimum of annual expense for dredging.
g. Moderate or small tidal range.
h. Moderate tidal currents.
i. Sufficient circulation to remove contaminants.
j. A low fouling rate and relative freedom from marine borers.
k. Freedom from seiches and surges.
l. Freedom from tidal bores.
m. Freedom from ice.
n. Freedom from fog.

The reasons for these requirements are clear enough so that no further explanation seems to be necessary. Most of these operational requirements can readily be translated into physical phenomena provided by land, i.e., by configuration of the coast or topography.

At this point the authors wish to state that the term environment as used in this paper, is meant to imply the natural physical environment only. The economic environment of harbors is an entirely different problem, beyond the scope of this paper and this conference.

Protection from waves of the open sea is a function of both isolation from the sea and the orientation of the entrance to the direction of the waves.

Protection from winds is generally provided by elevations of the land.

Depth and area are results of the topography of the submerged land, and a good holding ground for anchoring is controlled by the terrestrial sediments.

The natural maintenance of a deep draft entrance is a more complex problem. It depends not only on the topography of the sea bottom which has to form a sufficiently deep trough-like depression but also on other factors. To name just a few, there has to be a mechanism or factor which keeps this depression from being filled in, such as absence of large amounts of suspended sediments carried in by rivers, or currents strong enough to carry such sediments into the sea, and also absence of long-shore currents which may build spits across the entrance of the harbor. As an example it may serve to point out that rivers draining large areas of un-consolidated or semi-consolidated material are apt to carry large amounts of sediments in suspension, while rivers draining areas of igneous or metamorphosed rock carry a relatively small silt load. The Mississippi discharges only about eight times the amount of water of the combined discharge of Chesapeake Bay rivers, however, the silt load of the Mississippi is about 750 times that of the silt load carried by the combined rivers entering the Bay.

The annual expense of dredging depends upon the afore-mentioned factors.

So far we have dealt with requirements which were controlled by features of the land. The next group is influenced by astronomical, oceanic, atmospheric, and biological forces.

Tidal range and resulting tidal currents, only partly dependent upon the configuration of the coast, are also a function of latitude, wind direction, and wind velocity. Storm tides are generally higher than spring tides for a given location. Triangular shaped indentations of the coast make for high tidal ranges because of the so-called funneling effect. Also their shape and size have an influence on their natural period of oscillation. In cases where this natural period coincides with the tidal cycle, as in the Bay of Fundy, the ranges are greatly increased. But these local ranges are only superimposed on the oceanic tides which have their highest ranges around 45 degrees north or south latitude and their lowest ranges near the equator and the poles. As to the tidal currents it is a fair generalization to state that the higher the tidal range the higher the velocity of the resulting tidal current.

Circulation of a harbor, or in other words elimination of sewage and industrial contaminants, is, according to the most commonly accepted theory, a function of fresh water inflow and tidal ranges. Whenever either one of these two factors fluctuates from the norm, the time element is changed.

Fouling is a complex problem. Fouling rate depends upon temperature, salinity, nutrients, light, and various other factors. Its importance lies in the fact that harbors with a high fouling rate may infect ships.

Marine borers attack all unprotected wooden structures and vessels, and are widely distributed throughout the world. Since the most common forms are highly tolerant of wide salinity and temperature ranges, little can be done to prevent their depredations short of chemical treatment or metallic protection of exposed wooden surfaces.

Seiches, surges, and tidal bores are rather rare phenomena, are not too well understood, and may be left out of a general discussion such as the present one.

The formation of ice is a function of latitude and presents a special problem which has to be studied locally.

It is rather difficult to generalize on fog within the scope of this paper. Here we deal with local physiographic phenomena only, because these are the ones which have major importance in the quality of a harbor. Fog rarely forms over a small area but usually covers areas considerably larger than a harbor. Of the various common types of fog, only two, steam fog and advection fog, are of importance over water surfaces. Steam fog occurs when colder air comes in contact with warmer water. Then, the saturation vapor pressure with respect to the water is higher than the saturation vapor pressure of the air. Hence, the water vapor that evaporates into the air will condense and form fog. This type occurs most frequently during the low sun period in high latitudes.

Advection fog forms when the air moves over a colder surface so that it is cooled from below by contact. This condition exists in mid-latitudes on the west side of continents during the high sun period when cold water wells up and provides a cold surface.

With the advent of radar, fog has become less of a hazard to the mariner.

We can hardly expect to find a location which will provide all the operational requirements here discussed, and it is the job of the harbor designer to make adjustments where nature has failed from man's point of view. However, certain physiographic types of configuration of the coast line are better suited than others as sites of harbors and it is the purpose of this paper to investigate to what degree these types approach the ideal.

Obviously not all types and variations thereof can be discussed here and the following major ones have been chosen and defined (Fenneman 1931 and 1938, Holmes 1945, Lobeck 1939, Moore 1949):

BAY - an indentation of the coast.

a. Funnel-shaped Bay - a drowned mouth of a river.
b. Tectonic Bay - a bay formed by drowning of an orogenic belt where the structural grain is parallel to the coast. This type is generally confined to the shores of the Pacific Ocean.
c. Ria - a long, narrow, funnel-shaped bay caused by the submergence of a region of ridges and valleys, where these are not parallel to the coast. This type is generally confined to the shores of the Atlantic Ocean.
d. Fjord - a long, narrow, more or less steep-sided bay formed by glacial action.

RIVER - for the purpose of this paper, which deals only with salt water sites; Philadelphia, Pennsylvania, is defined as a river harbor because it has the aspects of a river despite the fact that it is still tidal.

DELTA - a fan-shaped alluvial tract formed at the mouth of a river.

a. Arcuate delta - a triangular-shaped delta.
b. Birds foot delta - a delta where the distributaries have built finger-like extensions into the sea.

LAGOON - A shallow stretch of water which is partly or completely separated from the sea by a narrow strip of land.

a. Atoll - a lagoon formed by a horseshoe or ring shaped coral reef.
b. Barrier reef lagoon - a lagoon separated from the sea by a coral reef.
c. Barrier bar lagoon - a lagoon separated from the sea by a sand bar.

Before we go into a more detailed examination of the enumerated physiographic features, it seems appropriate to discuss some of the parameters which apply to all of them.

One of these phenomena that seems to be important is the fact that any tidal inlet or indentation in the coast will have a flood side and an ebb side. This phenomenon is caused by the Coriolis' force deflecting any moving body to the right in the northern hemisphere and to the left in the southern hemisphere. The flood side, therefore, in the northern hemisphere is on the left hand side of an indentation in the coast looking seaward, and the ebb side is on the right hand side looking in the same direction. In the southern hemisphere the sides will be reversed.

At any given tidal inlet these sides have certain characteristics which seem worth mentioning. Mean sea level is higher on the flood side than on the ebb side and so are tidal ranges. Assuming that any tidal inlet has some sort of fresh water supply resulting in a net outflow, salinities are higher on the flood side where the sea water is brought in than on the ebb side where most of the fresh water flows out and, therefore, the fouling rate should be higher on the former. On the other hand, since the ebb side not only has to carry the waters brought in by the flood tide, but also the fresh water out to sea, the current velocities are higher on this side. The effect of the difference in current velocities is that coarser sediments will be found on the ebb side which may have bearing on the quality of the ground for anchoring. Furthermore, since most of the outflow takes place on the ebb side, it stands to reason that contaminants will be eliminated more readily on this side.

One might say that unless it is not advisable for other reasons, from a physical point of view, it seems more advantageous to construct a harbor on the ebb side of a tidal body of water rather than on the flood side.

However, if we hastily examine some of the major ports of the world, we find no clear cut relationship between ebb or flood side and port location. Economic factors such as easy location of terminals and access to the hinterland, overbalance the physical advantages apparently to be gained by location of a port on the ebb side of a tidal body of water.

This statement is presented here as a suggestion and as food for thought only. To the best of the knowledge of the authors this phenomenon has never been studied thoroughly and considerable research is necessary before more definite conclusions can be drawn.

FUNNEL-SHAPED ESTUARIES (Figure 1.)

From their nature as drowned mouths of rivers, these have certain characteristics. They were formed by rivers at a time when sea level stood lower than today and subsequently were invaded by the sea. Most of them still have a well-defined deep channel near their longitudinal axis representing the old river course. This channel is not necessarily continuous but in many cases is broken up into a series of elongated depressions. Funnel-shaped estuaries give good protection from waves provided that fetches are short enough to prevent generation of local waves, because the configuration of the coast line absorbs wave energy. On the other hand they are mostly located in coastal plains and do not

give protection from wind. They are generally deep enough for maneuvering and have good holding ground for anchorage. A deep draft entrance from the sea usually does not present a problem and dredging requirements are, therefore, small. The same configuration of the coast line, i.e., the funnel-shape, which gives good protection from the waves, tends to increase tidal ranges and resultant tidal currents. This increase, of course, makes for good circulation and elimination of contaminants. In summary, funnel-shaped estuaries offer good harbor sites except in latitudes where winds and tidal ranges make their location impracticable.

TECTONIC BAYS (Figure 2.)

This type of bay is formed by drowning of an orogenic belt where the structural grain is parallel to the coast. Examples are found on the Pacific shore. San Francisco is an excellent example of this type. They usually have a deep narrow entrance from the sea and widen considerably behind it. They give good protection from waves and also winds because of their mountain fringe. They also permit ships to maneuver in a large area and have good holding ground for anchorage. They require minimum expense for dredging. Tidal ranges may be fairly high and tidal currents fairly strong. However, because of the narrow entrance, circulation is rather poor and the elimination of contaminants, therefore, is slow. Nevertheless, they offer very good sites for harbors.

RIAS (Figure 3a and 3b.)

Rias are long, funnel-shaped indentations in the coast caused by the submergence of an orogenic belt where the trends are transverse to the coast. They are mostly confined to the shores of the Atlantic Ocean. The bay in which Brest is located is a good example of this type. Rias are generally V-shaped, in cross section, quite deep at their entrance, shallow landward and give good protection from waves and winds except in cases where they are oriented in the same direction as the prevailing wind. Area for maneuvering is sufficient and in the inner part of the ria there is good holding ground for anchoring. Tidal ranges are increased by the funnel-shape and tidal currents are fairly strong, making for good circulation and rapid elimination of contaminants. Generally speaking, rias make very good sites for harbors.

FJORDS (Figure 4.)

Fjords are long, comparatively narrow, more or less steep sided, U-shaped in cross section, submerged troughs which have

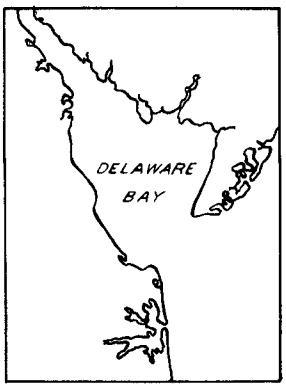


Fig. 1
Funnel shaped bay

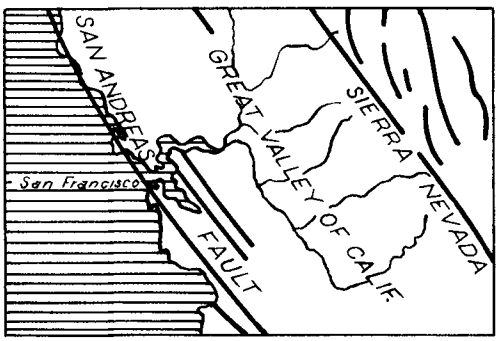
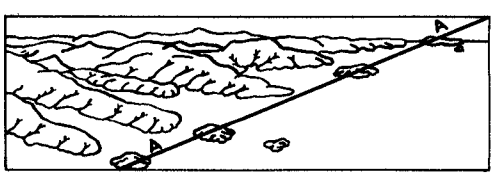


Fig. 2
Tectonic area of the
California coast



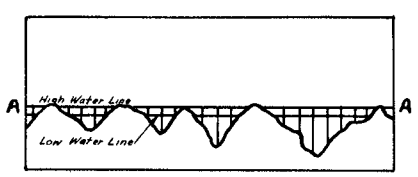


Fig. 3a
Ria-type coast line

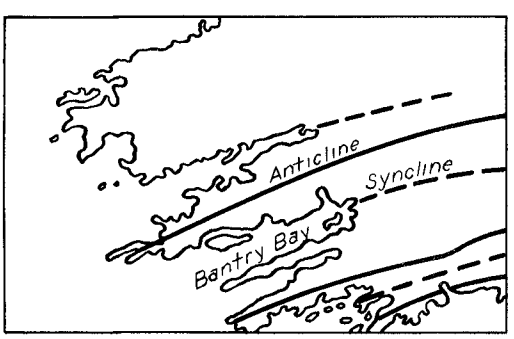


Fig. 3b
Rias of southwest Ireland

been formed by glacial action. Usually a fjord is quite deep, but becomes shallower towards its mouth, possibly because the glacier lost some of its powers of erosion as it melted or because a terminal moraine blocked the entrance. In other words, most fjords have a sill across the mouth, which may make entering hazardous. Protection from waves and winds is very good and so is the area for maneuvering; however, the bottom in fjords is mostly mud-covered, and holding ground for anchoring is poor because of the softness of the bottom as well as the fact that fjords are too deep and too much anchor chain has to be paid out. Tidal ranges and tidal currents do not present a problem. Fresh water inflow is usually small and for that reason as well as the fact that the sill at the entrance creates a pocket of rather stagnant water, circulation is poor and the elimination of contaminants very slow. Fjords make only fair sites for harbors.

TIDAL RIVERS (Figure 5.)

Tidal rivers usually make poor sites for harbors. Generally one can say that on a straight portion of the river, assuming that all other requirements are met, harbors may be constructed on either side. If the harbor is to be located on the river bend, the outer side of the bend is more suited. Every river bend has a slip-off side that is the inner curve and an undercut side, the outer curve. It is always deeper on the undercut side where the stream actively erodes its bed.

Rivers give good protection from waves. Protection from winds is mostly poor because the tidal portions of a river usually flow through the coastal plains. They have generally only limited areas for maneuvering but offer good holding ground for anchorage. Deep draft entrances from the sea are not very common and expenses for dredging are quite high. High tidal ranges and strong tidal currents together with a strong net outflow make for rapid elimination of contaminants. Because of low salinities, fouling rates are low. Generally speaking, tidal rivers offer rather poor sites for harbors.

DELTAS (Figures 6 and 7.)

A delta is a fan-shaped alluvial tract formed at the mouth of a river when it deposits more solid material there than can be removed by tidal or other currents. In other words, if a river forms a delta it is a good indication that oceanic conditions

Fig. 4
Fjords

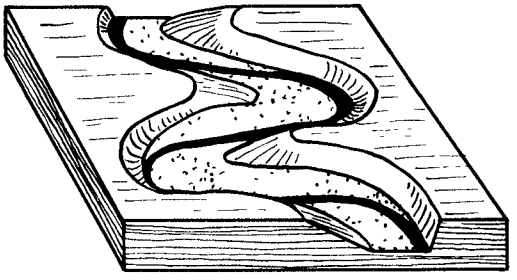


Fig. 5
River showing slip-off
and undercut sides

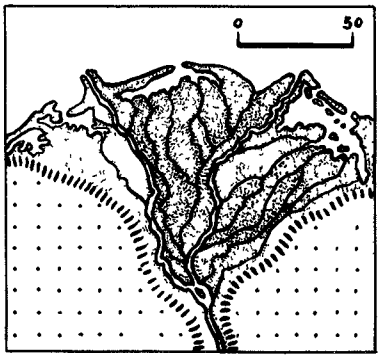


Fig. 6
Arcuate delta of the Nile river

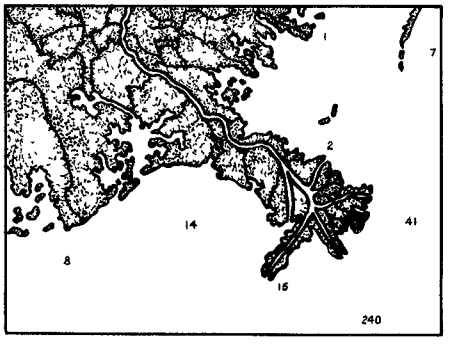


Fig. 7
Birds foot delta of the
Mississippi River

are rather calm. There are two types of deltas on which harbors have been located, the arcuate delta which the Nile has formed and the birdsfoot delta of which the Mississippi is a good example. Arcuate deltas make rather poor harbor sites. The distributaries give good protection from waves but protection from winds is poor because of the flat topography. The distributaries are also shallow, shift their courses, and require extensive and continuous dredging. Tidal ranges and tidal currents are small; however, a fairly steady river flow makes for quick elimination of contaminants. Conditions are better in the birdsfoot delta. Again, protection from waves is good, but protection from winds is poor. The finger-like distributaries flow between natural levees and are comparatively deep, requiring little expense for dredging. Tidal conditions and elimination of contaminants are the same as in the arcuate delta, with a small range but steady flow to produce rapid elimination.

LAGOONS (Figures 8 and 9.)

Lagoons are shallow stretches of water which are partially or completely separated from the sea by narrow strips of land. Two types of lagoons are interesting from the point of view of harbor construction: atoll and barrier reef lagoons, and barrier bar lagoons. In the case of atolls and barrier reef lagoons, separation from the sea is formed by coral growth and in the other case the separation is effected by a sand bar.

Both types offer fair protection from waves but poor protection from winds. Deep draft entrances are not very common and dredging requirements may be high. In shallow lagoons coral heads may also become navigational hazards and require removal. Atoll and barrier reef lagoons usually offer large areas for maneuvering, and holding ground for anchoring is good. Although tidal ranges are mostly small, and tidal currents weak, there are cases where they are fairly strong because of the large tidal prism plus the narrow passes. Elimination of contaminants is rather slow because of small tidal ranges and very little fresh water inflow and also because a pocket of stagnant water is formed inside the lagoon. In general, atoll and barrier reef lagoons make fairly good harbor sites.

Barrier bar lagoons usually have very small tidal ranges and very weak tidal currents. The area for maneuvering is restricted since this type of lagoon has a strong tendency to fill in; that is, it shallows in time, and barrier bars migrate slowly landward. Holding ground for anchoring is mostly good; however, because of the shallowness, dredging requirements are very high. Circulation is very weak and the elimination of contaminants very slow.

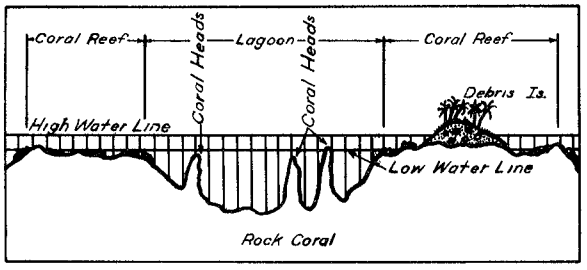


Fig. 8
Atolls and barrier reef lagoon

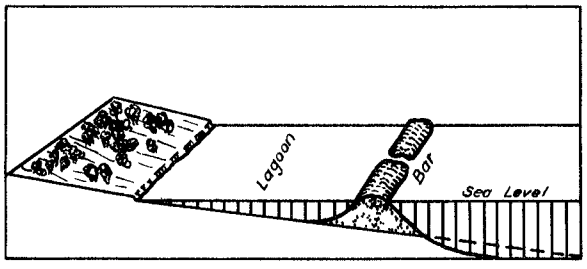


Fig. 9
Barrier bar lagoon

Venice is a good example of a harbor located in a barrier bar lagoon. It was a good harbor during the medieval ages, but lost its importance with the advent of larger ships with relatively deep draft.

In summary it may be said that the funnel-shaped estuarine bay (Delaware Bay), the tectonic bay (San Francisco), and the ria (Brest), afford very good harbor sites. Fjords (Trondheim) make only fair sites, and tidal rivers usually are poor for harbor locations. Arcuate deltas (the Nile) make rather poor harbors, but birdsfoot deltas (the Mississippi) are slightly better. Atoll and barrier reef lagoons make fairly good harbor sites. Barrier bar lagoons are generally poor because of the dredging requirements.

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