CHAPTER 4

ENVIRONMENTAL ASPECTS OF THE EBB SIDE AND FLOOD SIDE OF TIDAL ESTUARIES AS A FACTOR IN HARBOR LOCATIONS

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In a previous paper presented at the Second Conference on Coastal Engineering concerning the environmental aspects of harbors, mention was made of the fact that owing to the differences between the ebb and flood side of an estuary, the ebb side presented certain advantages which might make it the more suitable location for a harbor. No expanded discussion was attempted at that time, but the problem seemed to be of sufficient interest to warrant further study.

Generally speaking, the establishment of a new harbor or the development of an old one depends too often on local interests, adequate transportation, or access to the hinterland. Even though exhaustive studies of the phenomena of sedimentation, currents, salinity, and fouling at the proposed location are sometimes made, the viewpoint is quite often that remedial measures will be taken to combat these phenomena where they are found to be detrimental. In general, these forces of nature can be modified or at least ameliorated, but the possibility of cooperating with natural forces rather than combating them is often overlooked. It would seem more logical to choose a harbor site or develop a harbor where sedimentation is at a minimum rather than one where sedimentation is so rapid as to require almost constant dredging. Also it would be more logical to select a site where the incidence of marine borers and fouling organisms is slight rather than to develop and apply artificial measures which guarantee no permanent immunity from attack. It is the purpose of this paper to show that environmental characteristics of the ebb side of an estuary may provide a more suitable location for a port than the flood side.

The ebb side of an estuary in the northern hemisphere is considered to be the right side looking seaward toward the mouth of the estuary and the flood side the left bank looking in the same direction. Because of the Coriolis force, moving objects in the northern hemisphere are deflected to the right, therefore, it should be expected that the right side of an estuary would exhibit certain peculiarities. Recent observations have shown considerable differences in the two sides of most estuaries. Probably the clearest example is in the salinity distribution patterns of two bays along the east coast of the United States. It has been shown by Pritchard (1952) that surface isohalines in the Chesapeake Bay (Fig. 1) run obliquely across the estuary rather than running perpendicular to its long axis. The resulting effect is that salinities are lower on the ebb side and higher on the flood side. Although the salinity gradient of the ebb side is probably accented by the excess of fresh water inflow from the rivers of the western shore of the bay it should not be supposed that this is completely the cause of the lowered salinities. It has been pointed out (Pritchard, 1952) that even in narrow estuaries where the river inflow from both shores is approximately equal, the lateral gradient shows the salinities of less value to be on the ebb side. A similar

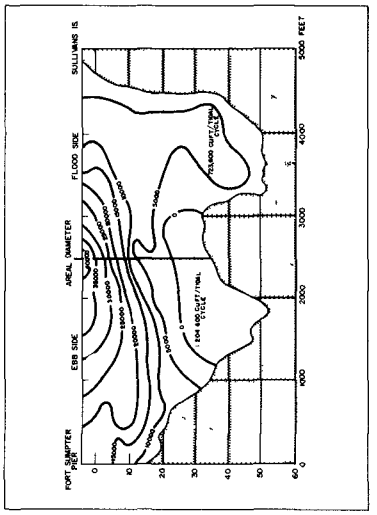

Fig. 2. Net outflow through the mouth of Charleston Harbor during one tidal cycle on 26 October 1950.

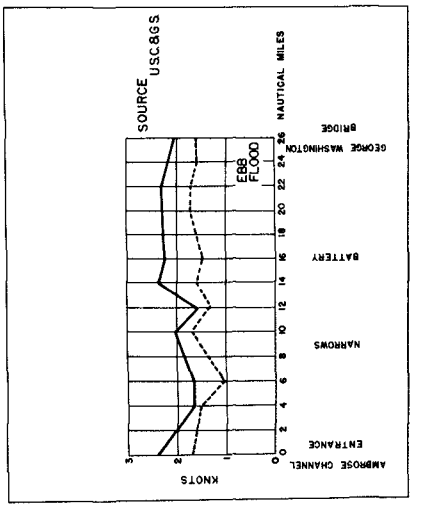

Fig. 3. Maximum ebb and flood current velocities in New York Harbor

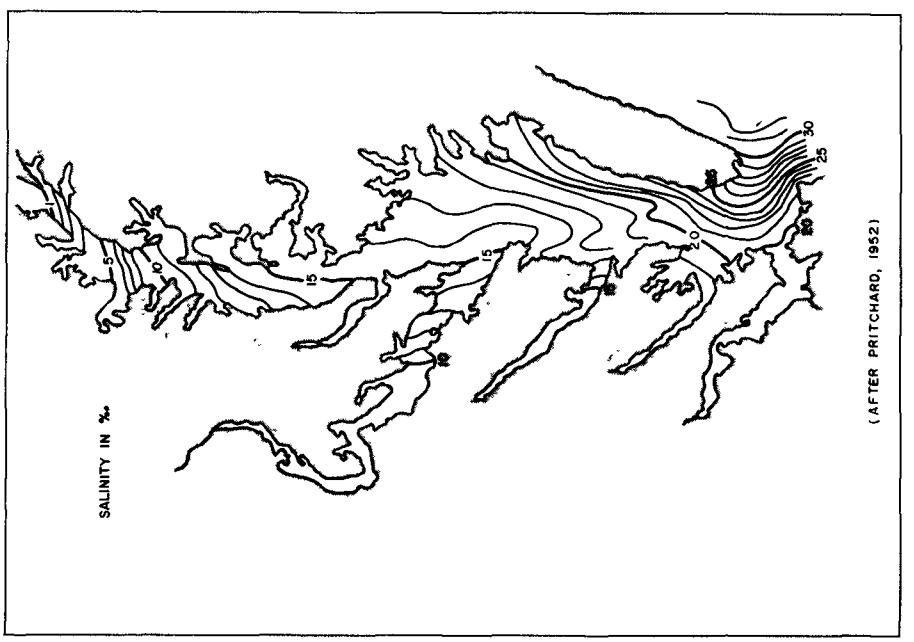

Fig. 1. Typical surface salinity pat-

condition obtains in Delaware Bay (Nelson, 1947) where the deflection of the ebb tide resulting from the earth's rotation carries out along the Delaware coast (ebb side) approximately five times as much fresh water as along the New Jersey shore (flood side). High salinities on the flood side near the mouth of Delaware Bay are further accented by excessive evaporation over the exposed flats in hot weather.

A further difference in the characteristics of the flood and ebb sides is in the large volume of water transported along the latter. This is strikingly shown in the net discharge through the mouth of Charleston Harbor. From data of the U. S. Corps of Engineers the net outflow through the mouth of Charleston Harbor has been computed for one tidal cycle (Fig. 2). The total transport during ebb tide and during flood tide has been measured in linear feet between Sullivans Island (flood side) and Fort Sumter (ebb side) and the net transport per tidal cycle is shown in the diagram. The areal diameter divides the total area into equal parts. When the net discharge volume is computed it is found that the total discharge from the ebb side is in the magnitude of 1,204,600 cubic feet per tidal cycle and from the flood side, 723,600 cubic feet per tidal cycle. This difference of 481,000 cubic feet shows the ebb side to carry out almost 25% more water than the flood side.

As a consequence of a greater amount of water to be discharged on the ebb side, the current velocities here must be greater during the tidal cycle. Higher ebb velocities are apparent in most inlets. At the entrance to Charleston Harbor, for example, maximum ebb velocities at the surface are consistently higher than the maximum flood velocities with the former varying between 1.8 to 3.3 knots and the latter varying only between 0.7 to 2.5 knots. This is further evidenced in New York Harbor (Fig. 3). In a section from above the George Washington Bridge to the Ambrose Channel Entrance, maximum ebb current velocities are greater than flood velocities at all stations. The maximum flood velocity is 1.7 knots and the maximum ebb velocity 2.4 knots (U. S. Coast and Geodetic Survey, 1951).

An additional important characteristic of the tide which will affect the ebb and flood sides is the duration of the respective flows. In general it may be said that the duration of ebb is greater than that of flood. Water particles or contaminants, therefore, experience a net seaward gain during the ebb tide. Even in places where the two tides are equivalent in duration or the flood tide continues slightly longer than the ebb tide, the greater velocities of the ebb current should compensate for this difference and particles will still experience a net seaward gain.

What then is the significance of these facts in choosing one or the other side of an estuary as a harbor site? From the standpoint of biological implications alone the ebb side would seem worthy of consideration. The problems encountered with fouling and boring organisms are of economic importance in the maintenance of a harbor. Although various methods have been developed to discourage both fouling and boring organisms the more

logical approach would be to choose a location which would be less susceptible to infestation. The ebb side appears to present an environment which is unfavorable for foulants and borers. In the lower salinity it is to be expected that there will be a less favorable environment for the development of mussels, oysters, barnacles, and borers. Although these will be present in some amount on the ebb side they will probably not be as numerous or grow as rapidly and well as those on the flood side. For example, in San Francisco Bay, creosoted wooden pilings may be expected to last only from 15-25 years on the San Francisco (flood)side, while elsewhere they may be expected to last from 20-30 years (Hcronjeff and Patrick, 1951).

Greater current speed may also tend to reduce the fouling problem on the ebb side. Fouling organisms have limiting current tolerance for the attachment of their larval forms. Three species of barnacles[1] have been shown to be unable to attach themselves at speeds greater than two knots and at least one of these[2] is unable to attach at speeds greater than 0.8 knots (Doochin, 1949). It has been shown (Smith, 1946) that after attachment of the larvae the growth rate is increased by currents less than 1.5 knots and decreased by currents in excess of this. Six hours after the larval form has attached, the growth rate is stopped by a current of 3 knots.

The problem of sedimentation is as important as the biological consideration. In this case the ebb side seems again to be a more suitable location. It has been shown (Sverdrup, Johnson, and Fleming, 1942) that higher current velocities favor the deposition of coarse particles rather than fine particles in suspension. Since the higher velocities occur on the ebb side it is logical to assume that the fine sediments would not be deposited here and would reduce dredging requirements. Strong currents however do not guarantee that only the coarse sedimentary materials will be deposited since they may still be accompanied by some small amount of fine materials. For example in Massachusetts Bay there are several estuaries where the current moves from 2-3 miles per hour. In one of these, Beverly Harbor, there is a tidal current channel with steep sides. In sediments examined from the shore to the north out into the channel there is a decided change found at the channel's edge. The strong current here does not eliminate the fine material but brings a mixture of coarse and some fine material together (Trowbridge and Shepard, 1932).

In areas where man disturbs the natural environment, the conditions postulated here are also upset, but farther removed from man's activity, where natural forces are allowed to act, the conditions are restored. Such a case occurred in San Pablo Bay where a considerable shoal was built up on the ebb shore in the years 1921 to 1931 due to the extensive government dredging in the vicinity, However, there is evidence that much of the light silt from the dredging here was carried farther downstream into San Francisco Bay and deposited on the eastern (flood) shores. This is further supported by the fact that between the years 1859 and 1903 there was marked shoaling south of Point Richmond (flood side). The sedimentary materials which occasioned this shoaling were probably the result of

1 Balanus amphitrite, B. eburneus, and B. improvisus
2 Balanus eburneus

hydraulic mining operations during the period (Beebe, 1931). The action of the tide is probably not the sole reason for deposition on the eastern (flood) shores of San Francisco Bay since the prevailing west and southwest winds keep the shoal water constantly agitated, thereby carrying silt in suspension on to the shore or into dredged channels.

Another important factor to be considered in the establishment of a harbor or the development of an already existing one is the problem of flushing. Even though theories of flushing are in a state of conflict and data are limited we may still make the conjecture at this point that the ebb side of an estuary should have a faster flushing time than the flood side. At least several of the conditions stated before seem to point to this. Since the greater volume of water is deflected to the ebb side, since the current velocity is greater, and since the ebb tide is of longer duration it seems that the net seaward gain of a water particle is greater and any contaminant would be more readily flushed from this side.

Little information is available to conclude definitely that the greater scouring action of the tidal forces would be on the ebb side but this is quite possible in view of the higher current velocities lasting over a longer period of time.

Unfortunately, we cannot say that the ebb side would be the best location for a harbor in every instance since various local factors may interfere with the expected conditions. The facts, however, indicate that it would be better to take advantage of the opportunity of cooperating with natural forces rather than fighting the battle of continued expense in harbor maintenance.

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